Evolution of cellular wireless systems from 2G to 5G

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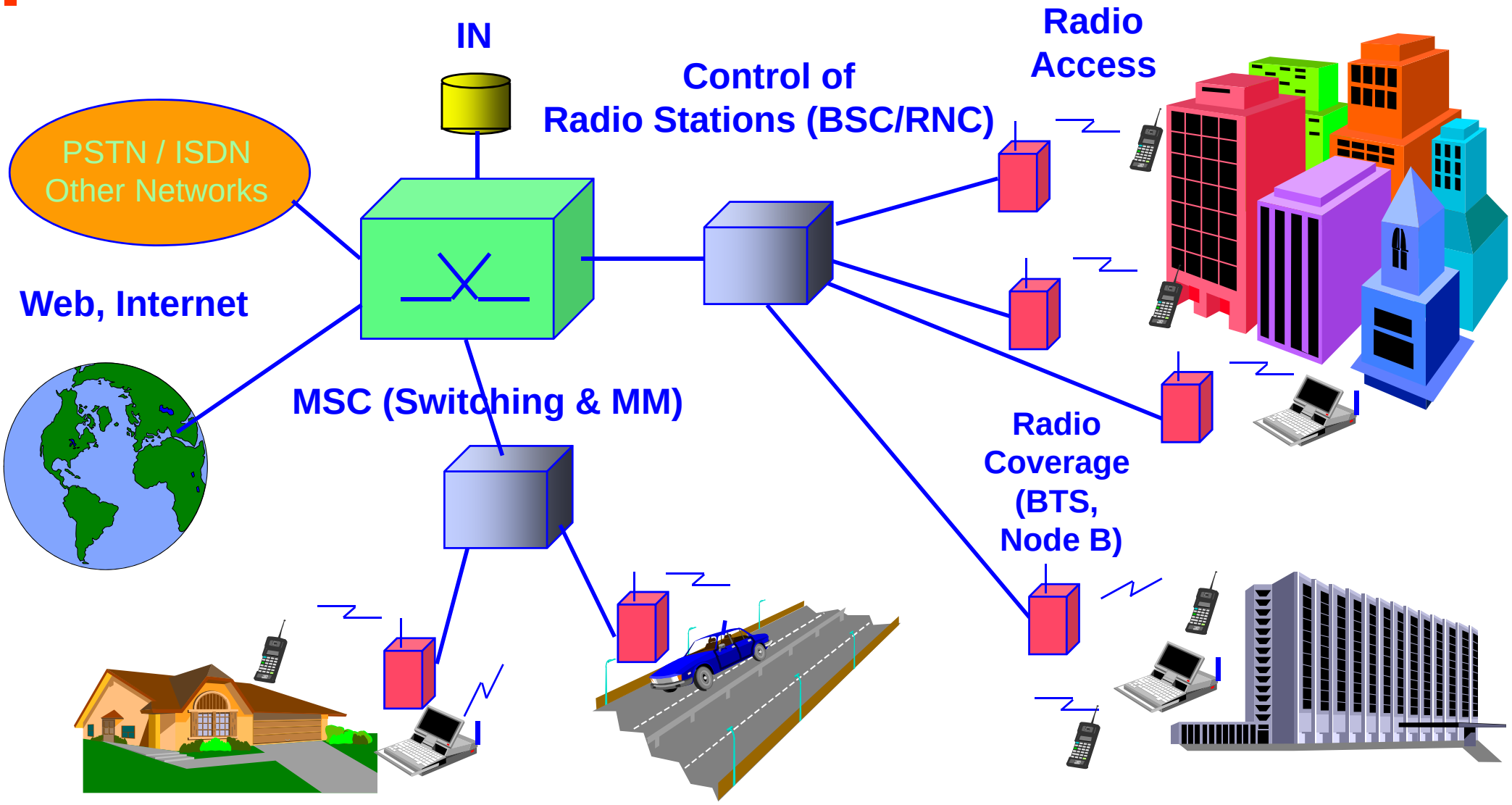
TIM INNOVATION DEPT.

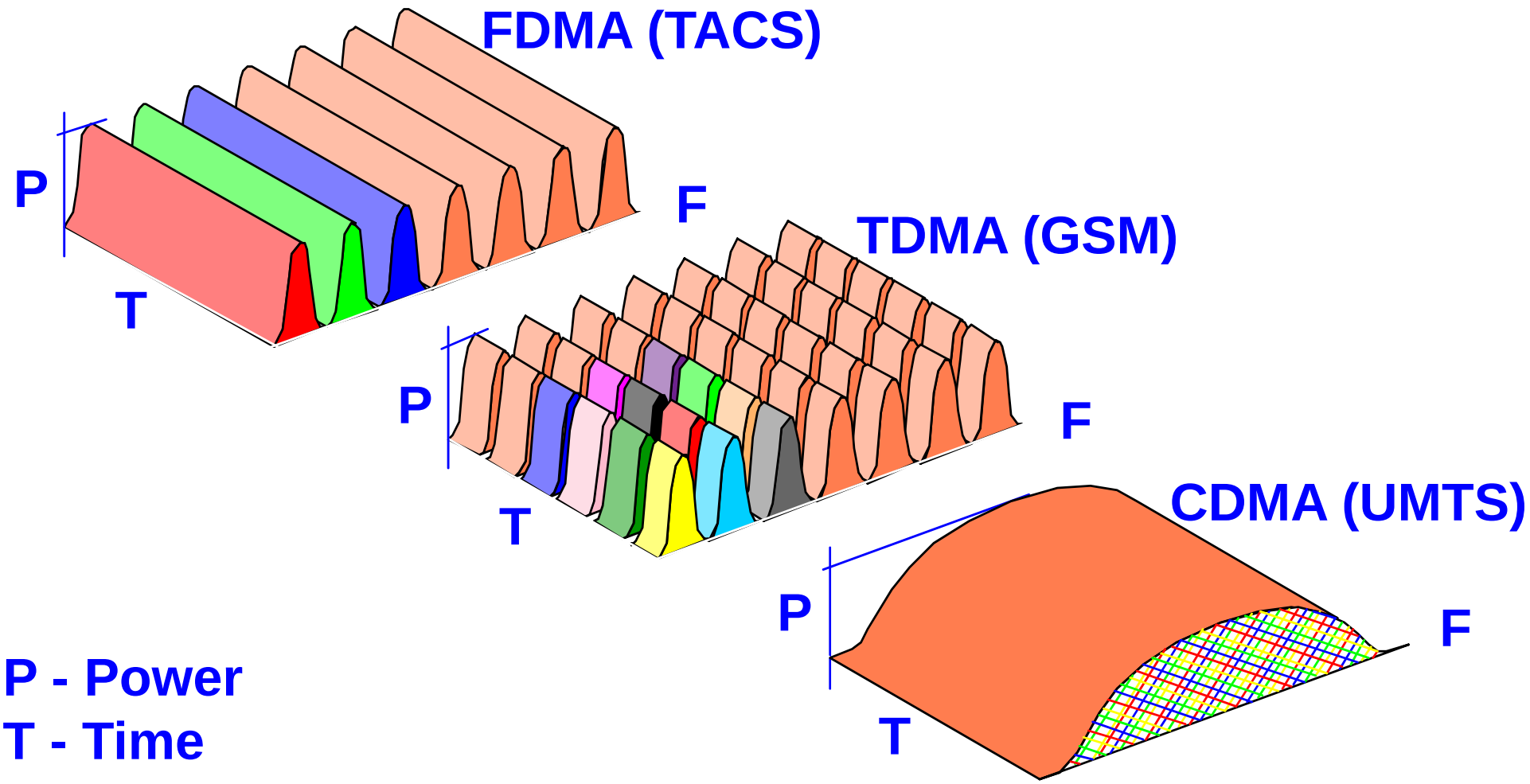
Outline- Part I

- Wireless mobile systems main concepts
- GSM & GPRS Overview
- UMTS R99 main characteristics
- HSDPA:
  - Rationale, main characteristics and differences vs R99
  - R5 UE categories
  - HSPA evolution hints

