# Introduction to WCDMA (Chapter 3)

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# Outline

- **What is spread spectrum and where does it come from**
- **Spreading**
- **Correlator and RAKE receiver**
  - **Matched Filter**
- **Uplink and downlink diversity**
- **WCDMA power control**
  - **Closed loop**
  - **Outer loop**
- **WCDMA handovers**
  - **Soft handover**
  - **Softer handover**
- **Concluding remarks**

# What is Spread Spectrum?

- **Transmission bandwidth is much larger than the information bandwidth**
- **Bandwidth is not dependant of the information signal**
- **Processing gain = Transmitted bandwidth / Information bandwidth**
- **Classification**
  - **<u>Direct Sequence</u> (spreading with pseudo noise (PN) sequence)**
  - **Frequency hopping (rapidly changing frequency)**
  - **Time Hopping (large frequency, short transmission bursts)**

  

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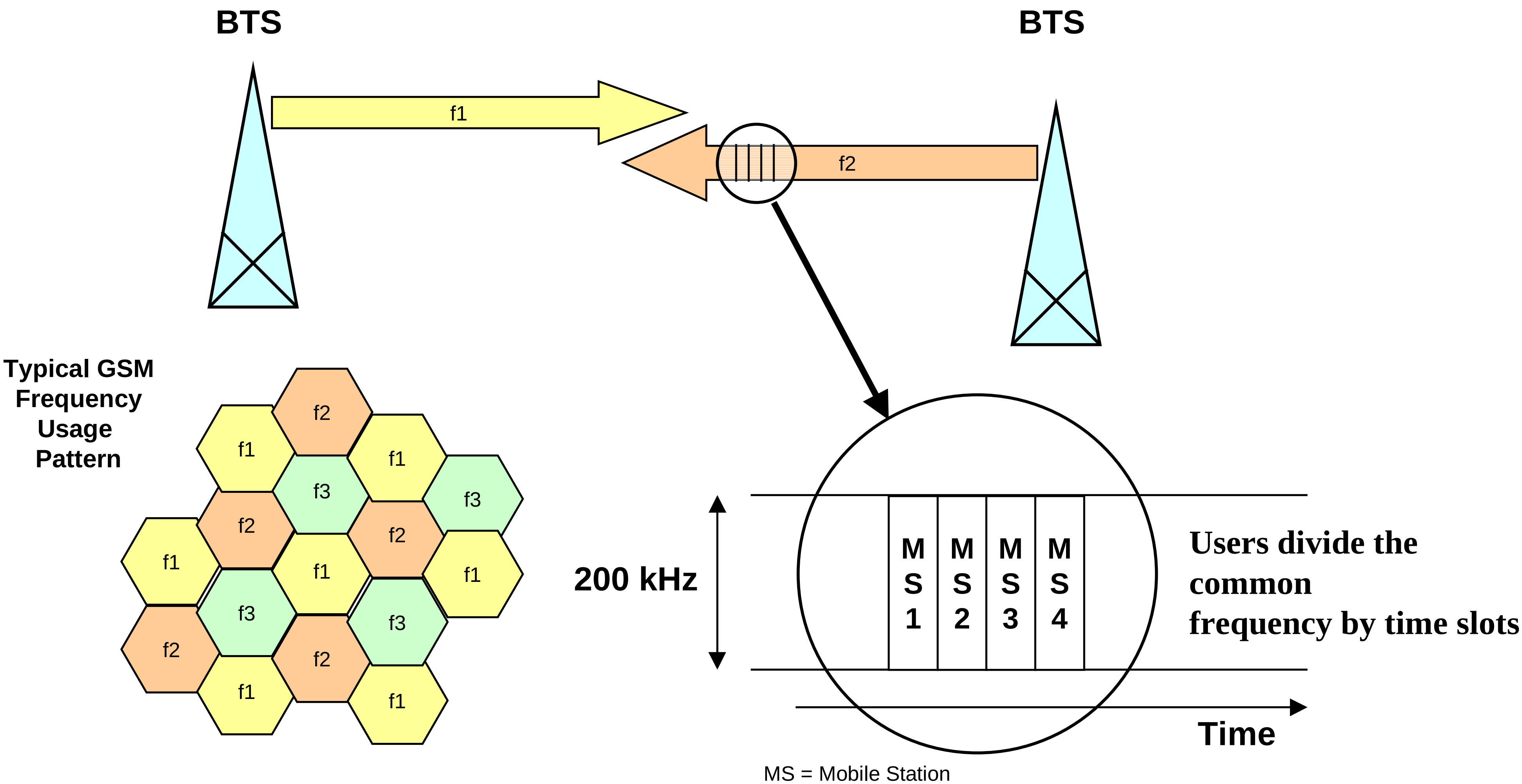
# Where Does Spread Spectrum Come from...

- First publications, late 40s
- First applications: Military from the 50s — Very low C/I
- Rake receiver patent 1956
- Cellular applications proposed late 70s
- Investigations for cellular use 80s
- IS-95 standard 1993
- 1997/1998 3G technology choice in ETSI/ARIB/TTA…

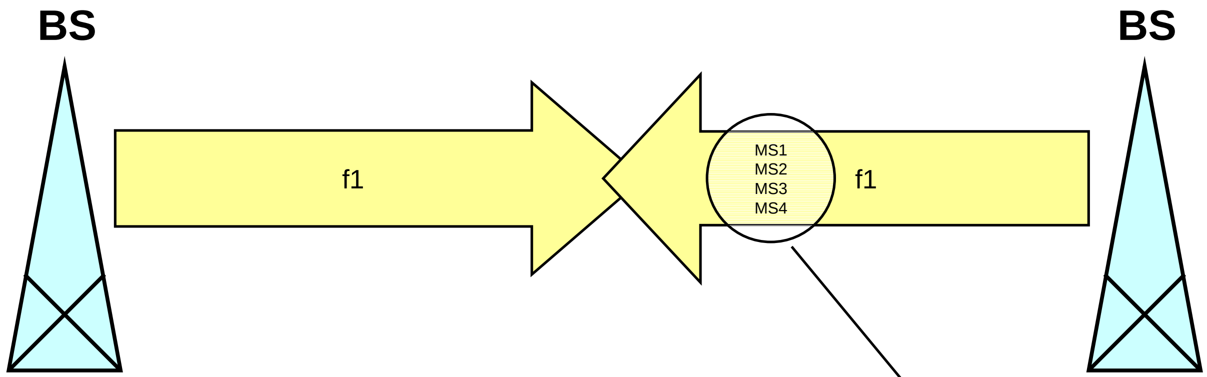
# ... and where is it heading to

- 2001/2002 Commercial launch of WCDMA technology

# GSM System is TDMA Based



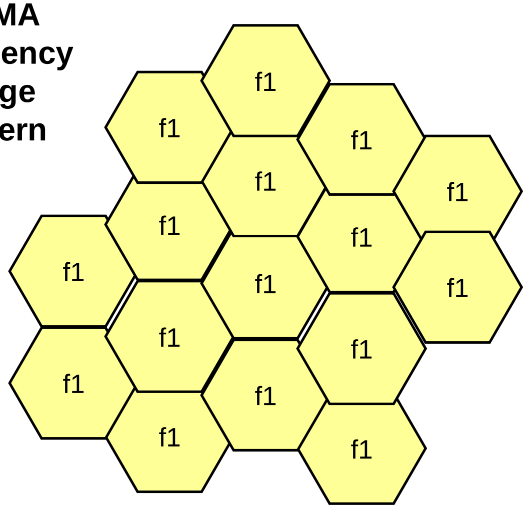
# UMTS System is CDMA Based

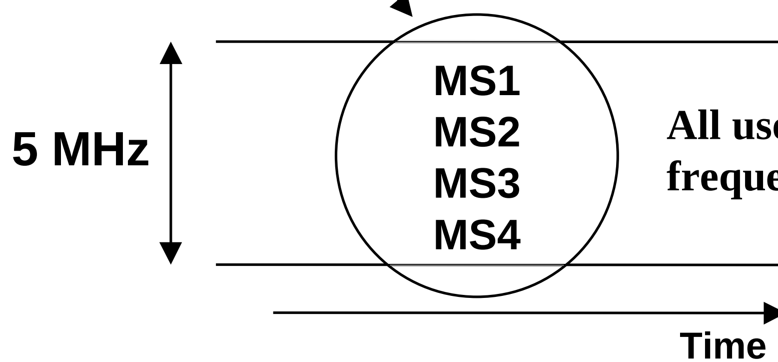



FDD = Frequency-division duplex
- Uplink and Downlink operate in separated frequency bands

TDD = Time-division duplex
- Uplink (UL) and downlink (DL) use the same frequency band, which is time-shared by the UL and DL

CDMA Frequency Usage Pattern

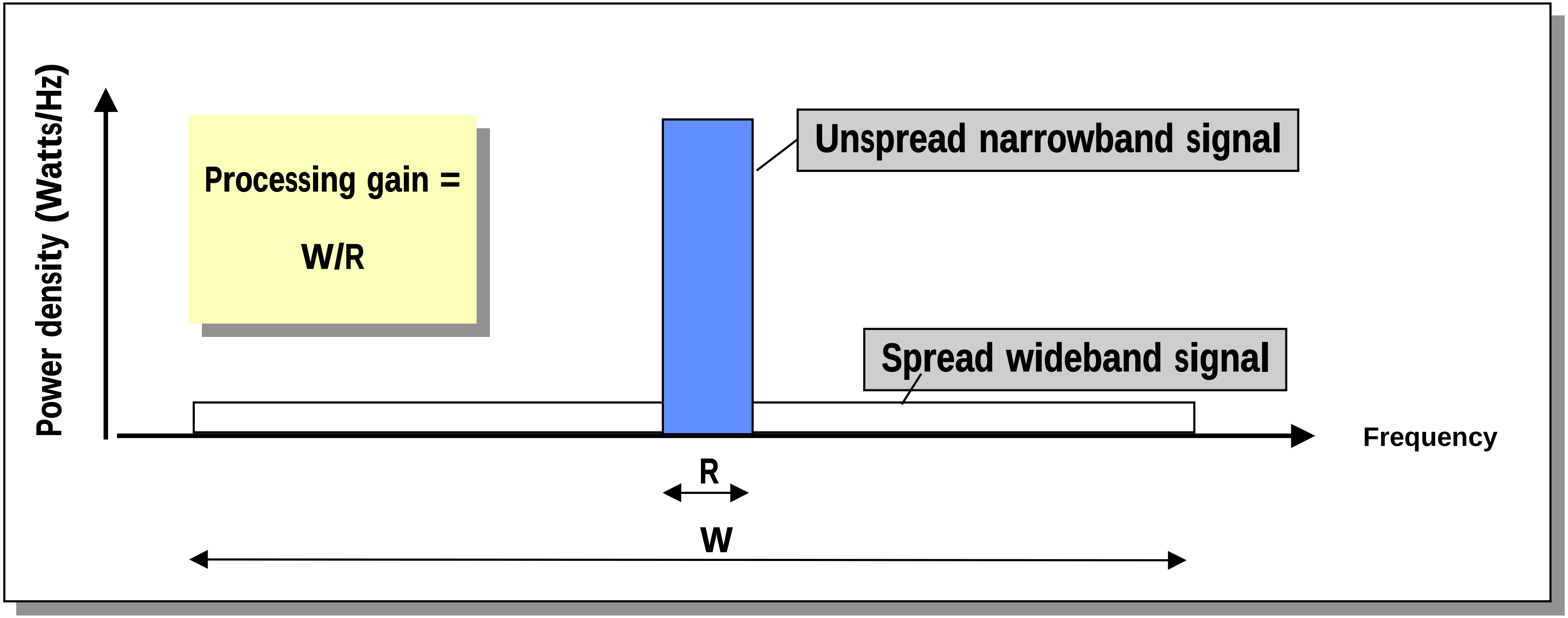


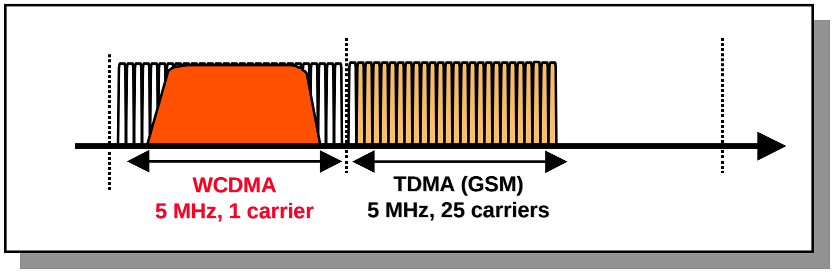




All users share the same frequency/time domain

# Processing Gain & Spreading

- A narrowband signal is spread to a wideband signal




- High bit rate means less processing gain and higher transmit power or smaller coverage



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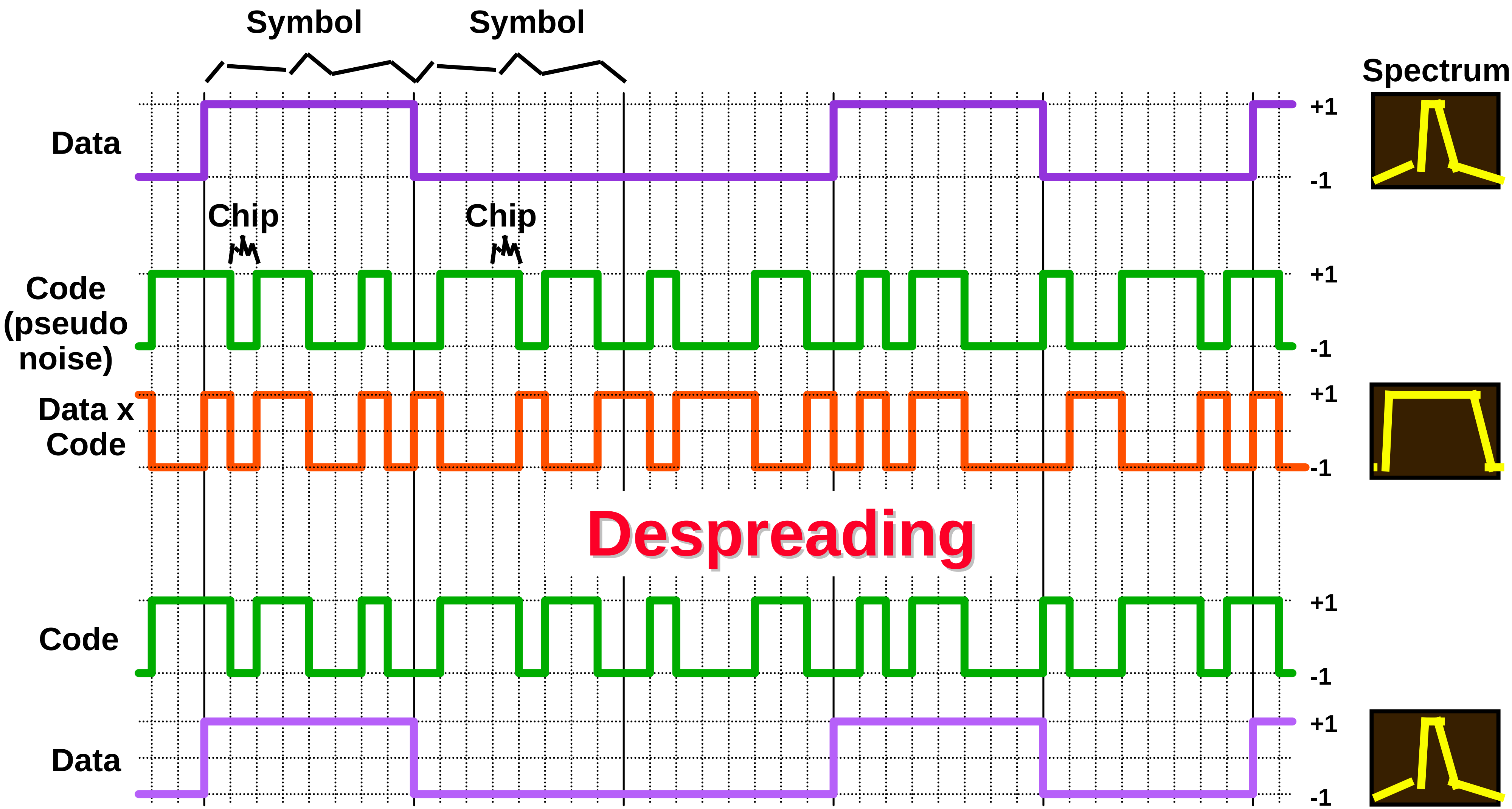
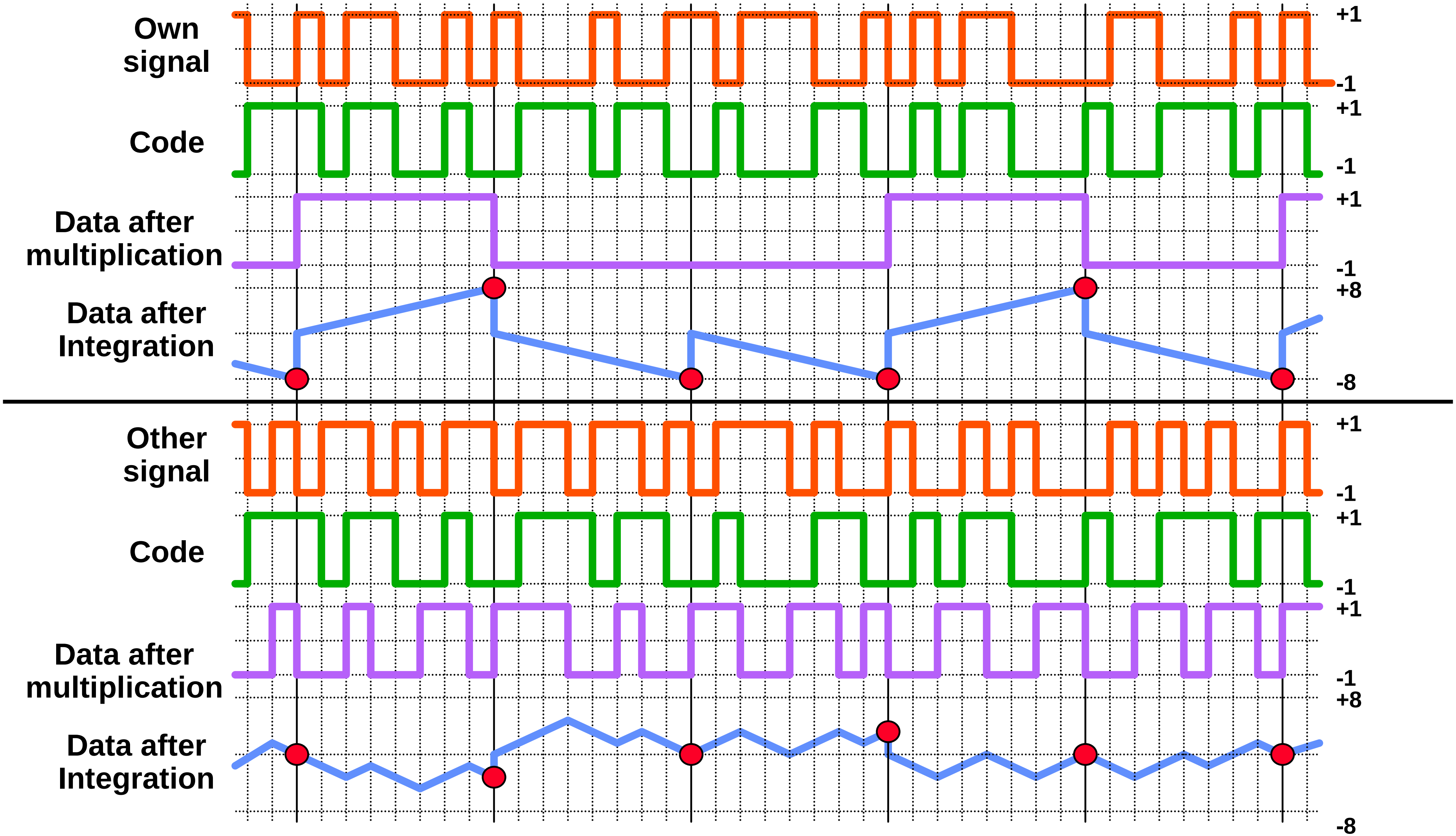
# Spreading

