TIES435 Radio Networks and Self-Organization

Prof. Tapani Ristaniemi

Details

- Lectures & exercises
  - 29.10. – 18.12.2013
  - Tuesdays 12:15 - 14:00, Ag Alfa
  - Wednesdays 10:15 - 12:00, Ag Alfa
  - Exercises: during some lecture hours, will be announced beforehand.
- Lectures by TR and couple of experts from industry.
- Goal: a student will get familiar with
  - Wireless standards (WCDMA,HSPA,LTE,LTE-A)
  - Basics of radio network planning and resource management
  - Self-organization in wireles networks
  - Radio channel characteristics
  - Radio interface techniques
  - Theory and practice

Details

- Material: The course is mostly based on:
  - Holma, Toskala: WCDMA for UMTS: HSPA Evolution and LTE, 4th Ed.
  - Dahlman *et. al.* : 3G Evolution - HSPA and LTE for Mobile Broadband
  - Hämäläinen *et.al:* LTE Self-organizing Networks (SON)
  - Lecture notes
  - a collection of scientific articles
- Lecture notes: http://users.jyu.fi/~riesta/TIES435_lecX.pdf , X=1,2,...
- Attendance to lectures and exercises is recommended, but not compulsory. It is possible to get considerable improvement in grading by actively participating the exercise sessions.
- Final exams: 18.12, 31.1.2014 or 21.3.2014
- 5 cu: passing the final exam
- 8 cu: passing the final exam + acceptance of a project work (project work titles will be announced later)

Contents (subject to change)

- Cellular concept and introduction to WCDMA
- WCDMA physical layer
- WCDMA radio link performance
- WCDMA radio resource management
- WCDMA radio network planning
- HSPA
- LTE design targets and overview
- LTE radio interface
- LTE physical layer
- LTE mobility and radio resource management
- Enhancements for LTE
- Radio channel characteristics
- R&D tools for industry and academia
- Introduction to SON
- LTE SON basics
- Recent advances in SON

TIES435 Radio Networks and Self-Organization

Introduction to WCDMA

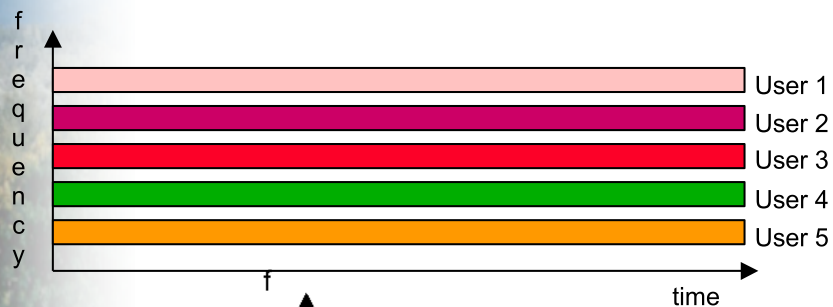
Prof. Tapani Ristaniemi

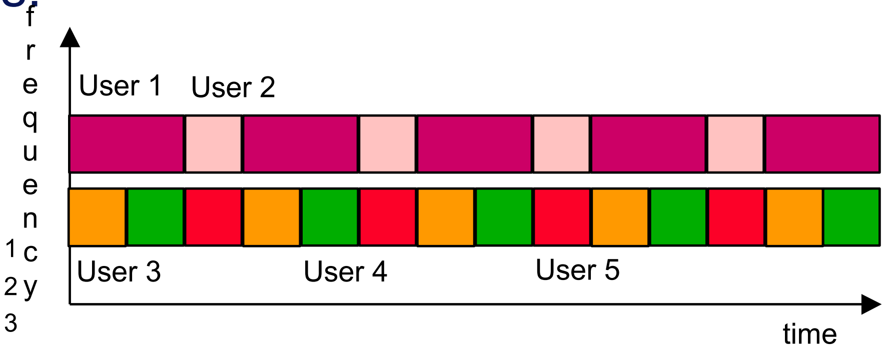
Contents

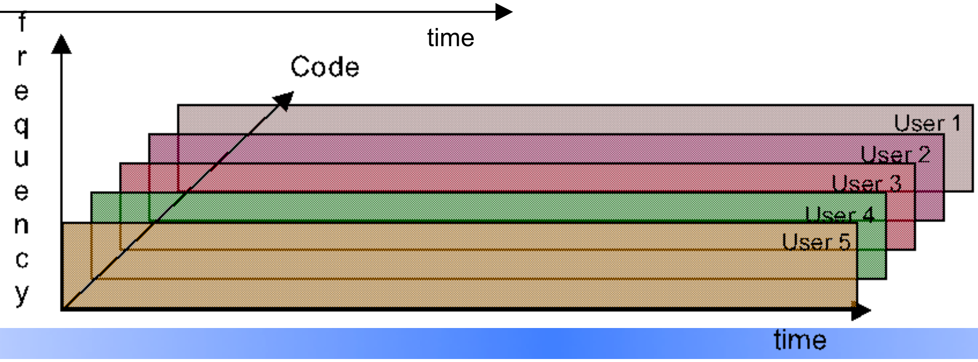
- The cellular concept
- Multiple access schemes
- Spread spectrum systems
- Multipath diversity, rake receiver
- Radio resource management
- WCDMA capacity

Motivation: limited radio spectrum

- Many users vs. the same media: sharing the media among users is mandatory → multiplexing
- By multiplexing we essentially understand division of available channel into several subchannels in time / frequency / code / space dimensions. Examples:

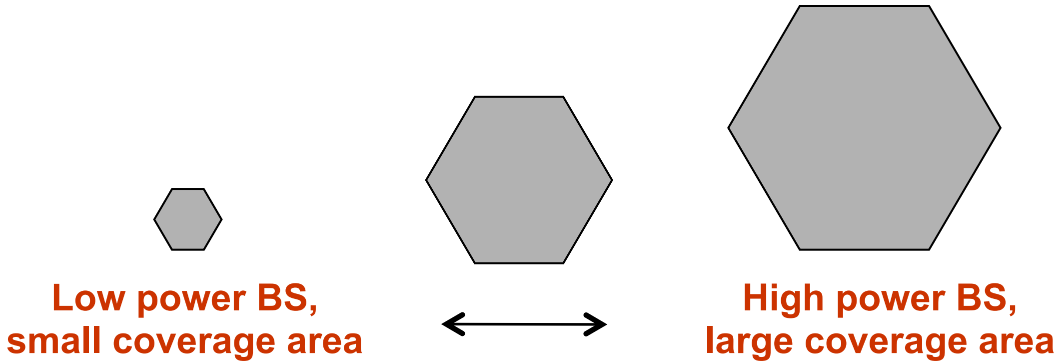






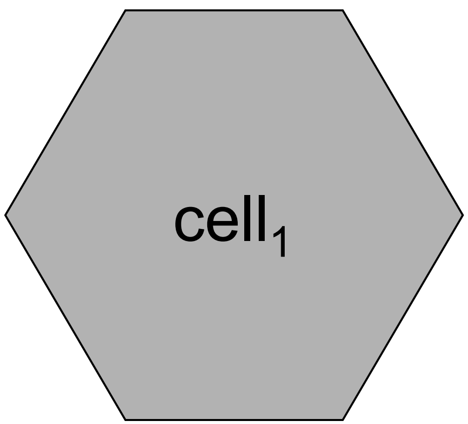
Motivation: limited radio spectrum

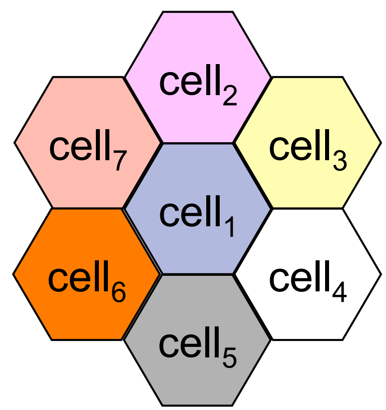
- How to cover large geographical area ?
- One could build up a system consisting only one serving base station (BS), which would divide the wireless channel among the mobiles by the means of either time, frequency, code or spatial multiplexing.
- However, this would immediately result in a major disadvantage: large coverage areas would be possible only via increased transmission power, which would be problematic for mobile handheld devices.



Motivation: limited radio spectrum

- The underlying idea of *cellular concept* is to introduce *geometrically smaller areas*; called *cells* among which the functionality of radio network is divided.
- In cellular system, each cell is characterized by one base station which serve the users within that geographical area.
- What is needed more to make inter-cell connections possible is a fixed (backbone) network which connects different base stations.





Resource reuse

- In cellular system, each cell have to have their own group of channels according to some multiplexing principle. Otherwise, inter-cell interferences would occur.
- On the other hand, radio signal attenuates as a function of distance, which means that same group of resources (time slot / frequency band / code) can be utilized again if the cells are far apart.
- This is because the interfering signal would then be weak enough until it reaches the other cell → no significant interference between the cells.
- *Resource reuse* defines how often the same resource can be used.