…A wireless mobile system

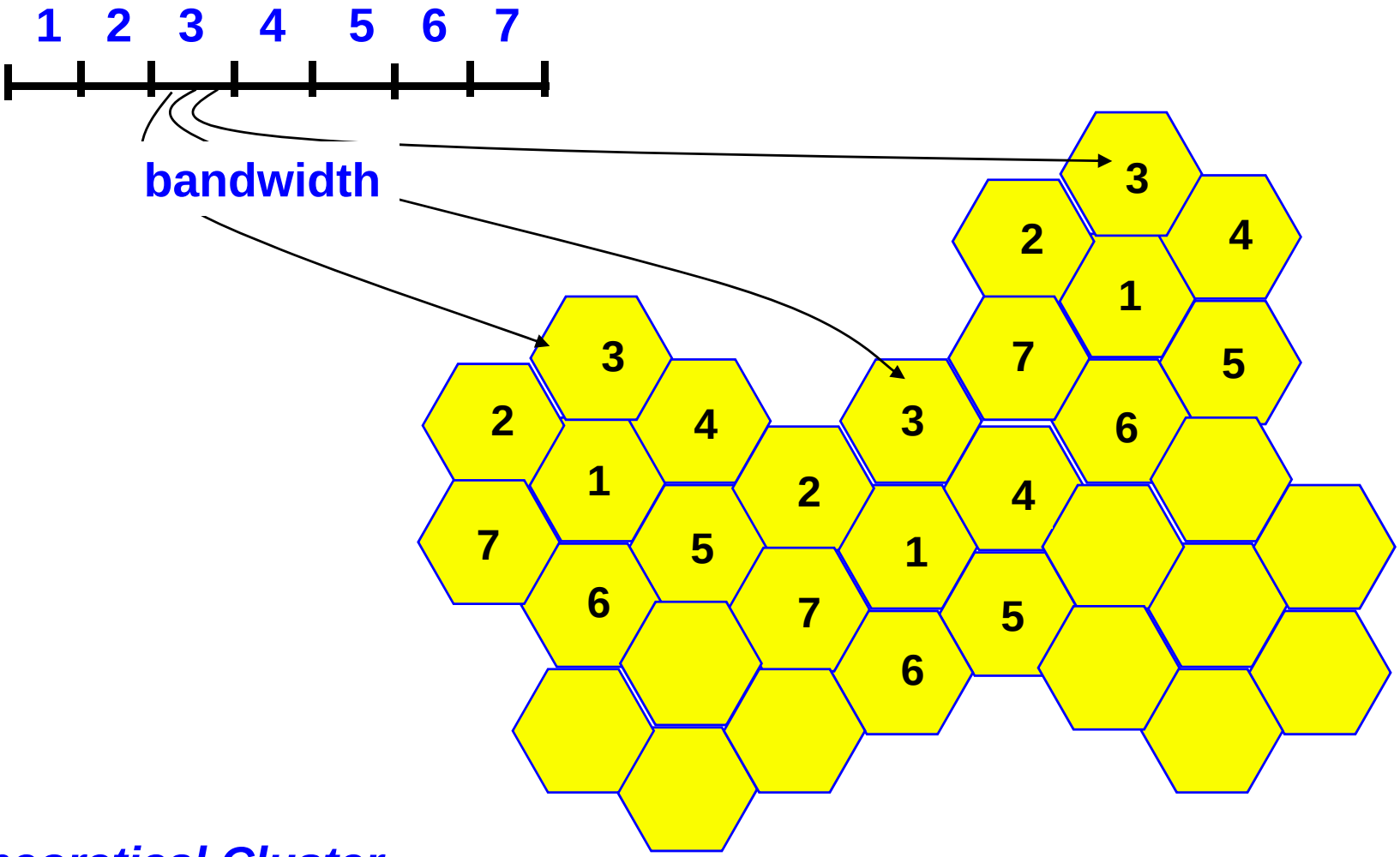


ACCESS TECHNIQUES FOR MOBILE COMMUNICATIONS



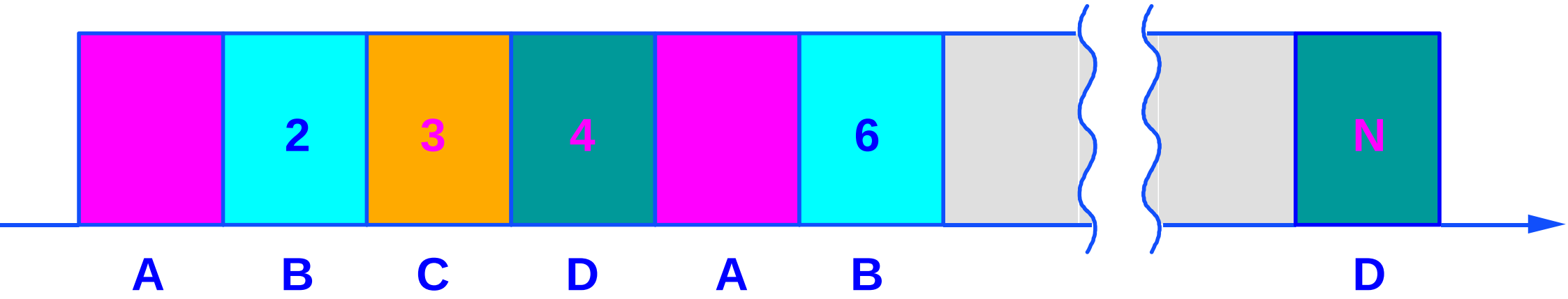
P - Power
T - Time
F - Frequency

Cellular System - Frequency Reuse



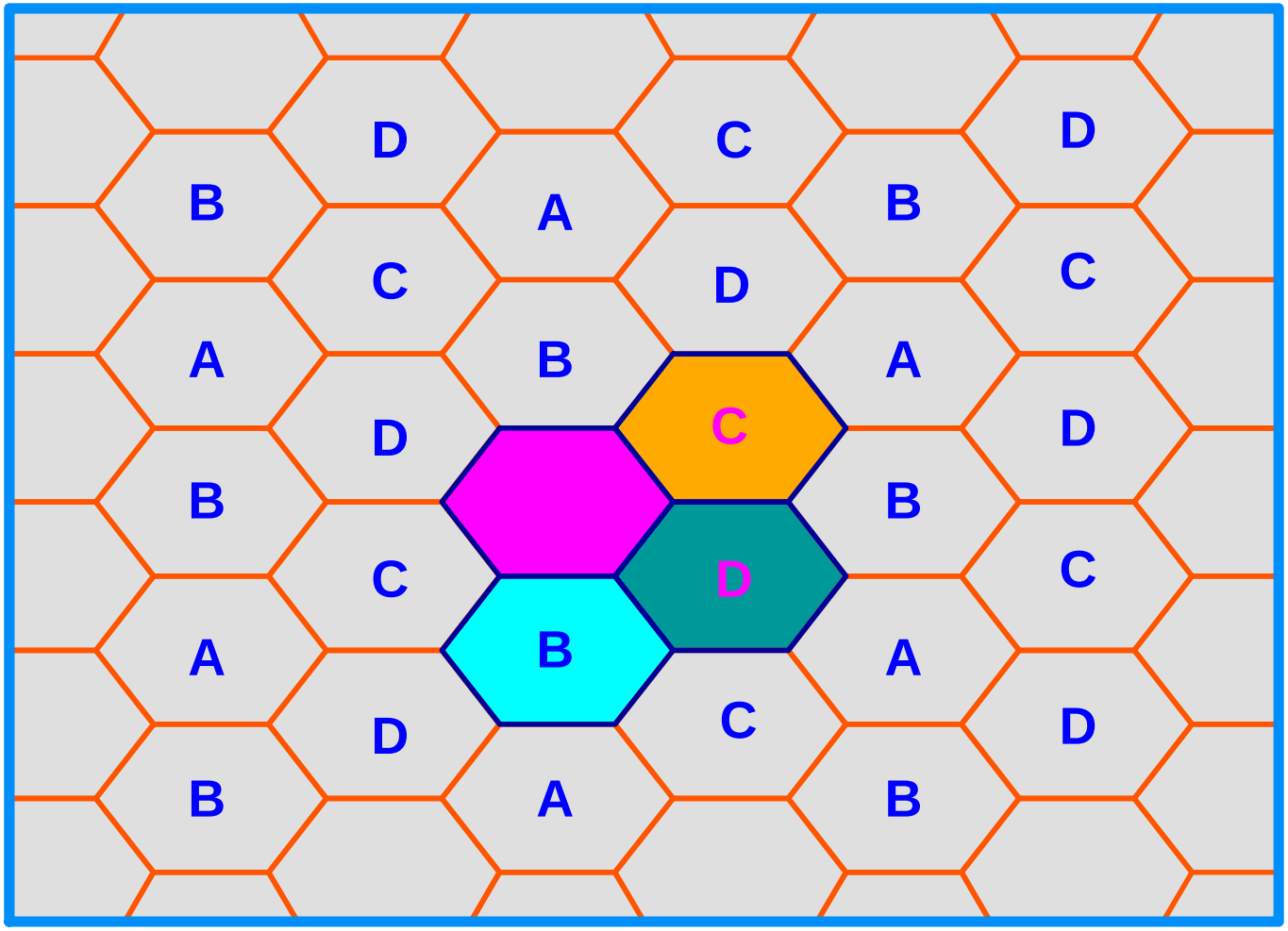
Theoretical Cluster

Cluster & channel grouping

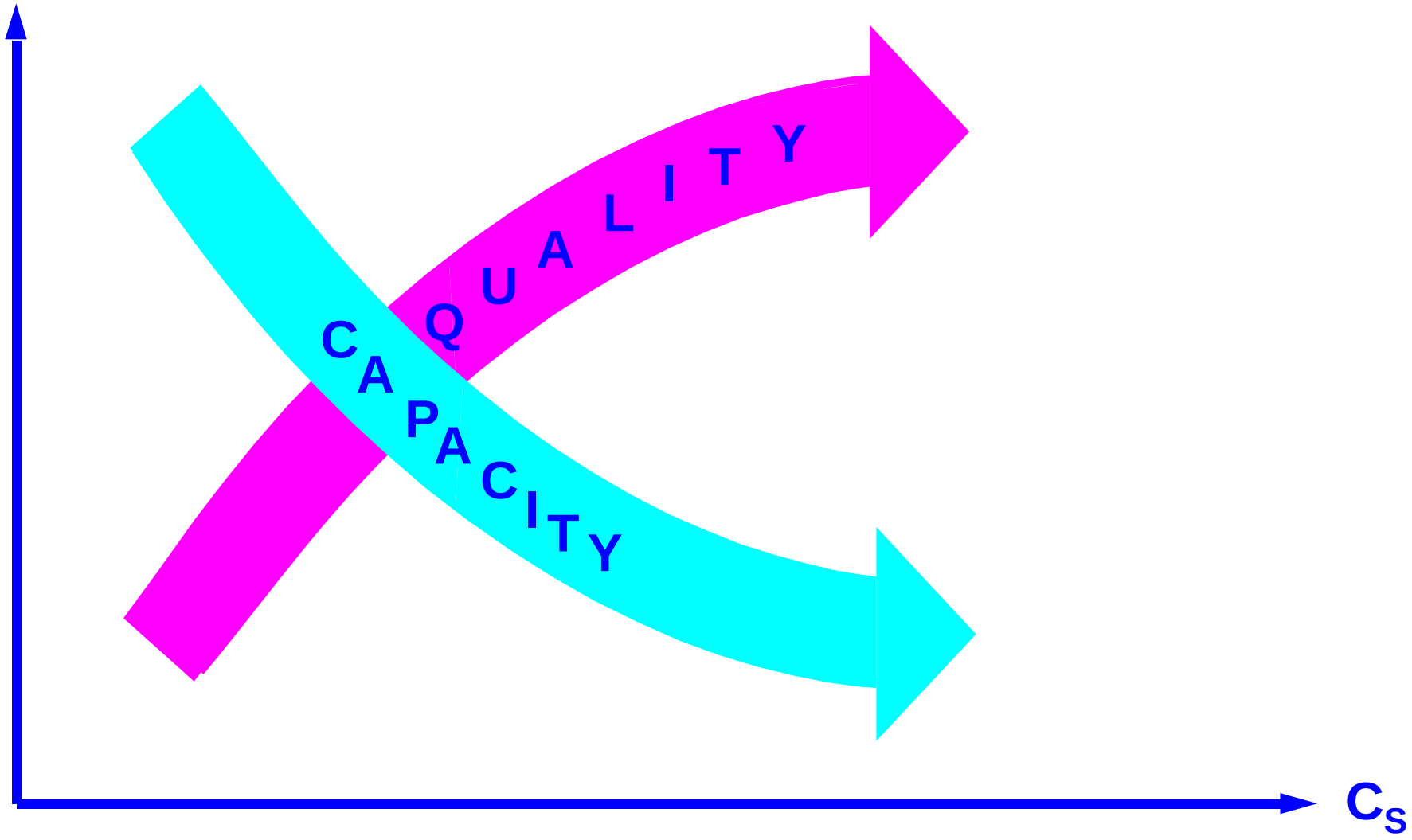


A = { 1, 5, 9, ...}

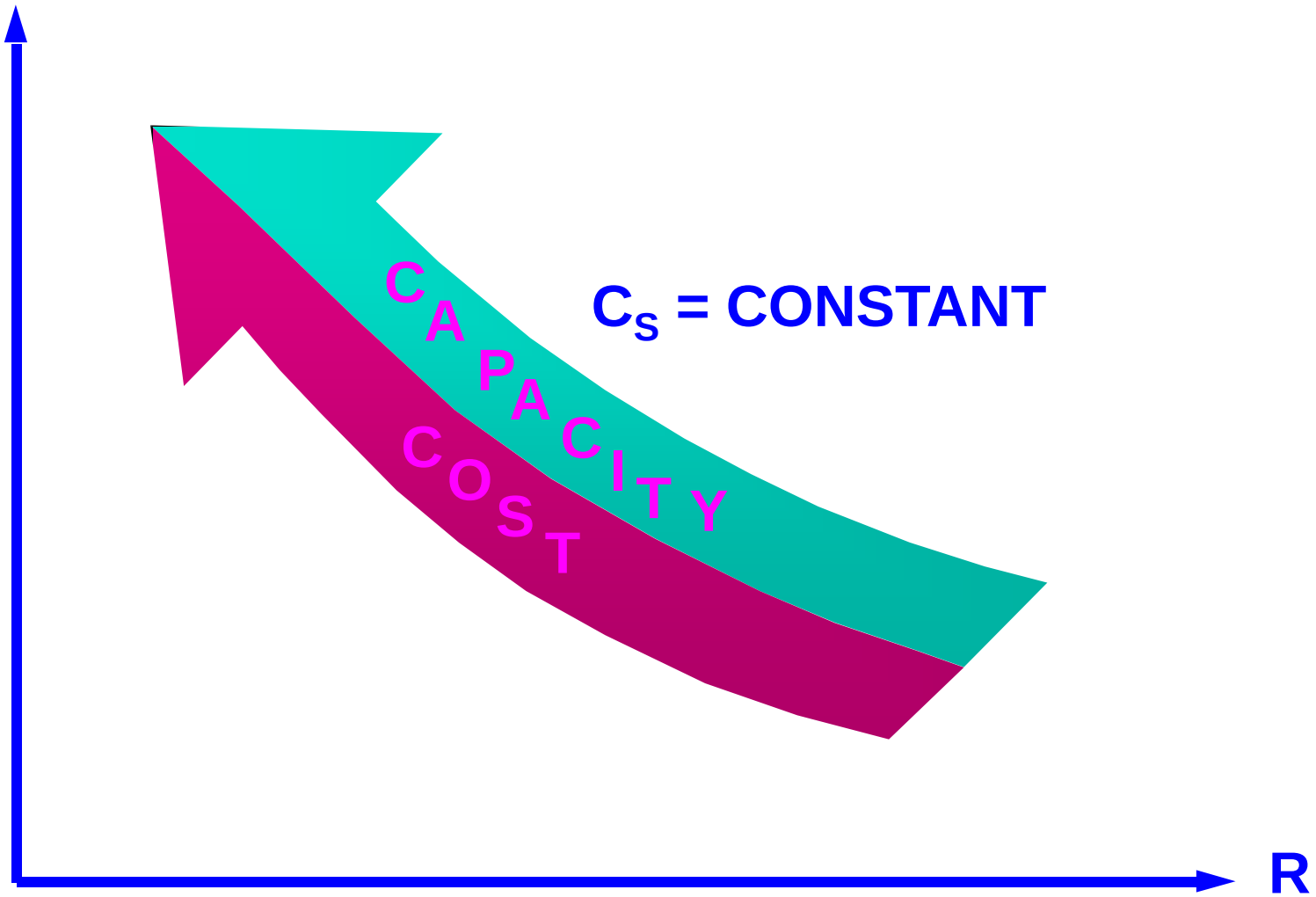
Frequency reuse concept



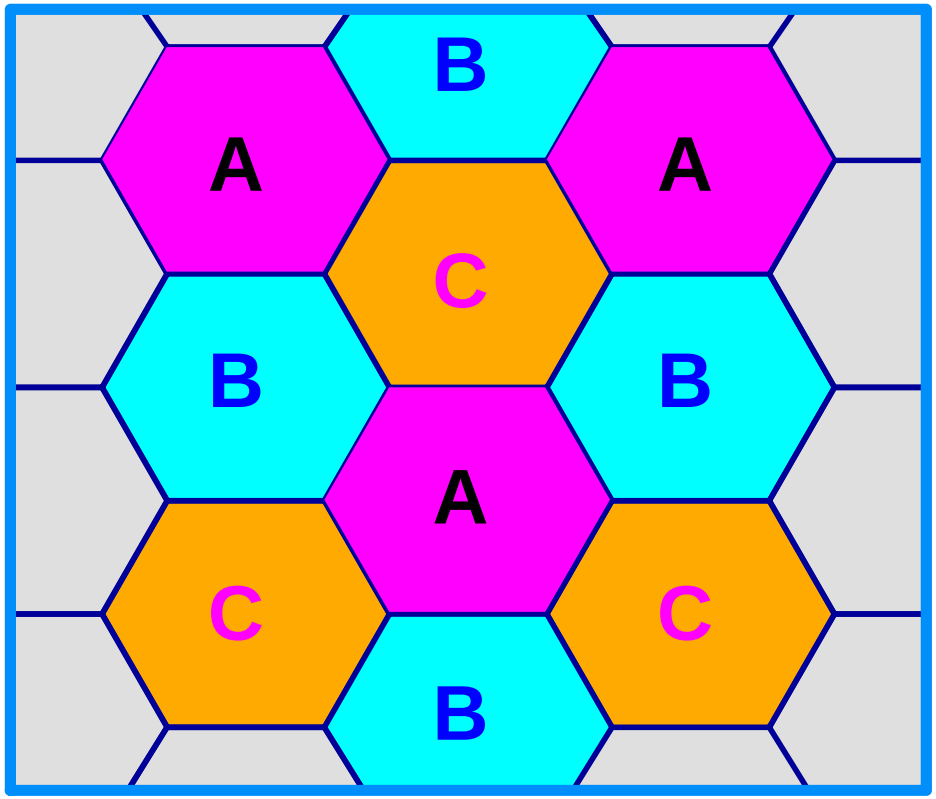
Choosing The Cluster Size



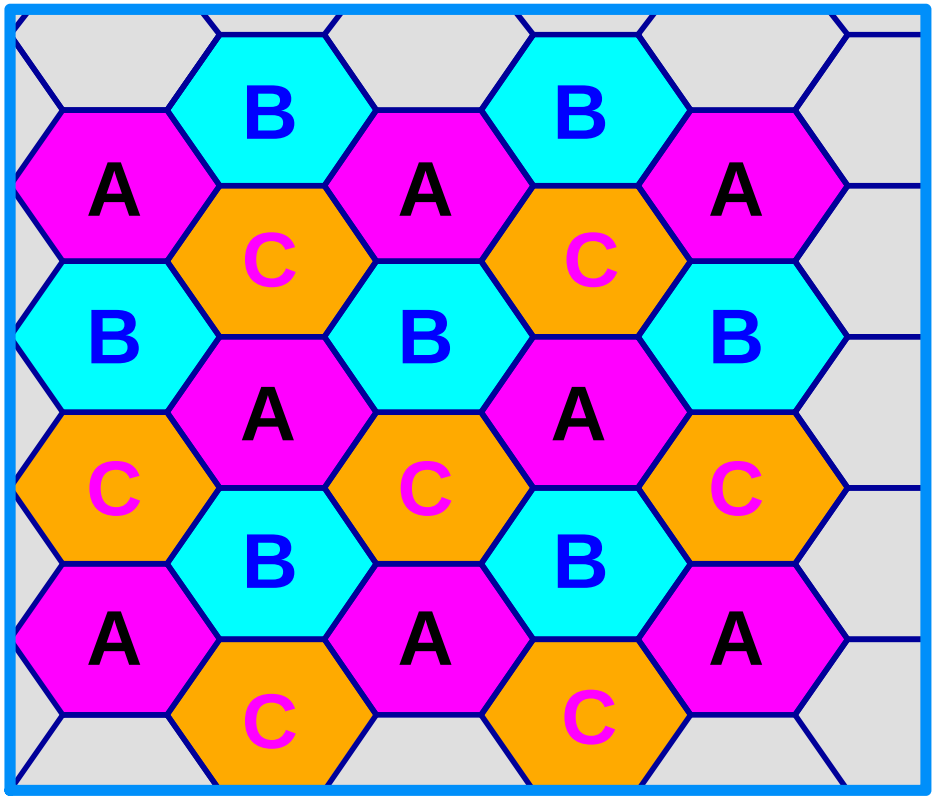
Choosing The Cell Size



Cell Size

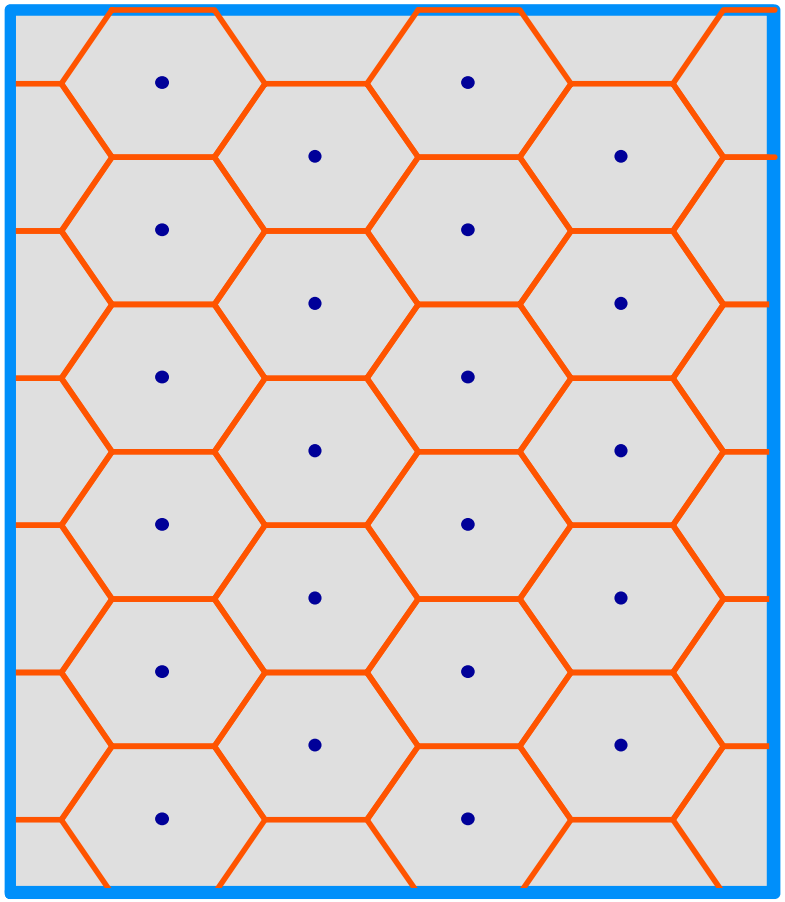


a)

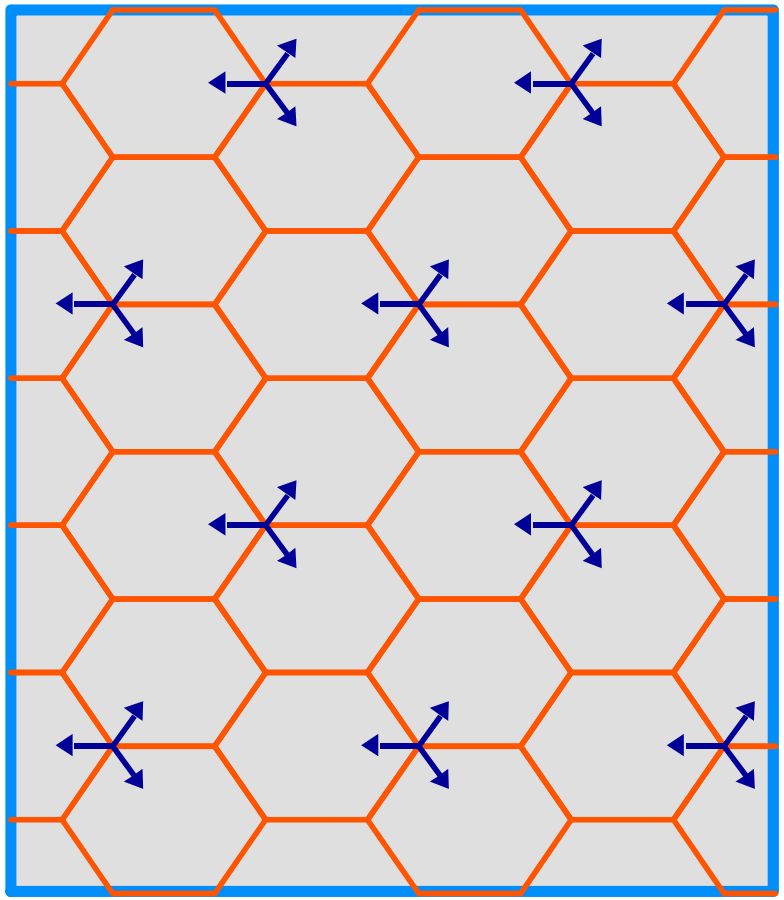


b)

Antenna solutions for cellular coverage



a)

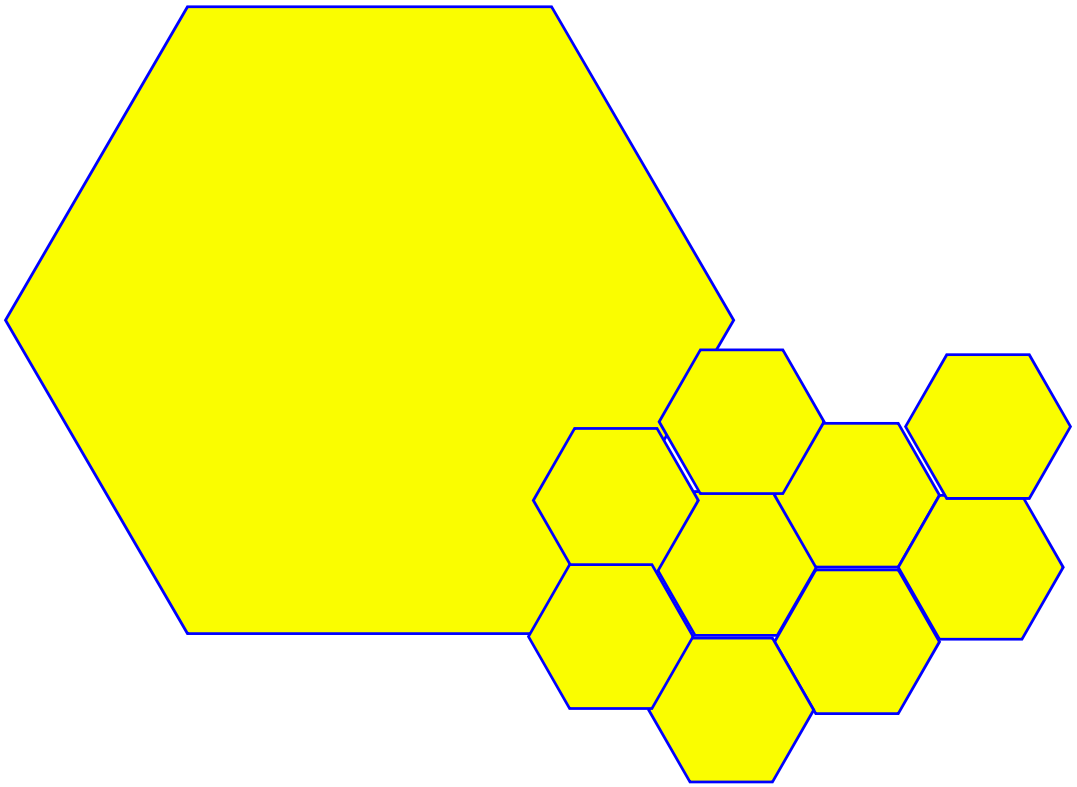


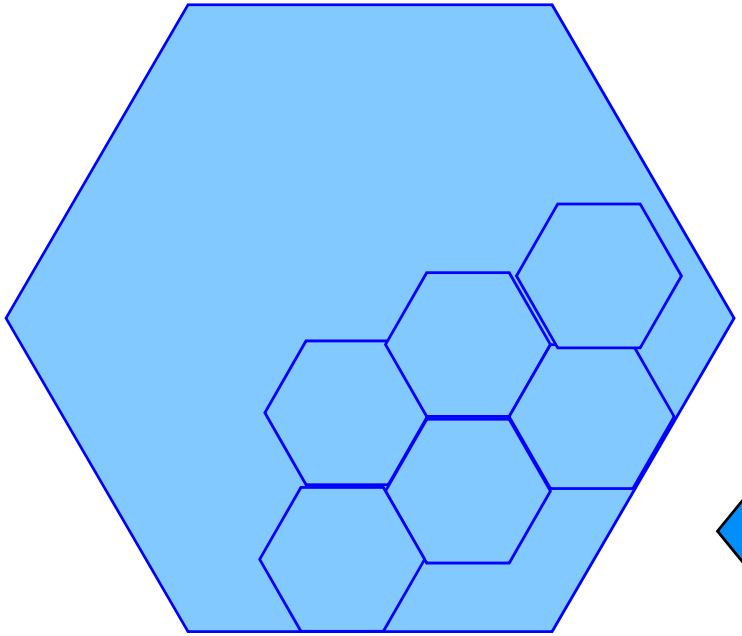
b)