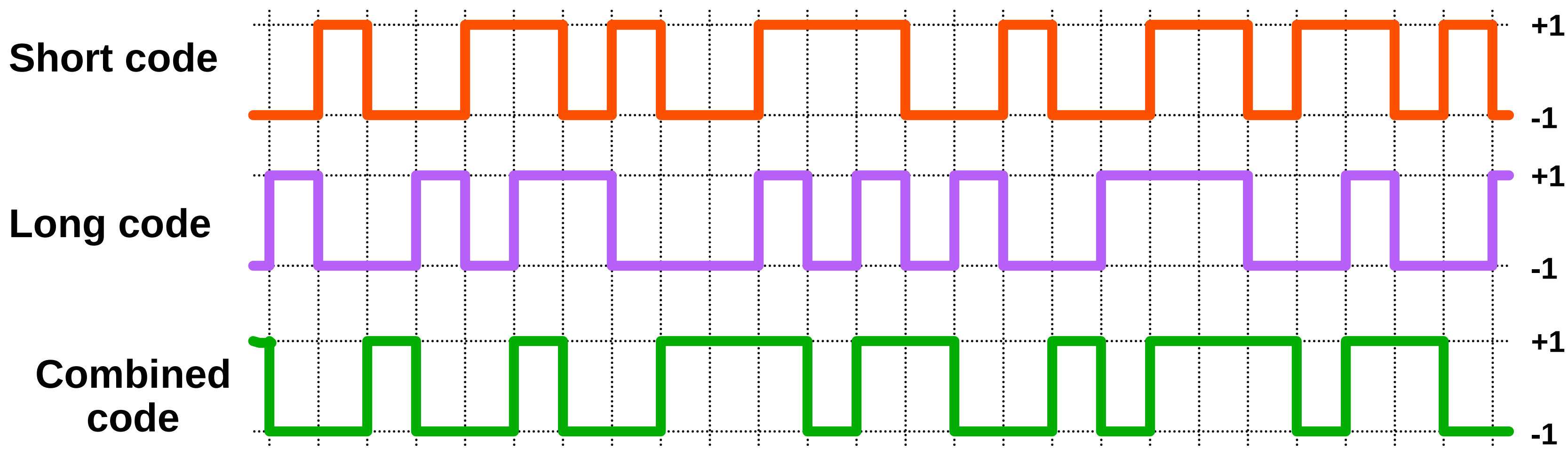

Symbol
Symbol
Spectrum
Data
+1
-1
Chip
Chip
Code (pseudo noise)
+1
-1
Data x Code
+1
-1
Despreading
Code
+1
-1
Data
+1
-1

# Detecting Own Signal. Correlator

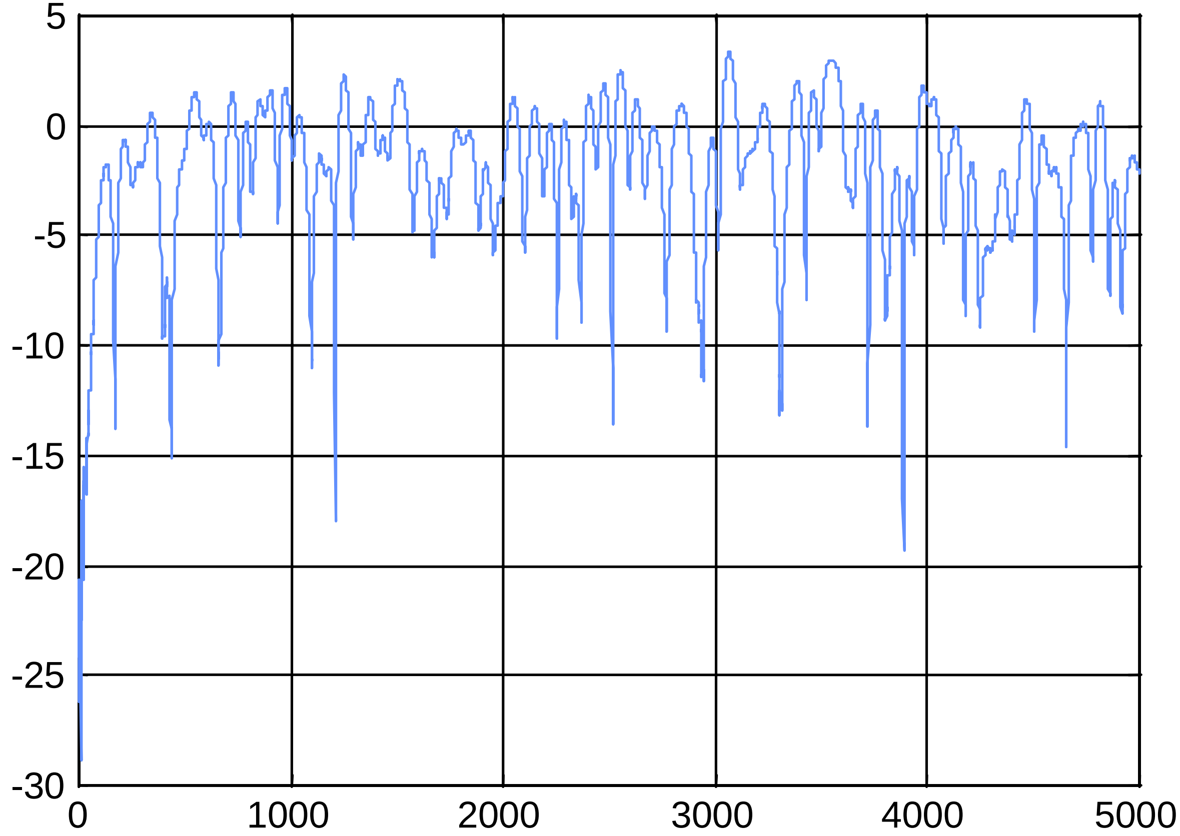


# WCDMA Codes

- Channelisation codes used for channel separation from a single source
  - same codes in all cells ==> need for scrambling
- Scrambling codes separate
  - Uplink: different mobiles
  - Downlink: different cells/sectors
  - Have good interference averaging (correlation) properties



# Fading of a Multipath Component



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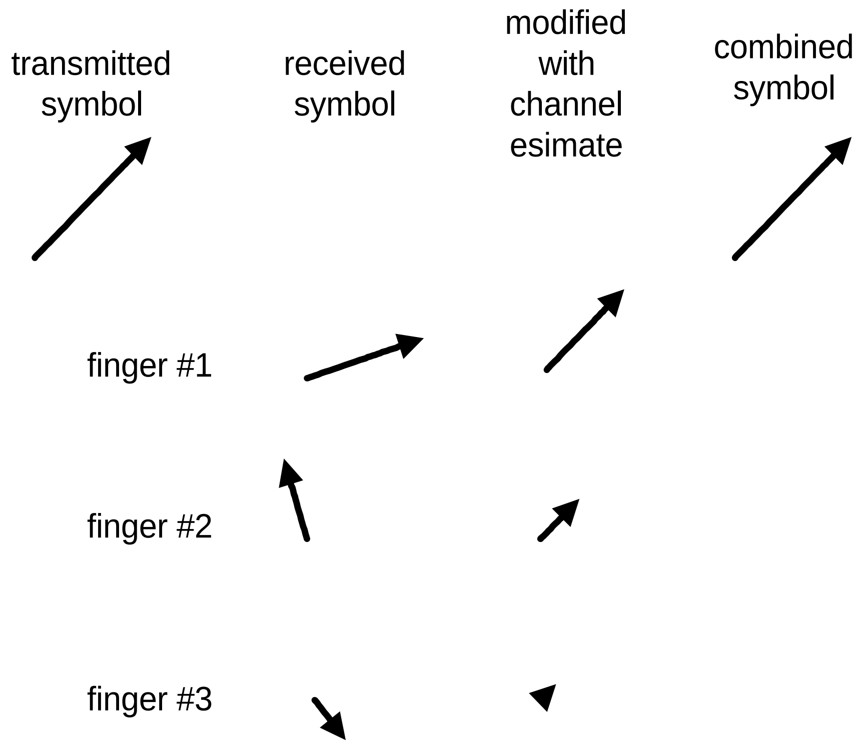
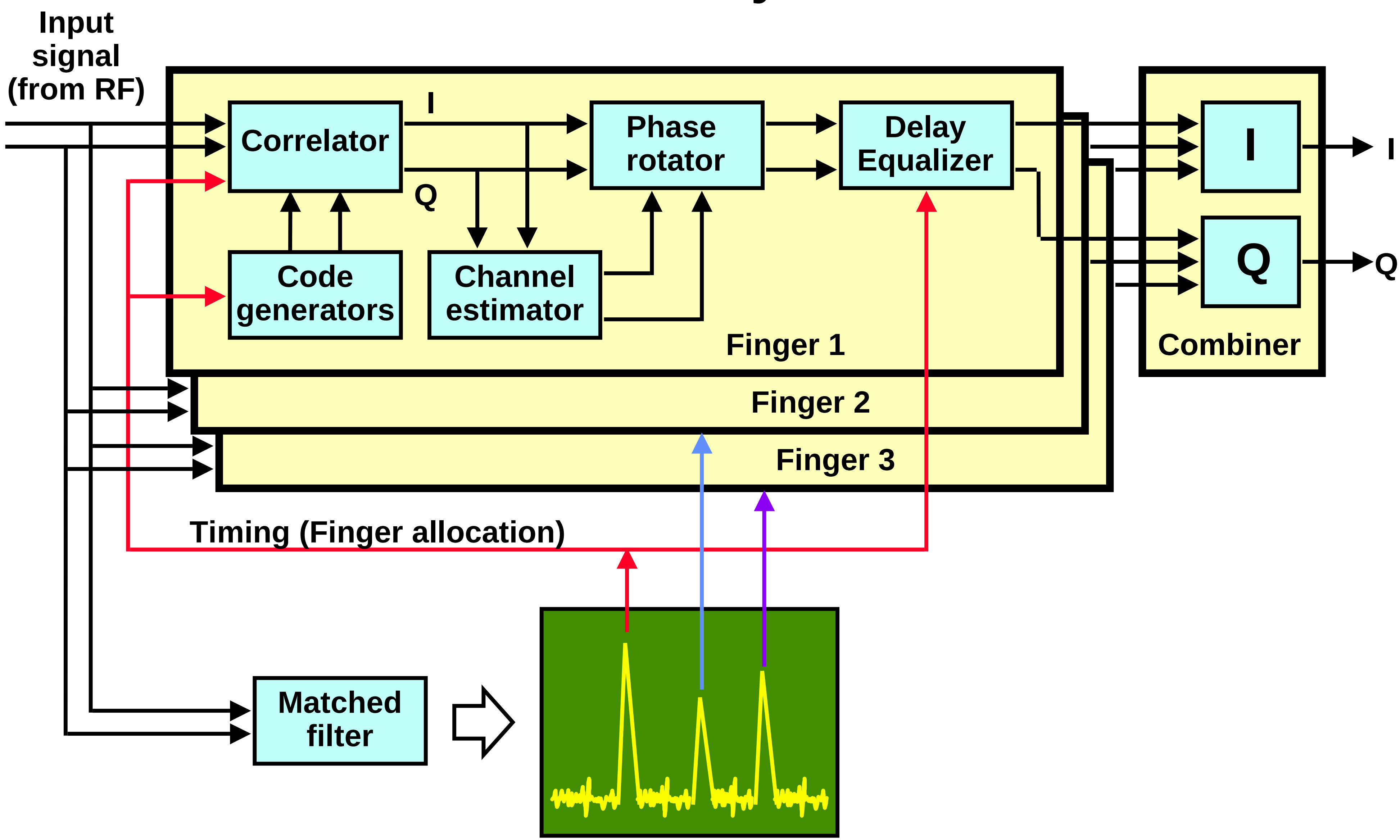
# Maximal Ratio ("RAKE") Combining of Symbols




- **Channel can rotate signal to any phase and to any amplitude**
- **QPSK symbols carry information in phase**
- **energy splitted to many fingers -> combining**
- **maximal ratio combining corrects channel phase rotation and weights components with channel amplitude estimate**

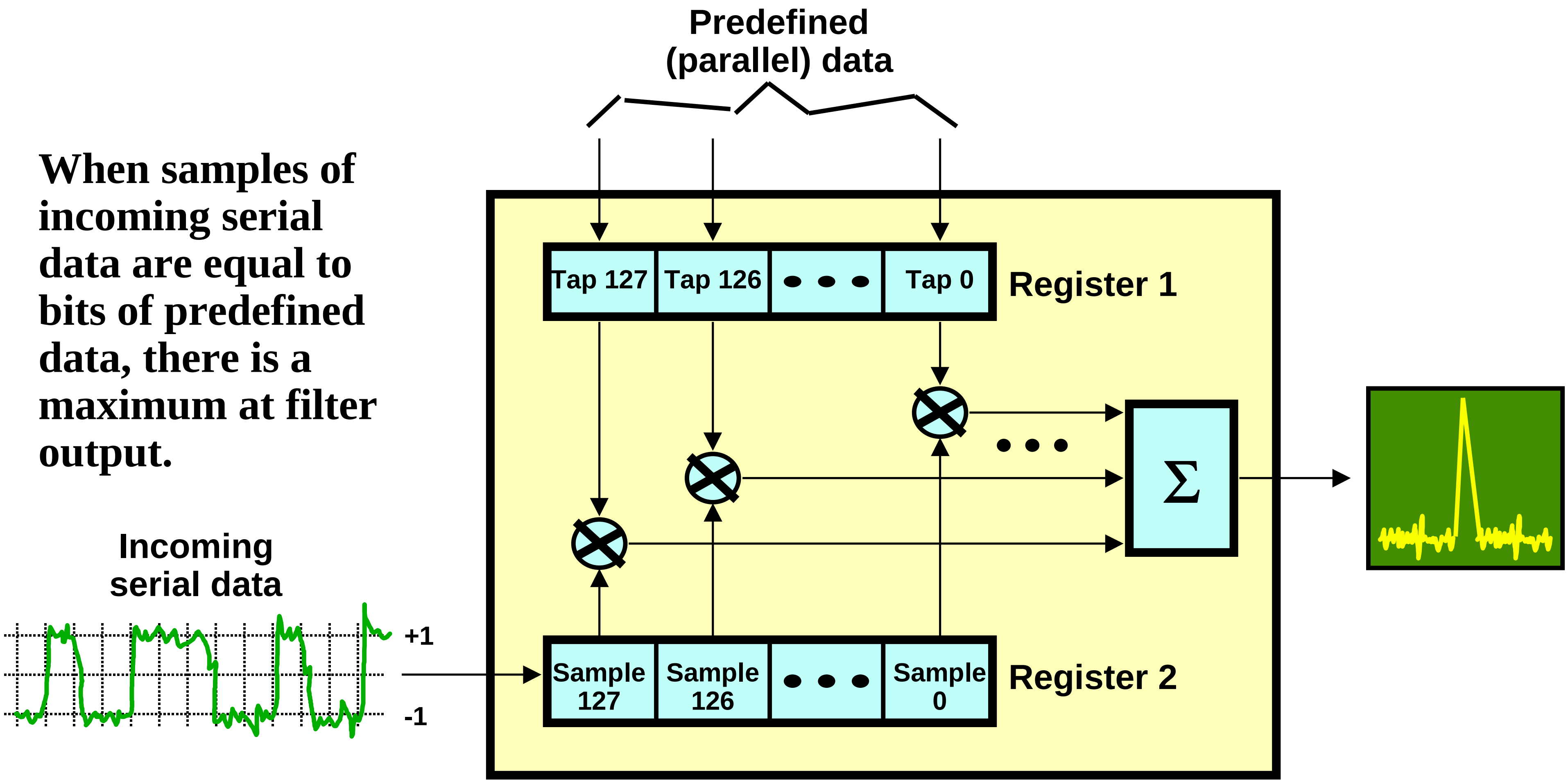
# RAKE Diversity Receiver



# Matched Filter

•To make a successful despreading, code and data timing must be known. Can be detected e.g. by a *matched filter*.

