3GPP Long Term Evolution eUTRAN

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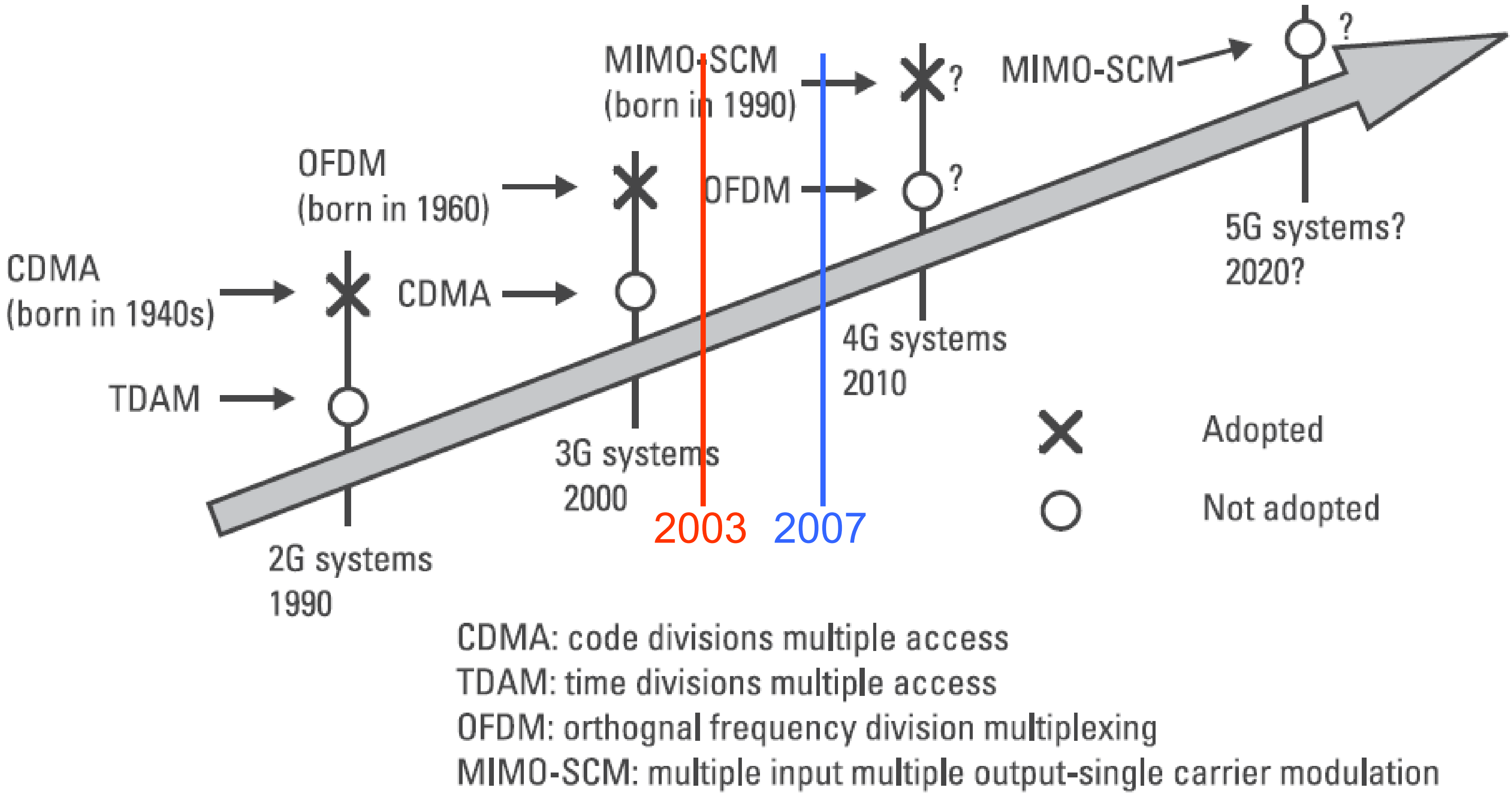
KTL FEI STU

2009

Agenda

- OFDM vs. CDMA
- LTE candidates
- Details of LTE design
- SAE/EPC
- LTE-Advanced

CDMA vs. OFDM



Ramjee Prasad, 2003

3GPP Feasibility Study

"The studies carried out within the study item indicates that the basic OFDM scheme offers the possibility for improved performance, compared to HSDPA release 5 with a Rake receiver, for channels with significant time dispersion. This performance advantage decreases for channels with less time dispersion. However, by the introduction of more advanced receiver structure, there is **no significant performance** difference between HSDPA release 5 and the performance of the OFDM."

3GPP TR 25.892

Texas Instruments

"With larger channel bandwidths, OFDM offers **advantage** over CDMA because of simplified receiver processing: 10 MHz, 20 MHz."

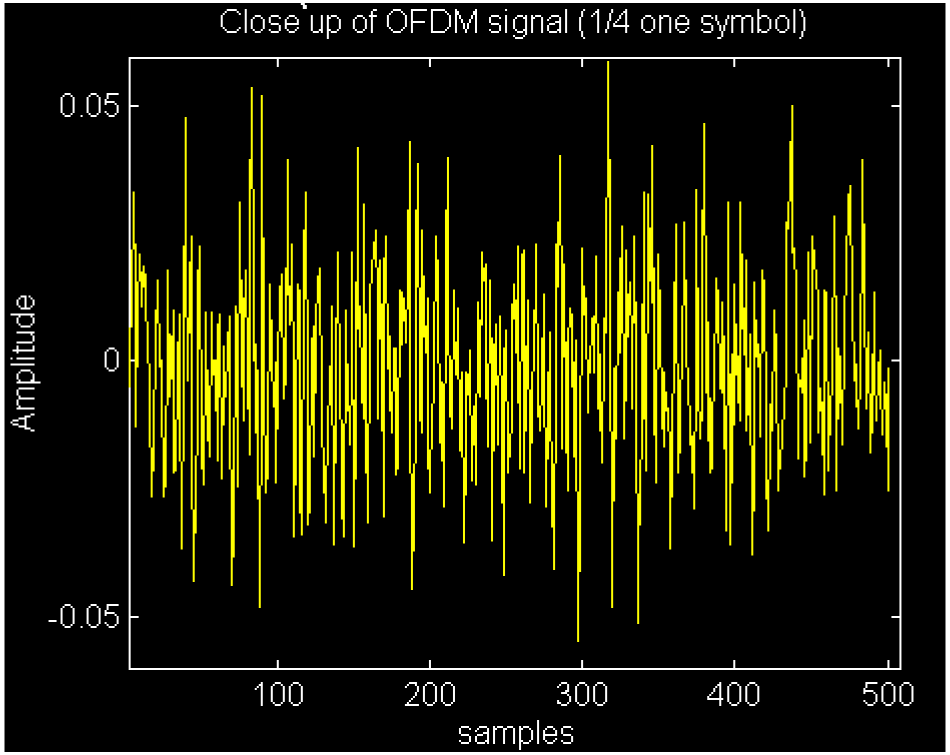
Not so fast…

- OFDMA
- MC-CDMA
- SC modulation (spread / not spread)

OFDM/OFDMA

PROS	CONS
• Resistance in frequency selective channels • ISI & ICI reduction • Simple equalization • Less sensitive to timing offsets • Resistance to NB interference • Spectrum efficiency • Spectrum flexibility	• Sensitive to frequency offsets & phase noise • Large PAPR

OFDM signal – time view



Peak power = **N** * average power (for N subcarriers)

MC-CDMA

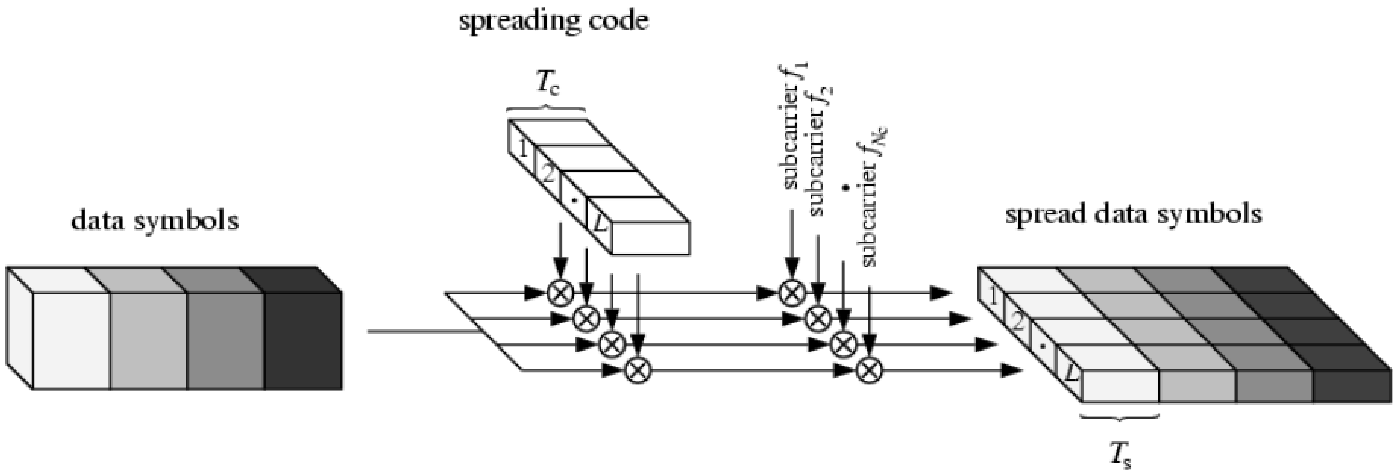
PROS

- Similar to OFDM
  - Multipath resistance
  - Flexible
  - Simple timing synchronization
  - Frequency diversity
- PAPR can be reduced by code allocation

