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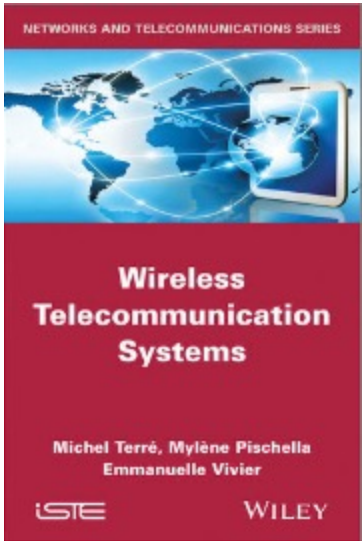


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# 3 G – 3.5 G : UMTS / HSPA

A GLOBAL INITIATIVE

UMTS Forum

HSPA. MOBILE BROADBAND TODAY

# Outline

- IMT 2000 context
- CDMA applied to UMTS
- UMTS Architecture
- Channel mapping in UMTS
- UTRAN physical layer
- Handover in UMTS
- Power control for UMTS
- HSPA
- Radio Dimensioning and Planning

# IMT2000 Context

# Markets

- 2000: 500 millions mobile subscribers
- 2005: 2 billions
- 2010: 4 billions
- 2011: 5.6 billions

| Technologies | Subscriptions | Market Share | Annual Growth |
|---|---|---|---|
| ALL | 5.66 billion | 100% | 14.6% |
| 3GPP family | 5.07 billion | 89.6% | 14.5% |
| *GSM* | *4.31 billion* | 76.2% | 11.2% |
| *WCDMA and HSPA* | *753.1 million* | 13.3% | 37.2% |
| *LTE* | *2 million* | 0.1% | 674% |
| CDMA/EV-DO | 533 million | 9.4% | 12.7% |
| Others | 56.5 million | 1% | 55.9% |

- 2015: 7 billions

| Technologies | Subscriptions | Market Share |
|---|---|---|
| ALL | 7 billion | |
| 3GPP family: | 6.3 billion | 90.4 % |
| • WCDMA and HSPA | 1.7 billion | |
| • LTE | 950 million | |

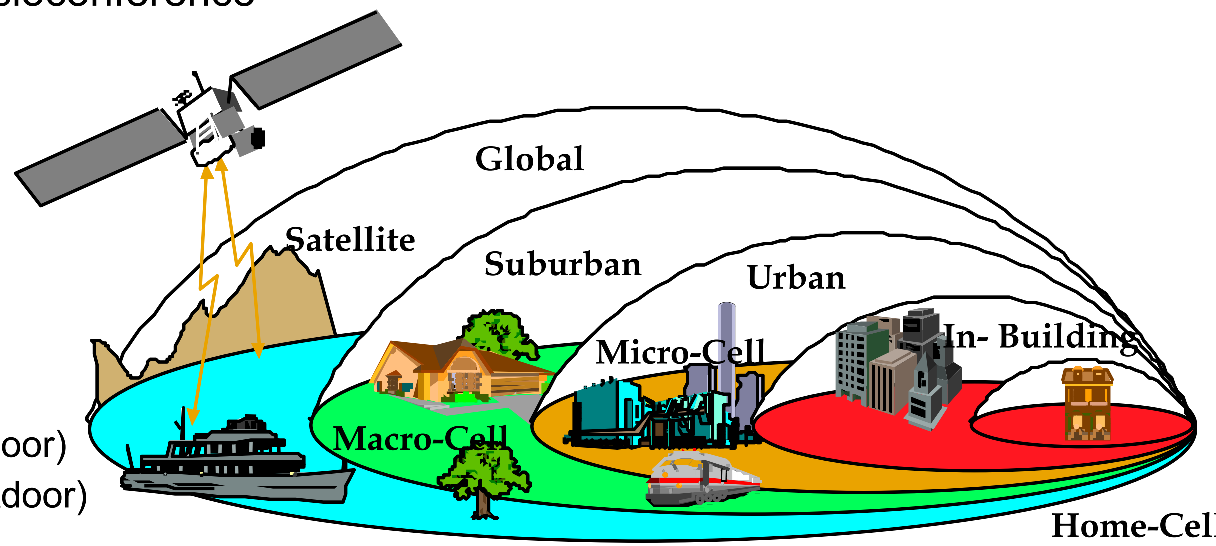
# IMT2000 (1/)

- International Mobile Telecommunications 2000 (ITU 1985) : "IMT2000"
  - Third Generation mobile system

- Objectives:
  - one single phone, everywhere in the world : a global network
  - data services integrated in the terminal (IT & Telecom convergence)
    - QoS:
      - voice quality, global coverage (« global roaming »), enhanced transmission delays
      - higher spectral efficiency (higher capacity)
      - cost

# IMT2000 (3/)

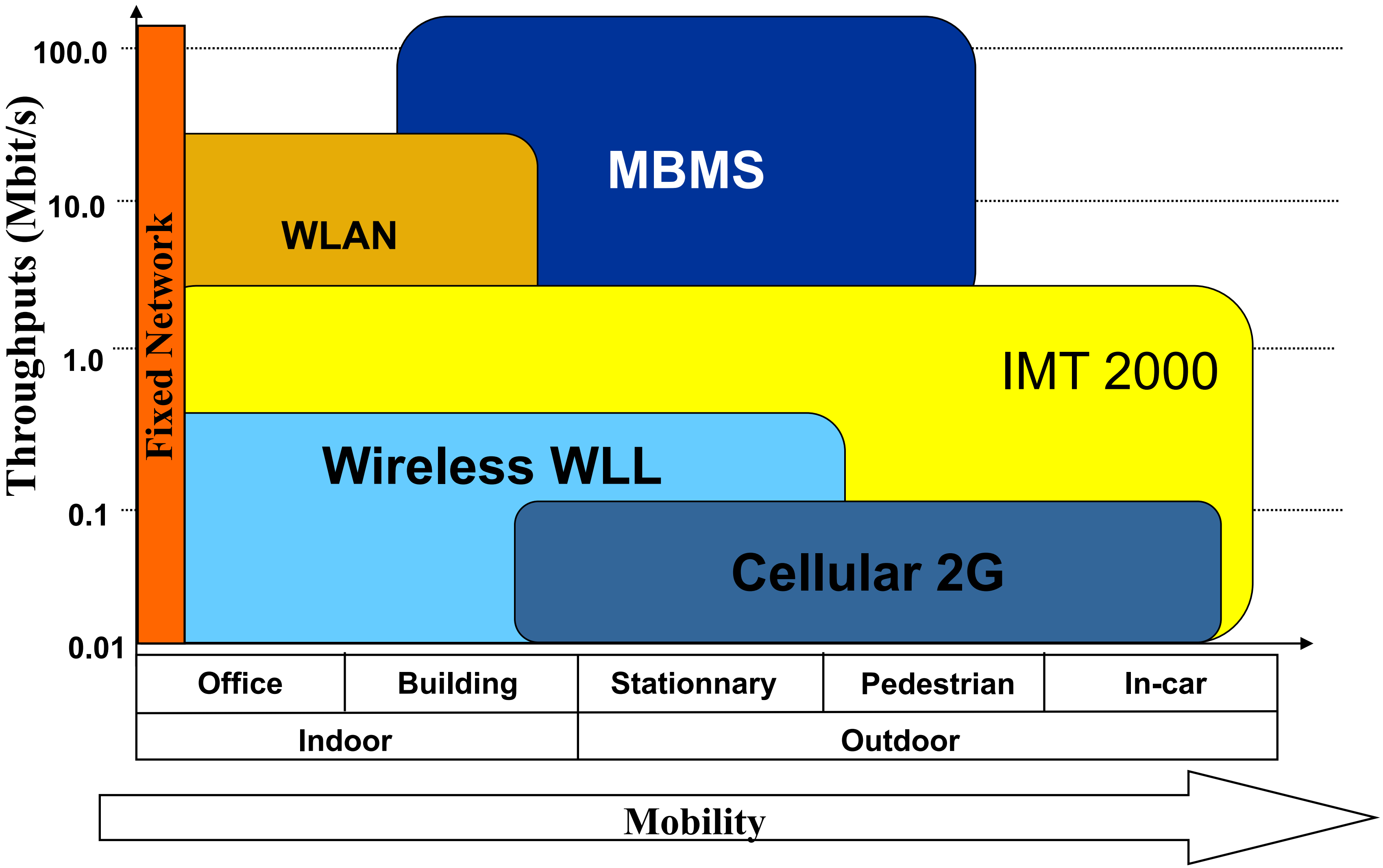
- Examples of services (asymetric!):
  - Mobile visiophony & visioconference
  - Teleworking
  - Internet access
  - Telesupervision
  - News reporting




- Throughputs:
  - UMTS:
    - 144 kbits/s (rural outdoor)
    - 384 kbits/s (urban outdoor)
    - 2 Mbit/s (stationnary)
  - CDMA2000:
    - 1X: v1: 144 kbits/s, v2: 614 kbit/s
    - 3X: 2 Mbits/s

- High flexibility for a better integration of new services

# IMT 2000 Positionning



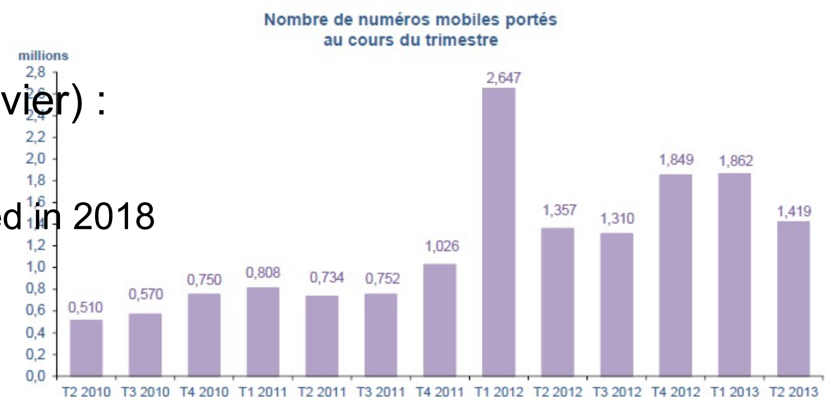
# IMT2000 Consortiums

- An international partnership:
  - 3rd Generation Partnership Projects 3GPP: "UMTS"
    - Japan (ARIB Association of Radio Industries and Business and TTC Telecommunication Technology Committee),
    - China (CCSA China Communications Standards Association)
    - Europe (ETSI European Telecommunications Standards Institute)
    - USA (T1)
    - Korea (TTA Telecommunications Technology Association)
  - supports 3G systems based on GSM evolution

- An international competition:
  - 3GPP 2: "CDMA 2000" (Qualcomm)
    - USA (TIA Telecommunications Industry Association)
    - Korea (TTA Telecommunications Technology Association)
    - Japan (TTC Telecommunications Technology Committee and ARIB Association of Radio Industries and Businesses)
    - China (CCSAChina Communications Standards Association)
  - supports 3G systems based on IS-95 evolution

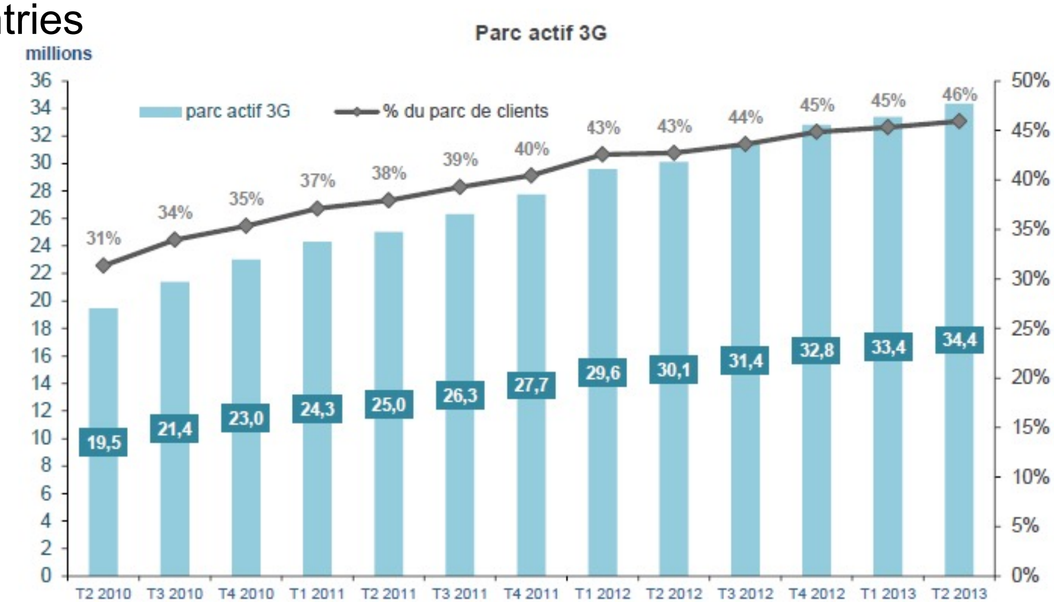
# UMTS : beginnings

- Standardized (1998-2001) by 3GPP
- Respects IMT2000 requirements
- First commercial launches:
  - Japan : Oct. 2001, by NTT DoCoMo
  - France :
    - Sept. / Oct. 2004
    - Dec. 2009 : Free Mobile obtains a 3G licence from ARCEP:
      - 240 millions €
      - commercial launch in 2012 (le 10 janvier) :
      - with Orange to ensure coverage
        - 90% of the population must be covered in 2018
      - very competitive subscription offers



# UMTS : penetration

- Subscribers:
  - Major part of the number of subscribers growth (2012: UMTS increasing rate > GSM increasing rate)
  - World:
    - end 2009 : 485 millions (including 180 millions HSPA)
      end 2011 : 800 millions (including 500 millions HSPA)
    - ~400 networks in 170 countries
    - >3000 devices
  - France
    - end 2009 : 15 millions (25% mobile market)
    - end 2012 : 33 millions (45% mobile market)

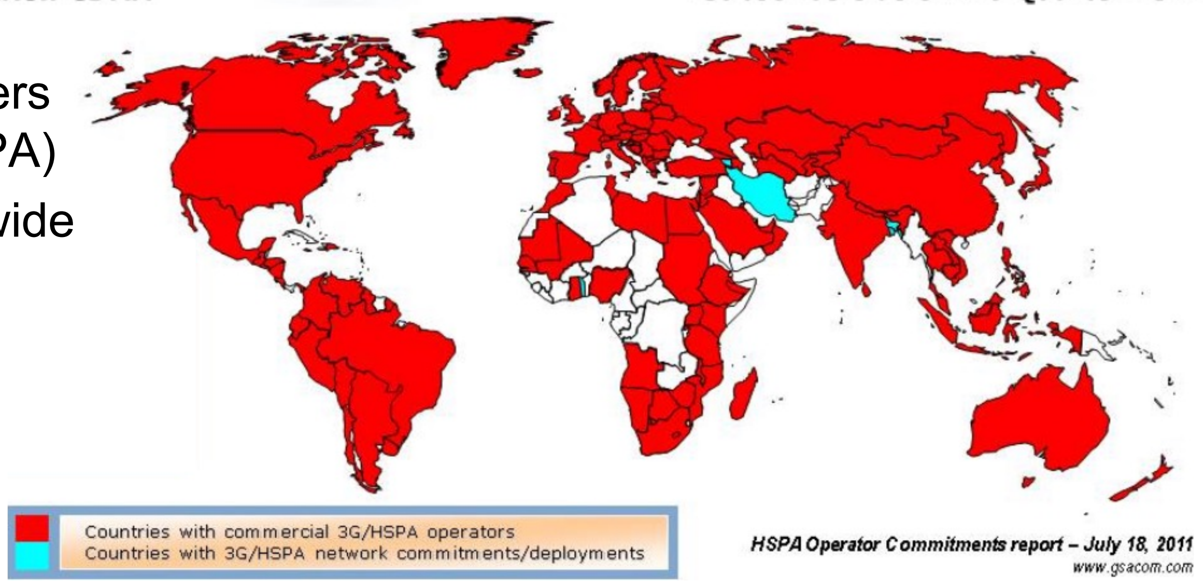



- Réseau concurrent :
  CDMA2000
  (évolution de l'IS-95, ~615 millions d'abonnés)

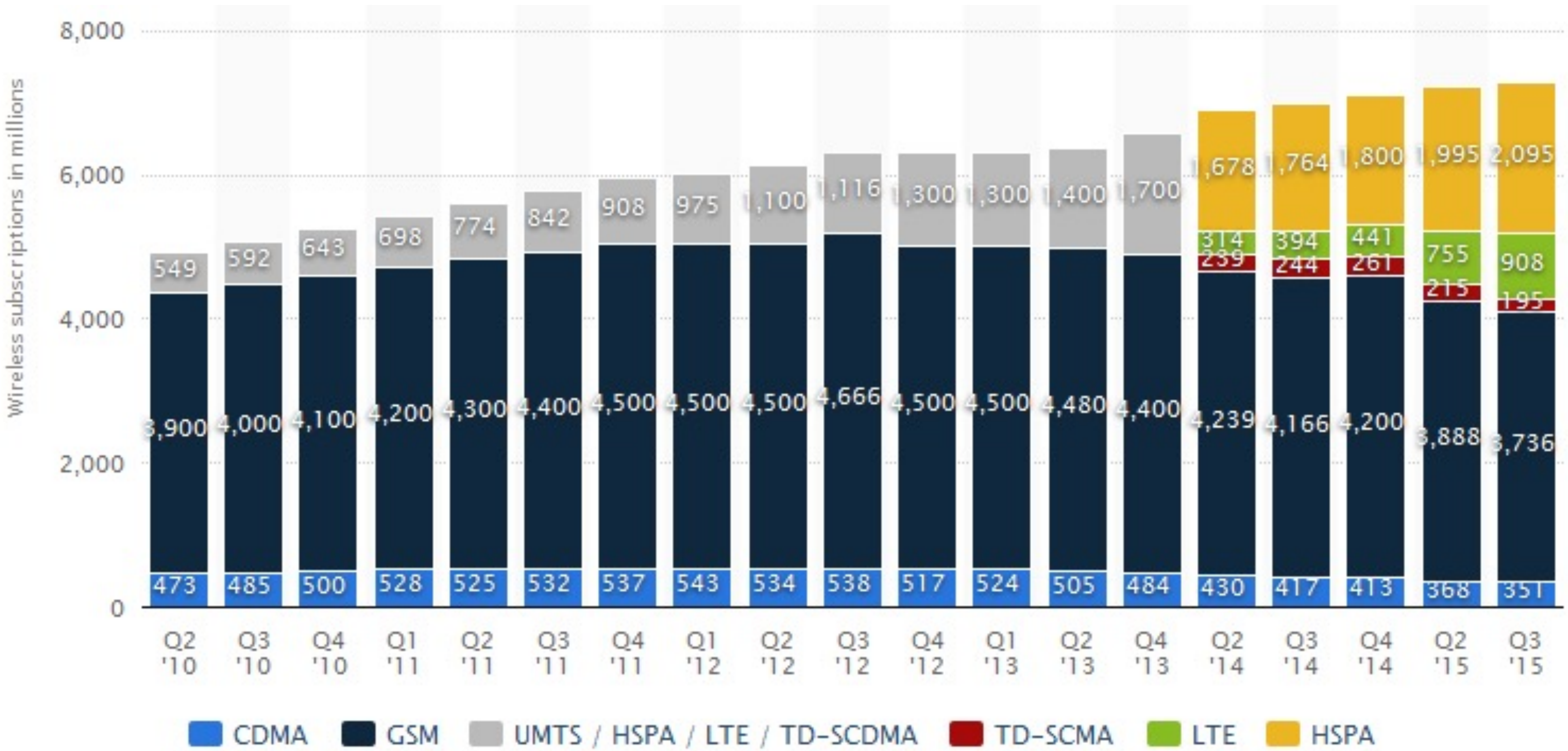
# IMT2000 markets

- CDMA 2000, end 2011:
  - ~600 millions subscribers
  - 300 operators, worldwide
  - 116 countries/territories
  - > 3000 devices


- UMTS, end 2011:
  - 800 millions subscribers (inc. 500 millions HSPA)
  - 300 operators, worldwide
  - 140 countries
  - > 3000 devices



# Mobile subscriptions



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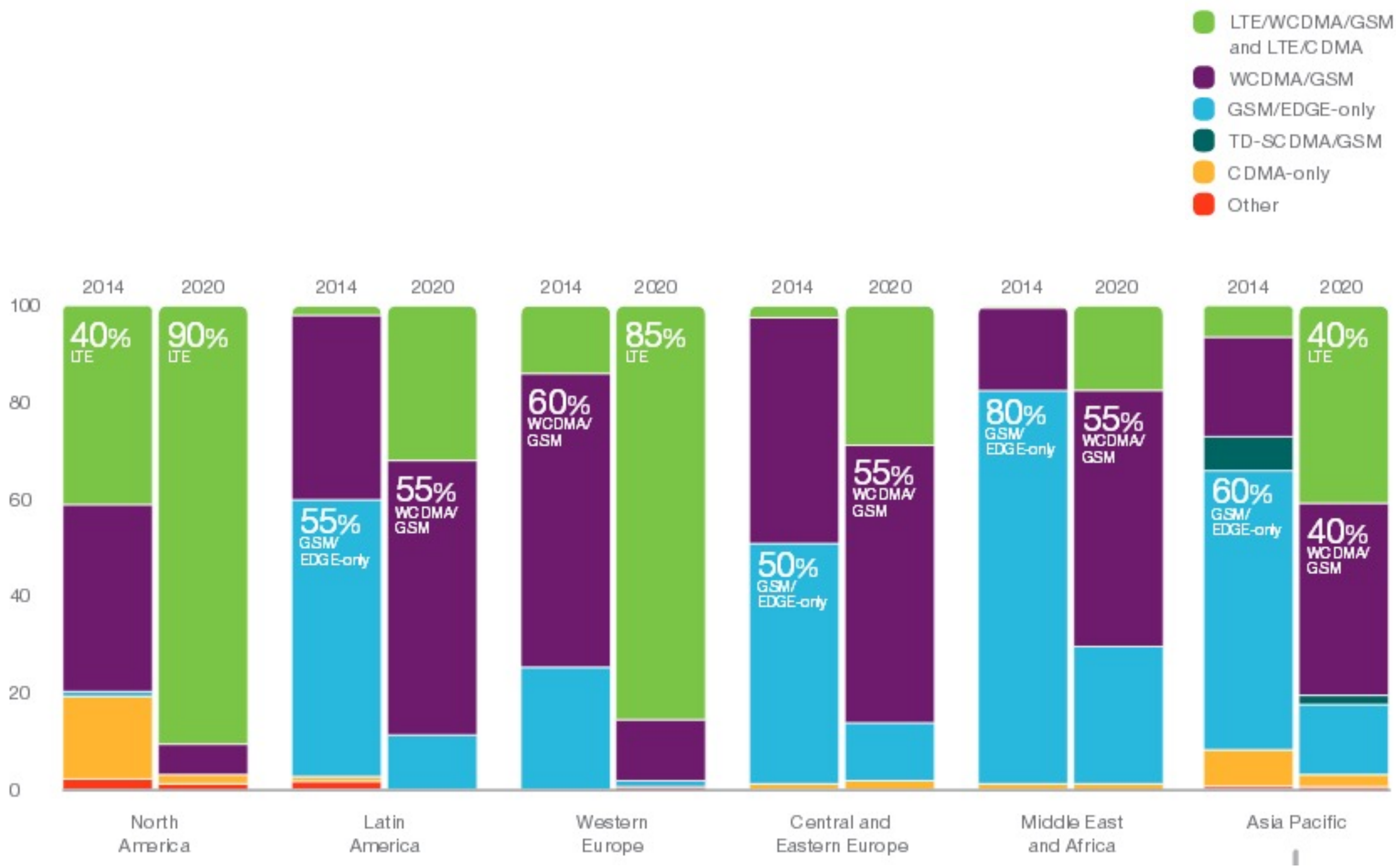
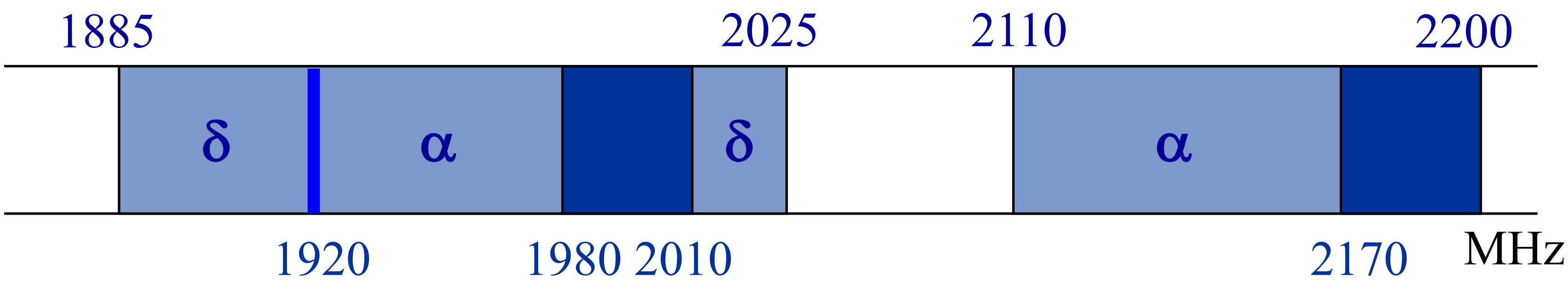
# Mobile subscriptions per region



# IMT2000 – UMTS : frequencies



- 2000 MHz band:




  - α: W-CDMA, FDD mode, appaired bands (12 × 5 MHz)
  - δ: TD-CDMA, TDD mode, non appaired bands (7+3 5 MHz bands)

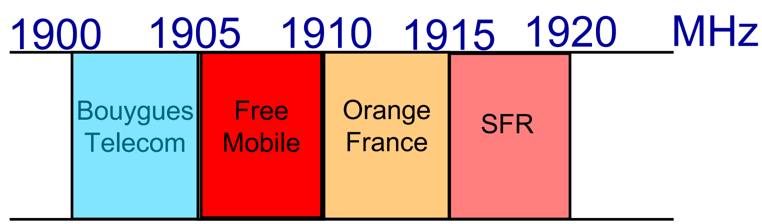
- 900 MHz band:
  - reuse of GSM band

- TD-CDMA: Time division CDMA
- W-CDMA: Wide band CDMA

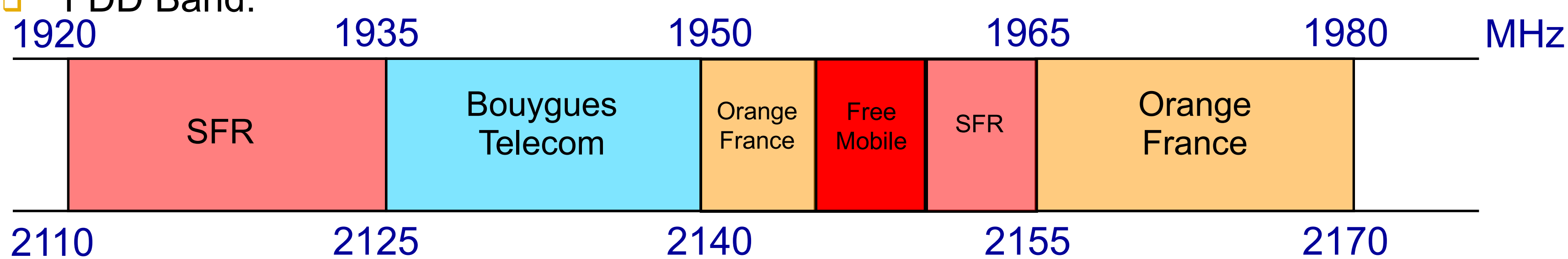
# UMTS Frequencies alloc. in France (1/)

- 4 operators (commercial launch):
  - SFR (06/2004)
  - Orange France (09/2004)
  - Bouygues Telecom (04/2007)
  - Free Mobile (2012)

- UMTS band:
  - TDD Band:



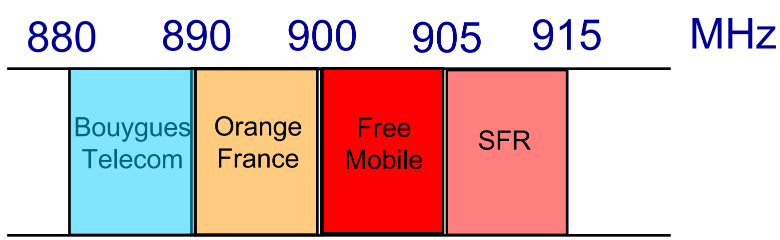

  - FDD Band:



# UMTS Frequencies alloc. in France (2/)



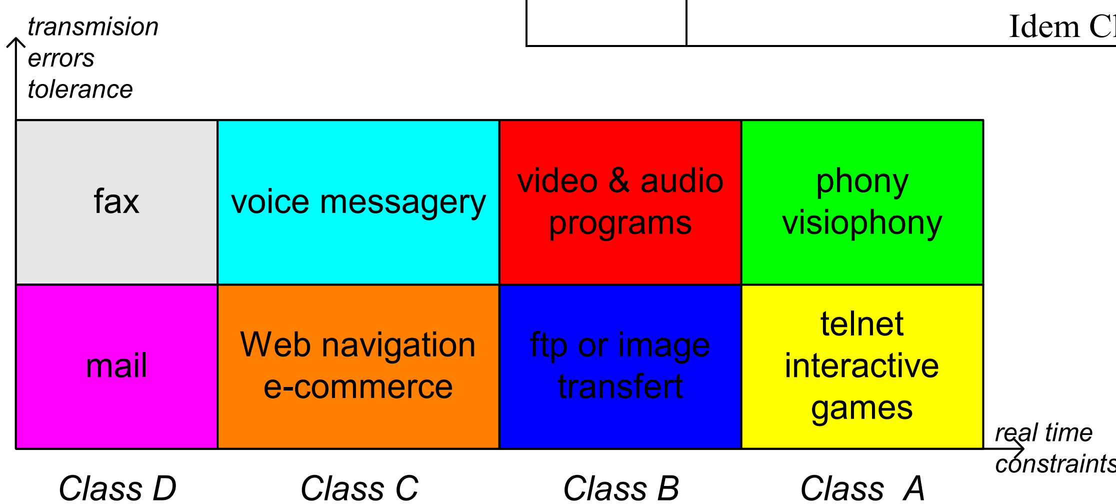
- GSM band
  - On Feb. 2008, ARCEP approved all GSM French operators to reuse their 900 MHz spectrum for 3G



# UMTS – Offered services

- 4 classes of services:

| | Use | Types of Services | Constraints |
|---|---|---|---|
| **Class A** | **conversational**<br>2 users or<br>group of users | ↑↓ symetrics | Low delays |
| **Class B** | **streaming**<br>User & data server,<br>without interactivity | ↑↓ asymetrics<br>(from server to user) | Low jitter |
| **Class C** | **interactive**<br>User & data server,<br>without interactivity | ↑↓ asymetrics<br>(from server to user) | 'High' delays<br>Low BER |
| **Class D** | **Background**<br>Idem Class C but lower priority | | |