Pros and cons of cellular concept

Advantages

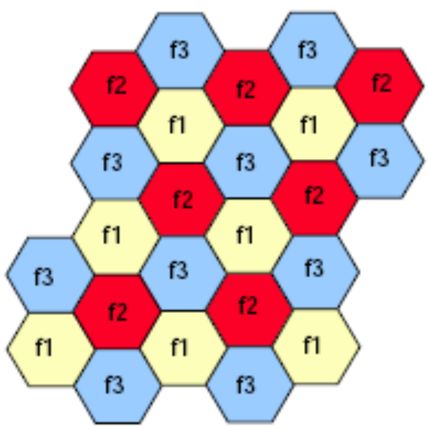
- Higher capacity
- Less transmission power
- Localized interference
- Robustness
- No technological challenges in deployment

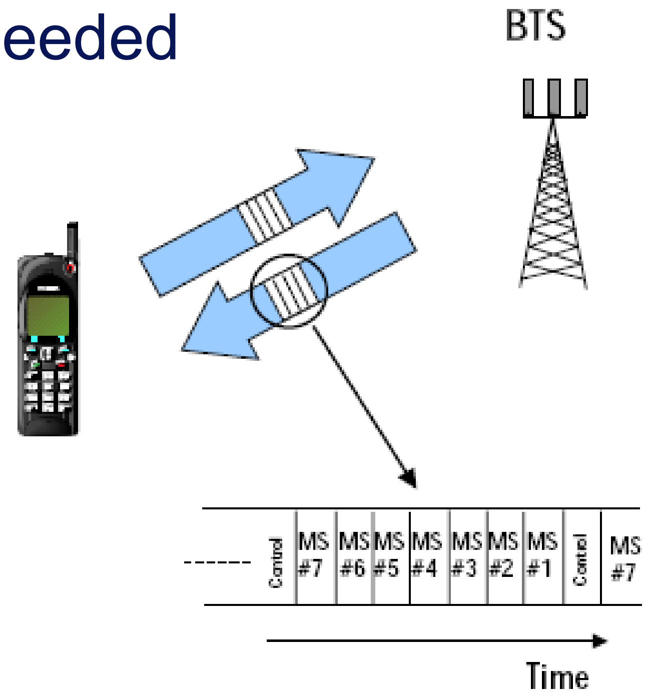
Disadvantages

- Massive infrastructure
- More complex mobility management
- Resource planning and management

2G GSM

- TDMA = Time Division Multiple Access
  - Users are separated in time domain (time slots)
- One carrier (200 kHz) includes 7 time slots for user speech + 1 control slot for the controlling the connection
- Careful frequency planning needed

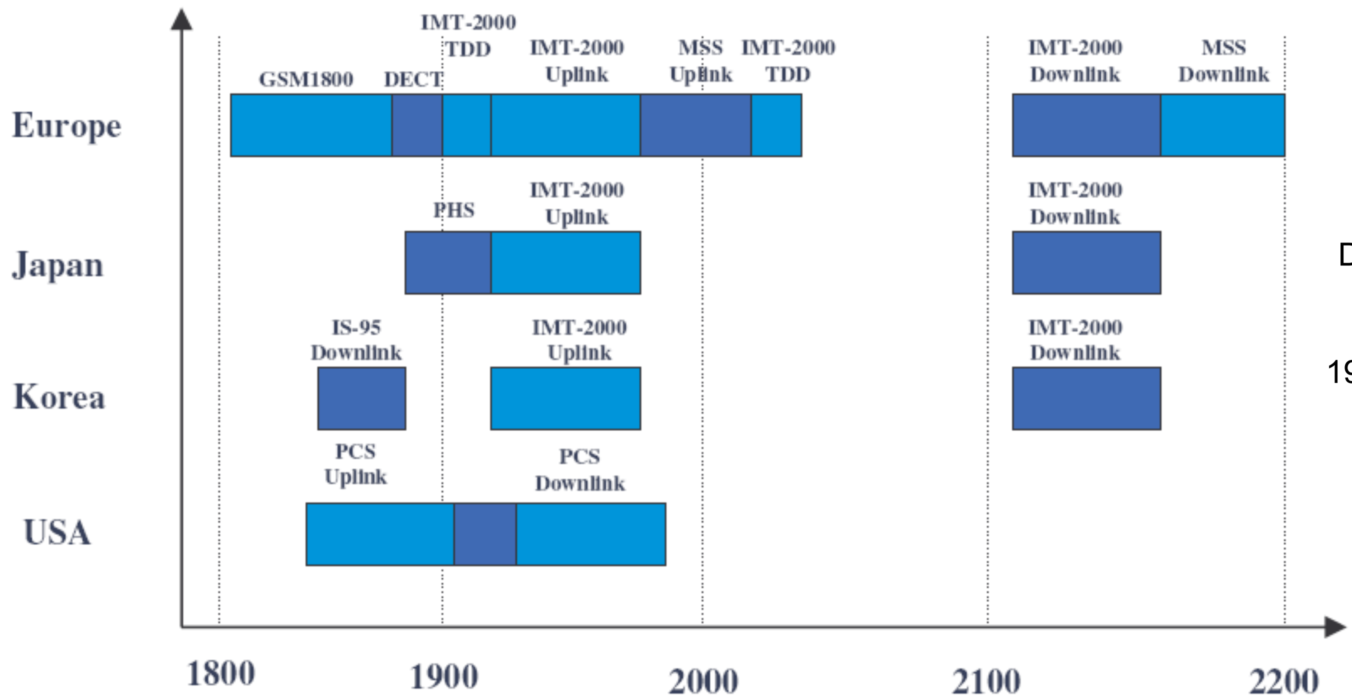




Why 3G UMTS?

- Need for universal standard
- Support for packet data services
- New services in mobile multimedia need flexible utilization of the spectrum (multiplexing, link adaptation).
- FDMA and TDMA are not efficient enough
  - silent periods in speech can not be utilized
  - **does not allow efficient frequency reuse**
- In 1997, WCDMA was selected for a radio access system for UMTS
- (At that time, the superiority of OFDM compared to DS-CDMA was actually not that well understood ….)

Frequency allocations for UMTS



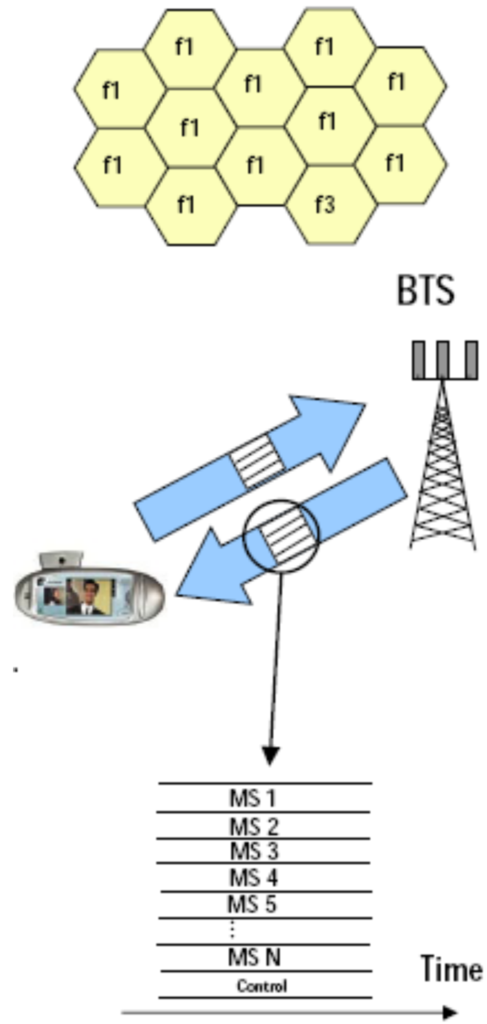
UMTS-FDD:
UL 1920-1980;
DL 2110-2170 MHz

UMTS-TDD:
1900-1920 MHz, and
"extension band"
2020-2025 MHz

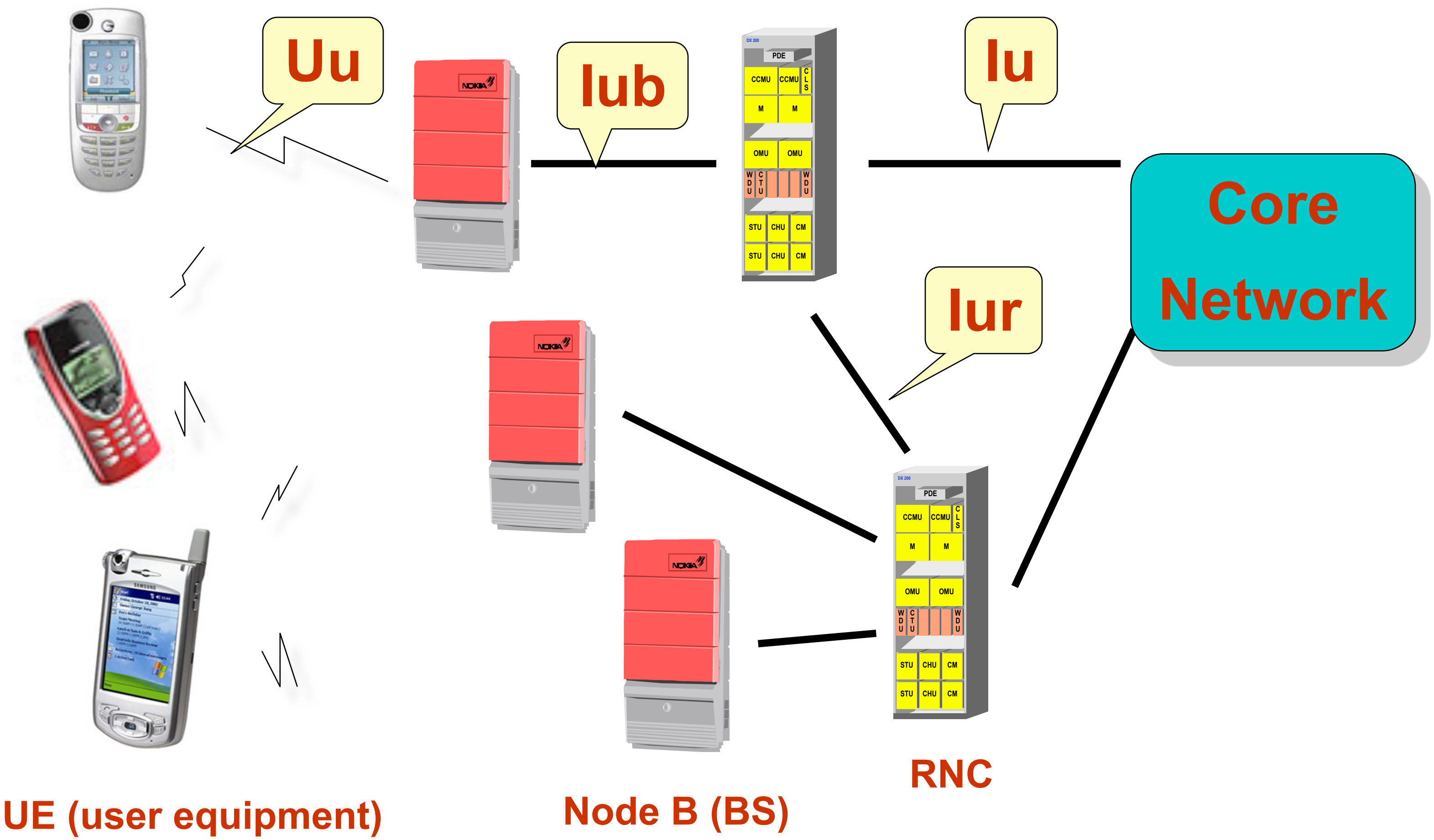
- Frequency plans of Europe, Japan and Korea are harmonized
- US plan is incompatible → IMT-2000 spectrum is there used for the US 2G standards
- IMT-2000 in Europe: FDD 2x60MHz, TDD 20MHz+15MHz
- Note: GSM band is close to the UMTS band in uplink (Interference!)