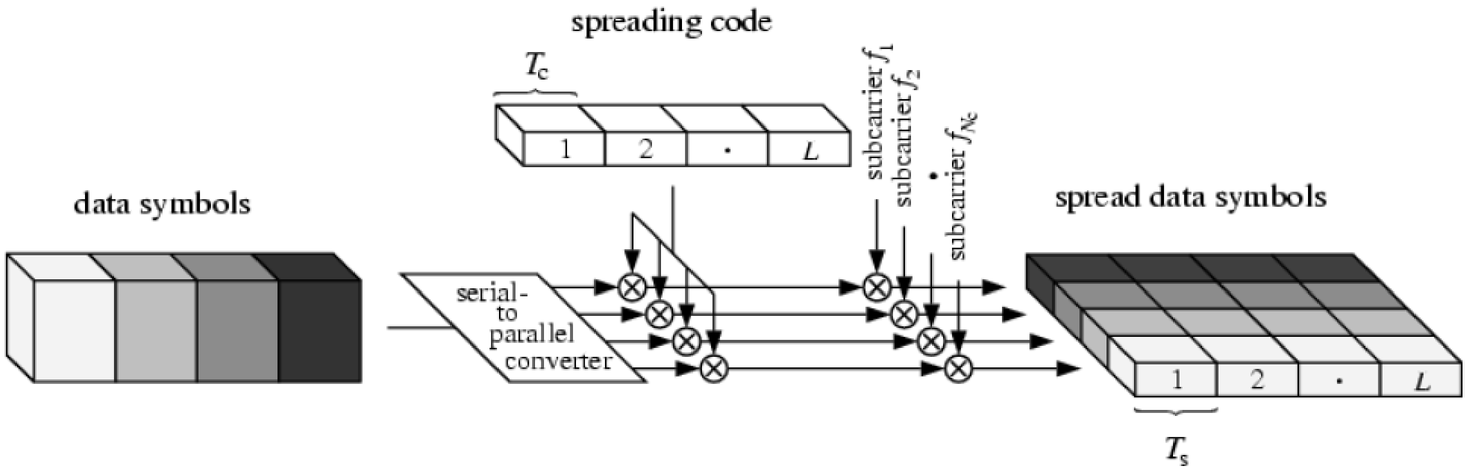
CONS

- Sensitive to frequency offsets & phase noise
- PAPR > Single carrier modulation

MC-CDMA

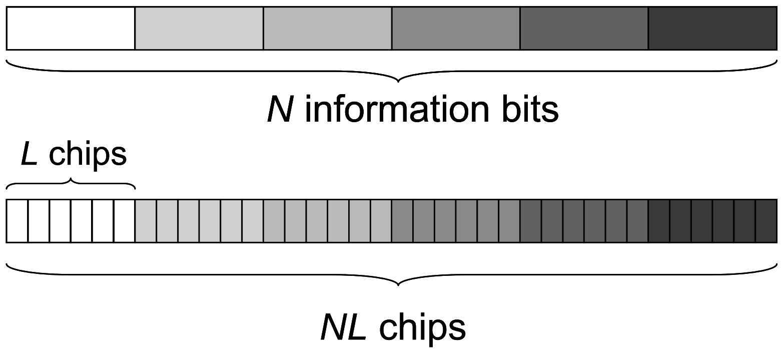

spreading code
T_c
1
2
L
subcarrier f_1
subcarrier f_2
subcarrier f_{N_c}
data symbols
spread data symbols
1
2
L
T_s

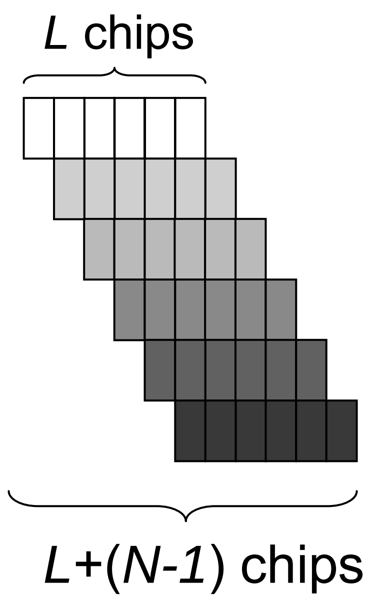
MC-DS-CDMA



spreading code
T_c
1
2
·
L
data symbols
serial-to parallel converter
subcarrier f_1
subcarrier f_2
subcarrier f_{N_c}
spread data symbols
1
2
·
L
T_s

Complementary code CDMA

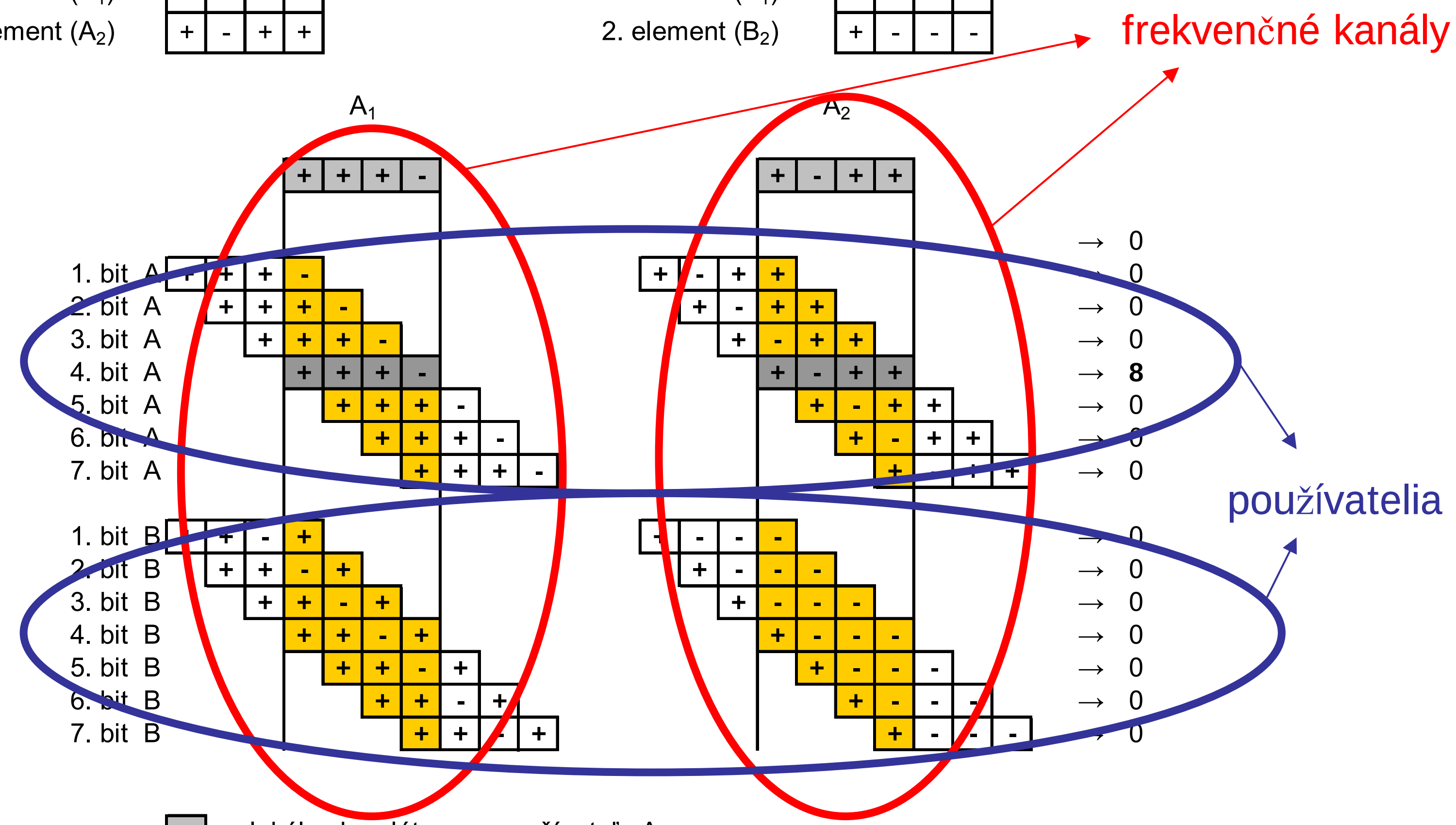




Complementary codes

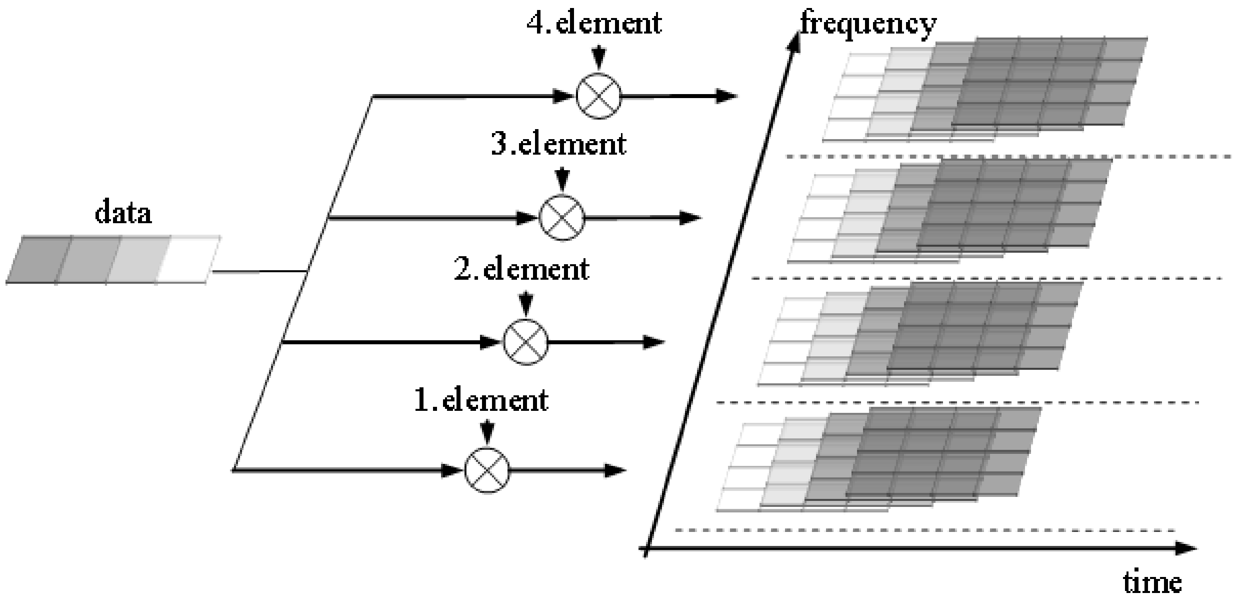
	1. signatúra			
1. element (A_1)	+	+	+	-
2. element (A_2)	+	-	+	+

