

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**
 - **Direct Sequence (spreading with pseudo noise (PN) sequence)**
 - **Frequency hopping (rapidly changing frequency)**
 - **Time Hopping (large frequency, short transmission bursts)**

Where Does Spread Spectrum Come from...

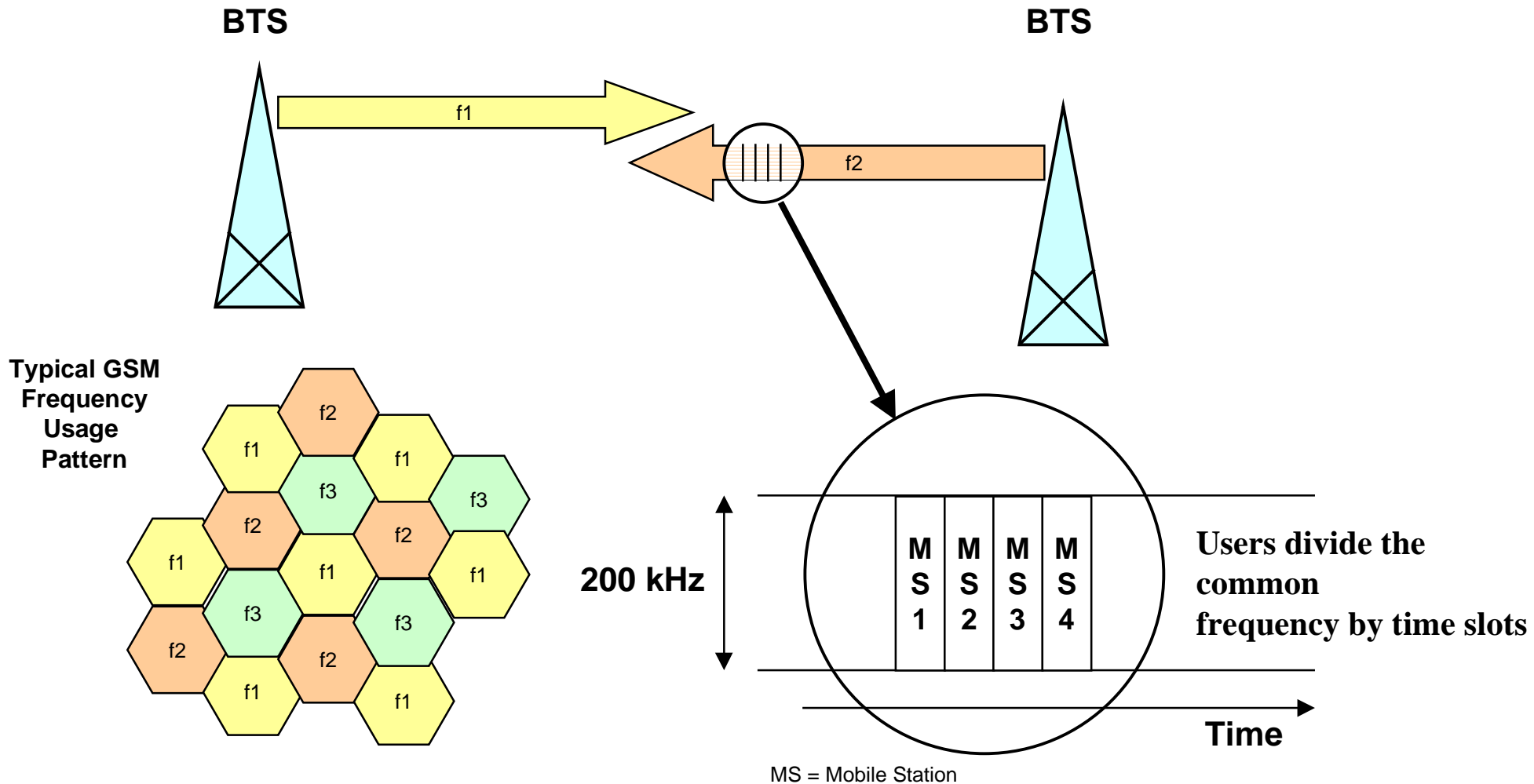
- **First publications, late 40s**
- **First applications: Military from the 50s**
- **Rake receiver patent 1956**
- **Cellular applications proposed late 70s**
- **Investigations for cellular use 80s**
- **IS-95 standard 1993**
- **1997/1998 3G technology choice in ETSI/ARIB/TTA...**

Very low C/I

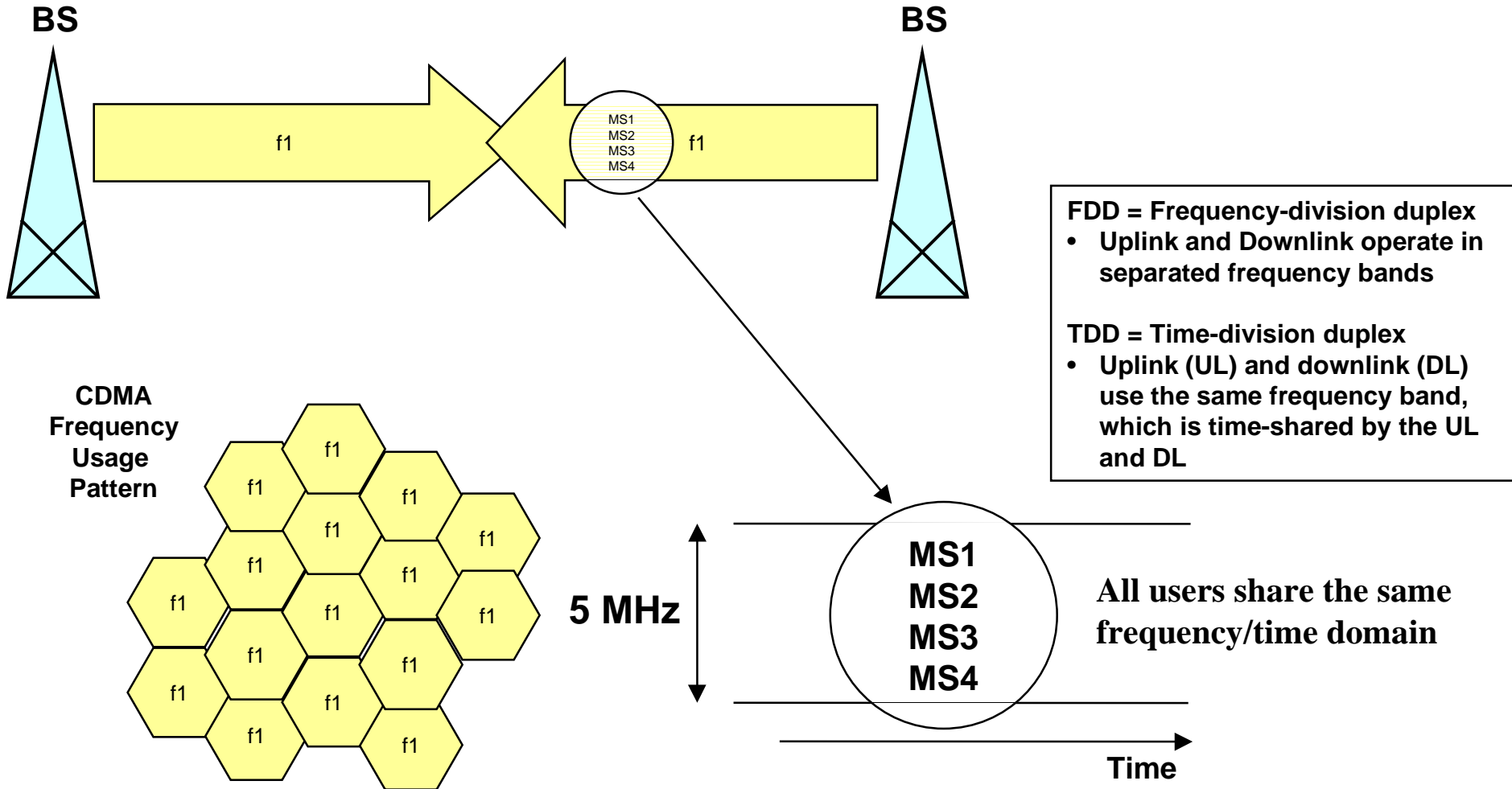
... and where is it heading to

- **2001/2002 Commercial launch of WCDMA technology**

GSM System is TDMA Based

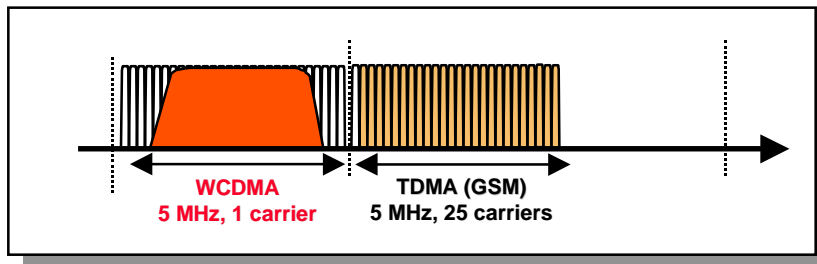
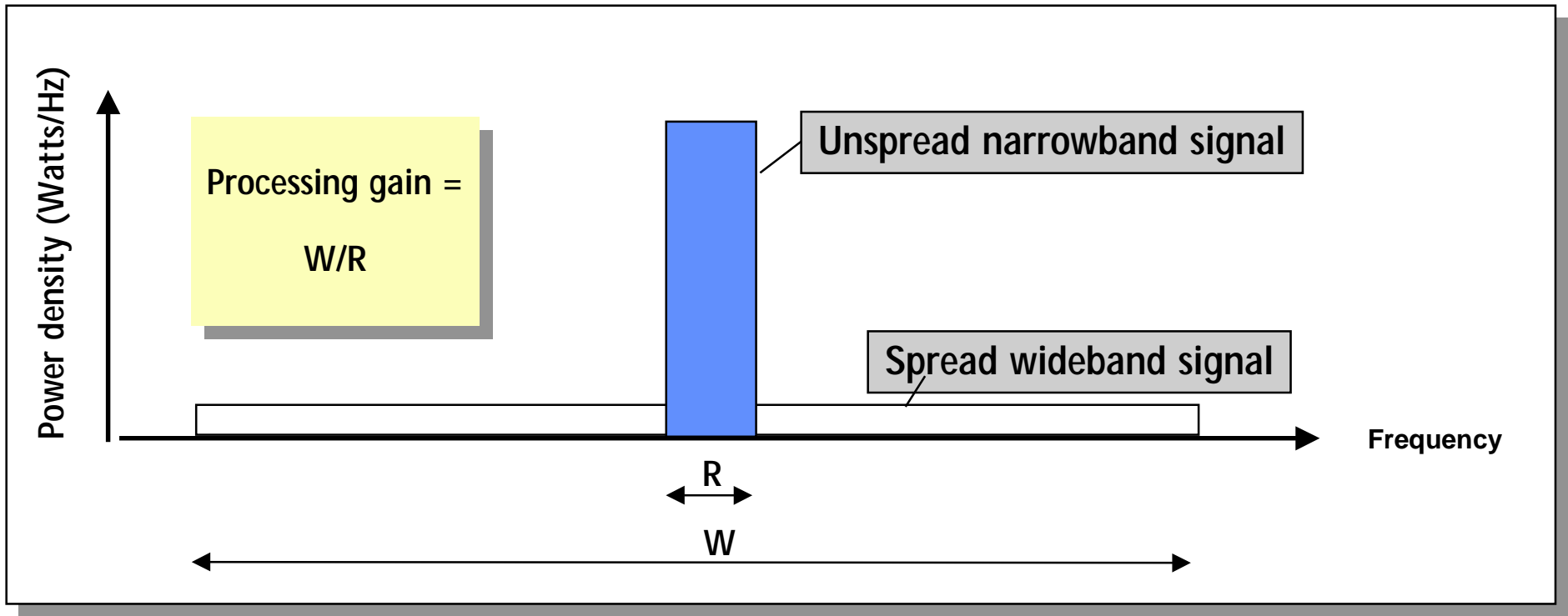


UMTS System is CDMA Based



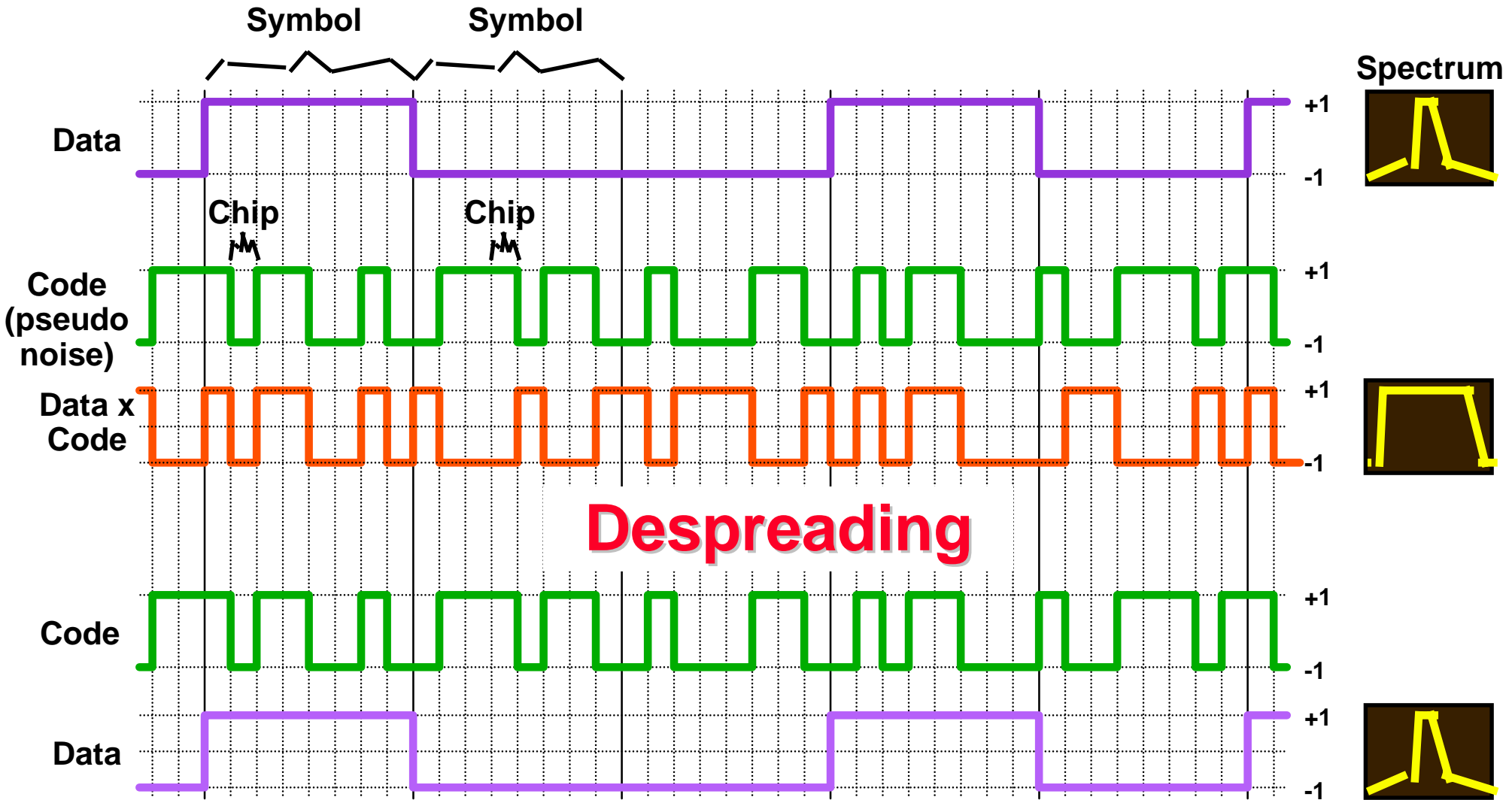
Processing Gain & Spreading

- A narrowband signal is spread to a wideband signal

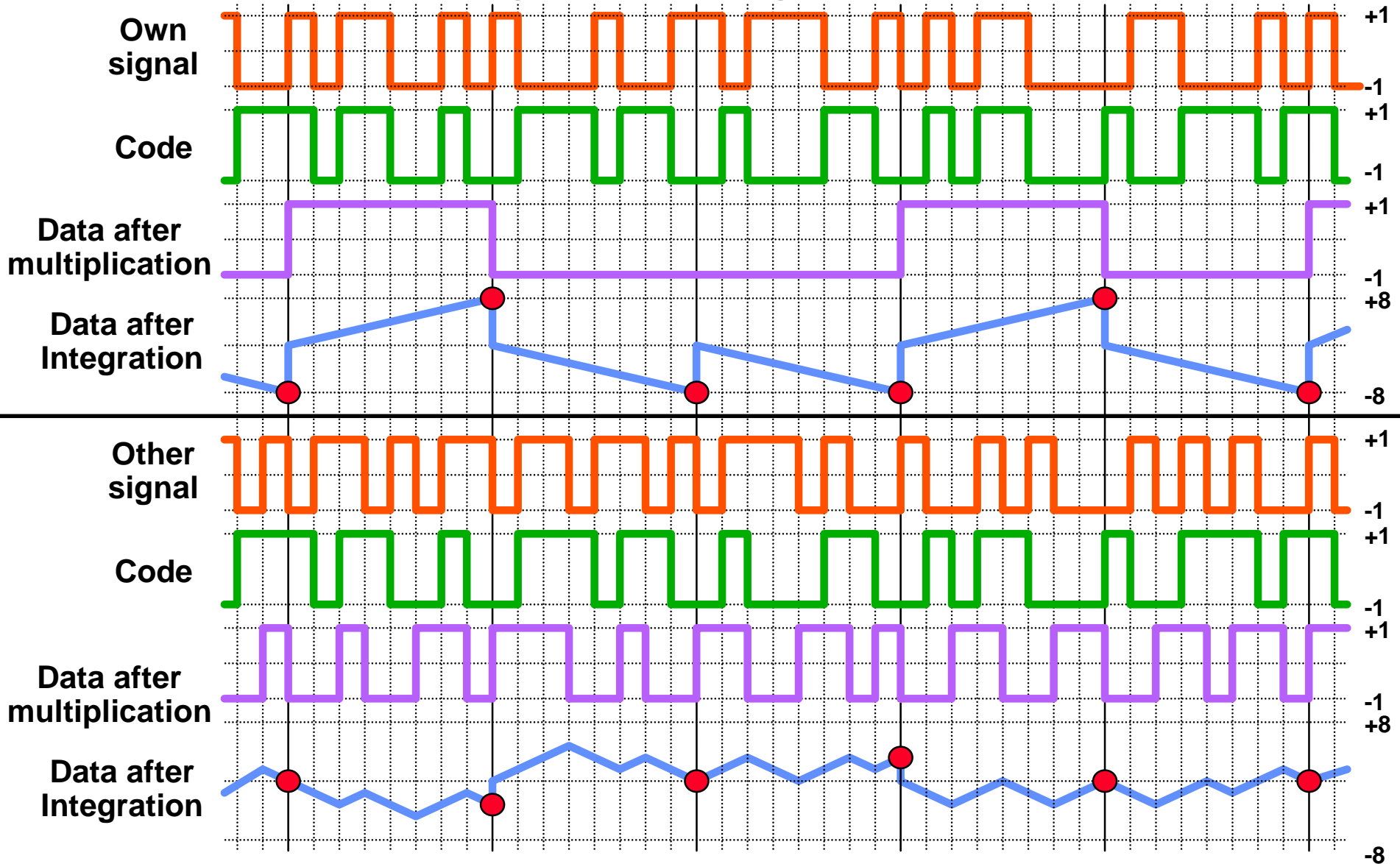


- High bit rate means less processing gain and higher transmit power or smaller coverage