3G WCDMA

- WCDMA = Wideband Code Division Multiple Access
- Users are separated with code sequences by which the data is spread over a wide frequency band.
- All the users share simultaneously the same frequency band (5 MHz carrier)
- Uplink and downlink are frequency separated (2×5MHz)
- Different users can use different services
- One user can use different services at the same time (e.g. video phone, voice)

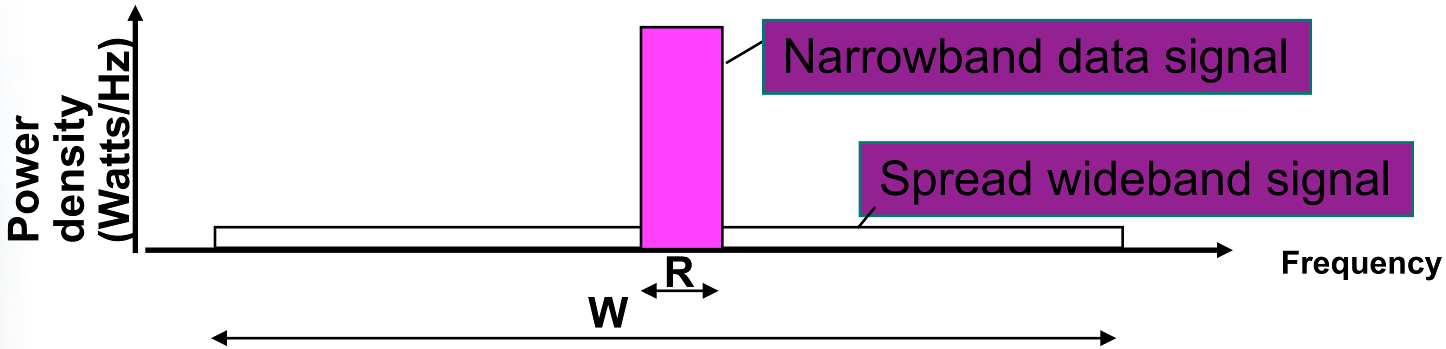


UTRAN (UMTS Terrestrial Radio Access Network) Architecture



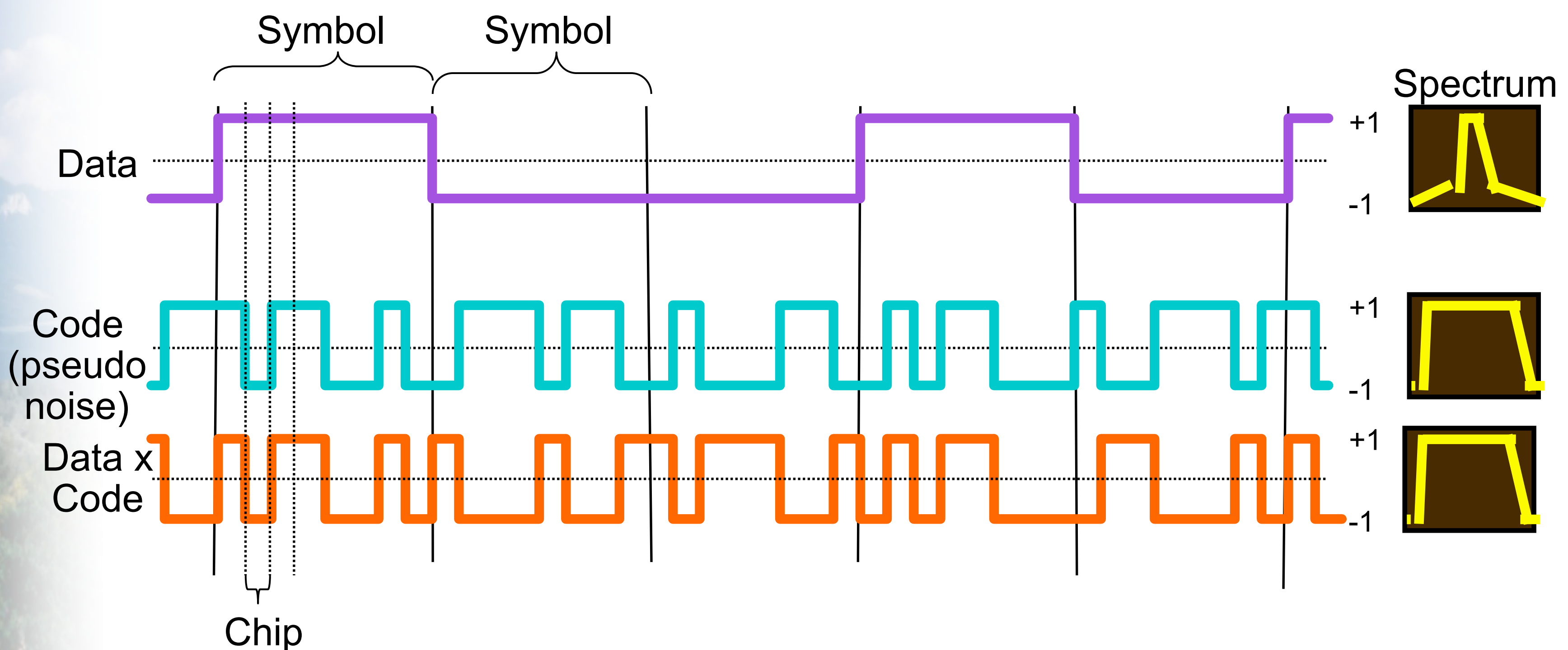
WCDMA is a spread spectrum system

- In spread spectrum (SS) communications, bandwidth of the transmitted signal is considerably larger than bandwidth of the information signal.



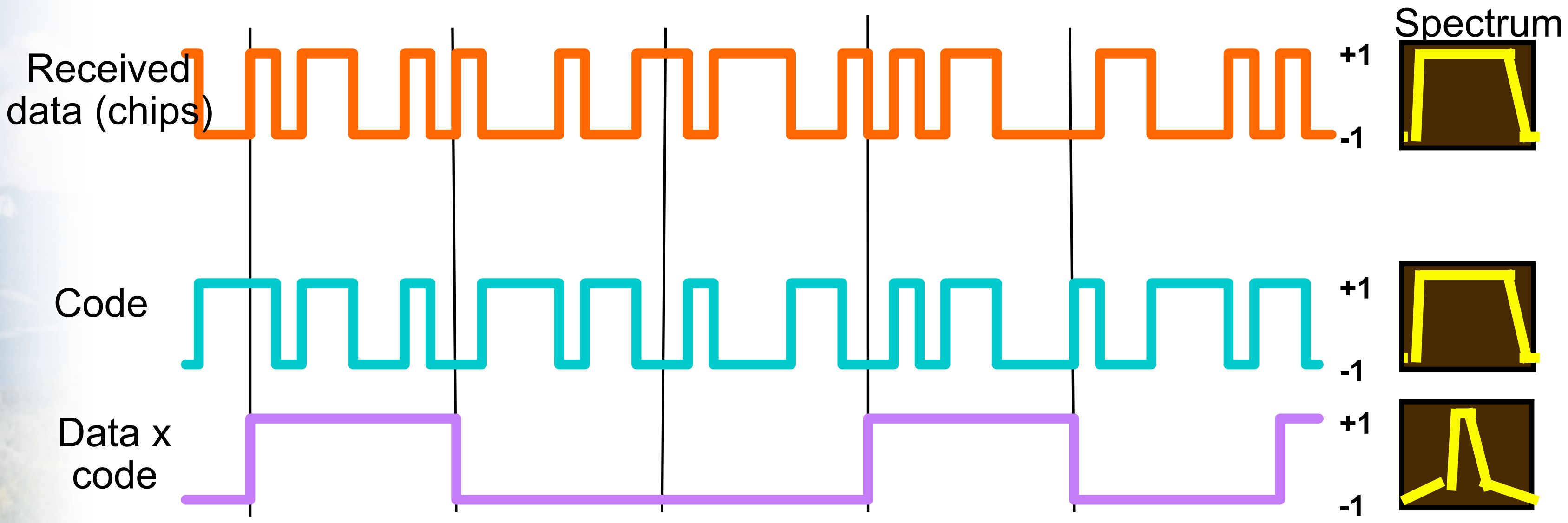
- Spreading operation does not depend on the information signal.
- Different ways to spread the signal in frequency domain:
  - Direct sequence (DS) spreading
  - Frequency hopping (FH)

DS-CDMA data (transmitted data)



This operation (”data * code” at the transmitter) is called *spreading*.