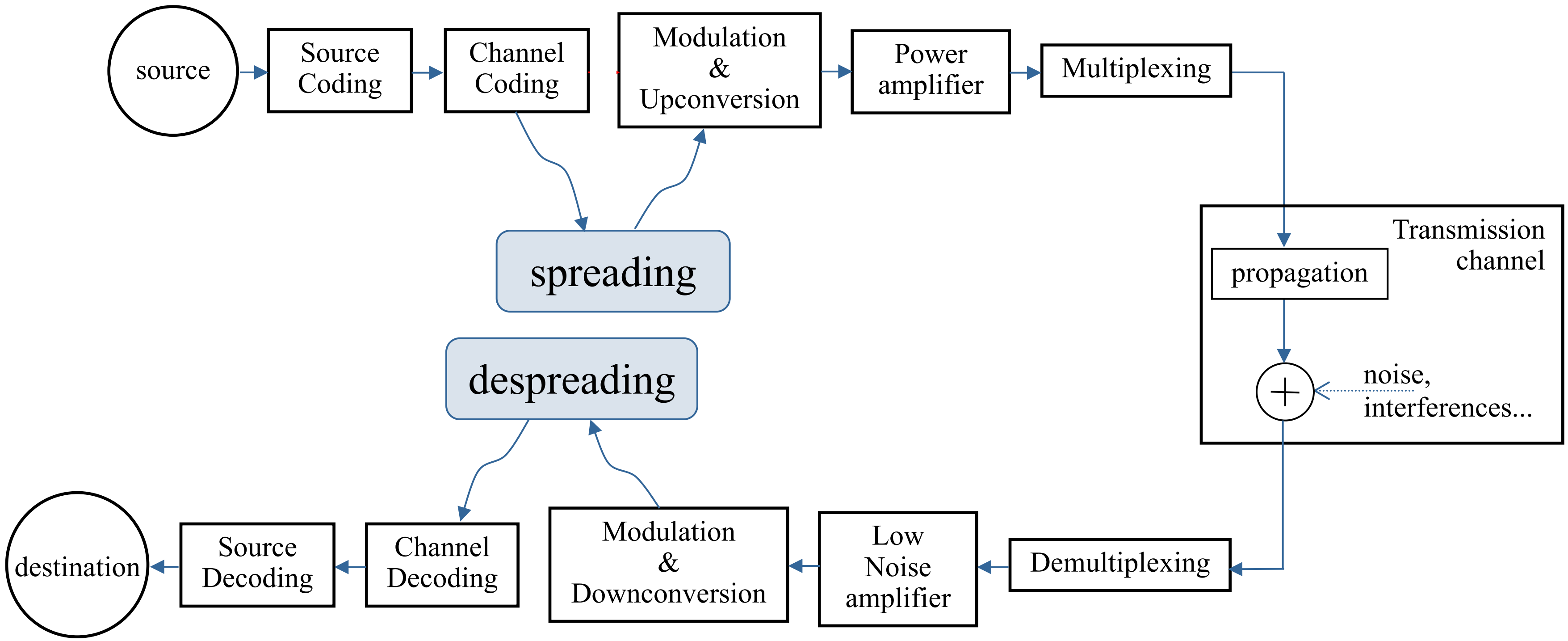


# UMTS – Quality of Service

- QoS expressed with:
  - delay (maximum, jitter = variation of delay in time)
  - loss rate (frame, bit)
  - throughputs (maximum, mean)
  - priority
  - size of packets
- Management principles:
  - parameters are set at the connection establishment
  - possibility for renegotiation during the connexion
  - several QoS contexts are simultaneously possible for a given user

- CDMA applied to UMTS

# Spreading a signal - Transmission chain



# Spreading a signal...

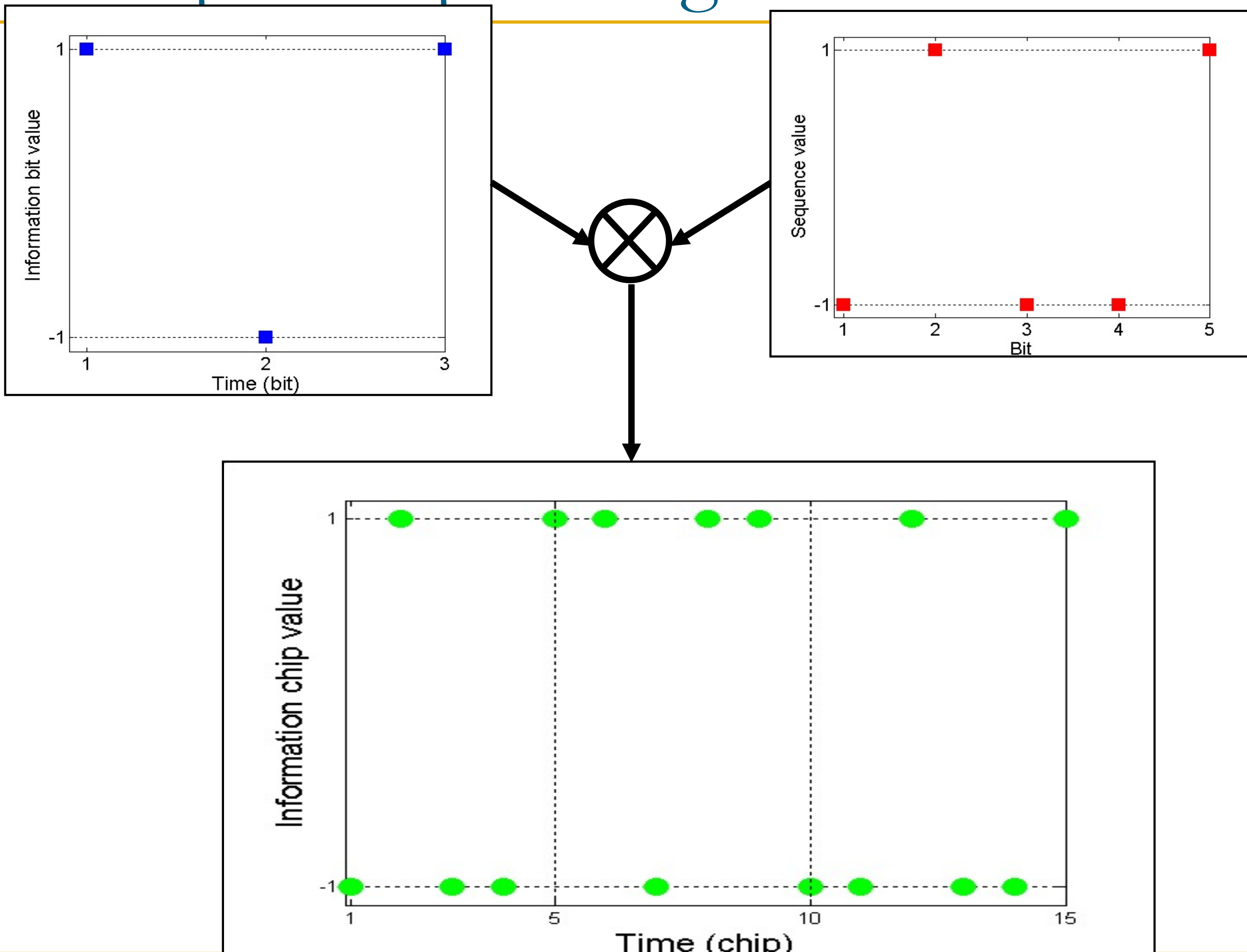
- Information to be spread =
  a n-long information bits: $b_1, b_2, \ldots b_n$ , at a bitrate: R bits/s
- Sequence to be used =
  a $N$-long sequence of bits: $s_1, s_2, \ldots, s_{N,}$ $N$ = spreading factor

$\Rightarrow$ Spreading the information bits gives:

- a $(n \times N)$-long information 'chips': $\mathbf{c}_1, \mathbf{c}_2, \ldots c_{nN}$
- obtained by a bit-to-chip multiplication:
  $c_1 = b_1 \times s_1,\ c_2 = b_1 \times s_2,\ \ldots,\ c_N = b_1 \times s_N,$
  $c_{1+N} = b_2 \times s_1,\ c_{2+N} = b_2 \times s_2 ,\ldots,\ c_{2N} = b_2 \times s_N$
  …
  $c_{nN-1} = b_n \times s_{N-1},\ c_{nN} = b_n \times s_N$
- at a chiprate: $R \times N$ chips/s

**Wider spectral occupancy : spread spectrum**

# Example of spreading



# Spreading limitations

The spread signal: ‘chips’,

- are highly autocorrelated in some values ≠ 0

⇒ difficulties for:

  - synchronization in reception
  - multipath detection

  which are essential in radiocommunications

- are highly intercorrelated in some values ≠ 0

⇒ difficulties for:

  - identifying information coming from desynchronized (i.e. different) transmitters

  which are unavoidable in radiocommunications

After spreading, a second step: **scrambling**, is essential in a wireless network where different users can simultaneously transmit their information, in order to ensure some orthogonality between them.

# UMTS – Spread spectrum & CDMA

- spreading sequence = 'channelization code'
  - *N* = spreading factor, SF:
    - FDD :
      - downlink: from 4 to 512
      - uplink: from 4 to 256
    - TDD : from 1 to 16
  - spreading sequence: Hadamard sequences

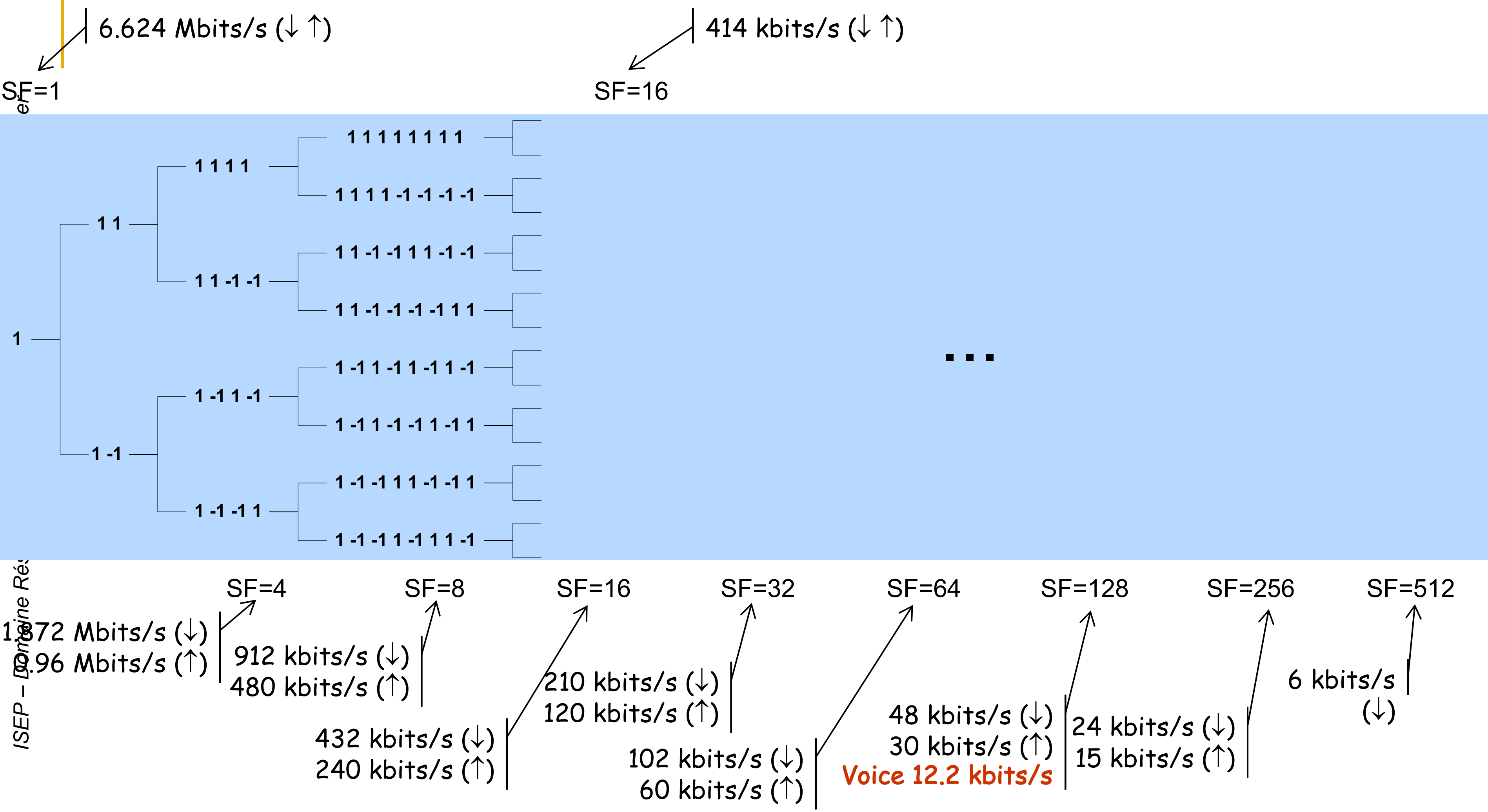
- scrambling sequences:
  - FDD: (↓ 512x512, ↑ $2^{24}$) Gold sequences
  - TDD: 128 predefined sequences

- CONSTANT chip rate,
  - 3.84 Mchips/s (complex chips),
  - whatever the data user rate

**The higher the data user throughput, the smaller the spreading factor**

# UMTS data rates

## TDD mode:




## FDD mode:

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# UMTS maximum data rates

- FDD:
  - uplink:
    - SF = 256 for radio signalisation
    - 960 kbps (data, SF = 4) + 15 kbps (radio signalisation)
  - downlink: (see tables in [3GPP 25.211])
    - 1872 kbps (data, SF = 4) + 48 kbps (radio signalisation, SF = 4)
- TDD:
  - SF=1
  - limited signalisation to 256 complex pilots bits
  - uplink& downlink: 6624 kbps (data, SF = 1)

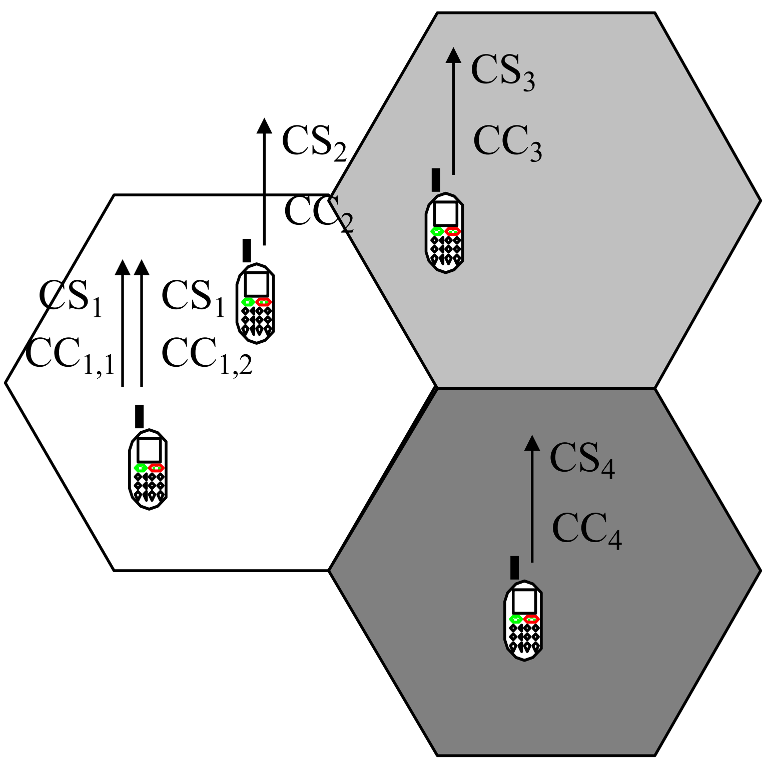
# UMTS – Using CC & CS

- Channelization codes:
  - Hadamard sequences, OVSF
  - spread information bits
  - differentiate bit-synchronized flows (perfect orthogonality), i.e. from one transmitter
    - One tree per MS in the uplink, one tree per BS in the downlink

- Scrambling codes:
  - Gold sequences
  - scramble spread data, i.e. chips
  - differentiate non synchronized flows, i.e. distinct transmitters
    - One code per MS in the uplink, one code per BS in the downlink

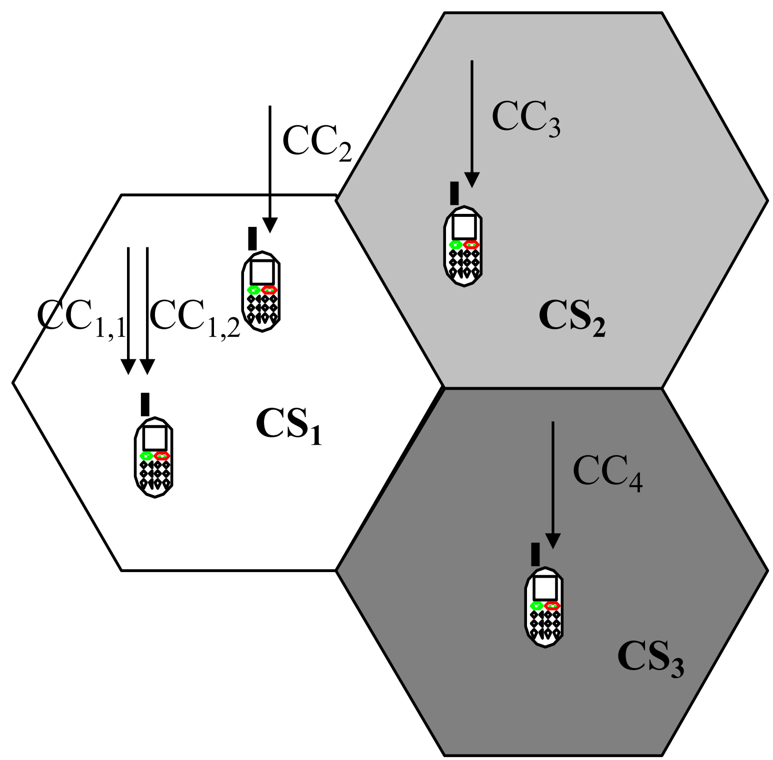
# UMTS – Using CC & CS (2/)

## UPLINK




- CS1 ≠ CS2 ≠ CS3 ≠ CS4
- $CC_{1,1} \perp CC_{1,2}$

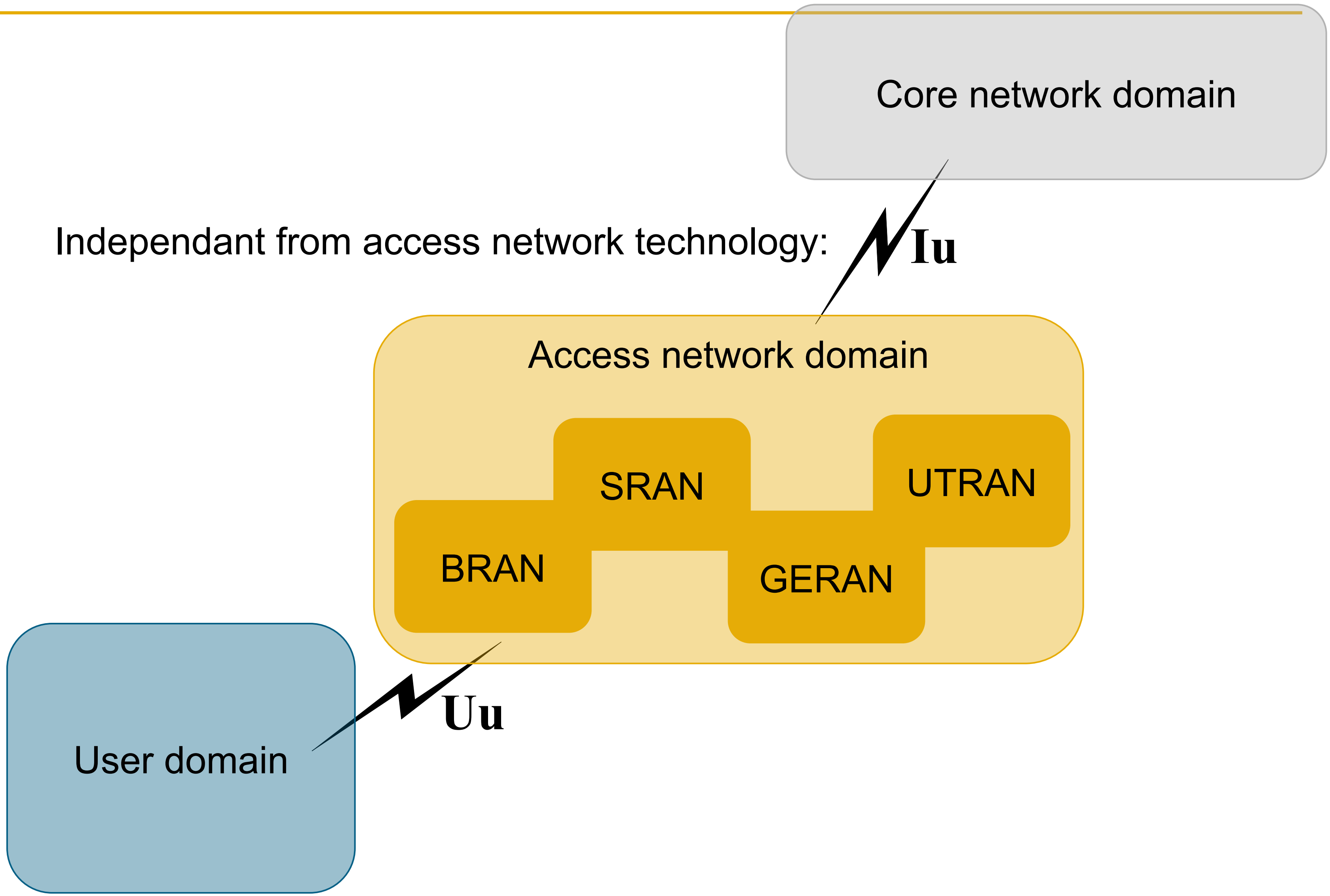
## DOWNLINK



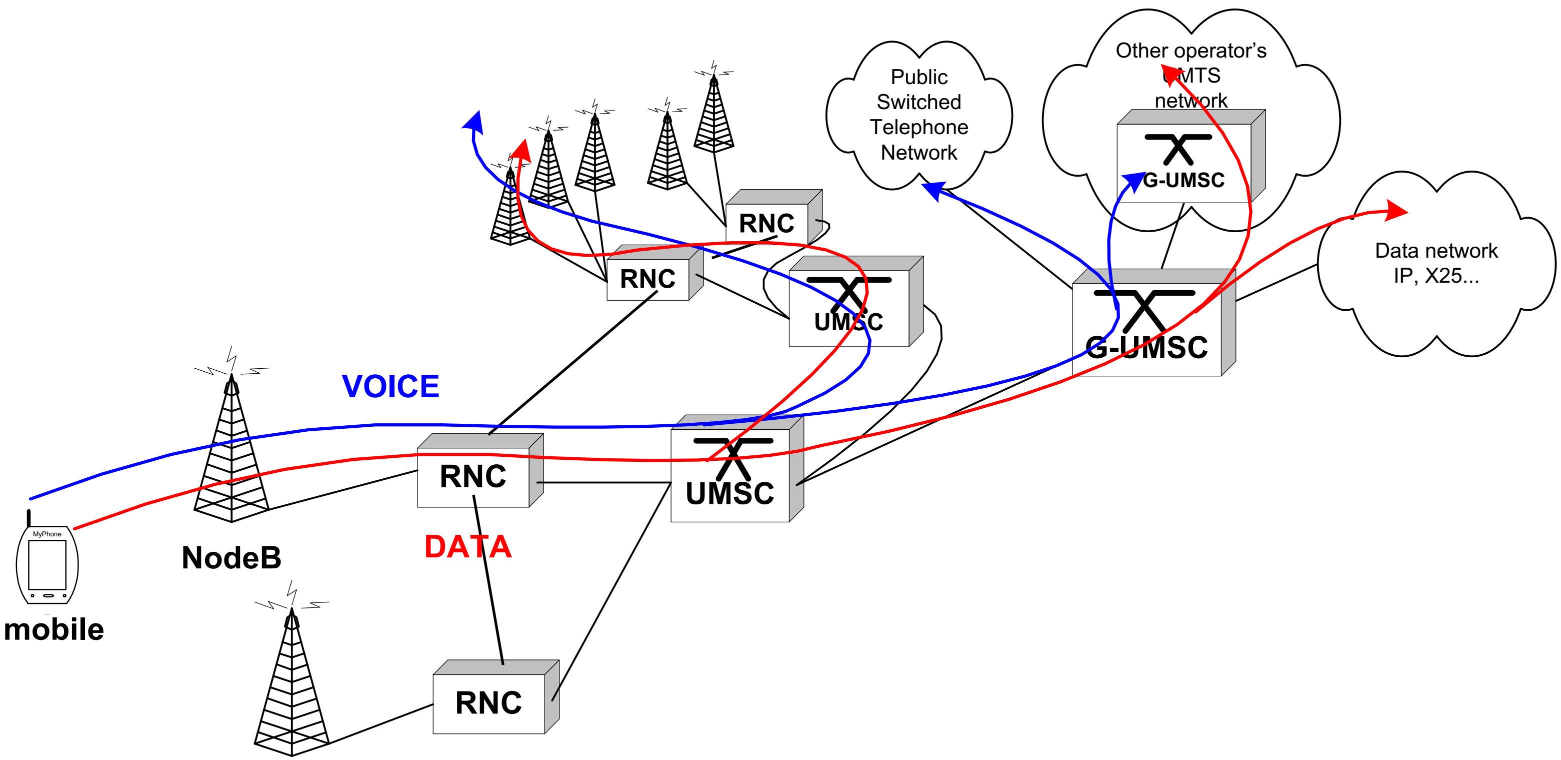

- CS1 ≠ CS2 ≠ CS3
- $CC_{1,1} \perp CC_{1,2} \perp CC_2$

# UMTS Architecture

# UMTS - Architecture



# UMTS - Architecture



# UTRAN - Architecture



- Mobile Station (MS) ⇒ User Equipment (UE)
- BTS ⇒ NodeB
  - Radio resources control ⇒ partial radio resource control
  - Radio link control
- BSC ⇒ Radio Network Controler (RNC)
  - Resources allocation
  - Radio link control
- MSC ⇒ UMSC: UMTS Mobile Switching Center
- BSS ⇒ RNS: Radio Network
- Abis (BTS/BSC) ⇒ Iub (NodeB/RNC)
- A (BSC/MSC) ⇒ Iu (RNC/CN)

# UMTS / GSM-GPRS

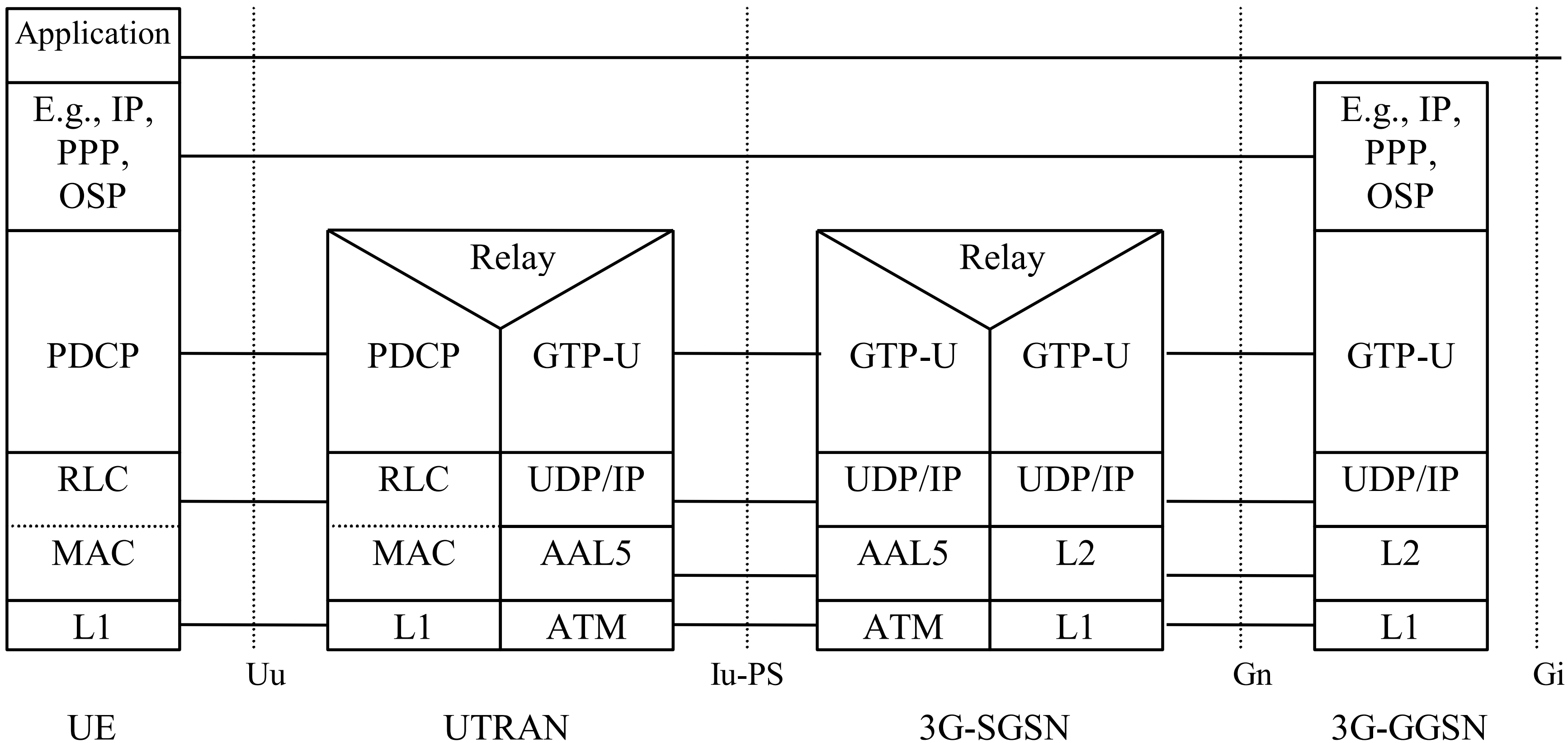
- GSM/GPRS network reuse

- Integrated Core network:
  - MSC/VLR & SGSN $\Rightarrow$ UMSC
  - reducing maintenance

- Combined localisation update (RA,LA)
  - by Gs or UMSC

- Towards « all IP »:
  - Protocols from Telecom world (GSM, GPRS) are replaced by protocols from IP world (IETF)