**When samples of incoming serial data are equal to bits of predefined data, there is a maximum at filter output.**



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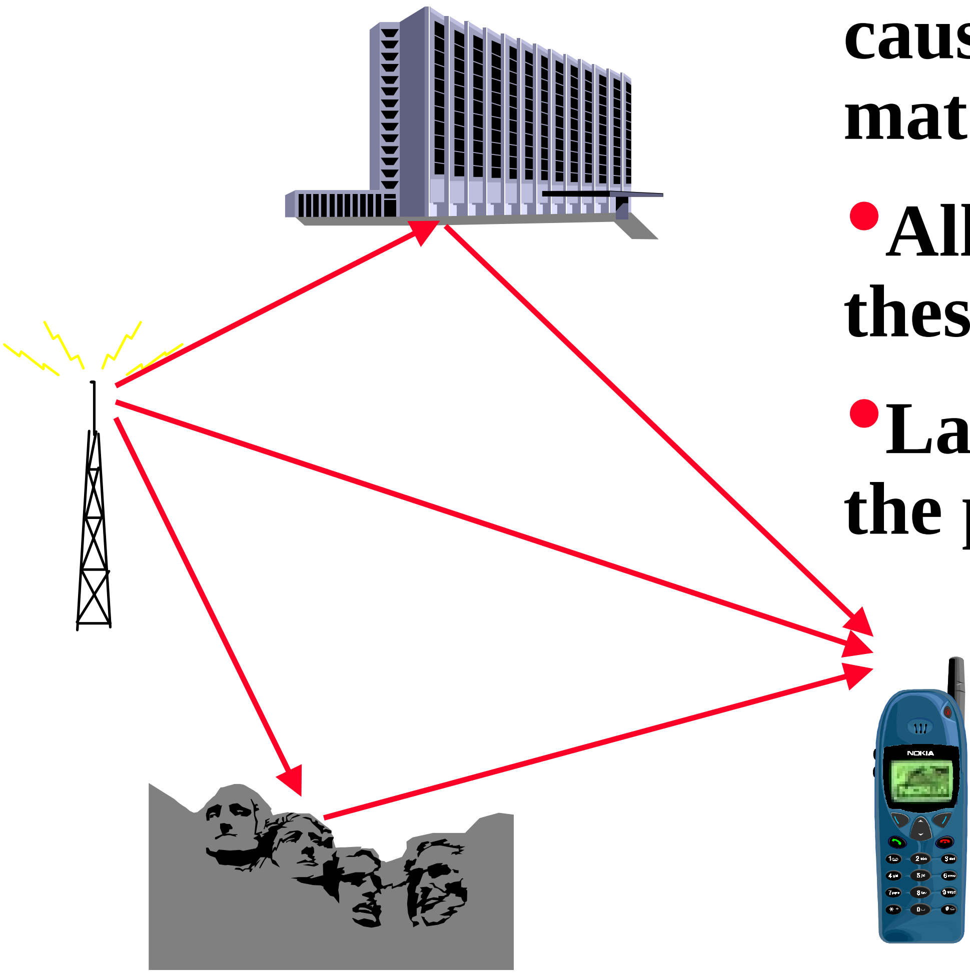
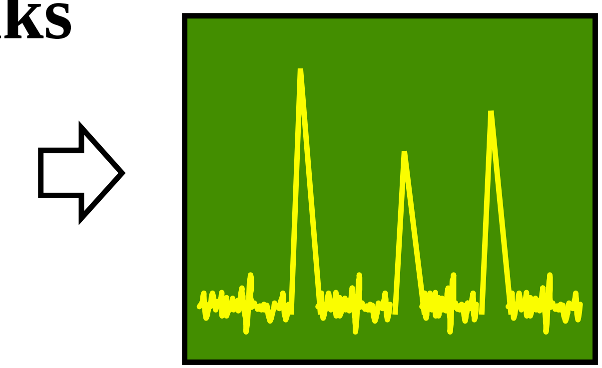
# Delay Profile Estimation with MF



- **Multipath propagation causes several peaks in matched filter (MF) output**
- **Allocate RAKE fingers to these peaks**
- **Later: track and monitor the peaks**





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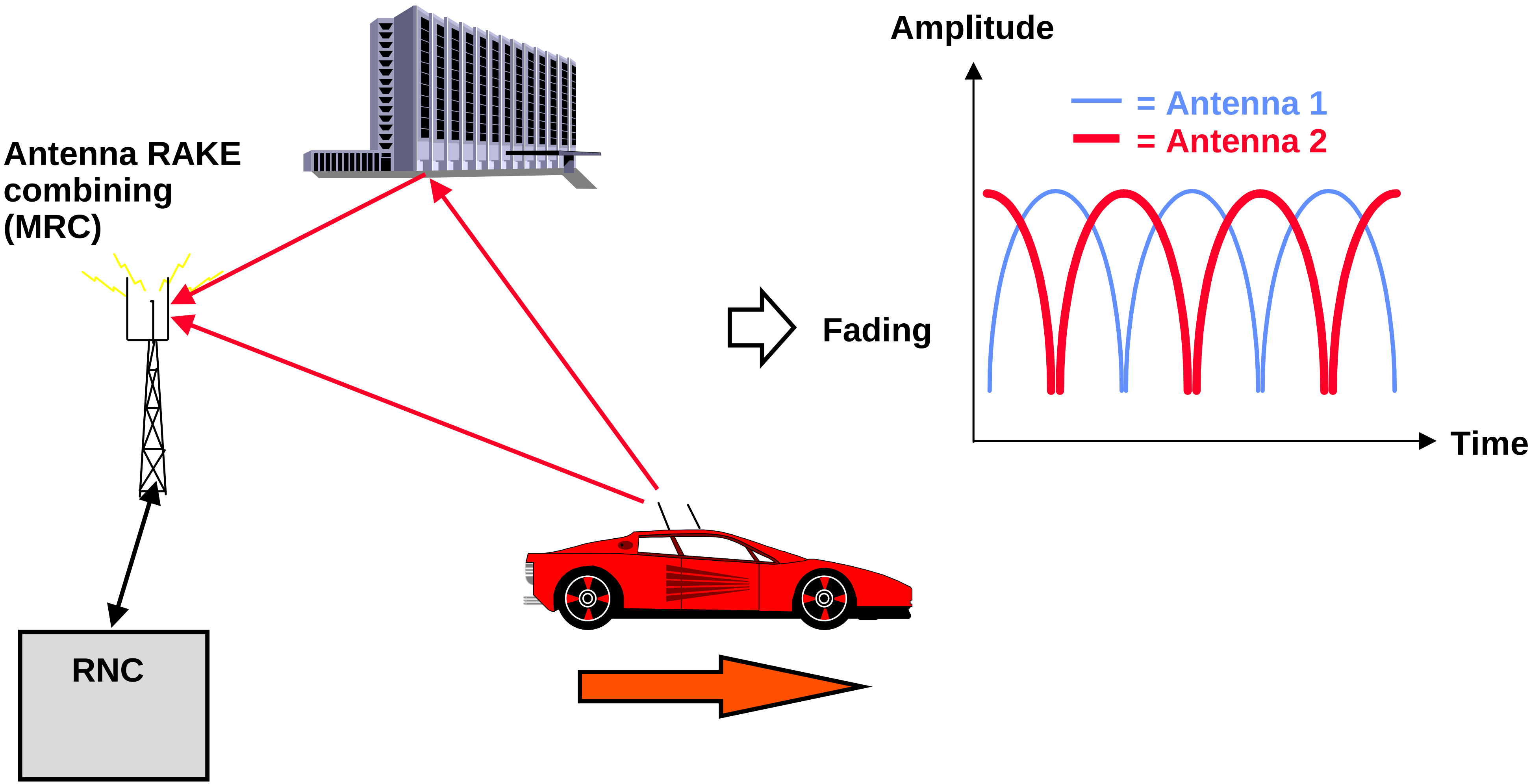
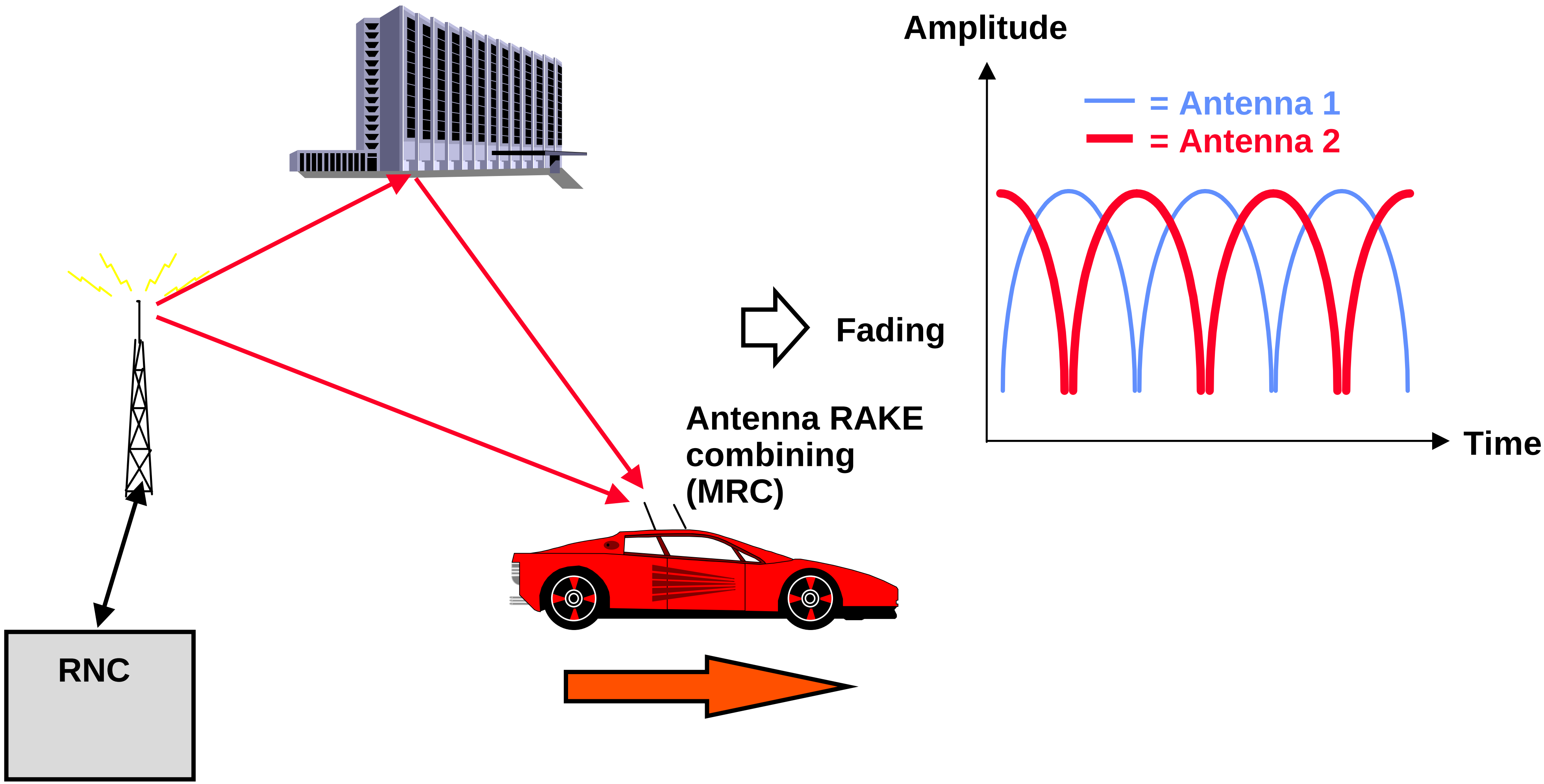
# UL Receiver Diversity (Space Diversity)



# DL Receiver Diversity (Space Diversity)



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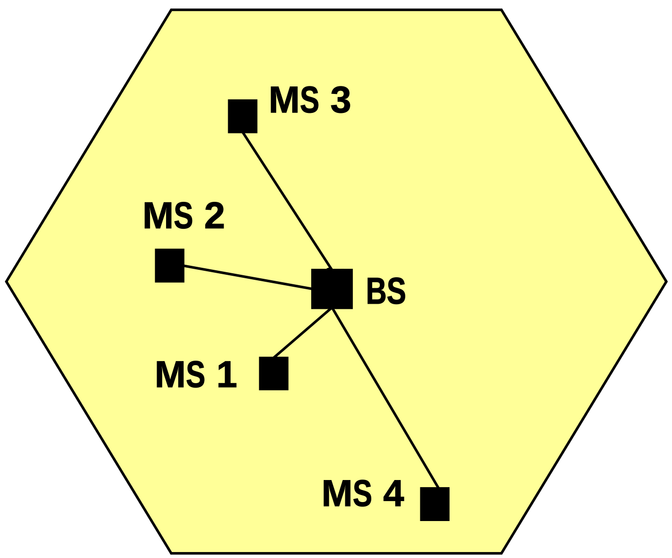
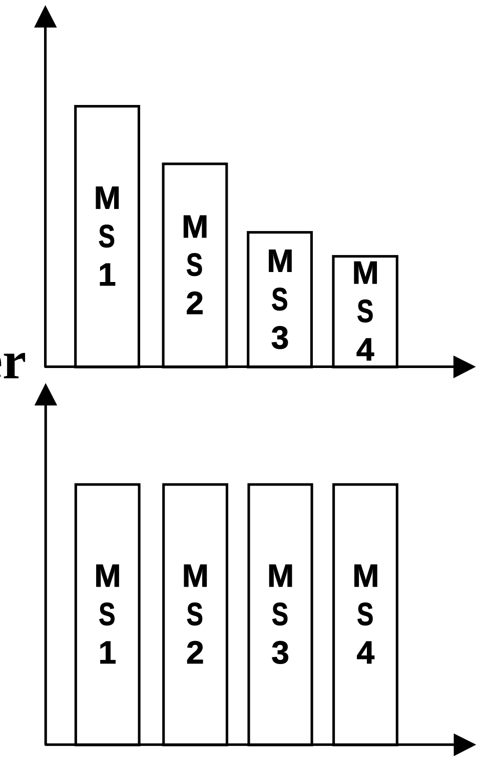
# WCDMA Power Control




Received Power at the BS




Without Power control

With Optimal Power control

**The purpose of power control is to ensure that each user receives and transmits just enough energy to properly convey information while interfering with other users no more that necessary**



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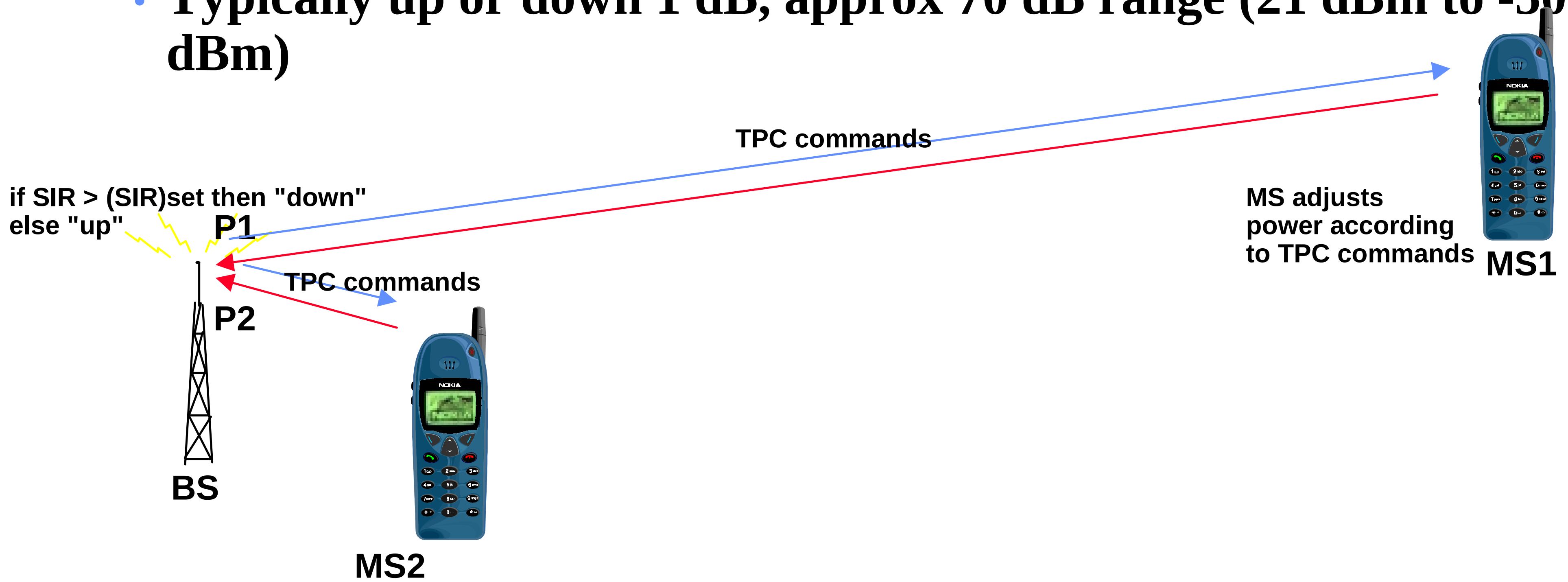
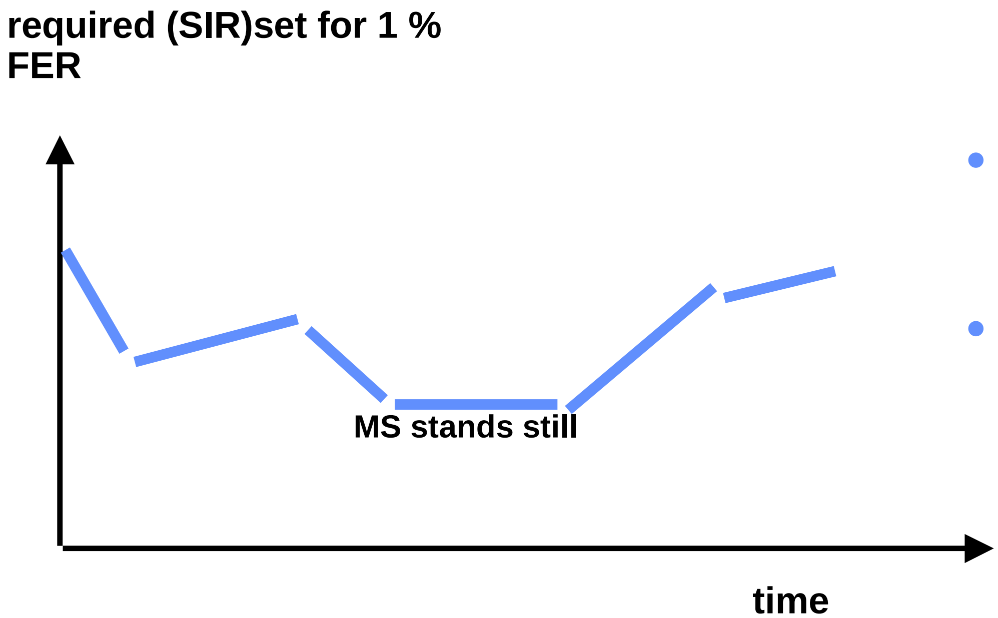
# Fast Closed Loop Power Control

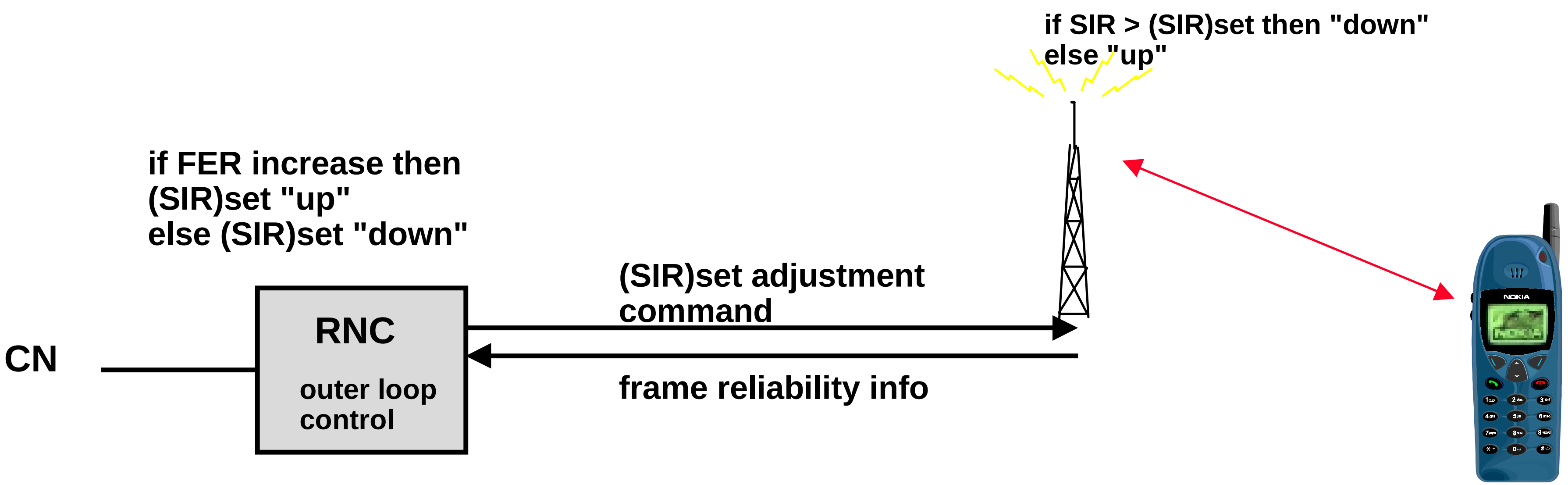
- Effective power control is essential in WCDMA due to frequency re-use 1
- open loop power control for *initial* power setting of the MS
- across the air-interface: closed loop power control 1.5 kHz
  - Eliminates near-far problem
  - Typically up or down 1 dB, approx 70 dB range (21 dBm to -50 dBm)