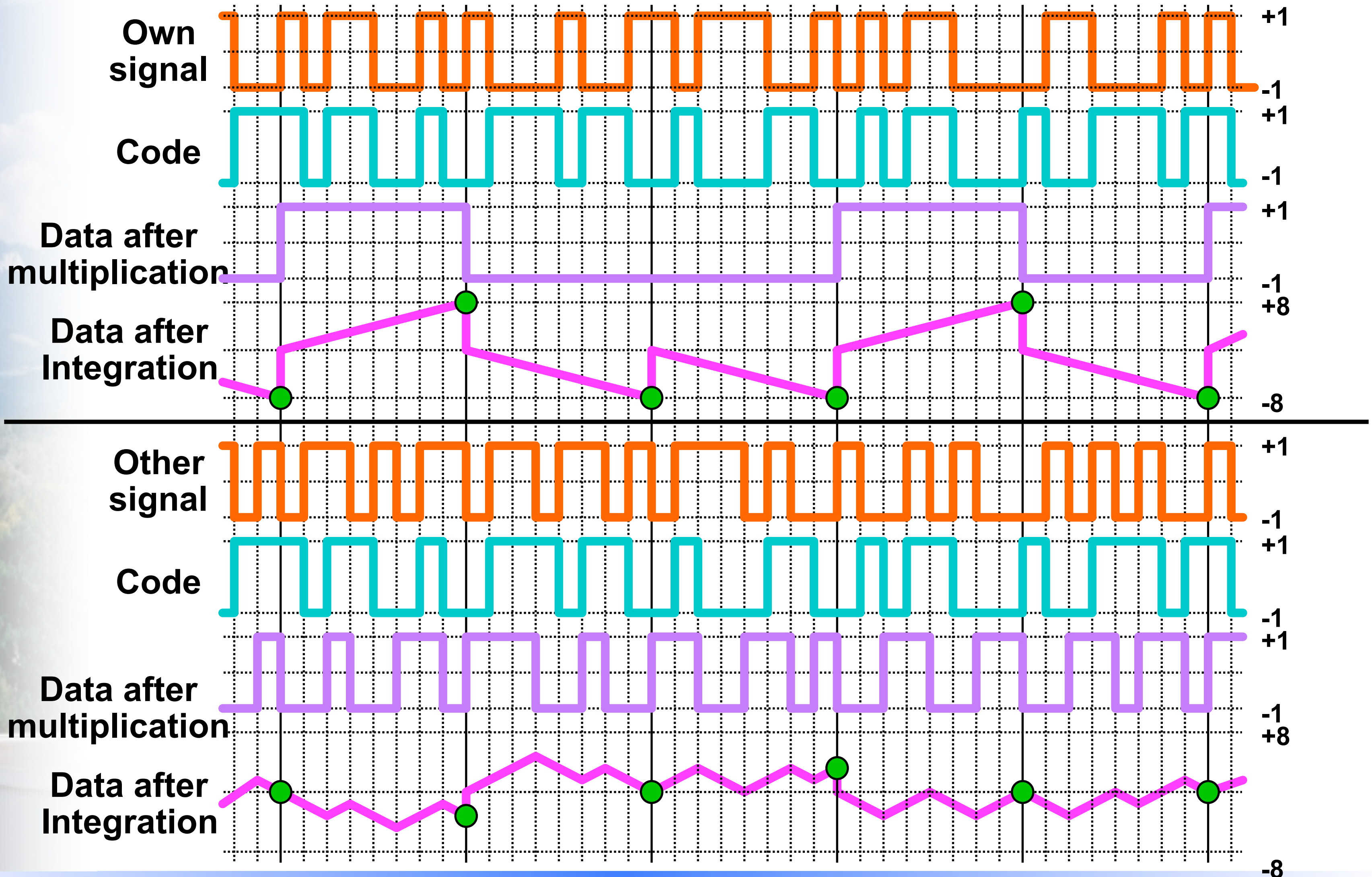
DS-CDMA data (detection at the receiver)



This operation (”data * code” at the receiver) is called *de-spreading*.

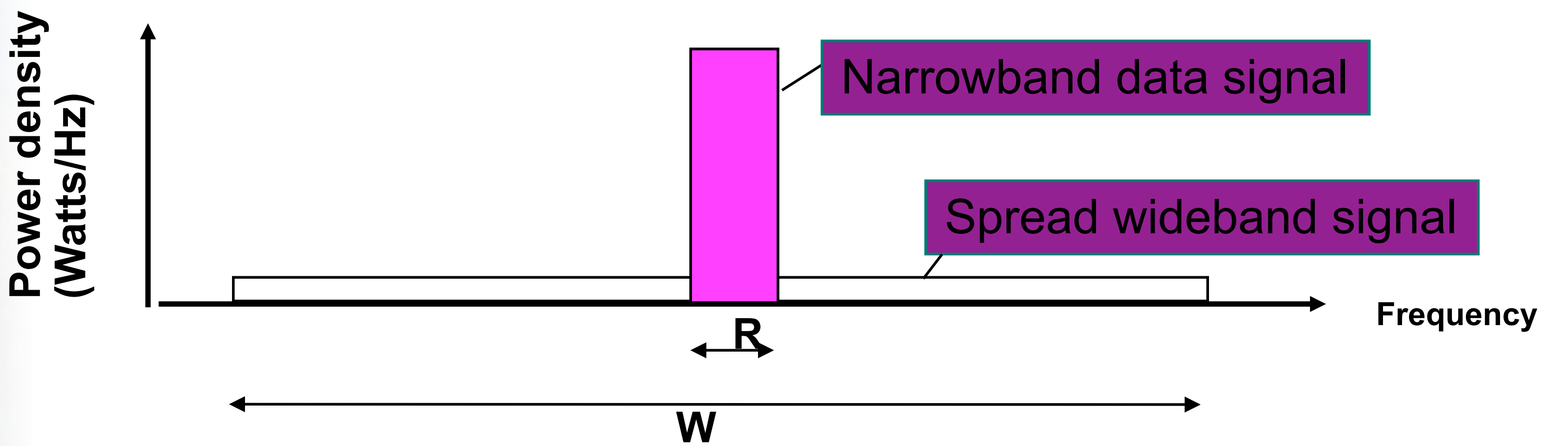
The received sequence of chips is multiplied with the *very same* code as in the transmitter.

DS-CDMA data detection – Correlator



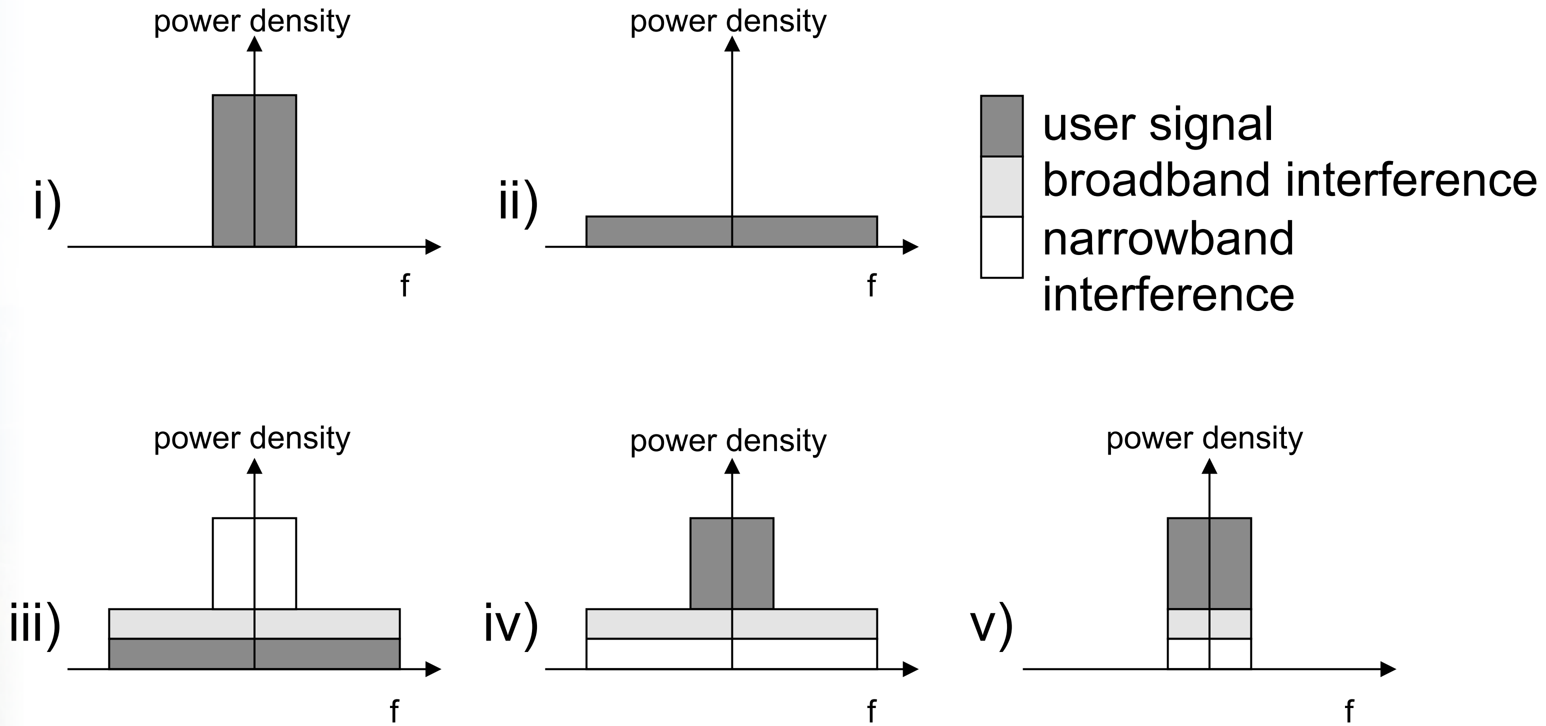
Spreading factor and Processing gain

- As can be seen from the previous example, the amplitude of the own signal increases on average by a factor of 8 relative to that of the user of the other interfering system, i.e. the correlation detection has *amplified* the desired user signal by the *spreading factor*, here 8, from the interference present in the CDMA system.
- This effect is termed '*processing gain*' and is a fundamental aspect of all CDMA systems, and in general of all spread spectrum systems.