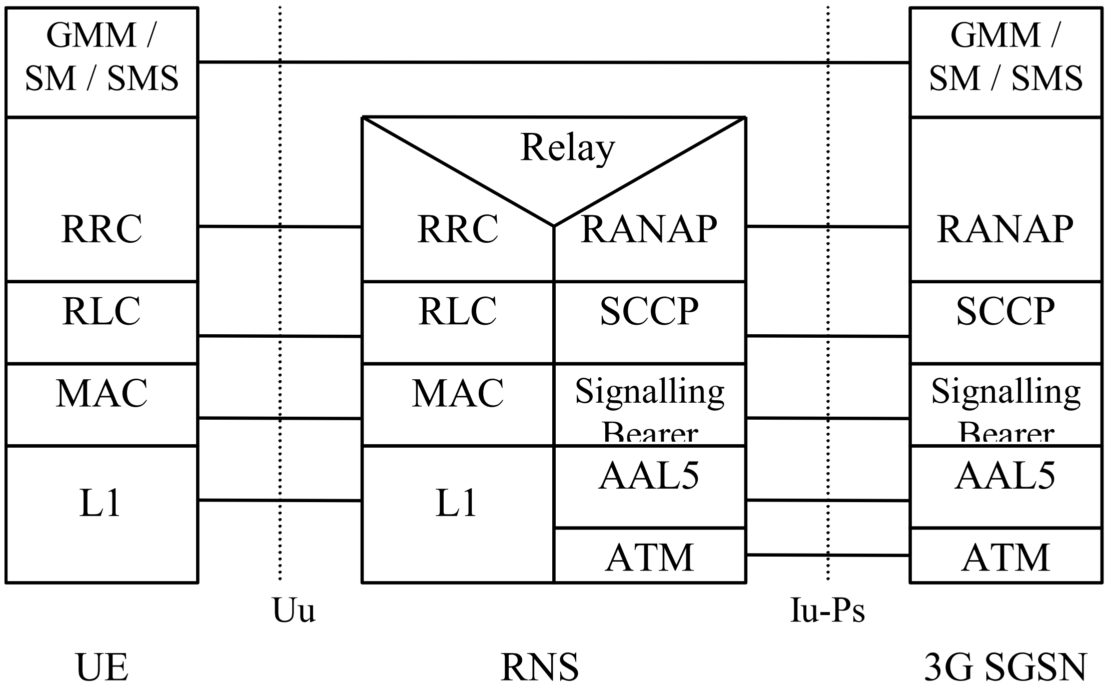
# UMTS Protocols (1/2)




**User Plan (R'99)**

# UMTS Protocols (2/2)

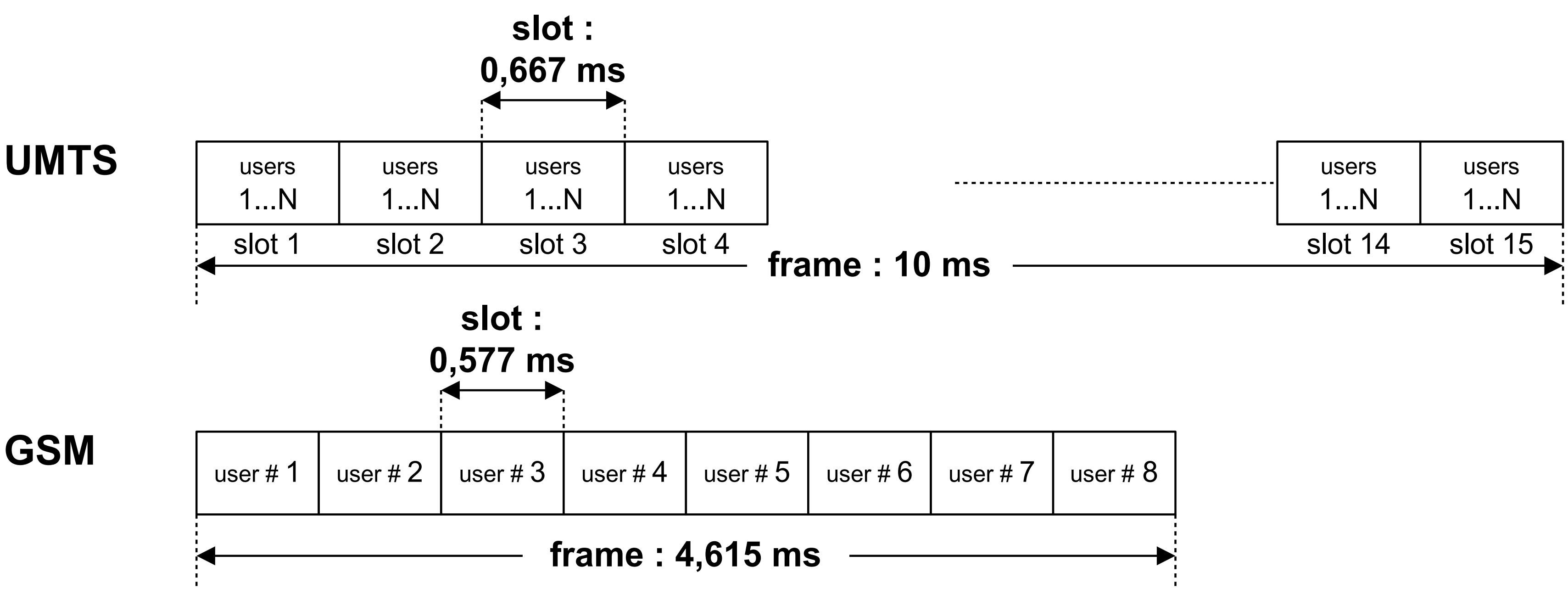




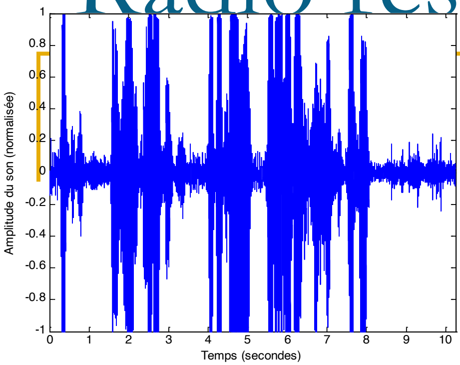

**Control Plan (R'99)**

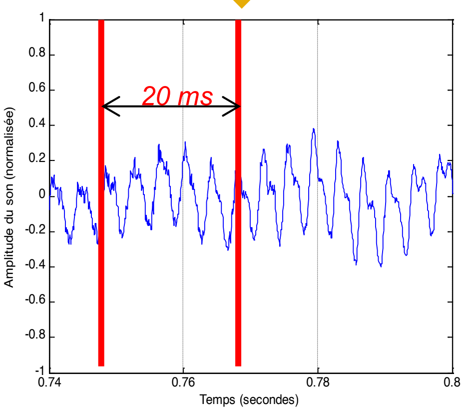
# UTRAN slot structure

- Modulation: QPSK
- in FDD mode:
  - Slot granularity: used for power control
  - 256 (512) flows can be simultaneously transmitted in each slot
  - 2560 (complex) chips per slot
  - 3.84 Mchips/s (complex)



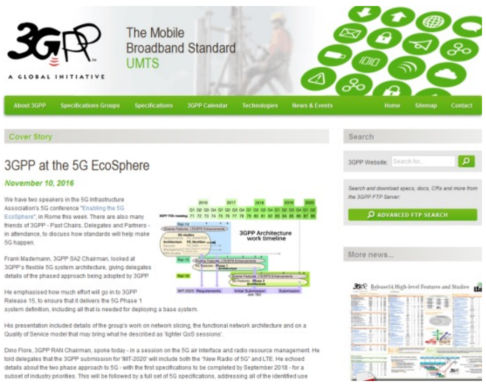
# Radio resources for a communication




codec

≤ 244 bits




compression, adaptation, segmentation,etc

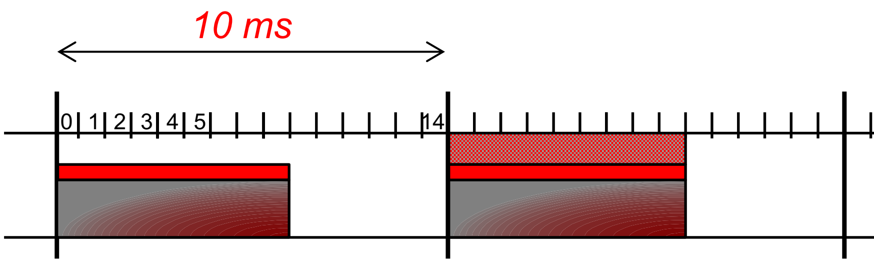
packets

channel coder

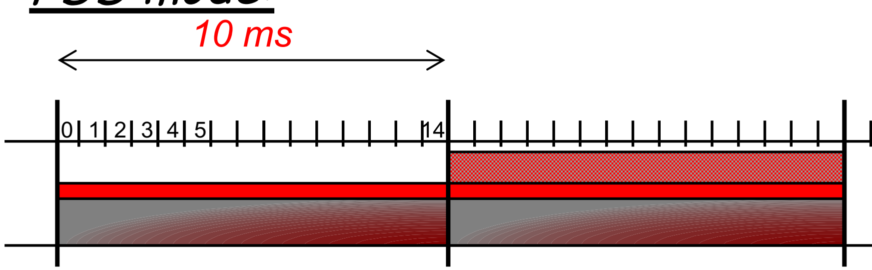
puncturer

interleaver

*TDD mode:*



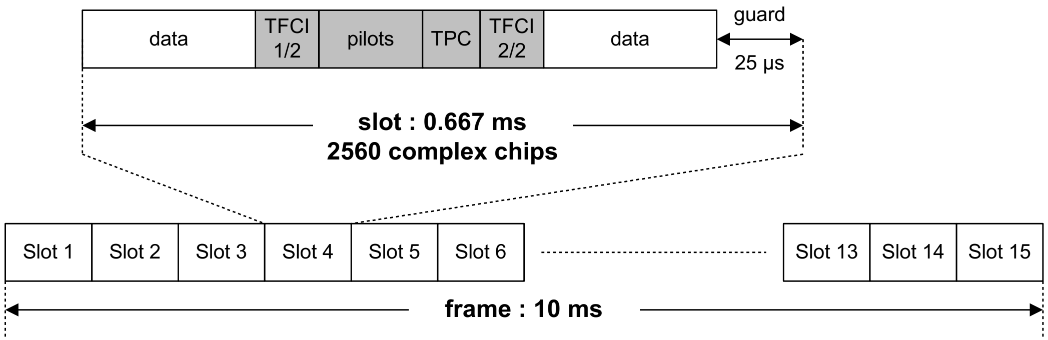

*FDD mode:*



# UMTS – UTRAN : slot structure ex.

**Slot structure for user traffic (dedicated mode):**

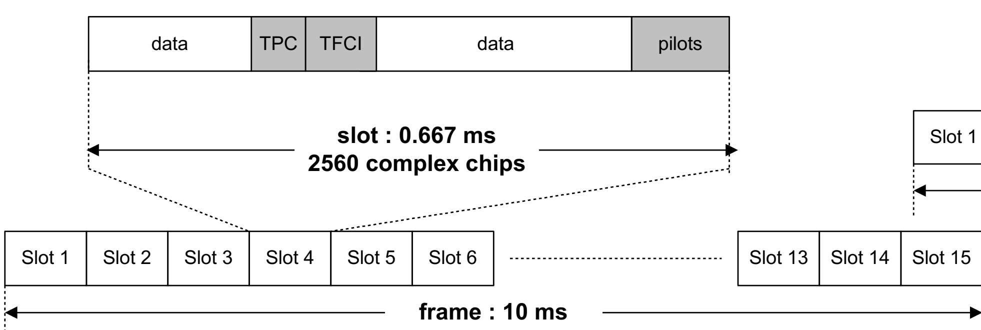
TDD mode:

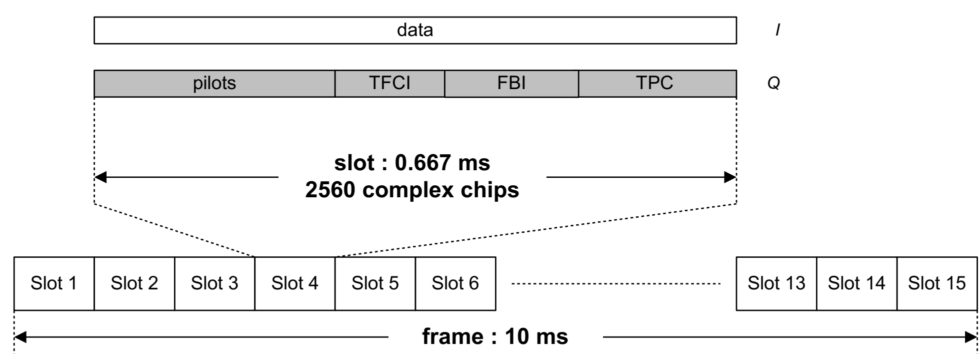



- pilots : training sequence (synchronisation, channel estimation, multipath detection)
- TFCI : data processing (SF, CC, interleaving, etc)
- TPC : power control
- FBI : closed loops feedback (diversity)

FDD mode

downlink




uplink

- Channel mapping in UMTS

# UTRAN – Channels

- Logical Channel:
  - representing the type of transmitted information
  - 2 types:
    - control
    - traffic
- Transport Channel:
  - representing the QoS
  - characterized by « Transport Formats »:
    - size of transmitted blocks, type of coding, interleaving length, spreading factor, etc.
  - 2 types:
    - dedicated
    - shared
- Physical Channel:
  - slot content
    - CC, CS

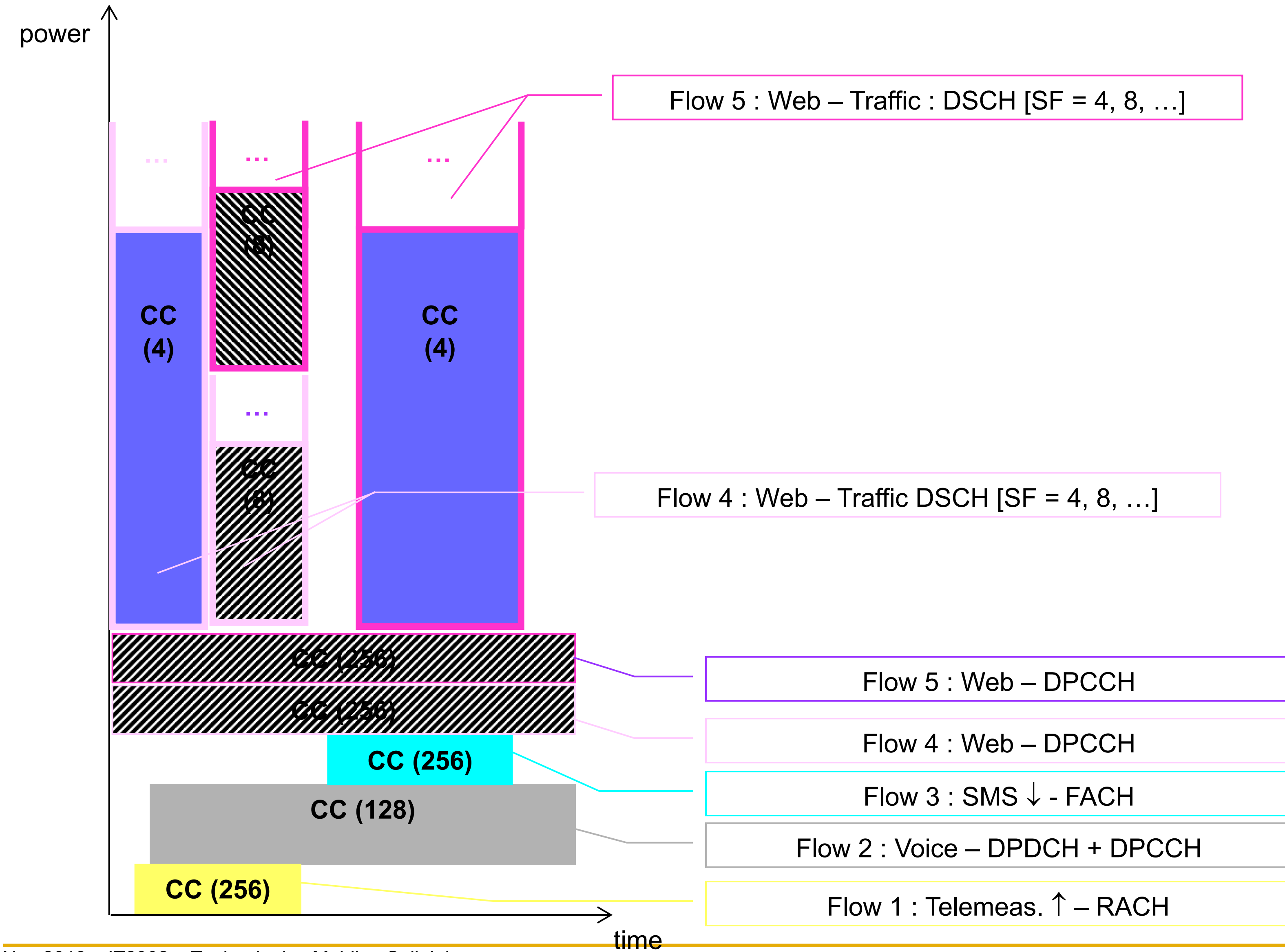
# UTRAN – Channel mapping

| | Physical Channel | Transport Channel | Logical Channel | Function |
|---|---|---|---|---|
| **Dedicated** | DPDCH ↓↑<br>(Dedicated Physical Data CHannel) | DCH ↓↑<br>(Dedicated CHannel) | DTCH ↓↑<br>(Dedicated Traffic CHannel) | User data |
| | | | DCCH ↓↑<br>(Dedicated Control CHannel) | User Signalling (HO, radio measurements, etc) |
| | DPCCH ↓↑<br>(Dedicated Physical Control CHannel) | | | DPDCH control |
| **Common** | PRACH ↑<br>(Physical Random Access CHannel) | RACH ↑<br>(Random Access CHannel) | | Initial random acces (= GSM RACH) |
| | | | DTCH ↑, DCCH ↑ | Occasional |
| | | | CCCH ↑<br>(Common Control CHannel) | Dedicated link establishment |
| | PDSCH ↓<br>(Physical Downlink Shared CHannel) | DSCH ↓<br>(Downlink Shared CHannel) | DTCH ↓↑ | Bursty transmissions (each channel requires a low rate DPCCH ↓↑) |
| | P-CCPCH ↓<br>(Primary Common Control Physical CHannel) | BCH ↓<br>(Broadcast CHannel) | BCCH ↓<br>(Broadcast Control CHannel) | System info broadcasting |
| | S-CCPCH ↓<br>(Secondary Common Control Physical CHannel) | PCH ↓<br>(Paging CHannel) | PCCH ↓<br>(Paging Control CHannel) | Paging |
| | (*associated*: Paging Indicator CHannel ↓) | FACH ↓<br>(Forward Access CHannel) | CTCH ↓<br>(Common Traffic CHannel) | Cell broadcasting news |
| | | | CCCH ↓ | Dedicated link establishment |
| | | | DTCH ↓, DCCH ↓ | Occasional |
| | AICH ↓<br>(Acquisition Indicator CHannel) | | | Answer to PRACH (= GSM AGCH) |
| | (P- & S-)SCH ↓<br>(Primary- & Secondary- Synchronisation CHannel) | | | Synchronization (= GSM SCH) |
| | CPICH ↓<br>(Common Pilot CHannel) | | | Cell Identification, Cell Pilots |

# UMTS – Channel mapping

- Example of 'mapping' :
  a DTCH can be used:
  - in circuit mode: radio resource allocated for all the communication
    - voice
    - transport channel DCH
  - in packet mode with mobile identification : radio resource shared with other users during all the connection (Web session )
    - high rate
      - transport channel DSCH
    - 'low' rate
      - transport channel FACH/RACH [with collision]

# UMTS – Channel mapping ex.



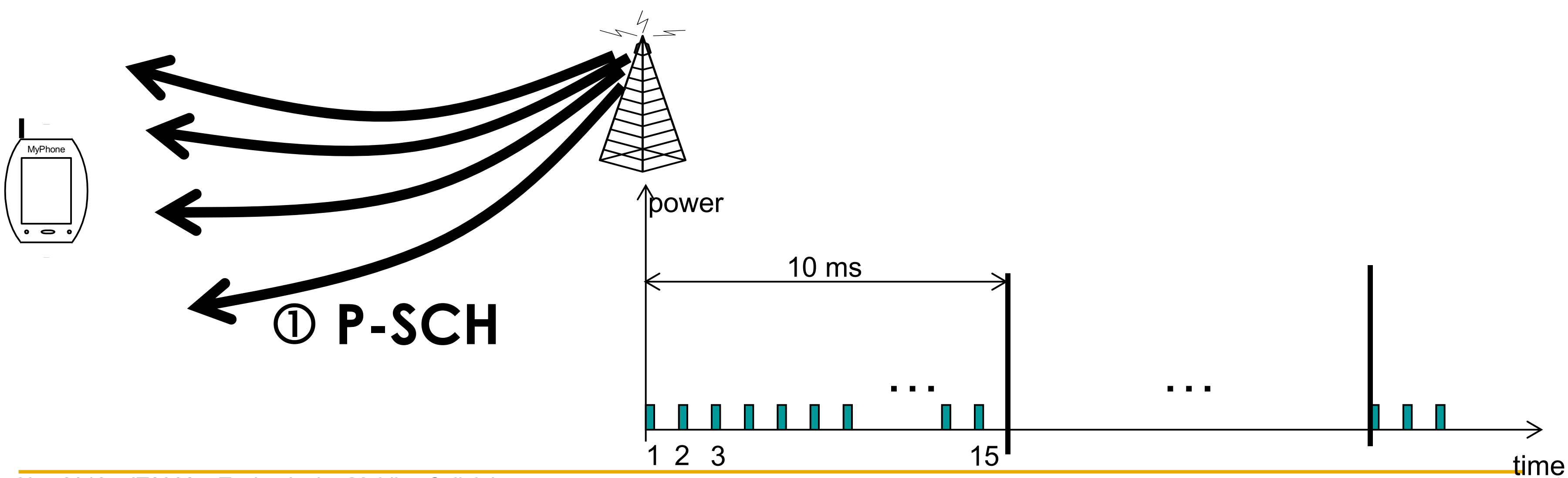
# UMTS – mobile switch-on

① P-SCH : Primary Synchronisation Channel

- in each slot, 256 identical pre-defined bits,
- sames for all NodesB.

→ the mobile:

- monitors UMTS frequencies
- detects correlation peaks (issued from all nearby NodesB)
  - NodesB detection
  - synchronization (slot level)



# UMTS – mobile switch-on

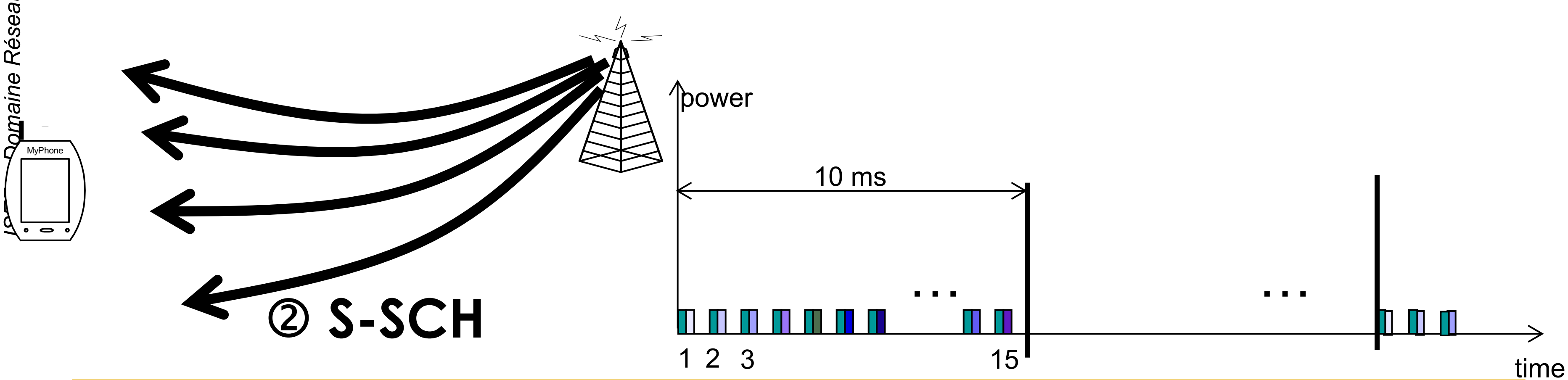
② S-SCH : Secondary Synchronization Channel in UMTS

- in each frame, a 15 x 256 pre-defined bit sequence.
- 64 different sequence-patterns are normalized.

→ the mobile:

- associates to each correlation peak one of the 64 possible sequences
- identifies the frame start
- separates the NodeBs
- selects the higher peak ('serving' cell)





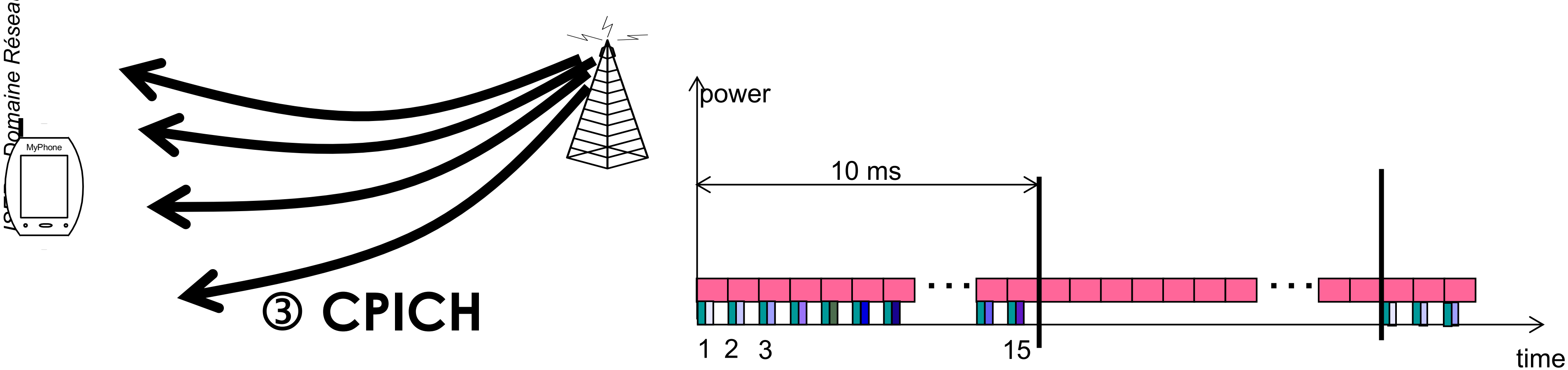
# UMTS – mobile switch-on

③ CPICH : Common Pilot Channel

- in each slot, a 20 bit-pre-defined sequence, SF=256,
- scrambled by the NodeB,
- each S-SCH sequence is associated with 8 possible CS.