Spreading

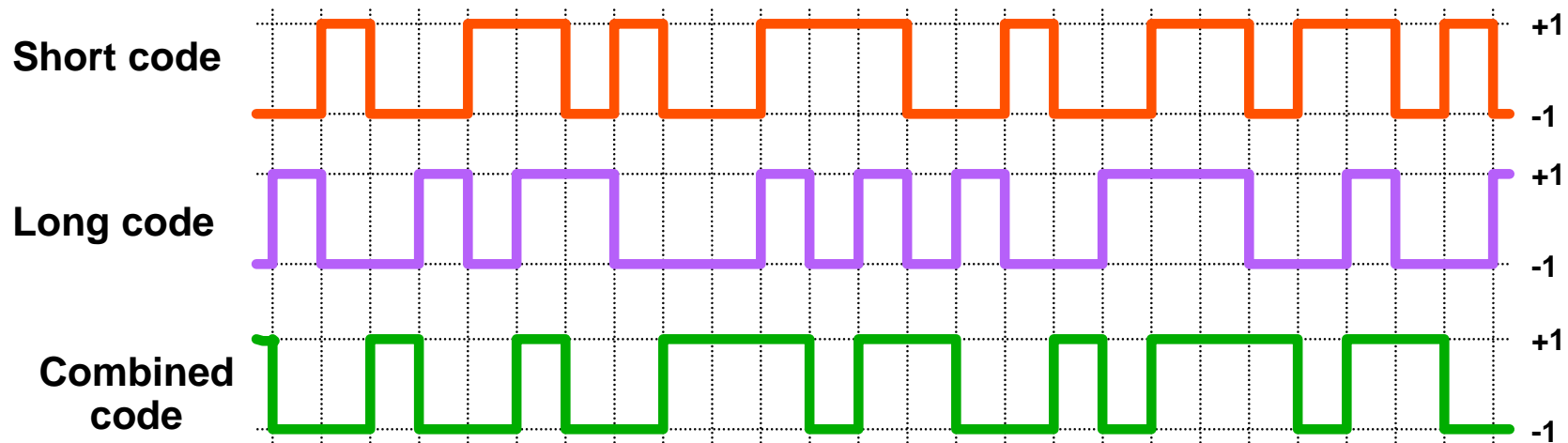


Detecting Own Signal. Correlator

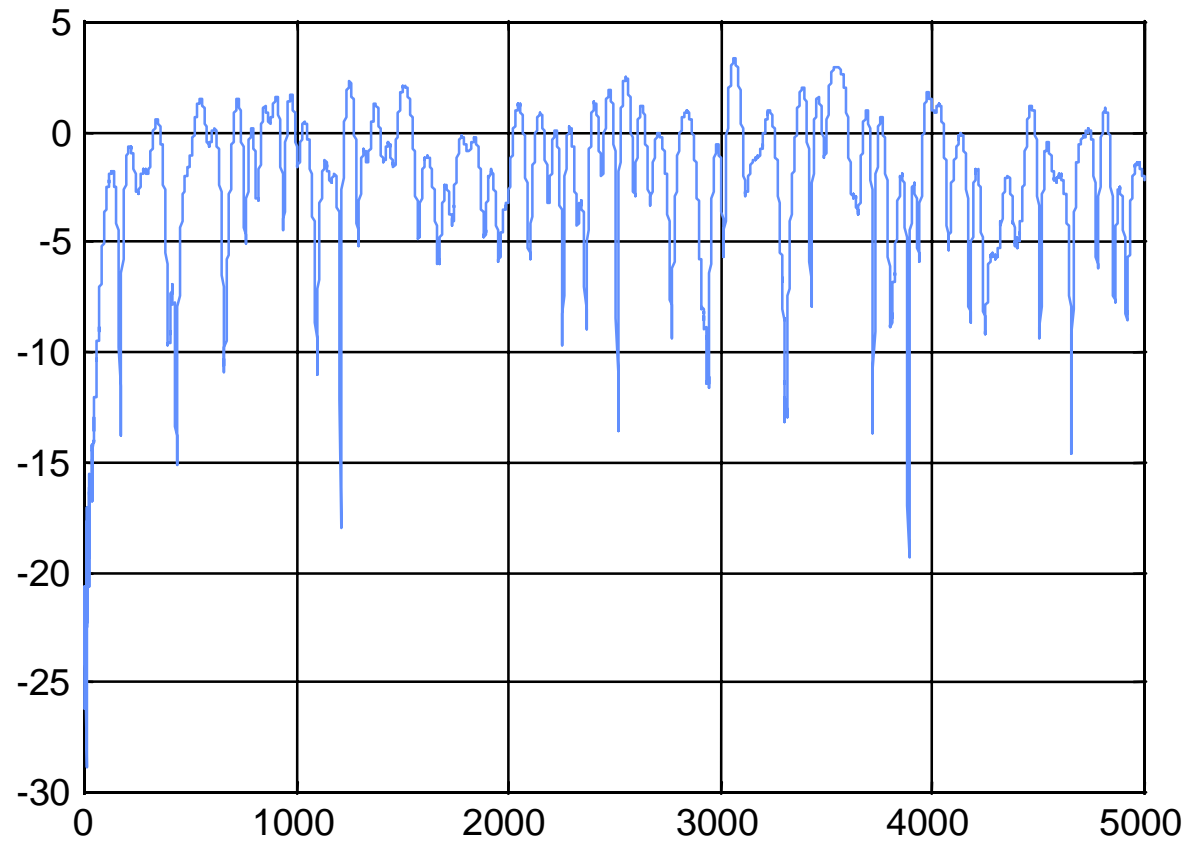


WCDMA Codes

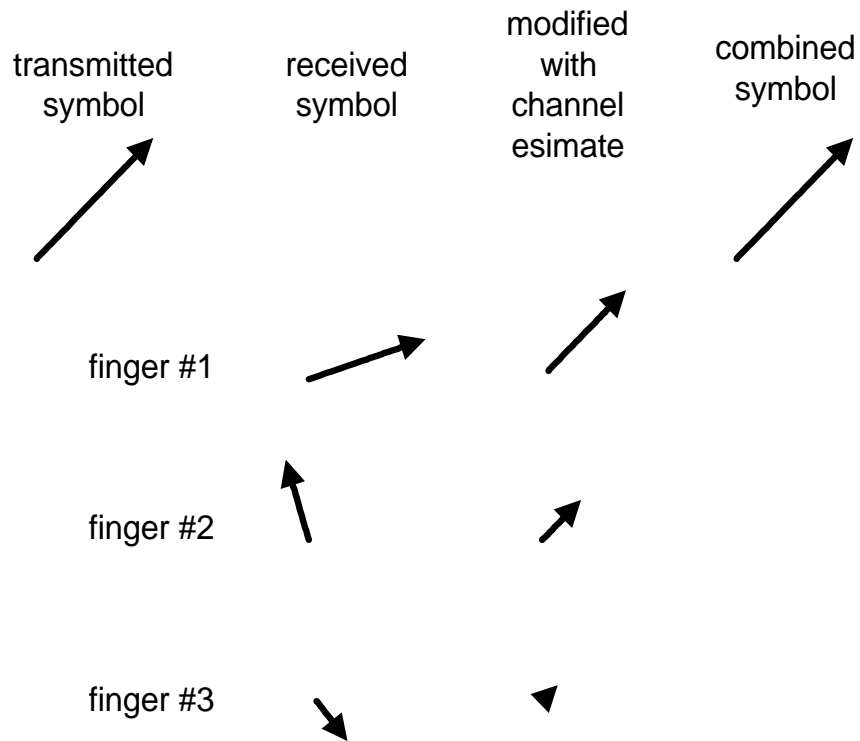
- **Channelisation codes used for channel separation from a single source**
 - **same codes in all cells ==> need for scrambling**
- **Scrambling codes separate**
 - **Uplink: different mobiles**
 - **Downlink: different cells/sectors**
 - **Have good interference averaging (correlation) properties**



Fading of a Multipath Component

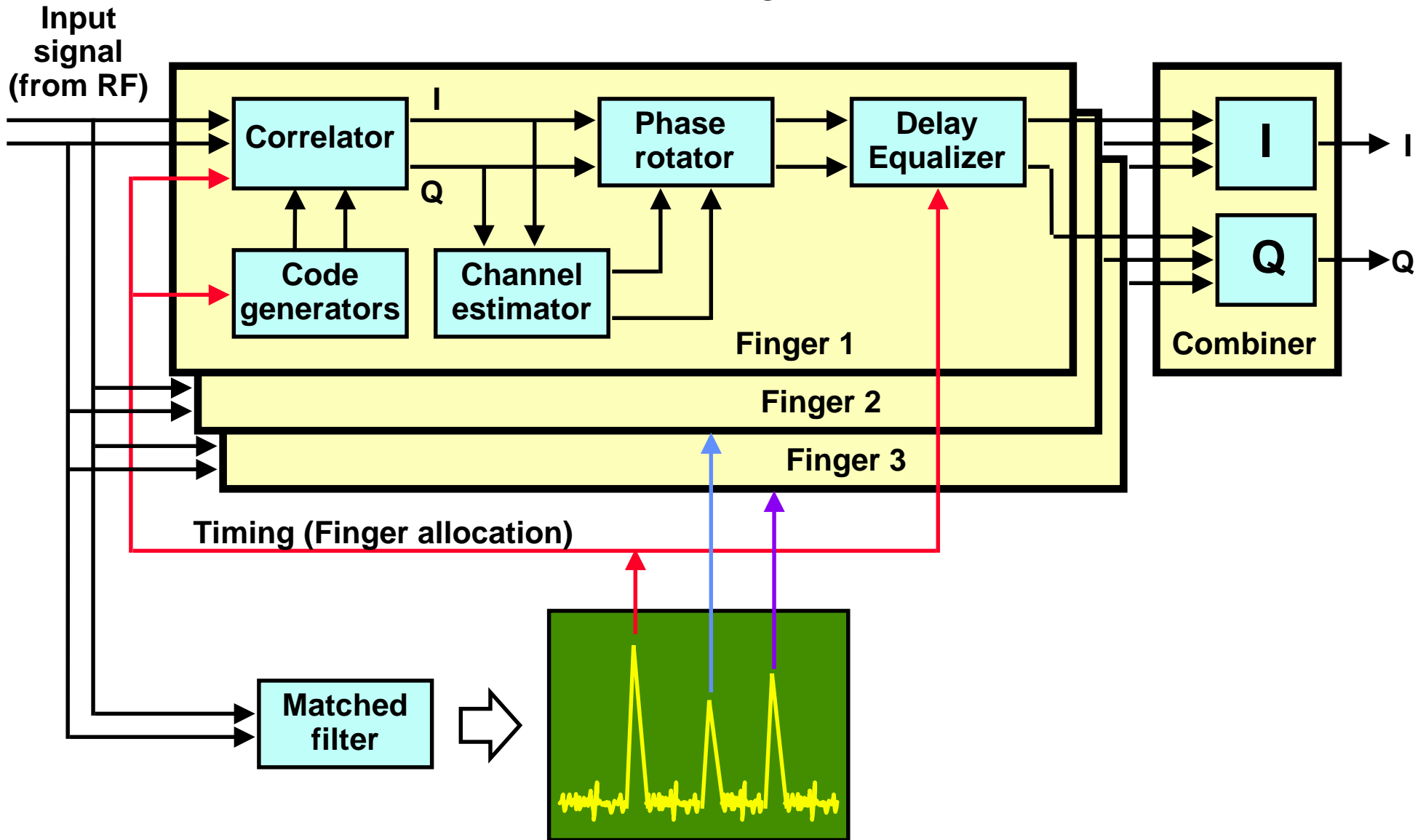


Maximal Ratio ("RAKE") Combining of Symbols



- **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**

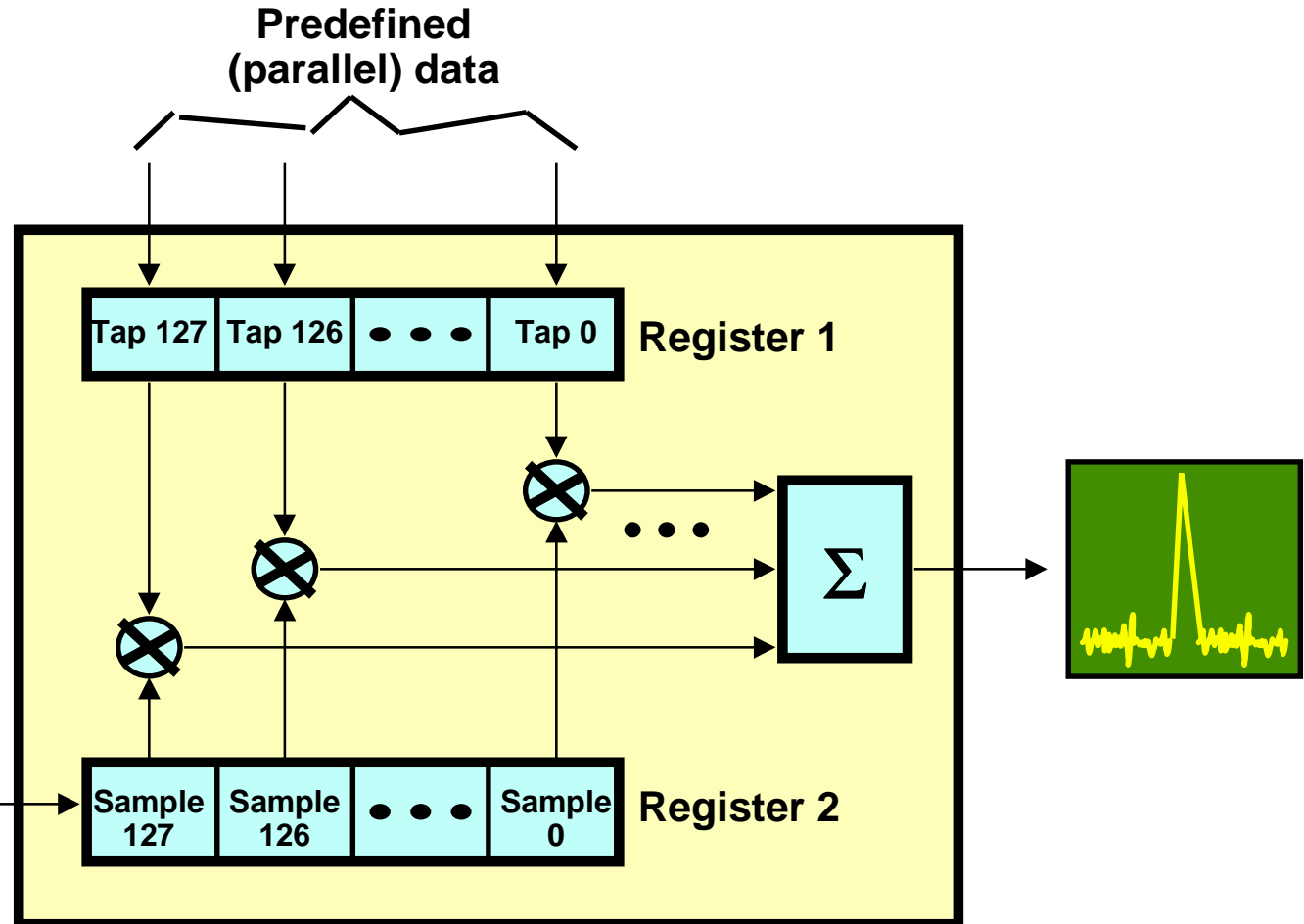
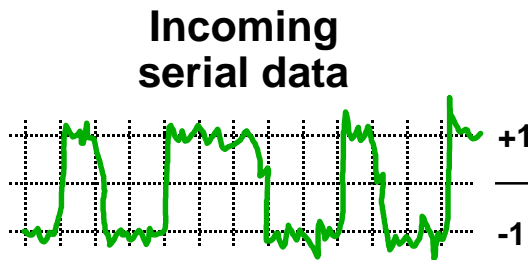
RAKE Diversity Receiver