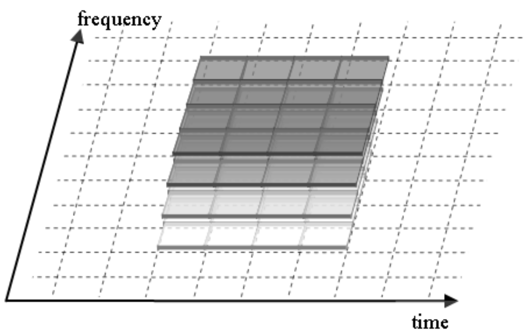
	2. signatúra			
1. element (B_1)	+	+	-	+
2. element (B_2)	+	-	-	-

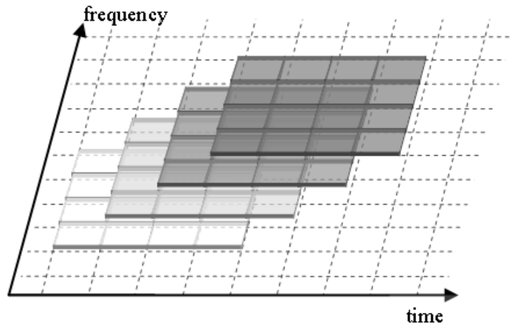


lokálny korelátor pre používateľa A
interferencia
požadovaný bit
čipy, ktoré nemajú vplyv

2D Complementary codes

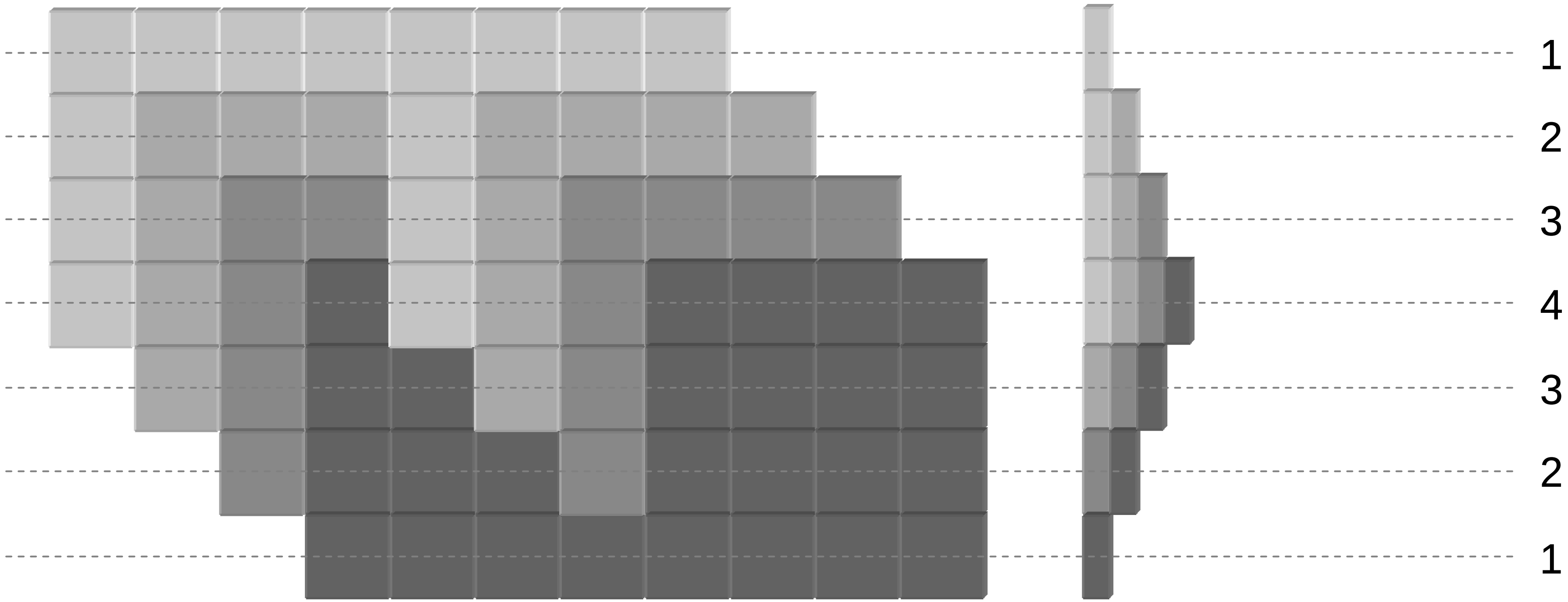






Transmission strategies

diagonal – 1 user



Single carrier modulation

Spread (SC-DS-CDMA)

- Pros
  - Low PAPR
  - Multipath fading resistance
  - NB, WB interference rejection
- Cons
  - Advanced receivers
  - MAI if not synchronized

TDMA / DFT-spread OFDMA

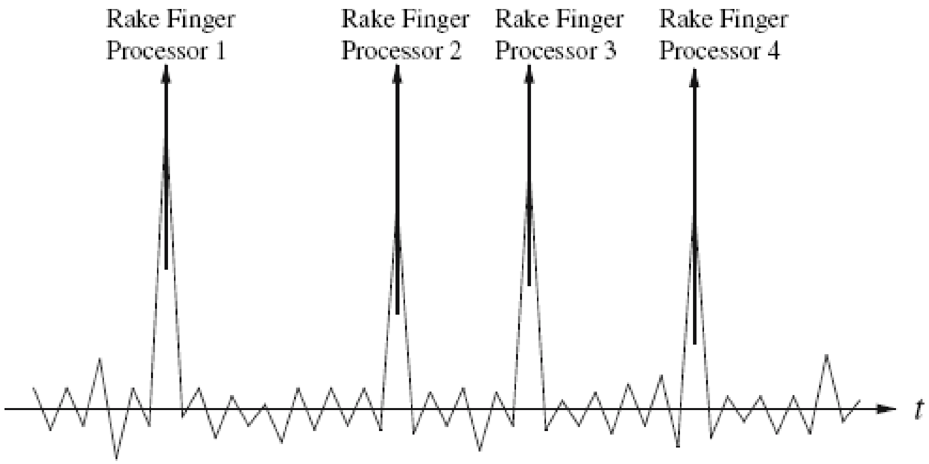
- Pros
  - Spectrum flexibility
  - Low PAPR
  - Intra cell orthogonality in time & frequency
- Cons
  - Advanced receivers
  - Tight frequency synchronization

Why not CDMA?

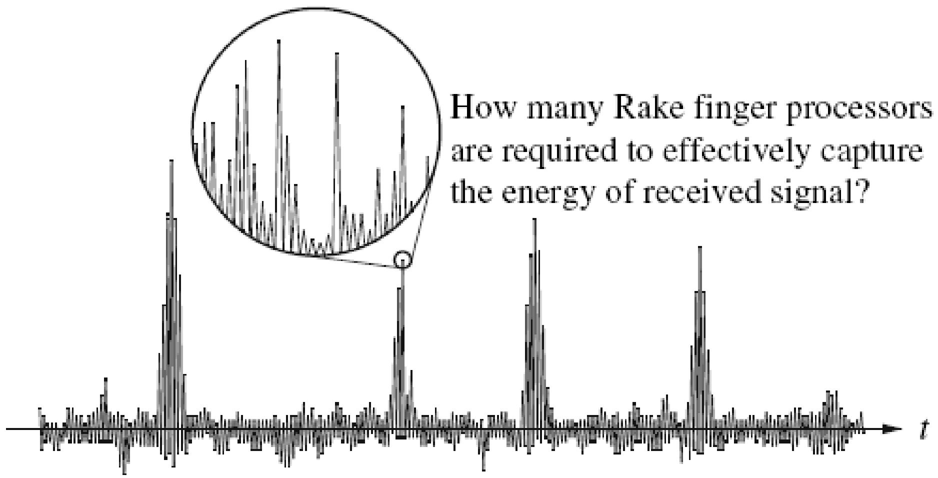
$$R_x \text{ paths} = \frac{T_{\text{delay spread}}}{T_{\text{chip}}} + 1$$