→ the mobile:

- identifies its 'serving' cell CS



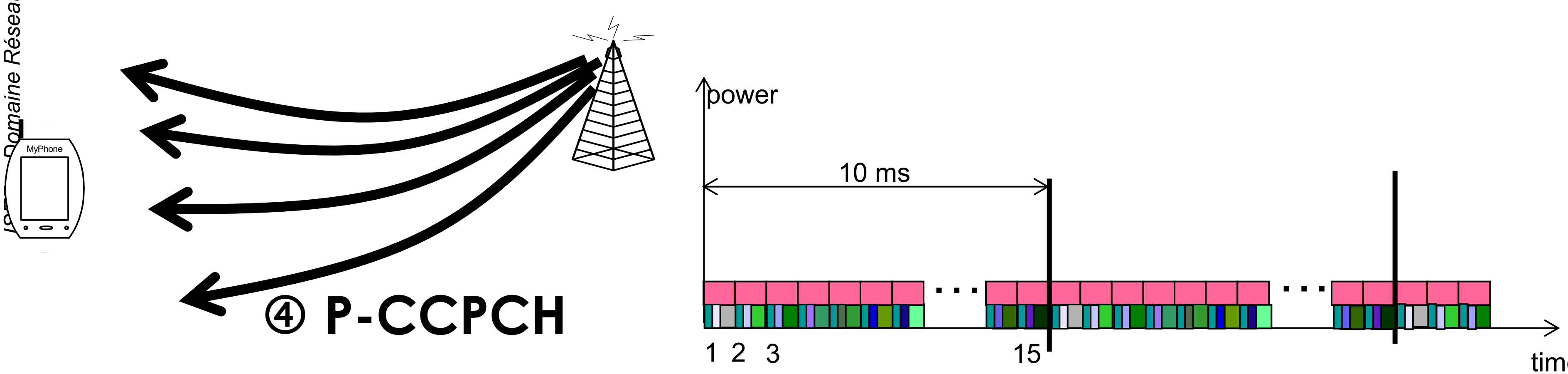
# UMTS – mobile switch-on

④ P-CCPCH: System Information

- spread by a pre-defined CC (SF=256),
- scrambled by the NodeB CS,
- following P-SCH and S-SCH in the burst (i.e. 18 bits /slot)

→ the mobile:

- knows its serving cell's physical channels organization (Paging Indicator Channel PICH, PCH, FACH)



# UMTS – mobile switch-on

⑤ Idle mode on the serving cell's CPICH:

- Radio measurements:
  - CPICH Received Signal Code Power : received power level on CPICH
  - UTRA carrier Received Signal Strength Indicator : received power level on UTRA carrier
  - CPICH $Ec/N_0$ : interference level on CPICH (= CPICH RSCP ÷ UTRA Carrier RSSI)
  - etc
- LU (by PRACH and S-CCPCH)
- neighboring cells' CPICH monitoring
- PCH listening (PICH)

# UMTS – Incoming call

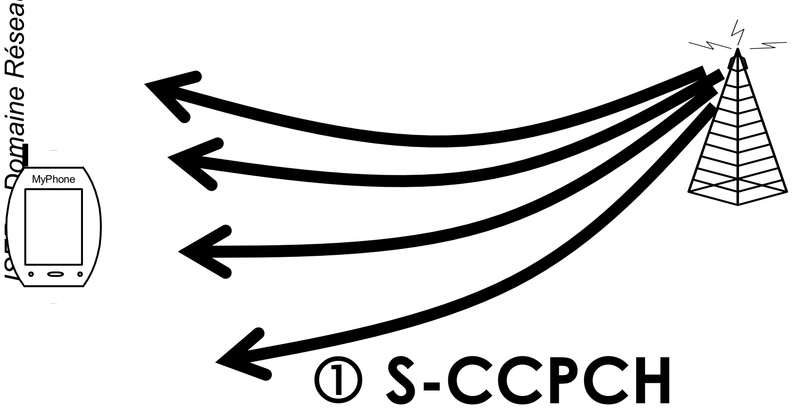
① The mobile is on idle mode on the serving cell's PICH:

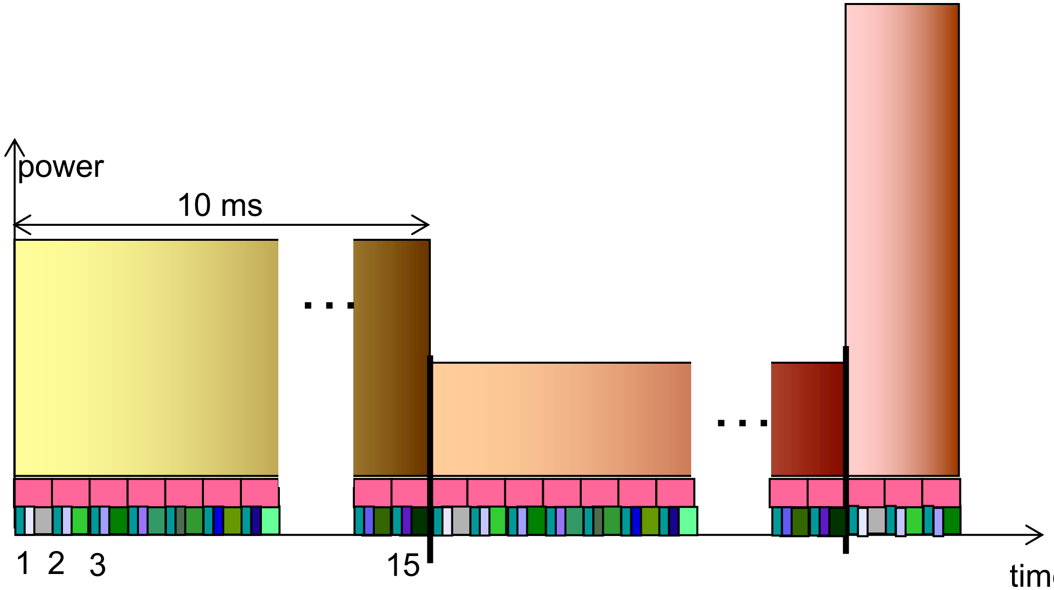
- Depending on their identity, the mobiles are divided into groups.
- Each group scans the S-CCPCH physical sub-channel PICH.
- The PICH indicates whether or not the mobiles should decode the PCH

⇒ mobile battery life increase

- S-CCPCH SF: 4 to 256 depending on the cell load (PCH rate increases with cell load)





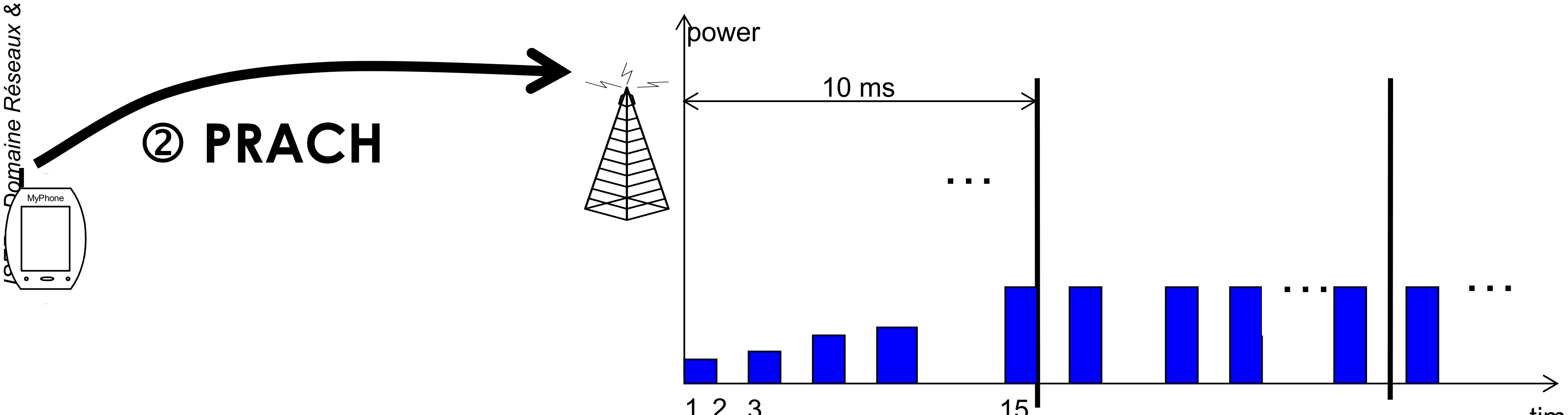



# UMTS – Incoming call

② The mobile attempts to access on PRACH:

TA estimation

1. selects 1 preambule (among 16) ⇒ 4096 symboles (≤ 5120)
2. transmits the preambule at low power (the power level is set from CPICH measurements)
3. Ramping process: the preambule is re-transmitted at increased power until the mobile receives a network ack

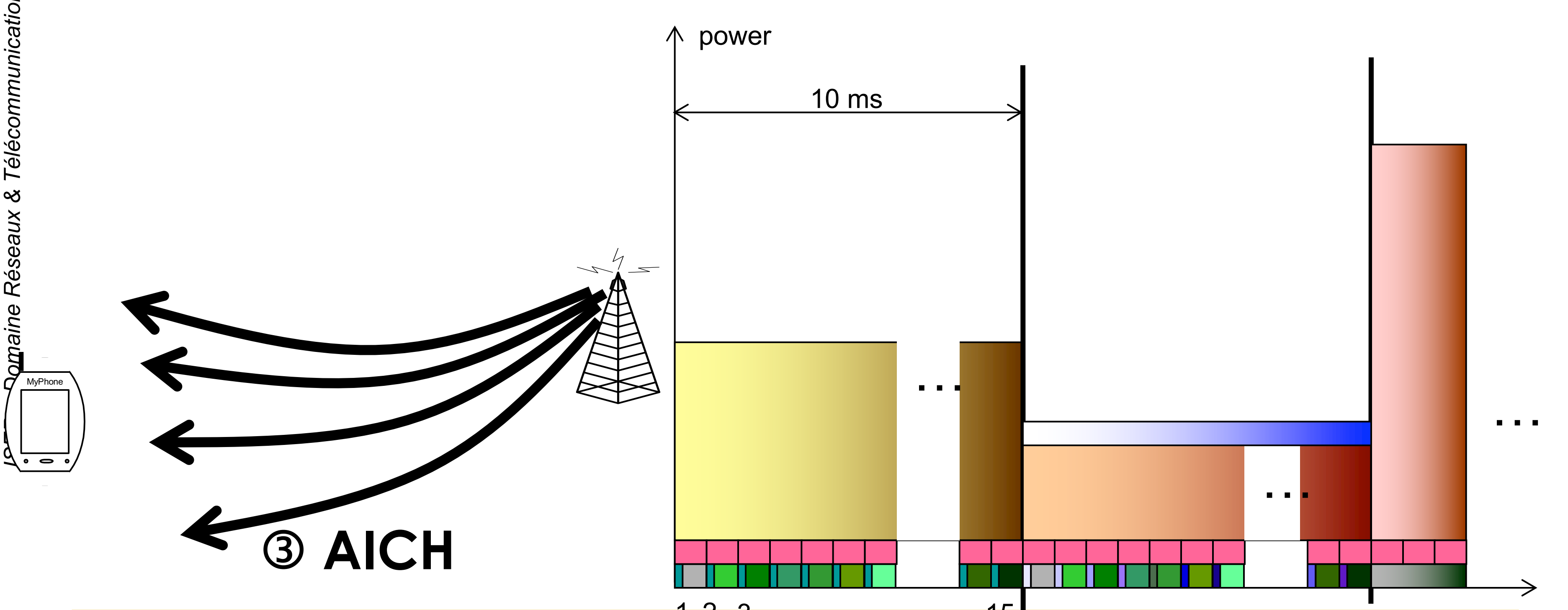


# UMTS – Incoming call

③ The network answers on AICH :

The network indicates, for each preambule, if it was correctly received or not.

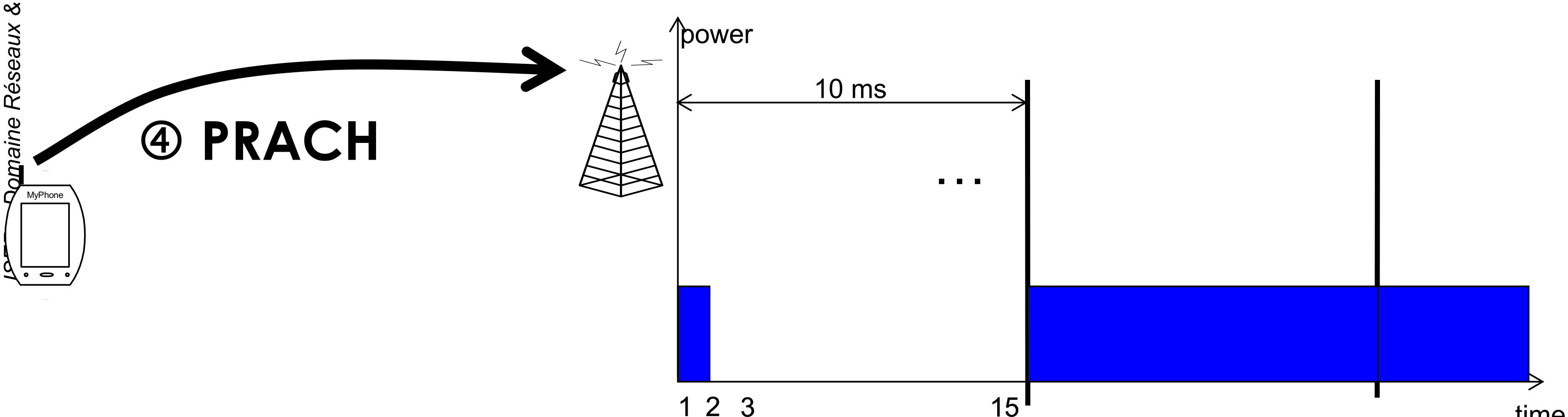
- AICH SF: 256



# UMTS – Incoming call

④ The mobile transfers its access message on PRACH :

- 1 message = 1 10 ms-frame
- message contents : ≤ 150 'useful' bytes (SF ≥ 32) + pilots + TFCI
- Repeated on the following 10 ms-frame



# UMTS – Incoming call

⑤ CCCH ↓↑ on S-CCPCH & PRACH:

Signalisation for dedicated link establishment:

- authentication
- ciphering
- DTCH channel allocation

⑥ DTCH ↓↑ on DPDCH (/ PDSCH/ PRACH/ S-CCPCH) :

Communication

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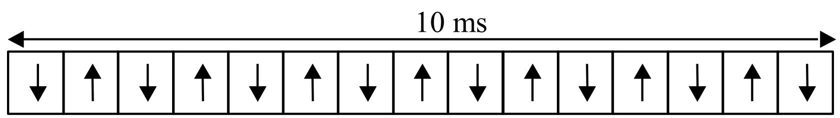
- UTRAN physical layer

# UTRAN: physical layer

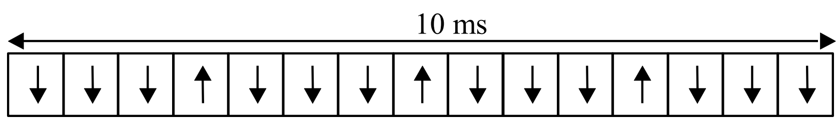
| | FDD | TDD |
|---|---|---|
| **Multiple access** | W-CDMA | TD-CDMA |
| **DL-UL duplexing** | FDD | TDD |
| **Spreading factor** | 256 (512) -4 | 16-1 |
| **Handover** | Soft | Hard |
| **Chip frequency** | 3,84 Mchips/s | |
| **Frame structure** | 15 slots per 10 ms frame | |
| **Pulse shape filter** | Raised cosinus, roll-off 0,22 | |
| **Carriers spacing** | 5 MHz | |
| **Frame** | 10 ms, 15 slots, 2 560 symbols/slot | |
| **Modulation** | QPSK | |
| **Coding** | Uncoded, convolutional, turbo | |
| **Interleaving** | 10, 20, 40 or 80 ms | |

# UTRAN: TDD mode (1/)

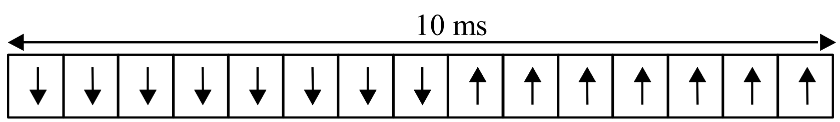
- 16 (8) flows can be simultaneously transmitted in each slot
- examples of frame configuration:



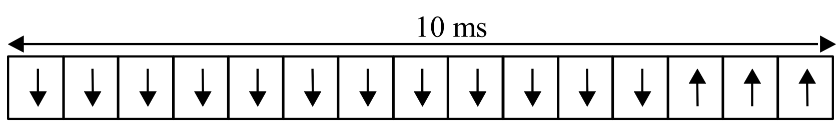

**Multiple-switching-point configuration (symmetric DL/UL allocation)**




**Multiple-switching-point configuration (asymmetric DL/UL allocation)**




**Single-switching-point configuration (symmetric DL/UL allocation)**

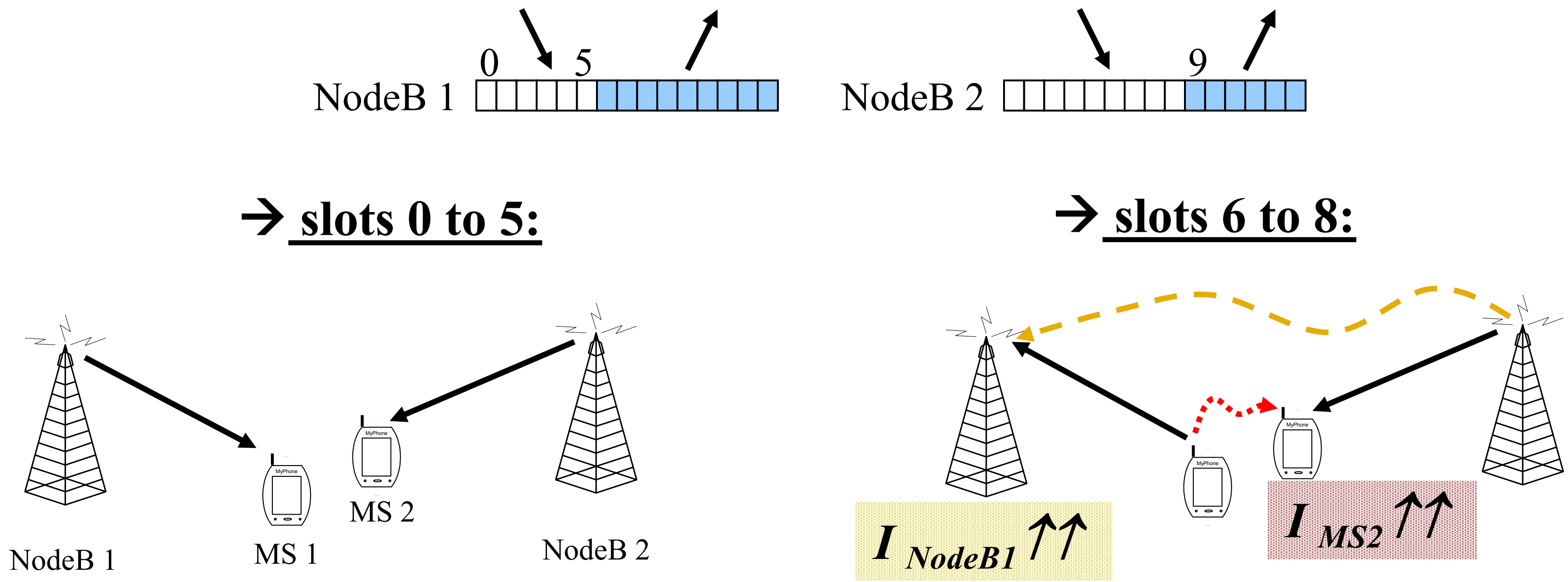



**Single-switching-point configuration (asymmetric DL/UL allocation)**

# UTRAN: TDD mode (2/)

To avoid mobile-to-mobile and NodeB-to-NodeB interferences, NodesB must be synchronized and the switching point must be the same in all the network.

<u>Interference example:</u>




Worst case: mobile at the border of the cell:

MS1 transmits at $p_{max}$ to fight against poor channel gain

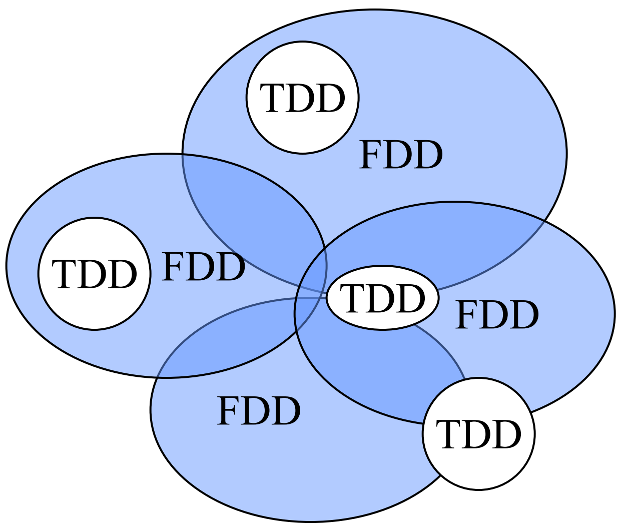
# UTRAN: TDD mode (3/)

- Identical switching point
  - flexibility loss in assymetry between uplink & downlink

- Non identical switching point
  - different frequency band from one cell to another (~impossible)

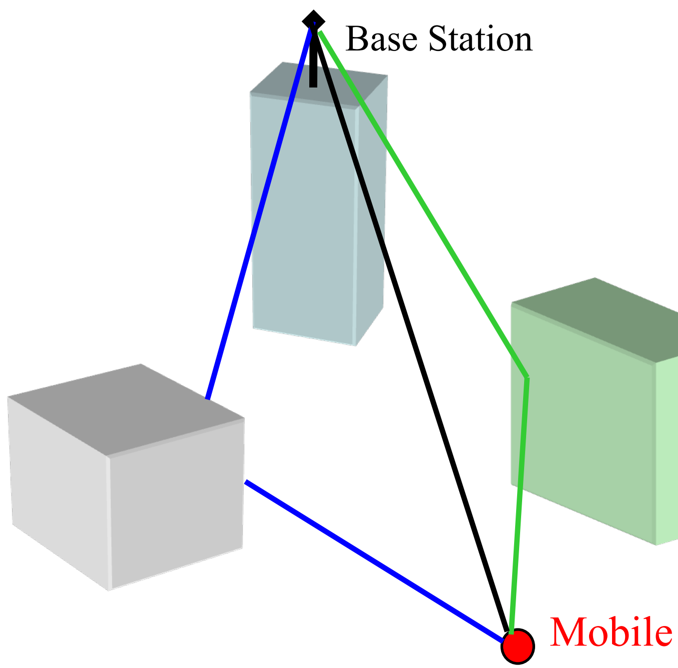
and/or

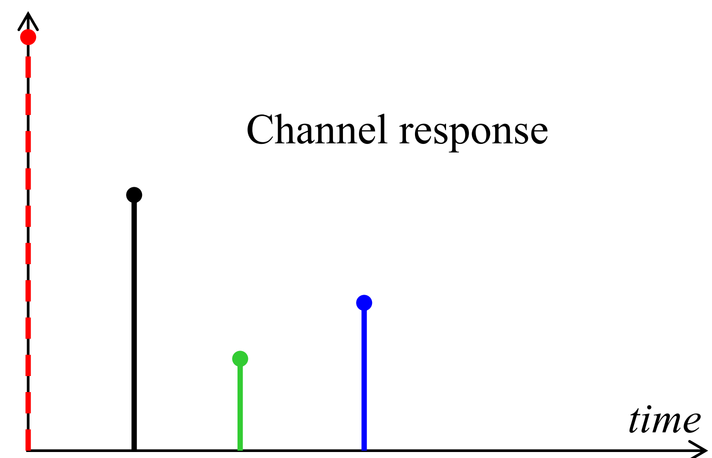
  - hot spots:



# Rake receiver

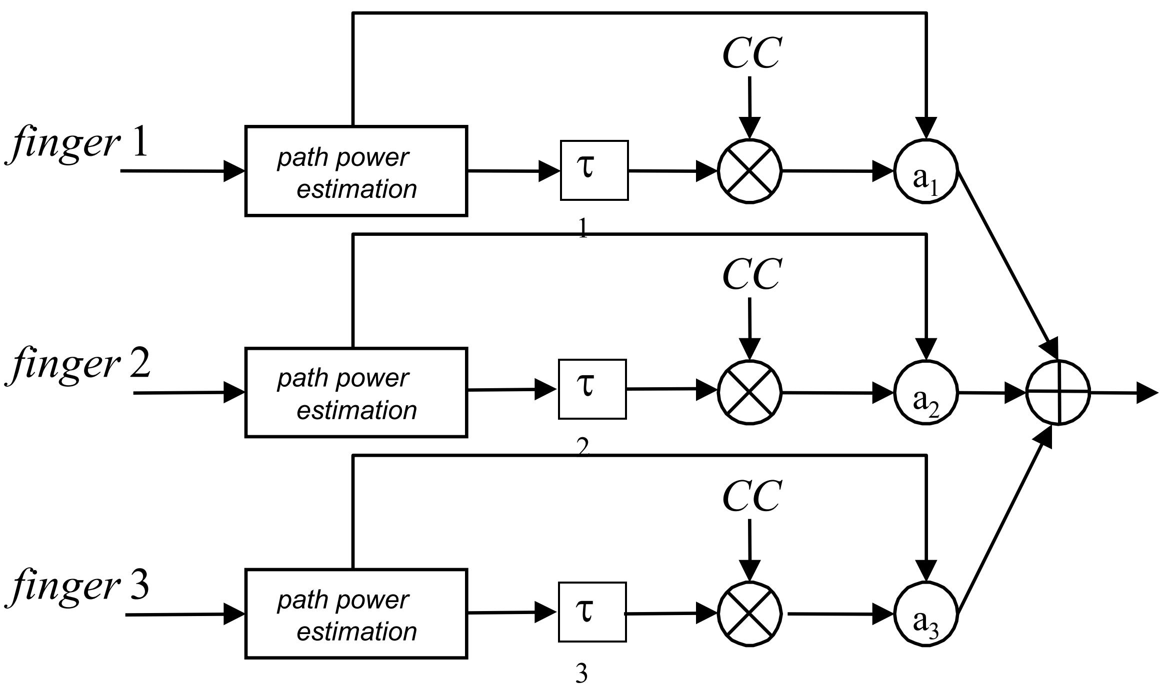




# Rake receiver

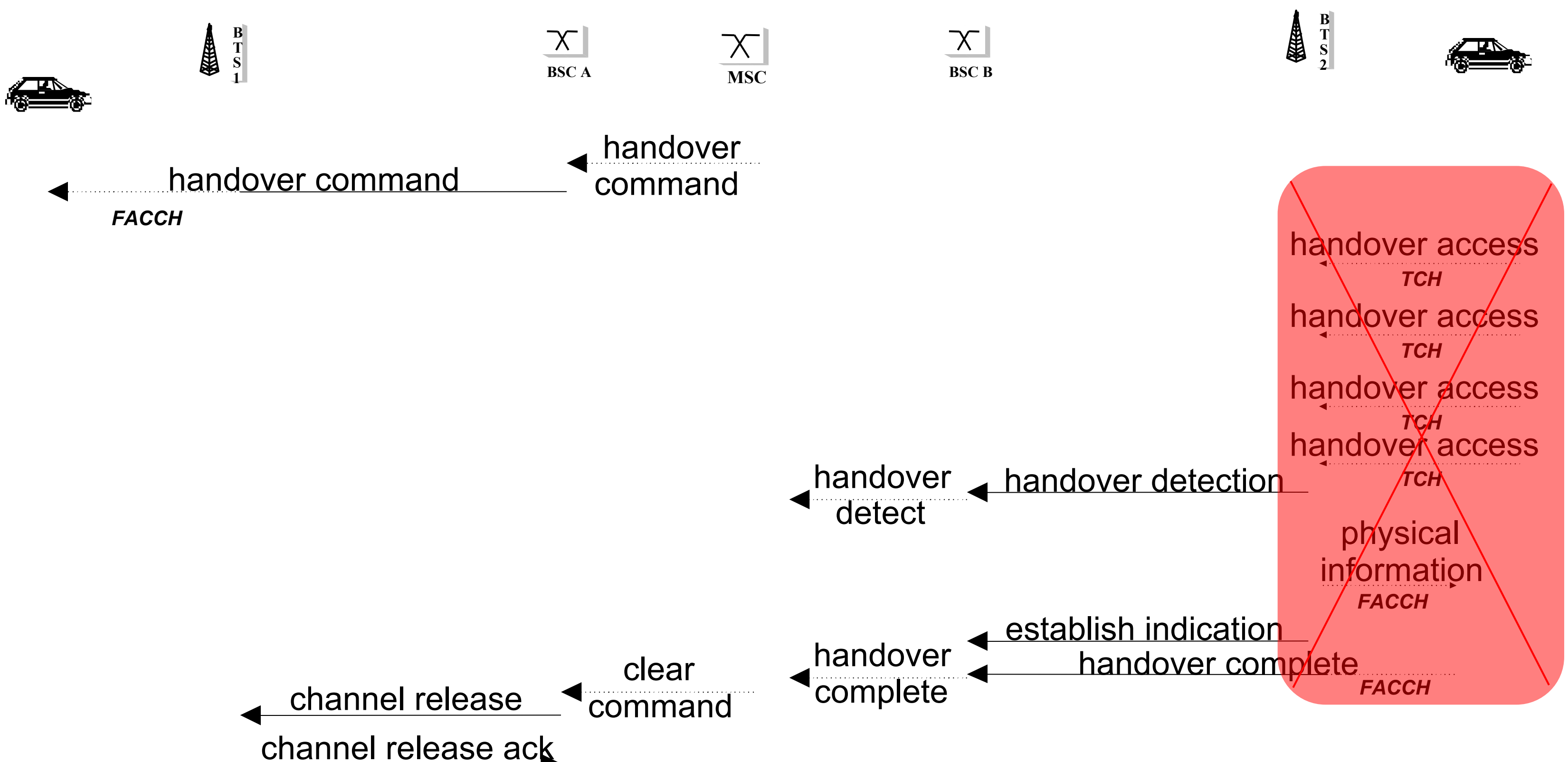
- Optimal receiver, recovering all replicas created by multipaths
  - known spreading code
  - delay line + correlation
  - channel intensity estimation
    - path power



# Handover in UMTS

# Hard handover in GSM

- Mobile is connected with a single one BTS.
- Channel switching
  - interrupted transmission (less disturbing for phony services)

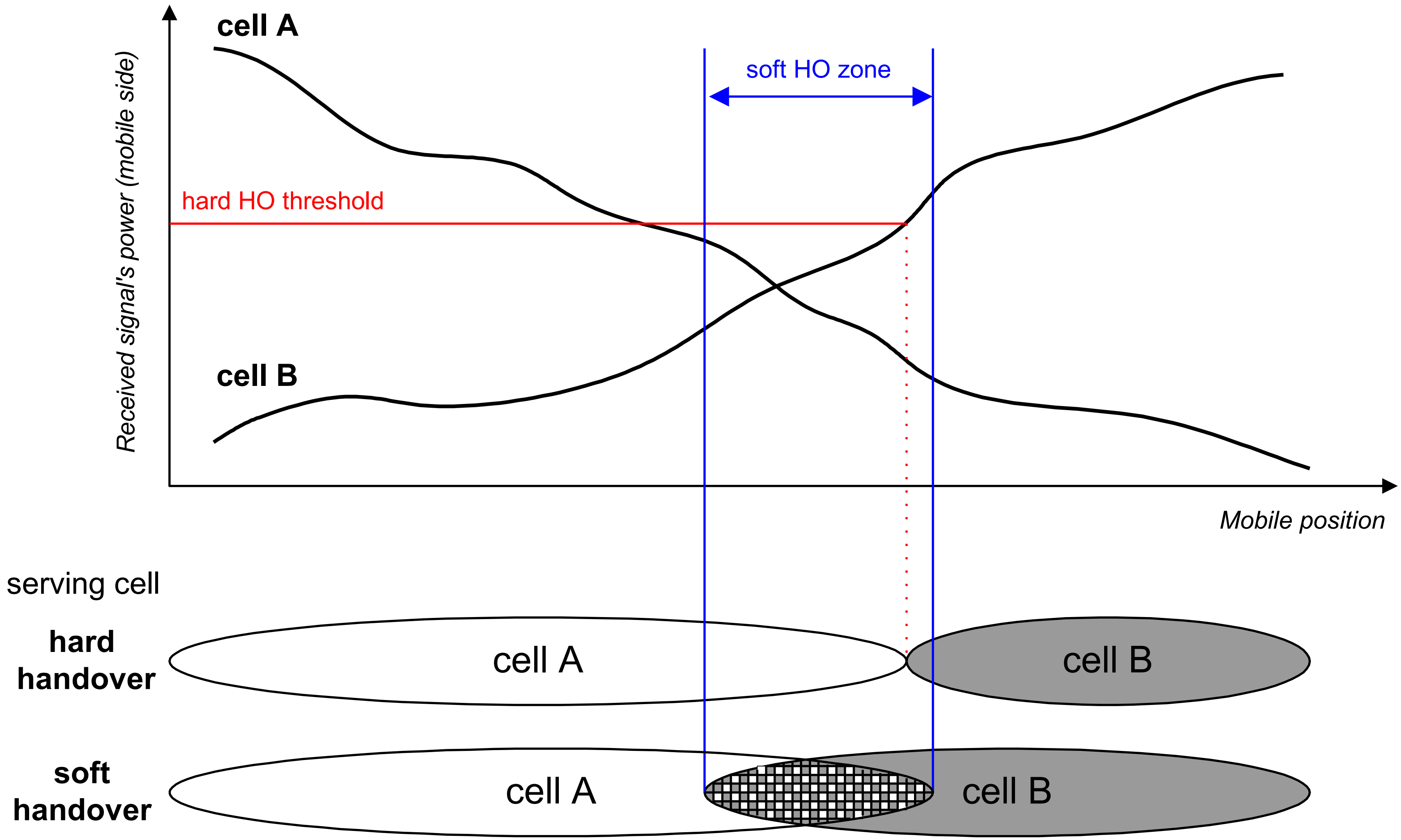


# Hard handover / Soft handover

- Data services
  - one or more RLC/MAC block(s) can be lost during the transmission's interruption
  - block(s) retransmitted by RLC protocol

- Soft HO:
  - The mobile is simultaneously connected with more than one base station
    - it receives the same information from the different base stations
    - when channel switching on one base station: no interrupted transmission