Processing gain = W/R

Effect of processing gain



transmitter: i) narrowband signal, ii) wideband signal after spreading

receiver: iii) received wideband signal, iv) de-spread signal,

v) signal after band-pass filtering: the power of interference is now ”small” compared to the signal of interest.

Example - processing gain

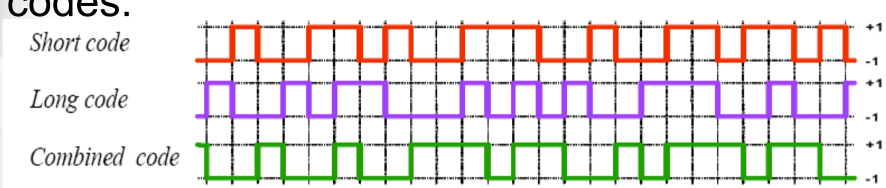
- Processing gain is what gives CDMA systems the robustness against self-interference that is necessary in order to reuse the available 5 MHz carrier frequencies over geographically close distances.
- Examples: Speech service with a bit rate of 12.2 kbps
  - processing gain 10 $\log_{10}(3.84e6/12.2e3) = 25$ dB
  - For speech service the required SINR is typically in the order of 5.0 dB, so the required wideband signal-to-interference ratio (also called "carrier-to-interference ratio, *C/I*) is therefore "5.0 dB minus the processing" = -20.0 dB.
  - In other words, the signal power can be 20 dB *under* the interference or thermal noise power, and the WCDMA receiver can still detect the signal.
  - Notice: in GSM, a good quality speech connection requires *C/I* = 9–12 dB.

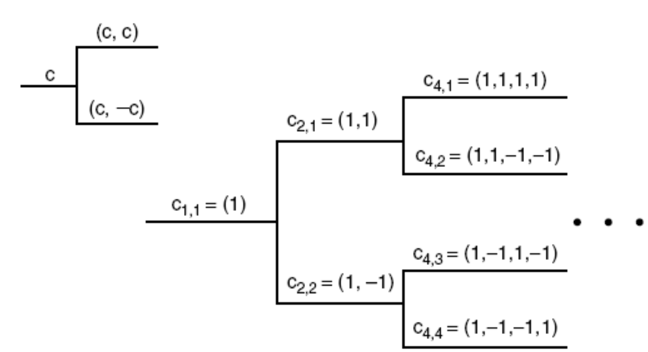
Spreading in WCDMA

	Channelisation Code (short code)	Scrambling Code (Long code)
Usage	**UL:** Separation of data and control channels from same user **DL:** Separation of connections to different users	**UL:** Separation of terminals **DL:** Separation of sectors (cells)
Code length	4 – 256 chips (DL also 512 chips)	38400 chips (10 ms) (DL also 256 chips)
Nbr of codes	Nbr of codes under one scrambling = *spreading factor, SF*	**UL:** several millions **DL:** 512
Code family	OVSF (orthogonal variable spreading factor)	Gold code (long)
Chip rate	3.84 Mcps	

Recall: vectors *v* and *w* are orthogonal if their inner product <*v*,*w*> equals zero.

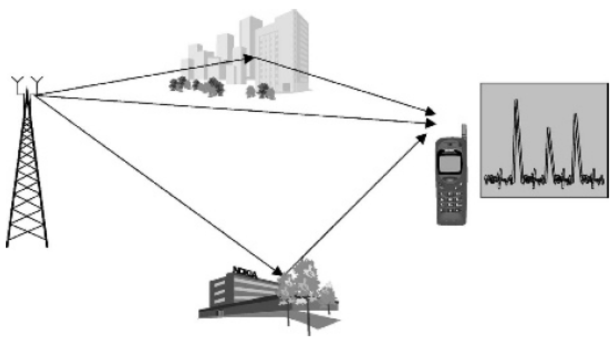
The final code is a mod-2 sum of these two codes:





Multipath radio channels

- Radio propagation is characterized by multiple reflections, diffractions and attenuation of the signal energy.
  - They are caused by buildings, hills and even foliage, etc. …
- Multipath propagation: The signal energy arrives at the receiver in different time instants. The arriving energy is 'smeared' into a certain multipath delay profile.

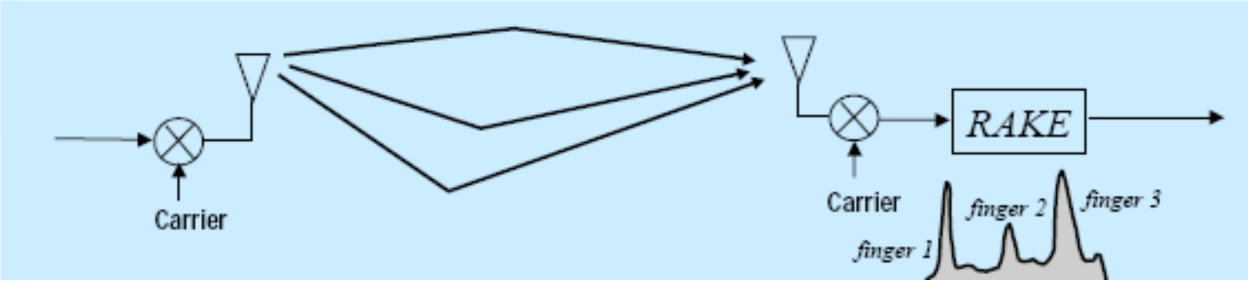


It depends on the signal bandwidth if the receiver is able to distinguish these different paths as distinct signal components, also called *multipath taps*.

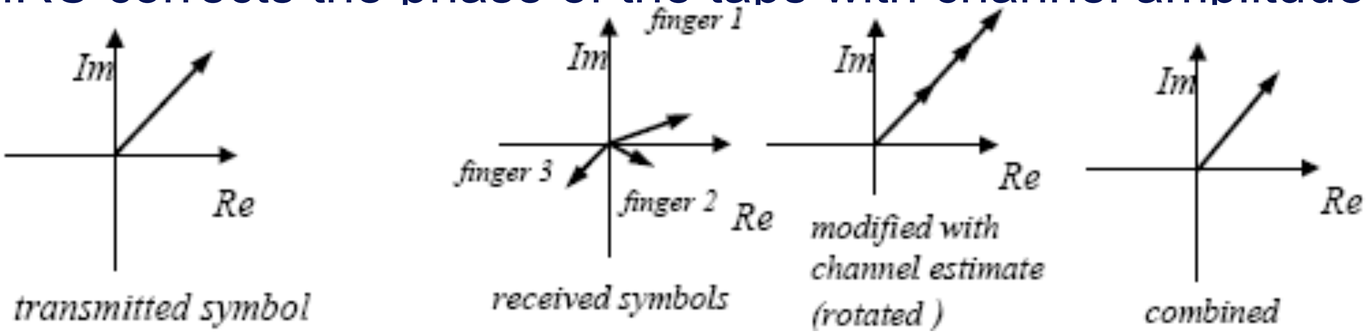
In WCDMA, the chip duration at 3.84 Mcps is 0.26 μs. If the time difference of the multipath components is at least 0.26 μs, the WCDMA receiver can separate those multipath components and combine them coherently to obtain *multipath diversity*.

Note: 0.26 μs corresponds to 78m in distance (speed of light / chip rate). This means that multipath diversity is available in small cells, too. This is not the case e.g. for IS-95 with 1 Mcps chip rate (300m).