@ 1,8 GHz $T_{\text{delay spread}}$ = 8 µsec

- Time domain equalization
  - not feasible for chip rates > ~ Mcps

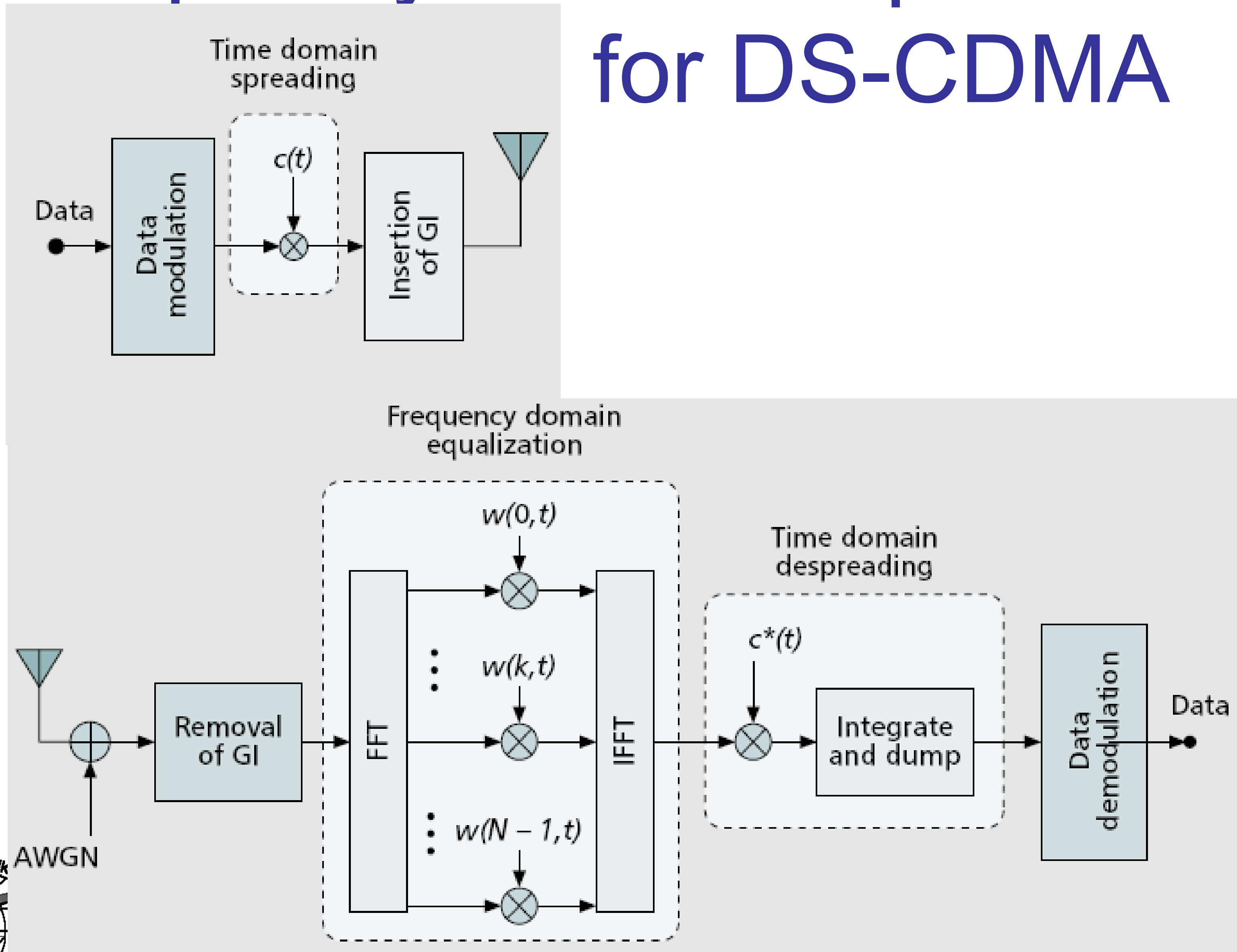


Matched filter output for the case of 2Mchips/sec



Matched filter output for the case of 100Mchips/sec

Frequency domain equalization for DS-CDMA



OFDM vs. CDMA

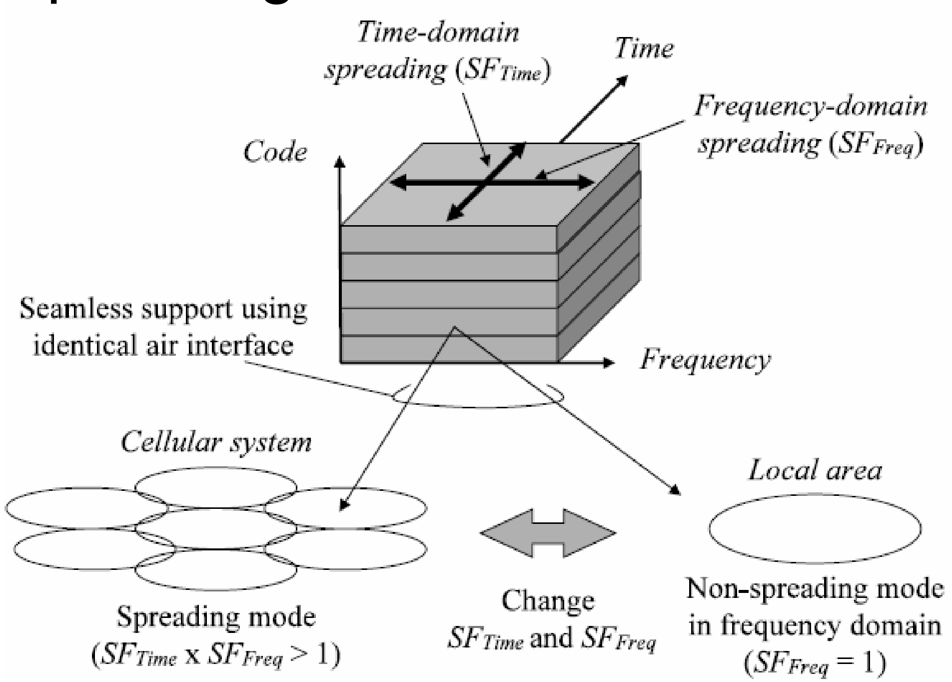
- always look for fair comparison
- take into account application & environment

- for 20 MHz channel, mobile usage, @ GHz carrier, multiple users & current technology capabilities
  - OFDM offers better (smaller) granularity
    - more efficient scheduling & resource utilization
  - OFDM gives better flexibility
    - scalable bandwidth
  - OFDM is better suited for MIMO
    - flat fading due to low rate parallel sub-channels

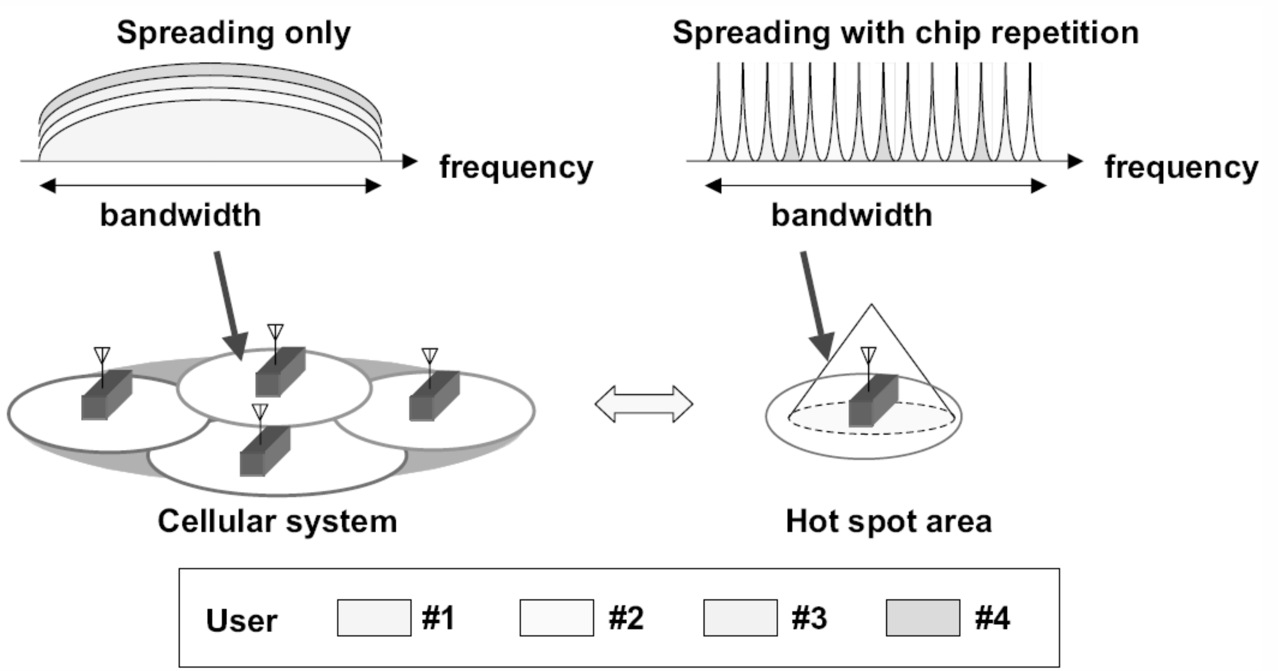
Way forward?

- NTT DoCoMo
- DL = VSF-OFCDM with 2D spreading
- UL = VSCRF-CDMA
- 64 QAM
- 12x12 MIMO

= 5 Gbps in 100 MHz (2007)



VSCRF-CDMA



Spreading only
frequency
bandwidth
Spreading with chip repetition
frequency
bandwidth
Cellular system
Hot spot area
User
#1
#2
#3
#4

LTE

S T U

3GPP candidates

- **Downlink**
  - OFDMA [FDD/TDD]
  - MC-WCDMA [FDD]
  - MC-TD-SCDMA [TDD]

$$960kchip/s = \frac{3{,}84Mchip/s}{5MHz} \cdot 1{,}25MHz$$

- **Uplink**
  - SC-FDMA [FDD/TDD]
  - OFDMA [FDD/TDD)
  - MC-WCDMA [FDD]
  - MC-TD-SCDMA [TDD]

Why LTE?