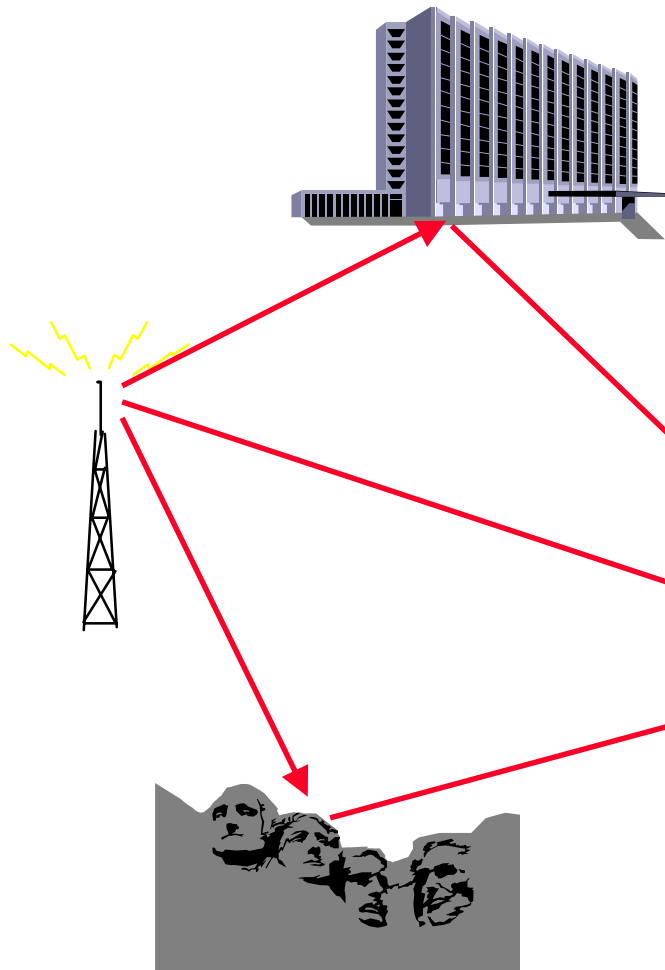
Matched Filter

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

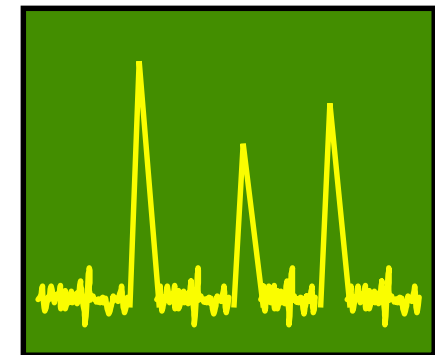
When samples of incoming serial data are equal to bits of predefined data, there is a maximum at filter output.



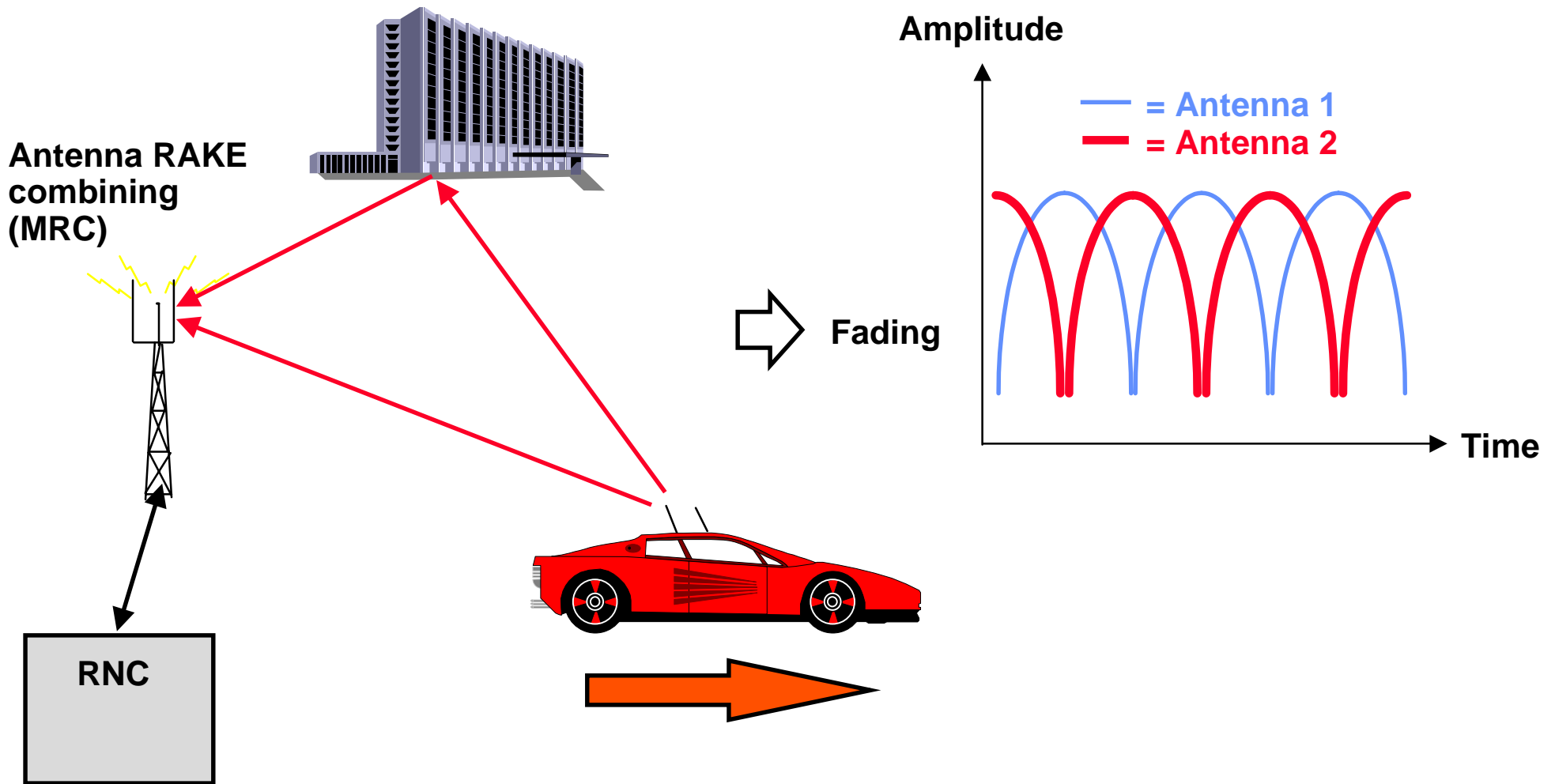
Delay Profile Estimation with MF



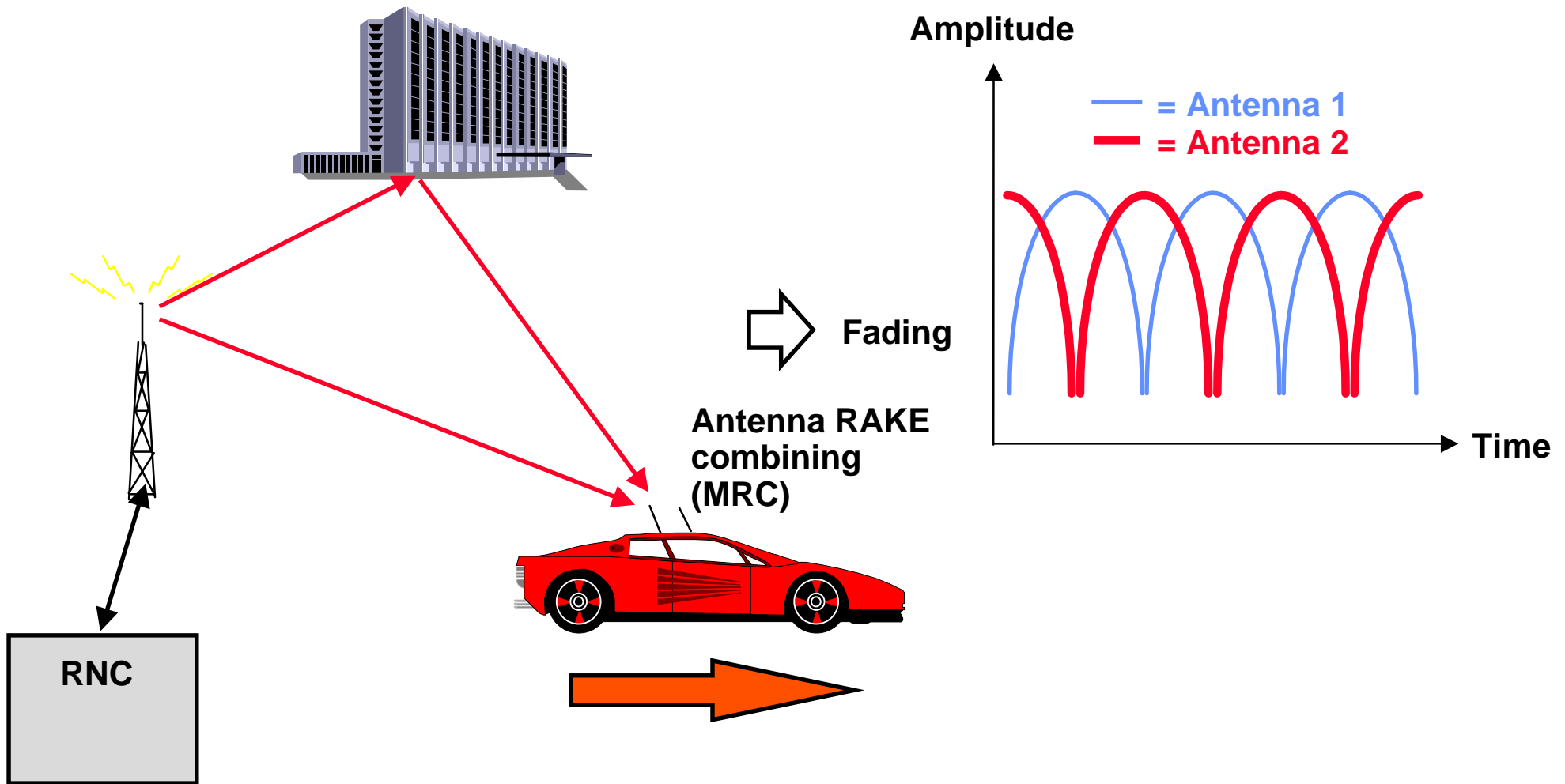
- **Multipath propagation causes several peaks in matched filter (MF) output**
- **Allocate RAKE fingers to these peaks**
- **Later: track and monitor the peaks**



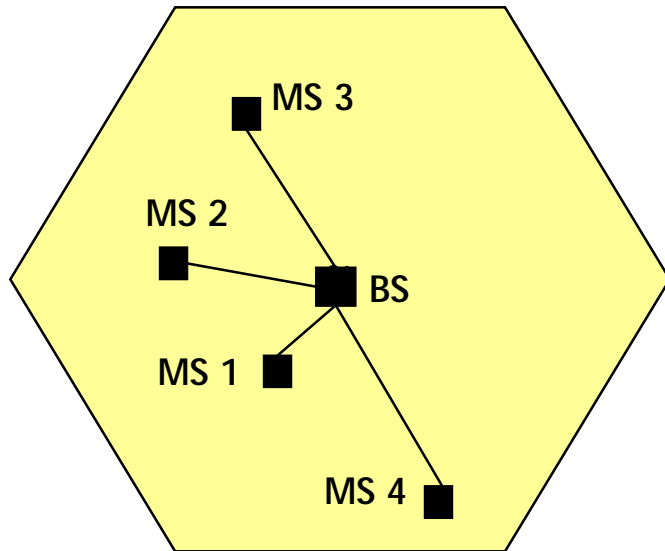
UL Receiver Diversity (Space Diversity)



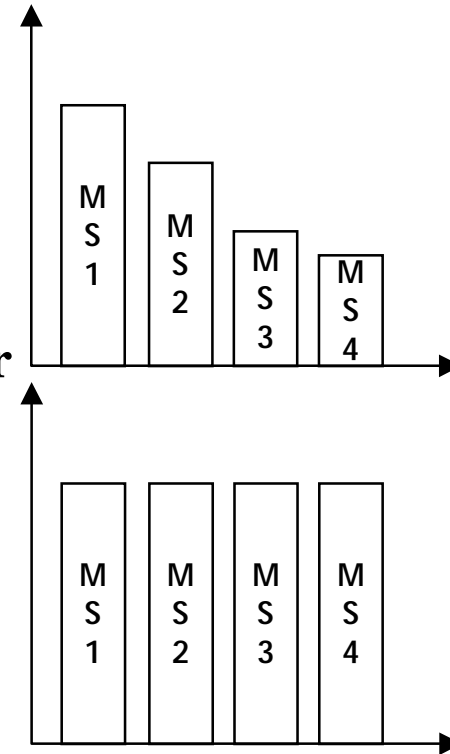
DL Receiver Diversity (Space Diversity)



WCDMA Power Control



Received Power
at the BS



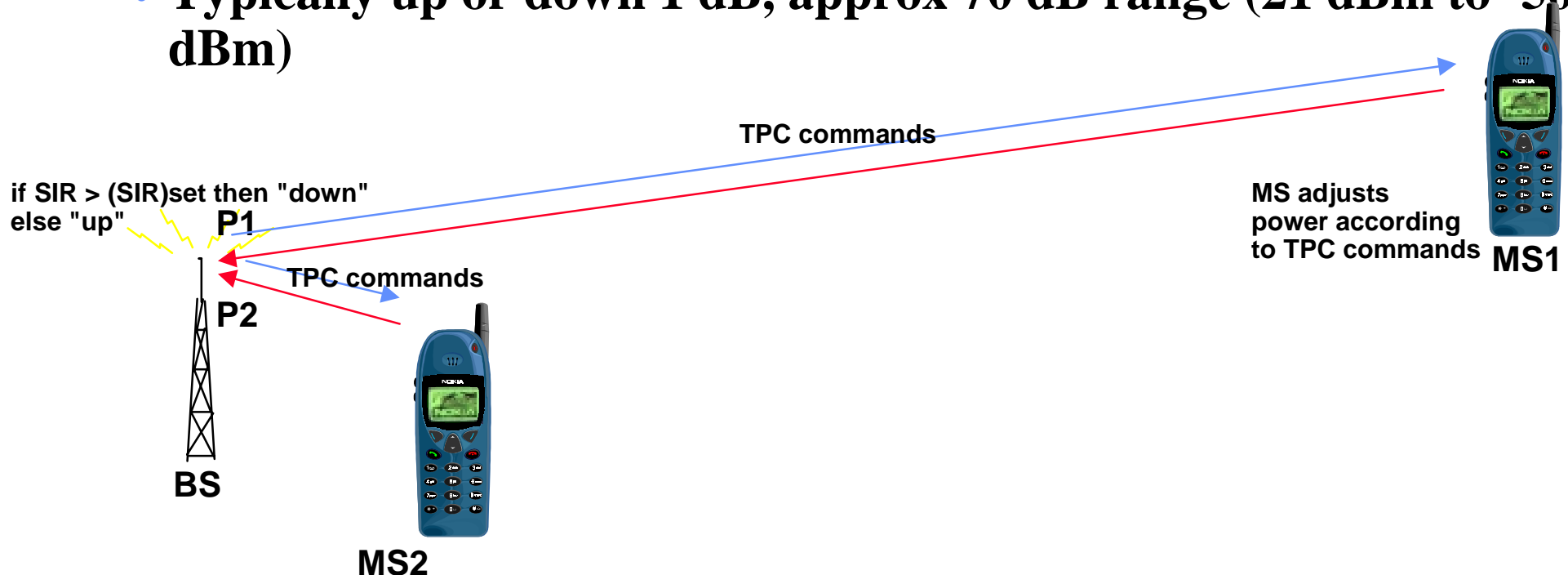
**Without
Power control**

**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 than necessary

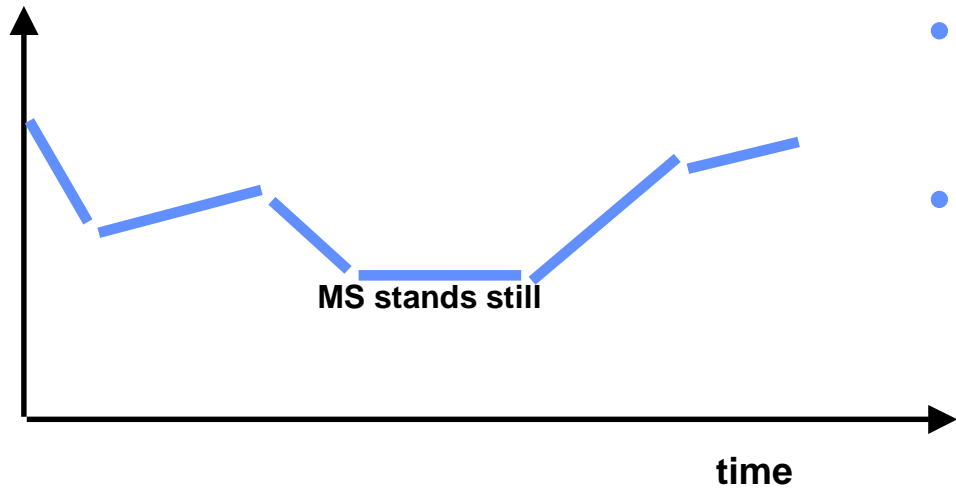
Fast Closed Loop Power Control

- 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)