Planning the cell size and layout

a matter of channel/Km2 requirements (traffic constraint)

tuning the cell size over a single layer

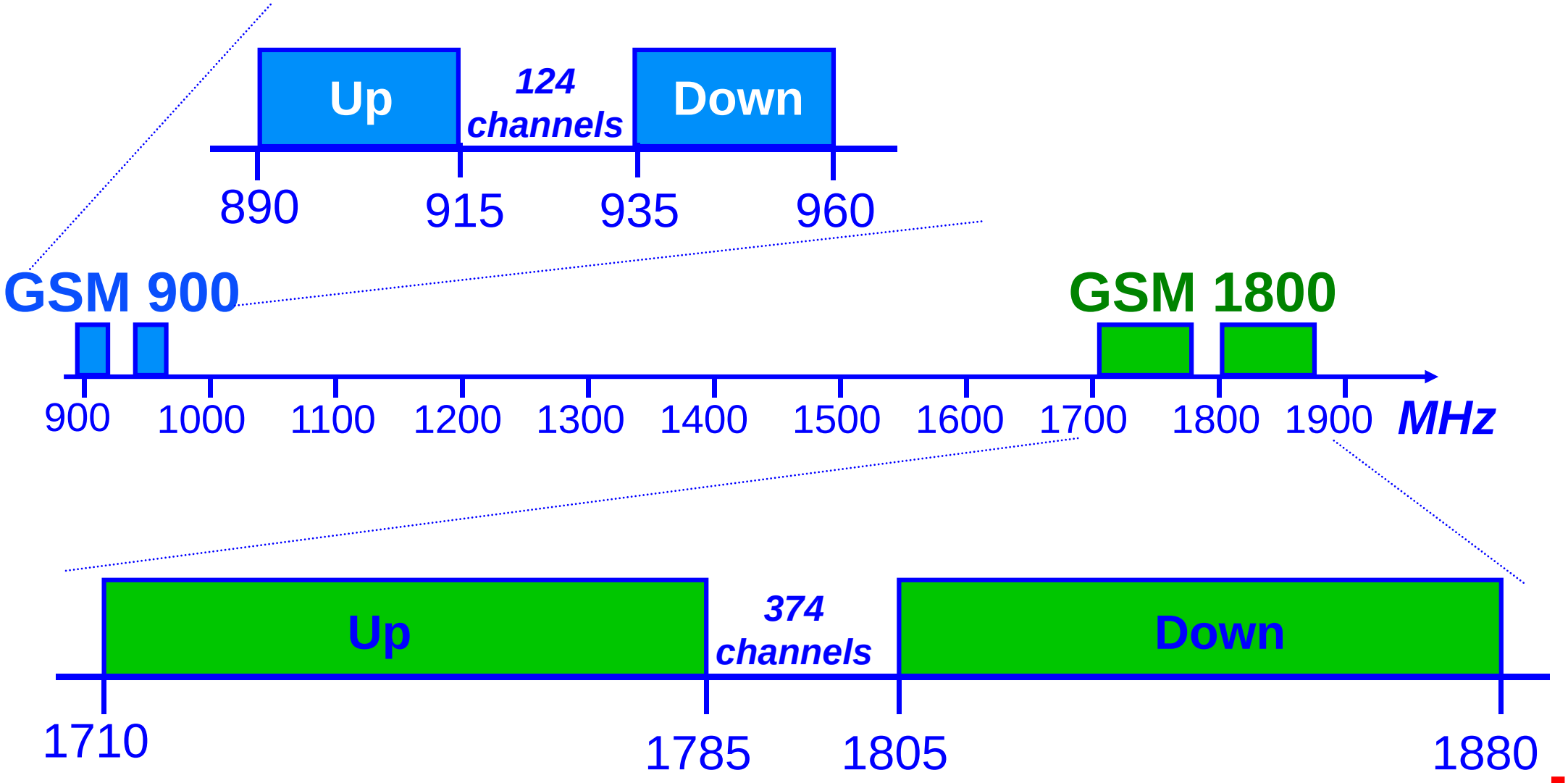




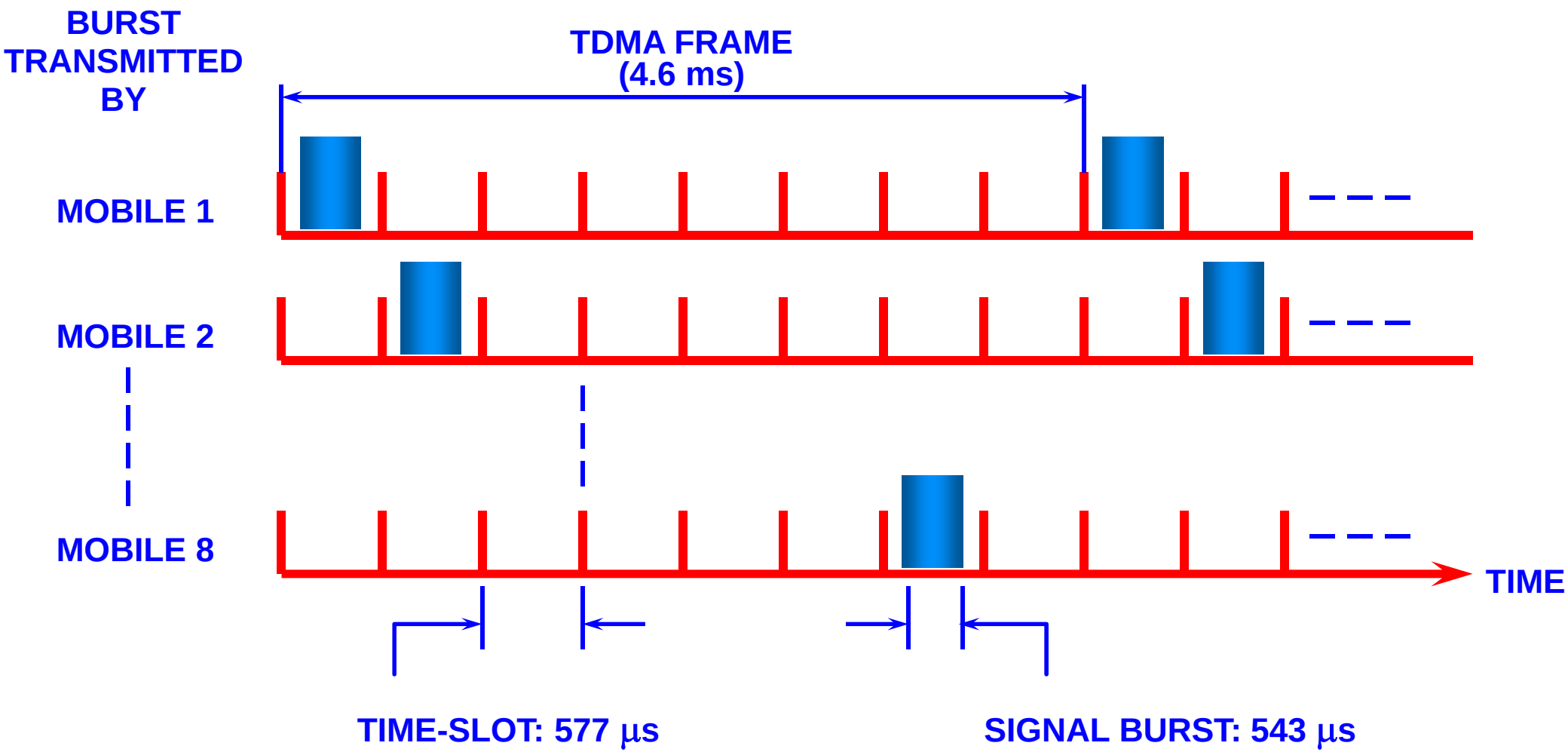
adopting overlapping coverage solutions (umbrella cells)

GSM/GPRS

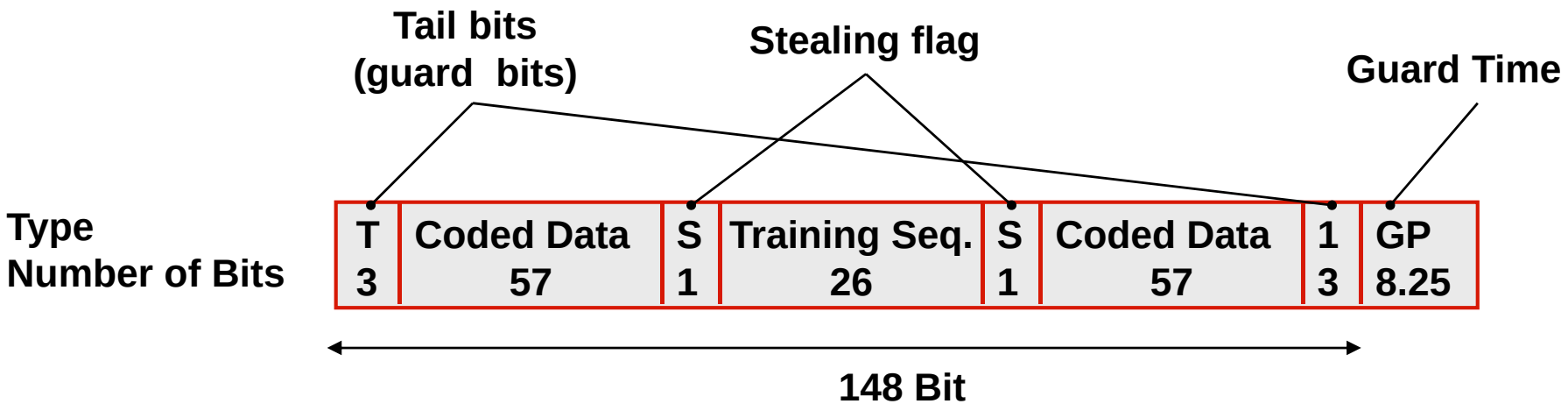
GSM FREQUENCIES



GSM functions - TDMA access technique

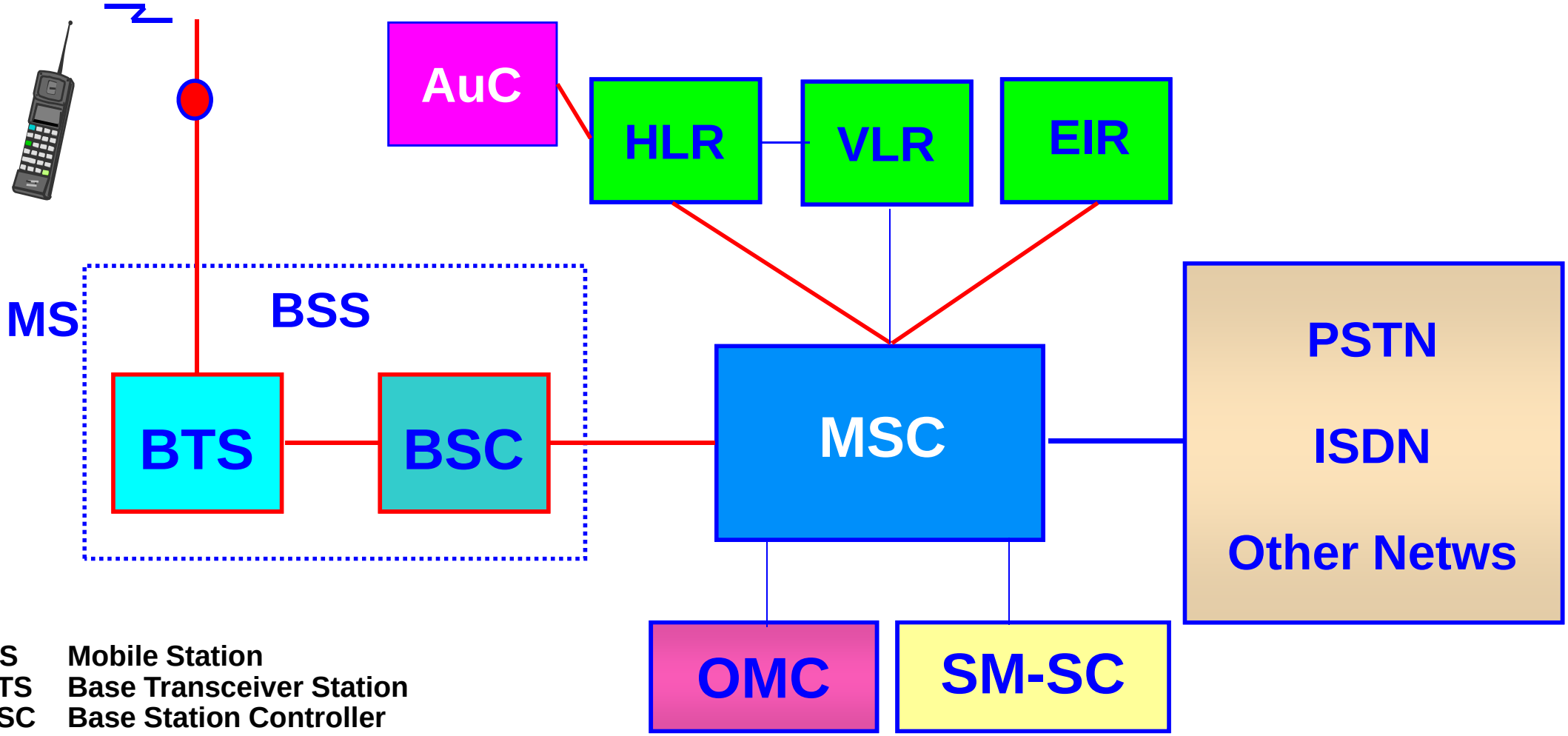


GSM traffic burst structure



The GSM system

Architecture & Equipment



MS Mobile Station
BTS Base Transceiver Station
BSC Base Station Controller
BSS Base Station Subsystem

MSC Mobile Switching Center
OMC Operations & Maxz intenance Center
SM-SC Short Message Service Center

HLR Home Location Register
VLR \ Center
EIR Equipment Identity Register

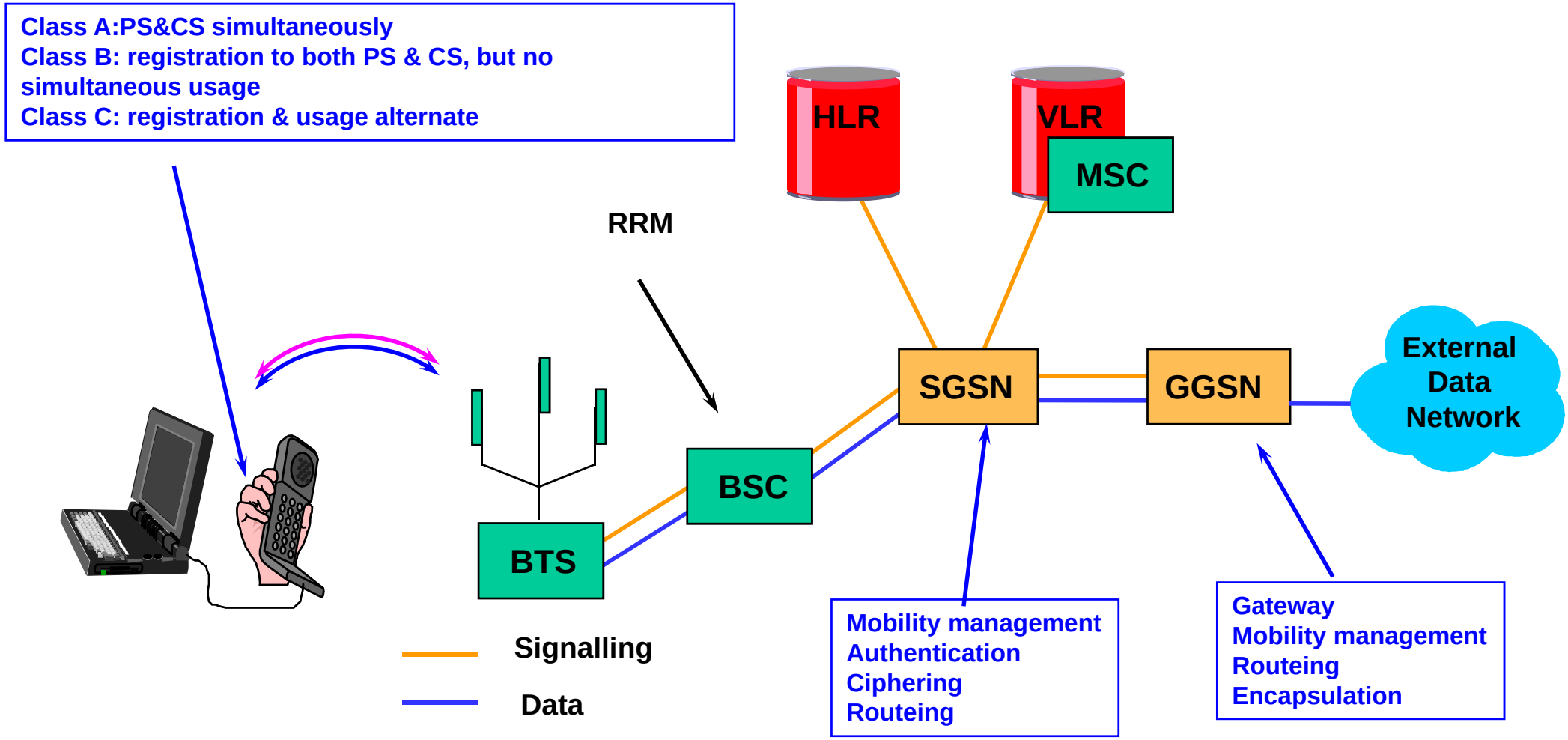
GSM Standard Evolution (I)

- **PHASE 1**
  - **Basic Services**
    - » ***Telephony***
    - » ***Emergency calls***
    - » ***Short Message Services (Mobile Terminated & Originated)***
    - » ***Group 3 Fax & CS data @ 9.6 kb/s***
    - » ***Call Forwarding & Barring***
- **PHASE 2**
  - **New Supplementary Services**
    - » ***Call Waiting & Call Hold***
    - » ***Line Identification & Multi-Party Call***
    - » ***Closed User Group & Advice of Charge***

GSM Standard Evolution (II)

- **PHASE 2+**
  - **CS & PS Data Services**
    - » ***HSCSD (High Speed Circuit Switched Data)***
    - » ***GPRS (General Packed Radio Service)***
    - » ***EDGE (Enhanced Data rate for the GSM Evolution)***
  - **Supplementary Services**
    - » ***CCBS (Completion of Call to Busy Subscriber)***
    - » ***USSD (Unstructured Supplementary Service Data)***
  - **Other**
    - » ***Specific services support (e.g. SIM Toolkit)***
    - » ***Mobile Number Portability***

General Packet Radio Service (GPRS)



- **Two (on 4) implemented coding scheme: CS1 & CS2, for a bit rate of 8 kb/s & 12kb/s per slot**
- **For a 4 (DL) +1 (UL) terminal, maximum bit rate @ 48kb/s (DL): the effective one is around 40kb/s**

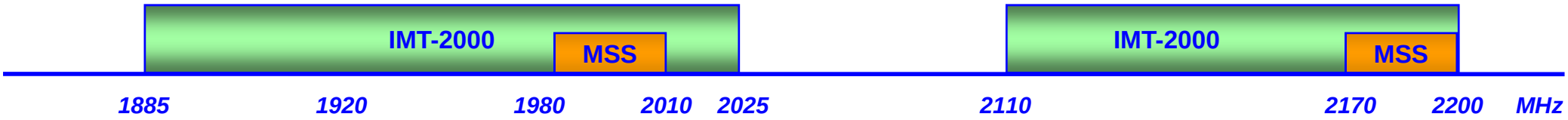
Enhanced Data rate for the GSM Evolution (EDGE)

- **New modulation scheme to increase the data rate per slot: 8 PSK**
- **Both CS (ECSD) & PS (EGPRS)**
- **ECSD: up to 32 kb/s x slot & peak rate of 64kb/s**
- **EGPRS: up to 59.2 kb/s per slot & peak rate of 384 kb/s**
- **New terminals (dual-mode EDGE/GSM) & new transceiver in BTSs**