# Uplink Outer Loop TPC




- **Outer loop TPC maintains link quality**
- ***during soft handover*: comes *after* soft handover frame selection**



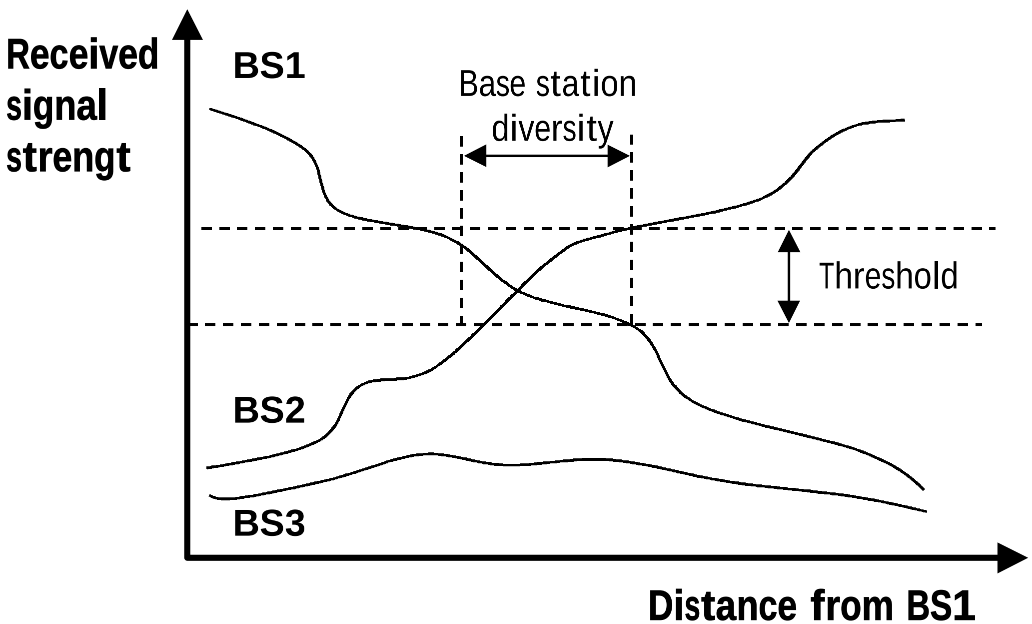

  

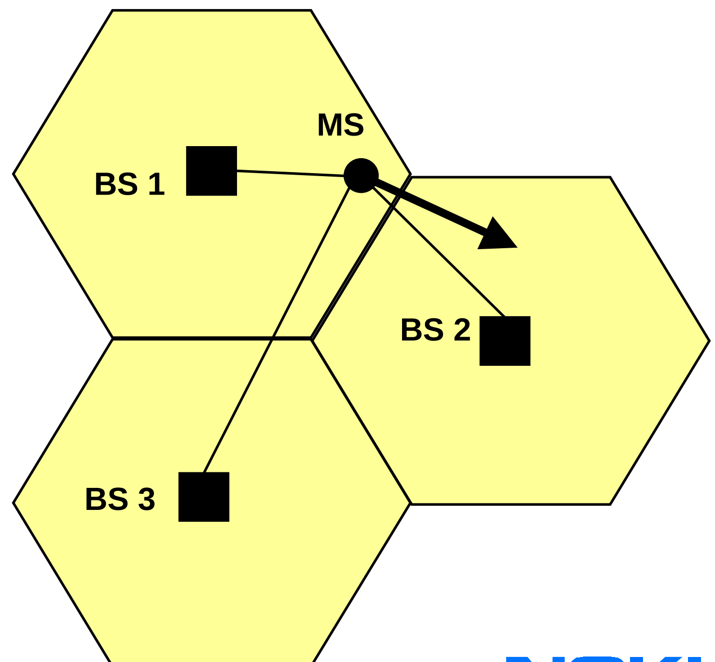
# WCDMA Handovers

Soft handover
- MS handover between different base stations

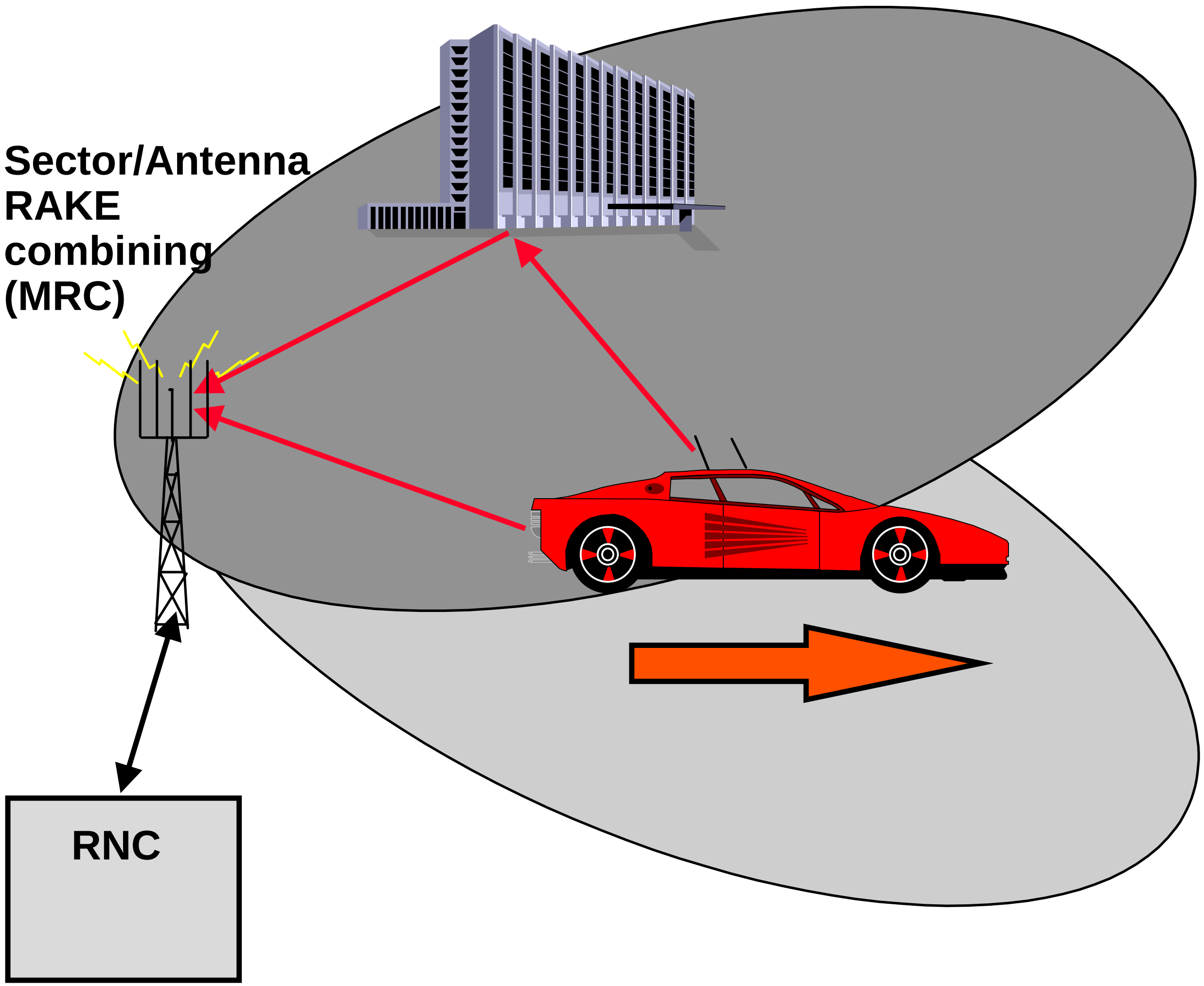
Softer handover
- MS handover within one cell between different sectors

Hard handover
- MS handover between different frequencies or  between WCDMA and GSM (or TDD)



# Softer Handover




- BTS internally
- No extra transmissions in the network side
- Same Rake processing basically
- Provides additional diversity gain



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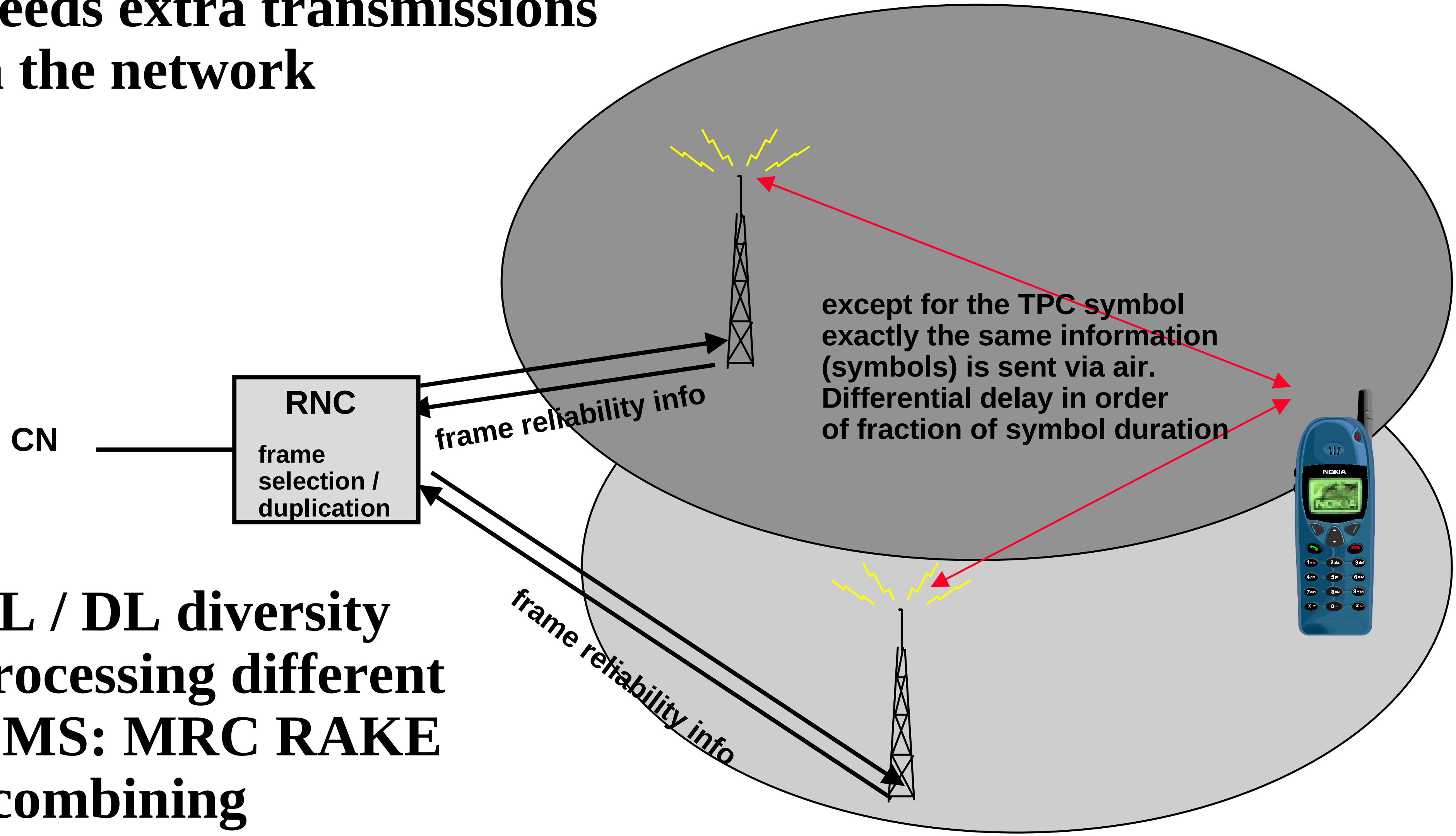
# Soft Handover

- Needs extra transmissions in the network




- UL / DL diversity processing different
  - MS: MRC RAKE combining
  - RNC: frame selection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# Concluding Remarks

- WCDMA benefits from and also requires:
  - Fast power control
    - Due near far problem
  - Soft/Softer handover
    - Due frequency reuse of 1

- WCDMA RAKE receiver
  - Allows various diversity methods
  - Is well known technology from research and 2nd generation systems



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# WCDMA Physical Layer (Chapter 6)

# Main 3G Requirements on Physical Layer

- High bit rates up to 2 Mbps
- Bandwidth-On-Demand = Flexible variable bit rate
- Multi-service = Multiplexing of different services on a single physical connection
- Efficient packet data operation = support for all-IP
- High spectral efficiency, especially in downlink

- How can we fulfill these requirements with WCDMA physical layer?

# Variable bit rate

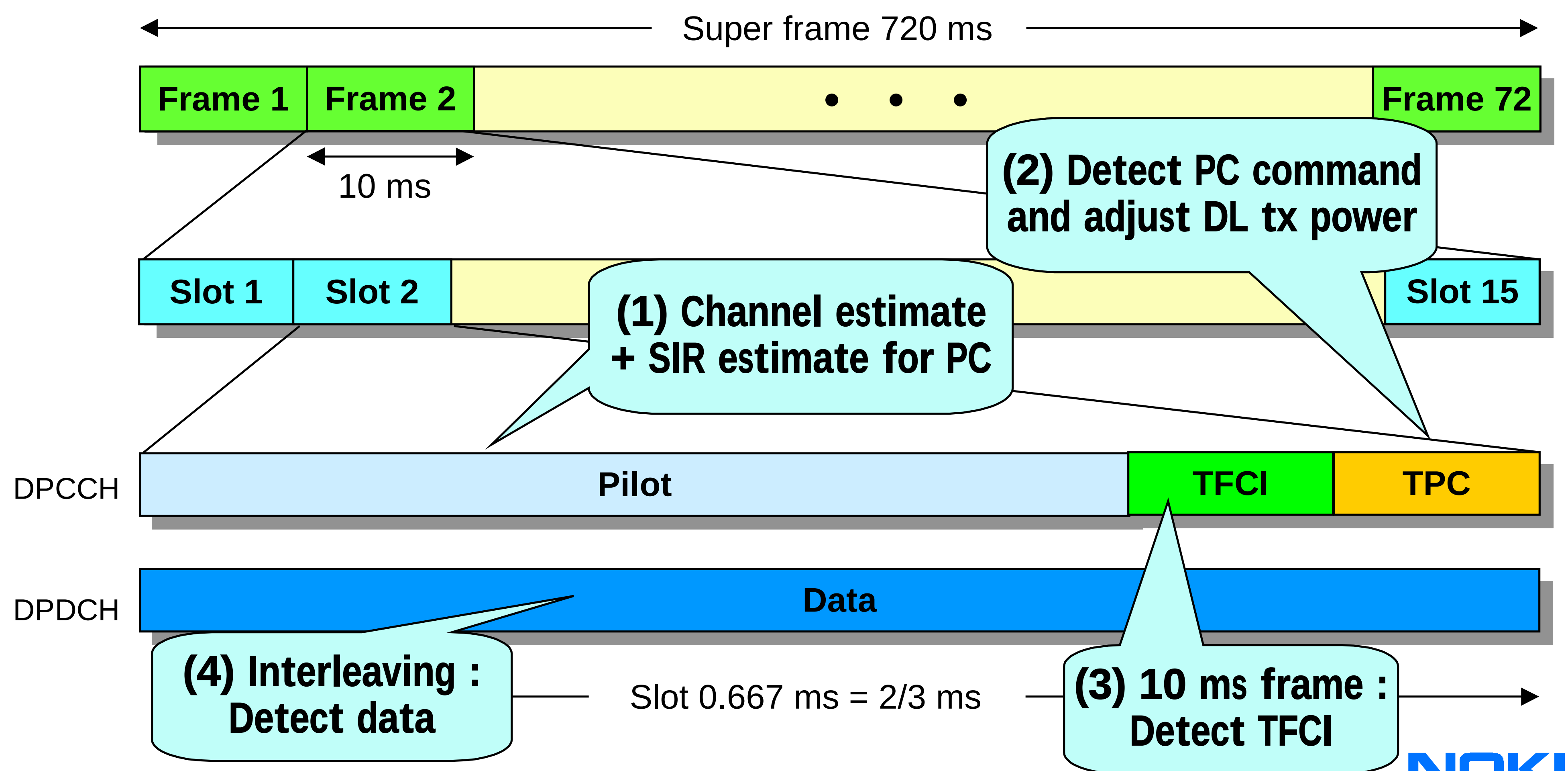
# Variable Bit Rate (Dedicated Channels)

- **DPCCH** (Dedicated physical control channel) is **constant** bit rate and carries all information needed to keep physical connection running
  - Reference symbols for channel estimation in coherent detection and for SIR estimation in fast power control
  - Power control signalling bits (TPC)
  - Transport format combination information (TFCI) = bit rate, interleaving
- **DPDCH** (Dedicated physical data channel) is **variable** bit rate
  - User data
  - Higher layer signalling, e.g. mobile measurements, active set updates, packet allocations
- DPDCH bit rate is indicated with TFCI bits on DPCCH

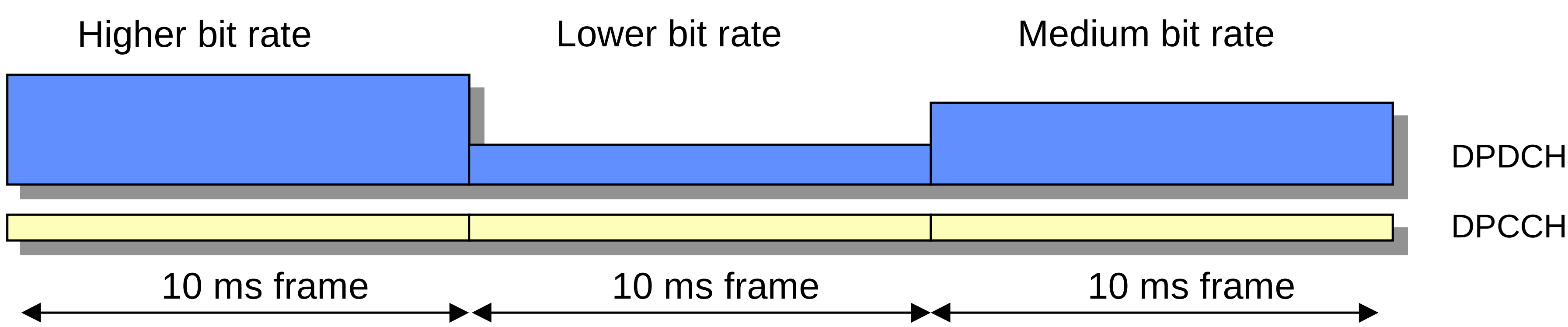
# Uplink Dedicated Physical Channel

- I-Q/code multiplexed DPCCH and DPDCH
- Frame 10 ms, slot 0.667 ms (=2/3 ms)



# Uplink Variable Rate

- DPDCH bit rate can change frame-by-frame (10 ms)
- Higher bit rate requires more transmission power
- Continuous transmission regardless of the bit rate
  - Reduced audible interference to other equipment (nothing to do with normal interference, does not affect the spectral efficiency)
  - GSM audible interference frequency ~217 Hz (=1/4.615 ms)
- Admission control in RNC allocates those bit rates that the connection can use on physical layer