# Soft Handover

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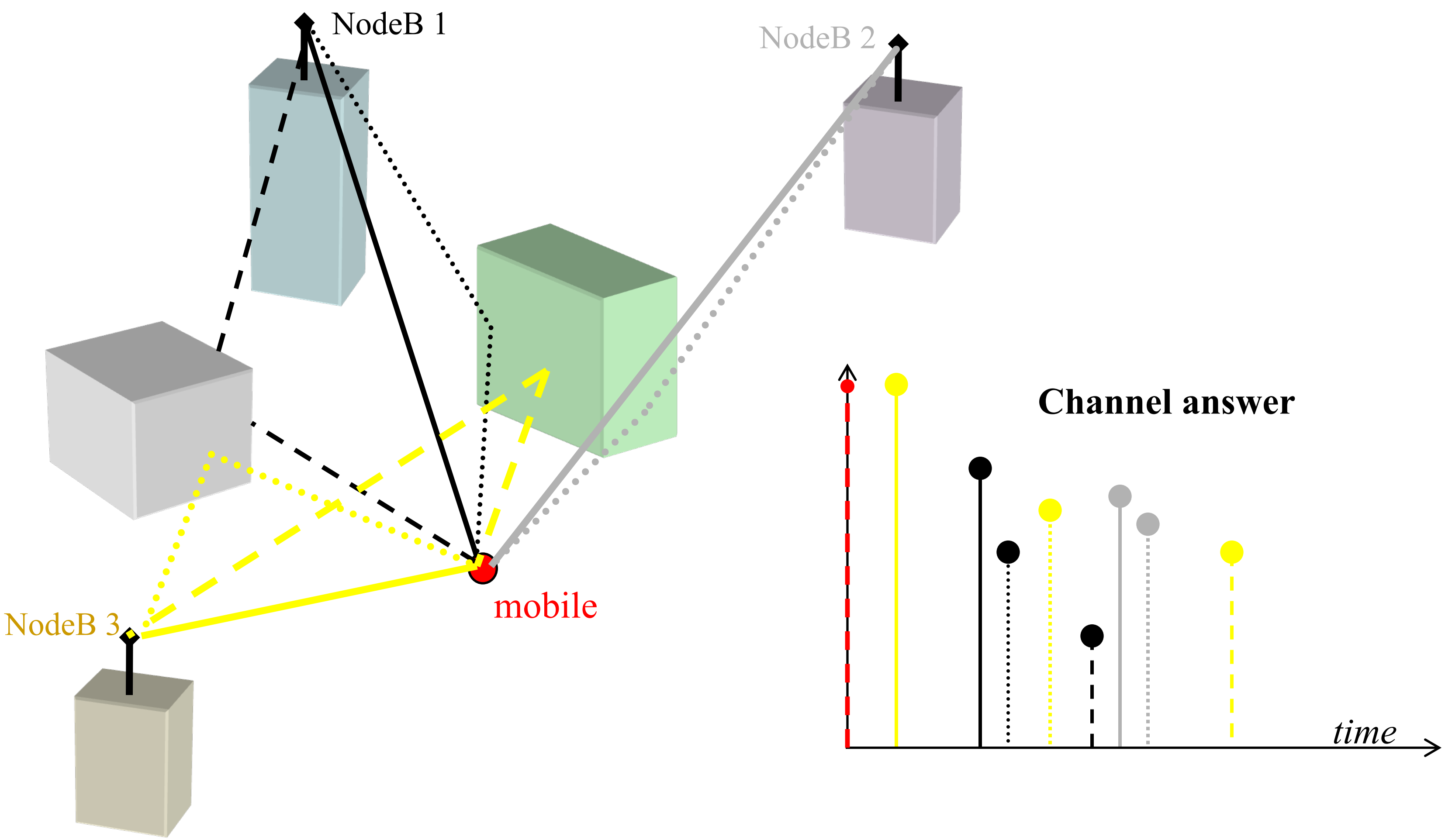
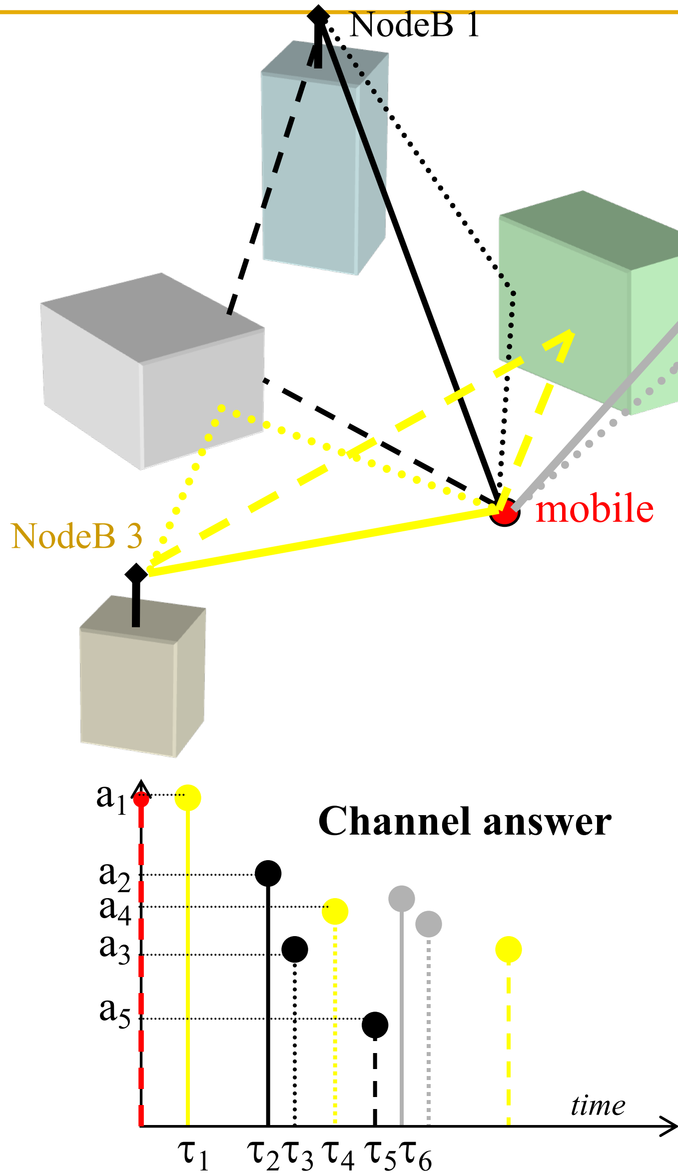
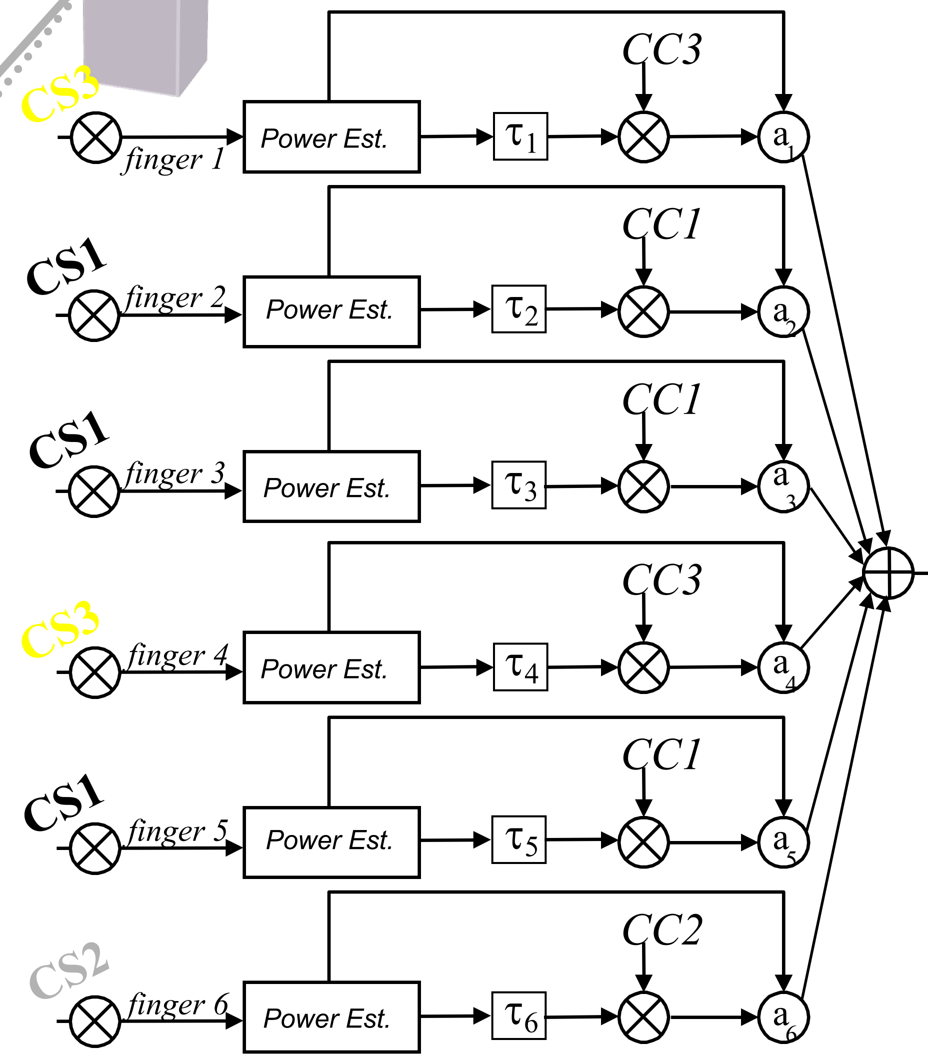
# Soft Handover in UMTS/FDD

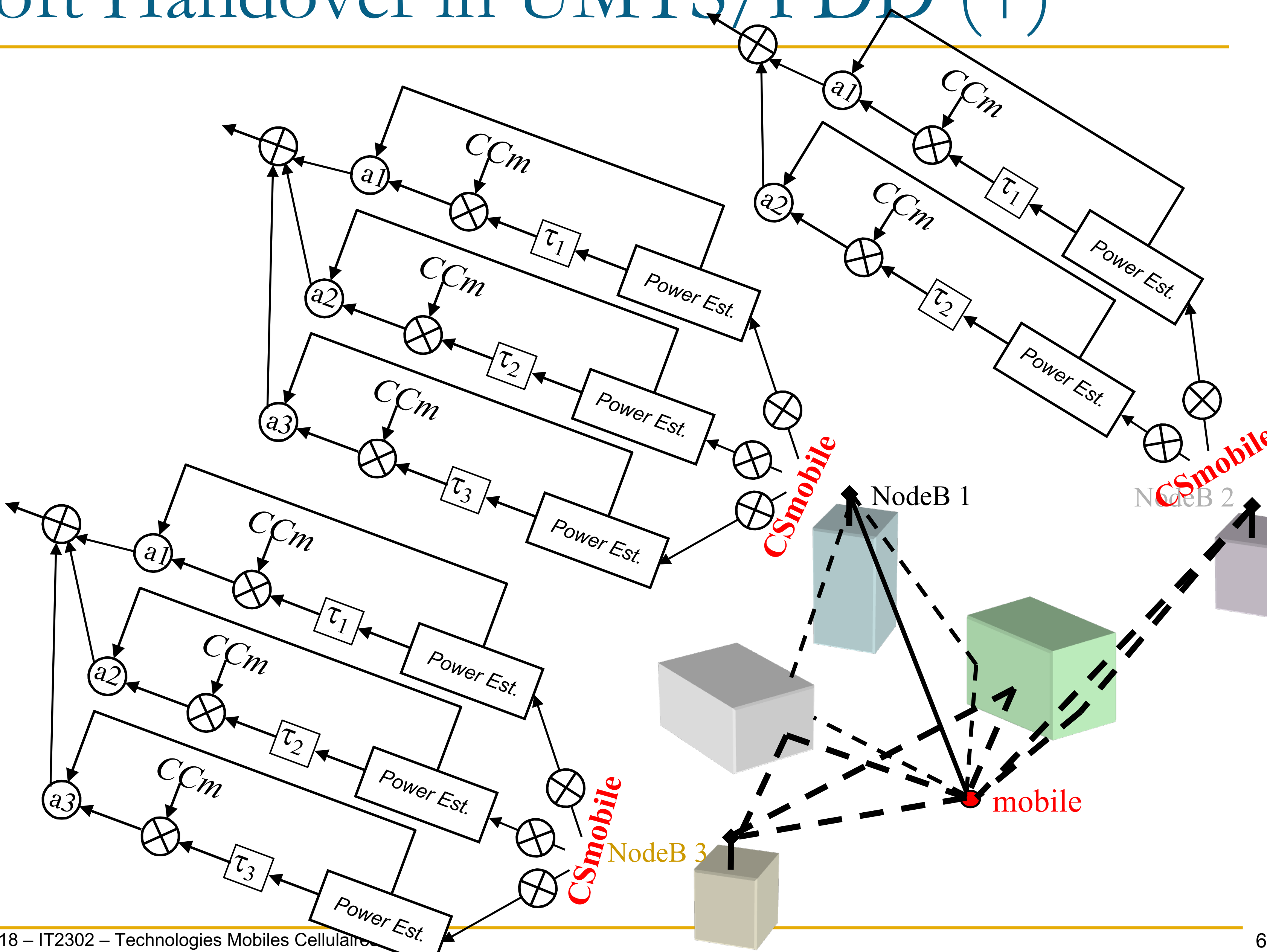


# Soft Handover in UMTS/FDD (↓)



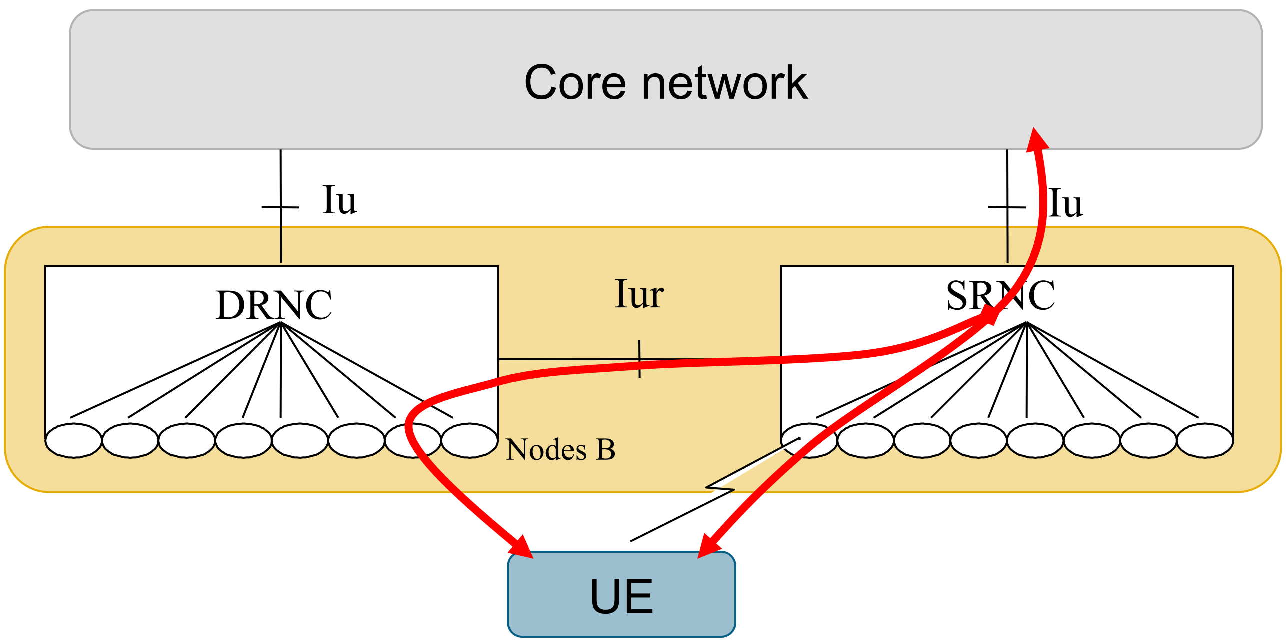
# Soft Handover in UMTS/FDD (↑)



# Soft Handover in FDD: RNC role

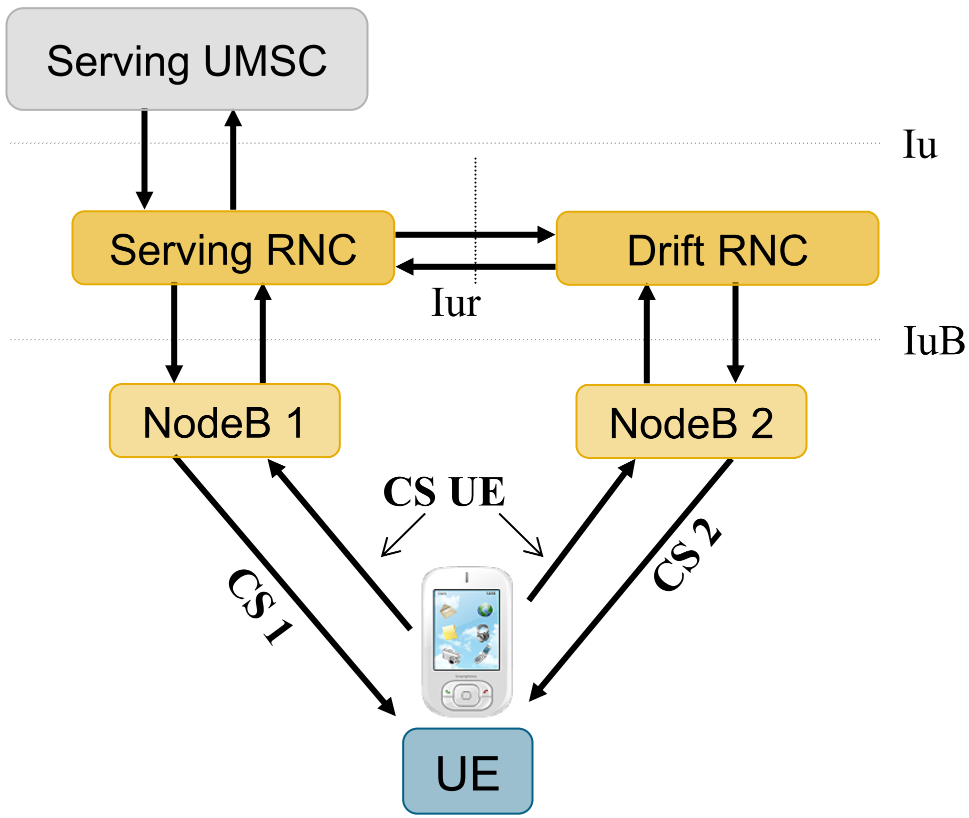
- Serving RNC purpose:
  - mobile connected to Core network
  - multipath combination (↑)

- Drift RNC purpose:
  - supplementary radio resources allocated to the mobile



# Soft Handover in UMTS/FDD (↓↑)

- downlink ↓ :
  - RAKE for each flow of data: {1 CS, 1 CC} per NodeB involved in the soft HO
  - multipath combination in the mobile
- uplink ↑ :
  - Probability {CSmobile already used in the other cells involved in the soft HO} ~0
  - multipath combination in the S-RNC



# Soft Handover in UMTS/TDD

Theoritically possible, BUT :

- FDD constraints must be respected (CC & CS)
- slot capacity limitation ↓↑:
  - only 8 flows (≠FDD : ∞ si CC ⊥)
  - the same slot must be used in all the cells involved in soft HO…
  
  ⇔ same switching point ↓↑ in all the network...
- downlink ↓: high precision for:
  - NodesB synchronization
  - ‘multi-users’ TA management for each NodeB
  - Timing Advance management by Serving-RNC (combination)
  
  ⇔ all information coming from the NodesB involved in the soft HO reach the mobile in the appropriate slot
- uplink ↑:
  - Timing Advance management, for each NodeB, by the mobile… or:
  - Information transmitted independently to each NodeB
  
  ⇔ all information coming from the mobile reach the NodesB involved in the soft HO in the appropriate slot

**NO SOFT HANDOVER in UMTS/TDD**

# Hard Handover in UMTS

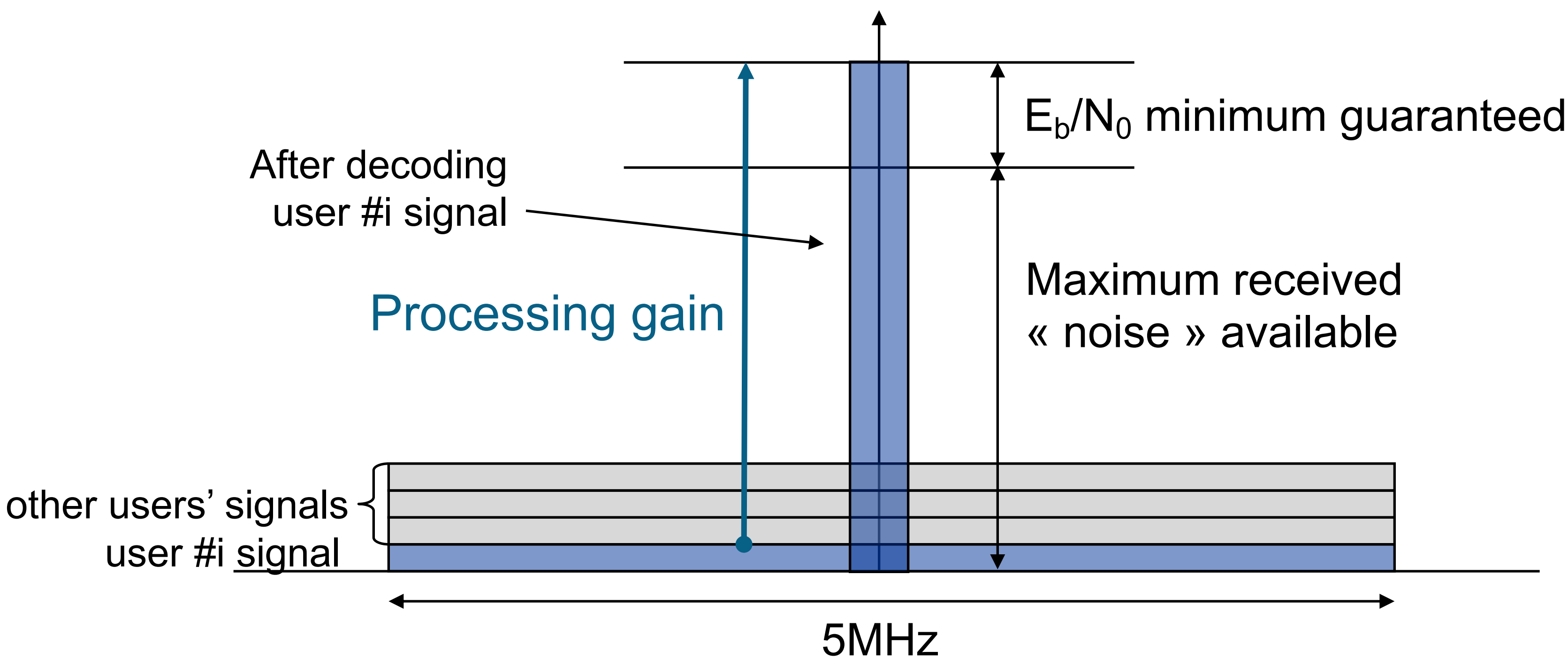
- Hard Handover is still necessary in UMTS:
  - for TDD mode
  - for inter-frequency handovers
    - macro / micro
  - for inter-systems handovers
    - UMTS (TDD) / GSM

- Power control for UMTS

# Spectral occupancy

- symbol rate = 3.84 Msymboles/s (QPSK)
- roll-off factor = 0.22

$\Rightarrow$ Bandwidth < 5 MHz



# Power control (1/)



- Without mobiles transmission power control:
  - signal received, at the base station level, from a mobile situated in the centre of the cell
    >>
    signal received, at the base station level, from a mobile at the border of the cell
- The ‘far’ signal is shadowed by the ‘near’ signal: ‘near-far effect’.

**All the signals must reach the NodeB with the same power, independently of their situation in the cell:**
**UPLINK POWER CONTROL**

# Power control (2/)

- On the downlink, (intra-cellular) interferences are less critical: all signals transmitted by a NodeB:
  - are perfectly synchronized & orthogonal
  - are affected by a single fading (for a given mobile)
  - orthogonality between signals is theoretically kept (in case of no multipath).

- Power control is:
  - essential on uplink
    - to avoid 'near-far effet'
  - still required on downlink:
    - to mitigate inter-cells interference
    - to minimize power consumption.

- Mean for power control management :
  - open loop / close loop
  - pilot bits examination $\Rightarrow$ TPC bits managment

# Power control (3/)

- $E_b/(N_0+I) \geq$ x dB (6 e.g.)
- $N_0 + I$ = Power Spectral Density of the Noise
  + Noise Power Spectral Density generated by other users.
  - Value is assumed to be constant
- $E_b$ given, $N$ being the SF:

$$E_b = N\,E_{ch} = N\,P_{ch}\,T_{ch}$$

$\Rightarrow N\,P_{ch}$ constant

$\Rightarrow N\,P_{sy}$ constant

$\Rightarrow$ $N$ low:

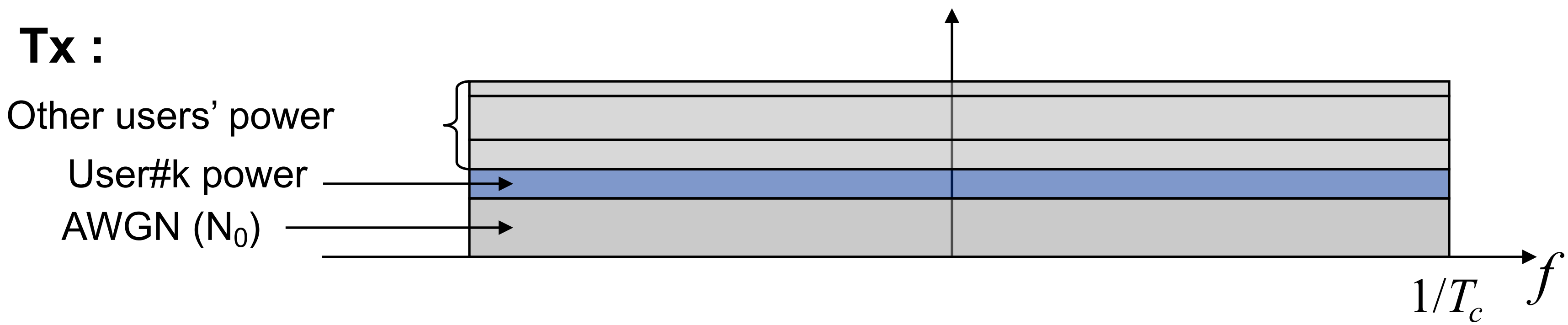
$N$ high:

$$\boxed{\begin{array}{l} D_{sy} \text{ high} \Leftrightarrow P_{sy} \text{ high} \\ D_{sy} \text{ low} \Leftrightarrow P_{sy} \text{ low} \end{array}}$$

# Power control (4/)

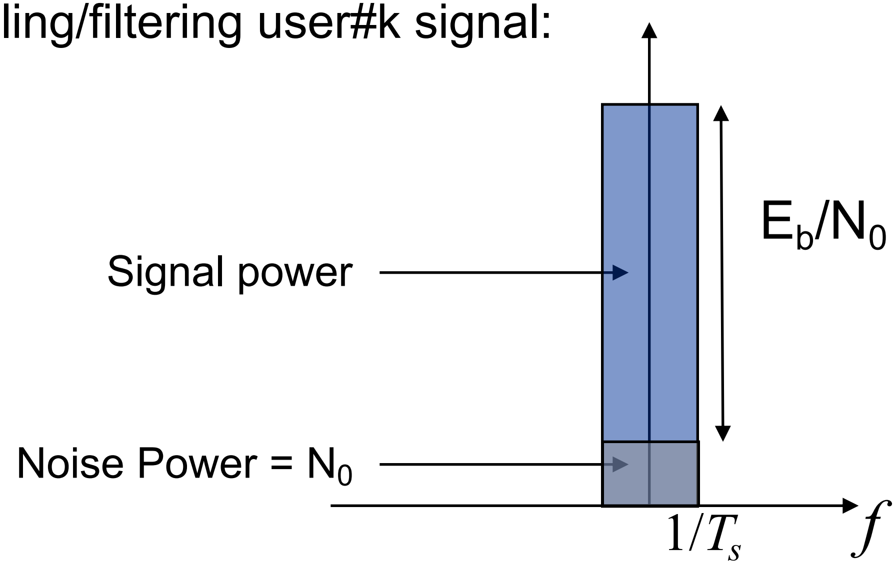
- Ideal case of perfectly orthogonal sequences :

**Tx :**




**Rx :**

After despreading/descrambling/filtering user#k signal:

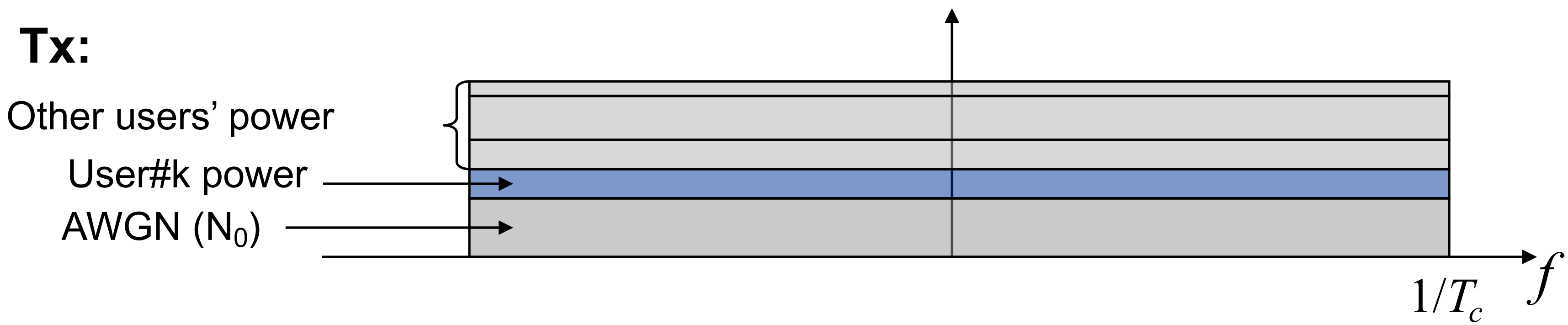


# Power control (5/)

- Reality: Non perfect codes orthogonality:
  - multipath (UPLINK & DOWNLINK)
    ⇒ non orthogonal replicas (scrambling codes autocorrelation)
  - **other users/cells interferences**
    (scrambling codes cross-correlation)