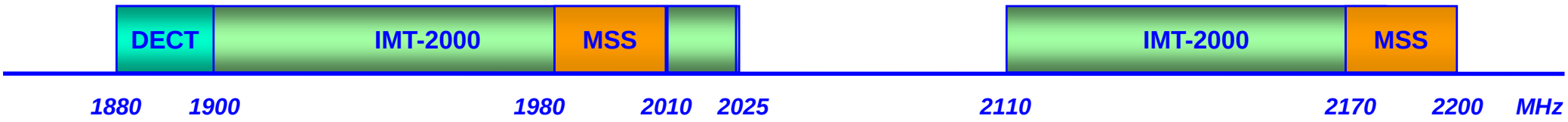
UMTS
R99

UMTS core bands assignment

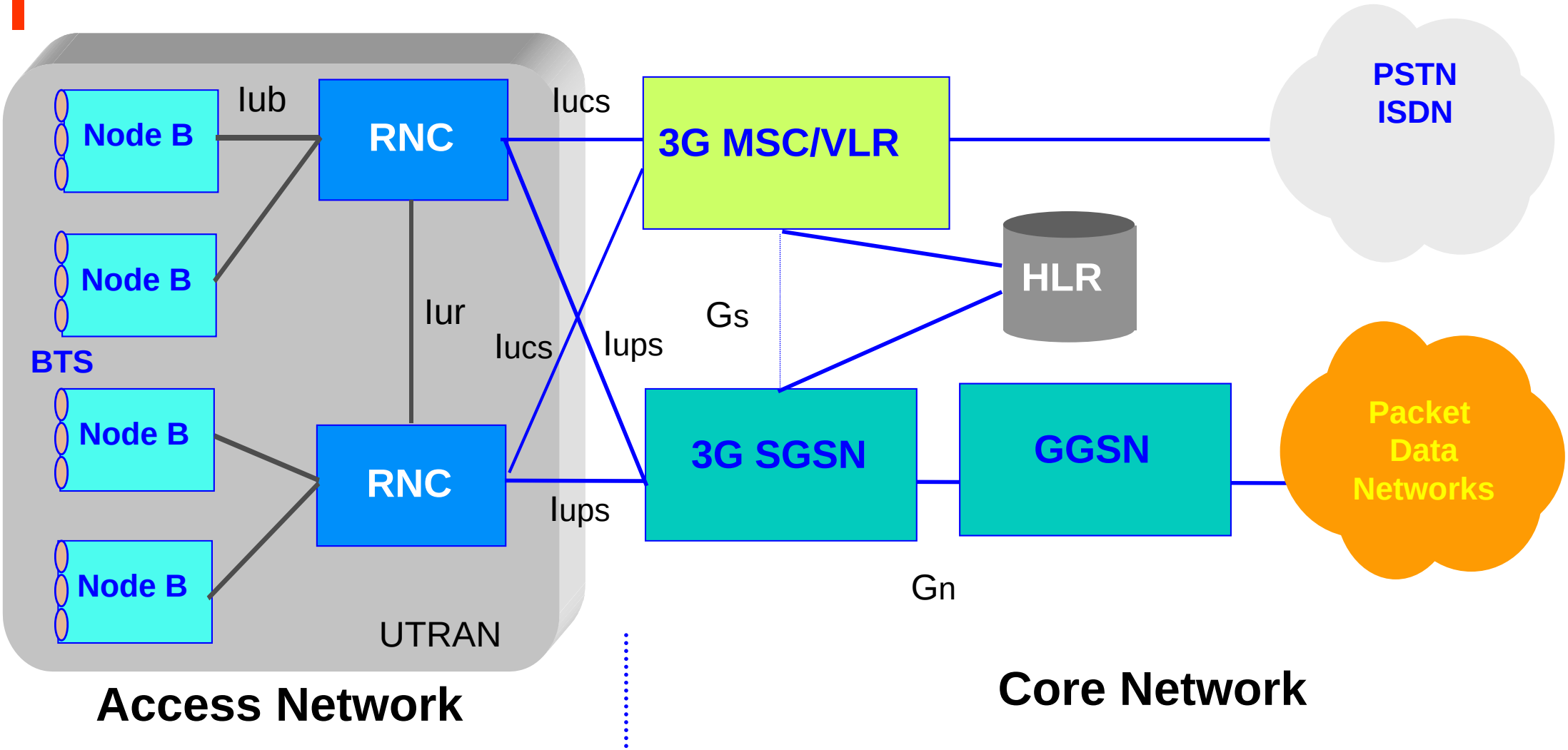
ITU



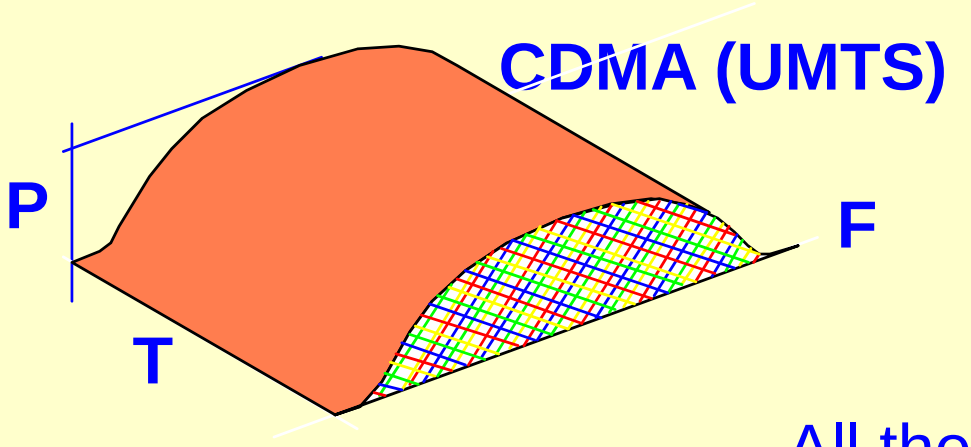
EUROPE



UMTS R99 architecture



FDD (WB-CDMA) technique



All the users are on the same frequencies and they are distinguished by means of a code

P - Power
T - Time
F - Frequency

Spread spectrum techniques

AWGN CAPACITY WITH LIMITED SPECTRUM

$$C = B \log_2 (1 + S/N)$$

[C]=bit/s [B]=Hz S/N=signal to noise ratio

A given bit rate R can be obtained through

- Narrow band and high S/N
- Wide band and low S/N

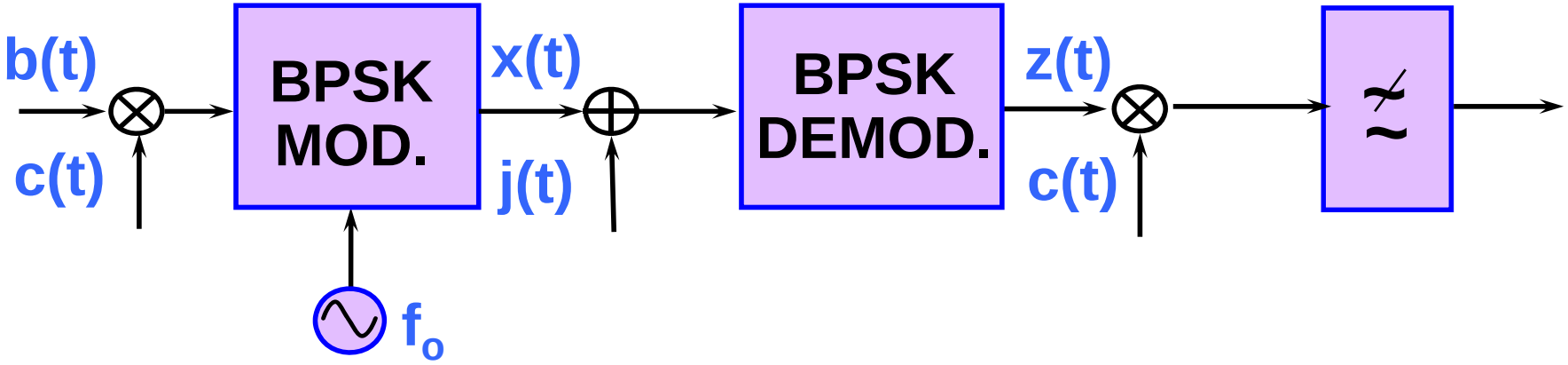
General characteristics of spread spectrum systems

- Robustness against jammers and fading
- Low interception probability
- Multiple access capability
- Frequency reuse 1

DS-CDMA

- Users sharing the same band are transmitted simultaneously on the same carrier
- Users are distinguished each other by means of a “code” and, the mutual interference is reduced during the “decoding” process
- In the DS-CDMA technique, the spreading is obtained multiplying the user signal by the signal associated to a “code” (a PN sequence or an orthogonal sequence)

Direct Sequence-CDMA



$$z(t) = b(t)c(t) + j(t)$$

$$z(t)c(t) = b(t)c^2(t) + j(t)c(t) = b(t) + \underbrace{j(t)c(t)}_{\text{spread interferer}}$$

Spreading and de-spreading

wideband interference

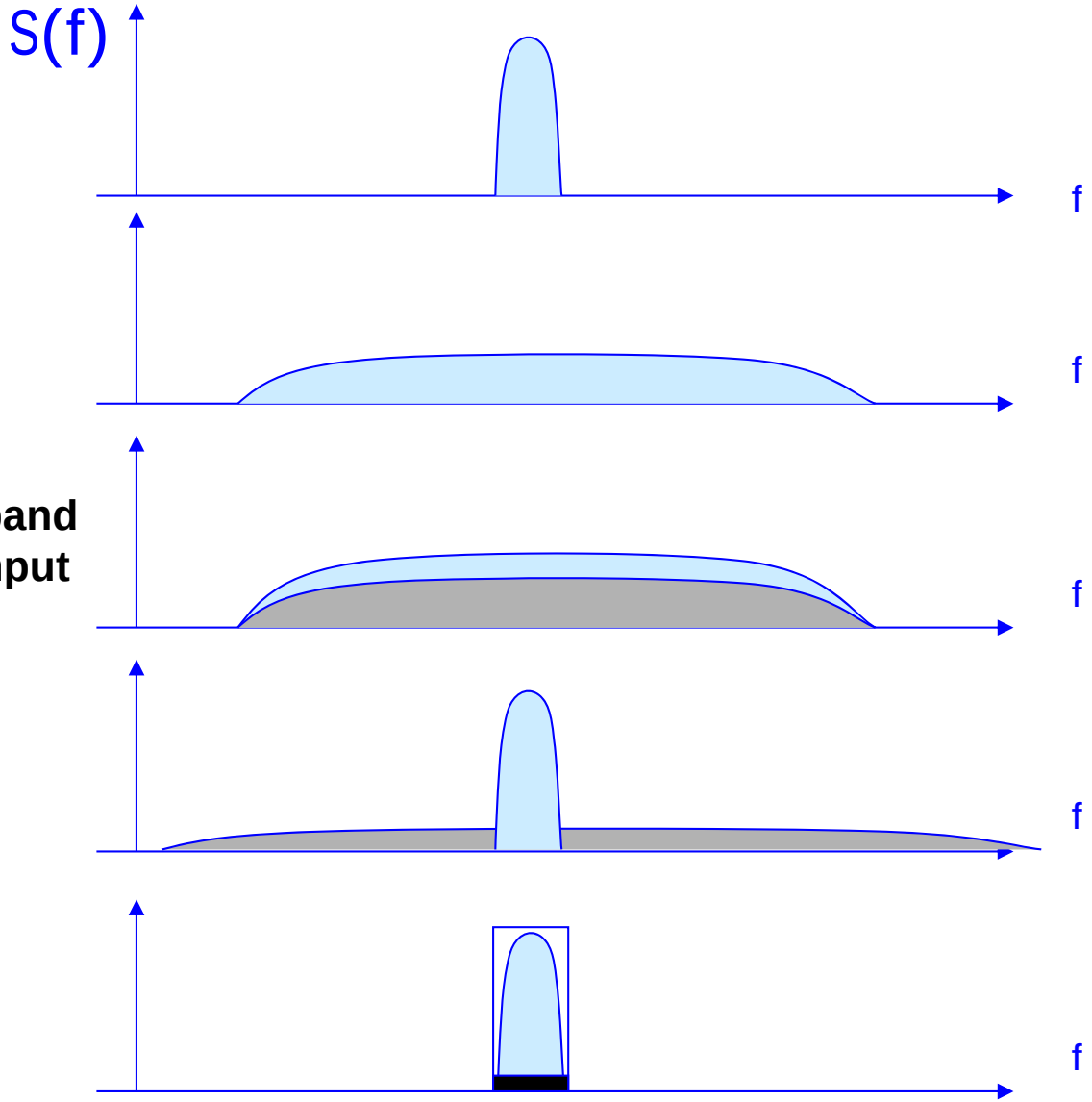
Original signal, band Bn

Spread signal, band Bw

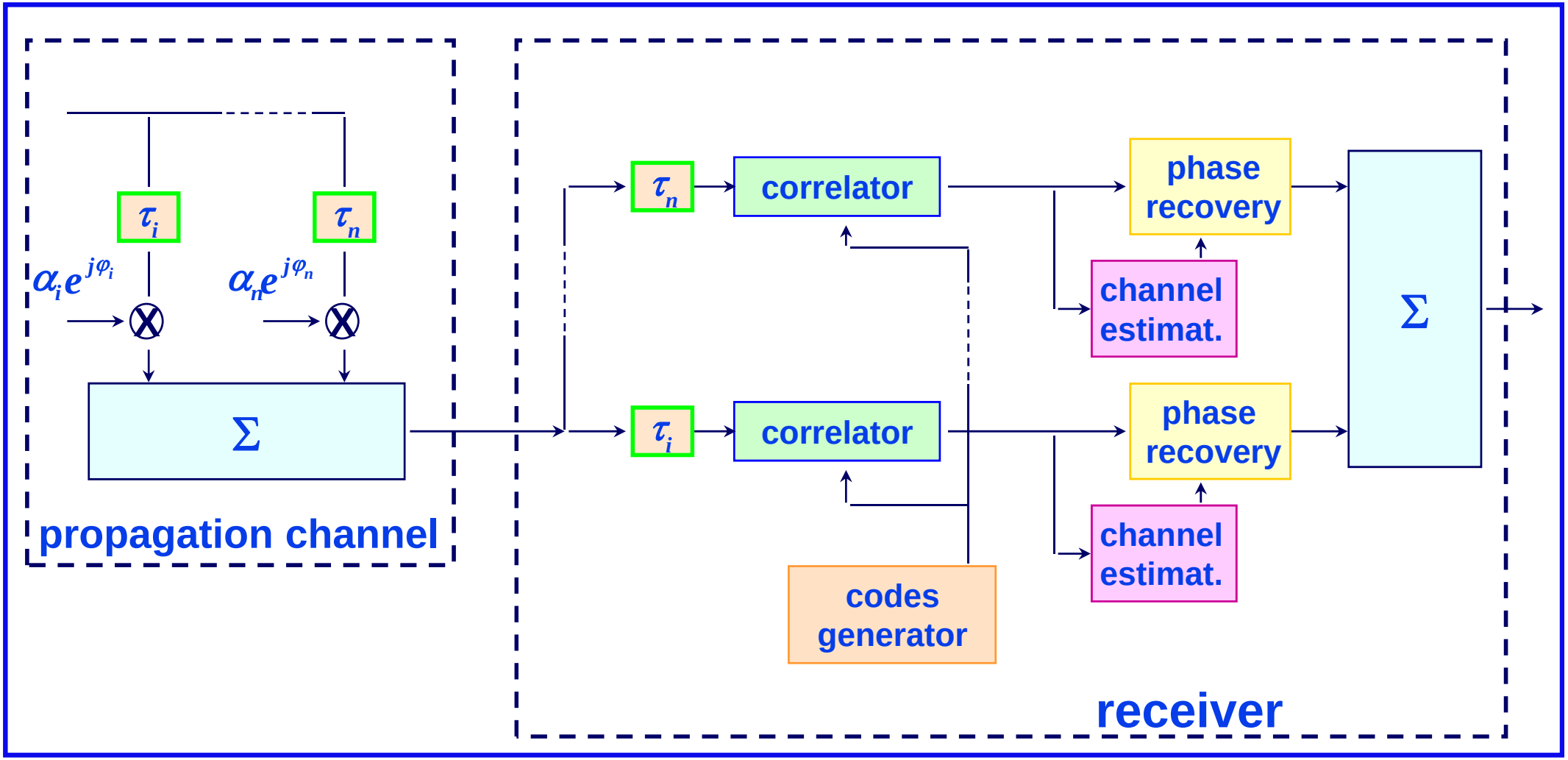
Expanded signal plus broadband interference in the receiver input