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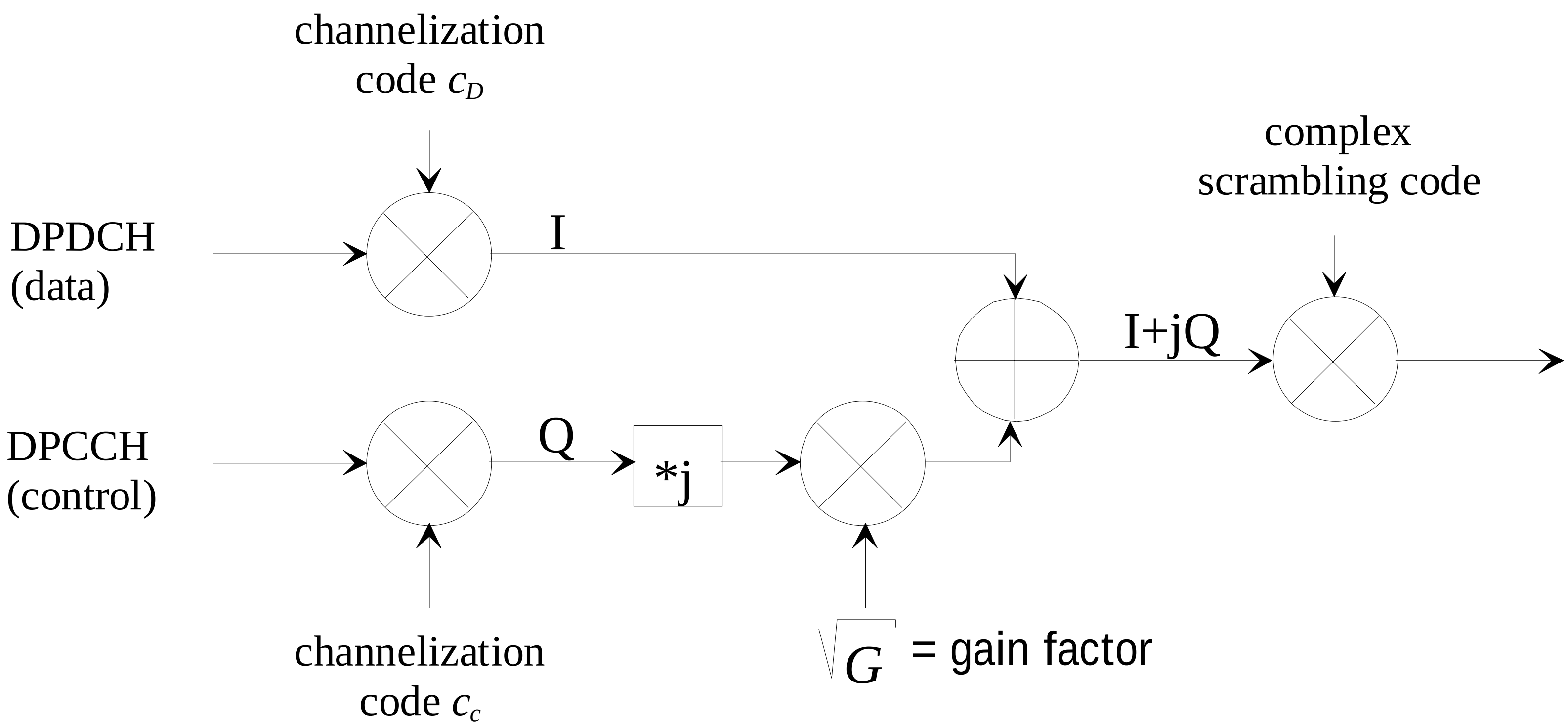
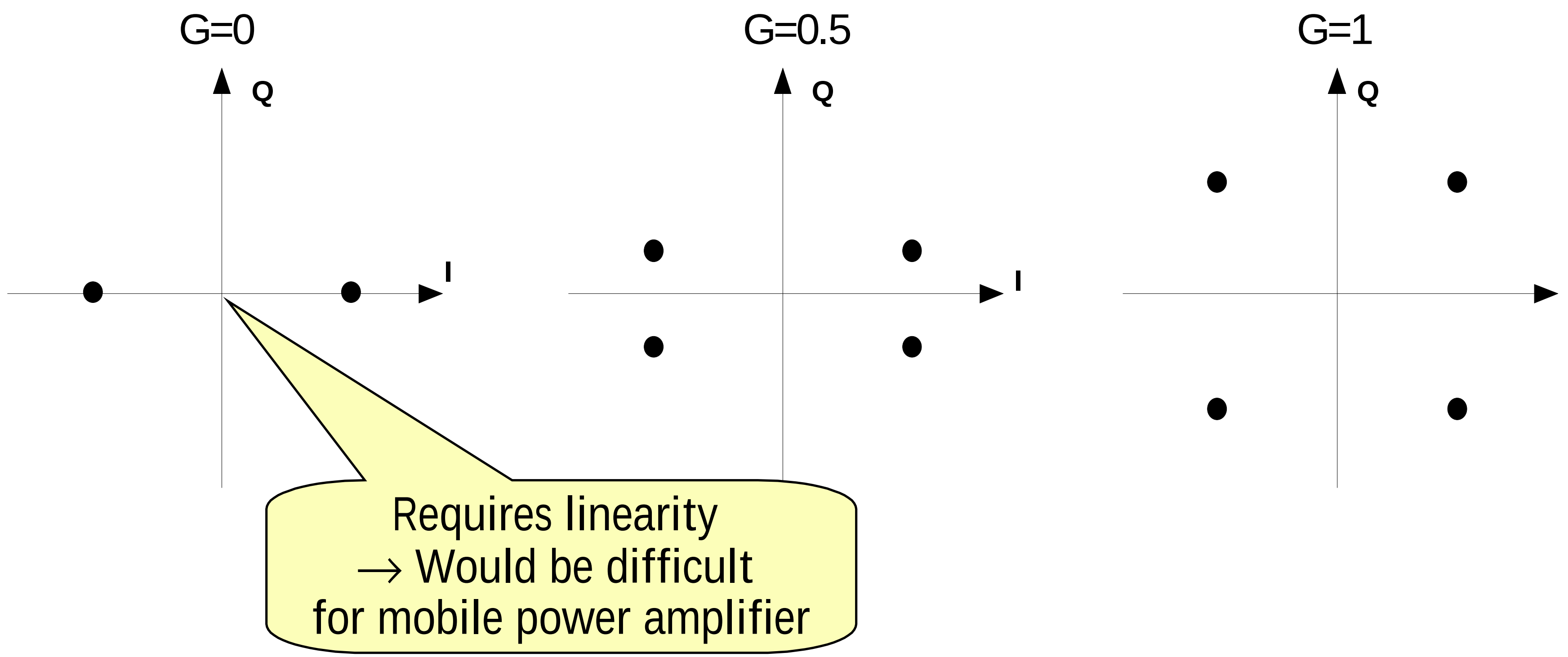
# I-Q/code Multiplexing in Uplink

- Code multiplexing of DPCCH and DPDCH → multicode transmission → envelope variations
- ETSI/WCDMA solution: I-Q/code multiplexing with complex scrambling (Dual channel BPSK)



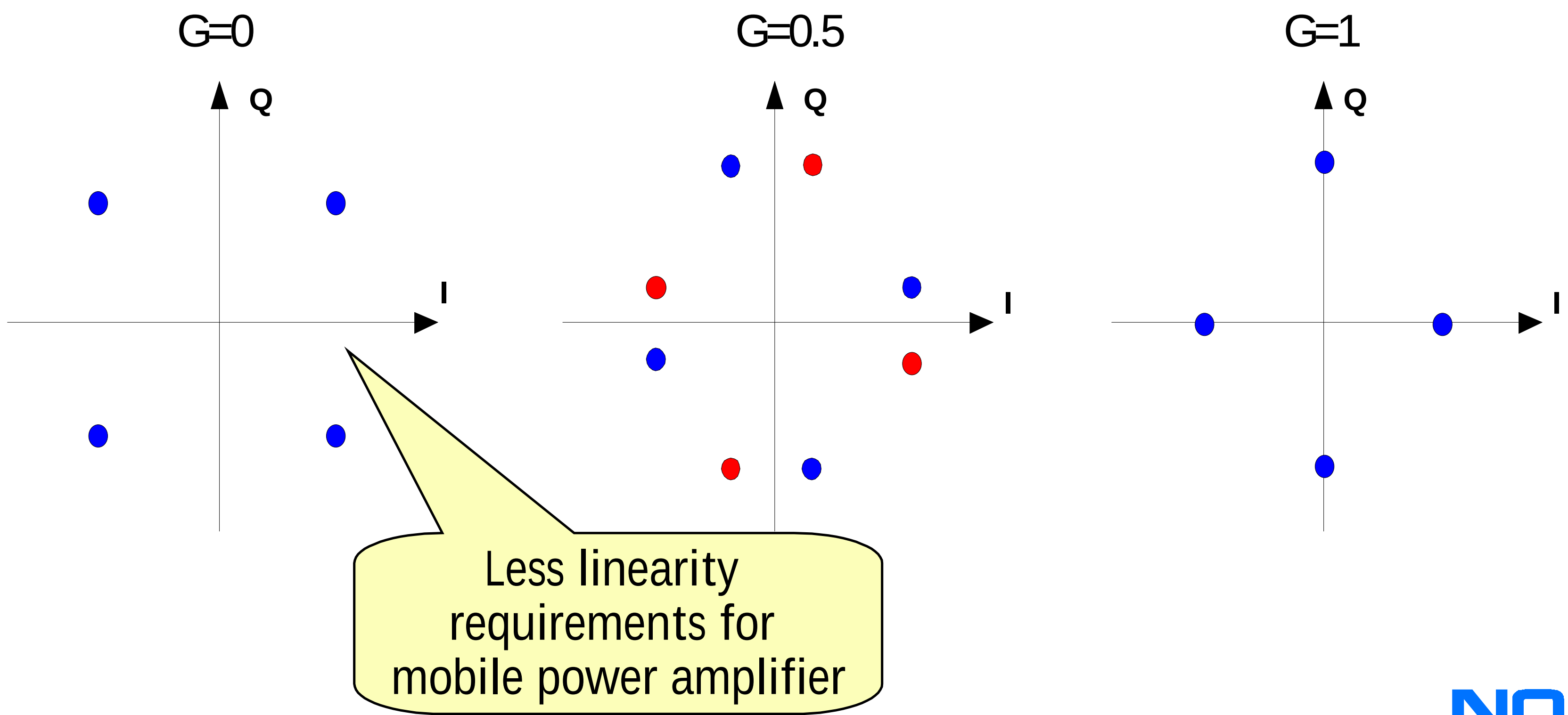
# I-Q/code Multiplexing in Uplink

- Signal constellation ***before*** complex scrambling
- Depending on *G*, constellation can be close to BPSK or QPSK
- *G* = power ratio between DPCCH and DPDCH



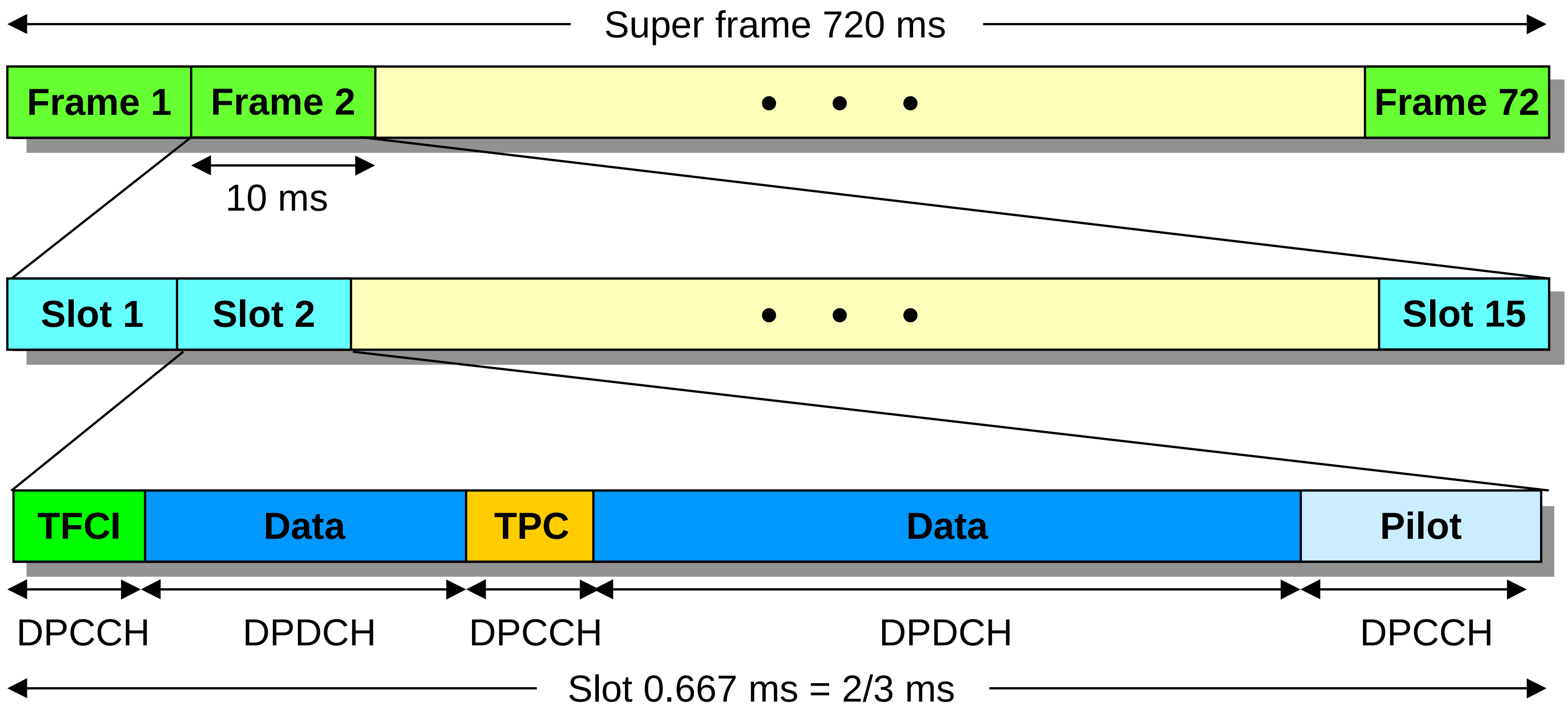
# I-Q/code Multiplexing in Uplink

- Signal constellation ***after*** complex scrambling (at power amplifier)
- Signal envelope variations are similar to single code QPSK with all values of *G*
- *G* = power difference between DPCCH and DPDCH



# Downlink Dedicated Physical Channel

- Time multiplexed DPCCH and DPDCH
- Support for blind rate detection
- Discontinuous transmission



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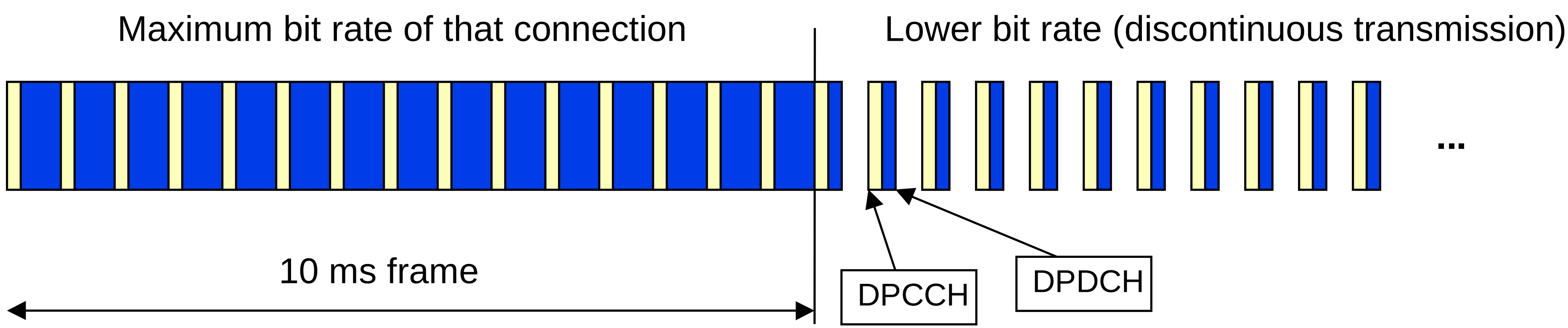
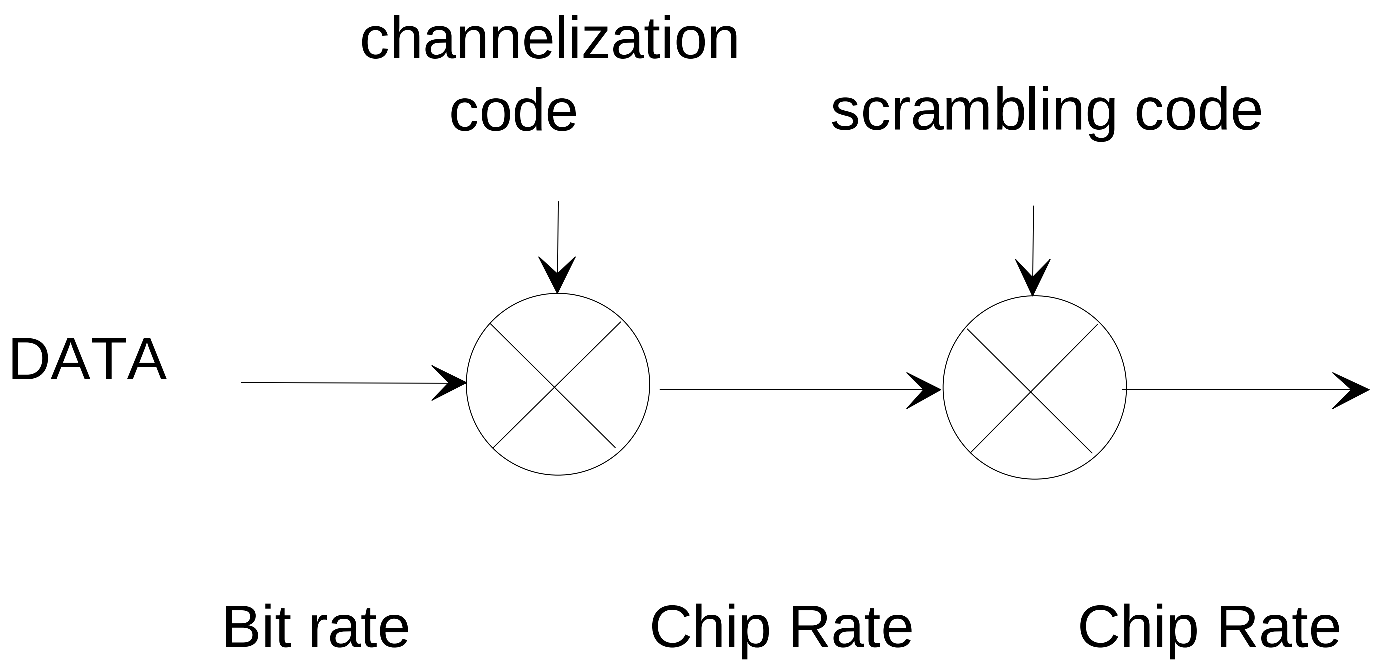
# Downlink Variable Rate