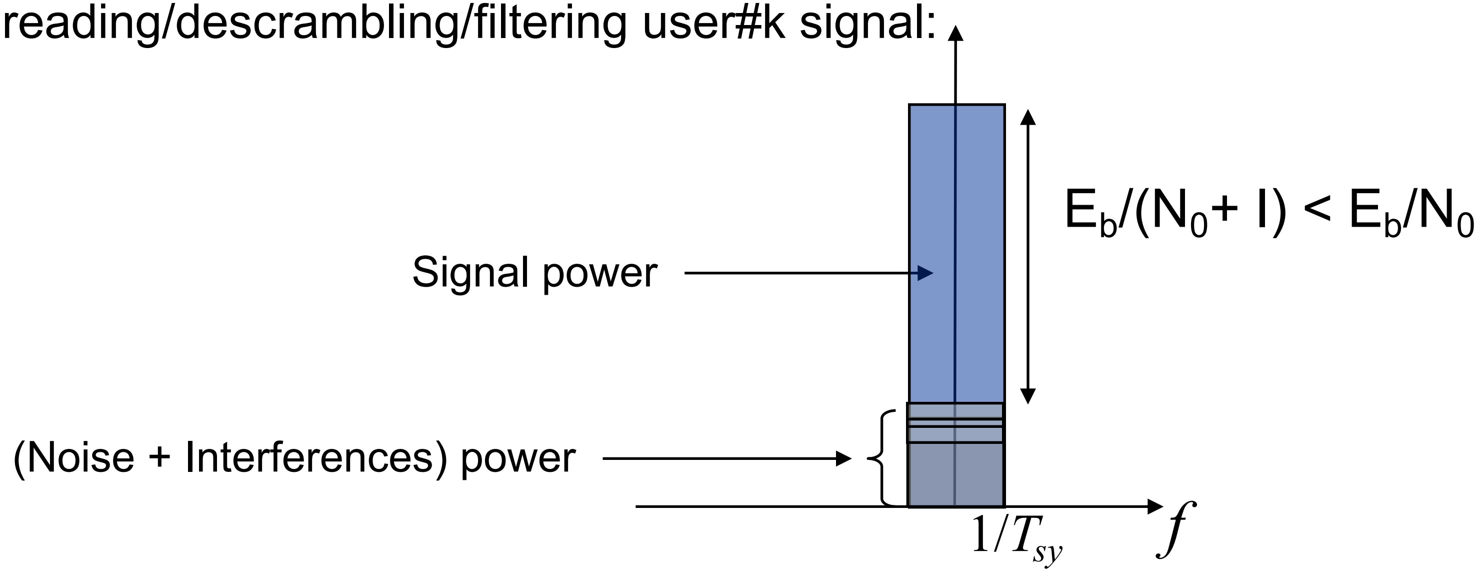
# Power control (6/)

**Tx:**

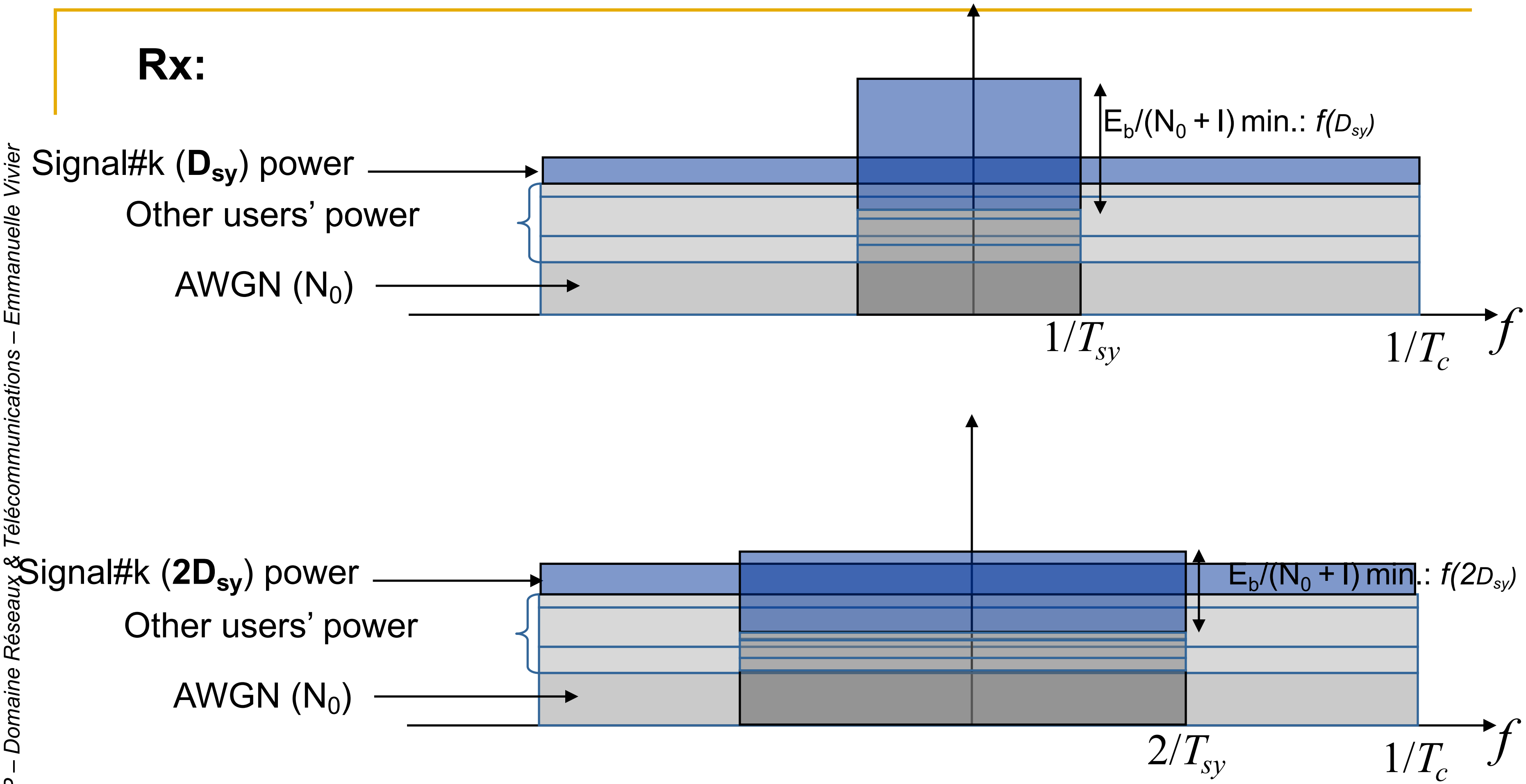



**Rx:**

After despreading/descrambling/filtering user#k signal:



# Power control (7/)



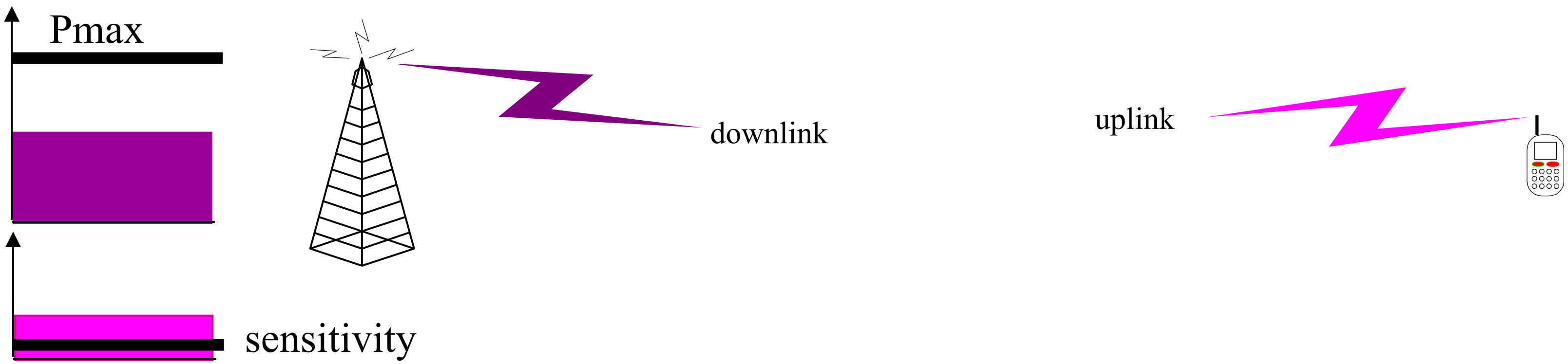

Minimum $E_b/(N_0 + I)$ requirements vary from one service to another

# Power control (8/)

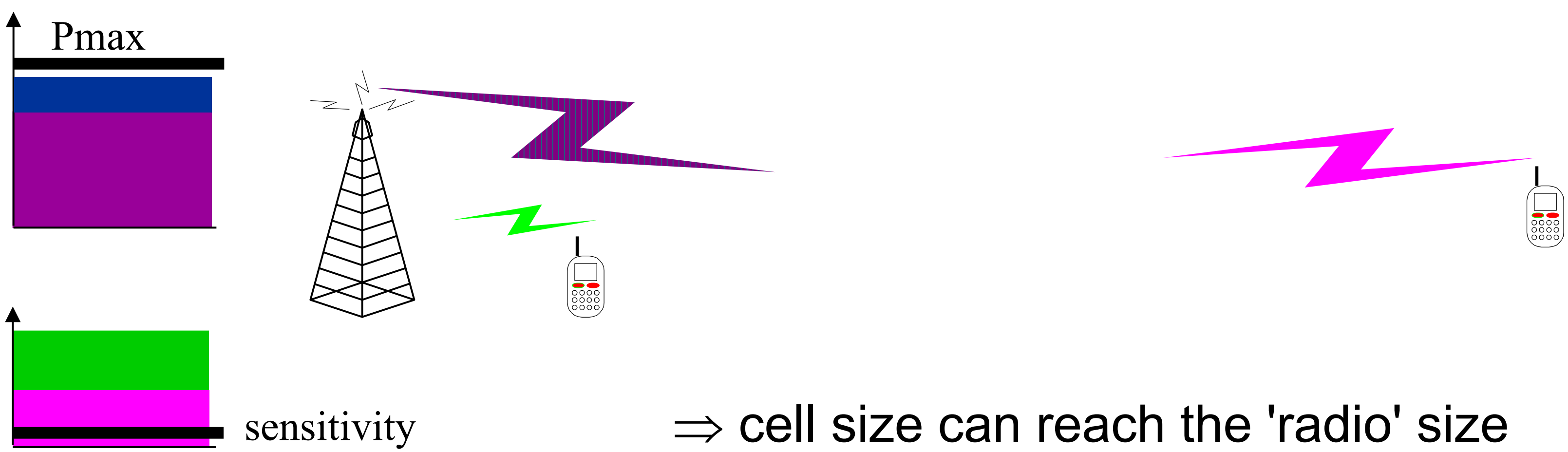
- As seen by user #k:
- $N_0$+ I :
  - (Noise + Interferences) spectral density generated by other users
  - $$= N_0 + T_s \sum_{i \neq k} \alpha_i \, p_i g_i \qquad (0 \leq \alpha_i \leq 1)$$
- tuning $E_b$ for user #k:
  - $E_b$ ($k$) ↑ ⇒ Interferences spectral density level ($\neq k$, if $\alpha_n \neq 0$) ↑
  - $E_b$ ($k$) ↓ ⇒ Interferences spectral density level ($\neq k$) ↓
  - System unstability
    - limited power of equipments

# Cell breathing (1/)

Radio coverage is supposed to be OK:



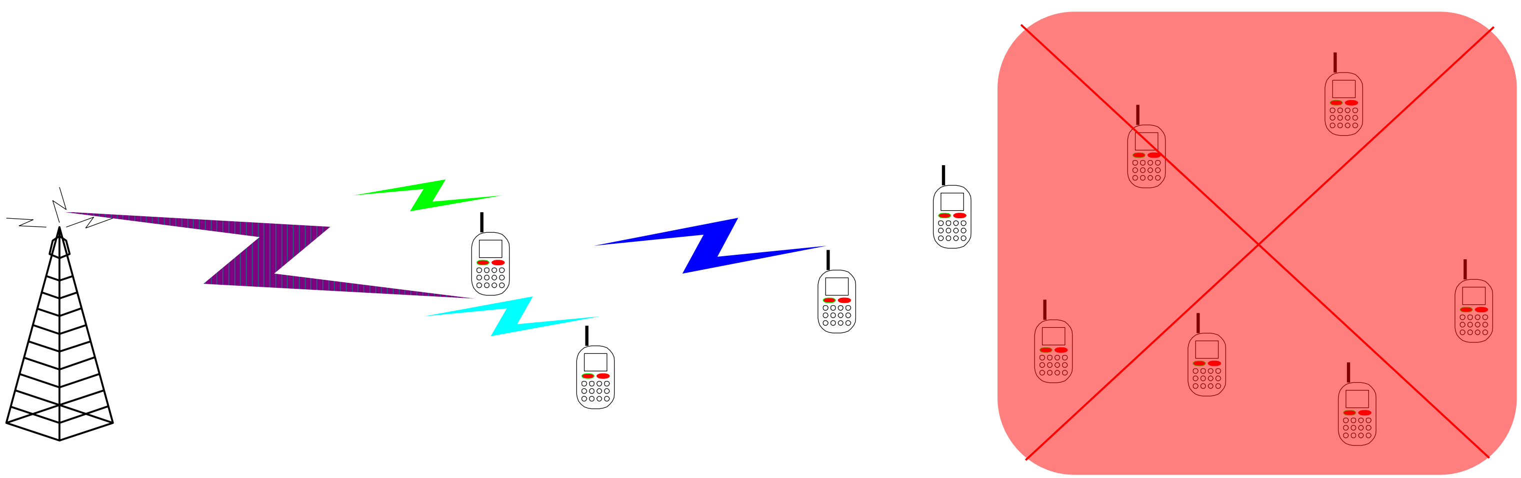

- in case of low density traffic:




⇒ cell size can reach the 'radio' size

# Cell breathing (2/)

- in case of high density traffic:
  - downlink:
    more users can be served when the 'nearest' ones are served first
  - uplink:
    limited transmission power
    - only the 'nearest' users can be served



⇒ cell effective size ↘

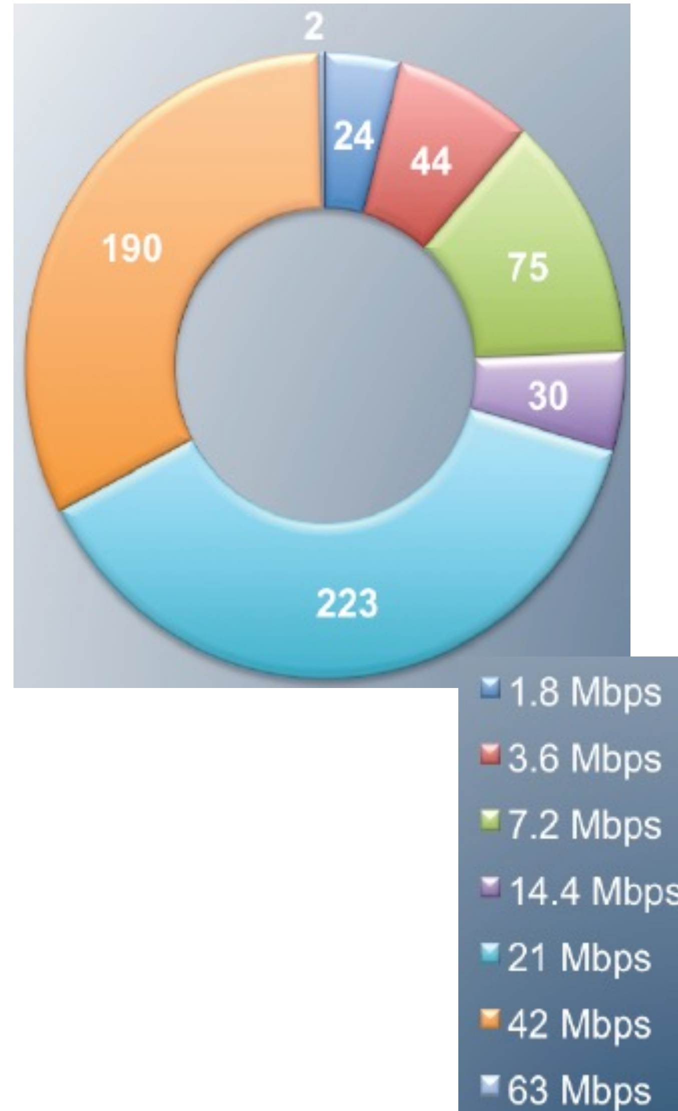
*'nearest' in the sense 'the ones benefiting from the best radio propagation'*

- HSPA

# HSPA



- High Speed Packet Access
  - Downlink: HSDPA
    - First launch: 2005
    - Offered thoughputs: 14.4 Mbits/s ↓
  - Uplink: HSUPA
    - First launch: 2007
    - Offered thoughputs: 5.76 Mbits/s ↑
  - Dual carrier
    - First launch : 2009 (Australia)
    - Offered thoughputs: 42 Mbits/s ↓
  - 3C HSPA+
    - 2015
    - Offered thoughputs: 63 Mbits/s ↓




- 2013:
  - 532 commercial networks
  - 203 countries
  - > 3000 devices
  - >250 suppliers

# HSDPA

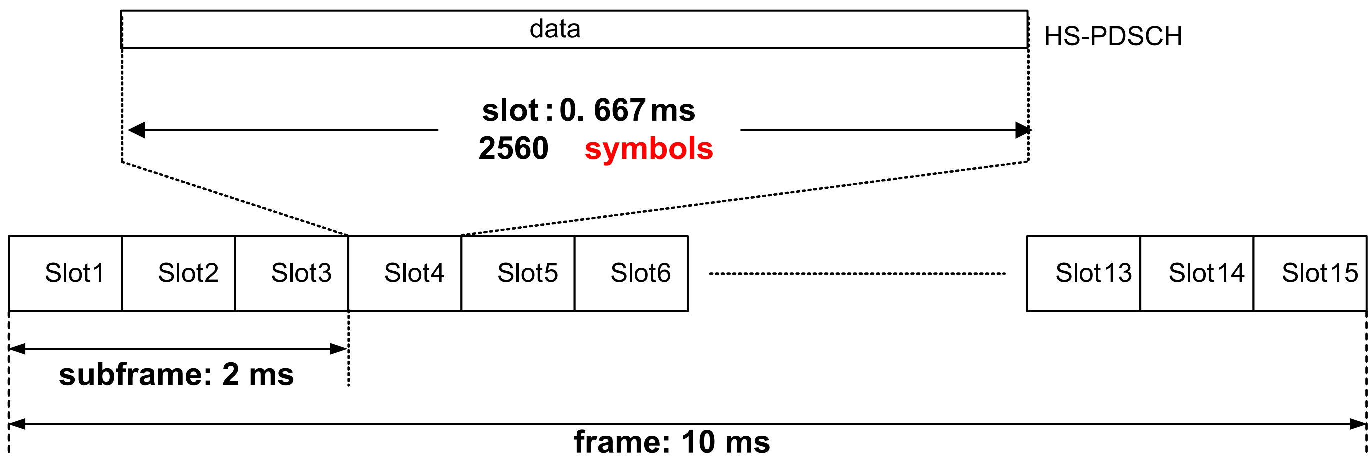
- High Speed DOWNLINK Packet Access

- Compared to UMTS:
  - fixed SF: 16
  - several spreading factors can be allocated to one user: up to 15
  - new modulation: 16 QAM, in addition to UMTS QPSK
    $\Rightarrow$ adaptive modulation
  - new TTI: 2 ms, in addition to UMTS TTI (min: 10 ms)
    $\Rightarrow$ shorter delay between retransmissions, fast scheduling
  - PHY layer retransmission combining, instead of UMTS RLC level retransmission
  - turbo-coding only (no convolutional coding),
    codes rates: from 1/4 to 3/4
    $\Rightarrow$ adaptive coding
  - no soft HO, no DTX

# HSDPA – new channels



- Downlink user traffic is carried by High Speed Physical Downlink Shared Channel (HS-PDSCH, QPSK or 16QAM, SF=16)




- PHY control is carried by High Speed Shared Control Channel (HS-SCCH, QPSK, SF=128, 60 kbps)
- Uplink feedback signalling related to HS-DSCH transmissions is carried by High Speed Dedicated Physical Control Channel
  (HS-DPCCH, QPSK, SF=256, 15kbps)
  associated with an UMTS DPCCH (QPSK, SF=256, 15kbps)

# HSDPA – Data rates

- HS-PDSCH : 2560 symbols/slot
  - SF=16 $\Rightarrow$ 160 symbols/slot
  - QPSK $\Rightarrow$ 320 bits/slot, i.e. 480 kbits/s
  - 16QAM $\Rightarrow$ 640 bits/slot, i.e. 960 kbits/s
- Data rates increase,
  from ~2 Mbps max. (UMTS) to 14.4 Mbps max (HSDPA)

| Channel bit rates QPSK | Channel bit rates 16 QAM | Spreading codes | Number of allocated spreading codes |
|---|---|---|---|
| 6 kbps – 1.872 Mbps | | 512 - 4 | 1 |
| 480 kbps | 960 kbps | 16 | 1 |
| 960 kbps | 1.92 Mbps | 16 | 2 |
| … | … | … | … |
| 7.2 Mbps | **14.4 Mbps** | 16 | 15 |

# HSUPA

- High Speed UPLINK Packet Access

- Compared to UMTS:
  - new spreading factor: 2
  - several spreading factors can be allocated to one user
  - new TTI: 2 ms, in addition to UMTS TTI (min: 10 ms)

    ⇒ shorter delay between retransmissions, fast scheduling
    - a 2ms-period signalisation consumes a lot of transmission power on both links
    - at high density traffic, the BS can not provide downlink signalling to a large number of users (⇒ 10 ms TTI)
  - PHY layer retransmission combining, instead of UMTS RLC level retransmission
  - same modulation: QPSK, as in UMTS
  - fast power control & soft HO, as in UMTS

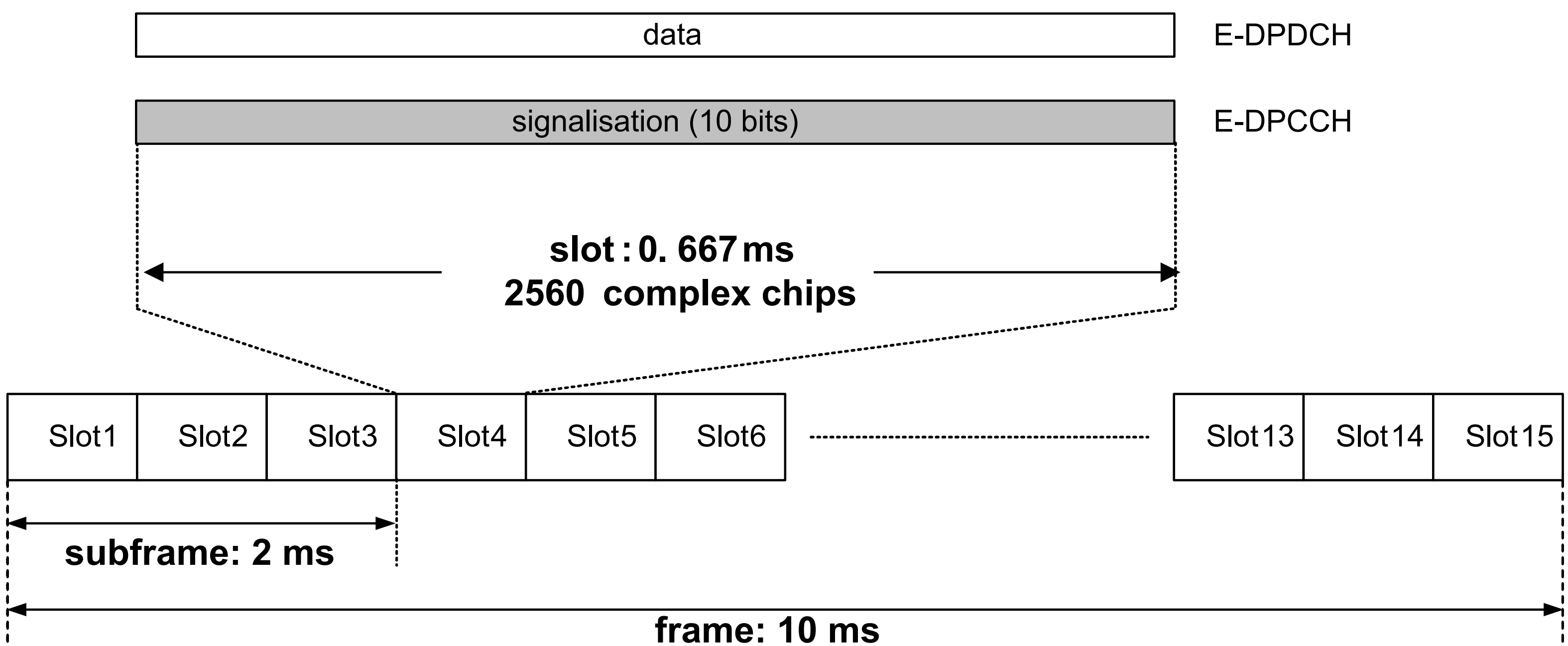
# HSUPA – Data rates

- Data rates increase,
  from 1 Mbps max. (UMTS) to 5.76 Mbps max (HSUPA)

| Channel bit rates | Number of allocated spreading codes | Spreading factors $N_i$ |
|---|---|---|
| 15 – 960 kbps | 1 | $N_i = 256 - 4$ |
| 1.92 Mbps | 2 | $N_i = 4$ |
| 3.84 Mbps | 2 | $N_i = 2$ |
| **5.76 Mbps** | 4 | $2 \times \{N_i = 4\} + 2 \times \{N_i = 2\}$ |

# HSUPA – slot structure ex.

Slot structure for user traffic
(dedicated mode, Enhanced-DPDCH & Enhanced-DPCCH):



# HSPA+

- Dual Carrier HSDPA


- 2 x 5 MHz = 10 MHz bandwidth
- Modulations:
  - 16 QAM ⇒ Channel bit rate : 11,5 Mbits/s per carrier
  - 64 QAM ⇒ Channel bit rate : 21 Mbits/s per carrier


- Max. achievable throughput: 42 Mbits/s
  - with 64 QAM + MIMO 2x2 in a single 5 MHz carrier, or
  - with 64 QAM + 2x5 MHz carrier


# Conclusion : towards 4G

- 3G = UMTS
  3.5G = HSPA

- 4G = LTE, WiMAX
  - 100/50 Mbps
  - LTE Networks :
    - Telia Sonera : Stockholm & Oslo, Dec. 2009
    - NTT Docomo : « Xi » (Cross i), Dec. 2010
    - Verizon : Chicago, New York, San Francisco, Los Angeles, Dec. 2010
    - End 2011:
      - 49 commercial networks, 29 countries
      - 200 devices, 50 suppliers
    - End 2013: 410 operators (93 countries) committed to deploy commercial LTE.
      - 250 commercial networks, 100 countries
      - 200 millions subscribers, ~50% in North America, 40% in APAC, 8% in Europe

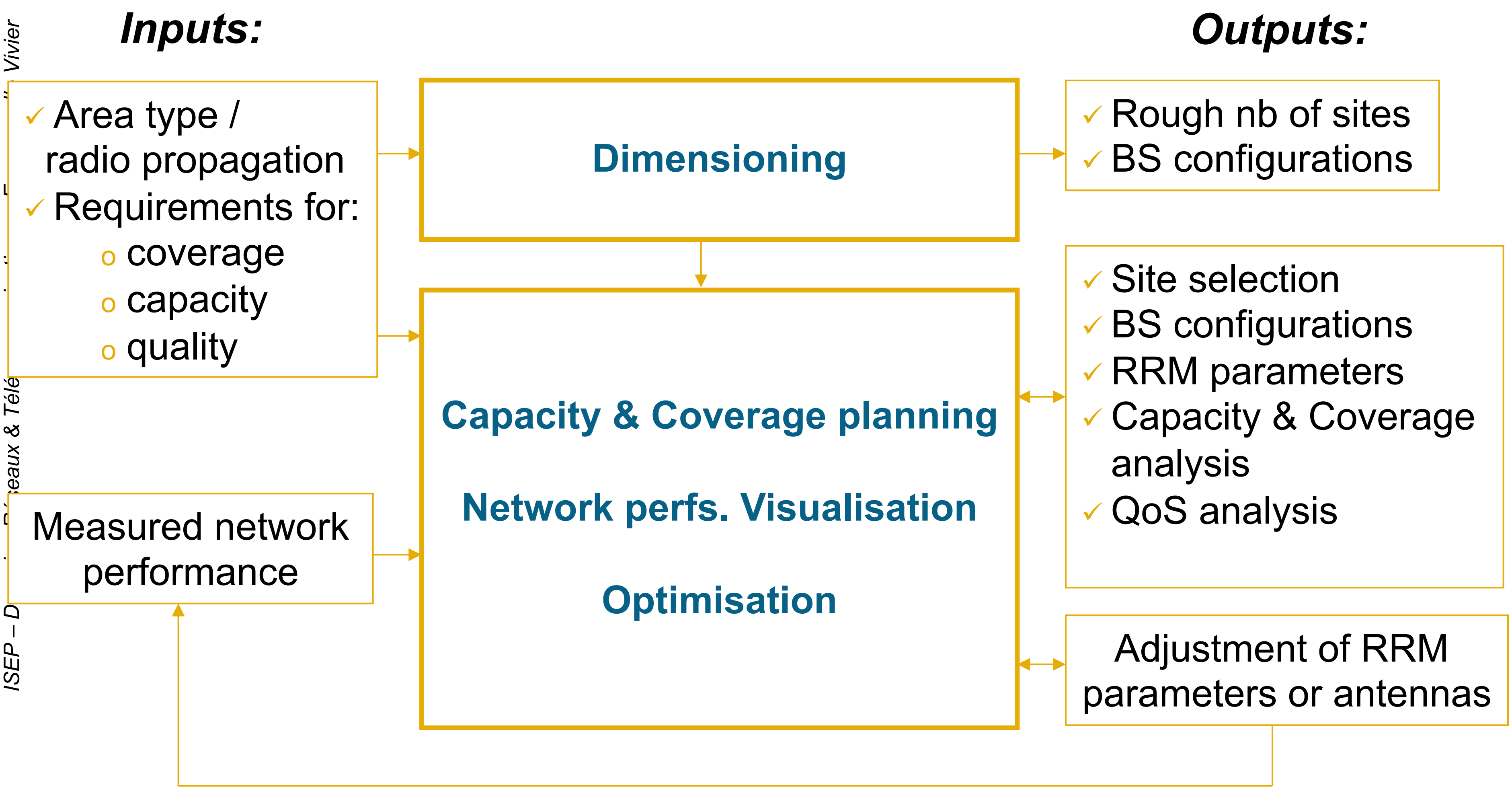
# Radio Dimensioning and Planning

# Outline

- Recall: GSM Radio Network Planning Process
- WCDMA Radio Network Planning Process
  - Dimensioning
    - One-cell network
    - General dimensioning
  - Capacity ↑↓
  - Radio Link Budget
  - RRM algorithms
  - Conclusion