Signals after de-spreading

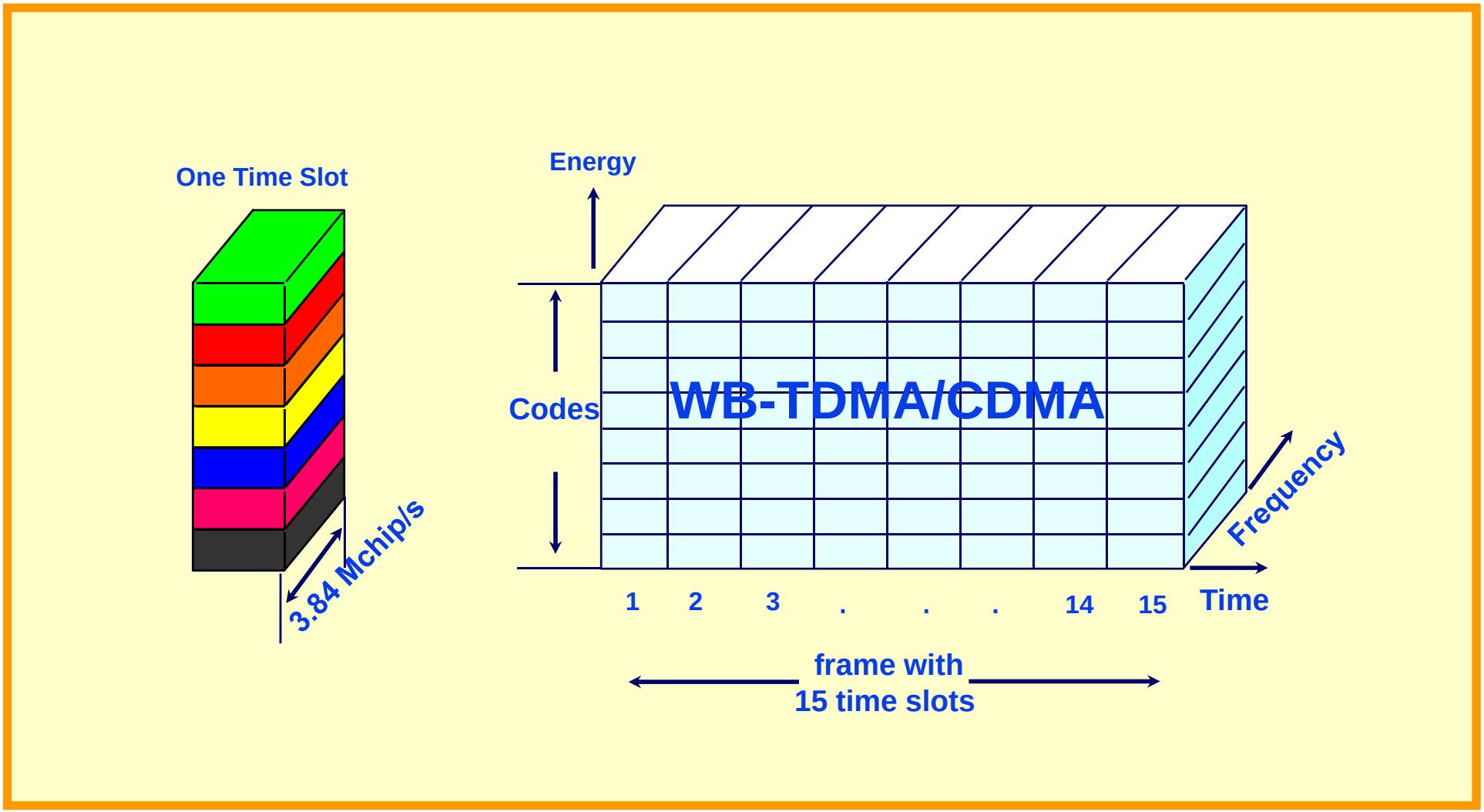
Signals after the reception filter



The rake receiver



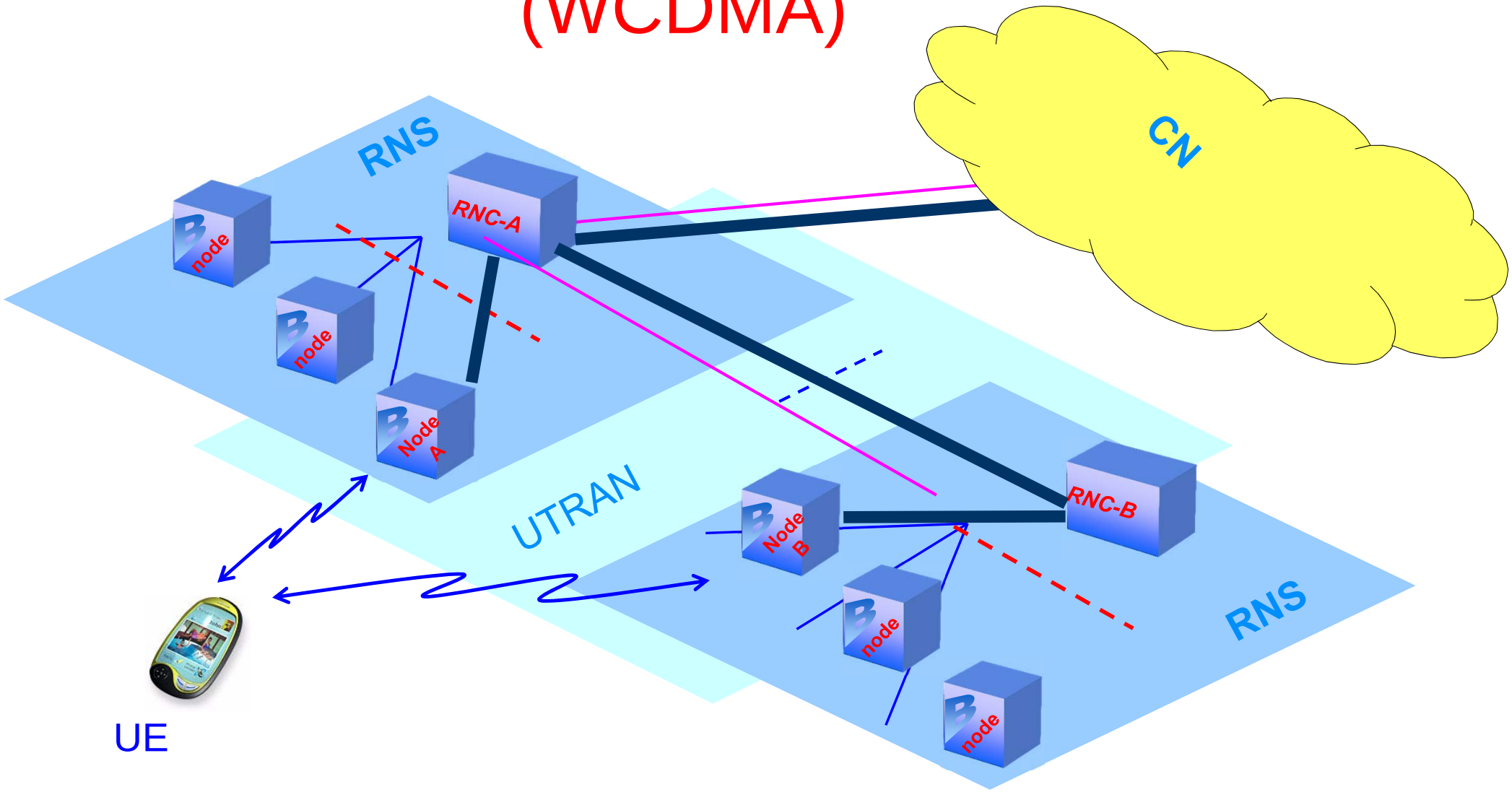
TDD (TD-CDMA) technique



Main parameters

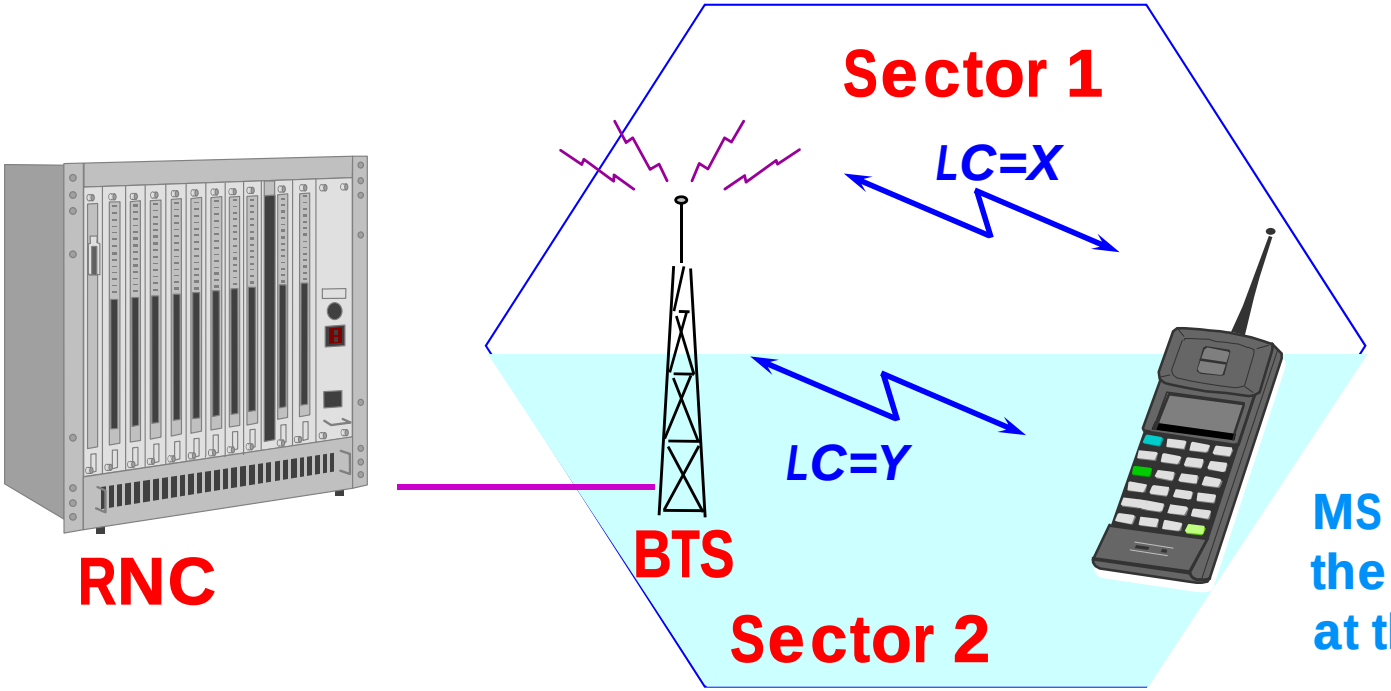
	UTRA/FDD	UTRA/TDD
Access technique	WCDMA	Hybrid WCDMA+TDMA
Chip rate	3.84 Mcps (SF FDD:4-256, TDD 1-16)	
Carrier spacing	4.4-5 MHz	
Frame duration	10 ms	
N. slot per frame	15	
BTS synchronization	Not required	Not required (advisable)
Modulation	DL: QPSK UL: Dual-channel QPSK	DL: QPSK UL: QPSK
Coherent receiver	Uplink e downlink	
Multi-rate	Variabile SF + Multi-code + Multi-slot (TDD)	

Soft Handover and Macrodiversity (WCDMA)



Softer HO

Dedicated Data Channel, Dedicated Packet Channel

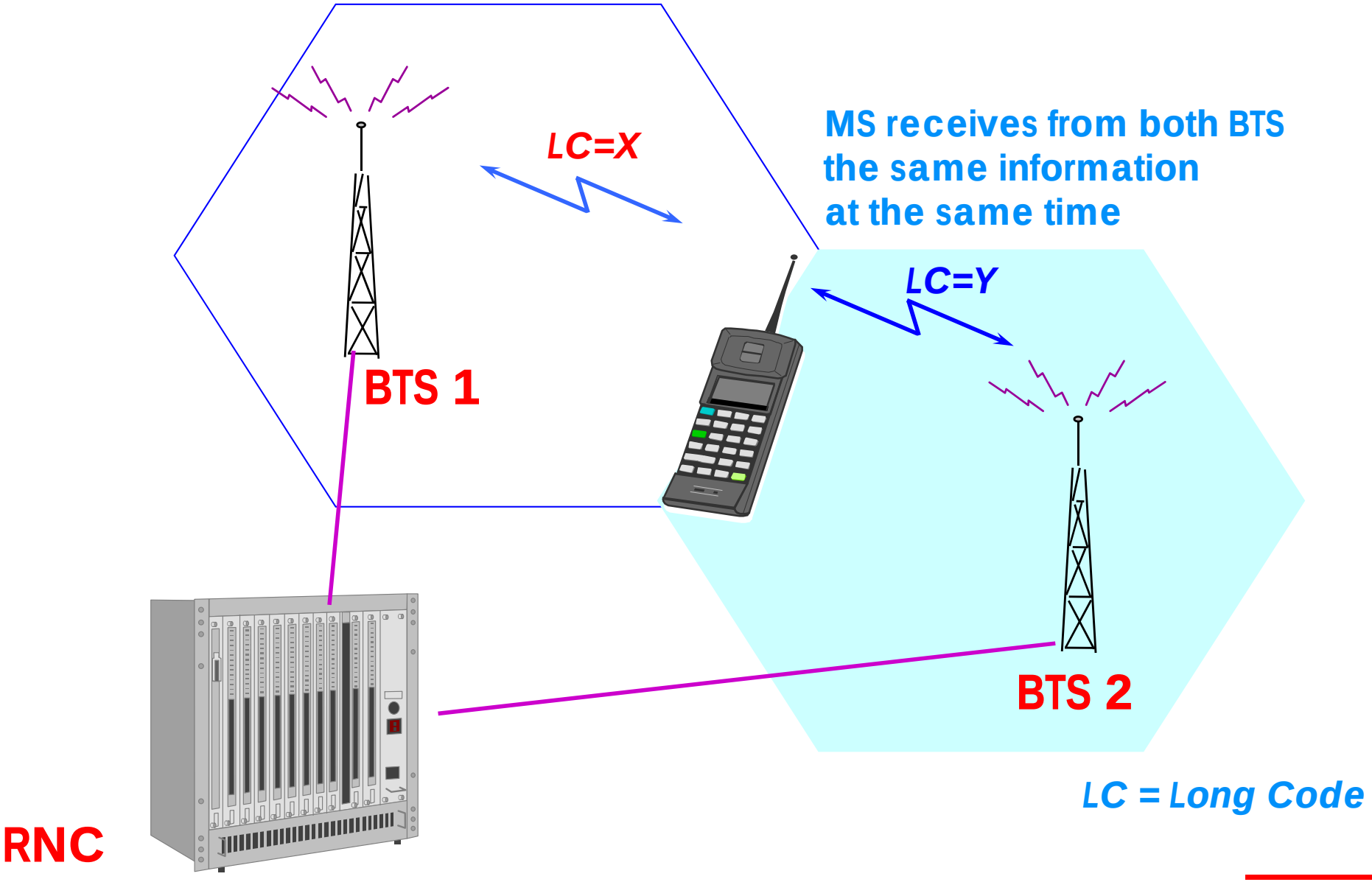


MS receives from both Sectors
the same information
at the same time

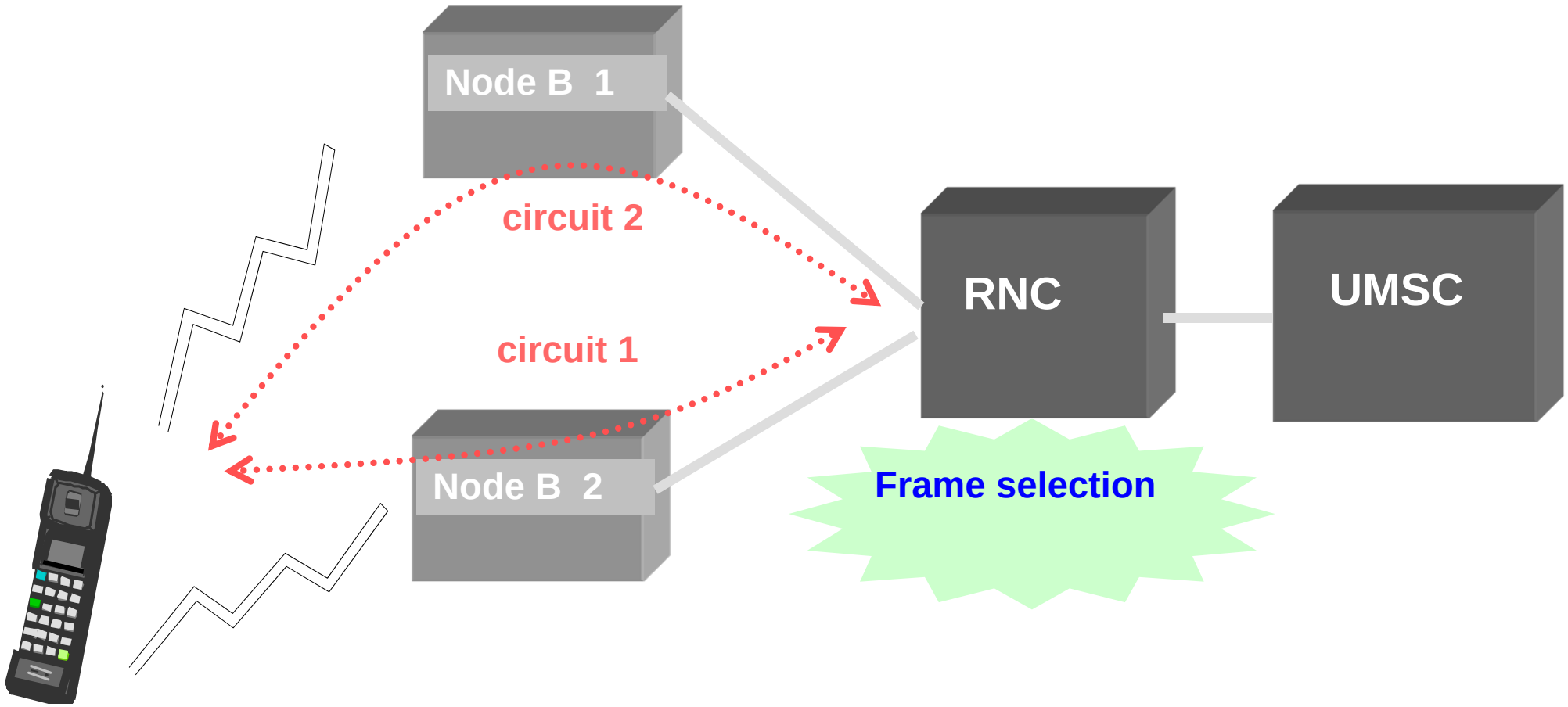
LC = Long Code

Soft HO

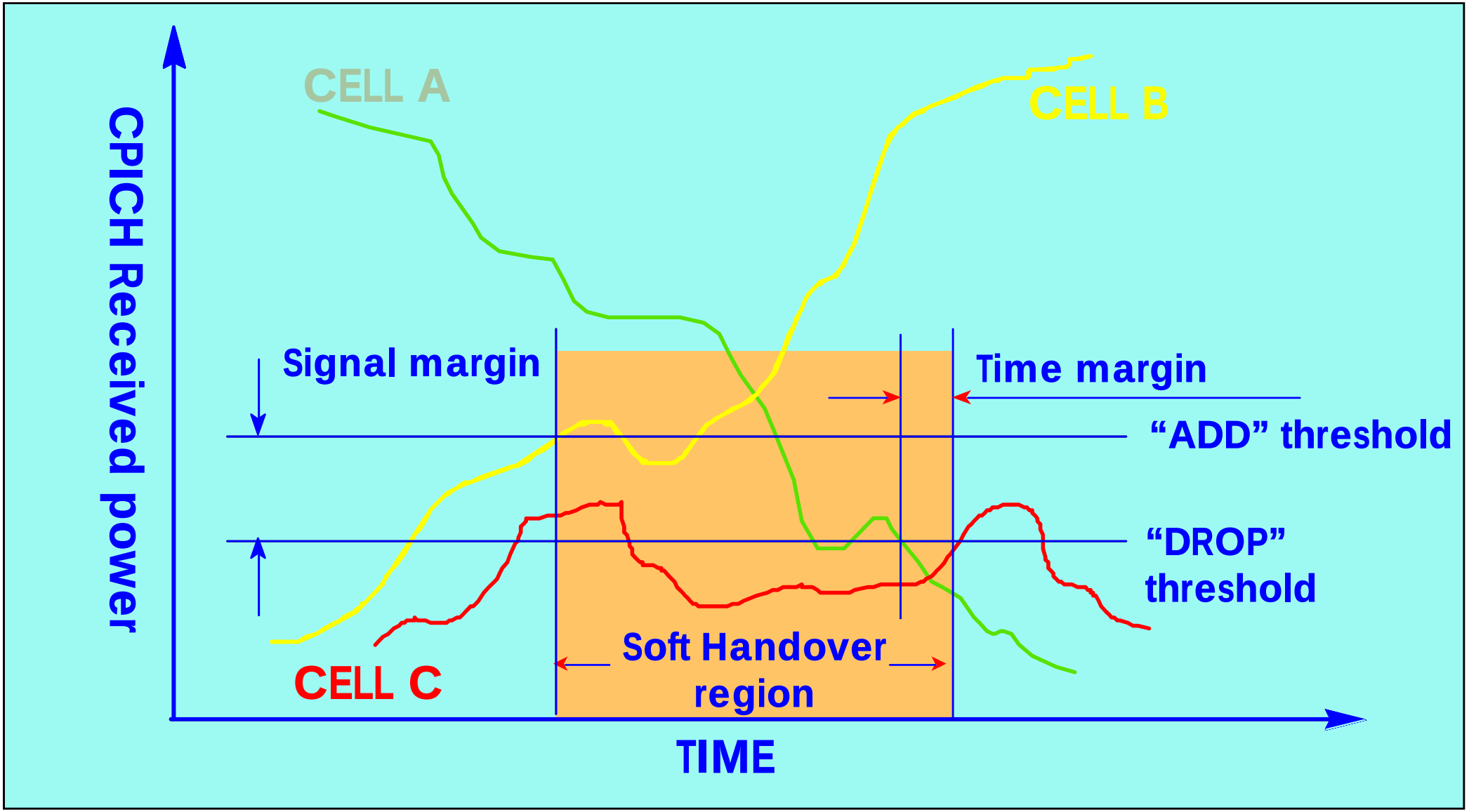
Dedicated Data Channel



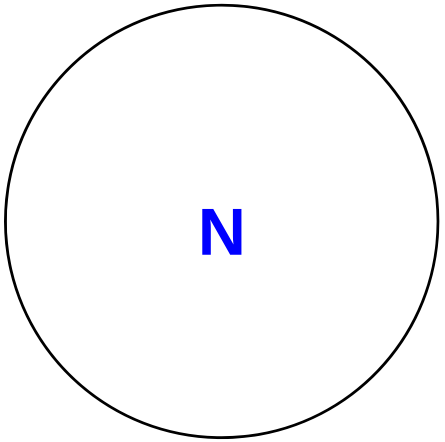
Macrodiversity



Soft Handover and macrodiversity

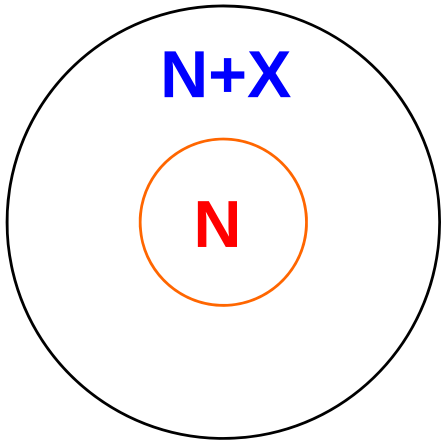


“Soft capacity & cell dynamic”