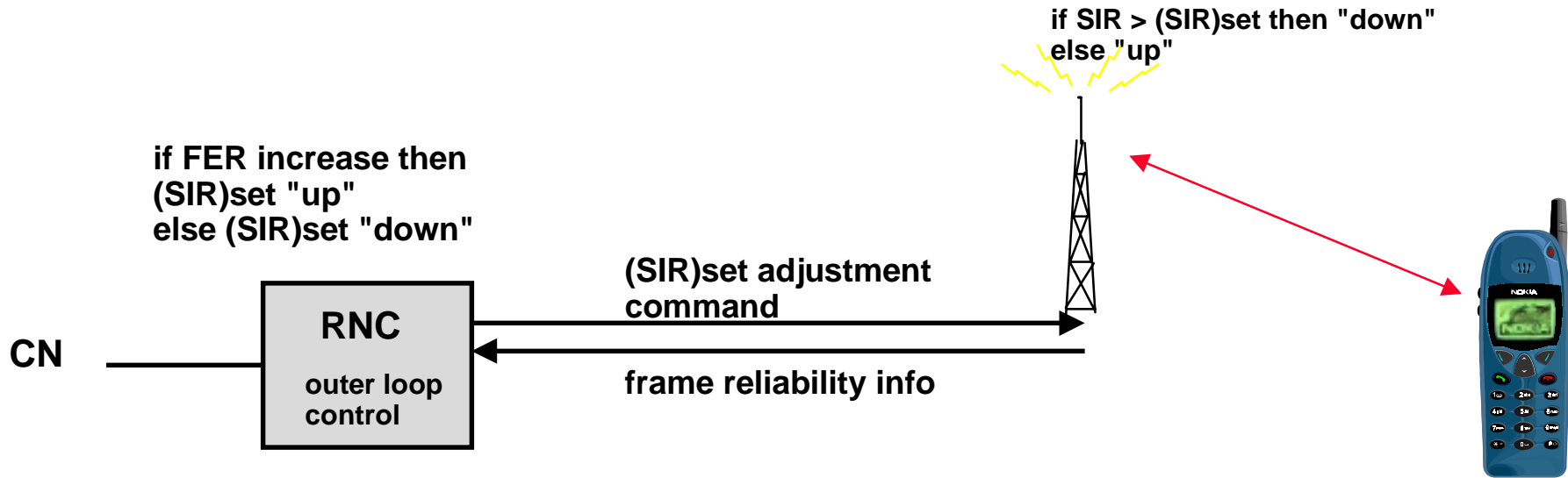


Uplink Outer Loop TPC

required (SIR) set for 1 % FER



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



WCDMA Handovers

Soft handover

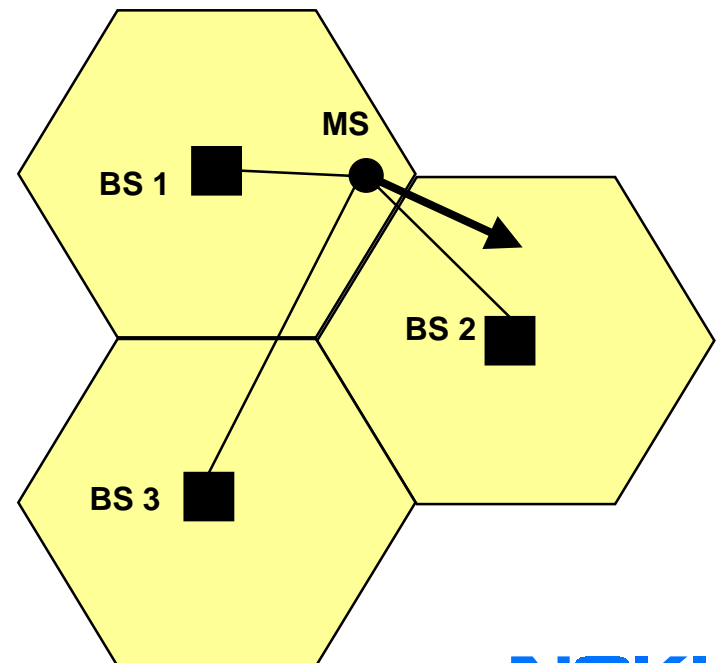
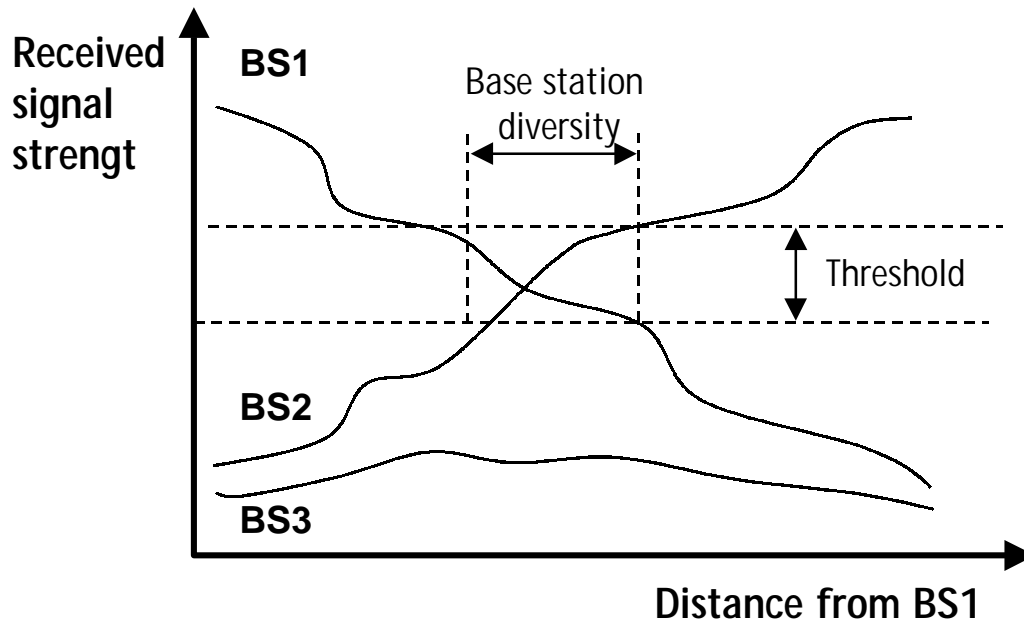
- MS handover between different base stations

Softer handover

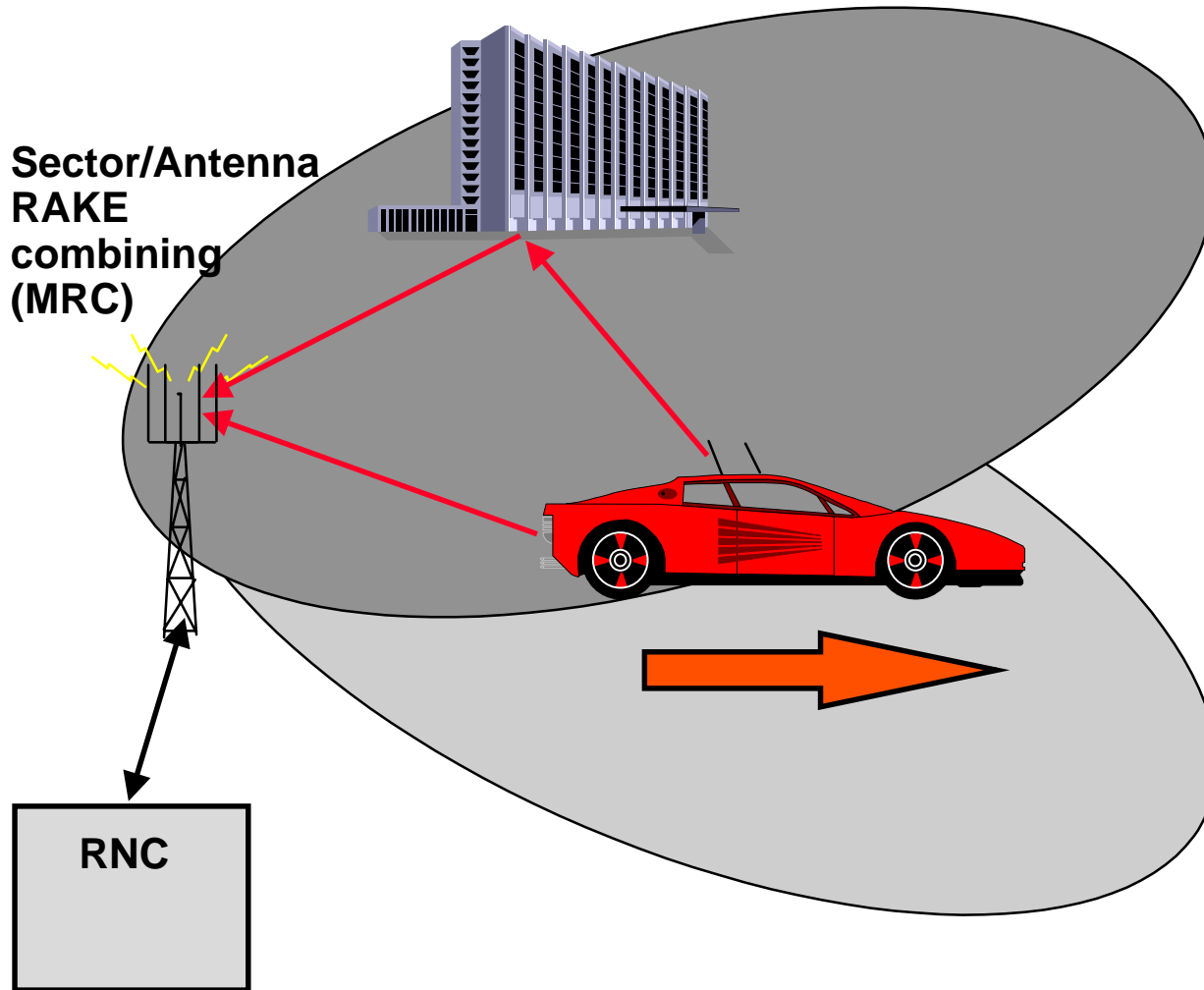
- MS handover within one cell between different sectors

Hard handover

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



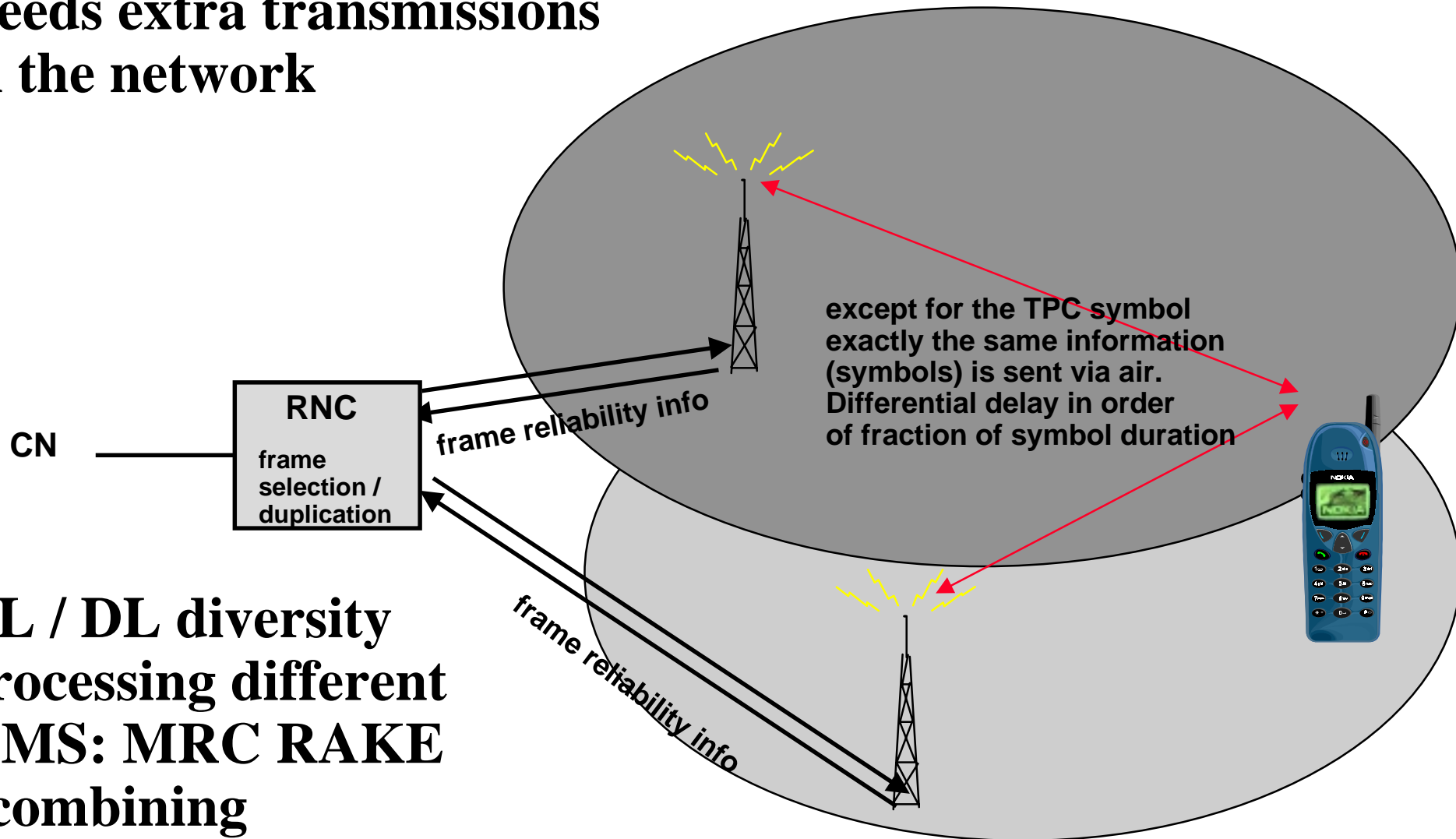
Softer Handover



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

Soft Handover

- Needs extra transmissions in the network



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

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**

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?