- 3 competing standards

LTE

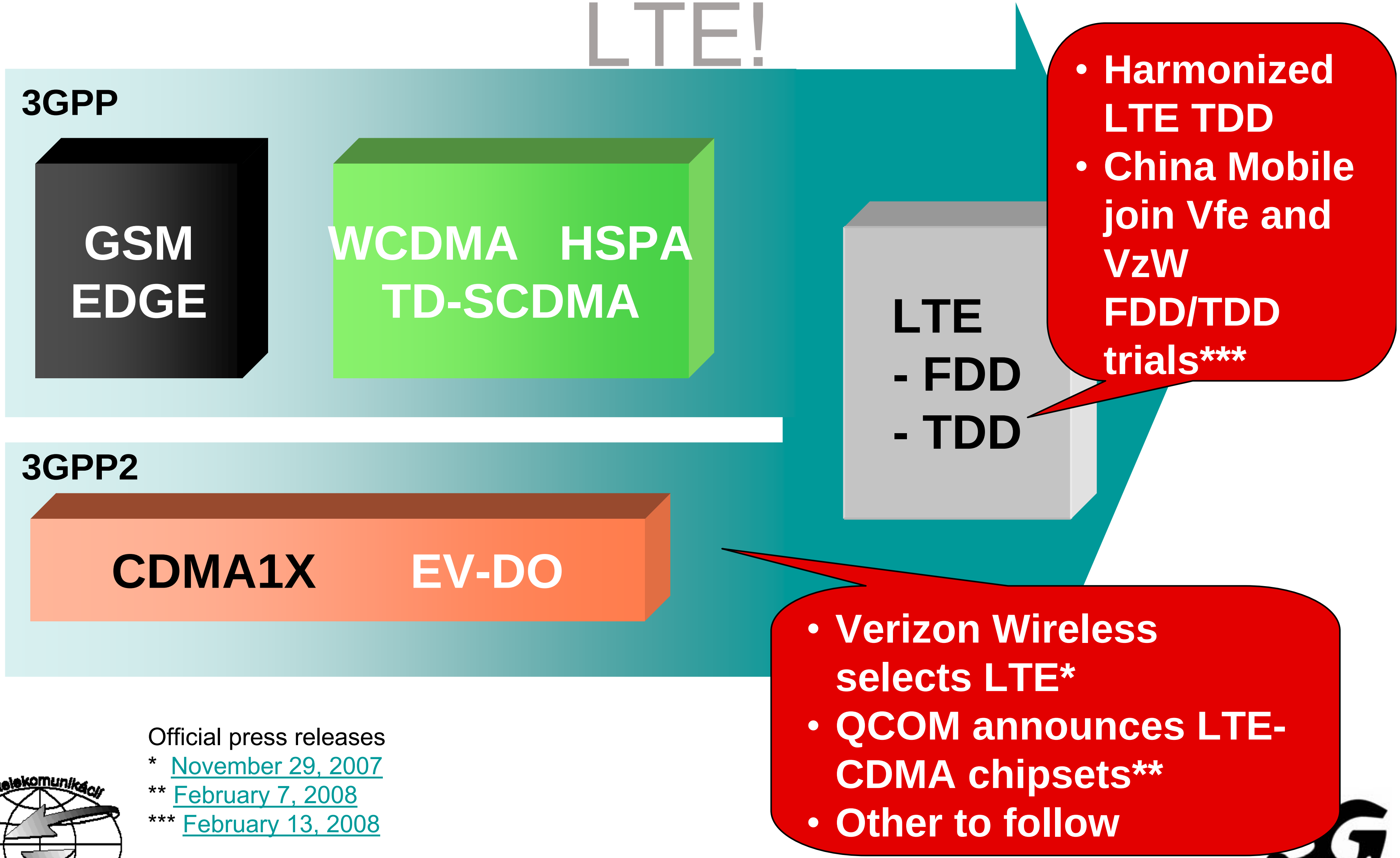
UMB

WiMAX

R.I.P.

2007-2008

Market situation – that's why LTE!



Official press releases
* November 29, 2007
** February 7, 2008
*** February 13, 2008

Concepts

Concepts - Terminology

- LTE = Long Term Evolution (of UTRAN)
- SAE = System Architecture Evolution (of Core)

} studies

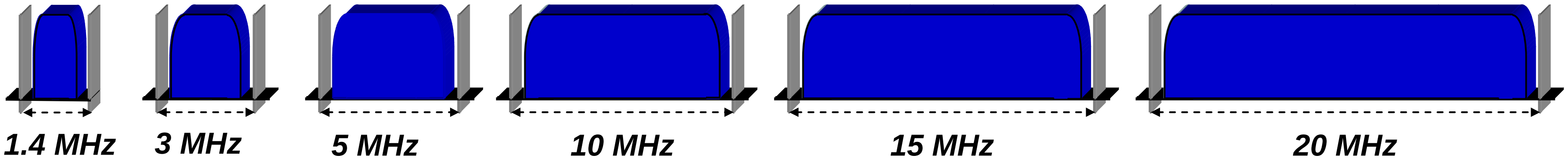
LTE resulted in E-UTRAN (Evolved UTRAN)
SAE resulted in EPC (Evolved Packet Core)

E-UTRAN + EPC = EPS (Evolved Packet System)

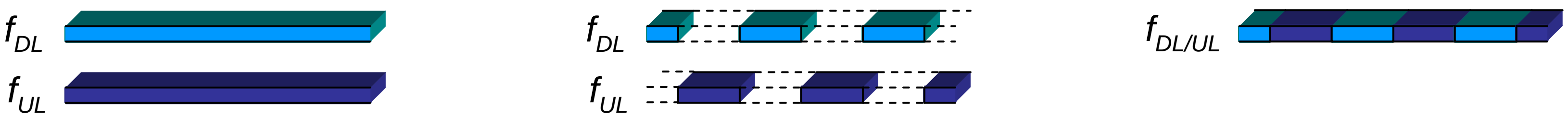
3GPP LTE – *Requirements/targets*

- **Focus on PS-domain services**
- **High data rates**
  - *Peak data rates:* Beyond 100 Mbps (DL) / Beyond 50 Mbps (UL)
  - *Average user throughput:* 3-4 times HSPA Release 6
  - *Cell-edge user throughput:* 2-3 times HSPA Release 6
- **Low latency**
  - *User plane:* Less than 10 ms (RAN RTT)
  - *Control place:* Less than 50 ms (dormant $\rightarrow$ active)
- **High spectral efficiency**
  - 3-4 times HSPA Release 6
  - Improved performance for broadcast services
- **Spectrum flexibility**
  - Deployable in a wide-range of different spectrum allocations of different sizes
  - Unpaired and paired spectrum

Spectrum / duplex flexibility



FDD | **Combined FDD/TDD** | **TDD**

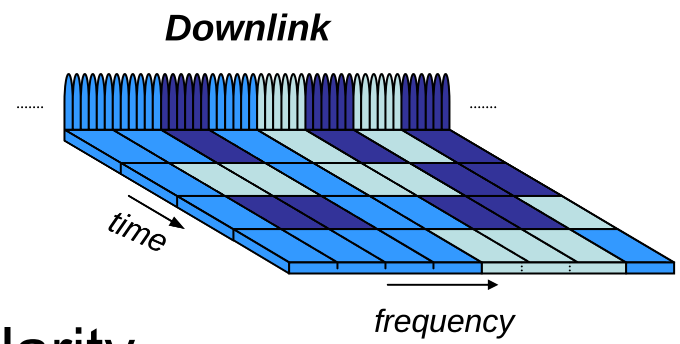


Highest data rates for given bandwidth and peak power

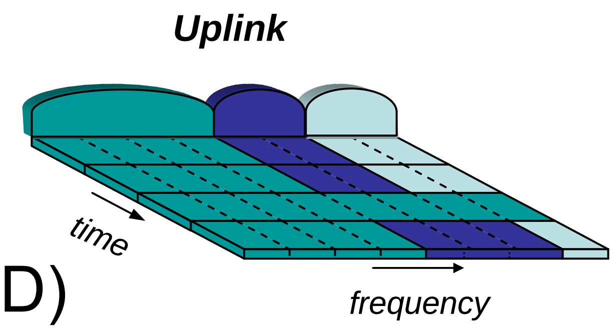
Reduced UE complexity

Unpaired spectrum

Key principles



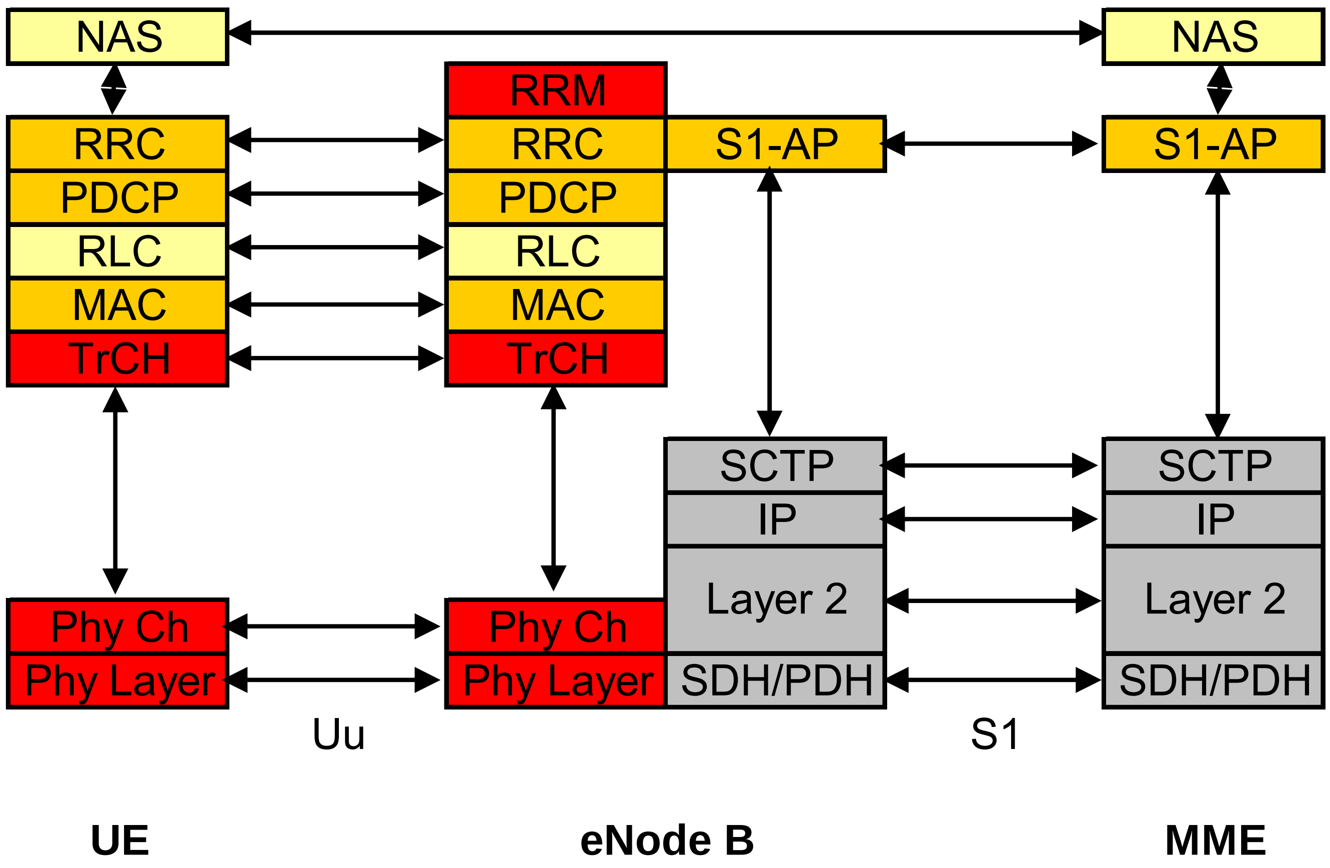
- OFDM on physical layer
- 1 ms / 180 kHz scheduling granularity
- Advanced Antenna System (MIMO, beamforming, …)