Cell with radius “R” and “N” users

$C/I \cong 1/N$



We assume that the user density increase:
Cell with radius “R” and (N+X) > N users

$(C/I)' \cong 1/(N+X) < C/I$

In the new load situation if we want to stick to the original C/I target we have to reduce the cell radius

Capacity: single cell, perfect PC

$$\frac{E_b}{I_o} = \frac{CT}{I/W} = \frac{C/R}{I/W}$$

C = user signal power

R = bit rate

W = spreading bandwidth

In case of perfect power control → $I=C(N-1)$

$$\frac{E_b}{I_o} = \frac{C/R}{C(N-1)/W} = \frac{W}{R} \cdot \frac{1}{(N-1)}$$

$$(N-1) = \frac{W}{R} \cdot \frac{1}{E_b/I_o}$$

Exploitation of source activity and sectorization

d: source activity factor (for voice, the ideal value is 0.38, actually, a typical assumption is 0.5)

G_{sect}: sectorization gain (2.2-2.4 for three sectored antenna)

$$N \cong \frac{W}{R} \cdot \frac{1}{E_b/I_o} \cdot \frac{1}{d} \cdot G_{sect}$$

Site capacity

Capacity: multiple cell

Intercell interference is taken into account introducing a factor usually indicated with "f" or "i" and defined as:

f = (other cell interference)/(intracell interference)

$$N \cong \frac{W}{R} \cdot \frac{1}{E_b/I_o} \cdot \frac{1}{d} \cdot G_{sect} \cdot 1/(1+f)$$

f, changes according to the scenario (typical values 0.4-0.6);
"f", is sometimes known as "reuse factor"
of the CDMA system

Cell dynamic

$$\frac{E_b}{I_0 + N_0} = \frac{q \cdot W / R_b}{1 + mS \dfrac{1+i}{N_0 W} + j}$$

S = signal power

$$\mathbf{q = \frac{S}{N_0 W}}$$

i = intercell interference to intracell interference ratio

j = external interference referred to the thermal noise power

m = number of coninuously active users

$$q = \frac{\dfrac{E_b}{I_0 + N_0} \cdot (1 + j)}{W/R_b - m \cdot (1 + i) \cdot \dfrac{E_b}{I_0 + N_0}}$$

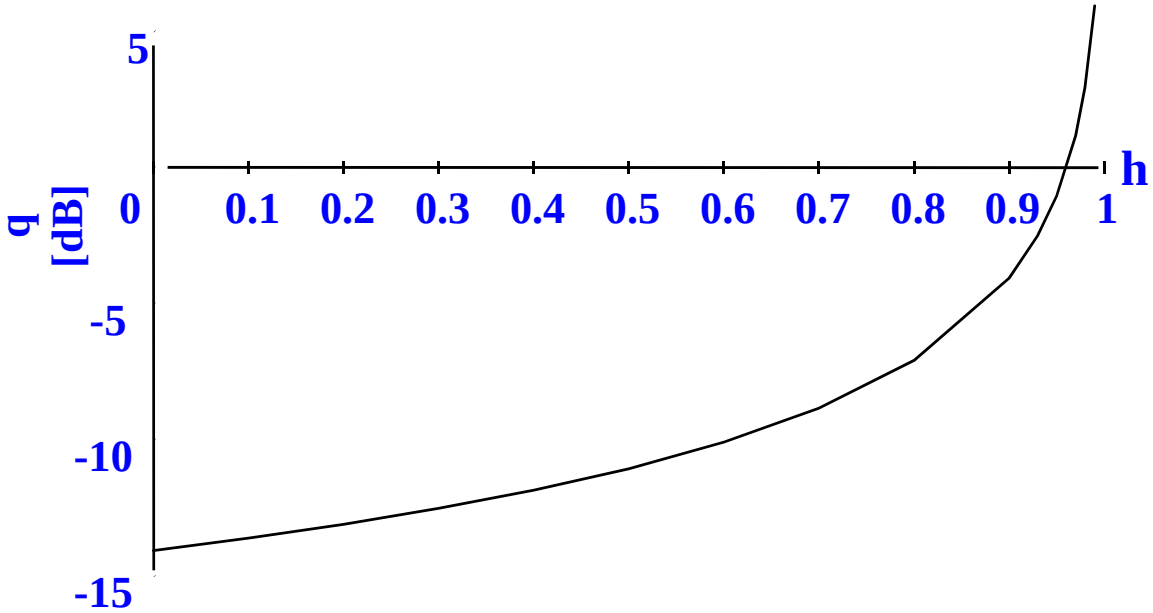
The "pole" of q is reached when m = m_{max}

$$m_{\max} = \frac{1}{(1 + i)} \cdot \frac{W}{R_b} \cdot \frac{I_0 + N_0}{E_b}$$

$$\eta = \frac{m}{m_{\max}}$$

$$q = \frac{1 + j}{\dfrac{W}{R_b} \cdot \dfrac{I_0 + N_0}{E_b} \cdot (1 - \eta)}$$

Example of signal to noise ratio (“q”) versus the load

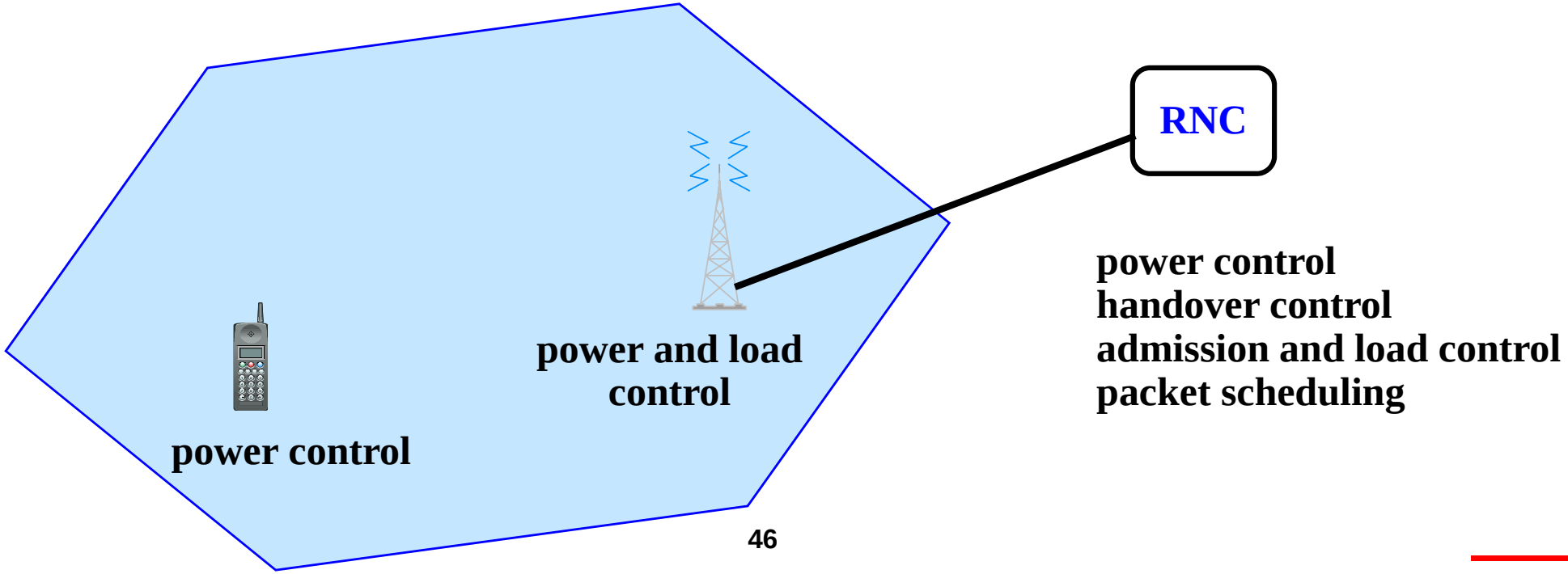


$$\frac{W}{R_b} = 128 \qquad \frac{E_b}{I_0 + N_0} = 7\ \text{dB} \qquad j = 0$$

W-CDMA – Radio Resource Management

RRM – role

- Quality of Service control
- Call Admission Control and Traffic measurement
- Handover
- Power control
- Packet scheduling



Admission Control

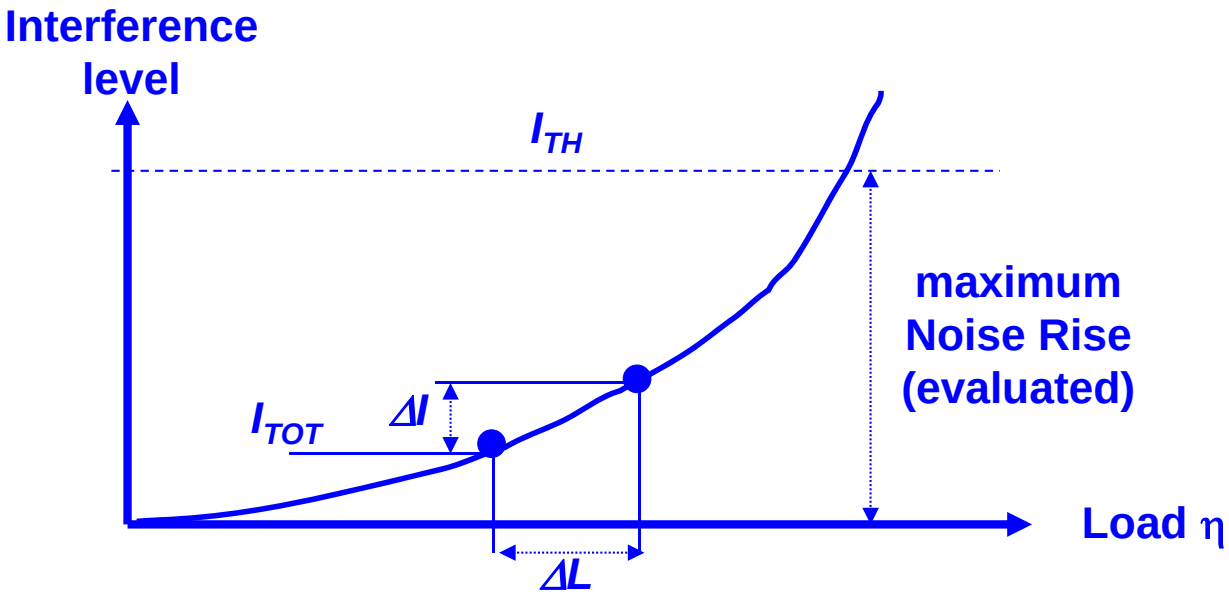
(up-link algorithm)

The Admission Control works through a *soft limit,* introduced to keep the inteference within a given threshold

$$I_{TOT} + \Delta I > I_{TH}$$

Threshold from the cell planning

Evaluation of the interference step



Power-based

$$\eta_{UL} = \frac{noise\ \ rise - 1}{noise\ \ rise}$$

Throughput-based

$$\eta_{UL} = \sum_i R_i \cdot \frac{\nu_i (E_b / N_0)_i}{W} \cdot (1 + f)$$

Congestion Control

(functional scheme)

Events modifying the operative status:

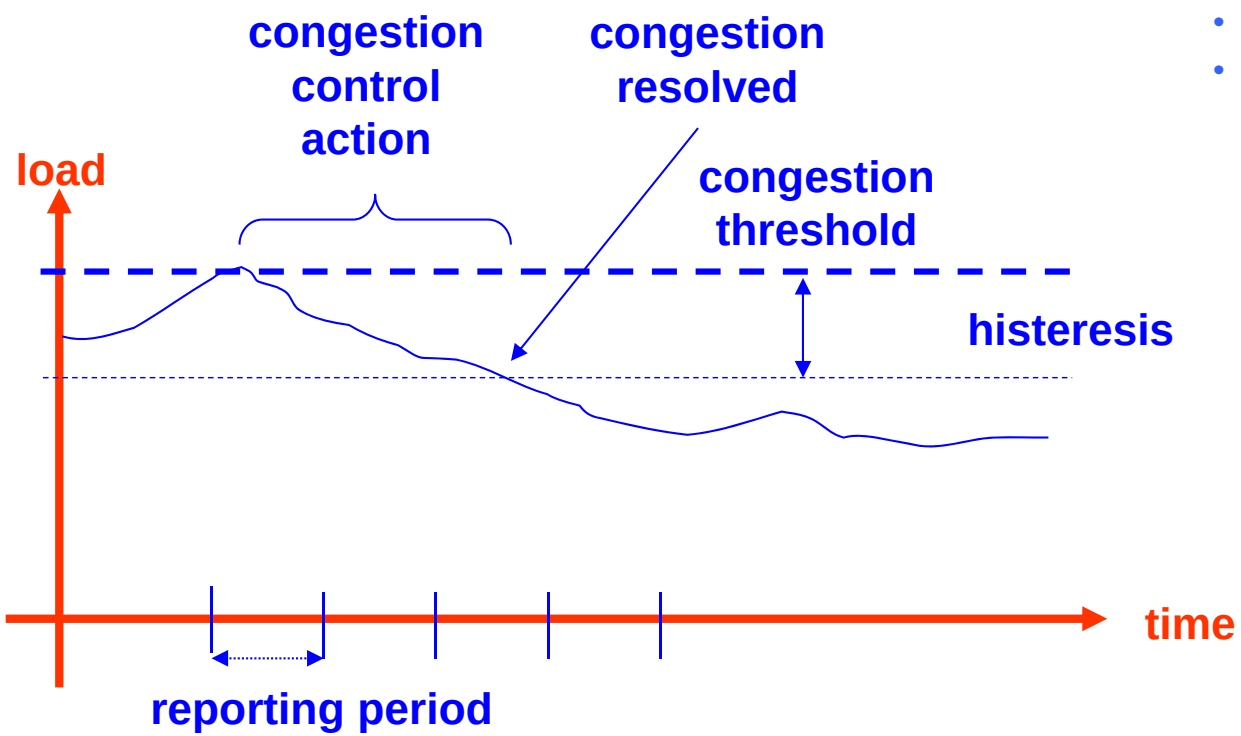
- resources are re-negotiated by the active calls
- the modification of the interference conditions
- the modification of the propagation conditions and power configuration

The control is acting on:

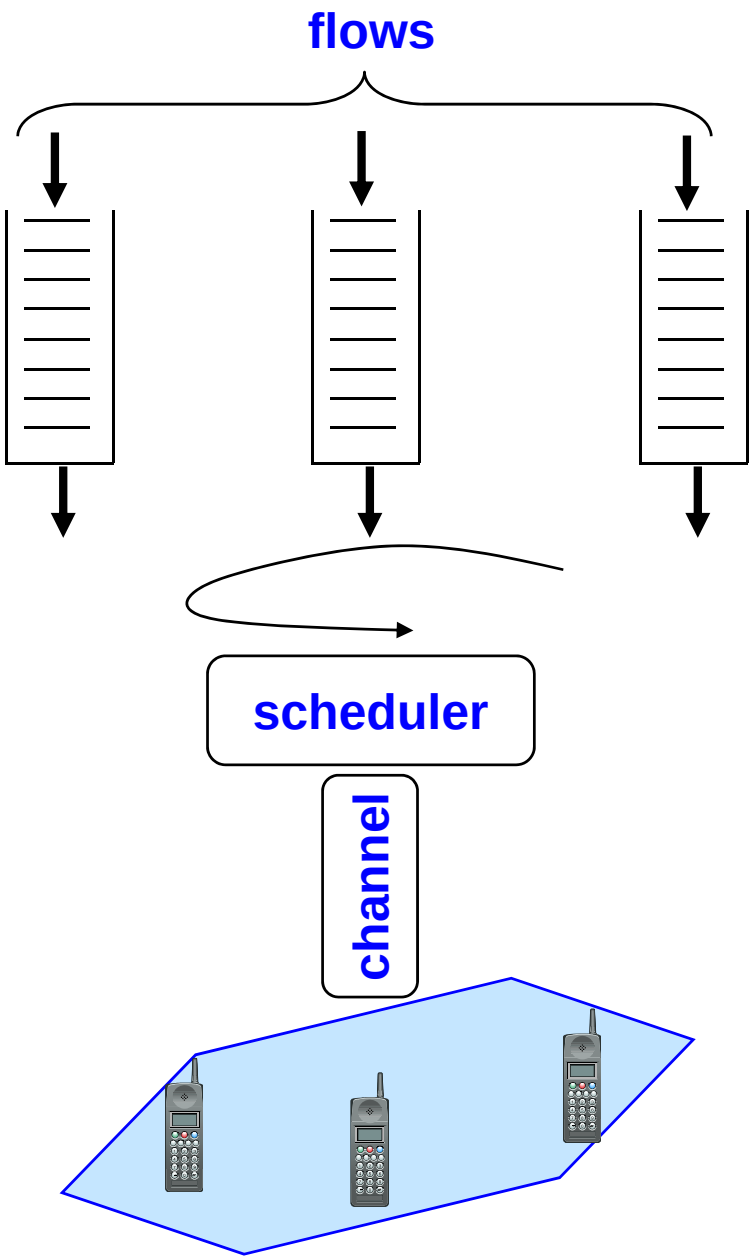
- the interference on the up link
- the power generated on the down link

Specific actions on:

- call admission
- cell ray
- BLER
- radio bearer configuration
- inter frequency handover