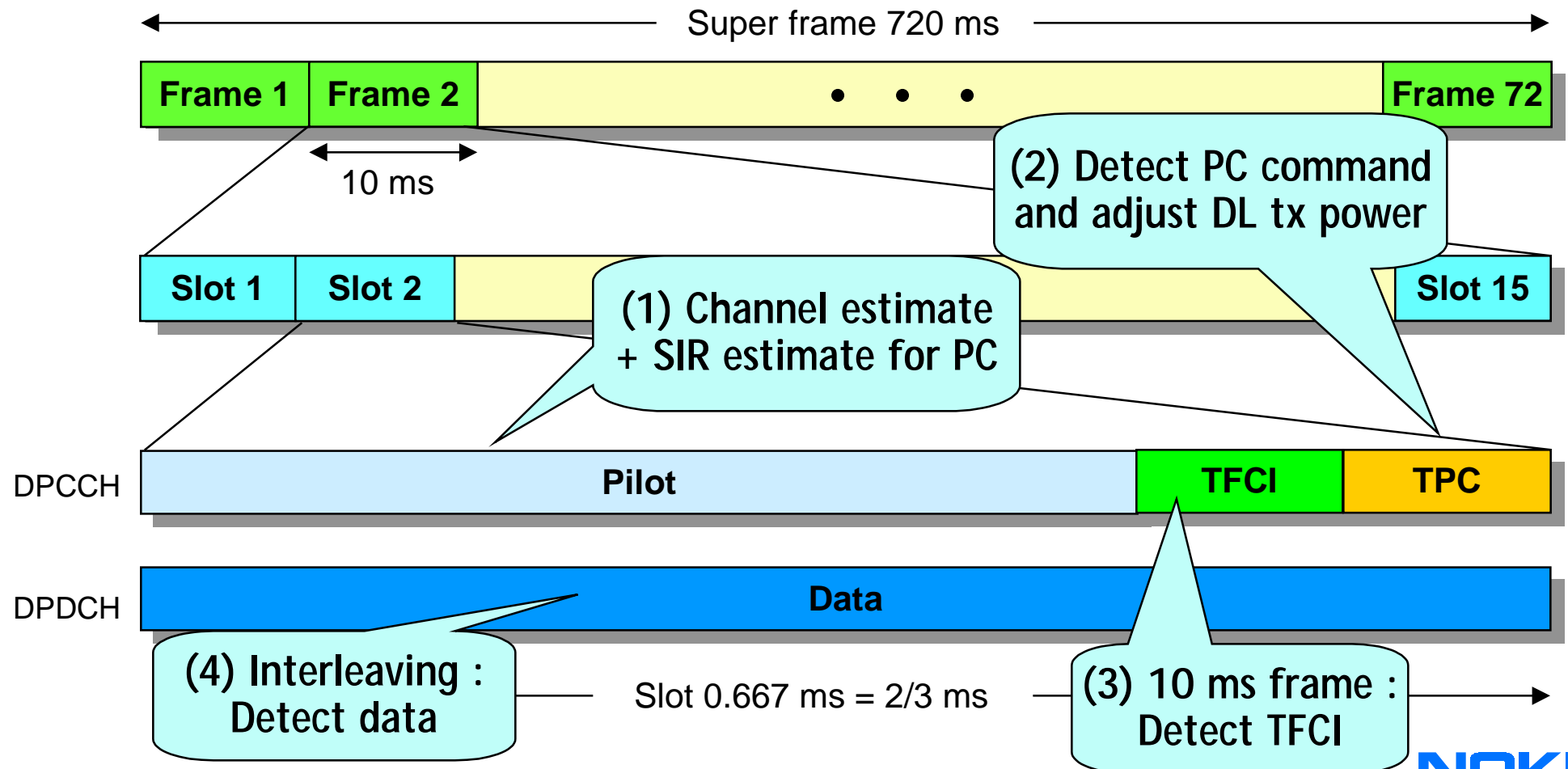
Variable bit rate

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

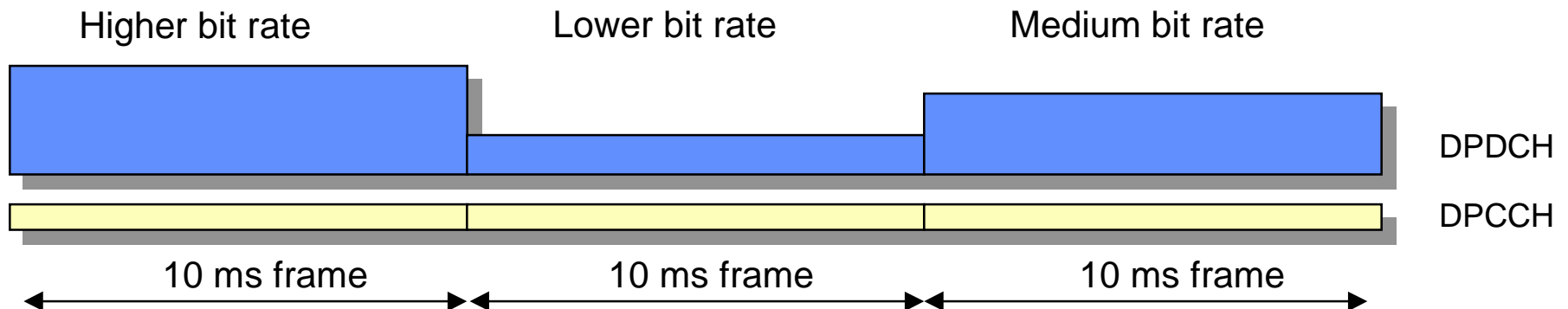
Uplink Dedicated Physical Channel

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



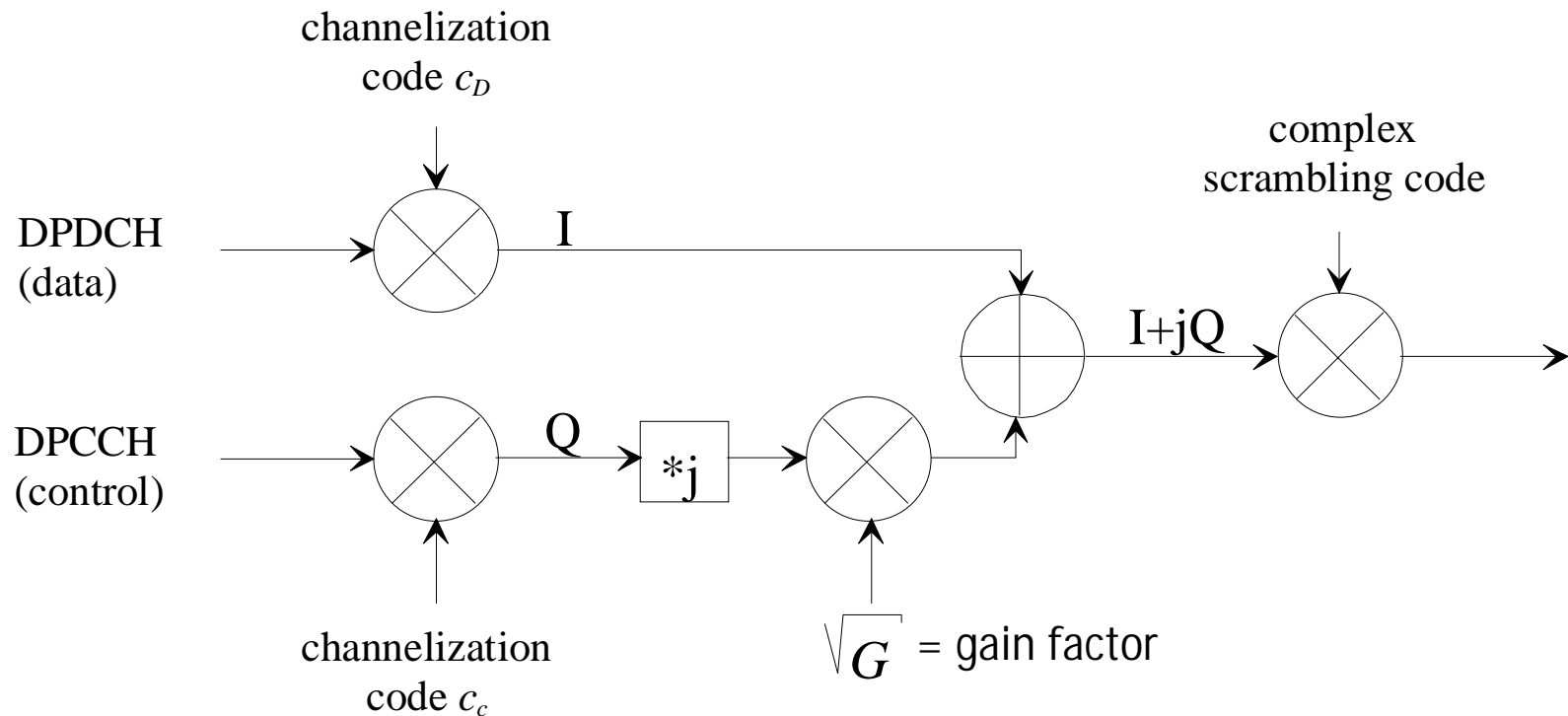
Uplink Variable Rate

- 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



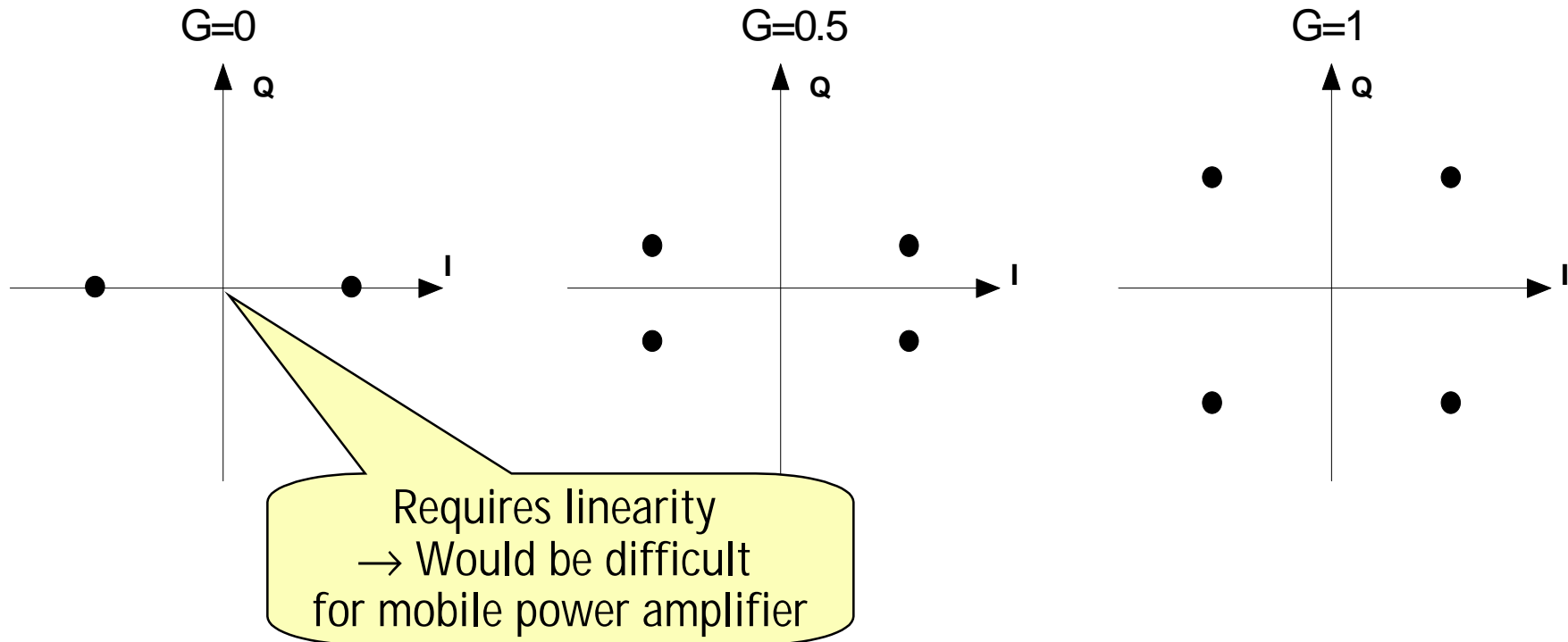
I-Q/code Multiplexing in Uplink

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



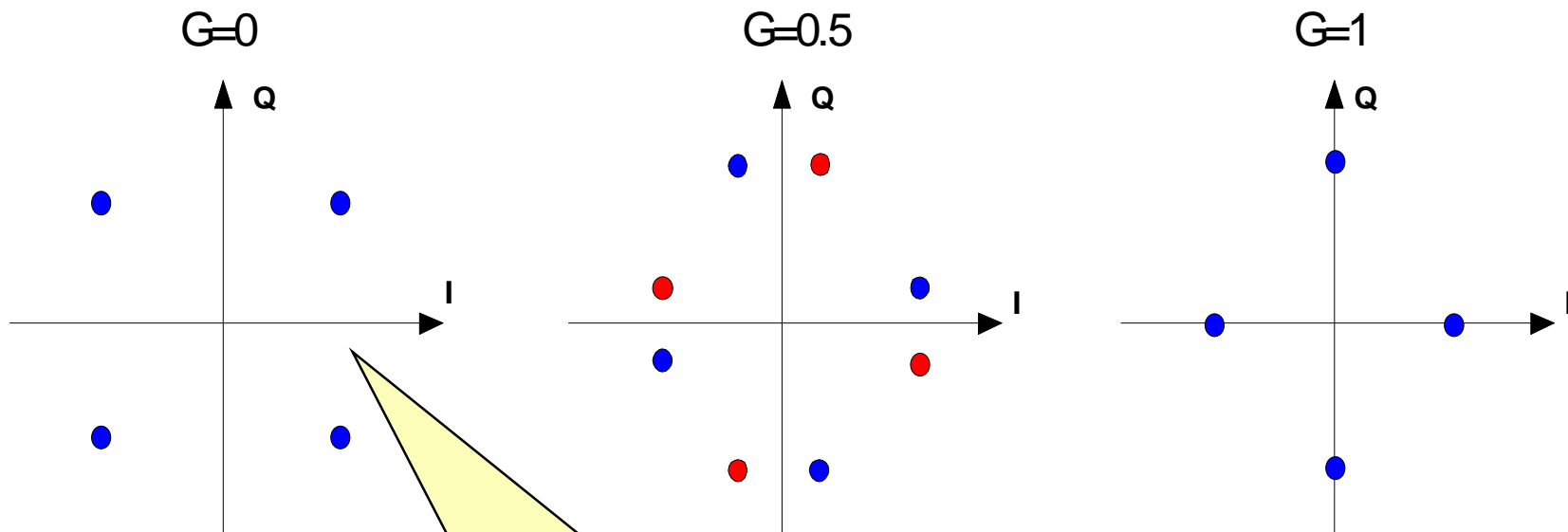
I-Q/code Multiplexing in Uplink

- 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

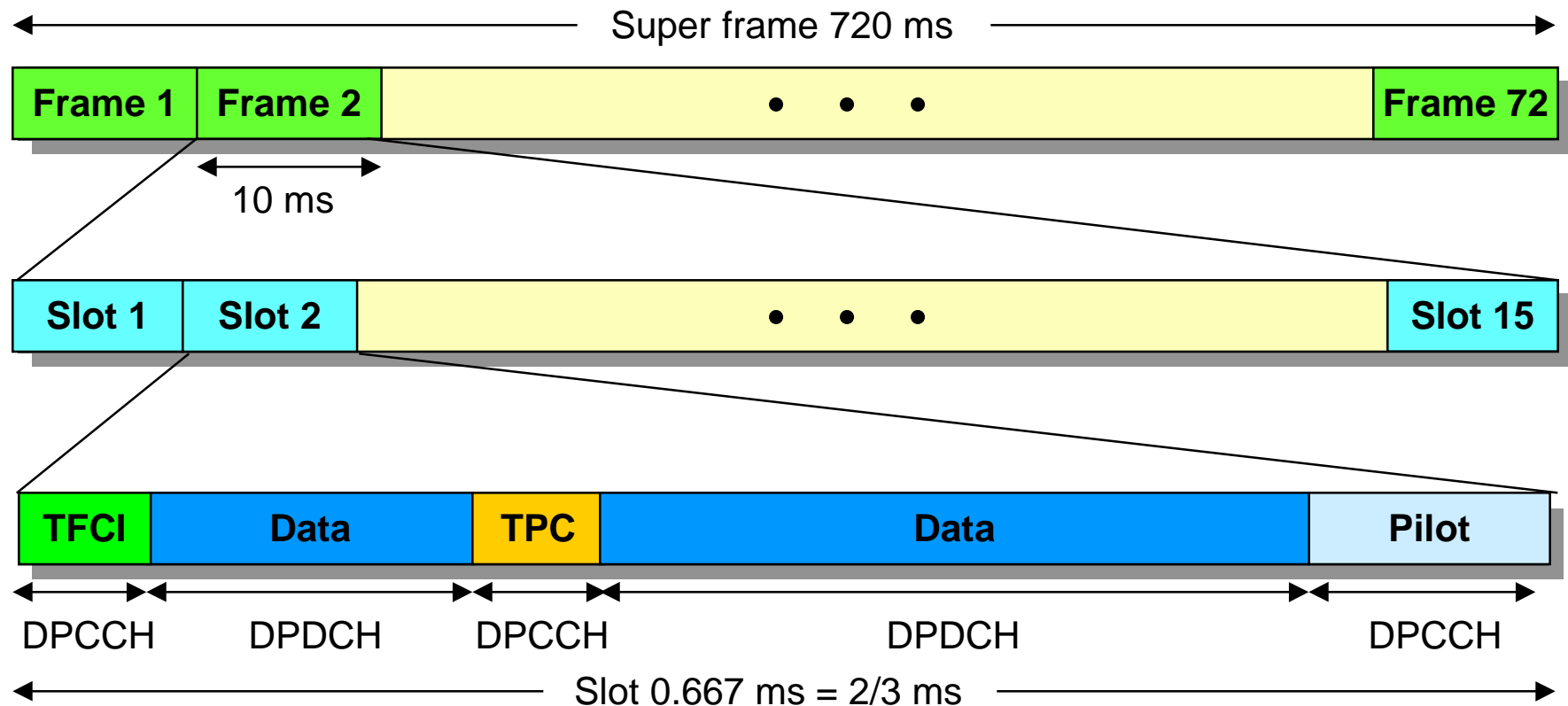
- Signal constellation *after* complex scrambling (at power amplifier)
- Signal envelope variations are similar to single code QPSK with all values of G
- G = power difference between DPCCH and DPDCH



Less linearity requirements for mobile power amplifier

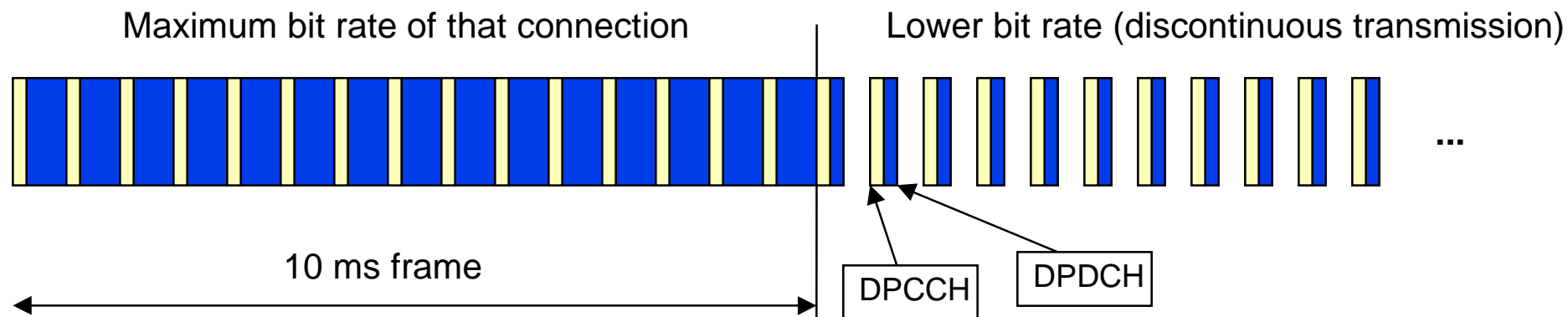
Downlink Dedicated Physical Channel

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



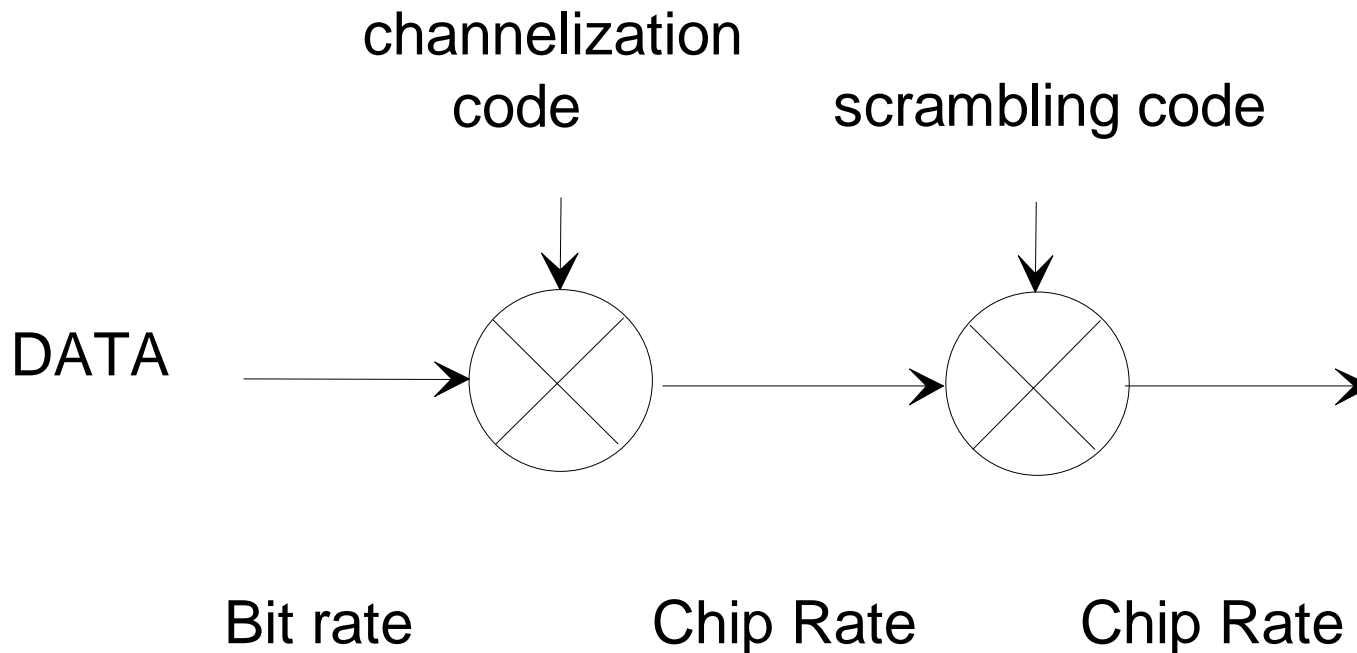
Downlink Variable Rate

- 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 Downlink: Separation of downlink connections to different users within one cell	Uplink: Separation of mobile Downlink: Separation of sectors (cells)
Length	4–256 chips (1.0–66.7 μ s) Downlink also 512 chips Different bit rates by changing the length of the code	Uplink: (1) 10 ms = 38400 chips or (2) 66.7 μ s = 256 chips Option (2) can be used with advanced base station receivers Downlink: 10 ms = 38400 chips
Number of codes	Number of codes under one scrambling code = spreading factor	Uplink: 16.8 million Downlink: 512
Code family	Orthogonal Variable Spreading Factor	Long 10 ms code: Gold code Short code: Extended S(2) code family
Spreading	Yes, increases transmission bandwidth	No, does not affect transmission bandwidth