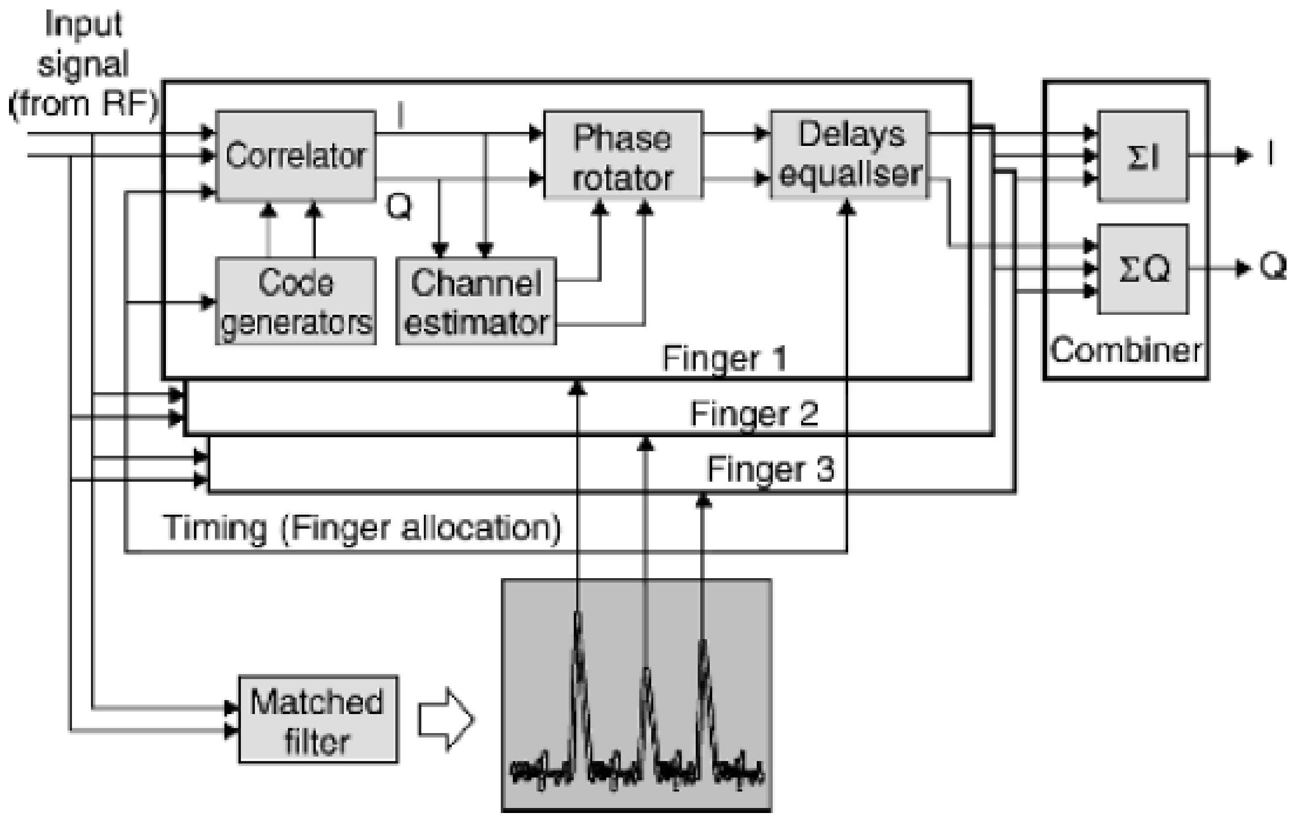
Maximal Ratio Combininb (MRC) in RAKE



- Each multipath change the amplitude and the phase of the transmitted signal
- The data in QPSK signal is in phase
- The signal energy is splitted to many multipath taps detected by the macthed filter
- MRC corrects the phase of the taps with channel amplitude estimate

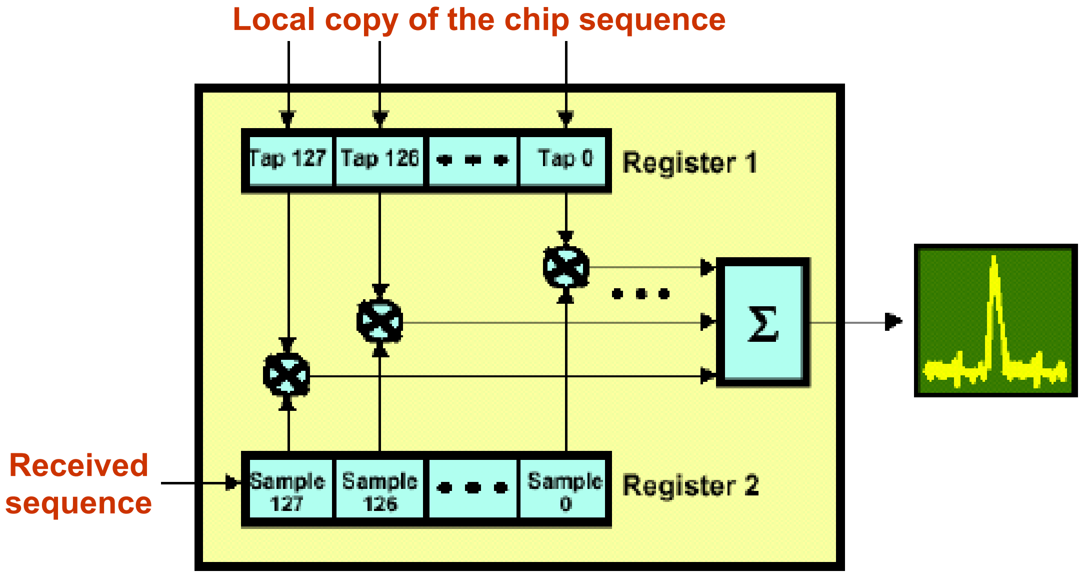


RAKE receiver



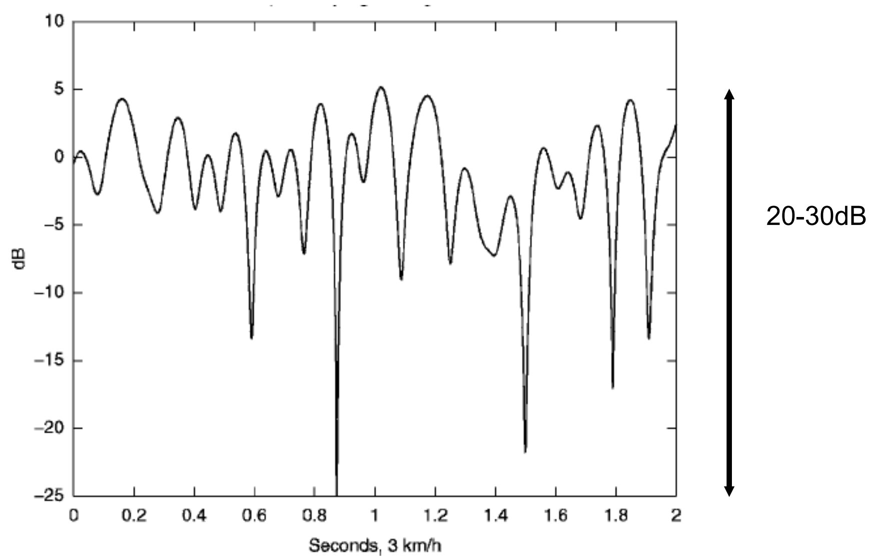
Matched filter

- The timing of the significant multipath taps have to be known. Otherwise despreading of the incoming signal is not possible.
- Timing and identification of multipath taps is carried out by a matched filter (MF).
- MF principle, roughly speaking: try and match every possible chip sequence timing and to despread the incoming signal by that. In case of ”high” output power you have found the a multipath tap and its timing.
- The granularity for acquiring the multipath delay profile is in the order of one chip duration (typically within the range of 1/4 – 1/2 chip duration)



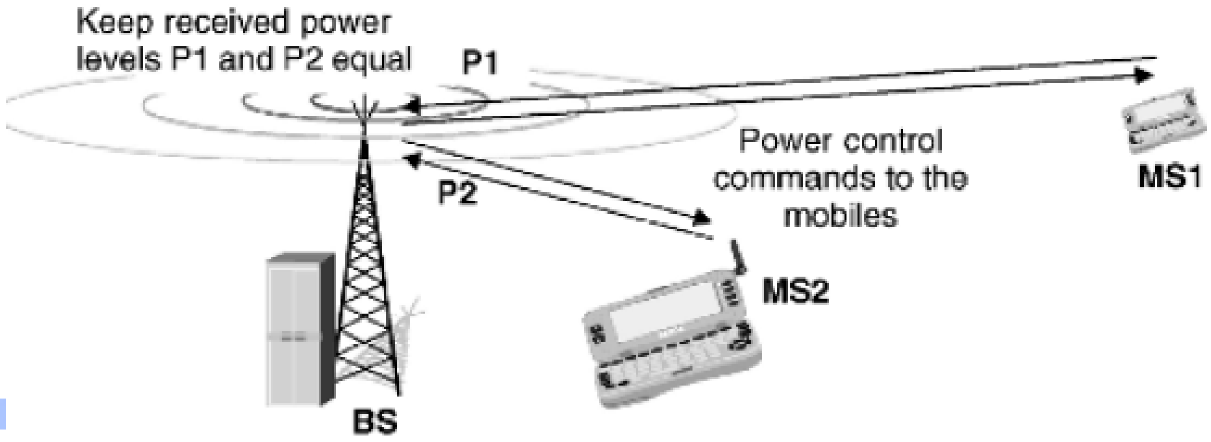
Fading of a multipath tap

- For a certain multipath tap there are usually many paths that contribute that tap.
- This is because most probably there exists many nearly equal-length propagation paths along which the radio signal travels.
- For example, paths with a length difference of half a wavelength (at 2 GHz this is approximately 7 cm) arrive at virtually the same time instant when compared to the duration of a single chip, which is 78 m at 3.84 Mcps.
- As a result, all the multipath components which arrive nearly at the same time, quite randomly either strengthen or weaken each other, depending on their relative phases.
- Example: received power from one multipath tap
- Fast fading calls for fast *power control*: use as little transmit power as possible, but increase it when signal starts to fade at the reception side.
- The goal is that the received power would be as constant as possible, regardless of the channel variation.



WCDMA needs power control

- As seen previously, equalizing the received power during a connection of one user is one of the reasons why PC is needed.
- Another need: the received powers of *all users* should not differ too much at the reception. Otherwise, near-far effect arises.
- Example: Mobile stations MS1 and MS2 operate within the same frequency. It may happen that MS1 at the cell edge suffers an signal attenuation due to distance, say 70 dB above that of MS2, which is near the base station BS. If there were no mechanism for MS1 and MS2 to be power-controlled to the same level at the base station, MS2 could easily overshout MS1 and thus block a large part of the cell.