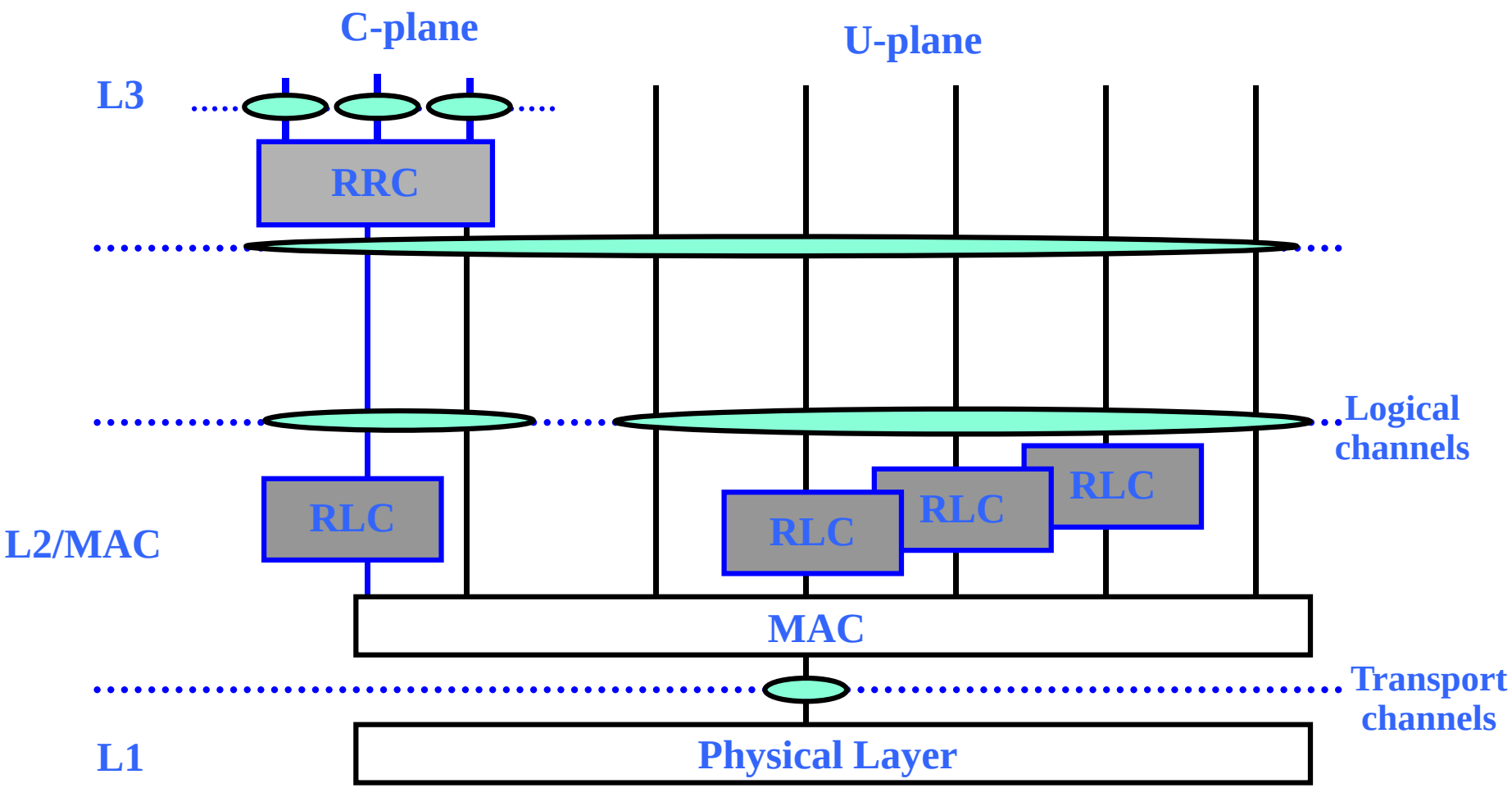
Packet scheduling



Scheduling options

- **Fair throughput (strict RR)**
- **Fair resource (time, power, codes) (unfair throughput, depending on the channel status)**
- **C/I based: priority to the users experimenting the best channel quality**
- **Max C/I: within the Transmission Time Interval, just users experimenting the max values of C/I (high delay for badly served users)**
- **Proportional fair resource: uses the control quality estimation and the remaining work**

Radio Interface - protocol architecture (3gpp 25.301)

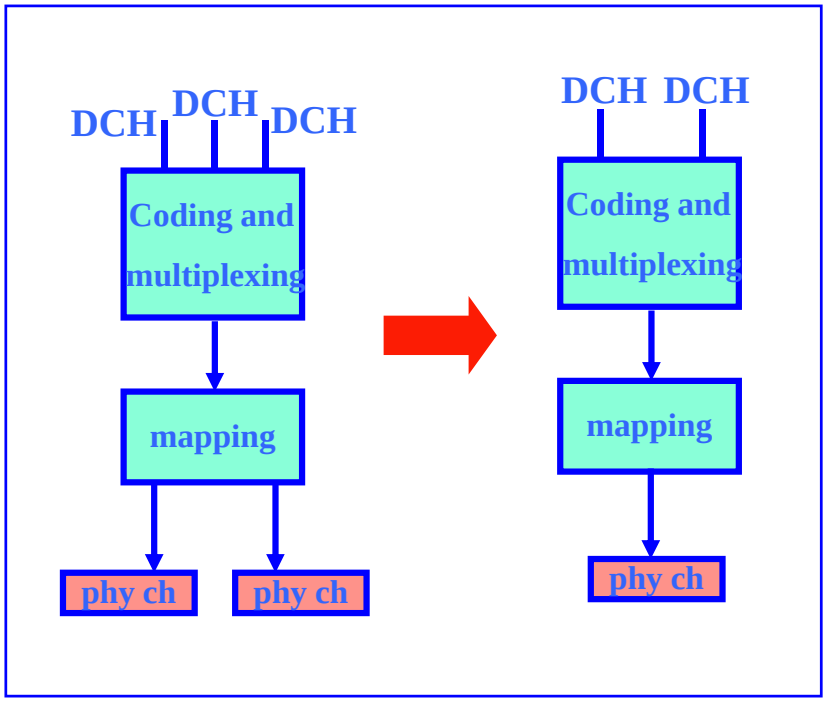


MAC Services and Functions

- set-up, release of logical channels
- data transfer service on logical channels
- allocation/re-allocation of radio resources
- measurement report

Functions

- Selection of the transport format
- Handling of priority within one user/between users
- Scheduling of control messages (broadcast, paging, notification)
- Multiplexing/de-multiplexing of higher layers PDUs on/from common or dedicated transport channels
- Contention control on the random access channel



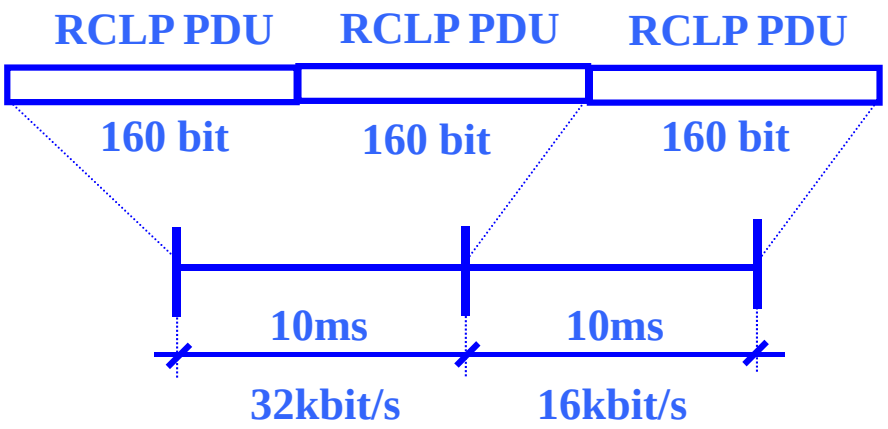
Retransmission Protocol - services and functions

- Layer 2 connection set-up and release
- transparent data transfer
- unacknowledged data transfer
- acknowledged data transfer

Services of RLC

Functions

- connection control
- segmentation and re-assembly
- error detection/recovery and in-sequence delivery
- transfer of user data
- flow control
- duplicate detection
- QoS adaptation

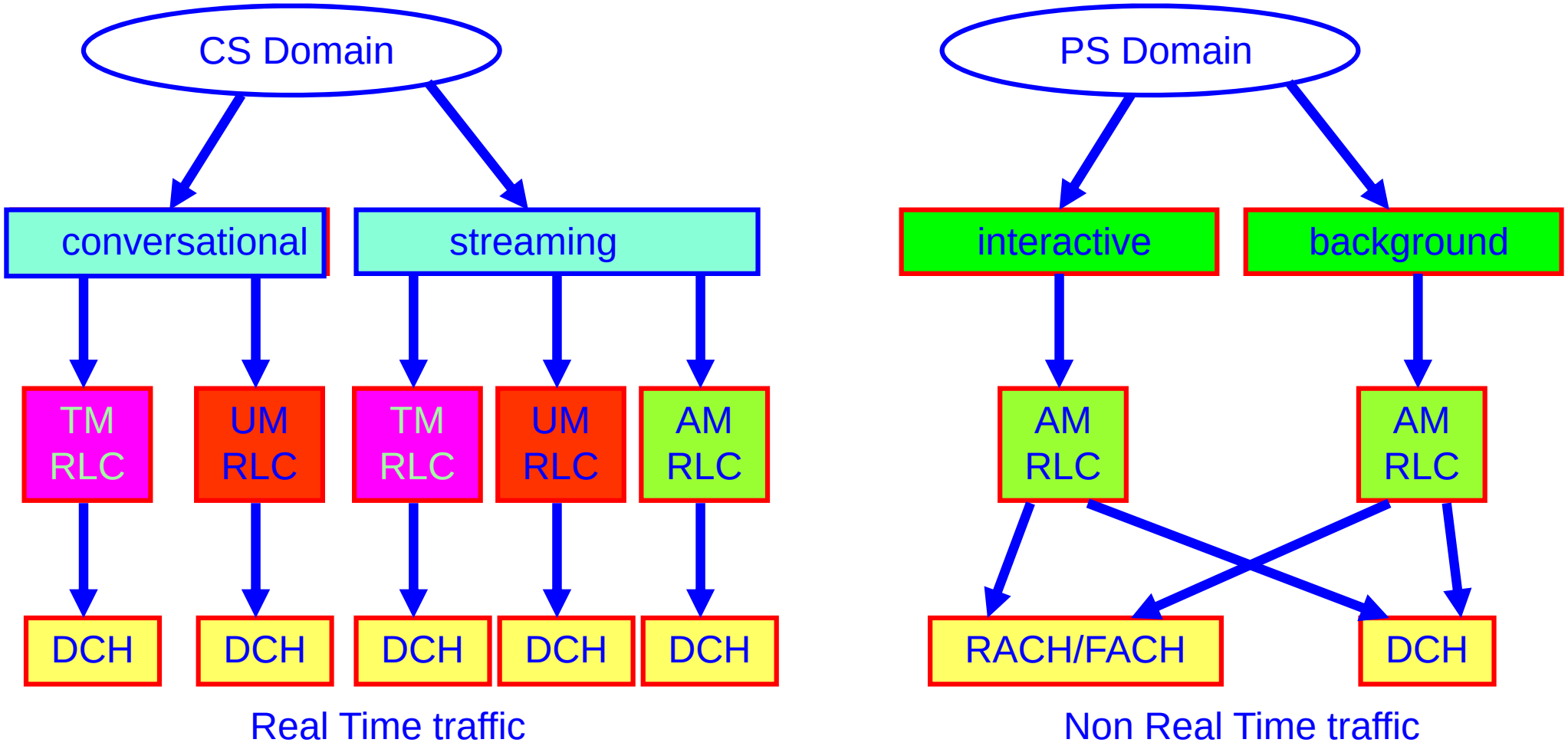


Radio Resource control - services and functions

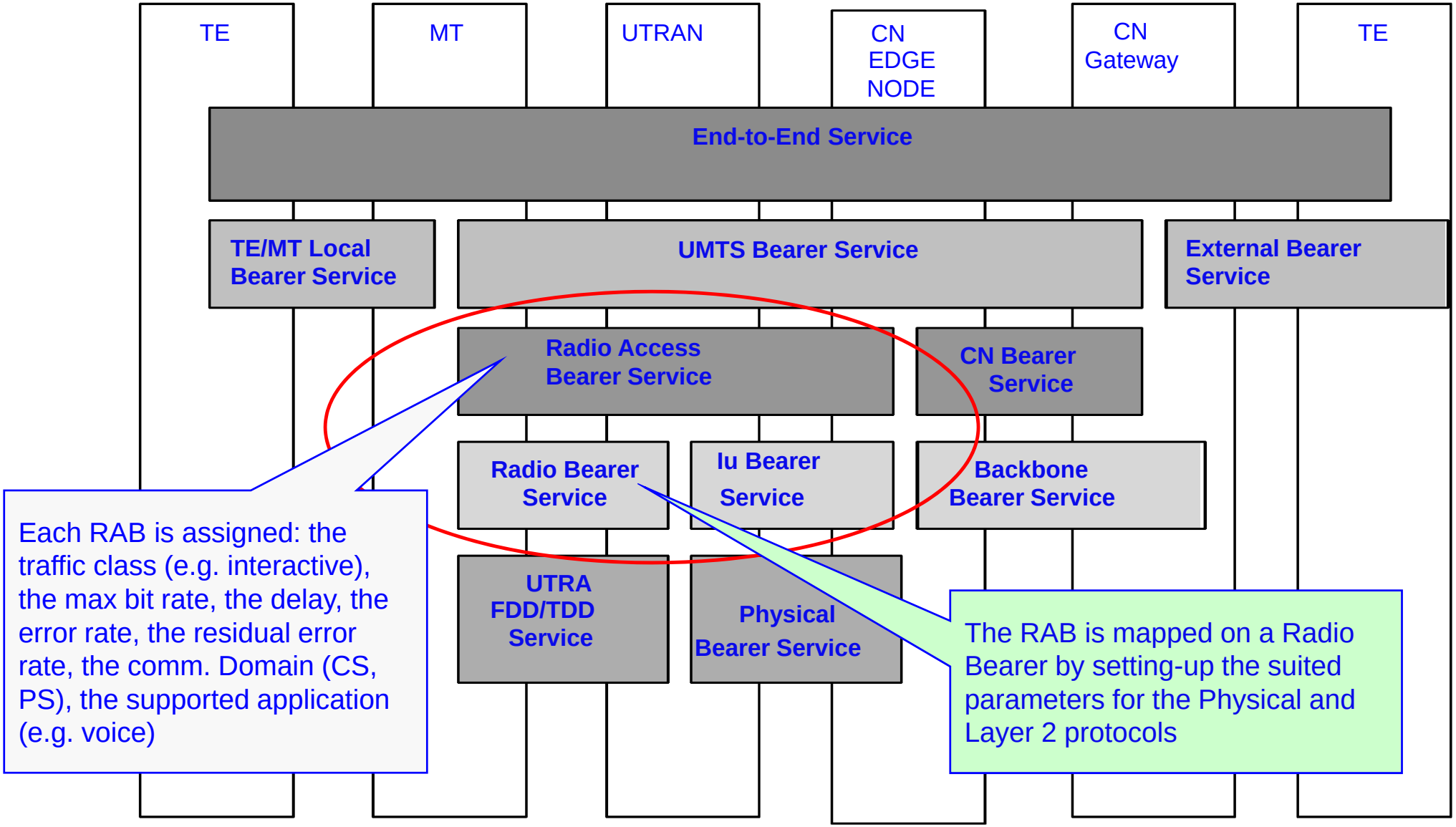
- Broadcast of information | provided by the Core Network related to the access segment
- Set-up, maintenance and release of an RRC connection
- Set-up, maintenance and release of radio bearers on the user plane
- Assignment, reconfiguration and release of radio resources for the connection
- Arbitration of radio resource allocation between cells
- RRC connection mobility functions
- Quality of Service control and radio resource allocation among the cells
- Admission and congestion control
- Control of the MS measurement reporting

Quality of Service

(mapping of the traffic casses on the RABs)



Radio Access Bearers (RAB) - 3GPP 23.107



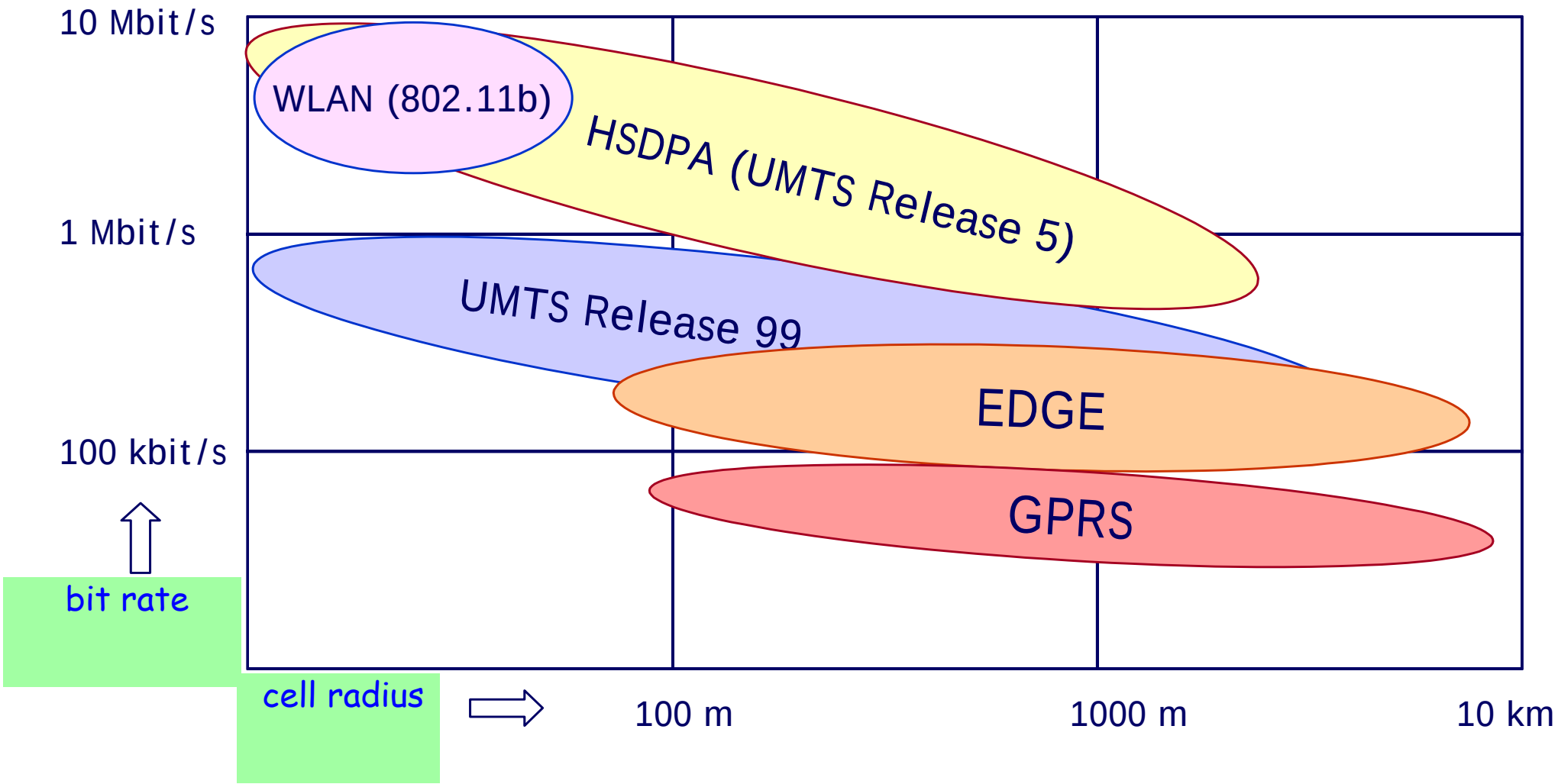
RAB as function of the service class - 3GPP TS 34.108