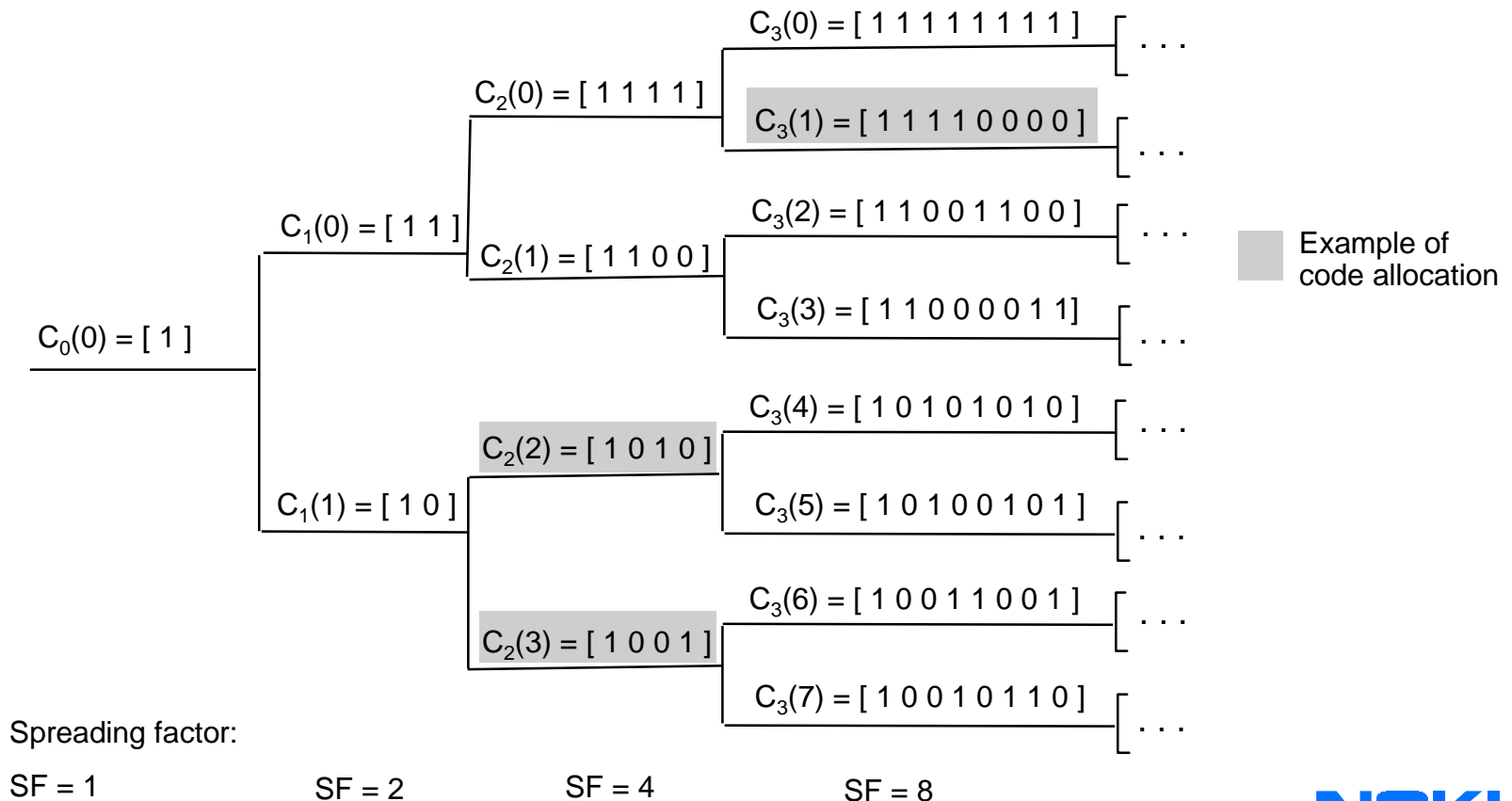
Downlink codes must be managed

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



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 1/2-rate coding (approx.)	
512	7.5	15	3–6	1–3 kbps	
256	15	30	12–24	6–12 kbps	Half rate speech
128	30	60	42–51	20–24 kbps	Full rate speech
64	60	120	90	45 kbps	
32	120	240	210	105 kbps	
16	240	480	432	215 kbps	144 kbps
8	480	960	912	456 kbps	384 kbps
4	960	1920	1872	936 kbps	
4, with 3 parallel codes	2880	5760	5616	2.3 Mbps	2 Mbps

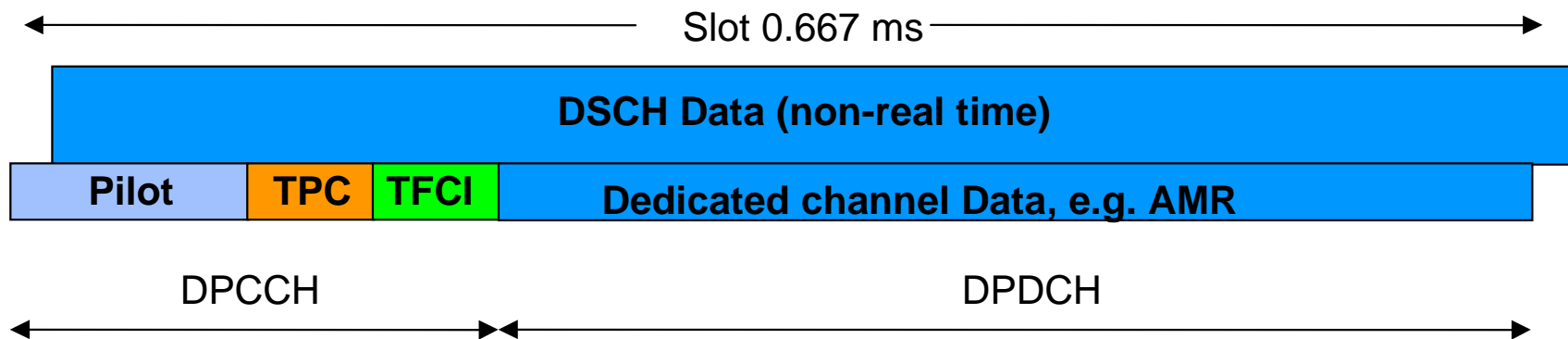
- The number of orthogonal channelization codes = Spreading factor
- The maximum throughput with 1 scrambling code ~2.5 Mbps or ~100 full rate speech users

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)

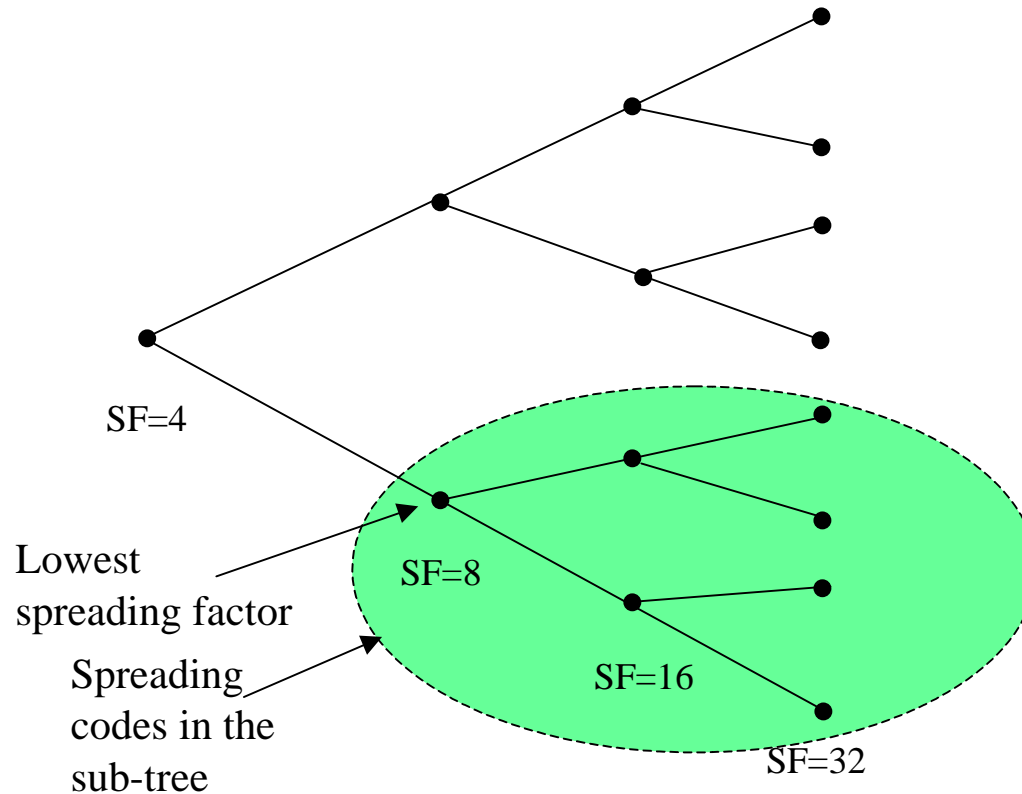
- The number of orthogonal codes in downlink is limited and the code is reserved according to the maximum bit rate in transport format set
 - ⇒ variable bit rate connections consume a lot of code resources
 - ⇒ downlink shared channel concept saves code space
- DSCH is shared between a group of downlink 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.

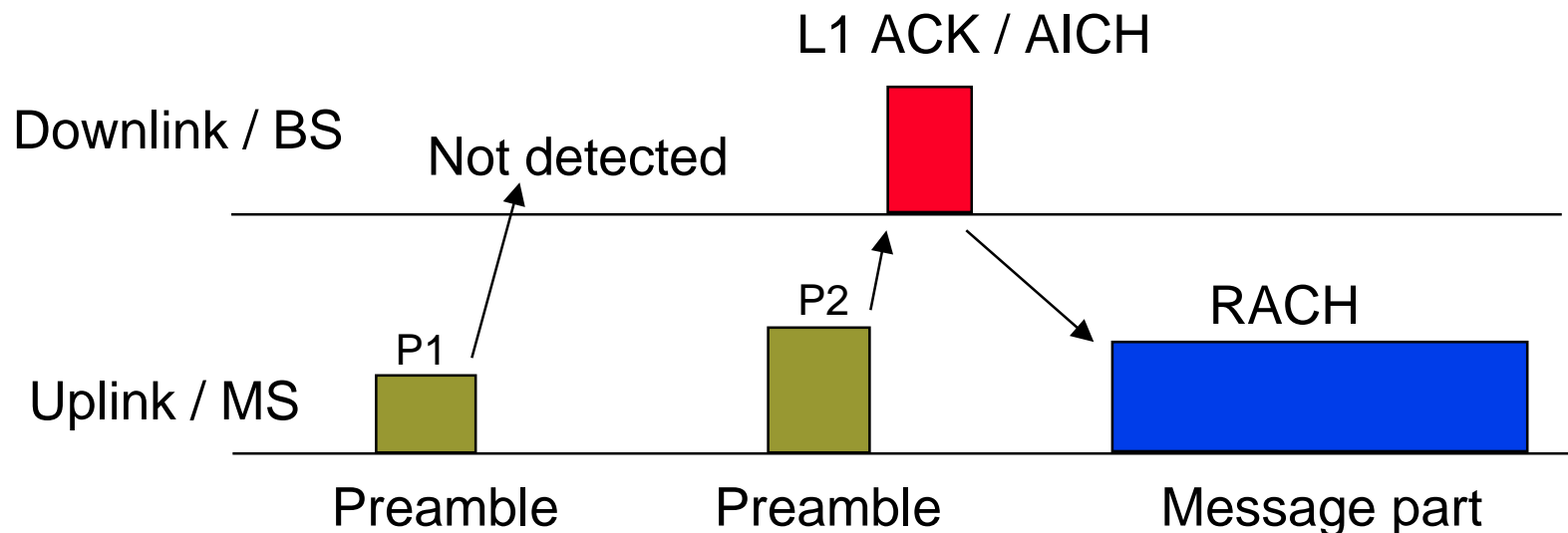
DSCH (2)

- 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.



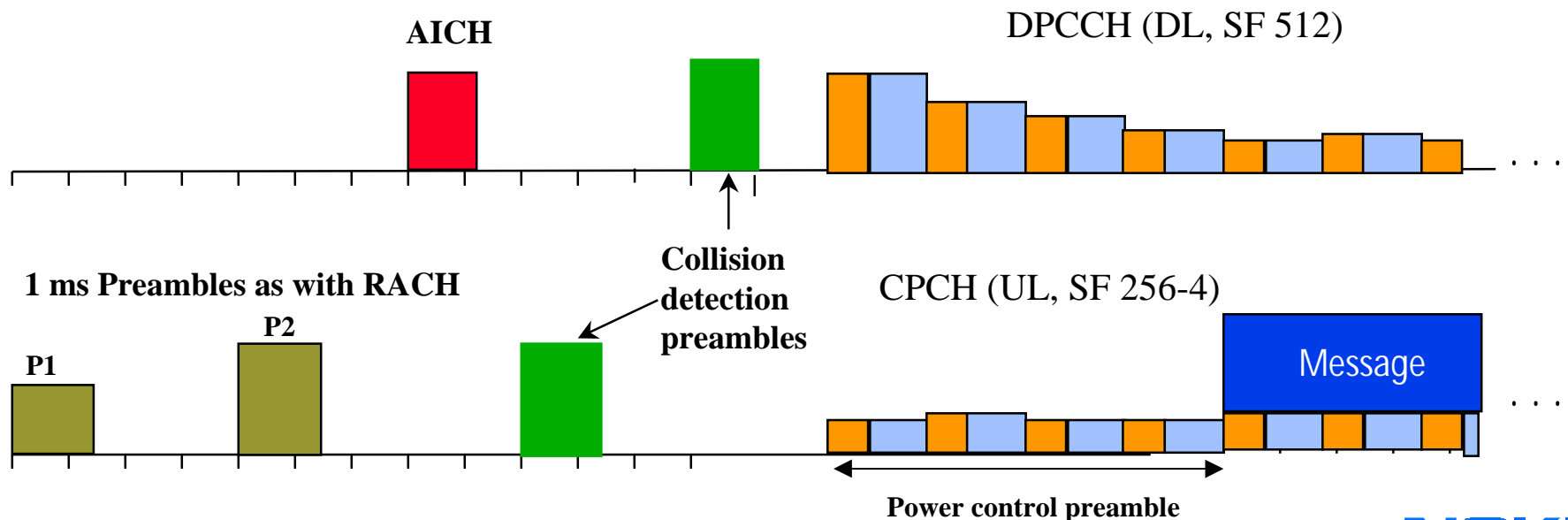
Random Access Channel (RACH)