# WCDMA Radio Network Planning

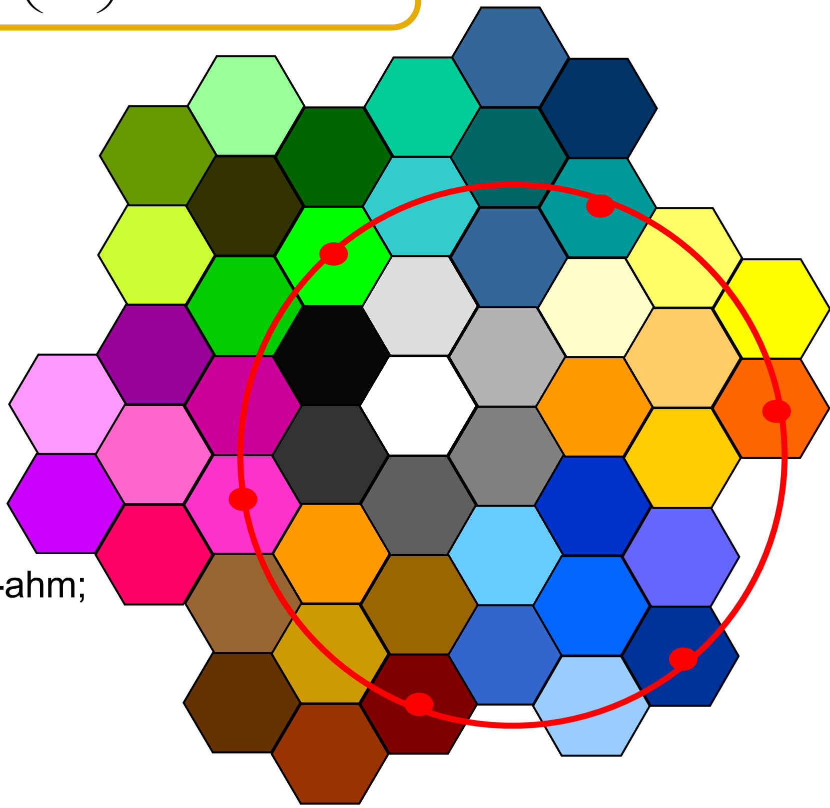
## Process



# GSM Radio Network Planning (1/)

$$\mathrm{SINR} \sim \frac{1}{6}\left(\frac{\mathrm{D}}{\mathrm{R}}\right)^{\gamma} = \frac{1}{6}\left(\sqrt{3\mathrm{K}}\right)^{\gamma}$$

- General formula:
  - $D$ : frequency reuse distance
  - $R$ : cell radius
  - $\gamma$ : propagation loss factor (2-4)
  - $K$ : frequency reuse pattern size



- $R$ computed with:
  - propagation law: (Okumura-Hata)
    - f=900 / 1800, Hb=40, hm=1.5;
    - ahm = (3.2*(log10(11.75*hm)).^2-4.97);
    - LHb = 44.9-6.55*log10(Hb);
    - LfHb = 69.55+26.16*log10(f)-13.82*log10(Hb)-ahm;

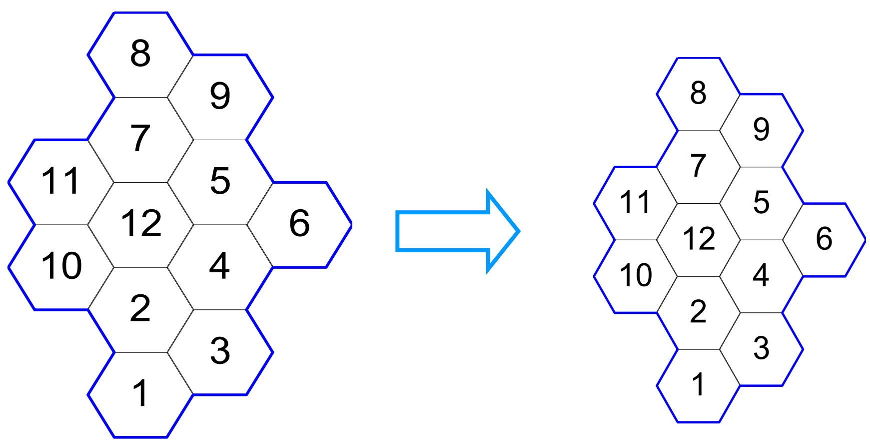
    $\Rightarrow L(r) = 10^{LfHb/10}\, r^{LHb/10}$
  - L(R) < EIRP – Sensitivity_Threshold
- $K$ computed with
  - GSM threshold: $C/I > 9\ dB$
  - additional margins: fading, shadowing, etc

# GSM Radio Network Planning (2/)

- Capacity:
  - $B$ : frequency band
  - 200 kHz: carrier spacing
  - $S_{cell}$ : cell surface area

$$\boxed{\frac{8 \times B / 200}{K \times S_{cell}} \text{ active users/km}^2}$$

- If density increases, decrease $R$ ($\Rightarrow S_{cell} \downarrow$, capacity $\uparrow$) :



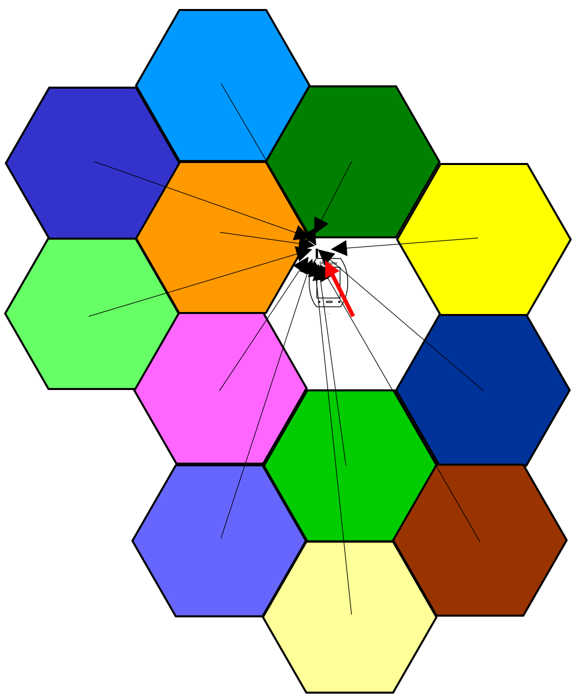
# GSM Radio Network Planning (3/)

- GSM Radio Network Planning
  - Application to WCDMA Radio Network Planning:
    - ***K*=1**
    - Downlink:
      $C \Rightarrow I$ varies with cell's load
    - Uplink:
      $I \Rightarrow C$ varies with cell's load
  - Cell's load must be estimated
  - The signal-to-noise-plus-interference ratio must be re-computed
  - Additional margins must be included in the radio link budget (soft HO)

# GSM Radio Network Planning (4/)

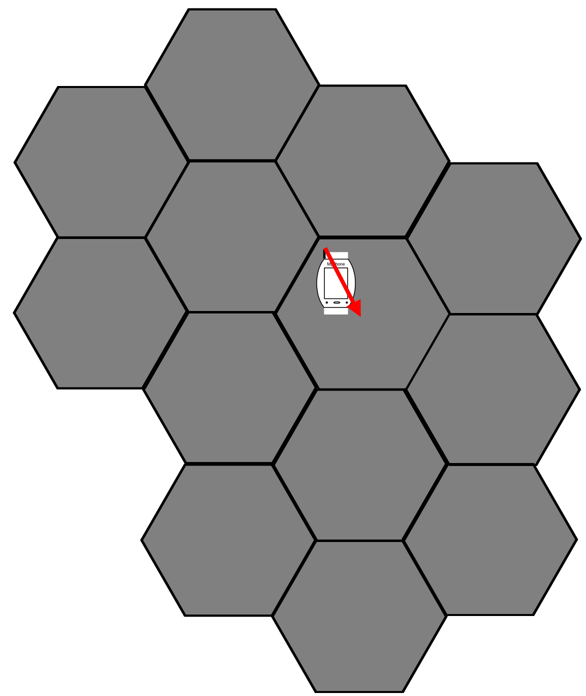


- Downlink:
  - intra-cell interferences
  - non ⊥ scrambling codes
    ⇒ inter-cell interferences



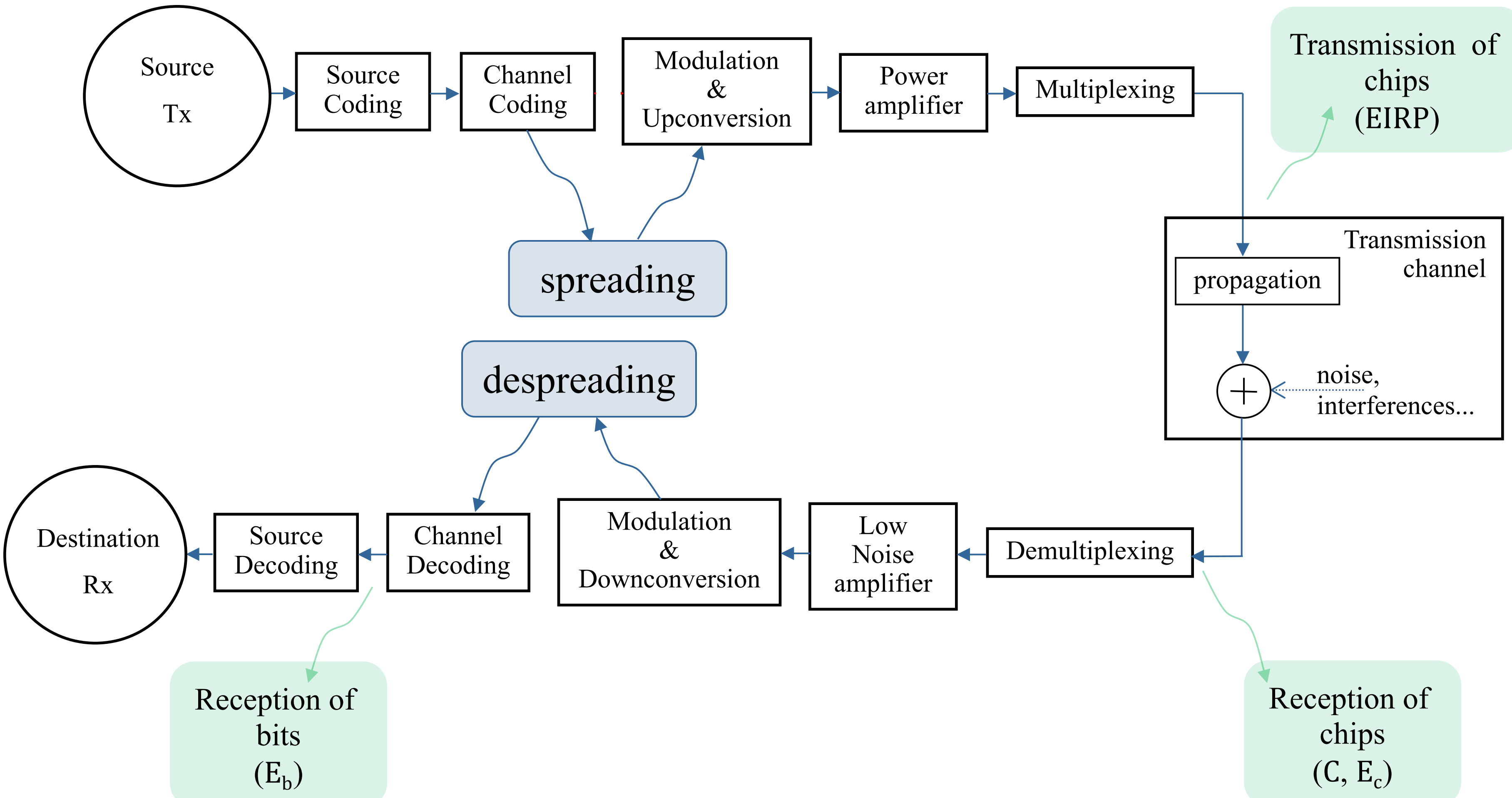
- Uplink:
  - non ⊥ scrambling codes
    ⇒ inter-cell interferences

    ⇒ intra-cell interferences



# SINR Computation for CDMA networks

Spreading /Despreading in the transmission chain:



# SINR Computation for CDMA networks

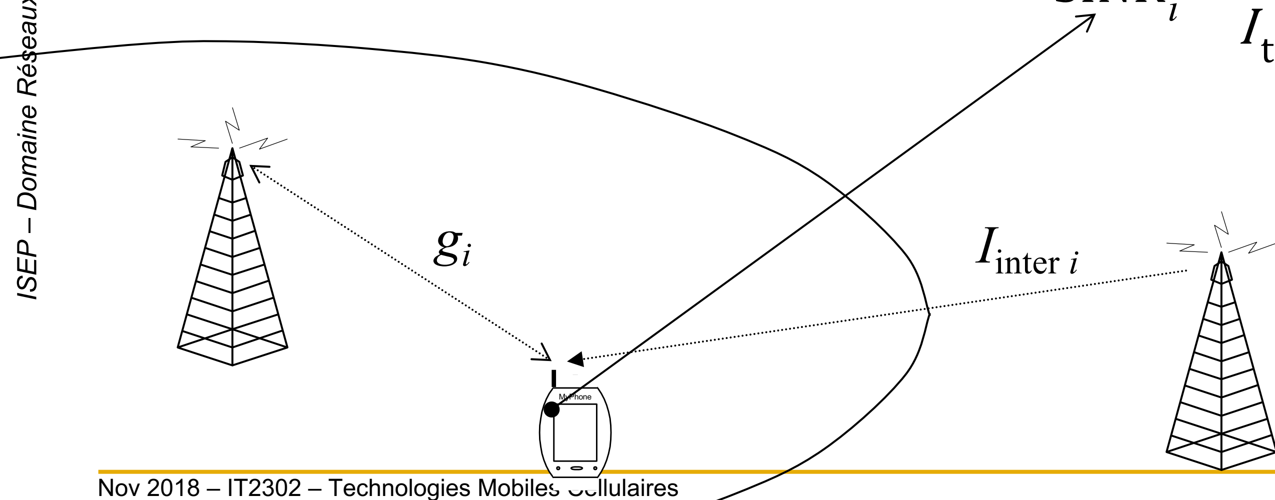
Before the user #i signal despreading: <u>chips</u> are considered

- $N_i$: SF allocated to user #i
- $p_i$: EIRP allocated to user #i
- $g_i$: radio channel gain between BS and MS #i
- $I_{\text{th}}$: noise power in the reception band: $N_0 \, \mathrm{W}_c$
- $I_{\text{intra}}$: intra-cell interference received power
- $I_{\text{inter}}$: inter-cell interference received power
- $P$ : BS EIRP
- $\alpha$ : SS cross-correlation factor

$$C_i = p_i \, g_i$$

$$I_i = I_{\text{th}} + I_{\text{intra}\,i} + I_{\text{inter}\,i}$$

$$\mathrm{SINR}_i = \frac{C_i}{I_{\text{th}} + I_{\text{intra}\,i} + I_{\text{inter}\,i}} \approx \frac{E_c}{I_0}$$



# CDMA Dimensioning

After the user #i signal despreading: bits are considered

- the useful signal power remains unchanged
- the reception bandwidth is reduced : from $W_c$ to $W_c / N_i$

  $\Rightarrow$ the noise power is reduced
- the signal-to-noise+interferences ratio SINR is denoted $\Gamma_i$ :

$$\frac{E_b}{N_0} = N_i \frac{E_c}{I_0 + N_0}$$

$$\boxed{\Gamma_i = N_i \,\mathrm{SINR}_i = N_i \frac{p_i \, g_i}{I_{\mathrm{th}} + I_{\mathrm{intra}\ i} + I_{\mathrm{inter}\ i}}}$$

$$\frac{E_b}{N_0} \approx \frac{E_b}{N_0 + I\, T_b} = \frac{N_i\, p_i \left(\frac{GA}{LO}\right)_{\mathrm{Rx}} g_i}{\left(I_{\mathrm{th}} + I_{\mathrm{intra}\ i} + I_{\mathrm{inter}\ i}\right) \times F_{\mathrm{Rx}}}$$

$$\Gamma_i^{\downarrow} = \frac{N_i\ p_i\ g_i}{I_{\mathrm{th}} + \alpha \left(P - p_i\right) g_i + I_{\mathrm{inter}\, i}}$$

$$\Gamma_i^{\uparrow} = \frac{N_i\ p_i\ g_i}{I_{\mathrm{th}} + \alpha \left(\sum_{k \neq i} p_k g_k\right)}$$

$$\boxed{\frac{E_b}{N_0} \approx \Gamma_i \left(\frac{GA}{LO}\right)_{\mathrm{Rx}} \frac{1}{F_{\mathrm{Rx}}}}$$

# $\alpha$ cross correlation factor

At the reception side

- Cross-correlation between different information flows
  ≈ trouble, disturbance between flows
- Uplink (FDD):
  - BS side
  - Cross-correlation between active users of the cell <u>and outside the cell</u>
  - As seen in SS lecture, desynchronised OVSF spreading sequences are no more orthogonal at all, and scrambling codes are not orthogonal

$\Rightarrow \boxed{\alpha^{\uparrow}=1}$

- Downlink:
  - MS side
  - Cross-correlation between active users of the cell
  - (synchronised orthogonal OVSF spreading sequences + scrambling codes) cross-correlation
  - As seen in SS lecture, Gold sequences cross-correlation is limited

$\Rightarrow \boxed{\alpha^{\downarrow}<1,\ \alpha^{\downarrow}: \sim 0.5\text{-}1}$

# CDMA radio dimensioning / one cell (1/)

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- $k$ users in the cell, $N_i = N$
- Uplink:
  - signal-to-noise+interferences ratio: $$\Gamma_i^{\uparrow} = \frac{N\ p_i\ g_i}{I_{\text{th}} + \alpha \left( \sum_k p_k\ g_k - p_i\ g_i \right)}$$
  - total received power at the BS input antenna: $\frac{k\,\Gamma^{\uparrow}\ I_{\text{th}}}{N + \alpha\,(1-k)\,\Gamma^{\uparrow}}$ (increases with $k$)
  - max. users in the cell: $k < 1 + \frac{N}{\alpha\,\Gamma^{\uparrow}}$
  - Individual powers received at the BS input antenna:
    - are equal
    - increase with $k$

Power transmitted by user #*i* increases when $g_i \downarrow$ and/or $k \uparrow$

# CDMA radio dimensioning / one cell (2/)

- Downlink:
  - signal-to-noise+interferences ratio: $\Gamma_i^{\downarrow} = \dfrac{N\ p_i\ g_i}{I_{\text{th}} + \alpha\left(P - p_i\right) g_i}$
  - BS EIRP: (increases with $k$) $P = \dfrac{\Gamma^{\downarrow}\ I_{\text{th}}}{N + \alpha\left(1-k\right)\Gamma^{\downarrow}}\left(\sum_i \dfrac{1}{g_i}\right)$
  - max. users in the cell: $k < 1 + \dfrac{N}{\alpha\ \Gamma^{\downarrow}}$
  - Transmitted power dedicated to user #$i$ (EIRP$_i$) **increases** :
    - with $\boldsymbol{P}$
    - when $\boldsymbol{g_i}$ decreases

Individual power dedicated to user #*i* increases when $g_i \downarrow$ and/or $k \uparrow$

# CDMA general radio dimensioning (1/)

- Parameters:

$Q$: nb of cells

$i_j$: index of user #i in cell #j

$N_{ji_j}$: SF allocated to user #i in cell #j

$p_{ji_j}$: power allocated to user #i in cell #j

$g_{ji_j}$: radio channel gain between BS#j and MS#i

$P_j$: BS#j EIRP

$P_j^R$: BS#j total received power at its input antenna

$k_j$: nb of users in cell #j

$\Gamma_{ji_j}$: signal-to-noise+interferences ratio for user #i in cell #j

# CDMA general radio dimensioning (2/)

- Downlink – relations:

$$\Gamma^{\downarrow}_{ji_j} = \frac{N_{ji_j}\, p_{ji_j}\, g_{ji_j}}{I_{\text{th}} + \alpha \left(P_j - p_{ji_j}\right) g_{ji_j} + \sum\limits_{q\neq j} P_q\, g_{qi_j}}$$

$$p_{ji_j} = \frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\,\Gamma^{\downarrow}_{ji_j} + N_{ji_j}} \left[\frac{I_{\text{th}}}{g_{ji_j}} + \alpha\, P_j + \sum\limits_{q\neq j} P_q \frac{g_{qi_j}}{g_{ji_j}}\right]$$

positive!

$$P_j\left(1-\sum_{i_j=1}^{k_j} \frac{\alpha\,\Gamma^{\downarrow}_{ji_j}}{\alpha\,\Gamma^{\downarrow}_{ji_j}+N_{ji_j}}\right) = I_{\text{th}}\sum_{i_j=1}^{k_j}\frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\,\Gamma^{\downarrow}_{ji_j}+N_{ji_j}}\frac{1}{g_{ji_j}} + \sum_{q\neq j}P_q\sum_{i_j=1}^{k_j}\frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\,\Gamma^{\downarrow}_{ji_j}+N_{ji_j}}\frac{g_{qi_j}}{g_{ji_j}}$$

$$\begin{bmatrix}
1-\sum\limits_{i_1=1}^{k_1}\frac{\alpha\,\Gamma^{\downarrow}_{1i_1}}{\alpha\,\Gamma^{\downarrow}_{1i_1}+N_{1i_1}} & -\sum\limits_{i_1=1}^{k_1}\frac{\Gamma^{\downarrow}_{1i_1}}{\alpha\,\Gamma^{\downarrow}_{1i_1}+N_{1i_1}}\frac{g_{2i_1}}{g_{1i_1}} & -\sum\limits_{i_1=1}^{k_1}\frac{\Gamma^{\downarrow}_{1i_1}}{\alpha\,\Gamma^{\downarrow}_{1i_1}+N_{1i_1}}\frac{g_{3i_1}}{g_{1i_1}} & \cdots & \cdots & -\sum\limits_{i_1=1}^{k_1}\frac{\Gamma^{\downarrow}_{1i_1}}{\alpha\,\Gamma^{\downarrow}_{1i_1}+N_{1i_1}}\frac{g_{Qi_1}}{g_{1i_1}} \\
-\sum\limits_{i_2=1}^{k_2}\frac{\Gamma^{\downarrow}_{2i_2}}{\alpha\,\Gamma^{\downarrow}_{2i_2}+N_{2i_2}}\frac{g_{1i_2}}{g_{2i_2}} & 1-\sum\limits_{i_2=1}^{k_2}\frac{\alpha\,\Gamma^{\downarrow}_{2i_2}}{\alpha\,\Gamma^{\downarrow}_{2i_2}+N_{2i_2}} & -\sum\limits_{i_2=1}^{k_2}\frac{\Gamma^{\downarrow}_{2i_2}}{\alpha\,\Gamma^{\downarrow}_{2i_2}+N_{2i_2}}\frac{g_{3i_2}}{g_{2i_2}} & \cdots & \cdots & -\sum\limits_{i_2=1}^{k_2}\frac{\Gamma^{\downarrow}_{2i_2}}{\alpha\,\Gamma^{\downarrow}_{2i_2}+N_{2i_2}}\frac{g_{Qi_2}}{g_{2i_2}} \\
\cdots & \cdots & & & & \cdots \\
-\sum\limits_{i_Q=1}^{k_Q}\frac{\Gamma^{\downarrow}_{Qi_Q}}{\alpha\,\Gamma^{\downarrow}_{Qi_Q}+N_{Qi_Q}}\frac{g_{1i_Q}}{g_{Qi_Q}} & -\sum\limits_{i_Q=1}^{k_Q}\frac{\Gamma^{\downarrow}_{Qi_Q}}{\alpha\,\Gamma^{\downarrow}_{Qi_Q}+N_{Qi_Q}}\frac{g_{2i_Q}}{g_{Qi_Q}} & \cdots & & -\sum\limits_{i_Q=1}^{k_Q}\frac{\Gamma^{\downarrow}_{Qi_Q}}{\alpha\,\Gamma^{\downarrow}_{Qi_Q}+N_{Qi_Q}}\frac{g_{(Q-1)i_Q}}{g_{Qi_Q}} & 1-\sum\limits_{i_Q=1}^{k_Q}\frac{\alpha\,\Gamma^{\downarrow}_{Qi_Q}}{\alpha\,\Gamma^{\downarrow}_{Qi_Q}+N_{Qi_Q}}
\end{bmatrix}
\begin{bmatrix} P_1 \\ P_2 \\ \cdots \\ \cdots \\ P_Q \end{bmatrix}
= I_{\text{th}}
\begin{bmatrix}
\sum\limits_{i=1}^{k_1}\frac{\Gamma^{\downarrow}_{1i}}{\alpha\,\Gamma^{\downarrow}_{1i}+N_{1i}}\frac{1}{g_{1i}} \\
\sum\limits_{i=1}^{k_2}\frac{\Gamma^{\downarrow}_{2i}}{\alpha\,\Gamma^{\downarrow}_{2i}+N_{2i}}\frac{1}{g_{2i}} \\
\cdots \\
\cdots \\
\sum\limits_{i=1}^{k_Q}\frac{\Gamma^{\downarrow}_{Qi}}{\alpha\,\Gamma^{\downarrow}_{Qi}+N_{Qi}}\frac{1}{g_{Qi}}
\end{bmatrix}$$

# CDMA general radio dimensioning (3/)

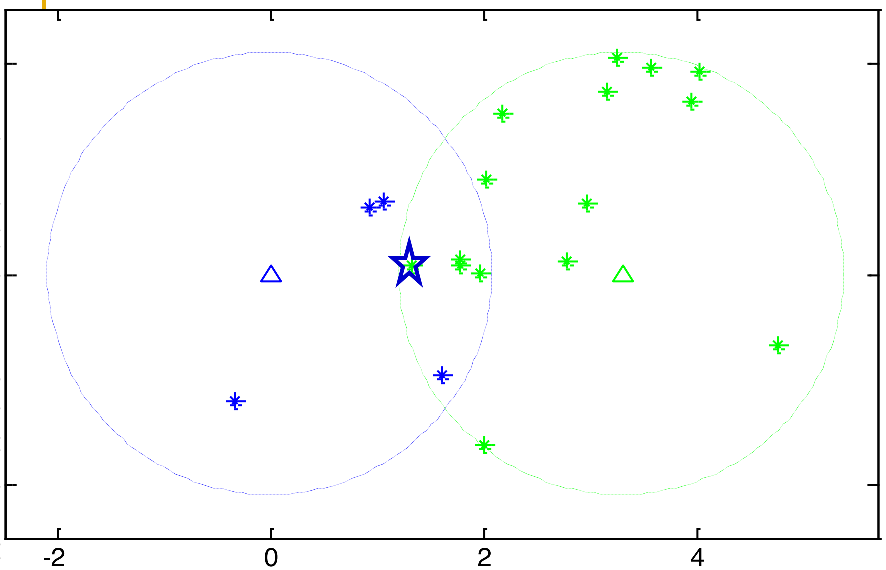


- Downlink – Example: Assuming:
  - EIRP = 30 W
  - MS sensitivity = -100 dBm (= reception threshold)
    - Okumura-Hata propagation law:
      - f=2000, Hb=40, hm=1.5;
      - ahm = (3.2*(log10(11.75*hm)).^2-4.97);
      - LfHb = 69.55+26.16*log10(f)-13.82*log10(Hb)-ahm;
      - LHb = 44.9-6.55*log10(Hb);

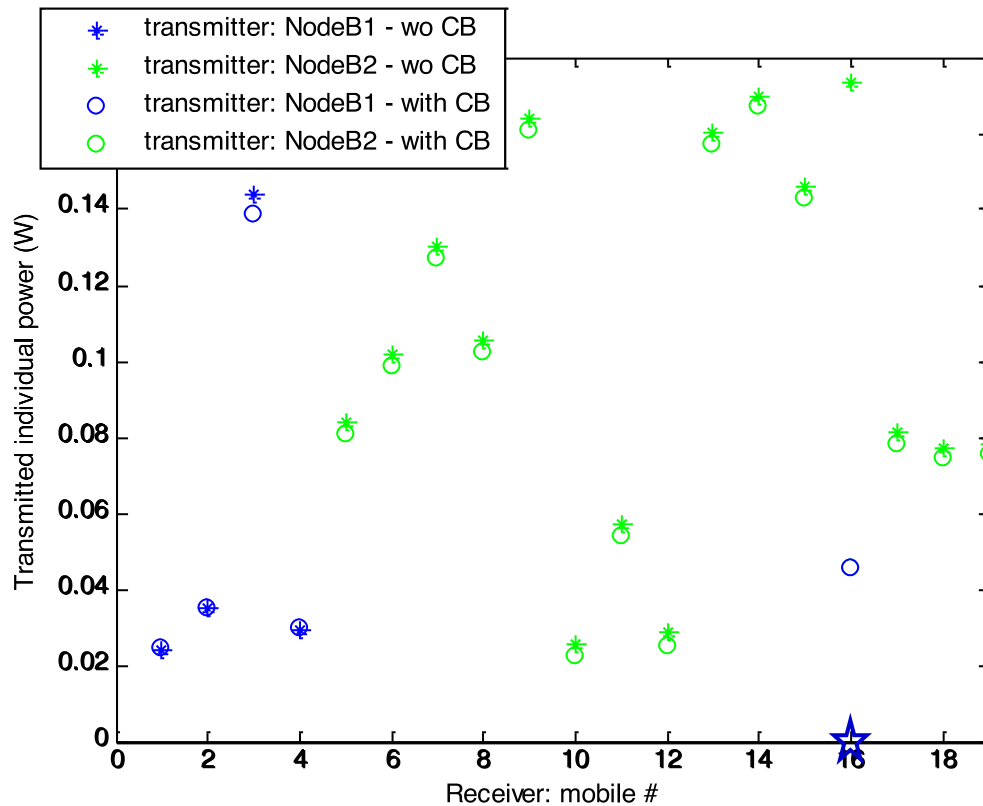
      $\Rightarrow L(r) = 10^{LfHb/10}\, r^{LHb/10} \Rightarrow R_c = 2$ km
  - a reuse pattern factor =1 $\Rightarrow D = \sqrt{3}\, R_c$ + soft HO zone: 0.5 $R_c$
  - a network with two cells only: $Q = 2$
  - $\Gamma^{\downarrow} = 6$ dB
  - $N = 128$
  - $\alpha = 0.5$
  - $k_1 = 4$, $k_2 = 15$
  - $k_{max} =$

$$\begin{bmatrix} 1-\sum_{i_1=1}^{k_1}\dfrac{\alpha\,\Gamma^{\downarrow}}{\alpha\,\Gamma^{\downarrow}+N} & -\sum_{i_1=1}^{k_1}\dfrac{\Gamma^{\downarrow}}{\alpha\,\Gamma^{\downarrow}+N_{1i_1}}\dfrac{g_{2i_1}}{g_{1i_1}} \\ -\sum_{i_2=1}^{k_2}\dfrac{\Gamma^{\downarrow}}{\alpha\,\Gamma^{\downarrow}+N}\dfrac{g_{1i_2}}{g_{2i_2}} & 1-\sum_{i_2=1}^{k_2}\dfrac{\alpha\,\Gamma^{\downarrow}}{\alpha\,\Gamma^{\downarrow}+N} \end{bmatrix}\begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = I_{\text{th}}\,\frac{\Gamma^{\downarrow}}{\alpha\,\Gamma^{\downarrow}+N}\begin{bmatrix} \sum_{i=1}^{k_1}\dfrac{1}{g_{1i}} \\ \sum_{i=1}^{k_2}\dfrac{1}{g_{2i}} \end{bmatrix}$$

# CDMA general radio dimensioning (4/)




- Without optimisation:
  - $P_1 = 0.23$ W
  - $P_2 = 1.58$ W
- With directed-retry:
  - $P_1 = 0.27$ W
  - $P_2 = 1.36$ W
  - $\Rightarrow$ interferences $\downarrow \Rightarrow$ capacity $\uparrow$