Service class	Peak bit rate [kbit/s]	Residual BER	Delay sensitivity	Transport Channel	Domain
Conversational (e.g. with adaptive encoding)	4,75 ÷ 12,2	$1 \cdot 10^{-3}$	Sensitive to delay and Jitter	DCH	Circuit
Conversationall (e.g. video call)	64; 128; 384	$1 \cdot 10^{-6}$	Sensitive to delay and Jitter	DCH	Circuit
Streaming	57,6	$1 \cdot 10^{-4}$	Sensitive to Jitter	DCH	Circuit
Streaming	64	$1 \cdot 10^{-4}$	Sensitive to Jitter	DCH	Packet
Interattive or Background	64 ÷ 384	$1 \cdot 10^{-4}$	Moderate sensitivity to delay	DCH	Packet
Interattive or Background	1200 ÷14400	$1 \cdot 10^{-4}$	Moderate sensitivity to delay	HS-DSCH *	Packet

* *High Speed DL Shared Channel*, used with the HSDPA (*High Speed Downlink Packet Access*) feature, introduced with Release 5 UMTS

UMTS- HSDPA (R5)

HSDPA positioning vs other solutions



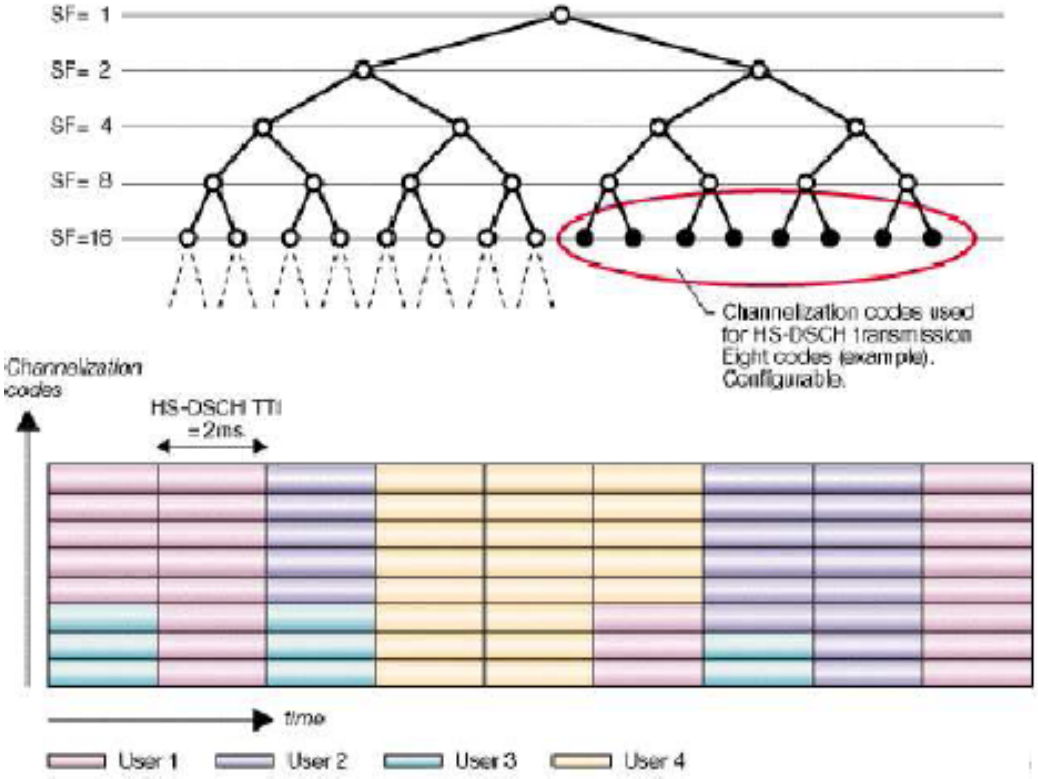
HSDPA rationale

- **to improve data speeds per user**
  - **High speed download (mails, video and mp3)**
  - **Video streaming**
  - **Highly interactive games**
  - **High speed browsing**
- **to improve service latency**
- **to improve Network Capacity**

- **The HSPA deployment is based on the reuse of 3G network infrastructure:**
  - **same NodeB (modified) and RNC**
  - **same Core Network**
  - **same site/mast/antennas.**

3GPP HSDPA – Rel.5

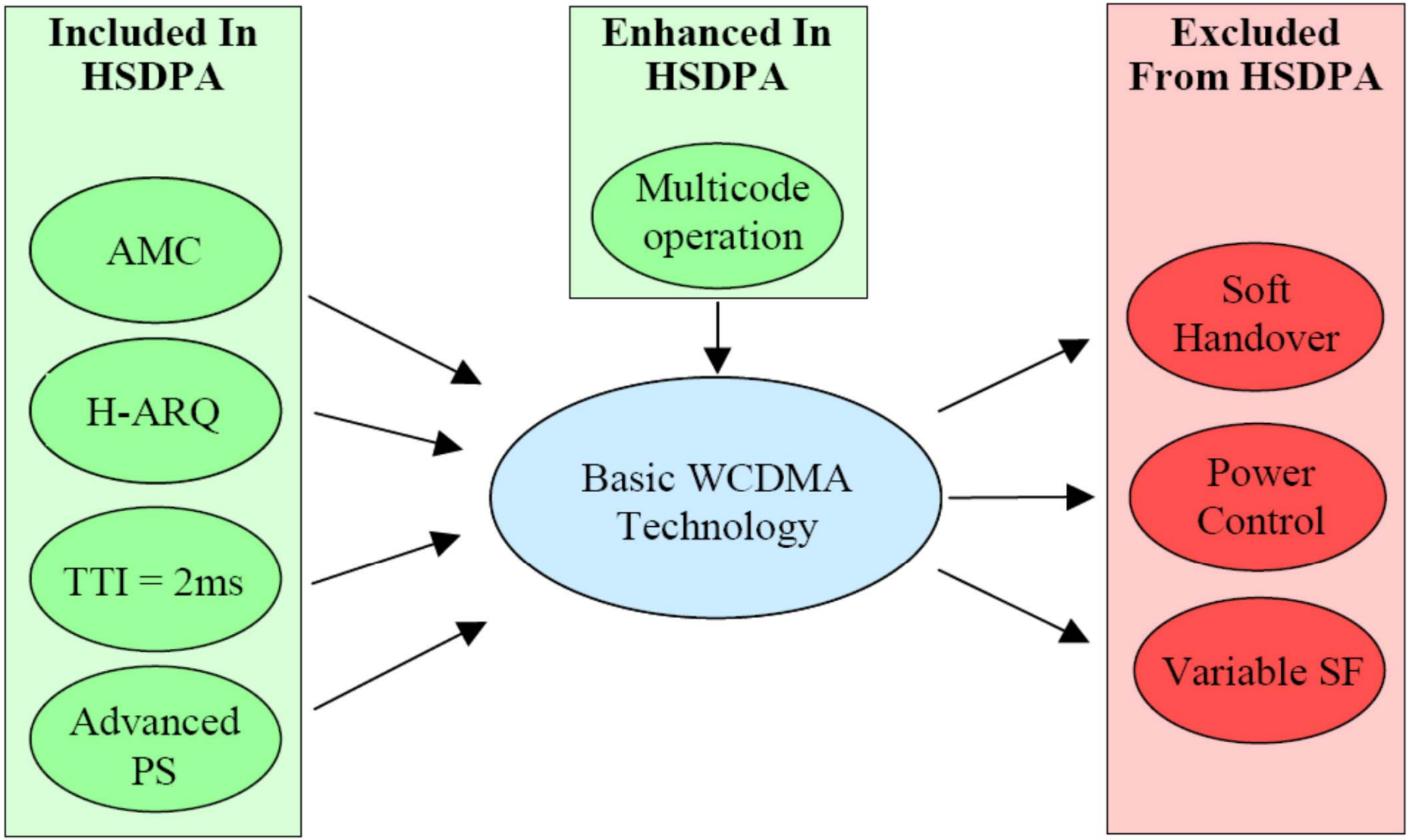
- Introduced in 3GPP – Release 5
- Main Characteristics vs R99:
  - » Shared packet transmission
  - » Higher order modulation (16QAM)
  - » Shorter TTI (2ms vs 10ms)
  - » Adaptive modulation & coding
  - » Fast Link Adaptation
  - » Fast Hybrid HARQ
  - » Advanced packet scheduling



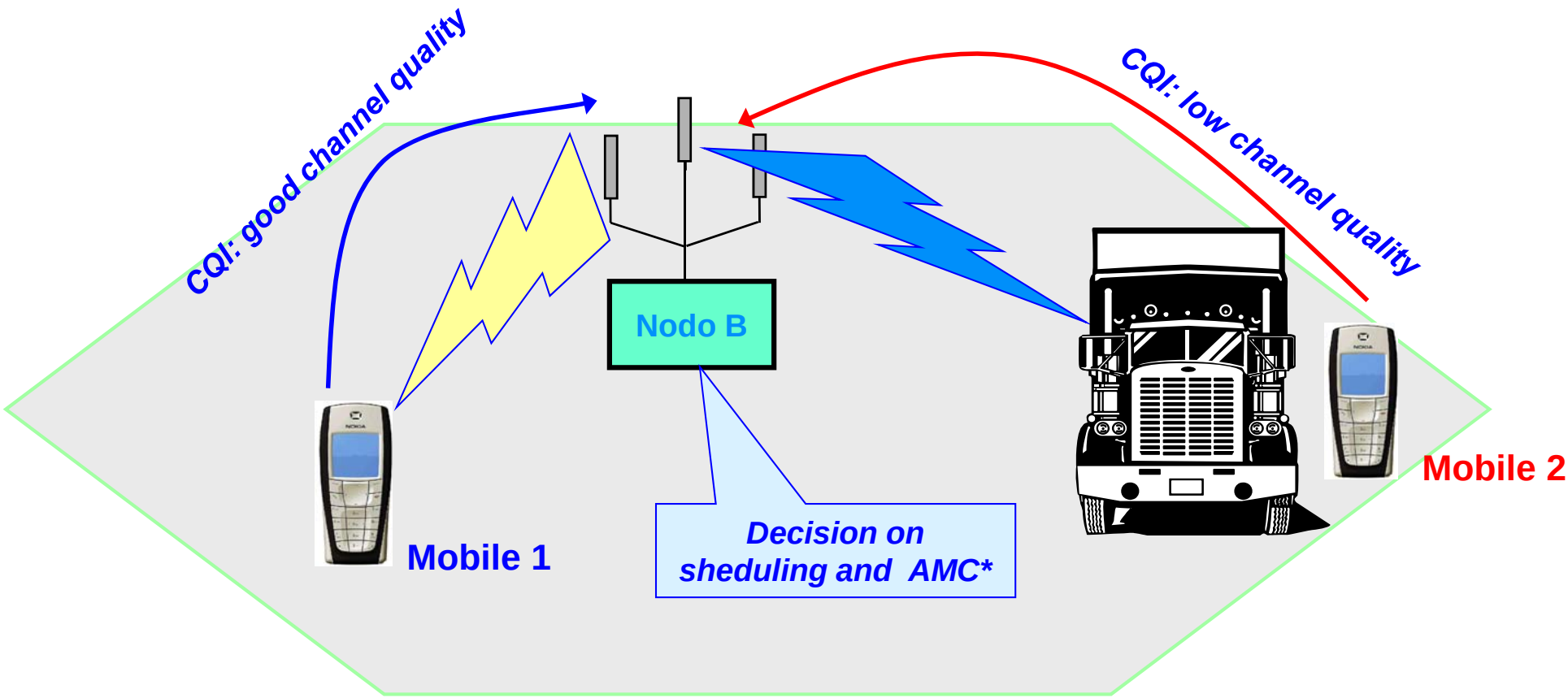
HSDPA – the innovative capabilities

- Single transmission channel shared among several users on the down link
- Scheduling of the transmission queues performed by the base station; MAC layer partially decentralised
- Multiplexing over the time domain (TTI - 2 ms)
- Hybrid techniques (H-ARQ, *Hybrid ARQ*) for corrupted radio blocks, managed by the B-node
- Adaptive modulation and coding, based on a channel quality indicator (CQI) transmitted by the mobile
- Use of 16-QAM modulation to increase the spectral efficiency whenever under good channel conditions
- Bit rate up to14 Mbit/s.

HSDPA: Main characteristics vs UMTS R99



Fast Scheduling and CQI – the CQI principle



The CQI (Channel Quality Indicator) is derived by the MS every 2 ms on the basis of the pilot channel (CPICH).
It specifies: power, modulation and coding scheme the MS is ready to receive for the subsequent TTI, to maintain a *Block Error Rate* (BLER) lower than 10%

** Adaptive Modulation & Coding*

R5 UE categories

UE categories defined on the basis of:

1) *Number of codes that can be elaborated per each* TTI
2) *Maximum bit rate over the entire frame*
3) *Minimum interval elapsing between two subsequent* TTIs
4) *Possible modulation schemes* (only QPSK, or both QPSK and 16-QAM)
5) *Storage dimension for the HARQ, e.g the less powerful class does not accept the* Incremental Redundancy at the maximum bit rate.

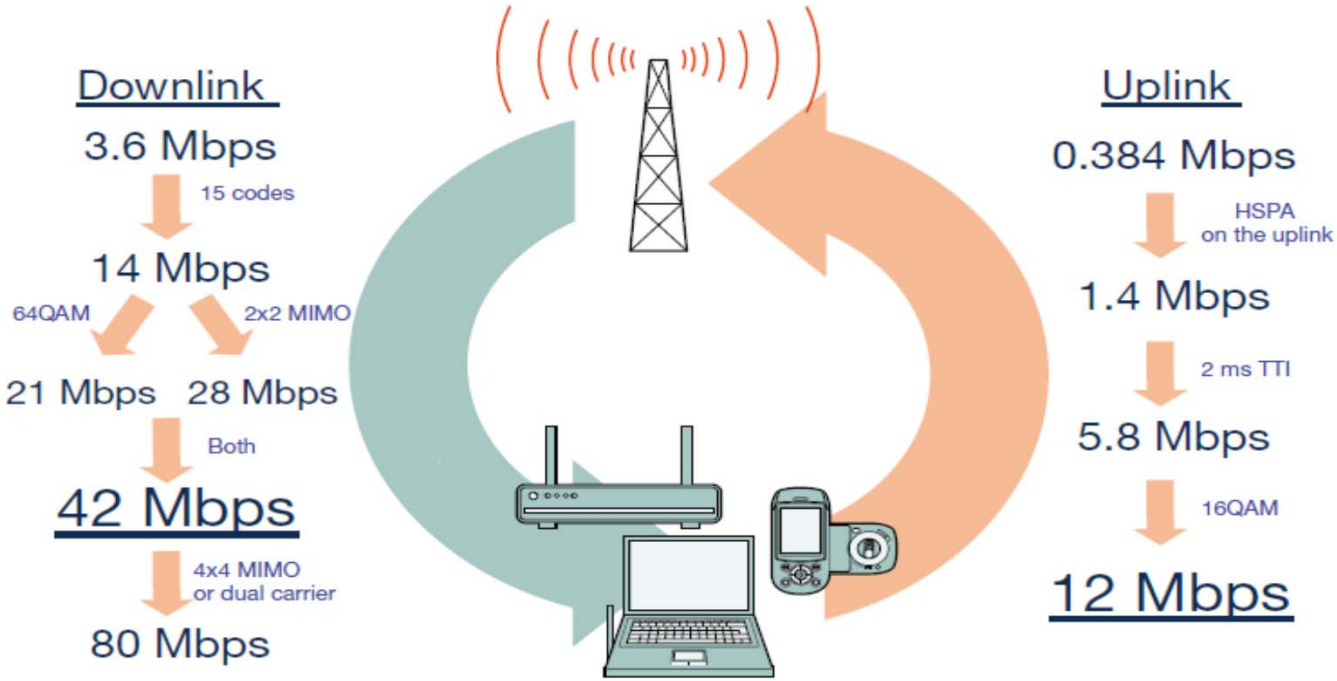
3GPP TS 25.306

R5 UE categories and related bit rates

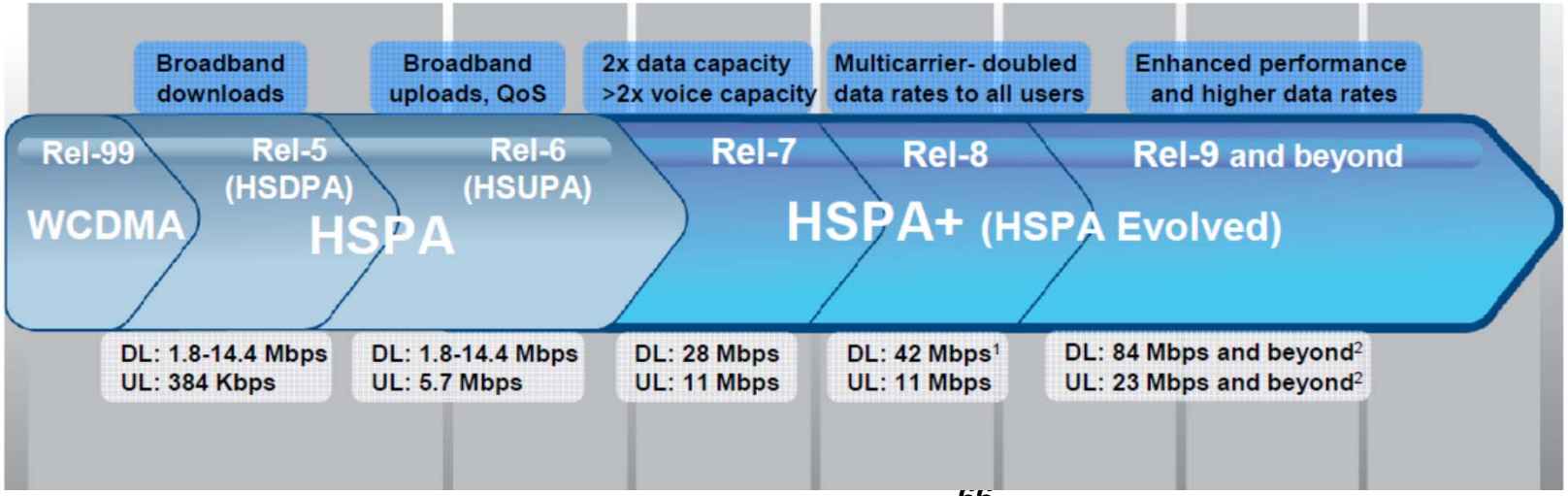
class	max codes #	minimum TTI interval	peak bit rate at layer 1 (mbps)	peak bit rate at RLC level (mbps)	IR at peak bit rate	supported modulation
1	5	3	**1,2**	1,1	No	QPSK, 16-QAM
2	5	3	**1,2**	1,1	Yes	QPSK, 16-QAM
3	5	2	**1,8**	1,6	No	QPSK, 16-QAM
4	5	2	**1,8**	1,6	Yes	QPSK, 16-QAM
5	5	1	**3,6**	3,4	No	QPSK, 16-QAM
6	5	1	**3,6**	3,4	Yes	QPSK, 16-QAM
7	10	1	**7,2**	6,7	No	QPSK, 16-QAM
8	10	1	**7,2**	6,7	Yes	QPSK, 16-QAM
9	15	1	**10**	9,6	No	QPSK, 16-QAM
10	15	1	**14**	13,4	No	QPSK, 16-QAM
11	5	2	**0,9**	0,8	No	QPSK
12	5	1	**1,8**	1,6	No	QPSK

3GPP TS 25.306

HSPA Evolution hints



"HSPA Evolution" 710 Ericsson White Paper: www.3g4g.co.uk/Hspa/HSPAE_WP_0710_Ericsson.pdf



"HSPA+ for Enhanced Broadband"

Qualcomm WP, 2009

Outline- Part II

COMING UP SOON……NEXT WEEK!!!

- LTE
- LTE Advanced
- 5G overview

…..STAY TUNED ☺

Thanks for your kind attention

☺