- 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



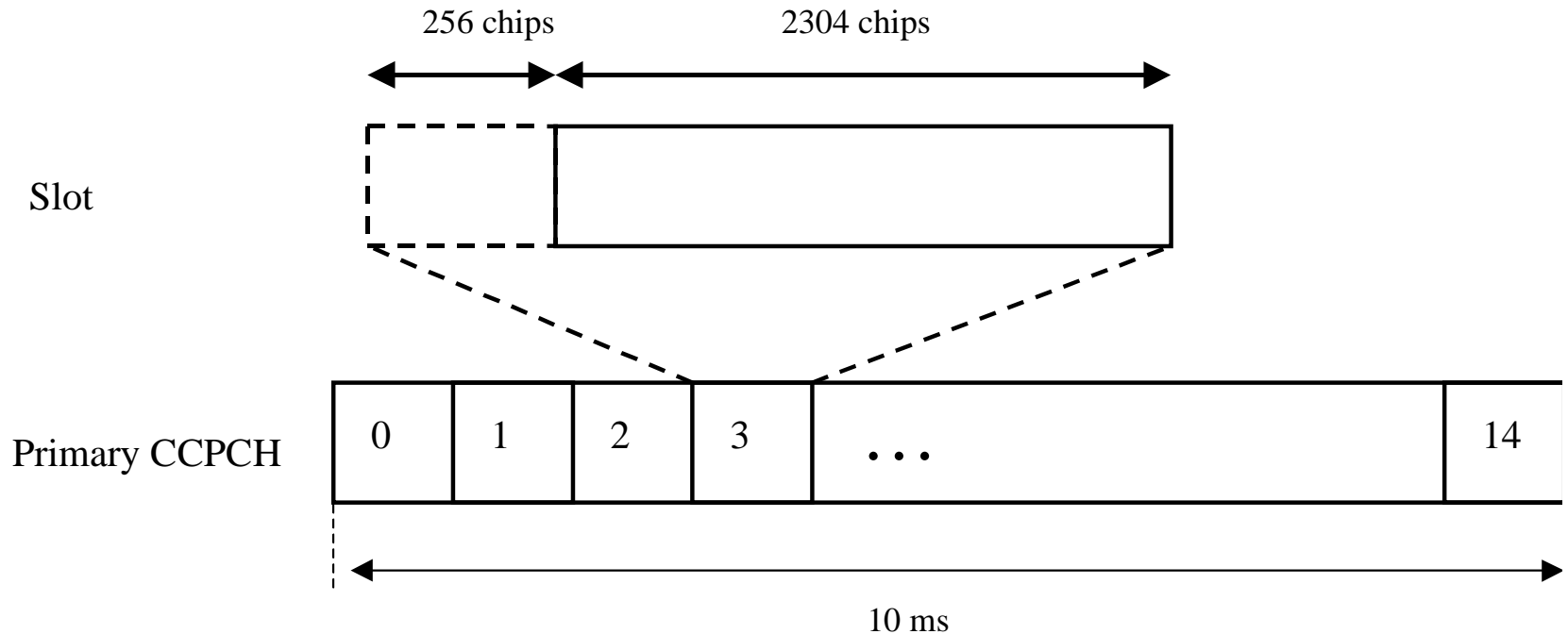
Uplink Common Packet Channel (CPCH)

- 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



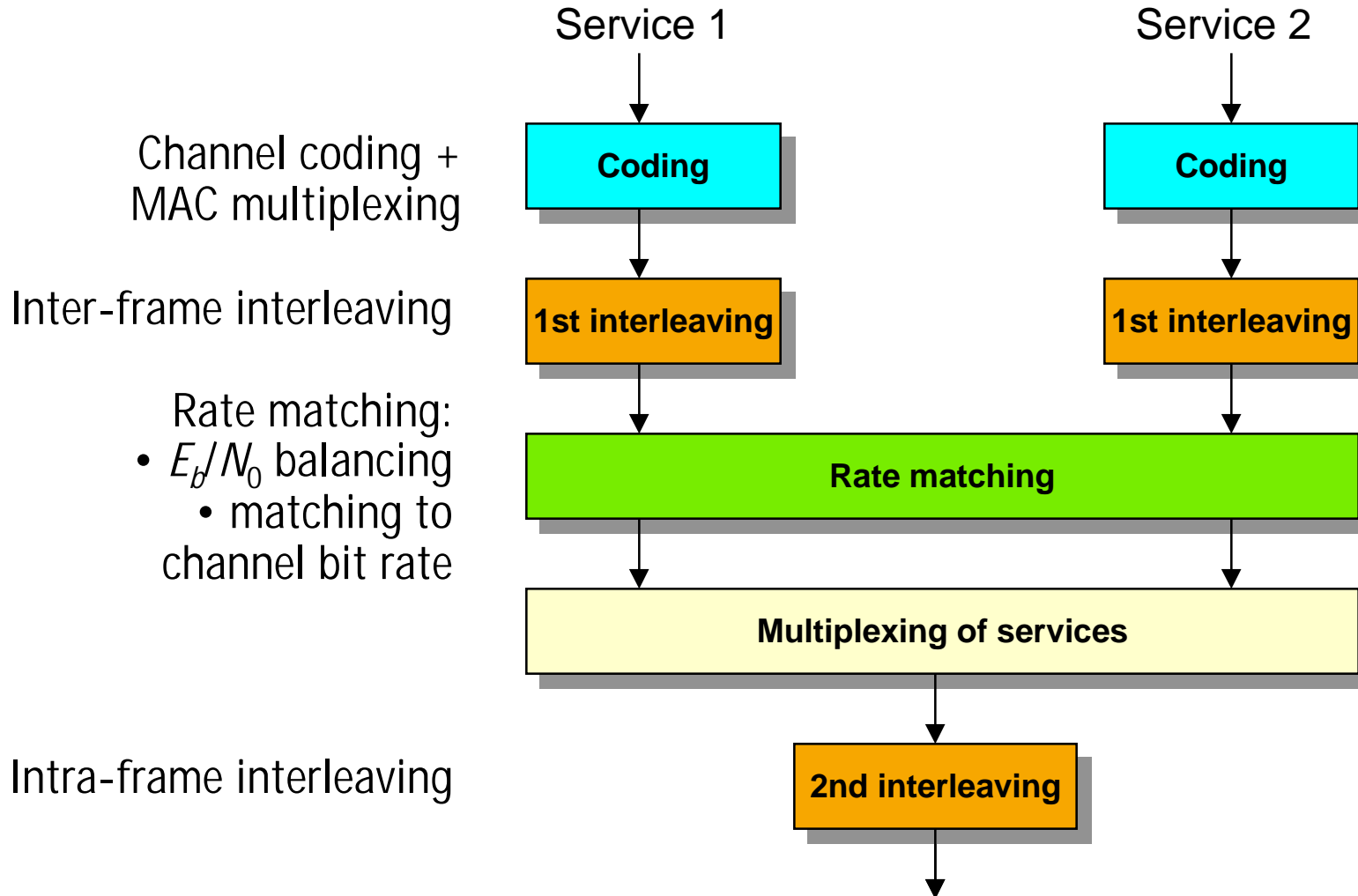
- Secondary CCPCH
 - carries FACH and PCH
 - variable bit rate

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



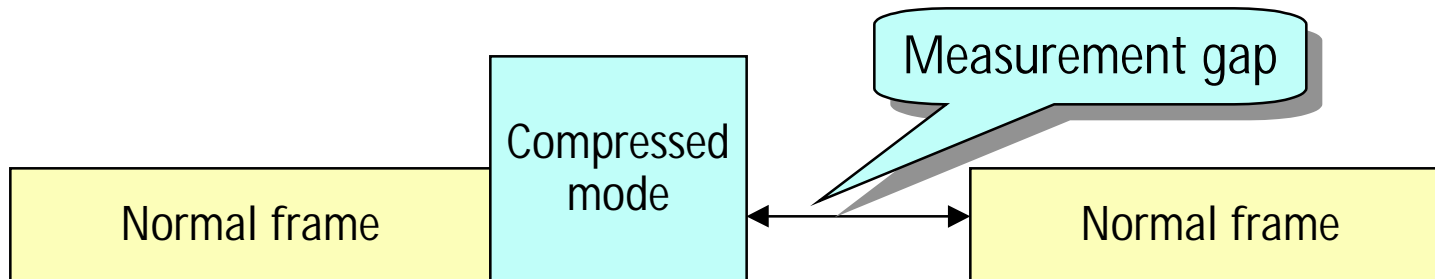
Channel Coding

- 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 ($\geq 32\text{kbps}$) and low BER requirements
 - Transmission without channel coding is also possible
- Other common channels
 - Convolutional code 1/2-rate, $K=9$

WCDMA ↔ GSM Inter-system Handovers

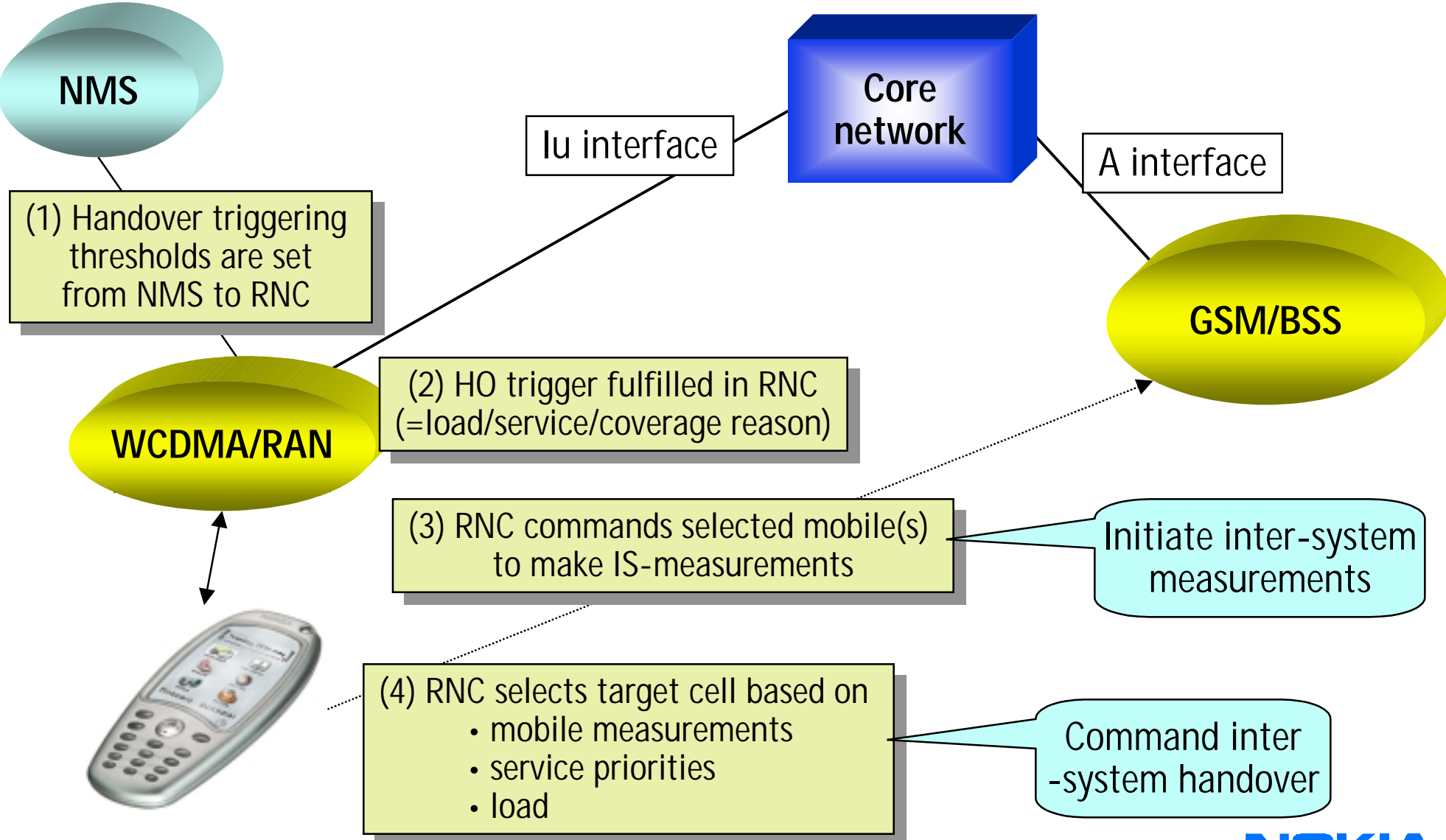
WCDMA Compressed Mode

	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



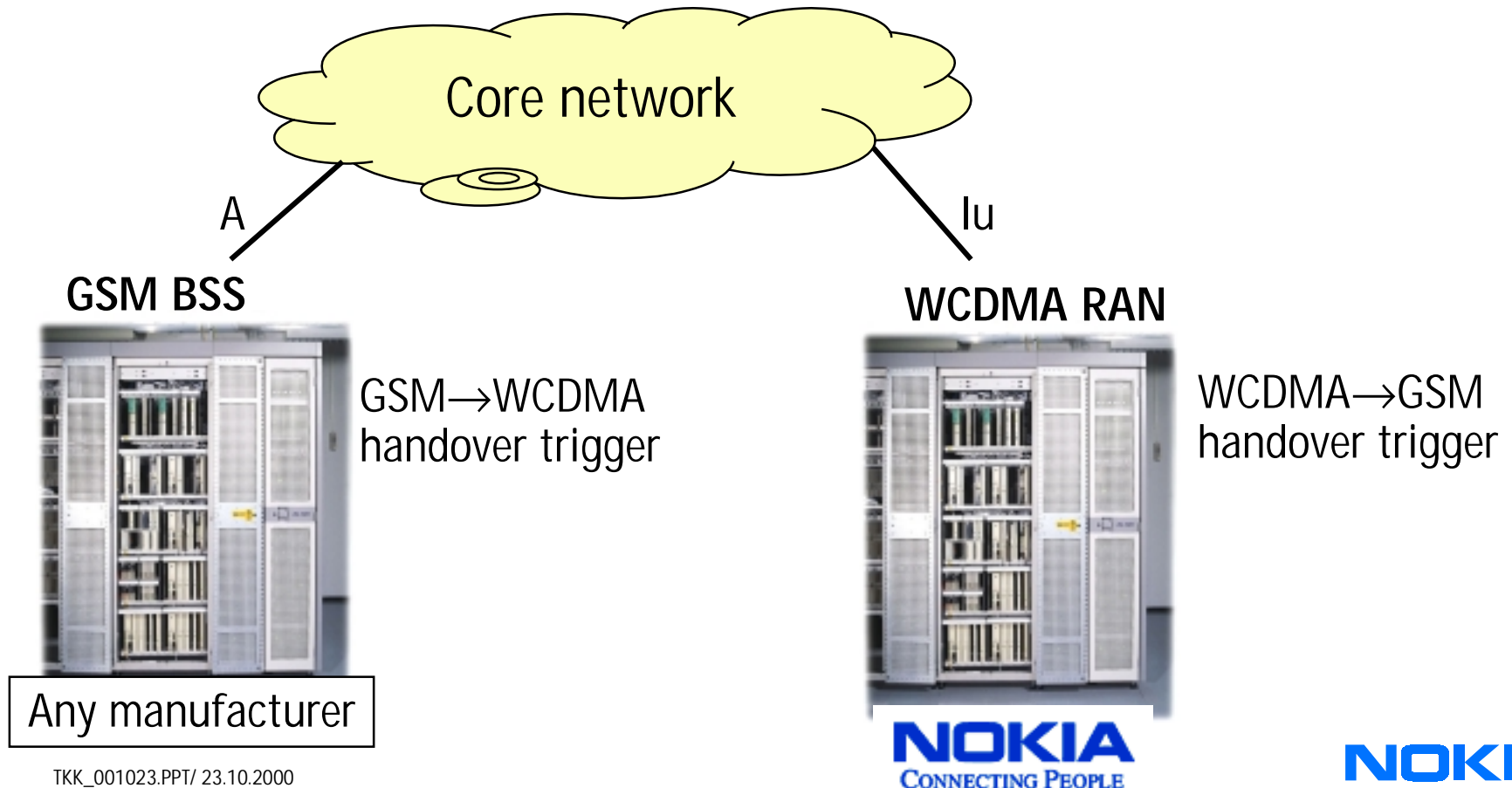
- More power is needed during compressed mode
 - => affects WCDMA coverage
- Power control cannot work during compressed frame => higher Eb/N0
 - => affects WCDMA capacity

Handover from WCDMA to GSM



Multivendor Inter-system Handovers

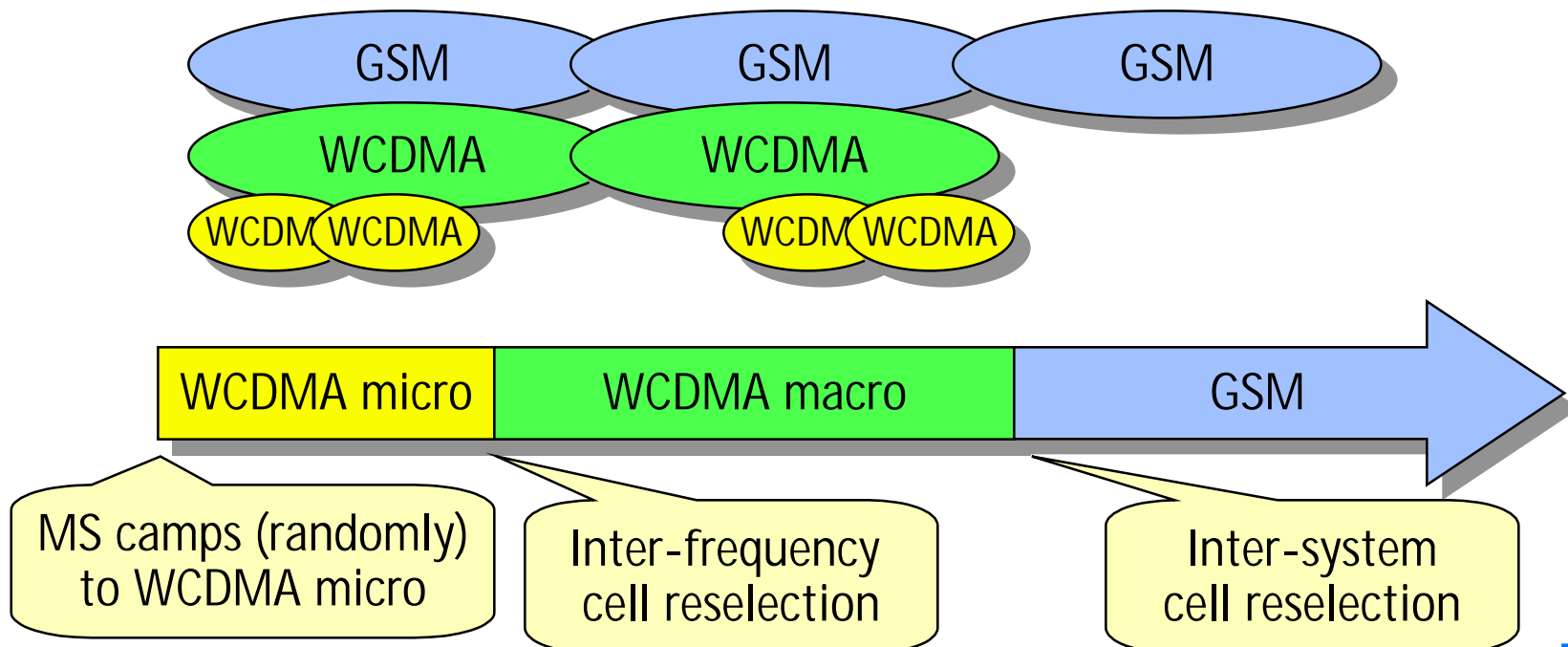
- Handovers between GSM and WCDMA can be done also between different vendors' networks
- Handovers from GSM to WCDMA are triggered in GSM BSS
- Handovers from WCDMA to GSM are triggered in WCDMA RAN