- DPDCH bit rate can change frame-by-frame (10 ms)
- Rate matching done to the maximum bit rate of that connection
- Lower bit rates obtained with discontinuous transmission (audible interference not a problem in downlink)
- Admission control allocates those bit rates that can be used on physical layer



# Spreading and Scrambling

- Channelization code (=short code) provides spreading = increase of the transmission bandwidth
- Scrambling code (=long code) provides separation of users / cells, and does not affect the transmission bandwidth



# Long and Short Codes

| | **Short code = Channelisation code** | **Long code = Scrambling code** |
|---|---|---|
| Usage | Uplink: Separation of physical data (DPDCH) and control channels (DPCCH) from same terminal<br>Downlink: Separation of downlink connections to different users within one cell | Uplink: Separation of mobile<br>Downlink: Separation of sectors (cells) |
| Length | 4–256 chips (1.0–66.7 µs)<br>Downlink also 512 chips<br>Different bit rates by changing the length of the code | Uplink: (1) 10 ms = 38400 chips or (2) 66.7 µs = 256 chips<br>Option (2) can be used with advanced base station receivers<br>Downlink: 10 ms = 38400 chips |
| Number of codes | Number of codes under one scrambling code = spreading factor | Uplink: 16.8 million<br>Downlink: 512 |
| Code family | Orthogonal Variable Spreading Factor | Long 10 ms code: Gold code<br>Short code: Extended S(2) code family |
| Spreading | Yes, increases transmission bandwidth | No, does not affect transmission bandwidth |

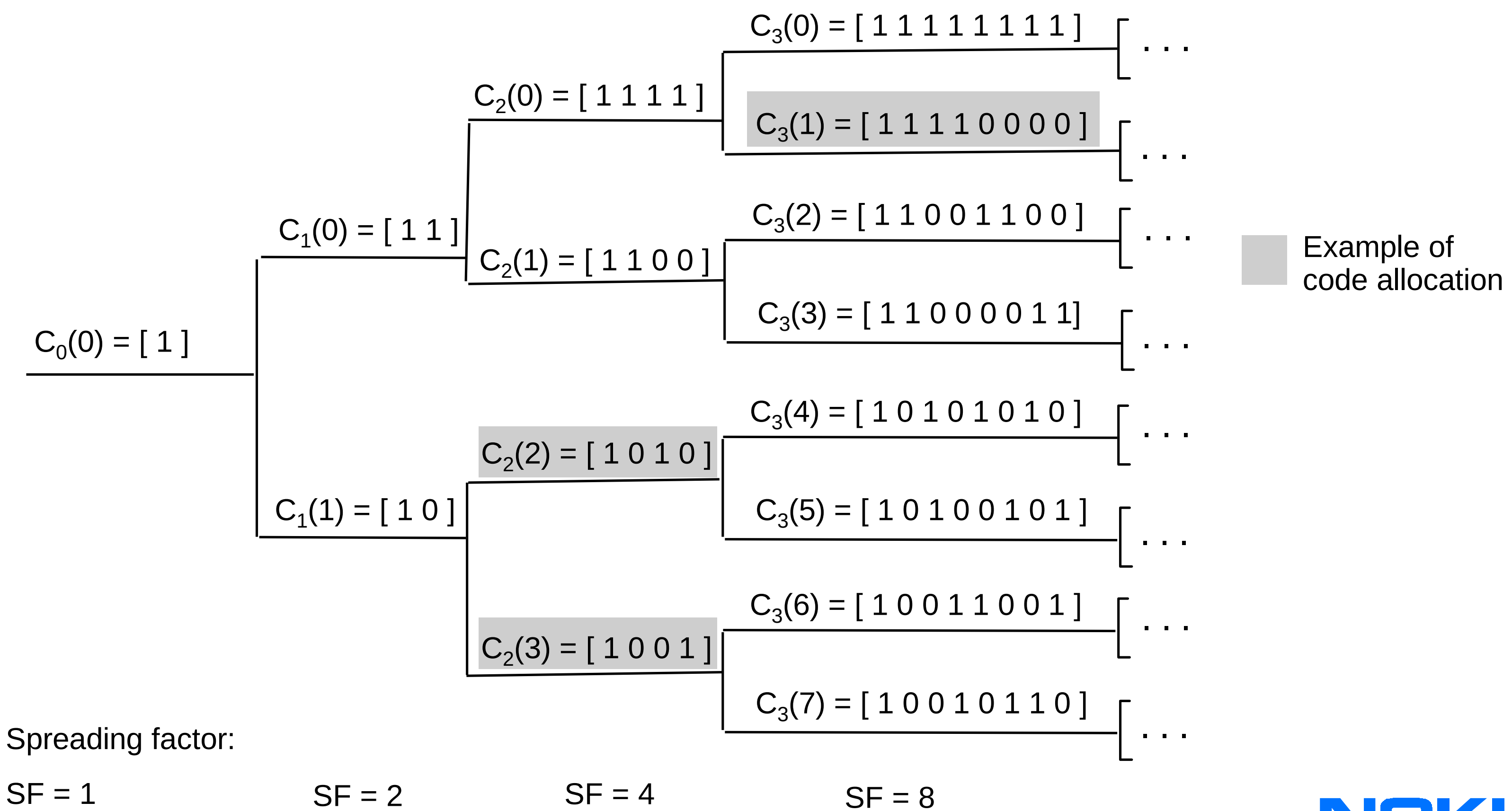
Downlink codes must be managed

Downlink codes are orthogonal

Simple code planning in downlink

# Tree of Orthogonal Short Codes in Downlink

- Hierarchical selection of short codes from a code tree to maintain orthogonality
- Several long scrambling codes can be used within one sector to avoid shortage of short codes



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# Physical Channel Bit Rates

# Physical Layer Bit Rates (Downlink)

| Spreading 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 parallel codes | 2880 | 5760 | 5616 | 2.3 Mbps |

Half rate speech
Full rate speech
144 kbps
384 kbps
2 Mbps

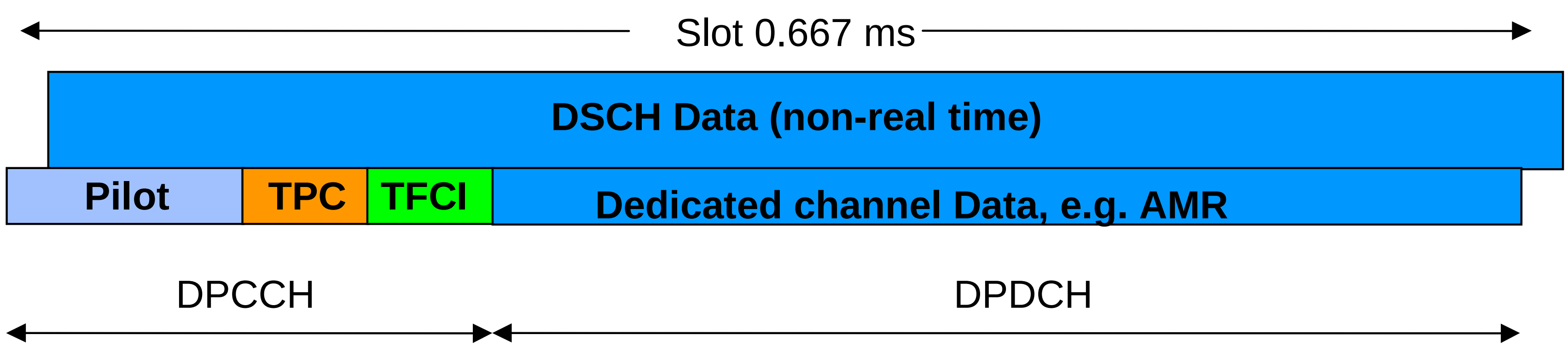
- The number of orthogonal channelization codes = Spreading factor
- The maximum throughput with 1 scrambling code ~2.5 Mbps  or ~100 full rate speech users

# Number of Orthogonal Codes in Downlink

- Part of the orthogonal codes must be reserved for
  - common channels
  - soft handover overhead
- The maximum capacity with one set of orthogonal codes = code limited capacity per sector per 5 MHz
  - Full rate speech (SF=128) : 98 channels
  - Half rate speech ≤ 7.95 kbps (SF=256) : 196 channels
  - Data : 2.5 Mbps
- Typically, air interface interference limits the capacity before the code limitation (see the capacity discussion later)
- Code limitation can be avoided with 2nd set of codes (which are not orthogonal) by using 2 scrambling codes per sector
- 2nd set of codes is probably needed with smart antennas which improve the air interface capacity.

# Downlink Shared Channel (DSCH)

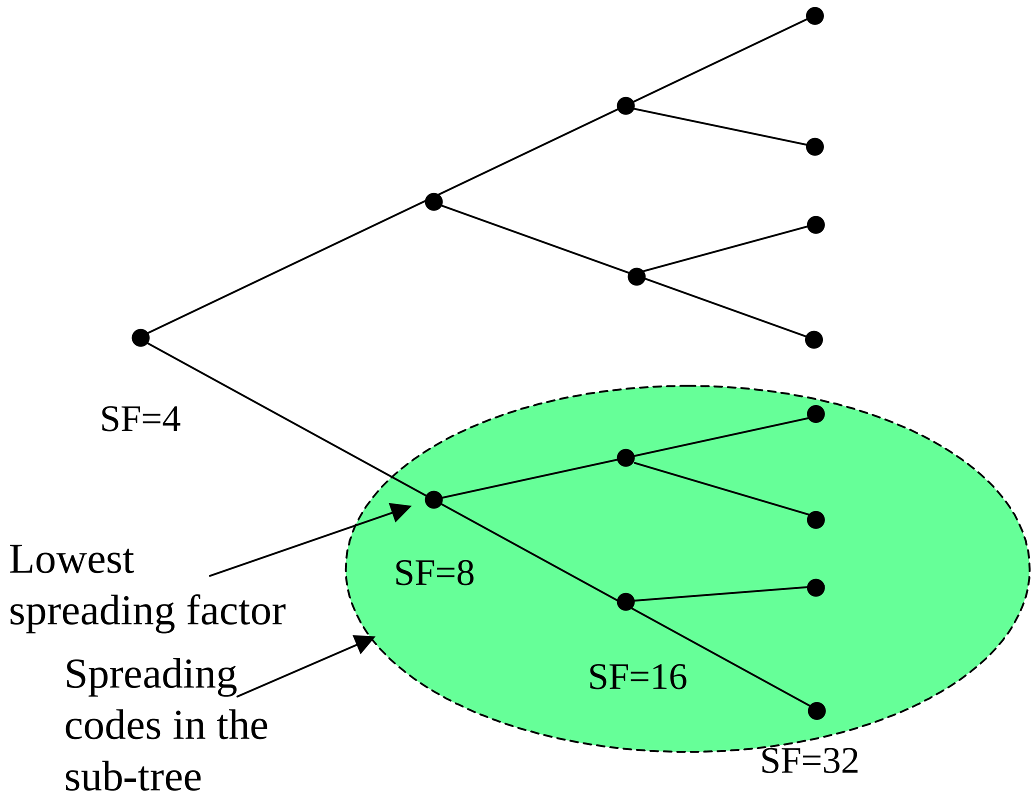
- The number of orthogonal codes in downlink is limited and the code is reserved according to the maximum bit rate in transport format set
  - variable bit rate connections consume a lot of code resources
  - downlink shared channel concept saves code space
- DSCH is shared between a group of downlink users
- Existence of data on DSCH for a particular user is indicated with TFCI (frame-by-frame) or with higher layer signalling (slower)
- DSCH is not frame synchronized with the corresponding dedicated channel.




**Frame structure for the DSCH when associated to a DCH.**

# DSCH (2)

- Conceptually DSCH can be seen as reserving a code resource and then sharing it in time and code domain.
- Example: frame N 1 user with SF 8, frame N+1 two users with SF 16.



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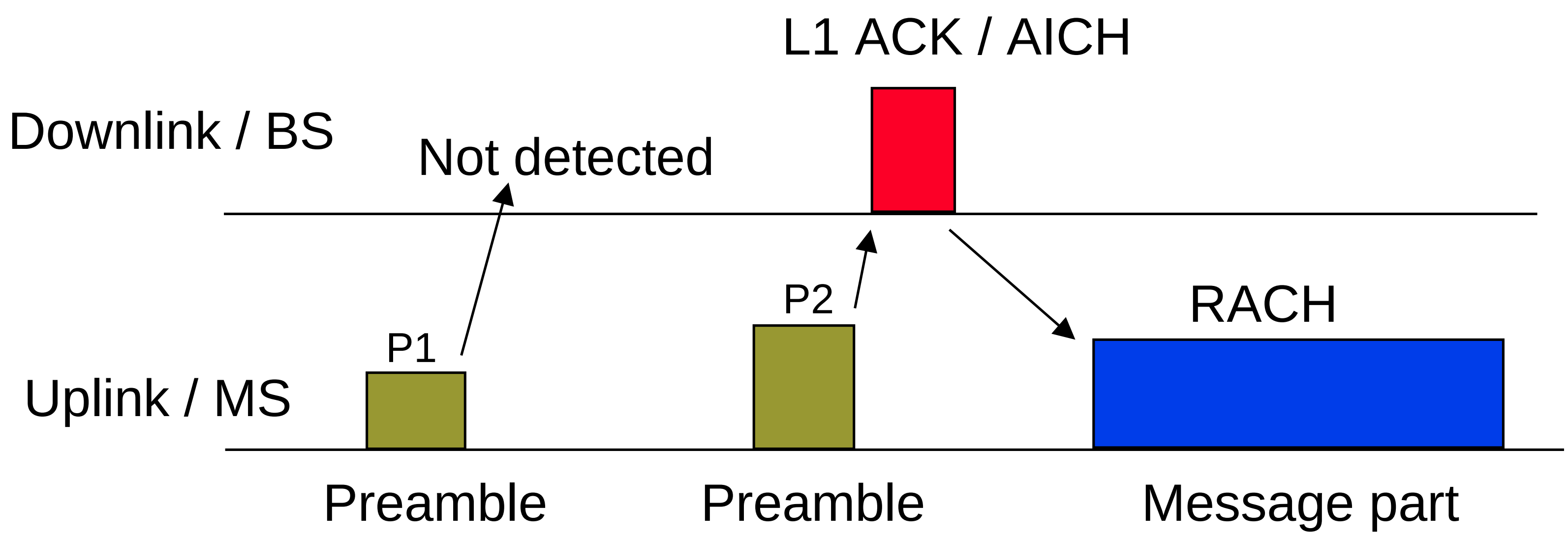
# Random Access Channel (RACH)

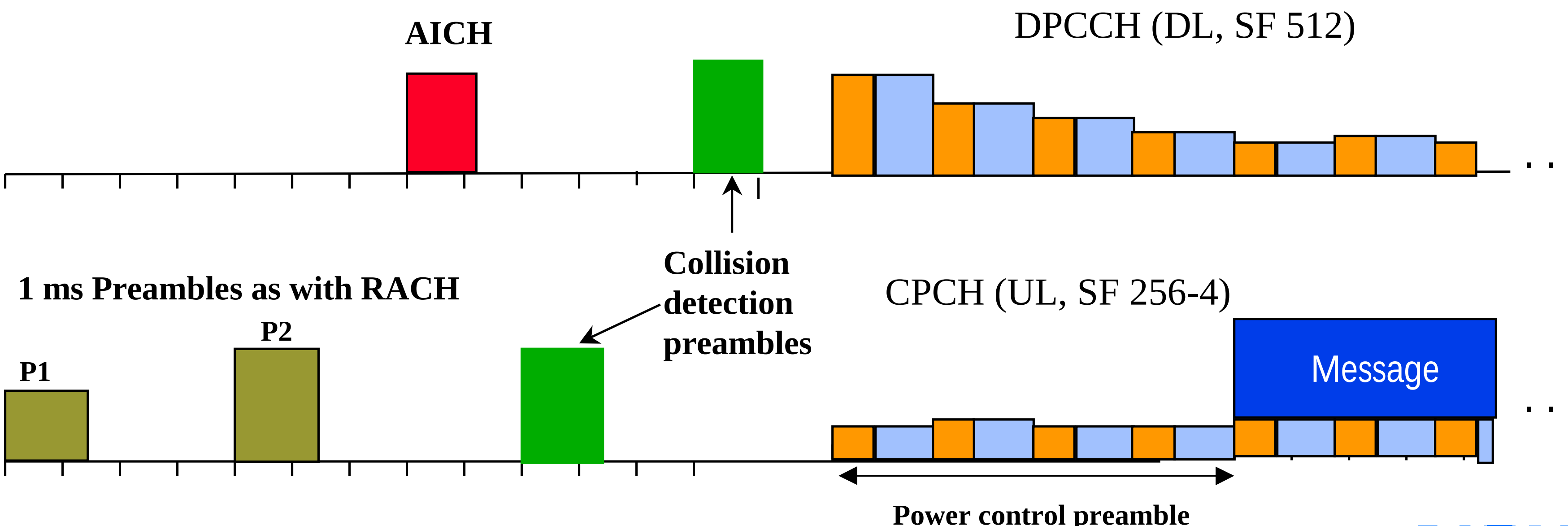
- With Random Access Channel (RACH) power ramping is needed with preambles since the initial power level setting in the mobile is very coarse with open loop power control
- Preamble: mobile sends 1 ms signature sequence with increasing power
- L1 acknowledgement: base station acknowledges the sequences received with high enough power level (AICH = Acquisition Indication CH)
- Mobile RACH message follows the acknowledgement



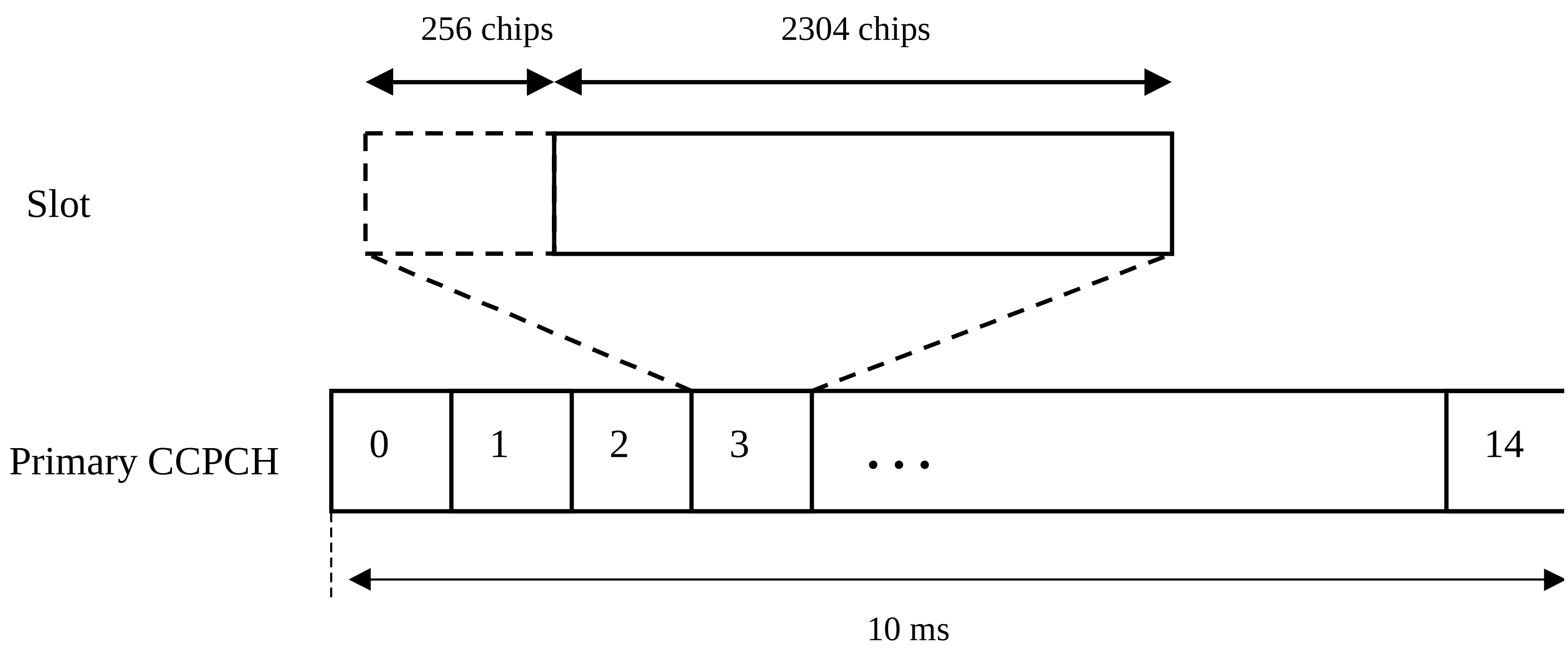
# Uplink Common Packet Channel (CPCH)