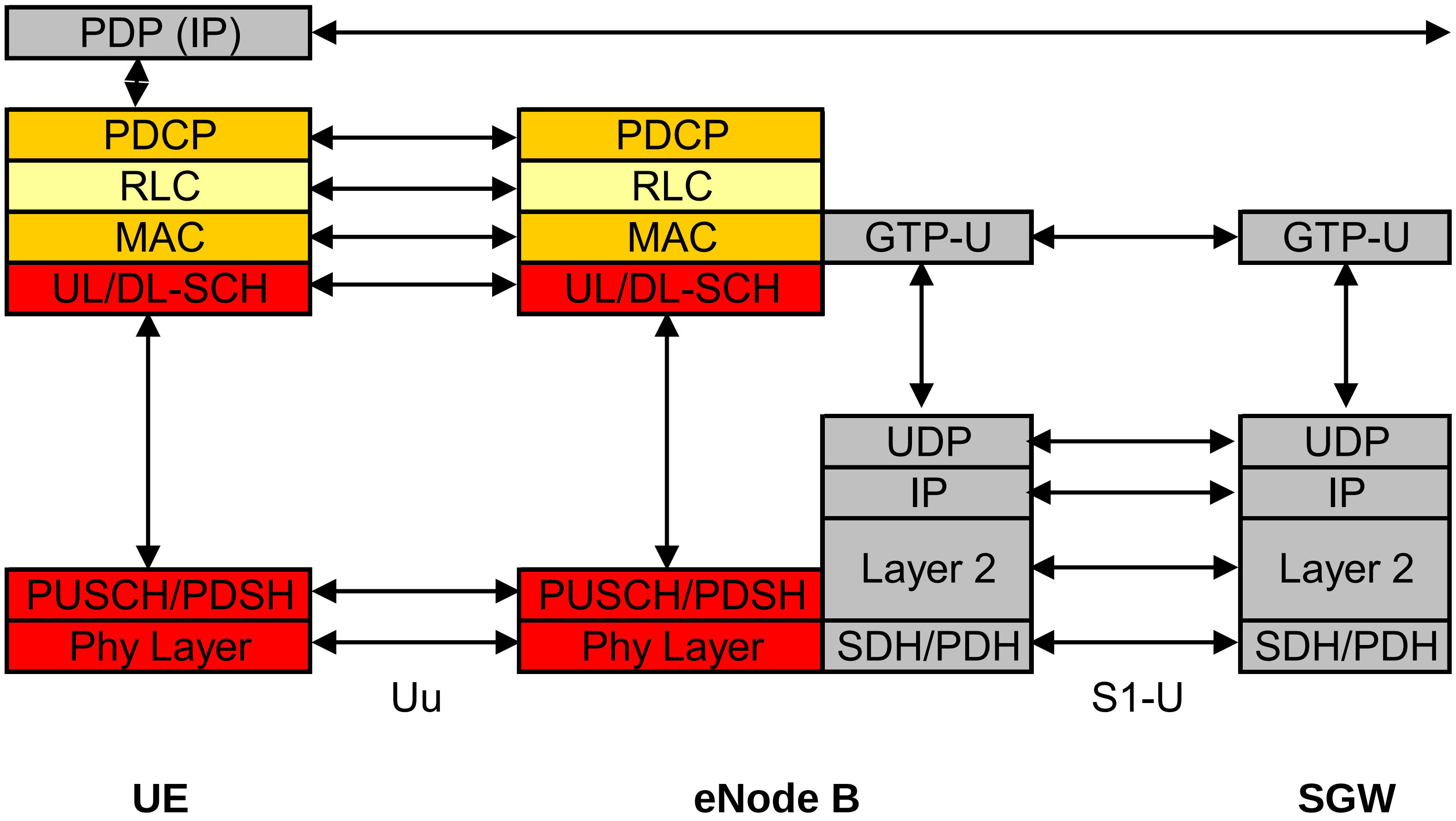
- 1 Node RAN architecture
- 1 phase access (UE → eNB → CN)
- 2 RRC states only (IDLE, CONNECTED)

- Signaling / user data split in CN (MME, SGW)