# CDMA general radio dimensioning (5/)



- Uplink: $$\Gamma_{ji_j}^{\uparrow} = \frac{N_{ji_j}\, p_{ji_j} g_{ji_j}}{I_{\mathrm{th}} + \alpha \sum_{k \neq j} p_{ji_k} g_{ji_k} + \sum_{q \neq j} \sum_{i_q} p_{qi_q} g_{ji_q}}$$

$$p_{ji_j} = \frac{\Gamma_{ji_j}^{\uparrow}}{\alpha\,\Gamma_{ji_j}^{\uparrow} + N_{ji_j}} \frac{1}{g_{ji_j}} \left( I_{\mathrm{th}} + \alpha \sum_{k} p_{ji_k} g_{ji_k} + \sum_{q \neq j} \sum_{i_q} p_{qi_q} g_{ji_q} \right)$$

$$\sum_k p_{ji_k} g_{ji_k} = P_j^R$$

positive!

$$P_j^R \left( 1 - \sum_{i_j=1}^{k_j} \frac{\alpha\,\Gamma_{ji_j}^{\uparrow}}{\alpha\,\Gamma_{ji_j}^{\uparrow} + N_{ji_j}} \right) = I_{\mathrm{th}} \sum_{i_j=1}^{k_j} \frac{\Gamma_{ji_j}^{\downarrow}}{\alpha\,\Gamma_{ji_j}^{\downarrow} + N_{ji_j}} + \sum_{q \neq j} \sum_{i_j=1}^{k_j} \frac{\Gamma_{ji_j}^{\downarrow}}{\alpha\,\Gamma_{ji_j}^{\downarrow} + N_{ji_j}} p_{qi_q} g_{ji_q}$$

- Complexity of the linear system to be solved: in $o\left(Q \times \left[\sum k_j\right]\right)$
- In real networks,
  - the nb of cells, $Q$, $\to \infty$,
  - the nb of MS, $i_q$, $\to \infty$,
- $\Rightarrow$ the size of the linear systems to solve $\to \infty$
- $\Rightarrow$ a new process must be developed, with other parameters…

# CDMA Capacity ↑ (1/)

- Uplink:
  - $\boxed{\alpha=1}$
  - User#$i_j$ load factor in cell#j:
    - *(power received by BS#j from user#i) to (total received power by BS#j) ratio*

$$\eta^{\uparrow}_{ji_j} = \frac{p_{ji_j} g_{ji_j}}{I_{\text{th}} + \sum_q \sum_{i_q} p_{qi_q} g_{ji_q}}$$

  - Cell#j interference ratio:
    - *inter-cell to intra-cell interference ratio*

$$f_j = \frac{\sum_{q \neq j} \sum_{i_q} p_{qi_q} g_{ji_q}}{\sum_{i_j} p_{ji_j} g_{ji_j}}$$

# CDMA Capacity ↑ (2/)

- Cell#j load factor:
  *Sum of all users' load factor (related to cell#j)*

$$\eta_j^{\uparrow} = \sum_q \sum_{i_q} \eta_{ji_q}^{\uparrow} \qquad \Rightarrow \qquad \eta_j^{\uparrow} = \left(1 + f_j\right) \sum_{i_j} \eta_{ji_j}^{\uparrow}$$

- Cell#j noise rise:
  *(total received power by BS#j) to (thermal noise received by BS#j)*

$$NR_j^{\uparrow} = \frac{I_{th} + \sum_q \sum_{i_q} p_{qi_q} g_{ji_q}}{I_{th}} \qquad \Rightarrow \qquad NR_j^{\uparrow} = \frac{1}{1 - \eta_j^{\uparrow}}$$

$$\Rightarrow \quad \boxed{\eta_j^{\uparrow} < 1}$$

Pole capacity: $\eta_j = 1$

# CDMA Capacity ↑ (3/)

- (high loaded network):

$$\eta^{\uparrow}_{ji_j} \sim \frac{\Gamma^{\uparrow}_{ji_j}}{N_{i_j}} \qquad \eta^{\uparrow}_{ji_j} \sim \frac{\Gamma^{\uparrow}_{ji_j}}{N_{i_j}} \varphi_{i_j}$$

user (# $j$) activity factor in the cell (# $i$)

$$\Rightarrow \quad \eta^{\uparrow}_{j} = \left(1+f_j\right)\sum_{i_j} \frac{\Gamma^{\uparrow}_{ji_j}}{N_{i_j}} \varphi_{i_j}$$

*When only 1 available service in cell j:*

$$NR^{\uparrow}_{j} = \frac{1}{1-\left(1+f_j\right) k_j \frac{\Gamma^{\uparrow}}{N}\varphi}$$

$$k^{\uparrow}_{j\ pole} = \frac{1}{\left(1+f_j\right)\frac{\Gamma^{\uparrow}}{N}\varphi}$$

$$k^{\uparrow}_{j\ \max} = \frac{NR^{\uparrow}_{j}-1}{\left(1+f_j\right)\frac{\Gamma^{\uparrow}}{N}\varphi\, NR^{\uparrow}_{j}} = \eta^{\uparrow}_{j}\, k^{\uparrow}_{j\ pole}$$

- individual transmitted power:
  - pole capacity ↔ unlimited transmission power
  - non linear rise with $K_j$

$$p_{ji_j} = NR^{\uparrow}_{j} \frac{I_{\mathrm{th}}}{g_{ji_j}} \frac{\Gamma^{\uparrow}_{ji_j}}{\Gamma^{\uparrow}_{ji_j}+N_{ji_j}}$$

# CDMA Capacity ↑ (4/)

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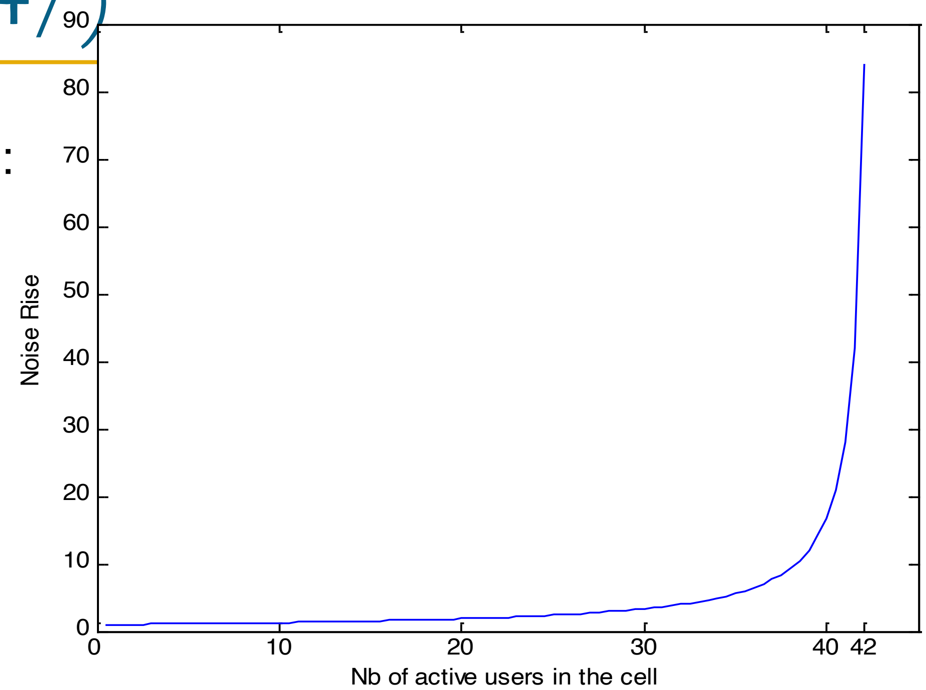
- Example with one service in a cell:
  - $\varphi_{i_j} = \varphi = 0.5$
  - $f_j = 0.55$ [VIT 94]
  - $\Gamma^{\uparrow} = 6$ dB
  - $N = 128$

$$k_{j\ pole}^{\uparrow} =$$

$$NR_j^{\uparrow} = \frac{1}{1 - \frac{k}{41}}$$

$$p_{ji_j} = 0.03\ NR_j^{\uparrow} \frac{I_{\mathrm{th}}}{g_{ji_j}}$$




$$k_j = 1 \Rightarrow p_{ji_j}(1) = 0.03 \frac{I_{th}}{g_{ji_j}}$$

$$k_j = 20 \Rightarrow p_{ji_j}(20) = 1.9\ p_{ji_j}(1)$$

$$k_j = 30 \Rightarrow p_{ji_j}(30) = 3.6\ p_{ji_j}(1)$$

$$k_j = 40 \Rightarrow p_{ji_j}(40) = 40\ p_{ji_j}(1)$$

# CDMA Capacity ↓ (1/)

- Downlink, in cell #j:

  identical BS EIRP: $P$
  - Regular pattern
  - Uniform traffic
  - Similar propagation conditions

  or:
  - Peak hours dimensioning

$$\Rightarrow \Gamma^{\downarrow}_{ji_j} = \frac{N_{ji_j}\, p_{ji_j}\, g_{ji_j}}{I_{\text{th}} + \alpha\left(P - p_{ji_j}\right) g_{ji_j} + P \sum_{q \neq j} g_{qi_j}}$$

$$p_{ji_j} = \frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\, \Gamma^{\downarrow}_{ji_j} + N_{ji_j}} \left[ \frac{I_{\text{th}}}{g_{ji_j}} + \left( \alpha + \underbrace{\frac{\sum_{q \neq j} g_{qi_j}}{g_{ji_j}}}_{f_{i_j}} \right) P \right]$$

$$P = \frac{I_{\text{th}} \sum_{i_j} \frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\, \Gamma^{\downarrow}_{ji_j} + N_{ji_j}} \frac{1}{g_{ji_j}}}{1 - \sum_{i_j} \frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\, \Gamma^{\downarrow}_{ji_j} + N_{ji_j}} \left(\alpha + f_{i_j}\right)}$$

# CDMA Capacity ↓ (2/)



- Introducing the following parameters:
  - $$\eta^{\downarrow}_{ji_j} = \frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\,\Gamma^{\downarrow}_{ji_j} + N_{ji_j}}\left(\alpha + f_{i_j}\right)$$
    $$\Rightarrow \quad \eta^{\downarrow}_{j} = \sum_{i_j} \frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\,\Gamma^{\downarrow}_{ji_j} + N_{ji_j}}\left(\alpha + f_{i_j}\right)\varphi_{i_j}$$

  and

  - $$NR^{\downarrow}_{j} = \frac{1}{1-\eta^{\downarrow}_{j}}$$

*When only 1 available service in cell j:*

$$NR^{\downarrow}_{j} = \frac{1}{1-\left(\alpha + f_j\right)k_j \dfrac{\Gamma^{\downarrow}}{\alpha\,\Gamma^{\downarrow} + N}\varphi}$$

$$k^{\downarrow}_{j\ pole} = \frac{\alpha\,\Gamma^{\downarrow} + N}{\Gamma^{\downarrow}\left(\alpha + f_j\right)\varphi}$$

$$k^{\downarrow}_{j\max} = \frac{NR^{\downarrow}_{j} - 1}{\dfrac{\Gamma^{\downarrow}}{\alpha\,\Gamma^{\downarrow} + N}\left(\alpha + f_j\right)\varphi\, NR^{\downarrow}_{j}}$$
$$= \eta^{\downarrow}_{j}\ \ k^{\downarrow}_{j\ pole}$$

The BS EIRP becomes:

$$P = NR^{\downarrow}_{j}\ I_{\mathrm{th}} \sum_{i_j} \frac{\Gamma^{\downarrow}_{ji_j}}{\alpha\,\Gamma^{\downarrow}_{ji_j} + N_{ji_j}}\,\frac{1}{g_{ji_j}}$$

# CDMA Capacity ↓ (3/)

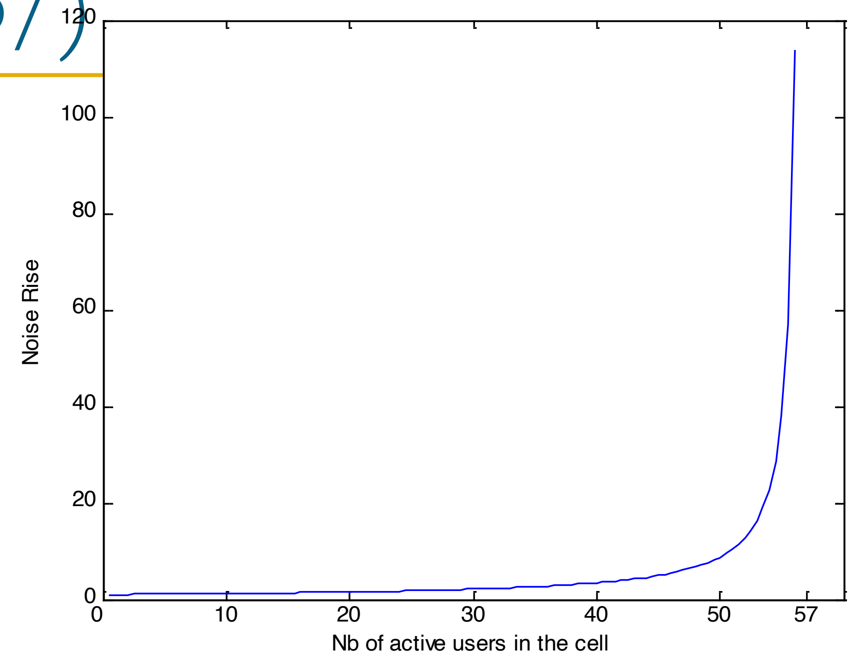


- Example:
  - $\varphi_{i_j} = \varphi = 0.5$
  - $f_j = 0.55$ [VIT 91]
  - $\Gamma^{\downarrow} = 6$ dB
  - $N = 128$
  - $\alpha = 0.6$

$$k^{\downarrow}_{j\ pole} =$$

$$NR^{\downarrow}_j = \frac{1}{1 - \frac{k_j}{56}}$$

$$P = 0.03\ NR^{\downarrow}_j\ I_{\text{th}} \sum_{i_j} \frac{1}{g_{ji_j}}$$




$$k_j = 1 \Rightarrow P(1) = 0.031 \frac{I_{th}}{g_{ji_j}}$$

$$k_j = 20 \Rightarrow P(20) = 0.047\ I_{th} \sum_{i_j} \frac{1}{g_{ji_j}}$$

$$k_j = 30 \Rightarrow P(30) = 0.066\ I_{th} \sum_{i_j} \frac{1}{g_{ji_j}}$$

$$k_j = 40 \Rightarrow P(40) = 0.1\ I_{th} \sum_{i_j} \frac{1}{g_{ji_j}}$$

# CDMA Capacity - ↓↑

- Function of the cell's load $NR_j$, maximal number $k_j$ of users in the cell #$j$ in case of multiservices:
  - $k_{s,j}$ is the number of users for service #$s$ in the cell #$j$,
  - $k_{\%s,j}$ is the proportion of users for service #$s$ in the cell #$j$,
  - $N_s$, $\varphi_s$, $\Gamma_s$ are the characteristics of service #$s$,

$$k_j = \sum_s k_{s,j}$$

$$k_{\%s,j} = \frac{k_{s,j}}{k_j}$$

$$NR_j^{\uparrow} = \frac{1}{1 - \sum_{ij} \frac{\Gamma_{ji_j}^{\uparrow}}{N_{ji_j}} \left(1 + f_{i_j}\right) \varphi_{i_j}} = \frac{1}{1 - \left(1 + f_j\right) \sum_s k_{s,j} \frac{\Gamma_s^{\uparrow}}{N_s} \varphi_s}$$

$$NR_j^{\uparrow} = \frac{1}{1 - \left(1 + f_j\right) k_j \sum_s k_{\%s,j} \frac{\Gamma_s^{\uparrow}}{N_s} \varphi_s}$$

$$NR_j^{\downarrow} = \frac{1}{1 - \sum_{ij} \frac{\Gamma_{ji_j}^{\downarrow}}{\alpha\, \Gamma_{ji_j}^{\downarrow} + N_{ji_j}} \left(\alpha + f_{i_j}\right) \varphi_{i_j}} = \frac{1}{1 - \left(\alpha + f_j\right) \sum_s k_{s,j} \frac{\Gamma_s^{\downarrow}}{\alpha\, \Gamma_s^{\downarrow} + N_s} \varphi_s}$$

$$NR_j^{\downarrow} = \frac{1}{1 - \left(\alpha + f_j\right) k_j \sum_s k_{\%s,j} \frac{\Gamma_s^{\downarrow}}{\alpha\, \Gamma_s^{\downarrow} + N_s} \varphi_s}$$

# CDMA Capacity - ↓↑

$$k_{j\,\max}^{\uparrow} = \frac{NR_j^{\uparrow} - 1}{NR_j^{\uparrow}\left(1 + f_j\right)\sum_s k_{\%s,j} \frac{\Gamma_s^{\uparrow}}{N_s} \varphi_s}, \quad k_{j\,pole}^{\uparrow} = \frac{1}{\left(1 + f_j\right)\sum_s k_{\%s,j} \frac{\Gamma_s^{\uparrow}}{N_s} \varphi_s}$$

$$k_{j\,\max}^{\downarrow} = \frac{NR_j^{\downarrow} - 1}{NR_j^{\downarrow}\left(\alpha + f_j\right)\sum_s k_{\%s,j} \frac{\Gamma_s^{\downarrow}}{\alpha\,\Gamma_s^{\downarrow} + N_s} \varphi_s}, \quad k_{j\,pole}^{\downarrow} = \frac{1}{\left(\alpha + f_j\right)\sum_s k_{\%s,j} \frac{\Gamma_s^{\downarrow}}{\alpha\,\Gamma_s^{\downarrow} + N_s} \varphi_s}$$

For a given $\Gamma_s$, $k_j^{\downarrow} > k_j^{\uparrow}$ because:

- Intercorrelation is equal to 1 on the ↑
- Hugh load is assumed on the ↑ (assumption not essential for the ↓)

However, usually, $\Gamma_s^{\downarrow} \ll \Gamma_s^{\uparrow}$ and therefore $k_j^{\downarrow} \ll k_j^{\uparrow}$

# CDMA Capacity - ↓↑

- Cell breathing (illustration with only one available service in the cell)
  - downlink:

$$\sum_{i_j} \frac{1}{g_{ji_j}} = \frac{\alpha\,\Gamma^{\downarrow} + N}{NR_j^{\downarrow}\, I_{\mathrm{th}}\, \Gamma^{\downarrow}} P$$

when the load increases:

- the nb of simultaneous users decreases

or

- their channel gain increase

Cell breathing:
when the cell's load ↑,
the cell's size ↓

- uplink:

$$g_{\min} = NR_j^{\uparrow} \frac{I_{\mathrm{th}}}{p_{\max}} \frac{1}{1 + \frac{N}{\Gamma^{\uparrow}}}$$

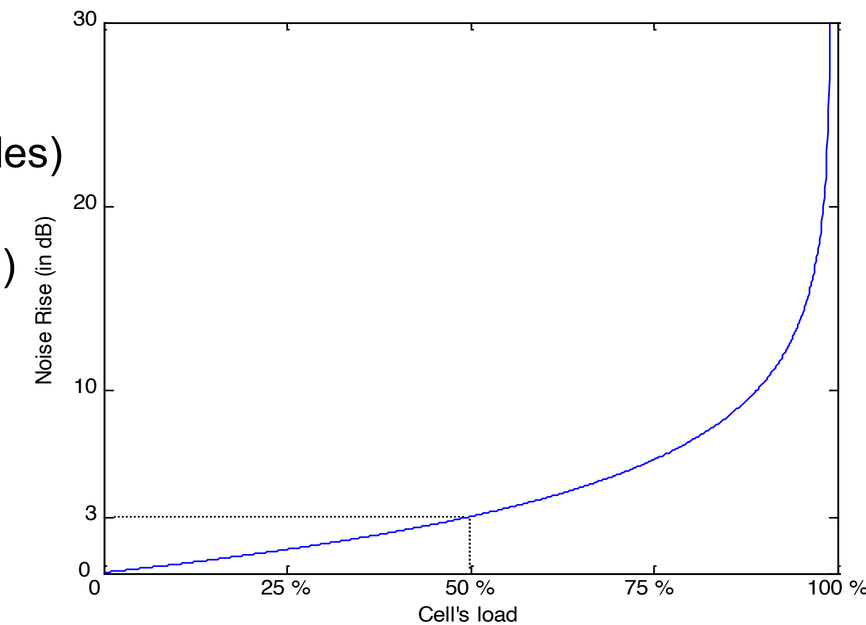
when the load increases, $g_{min}$ increases

# Radio Link Budget: Parameters

$$\Gamma_i = \frac{N_i \; p_i \; g_i}{I_{\text{th}} + I_{\text{intra } i} + I_{\text{inter } i}} \sim \frac{N_i \; p_i \; g_i}{I_{\text{th}} \; NR_i}$$

$$\frac{E_b}{N_0} = \frac{N_i \; p_i \; g_i}{I_{\text{th}} \; NR_i} \left(\frac{GA}{LO}\right)_{Rx} \frac{1}{F_{Rx}}$$

- Interference margin (Noise Rise)
  – typical values: 1-3 dB
- Receiver Noise Figure (C/I degradation)
  – typical values: 5 (BS) - 9 (MS) dB
- Additional margins:
  - Fast fading margin (slow moving mobiles)
    – typical values: 2-5 dB
  - Soft HO gain (fight against slow fading)
    – typical values: 2-3 dB
  - Incar loss
    – typical values: 8 dB
  - Indoor loss
    – typical values: 15 dB
  - …



# Outdoor voice service (RT)



| | | |
|---|---|---|
| Throughput (kbps) | 12,2 | *a* |
| Spreading Factor | 128 | *b* |
| Processing Gain (dB) | 21 | *c* |
| Required Eb/N0 (dB) | 5 | *d* |
| Thermal Noise (dBm/Hz) | -174 | *e* |
| Noise rise (50% load) (dB) | 3 | *f* |
| Fast Fading margin (dB) | 4 | *g* |
| Soft HO gain (dB) | 3 | *h* |

| BS: | | |
|---|---|---|
| Noise figure (dB) | 5 | *i* |
| Antenna Gain (dBi) | 18 | *j* |
| Cable Loss (dB) | 2 | *k* |
| Max. transmission power (W) | 20 | *l* |

| MS: | | |
|---|---|---|
| Noise figure (dB) | 9 | *m* |
| Antenna Gain + Cable loss (dB) | 0 | *n* |
| Body loss (dB) | 3 | *o* |
| Max. transmission power (W) | 0,125 | *p* |

*To be checked with equipment characteristics*

| UPLINK | |
|---|---|
| **BS** | |
| I+N (dBm) | -100 |
| Rec. Threshold (dBm) | -132 |
| **MS** | |
| EIRP (dB) | -12 |
| Path Loss (dB) | 150 |
| Propagation Loss (dB) *(Fast Fading, Soft HO)* | 149 |

| DOWNLINK | |
|---|---|
| **MS** | |
| I+N (dBm) | -93 |
| Rec. Threshold (dBm) | -109 |
| **BS** | |
| EIRP (dB) | 29 |
| Path Loss (dB) | 168 |
| Propagation Loss (dB) *(Fast Fading, Soft HO)* | 167 |
| BS Trans. power (W) | 0,314 |

***314 mW is the BS Tx power dedicated to a MS at the edge (2.7 km) of a 50% loaded cell***

Okumura-Hata propagation law:

- f=2000, Hb=40, hm=1.5;
- ahm = (3.2*(log10(11.75*hm)).^2-4.97);
- LfHb = 69.55+26.16*log10(f)-13.82*log10(Hb)-ahm;
- LHb = 44.9-6.55*log10(Hb);

$\Rightarrow L(r) = 10^{LfHb/10}\, r^{LHb/10}$

$\Rightarrow D_{Tx\text{-}Rx} = 2.7$ km

# Indoor 144 kbps data service (NRT) – no soft HO



| | | |
|---|---|---|
| Throughput (kbps) | 144,0 | *a* |
| Spreading Factor | 32 | *b* |
| Processing Gain (dB) | 15 | *c* |
| Required Eb/N0 (dB) | 1,5 | *d* |
| Thermal Noise (dBm/Hz) | -174 | *e* |
| Noise rise (50% load) | 3 | *f* |
| Fast Fading margin (dB) | 4 | *g* |
| Indoor loss (dB) | 15 | *h* |

| | | |
|---|---|---|
| BS: | | |
| Noise figure (dB) | 5 | *i* |
| Antenna Gain (dBi) | 18 | *j* |
| Cable Loss (dB) | 2 | *k* |
| Max. transmission power (W) | 20 | *l* |

| | | |
|---|---|---|
| MS: | | |
| Noise figure (dB) | 9 | *m* |
| Antenna Gain + Cable loss (dB) | 0 | *n* |
| Body loss (dB) | 3 | *o* |
| Max. transmission power (W) | 0,125 | *p* |

**UPLINK**

| | |
|---|---|
| **BS** | |
| I+N (dBm) | -100 |
| Rec. Threshold (dBm) | -129,5 |
| | |
| **MS** | |
| EIRP (dB) | -12 |
| Path Loss (dB) | 147,5 |
| Propagation Loss (dB) *(Fast Fading, Soft HO)* | 128,5 |

**DOWNLINK**

| | |
|---|---|
| **MS** | |
| I+N (dBm) | -93 |
| Rec. Threshold (dBm) | -106,5 |
| | |
| **BS** | |
| EIRP (dB) | 29 |
| Path Loss (dB) | 165,5 |
| Propagation Loss (dB) *(Fast Fading, Soft HO)* | 146,5 |
| BS Trans. power (W) | 0,314 |

***314 mW is the BS Tx power dedicated to a MS at the edge (0.7 km) of a 50% loaded cell***

Okumura-Hata propagation law:

- f=2000, Hb=40, hm=1.5;
- ahm = (3.2*(log10(11.75*hm)).^2-4.97);
- LfHb = 69.55+26.16*log10(f)-13.82*log10(Hb)-ahm;
- LHb = 44.9-6.55*log10(Hb);

$\Rightarrow L(r) = 10^{LfHb/10}\ r^{LHb/10}$

$\Rightarrow D_{Tx\text{-}Rx} = 0.7$ km

# Outdoor 384 kbps data service (NRT) – no soft HO



| | | |
|---|---|---|
| Throughput (kbps) | 384,0 | *a* |
| Spreading Factor | 8 | *b* |
| Processing Gain (dB) | 9 | *c* |
| Required Eb/N0 (dB) | 1 | *d* |
| Thermal Noise (dBm/Hz) | -174 | *e* |
| Noise rise (50% load) | 3 | *f* |
| Fast Fading margin (dB) | 4 | *g* |

| | | |
|---|---|---|
| BS: | | |
| Noise figure (dB) | 5 | *i* |
| Antenna Gain (dBi) | 18 | *j* |
| Cable Loss (dB) | 2 | *k* |
| Max. transmission power (W) | 20 | *l* |

| | | |
|---|---|---|
| MS: | | |
| Noise figure (dB) | 9 | *m* |
| Antenna Gain + Cable loss (dB) | 0 | *n* |
| Body loss (dB) | 3 | *o* |
| Max. transmission power (W) | 0,125 | *p* |

**UPLINK**

| | |
|---|---|
| **BS** | |
| I+N (dBm) | -100 |
| Rec. Threshold (dBm) | -124 |
| **MS** | |
| EIRP (dB) | -12 |
| Path Loss (dB) | 142 |
| Propagation Loss (dB) | 138 |
| *(Fast Fading, Soft HO)* | |

**DOWNLINK**

| | |
|---|---|
| **MS** | |
| I+N (dBm) | -93 |
| Rec. Threshold (dBm) | -101 |
| **BS** | |
| EIRP (dB) | 29 |
| Path Loss (dB) | 160 |
| Propagation Loss (dB) | 156 |
| *(Fast Fading, Soft HO)* | |
| BS Trans. power (W) | 0,314 |

***314 mW is the BS Tx power dedicated to a MS at the edge (1.3 km) of a 50% loaded cell***

Okumura-Hata propagation law:

- f=2000, Hb=40, hm=1.5;
- ahm = (3.2*(log10(11.75*hm)).^2-4.97);
- LfHb = 69.55+26.16*log10(f)-13.82*log10(Hb)-ahm;
- LHb = 44.9-6.55*log10(Hb);

$\Rightarrow L(r) = 10^{LfHb/10}\, r^{LHb/10}$

$\Rightarrow D_{Tx\text{-}Rx}$ = 1.3 km

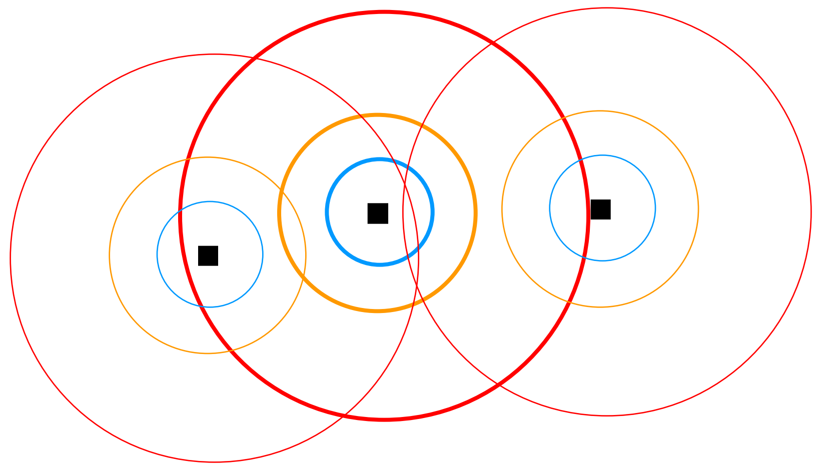
# Conclusion 1/

- The link budget gives :
  - the BS Tx power allocated to the considered MS (at the cell's edge) ***-5 dB***
  - the considered MS Tx power and/or EIRP ***-12 dB***
  - the propagation loss ***149 dB***
  - the reception threshold at the RX antenna input for a perfect Power Control ***-132 dBm ↑, -109 dBm ↓***

- From the link budget we can deduce :
  - the maximum Tx-Rx distance ***2,7 km***
  - the maximum nb of simultaneously active users $k_j^{\downarrow} = 2$ $k_j^{\uparrow} = 274$
  - the BS EIRP ***≤ 2x12,5 = 25 W (for two MS at the edge of the cell)***
  - the BS Tx power ***≤ 2x314 mW = 628 mW (for two MS at the edge of the cell)***

# Conclusion 2/

- Radio coverage planning:
  Voice 12.2 kbps / 384 kbps (outdoor) / 144 kbps (indoor)



- Traffic coverage planning:
  - To be checked with the geo-marketing data

# General Conclusion

- Dimensioning process:
  - Link budgets are established, considering a specific cell's load (50 %)
    $\Rightarrow$ some service areas appear in the considered zone
  - Densification can be decided, depending on the marketing data targets
  - Outputs:
    BS configurations, estimation of the amount of network equipments, coverage analysis, capacity estimation
- Radio Resource Management:
  - many RRM algorithms exist:
    FIFO, RT / NRT, max. throughput, max. MS, etc
  - operator & zone -dependant

# Case Study