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

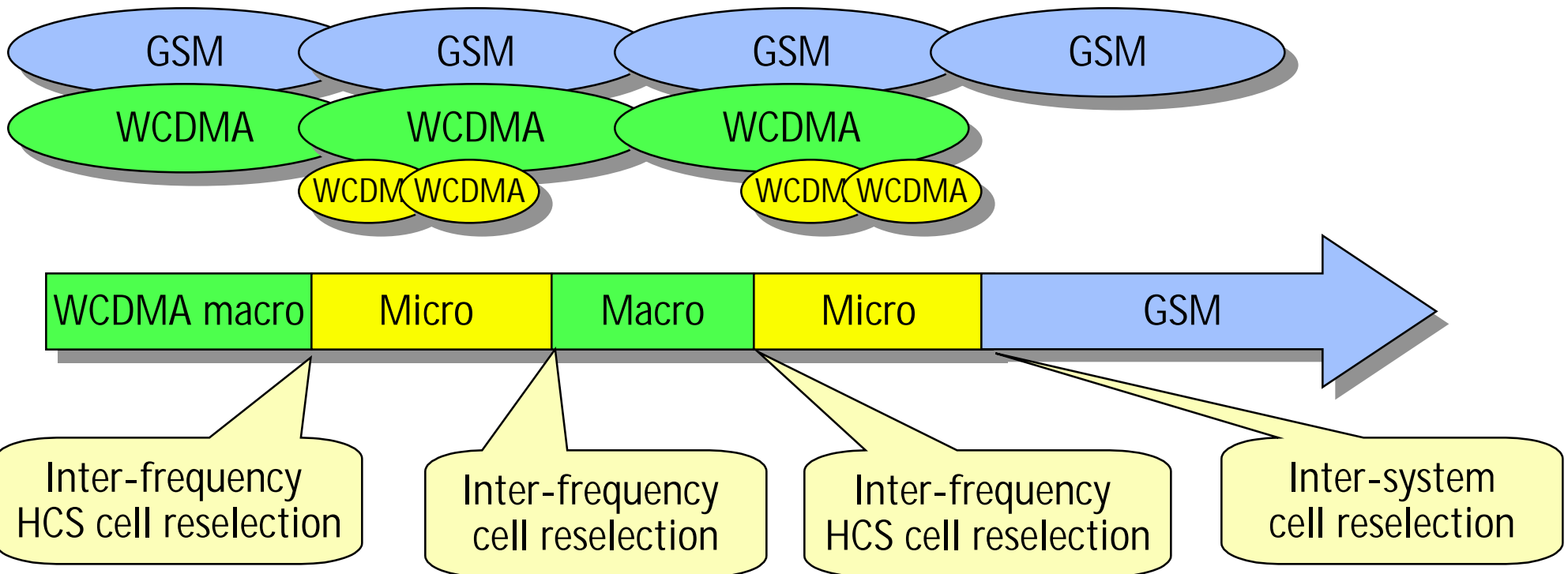
Without Hierarchical Cell Priorities

- Mobile stays within one frequency if received pilot E_c/I_0 is good enough = above $S_{\text{intersearch}}$ and $S_{\text{searchRATn}}$
- $S_{\text{intersearch}}$ threshold for starting inter-frequency measurements
- $S_{\text{searchRATn}}$ threshold for starting inter-frequency measurements
- Inter-frequency and inter-system measurements consume more battery in terminal → thresholds must be low enough



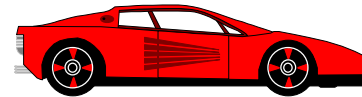
With Hierarchical Cell Priorities

- 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

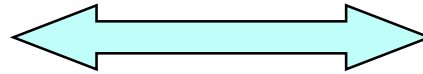
- High mobile speeds can be directed to macro cells in idle mode based on the frequency of the cell re-selections
 - Parameters N_{CR} / T_{CRmax}
 - If the number of cell reselections during time period T_{CRmax} exceeds N_{CR} , high-mobility has been detected



- 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

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
<ul style="list-style-type: none">• Less location updates• 3G → 2G handover is not necessary• Lower MS power consumption in idle mode	<ul style="list-style-type: none">• 3G services available for all dual-mode mobiles even without 2G→3G handover or network controlled cell reselection• 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

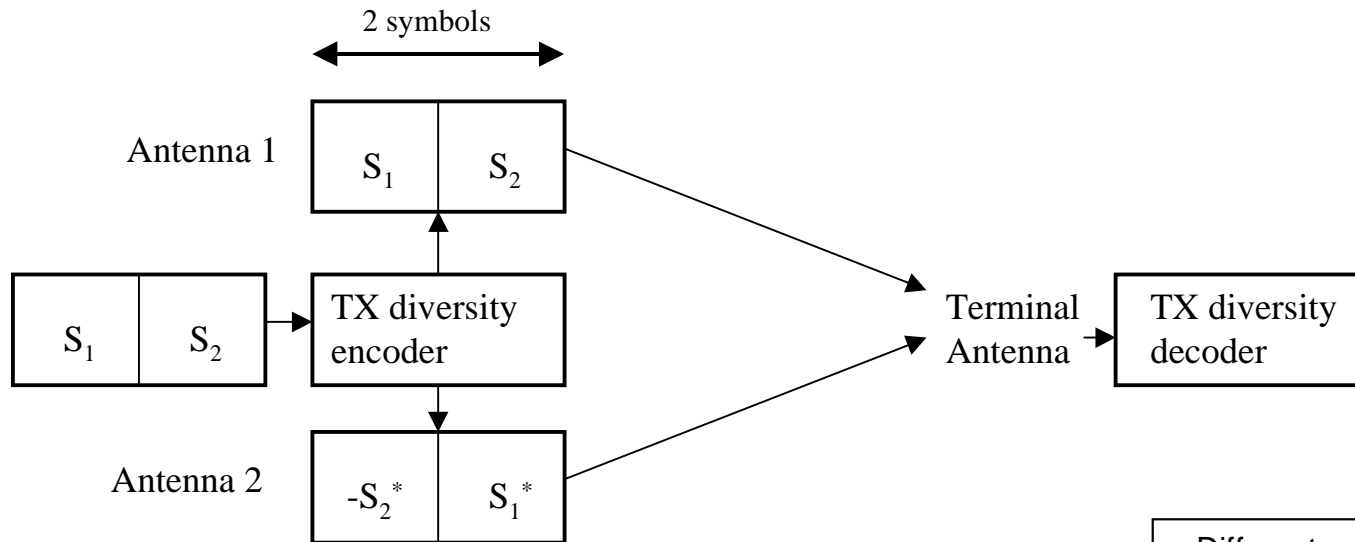
- Equal idle mode priority could also be used for GSM and for WCDMA, especially when dual-mode penetration and traffic in WCDMA increases

Downlink Transmit Diversity

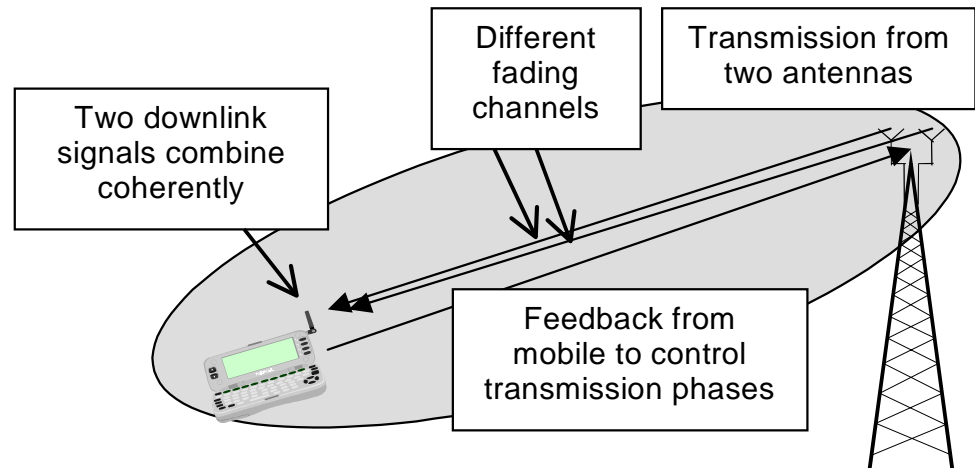
- Background
 - More capacity expected to be needed in downlink than in uplink
 - Uplink capacity tends to be higher than downlink because better receiver techniques can be applied in the base station than in the mobile (antenna diversity and multiuser detection)
 - Antenna diversity not practical for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

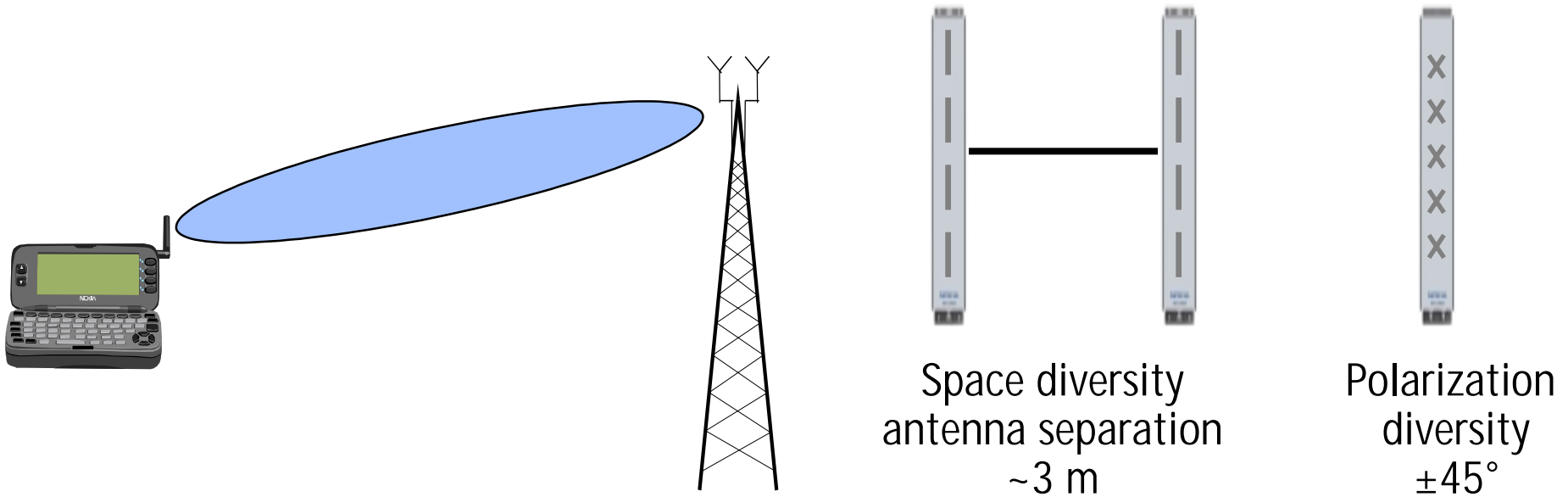


- Closed loop transmit diversity



Downlink Transmit Diversity

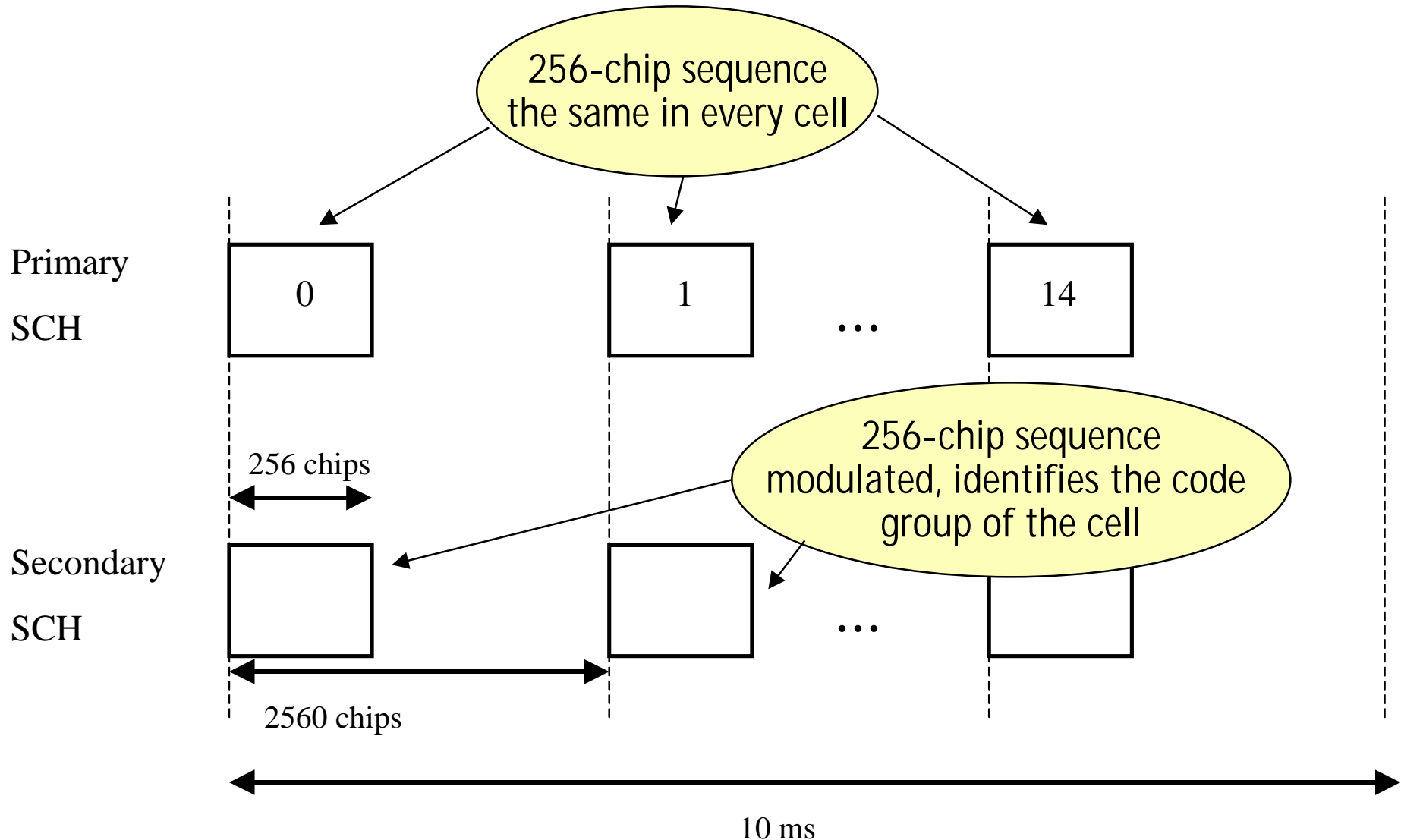
- Transmission from two base station antennas
- Both modes give gain against fading
- Closed loop mode targets for coherent combining of the received signals in the mobile



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 Discrete steps in feedback loop Delay in feedback loop 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: ITU Pedestrian A: 2.8 dB 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

	WCDMA	GSM
High bit rates		
Spectral efficiency	5 MHz	200 kHz
	1	1-18
	1500 Hz	2 Hz or lower
Different quality requirements	Radio resource management algorithms	Network planning (frequency planning)
	5 MHz bandwidth gives multipath diversity with Rake receiver	Frequency hopping
Efficient packet data	Load-based packet scheduling	Time slot based scheduling with GPRS
Downlink capacity	Supported for improving downlink capacity	Not supported by the standard, but can be applied

Differences Between WCDMA and IS-95

	WCDMA	IS-95
High bit rates	5 MHz	1.25 MHz
High quality services + capacity	3.84 Mcps	1.2288 Mcps
Micro + indoor cells	1500 Hz, both uplink and downlink	Uplink: 800 Hz Downlink: slow power control
Several carriers per base station	Not needed	Yes, typically obtained via GPS
Different quality requirements	Yes, measurements with slotted mode	Possible, but measurement method not specified
Efficient packet data	Yes, provides required quality of service	Not needed for speech only networks
Downlink capacity	Load-based packet scheduling	Packet data transmitted as short circuit switched calls
	Downlink transmit diversity	Not supported by the standard

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.
 - $3.84 \text{ Mcps} \Leftrightarrow 1 \text{ chip}$ corresponds to 78 m ($=3e8/3.84e6$)
 - $1.2288 \text{ Mcps} \Leftrightarrow 1 \text{ chip}$ 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