- The CPCH is basically RACH with:
  - Longer message duration (up to 640 ms vs. 10 or 20 ms on RACH)
  - Power controlled (power control commands provided in the DPCCH in the downlink)
  - Status indication provided in the downlink to avoid collisions
- In Release -99 optional for all terminals, Release 2000 developments remain to be seen



# Downlink Common Channels

- Primary common control physical channel (primary CCPCH)
  - carries BCH
  - constant symbol rate of 27 ksps




- Secondary CCPCH
  - carries FACH and PCH
  - variable bit rate

# Service Multiplexing

# Service Multiplexing

- MAC layer multiplexing
  - No further requirements on the physical layer
  - The same quality provided for all multiplexed services

- Physical layer multiplexing
  - Can provide different quality for different services
    - e.g. speech FER=1%, packet data FER=10%, video FER<0.1%
  - Different quality is obtained by rate matching
    - Higher quality required ⇨ more repetition coding applied

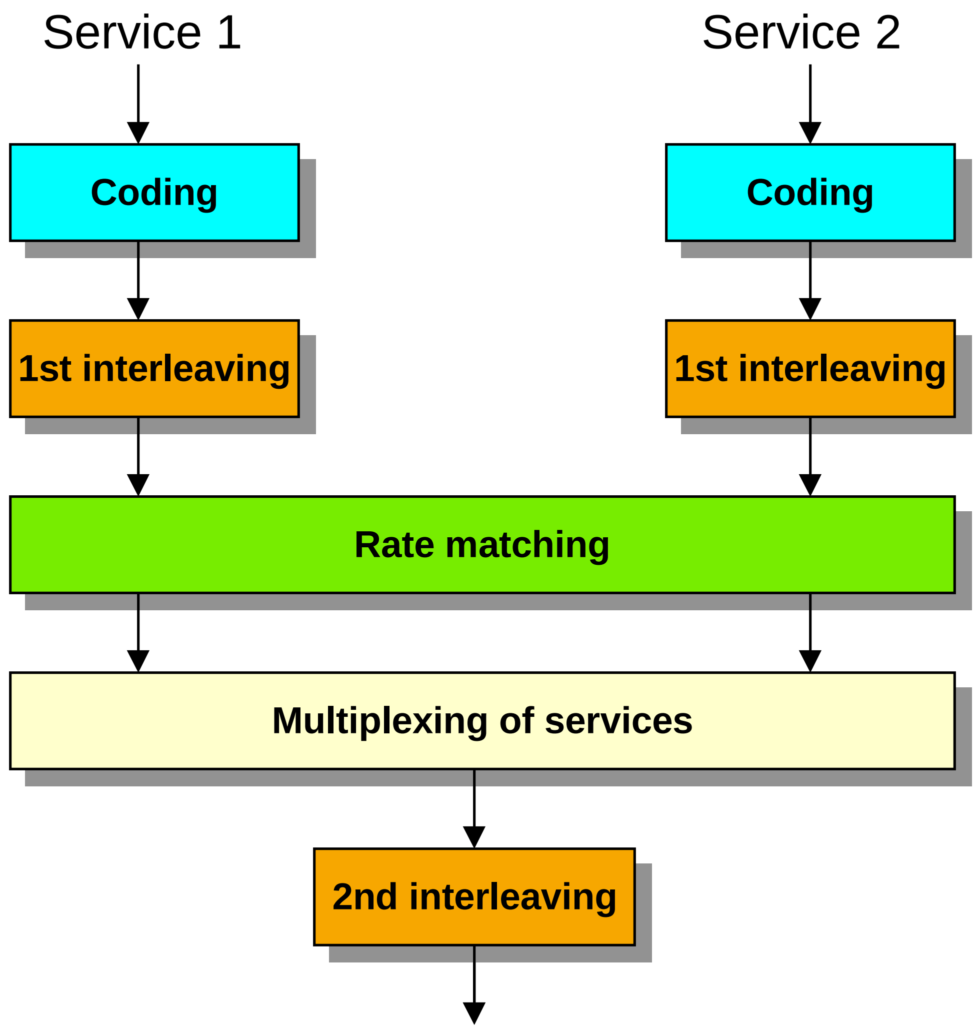
# Physical Layer Multiplexing

Channel coding + MAC multiplexing

Inter-frame interleaving

Rate matching:
• $E_b/N_0$ balancing
• matching to channel bit rate

Intra-frame interleaving



# Channel Coding

- Dedicated channel (DCH) and the following common channels (CPCH, DSCH and FACH)
  - Convolutional code 1/3-rate or 1/2-rate, $K$=9
    - Mainly for speech service and other low bit rate services
  - Turbo codes 1/3-rate, $K$=3
    - Gives gain over convolutional code especially for high bit rates (>=32kbps) and low BER requirements
  - Transmission without channel coding is also possible

- Other common channels
  - Convolutional code 1/2-rate, $K$=9



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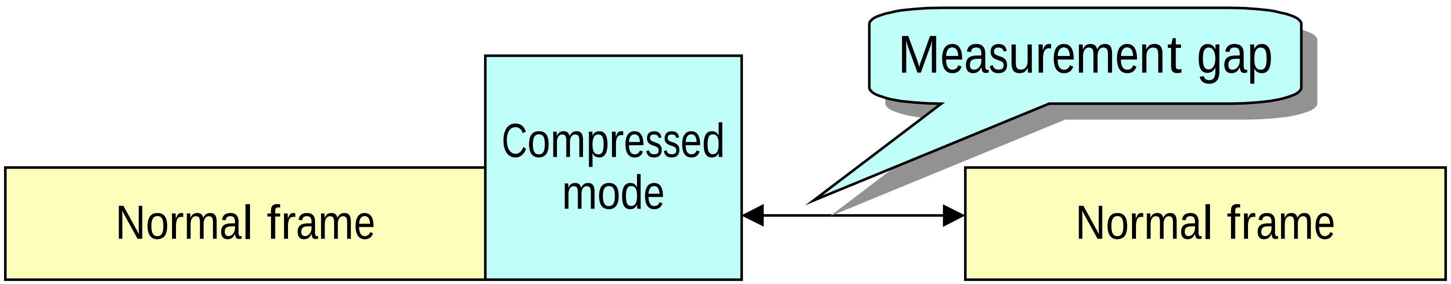
# WCDMA $\leftrightarrow$ GSM Inter-system Handovers

# WCDMA Compressed Mode

| | **WCDMA** | IS-95A | GSM |
|---|---|---|---|
| Why inter-frequency measurements? | For inter-frequency & inter-system handovers | No IF-measurements => utilization of multiple frequencies difficult | For all handovers |
| How to make IF-measurements | **Compressed mode** | | Simple since discontinuous tx & rx |




- More power is needed during compressed mode
  - => affects WCDMA coverage
- Power control cannot work during compressed frame => higher Eb/N0
  - => affects WCDMA capacity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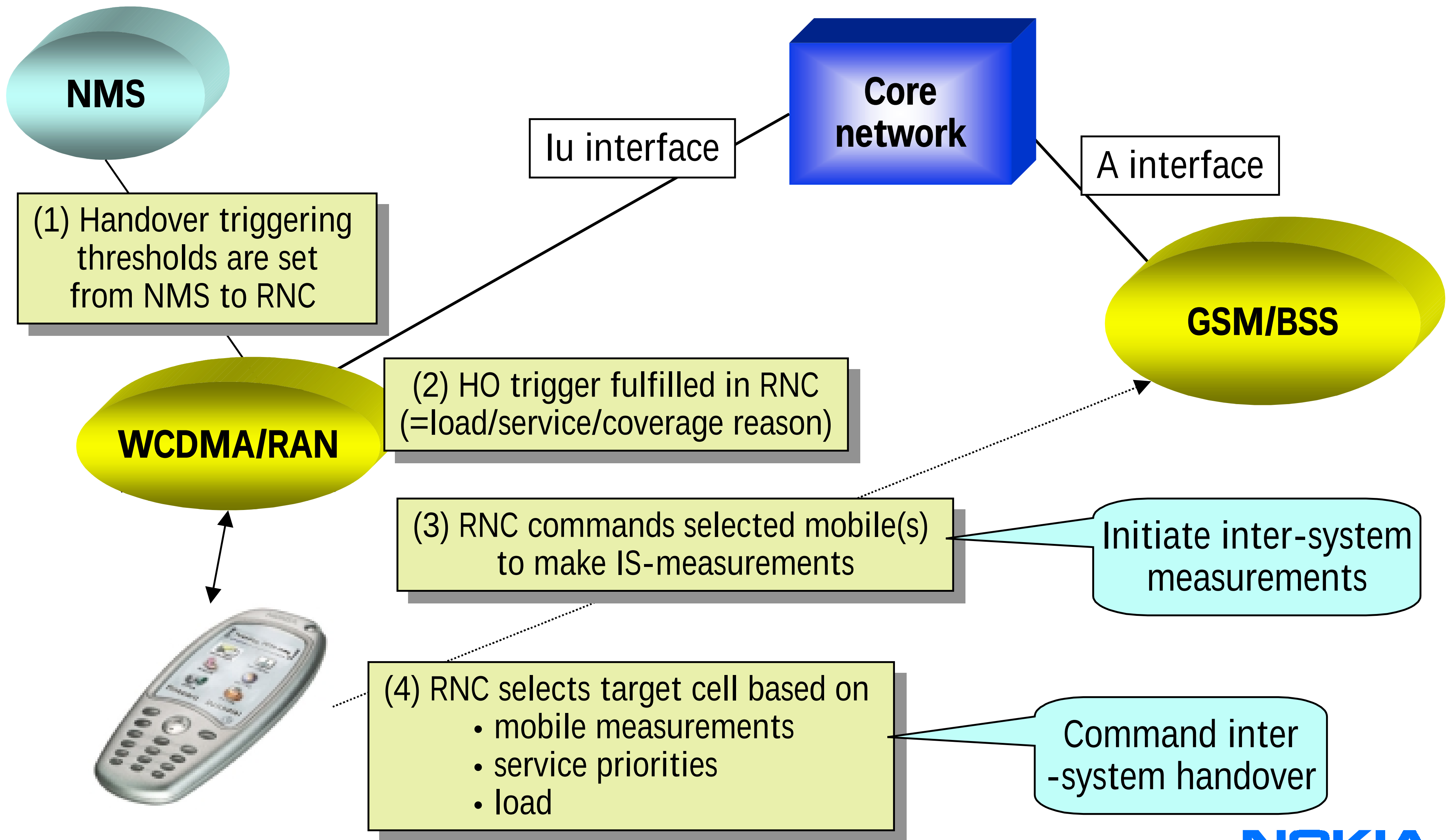
# Handover from WCDMA to GSM



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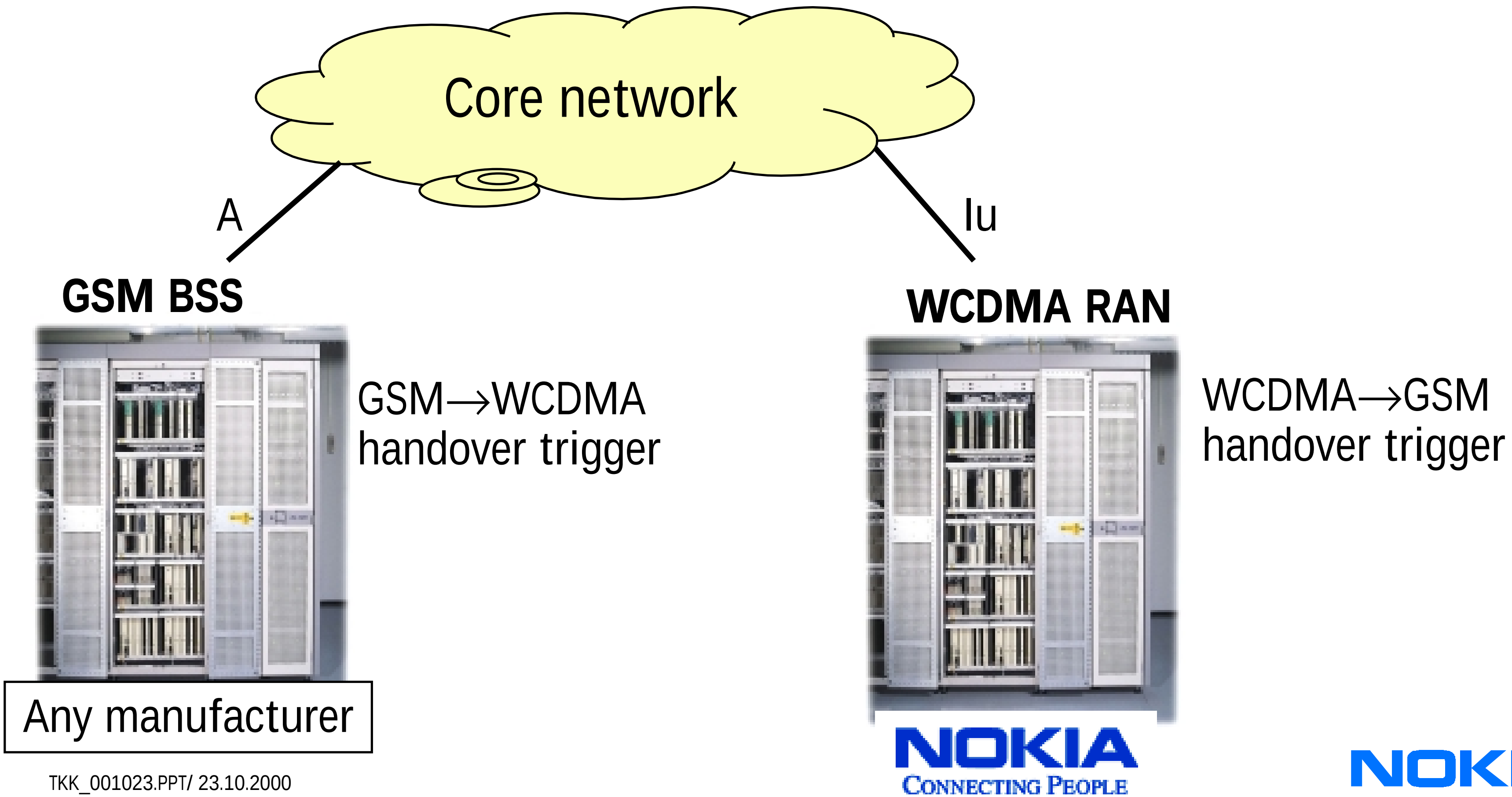
# Multivendor Inter-system Handovers

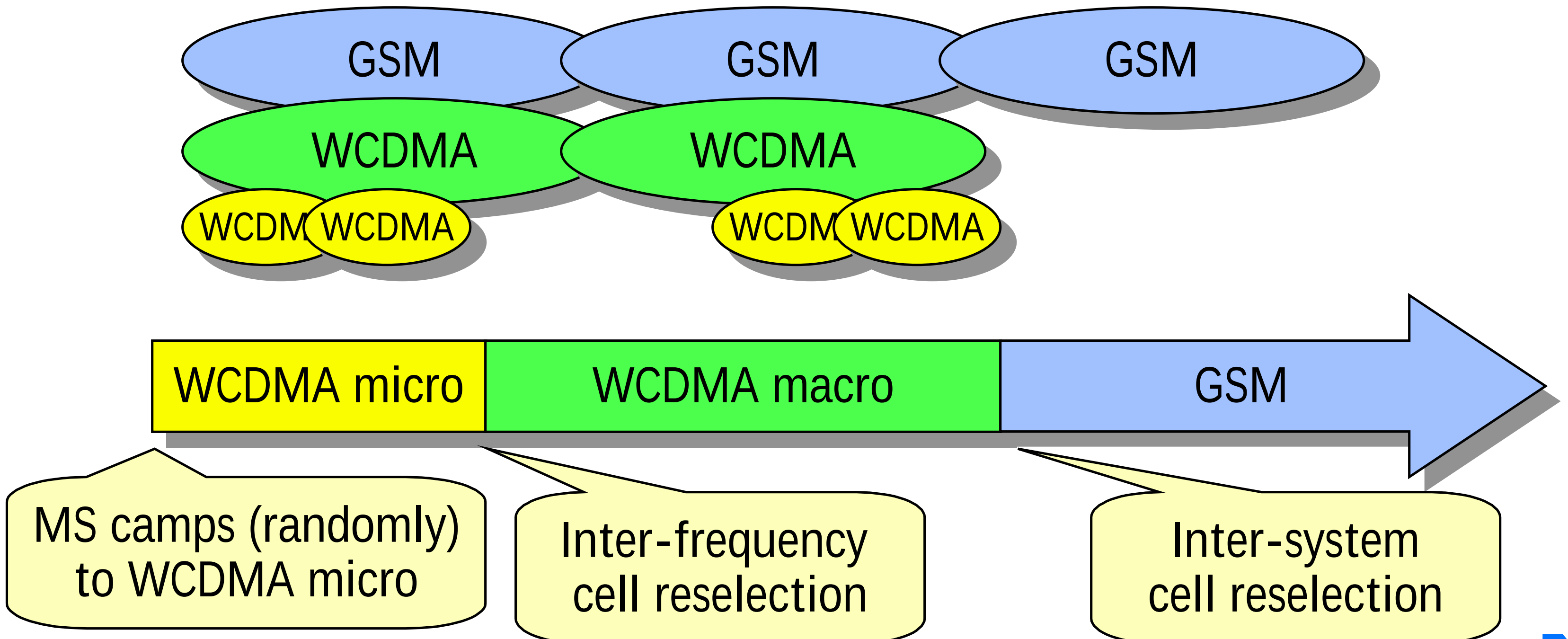
- Handovers between GSM and WCDMA can be done also between different vendors' networks
- Handovers from GSM to WCDMA are triggered in GSM BSS
- Handovers from WCDMA to GSM are triggered in WCDMA RAN