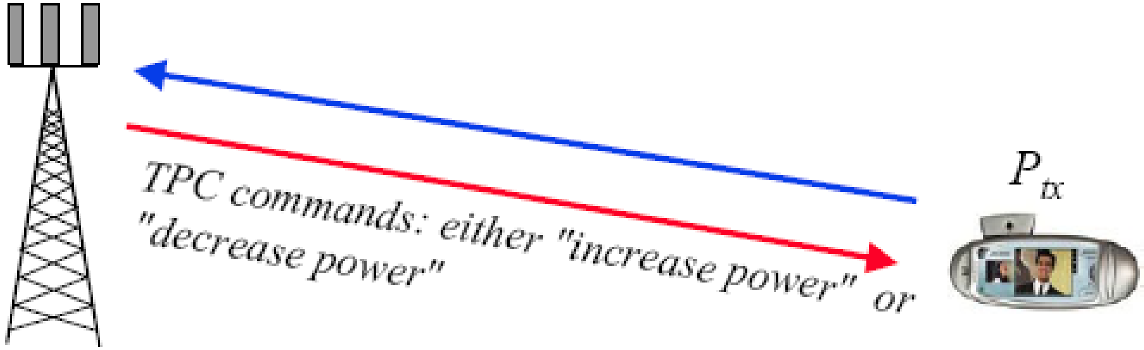
Power control loops in WCDMA

- Purpose of the power control (PC) is to ensure that every mobile and base station transmit **just enough** energy to convey information while interfering other users as little as possible.
- Three different power control mechanisms:

1. Open loop power control
   - Only for the *initial* power setting of the MS
   - Based on distance attenuation estimation from the downlink beacon signal
2. Closed loop transmitter power control (CL TPC) at a rate of 1.5 KHz
   - Mitigates fading processes (fast and slow fading)
   - Both in UL and DL
   - Uses quality targets in MS / BS
3. Outer loop PC
   - Sets the quality target used by the closed loop PC
   - Compensates the changes in the propagation conditions
   - adjusts the quality target
   - Both in UL and DL

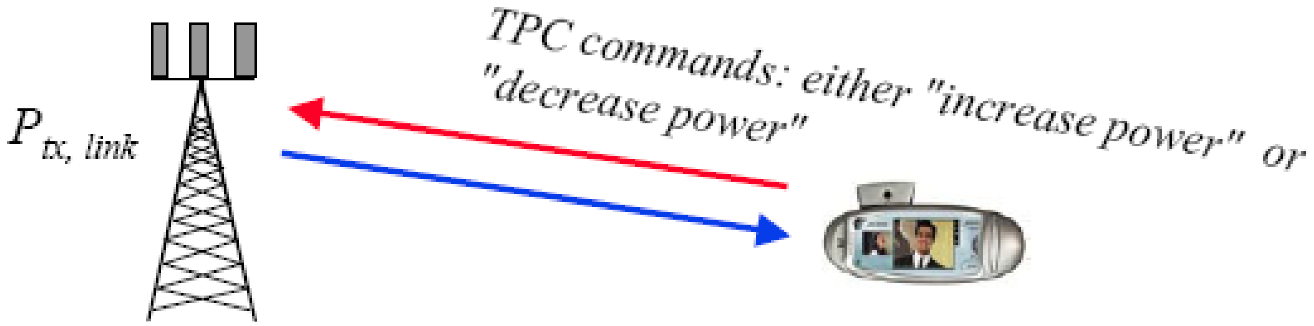
Closed loop PC: uplink

- Outer loop PC (running in the radio network controller, RNC) defines SIR target for the BS.
- If the measured SIR at BS is lower than the SIR-target, the MS is commanded to increases its transmit power. Otherwise MS is commanded to decrease its power
- Power control rate 1500 Hz (fast CL PC)
- Power control dynamics at the MS is 70 dB



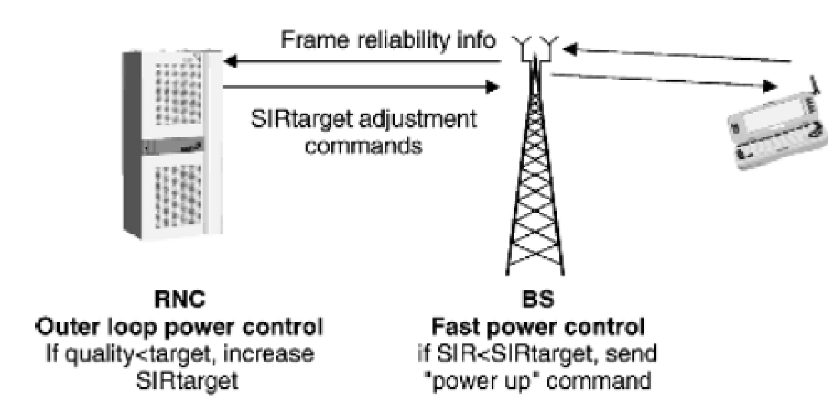
Closed loop PC: downlink

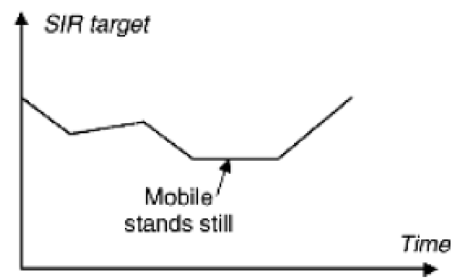
- Outer loop PC (running in the MS) defines SIR target for the MS
- If the measured SIR at the MS is lower than the SIR-target, the BS is commanded to increases its transmit power for that MS. Otherwise, BS is commanded to decrease its power.
- Power control rate 1500 Hz
- Power control dynamics is dependent on the service
- There's no near-far problem in DL due to one-to-many scenario. However, it is desirable to provide a marginal amount of additional power to mobile stations at the cell edge, as they suffer from increased other-cell interference.



Outer loop PC

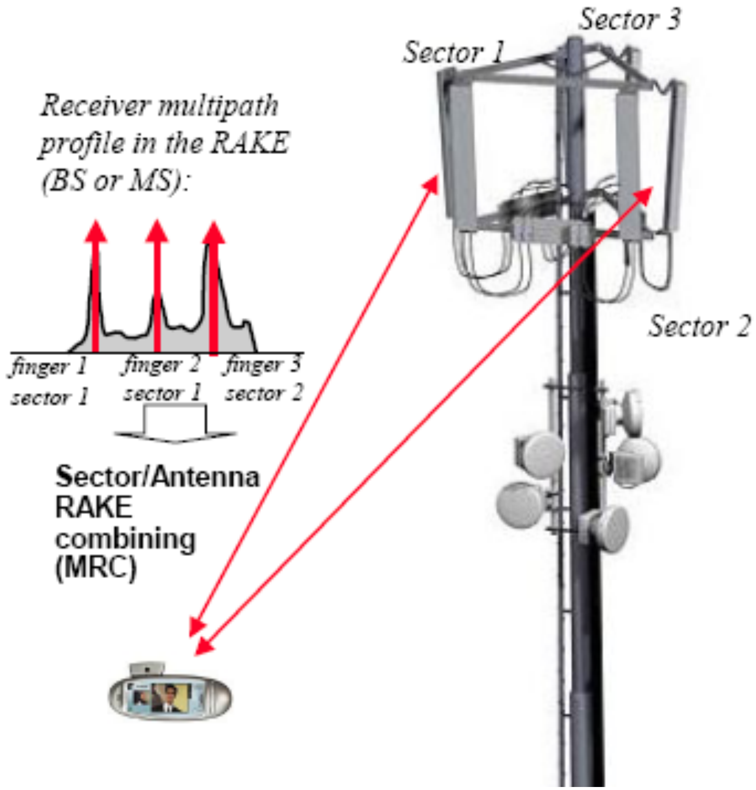
- Closed loop power control tries to keep the received SIR as close to the target SIR as possible.
- However, the constant SIR alone does not actually guarantee the required frame error rate (FER) which can be considered as the quality criteria of the link/service.
  - There's no *unique* SIR that automatically gives a certain FER
  - FER is a function of SIR, but also depends on mobility and propagation environment.
- Therefore, the frame reliabilility information has to be delivered to outer loop control, which can tune the SIR target if necessary.





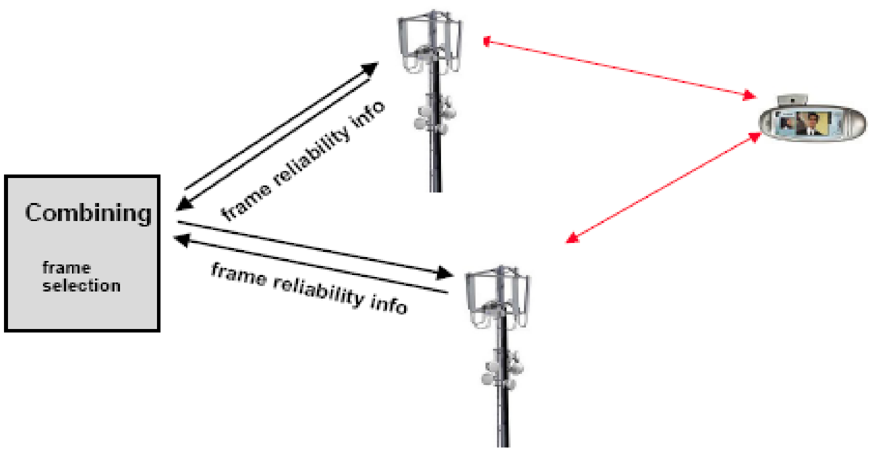
Handovers: softer handover

- During softer handover, a mobile station is in the overlapping cell coverage area of two adjacent sectors of a base station.
- The communications between mobile station and base station take place simultaneously but via two different air interface channels: one for each sector separately.
- This requires the use of two separate codes in the downlink direction, so that the mobile station can distinguish the signals.
- At the MS, separate RAKE fingers are allocated to both sectors.
- Softer HO probability ~ 5-15%



Handovers: soft handover

- During soft handover, a mobile station is in the overlapping cell coverage area of two sectors belonging to *different* base stations.
- As in softer handover, the communications between mobile station and base station take place simultaneously via two air interface channels from each base station separately.
- RAKE processing is applied as well.
- Soft HO probability ~ 20-40%



- Differences is UL/DL
  - DL: MS uses additional RAKE fingers, just like in softer HO
  - UL: both BSs route the received signal to RNC for combining

Why soft/softer handovers?