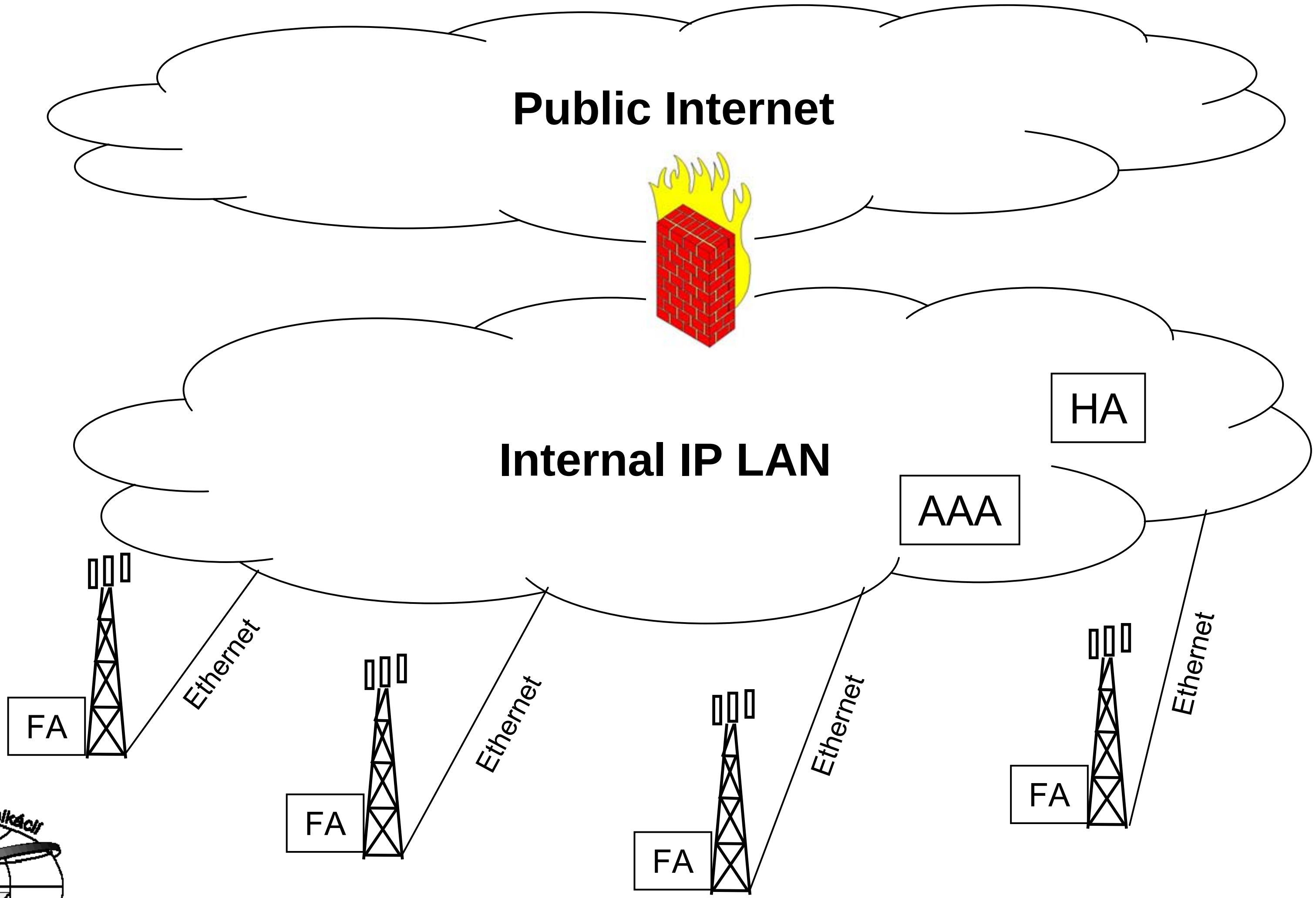
Protocol model – control plane



Protocol model – user plane

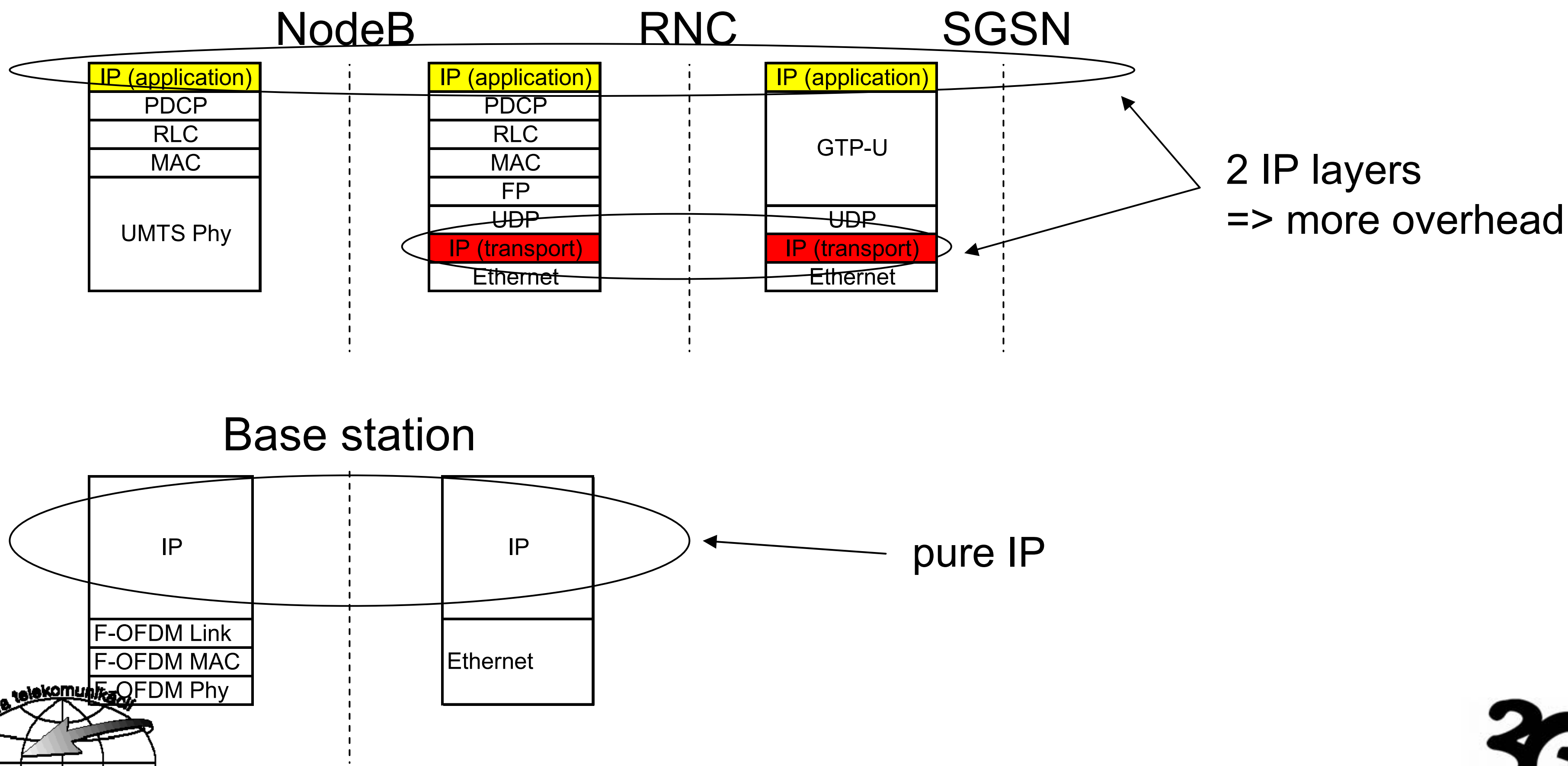


Flat all IP architecture

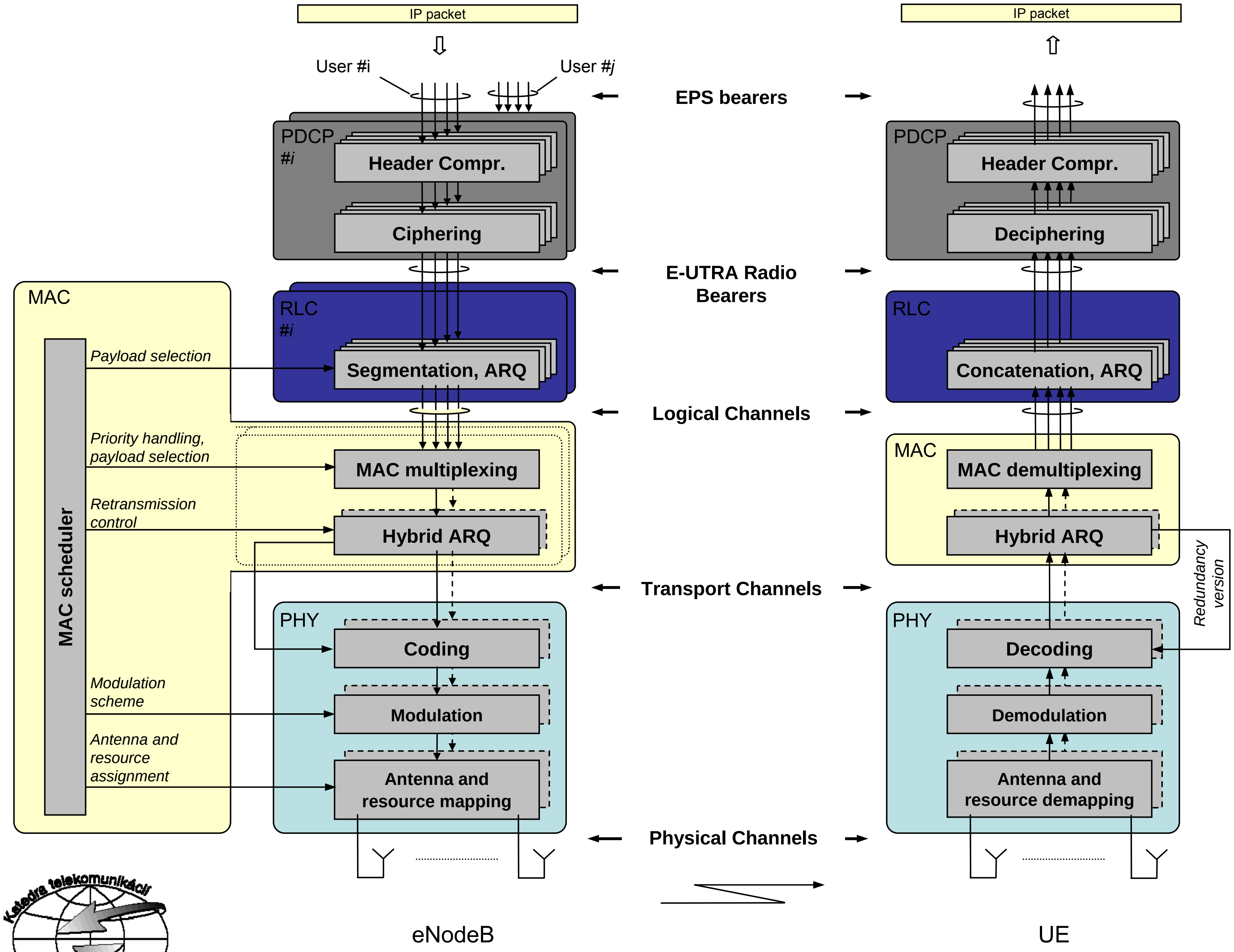


All IP – a comparison

- UMTS all IP vs. F-OFDM all IP

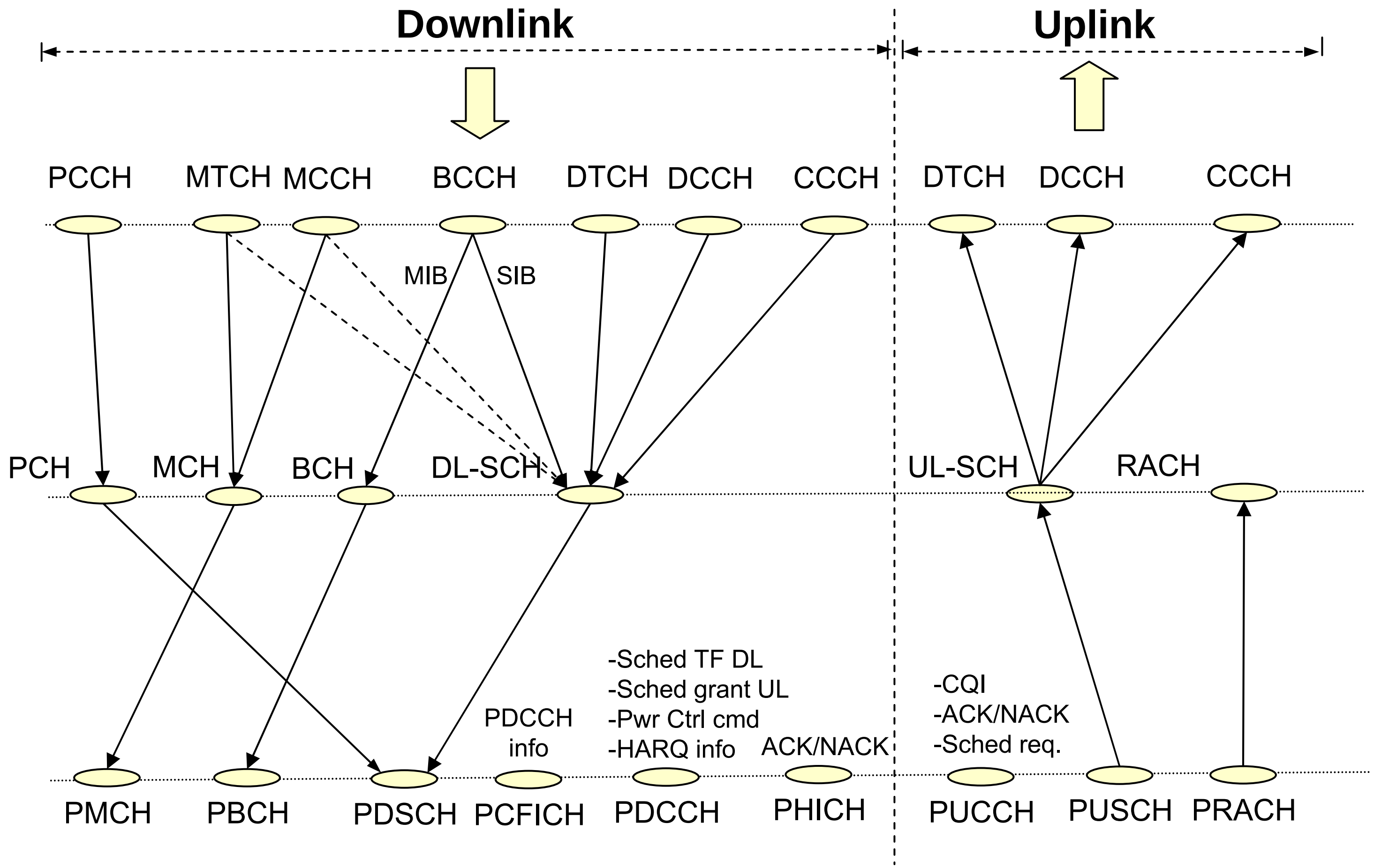


Channel Structure



IP packet
User #i
User #j
EPS bearers
PDCP
#i
Header Compr.
Ciphering
E-UTRA Radio Bearers
MAC
RLC
#i
Payload selection
Segmentation, ARQ
Logical Channels
Priority handling, payload selection
MAC multiplexing
Retransmission control
Hybrid ARQ
MAC scheduler
Transport Channels
PHY
Coding
Modulation scheme
Modulation
Antenna and resource assignment
Antenna and resource mapping
Physical Channels
eNodeB
IP packet
PDCP
Header Compr.
Deciphering
RLC
Concatenation, ARQ
MAC
MAC demultiplexing
Hybrid ARQ
Redundancy version
PHY
Decoding
Demodulation
Antenna and resource demapping
UE