# WCDMA ↔ GSM Inter-system Idle Mode Cell Re-selection

# Without Hierarchical Cell Priorities

- Mobile stays within one frequency if received pilot Ec/I0 is good enough = above $S_{intersearch}$ and $S_{searchRATn}$
- $S_{intersearch}$ threshold for starting inter-frequency measurements
- $S_{searchRATn}$ threshold for starting inter-frequency measurements
- Inter-frequency and inter-system measurements consume more batter in terminal → thresholds must be low enough



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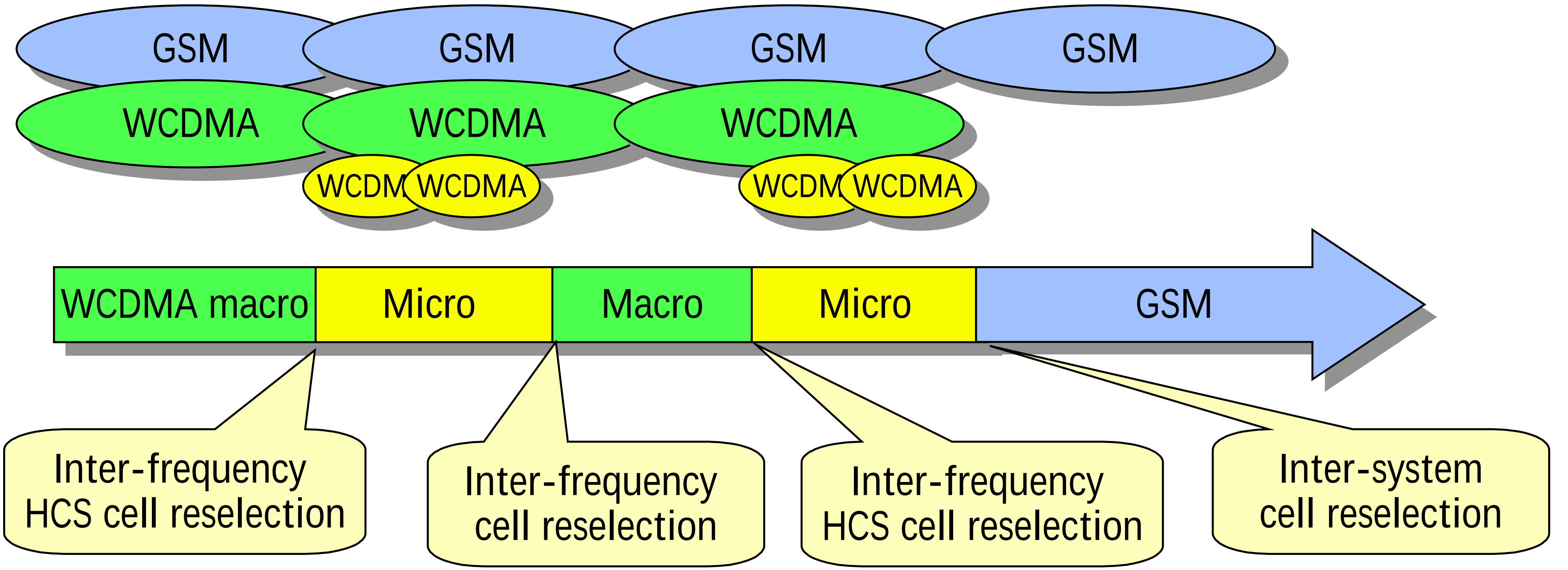
# With Hierarchical Cell Priorities

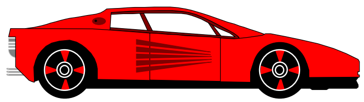
- Parameter HCS_PRIO
  - HCS priority value 0..7
  - For keeping idle mobiles in micro layers, example below
  - For keeping idle mode mobiles in one system (GSM or WCDMA)



# Further Notes

- High mobile speeds can be directed to macro cells in idle mode based on the frequency of the cell re-selections
  - Parameters $N_{CR}$ / $T_{CRmax}$
  - If the number of cell reselections during time period $T_{CRmax}$ exceeds $N_{CR}$, high-mobility has been detected



- Mapping rule can be optionally used between WCDMA and GSM
  - WCDMA RSCP and GSM RSSI can also be directly compared by using just offset parameters = default case



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# Why to Force Dual-modes to Camp to GSM or to WCDMA?

Any intermediate cases can also be used between these two extremes

↔

| Camping to GSM | Camping to WCDMA |
|---|---|
| • Less location updates<br>• 3G → 2G handover is not necessary<br>• Lower MS power consumption in idle mode | • 3G services available for all dual-mode mobiles even without 2G→3G handover or network controlled cell reselection<br>• 3G network is utilized as fully as possible |

Useful if 3G→2G handover is not supported, and 3G coverage is not continuous

Initial phase solution to fully utilize 3G network and to provide 3G services

- Equal idle mode priority could also be used for GSM and for WCDMA, especially when dual-mode penetration and traffic in WCDMA increases



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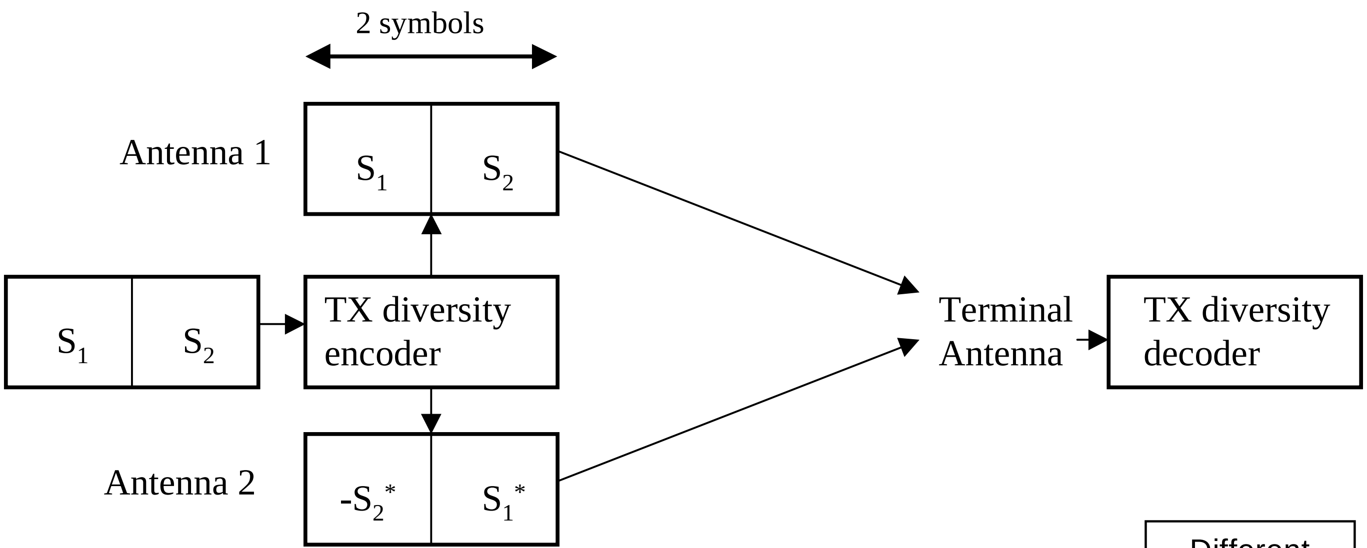
# Downlink Transmit Diversity

- Background
  - More capacity expected to be needed in downlink than in uplink
  - Uplink capacity tends to be higher than downlink because better receiver techniques can be applied in the base station than in the mobile (antenna diversity and multiuser detection)
  - Antenna diversity not practical for low-priced mobiles

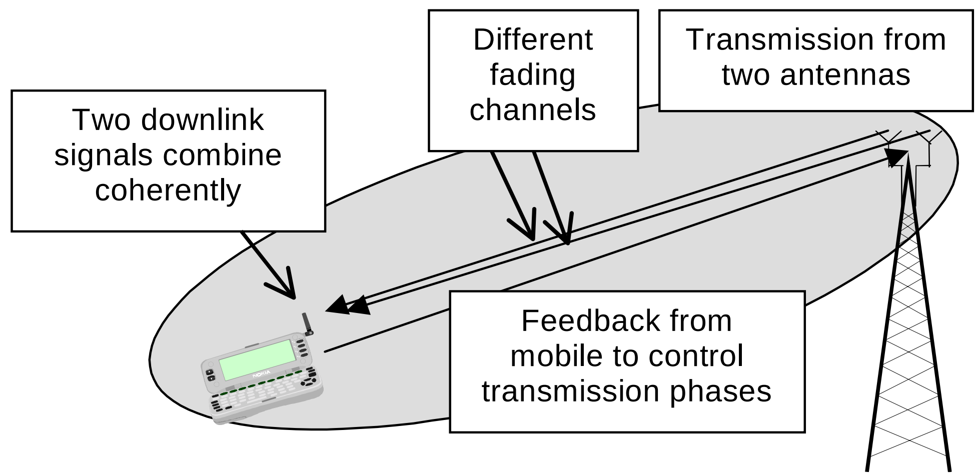
- Three transmit diversity modes specified
  - Open loop transmit diversity mode with space-time coding
  - Closed loop transmit diversity mode with feedback from the mobile
    - mode 1 : with frequency of 1500 Hz, adjust only relative phases of the two antennas
    - mode 2 : with frequency of 1500/4 Hz, adjust both relative phase and amplitudes from the two antennas (Command Bit rate 1500 Hz, 4 bits combined together for phase and amplitude adjustment)

# Downlink Transmit Diversity

- Open loop transmit diversity



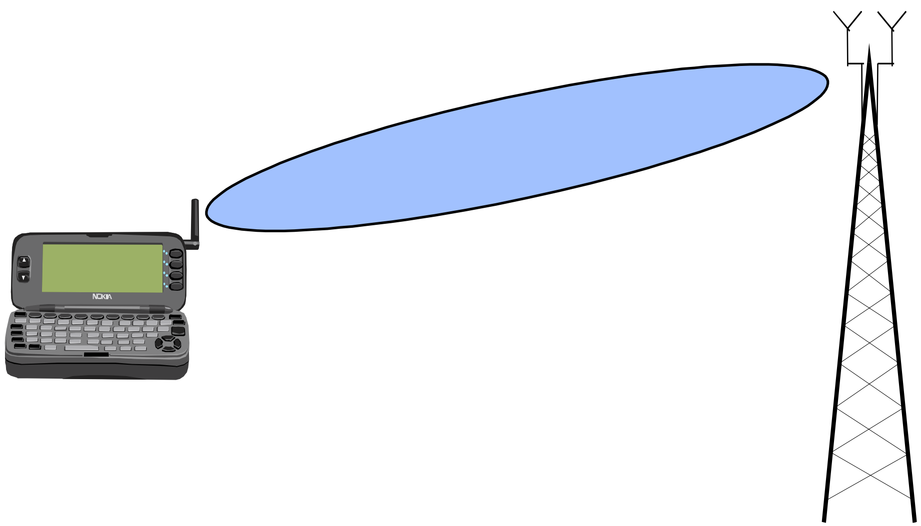

- Closed loop transmit diversity

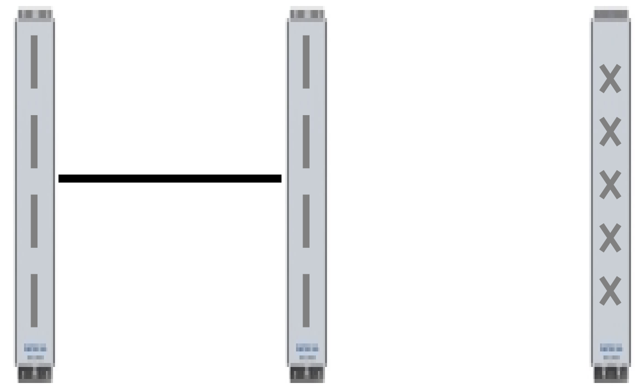


# Downlink Transmit Diversity

- Transmission from two base station antennas
- Both modes give gain against fading
- Closed loop mode targets for coherent combining of the received signals in the mobile





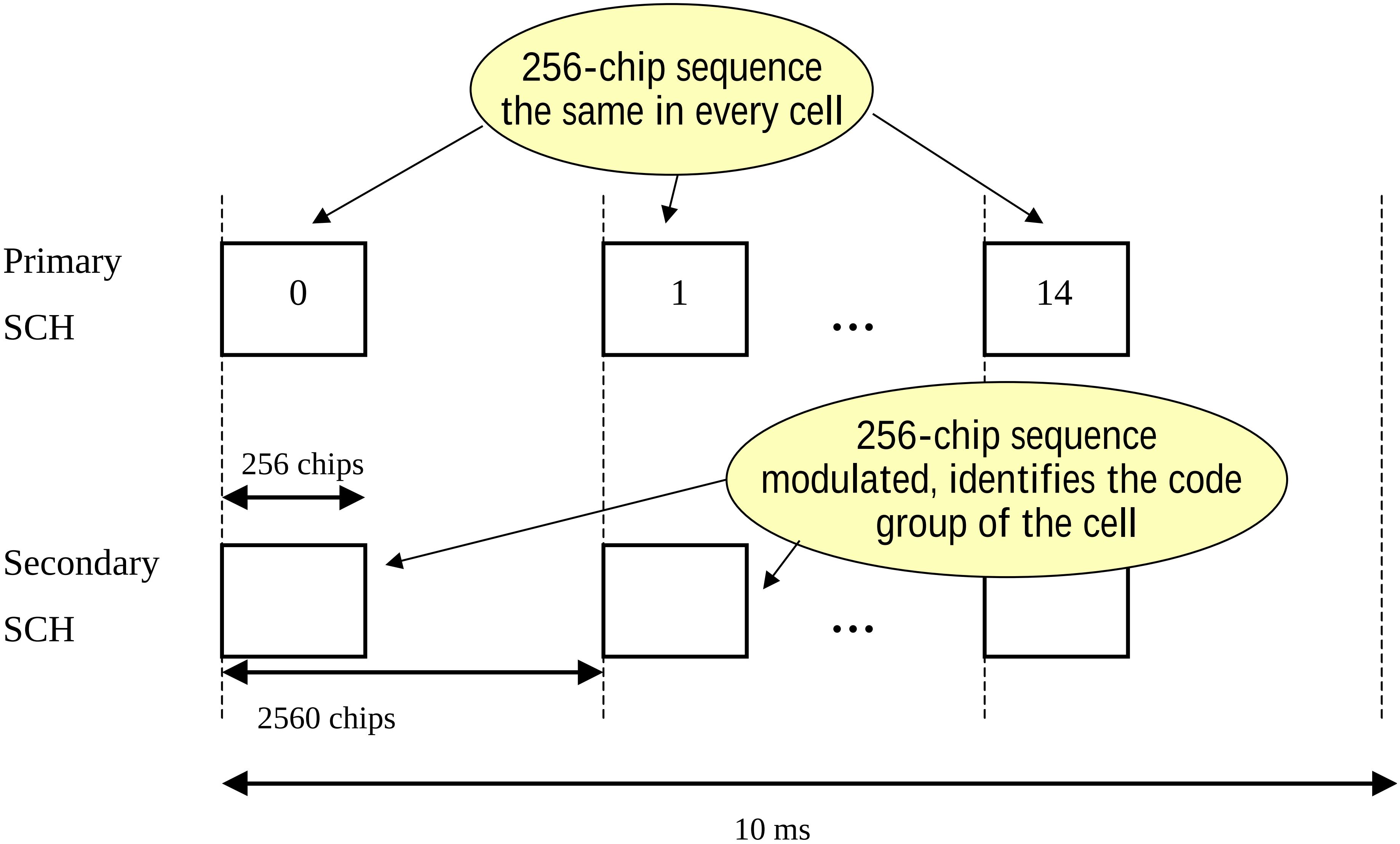
Space diversity antenna separation ~3 m

Polarization diversity ±45°

# Receive Diversity vs. Transmit Diversity

| | **Uplink receive diversity** | **Downlink transmit diversity with feedback** |
|---|---|---|
| **(1) Coherent combining gain** | | |
| Gain from ideal coherent combining is 3.0 dB with two antennas | | |
| How to obtain coherent combining | Rake receiver with channel estimation from pilot symbols | Feedback loop from mobile to base station to control the transmission phases to make received signals to combine coherently in mobile |
| Non-idealities in coherent combining | Inaccurate channel estimation in Rake receiver | Inaccurate channel estimation in mobile<br>Discrete steps in feedback loop<br>Delay in feedback loop<br>Multipath propagation |
| Practical gain of coherent combining | 2.5–3.0 dB gain | Gain is lower than with receive diversity |
| **(2) Diversity gain against fading** | | |
| Diversity gain with fast power control | Diversity gain = reduction of power rise. Example values:<br>ITU Pedestrian A: 2.8 dB<br>ITU Vehicular A: 0.8 dB | |
| **Total gain in reduction of transmission powers** | | |
| Total gain from antenna diversity | 3.0–6.0 dB | 0.0–5.0 dB |

# Cell Search / Synchronization Channel (SCH)



# Cell Search

1. The terminal searches the 256-chip **Primary SCH**, being identical for all cells.
    - Chip, symbol and slot synchronization can be obtained
2. The terminal seeks the largest peak from the **Secondary SCH** code word. There are 64 possibilities for the secondary synchronization code word. The terminal needs to check all 15 positions, as the frame synchronization is not known from Primary SCH.
    - Frame synchronization and code group of the cell can be obtained
3. The terminal then seeks the primary **scrambling codes** that belong to that particular code group. Each group consists of eight primary scrambling codes. These need to be tested for a single position only, as the starting point is known already.
    - Scrambling code of the cell can be obtained

# Differences Between 3G/WCDMA and 2G/GSM and 2G/IS-95

# Differences Between WCDMA and GSM

High bit rates

Spectral efficiency

Different quality requirements

Efficient packet data

Downlink capacity

| | 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 IS-95

- High bit rates
- High quality services + capacity
- Micro + indoor cells
- Several carriers per base station
- Different quality requirements
- Efficient packet data
- Downlink capacity

| | 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<br>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 |

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# Differences Between WCDMA and IS-95

- Wider bandwidth: WCDMA: 3.84 Mcps / IS-95: 1.2288 Mcps
  - Multipath diversity improves coverage performance. In small cells ~1MHz bandwidth does not provide multipath diversity.
  - 3.84 Mcps ⇔ 1 chip corresponds to 78 m (=3e8/3.84e6)
  - 1.2288 Mcps ⇔ 1 chip corresponds to 244 m (=3e8/1.2288e6)
  - Higher multiplexing gain especially for high bit rates
- Fast closed loop power control in downlink
  - Improves downlink performance
  - Requires new functionalities in the mobile: SIR estimation, outer loop PC
- Inter-frequency handovers
  - Support for several carriers per base station

# Differences Between WCDMA and IS-95

- Soft handover algorithm with relative thresholds in WCDMA
  - Easier parameterization + optimization
- Asynchronous base stations
  - No need for synchronization from GPS
- Support for advanced radio resource management algorithms
  - Provides efficient packet data
  - Guarantees the quality of service
  - Prevents effectively cell breathing which exceeds planned limits
- Most differences between WCDMA and IS-95 reflect the 3G requirements of WCDMA

  