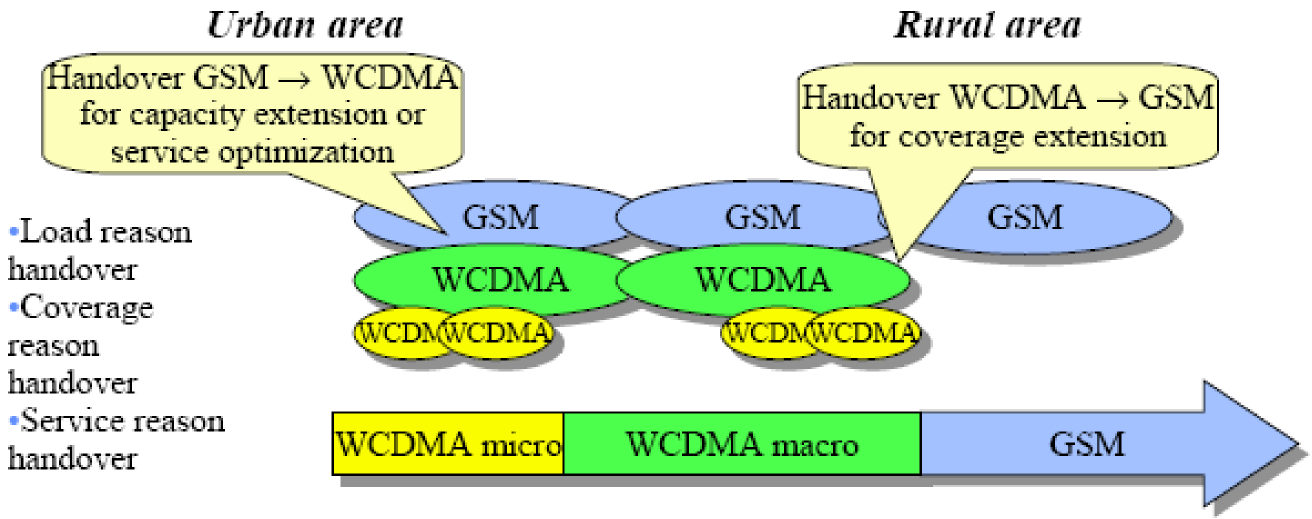
- Recall: in WCDMA all the users share the same frequency band simulateneously, which means that interference situations arise
- Roughly speaking: ”transmit power” = ”interference to the system”, so it’s beneficial to use as little power as possible.

1. Soft/softer HO’s help in reducing transmit powers:
   - Uplink: if two BS’s (or two sectors of one BS) are both receiving the signal of a particular MS, then MS can reduce its transmit power.
   - Downlink: if two BS’s are sending the same signal for the same MS, both BS’s can reduce their transmit power.
2. Soft HO’s give coverage gains
   - The signal to other BS can be temporarily very weak. However, it is more unlike that *both* links are weak at the same time is. Hence, due to the existence of soft/softer handover situation the resulting signal can be relatively good.
   - Seamless handover (compared to hard handover)

- The downsides of HO:
  - Additional RAKE fingers at BS/MS, additional links between BS and RNC
  - Additional signalling

Inter-system handover

- Seamless coverage extension for WCDMA with, for example, existing GSM network.
- Capacity extension for GSM with load sharing between WCDMA and GSM
- Service control - different services to different networks



WCDMA capacity

- Suppose a WCDMA cell has *k* users having the same service of data rate *R*.
- Consider WCDMA uplink (MS to BS): Denote by *S* the received power (Watts) at WCDMA BS from one mobile.
- The signal- to-interference plus noise ratio (SINR) at the output of the receiver equals

$$\frac{\frac{W}{R}S}{(k-1)S+N} \geq \rho$$

- Here *N* is the noise power at the reception, *W* is the chip rate and *ρ* is called a target SINR.
- The maximum capacity is reached when the target is met with equality:

$$k = \frac{\frac{W}{R}S - \rho N}{\rho S} + 1$$

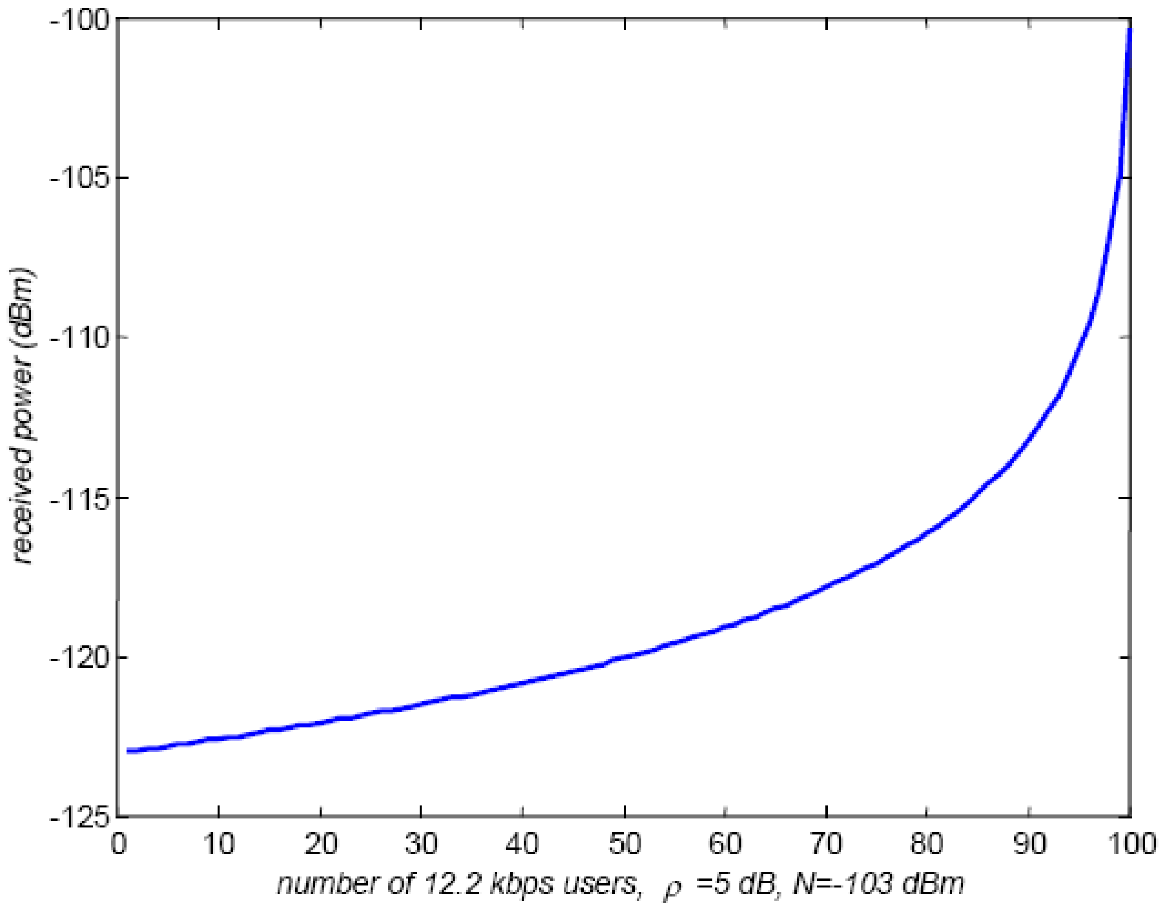
- The maximum capacity (pole capacity) is thus:

$$\lim_{S\to\infty} \frac{\frac{W}{R}S - \rho N}{\rho S} + 1 = \lim_{S\to\infty} \frac{\frac{W}{R} - \frac{\rho N}{S}}{\rho} + 1 = \frac{W}{\rho R} + 1$$

Example: pole capacity

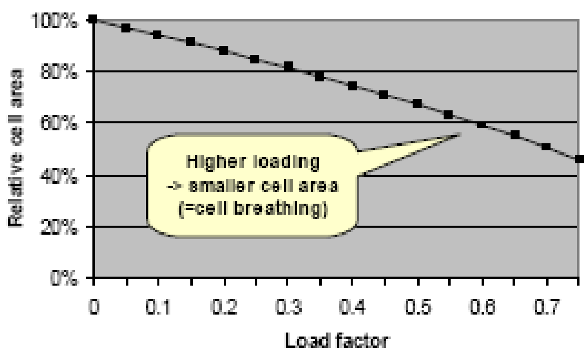
- Received power of one user as a function of users per cell
- N=-103 dBm
- ρ=5 dB
- R=12.2 kbps
- W=3.84 Mcps

- Homework: Use Matlab (or Excel) to get the curve.



Capacity & coverage

- In CDMA coverage and capacity are tight together:
  - When the number of users increases, the interference levels increases, too, and therefore also increased transmit powers are needed in order to keep constant quality.
  - Due to infinite power resources, the more users BS serves the less power BS has for each MS. That is, the coverage will decrease.
- This leads to *cell breathing*: the coverage area changes as the load of the cell changes.
- Therefore, the coverage and the capacity has to plan simultaneously
- Radio resource management (RRM) is needed in WCDMA to effectively control cell breathing.



Exercises

Task 1. Two DS-CDMA spreading codes are s_1=[-1 1 1 -1 1] and s_2=[1 -1 1 -1 1].

a) Are the codes orthogonal ?

b) Suppose a BS is sending user #1 bits [-1 1] with a code s_1 and user #2 bits [1 -1] with a code s_2 at the same time. Generate the data that a BS is sending at the chip level.

c) Suppose that the channel is ideal, so there is no noise and the users receive exactly what was sent by the BS. Detect the bits for user #1 and #2 using their own codes. Are the bits going to be detected correctly?

Task 2. Suppose that bits [1 -1 1 -1] are spread with a DS-CDMA code s_1= [-1 1 1 -1]. Calculate the amplitude of the signal and the interference for every bit if the channel response is the following:

Path amplitude:	0.5	0.3	0.2
Path delay in chips:	0	1	2

Assume that the correlator is tuned to the first path, that is, the first path is considered as the "information" and the other remaining paths give the "interference".

Task 3. Suppose there exists 5, 10, 15 or 20 simultaneous connections of 12.2 kbps data rate in a single WCDMA cell, and each connection has 5dB target for SINR. Determine the total received power by the BS when the noise power at the BS equals -102 dBm. You can assume ideal power control been used.