Channel mapping



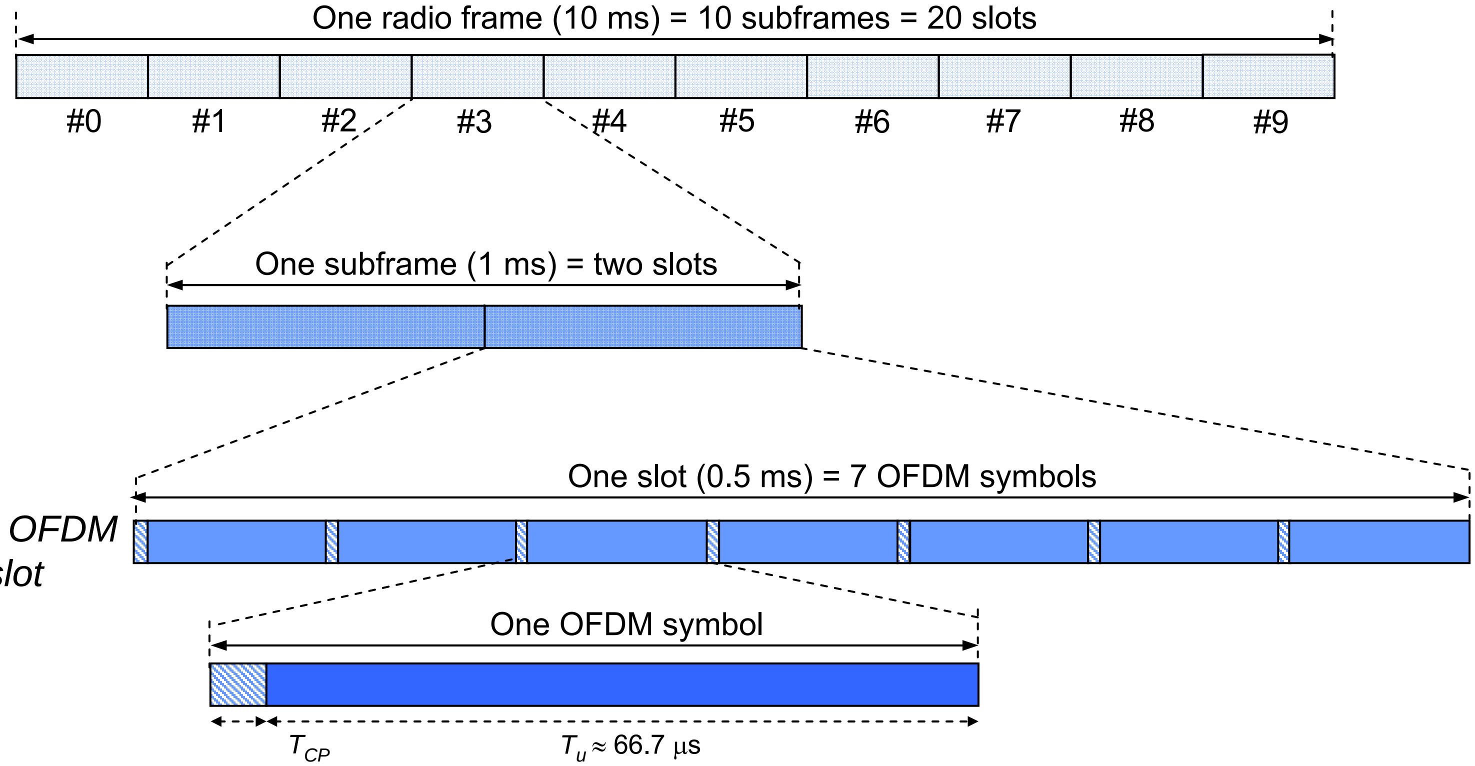
Logical Channels
"type of information"
(traffic/control)

Transport Channels
"how and with what characteristics"
(common/shared/mc/bc)

Physical Channels
"bits, symbols, modulation, radio frames etc"

Time-domain Structure

Time-domain Structure (FDD)

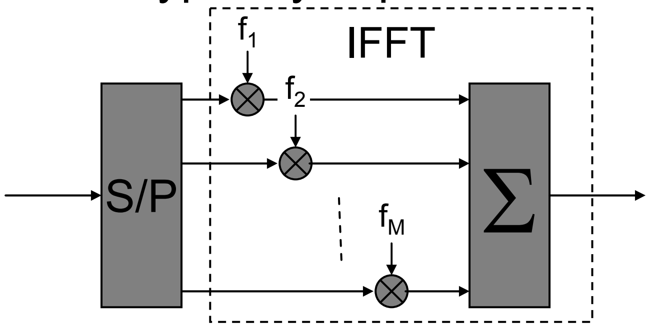


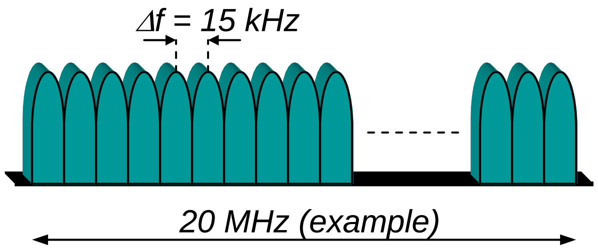
Normal CP, 7 OFDM symbols per slot

L1 basics

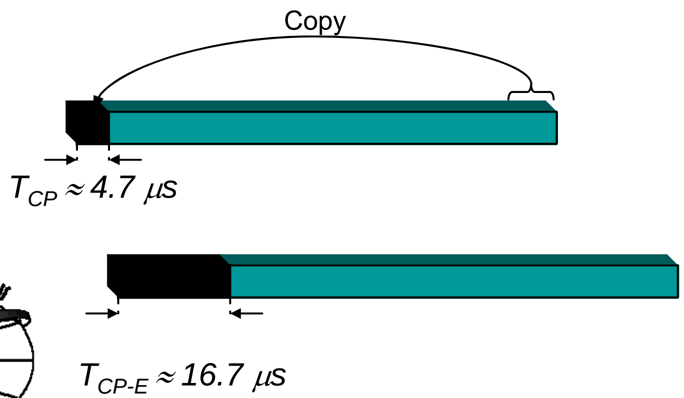
Downlink – OFDM with Cyclic Prefix

- Parallel transmission using a large number of narrowband “sub-carriers”
- “Multi-carrier” transmission
  - Typically implemented with FFT (Fast Fourier Transform) and Inverse FFT





- Insertion of cyclic prefix prior to transmission
  - Improved robustness in time-dispersive channels – *requires CP > delay spread*
  - Spectral efficiency loss

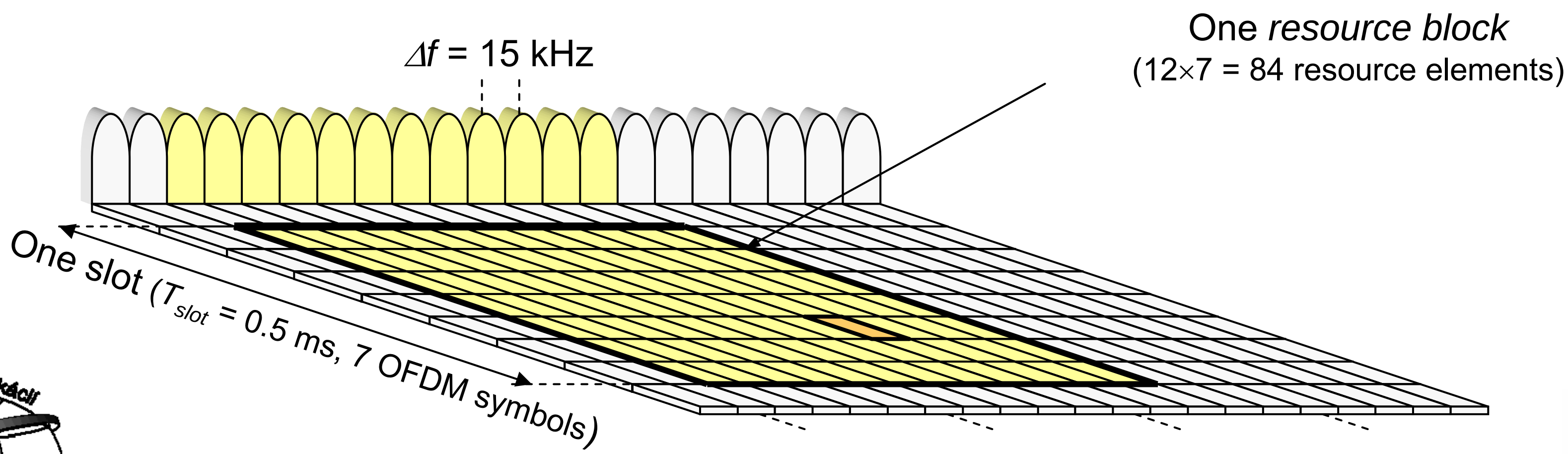


Configuration, Δf		CP length	Symbols per slot
Normal	15 kHz	≈4.7 µs*	7
Extended	15 kHz	≈16.7 µs	6
	7.5 kHz	≈33.3 µs	3

* First symbol of each slot has a CP length of 5.2 µs

Resource Blocks

- The basic TTI (Transmission Time Interval) for DL-SCH is 1 ms
  - TTI is a *transport channel property*
  - Subframe is a *physical channel property*
  - One (or two) transport blocks per TTI sent to L1
- One resource block is 12 subcarriers during one 0.5 ms slot



Downlink Coding Chain

Segmentation for per-stream channel coding/decoding and error detection

24 bit CRC addition

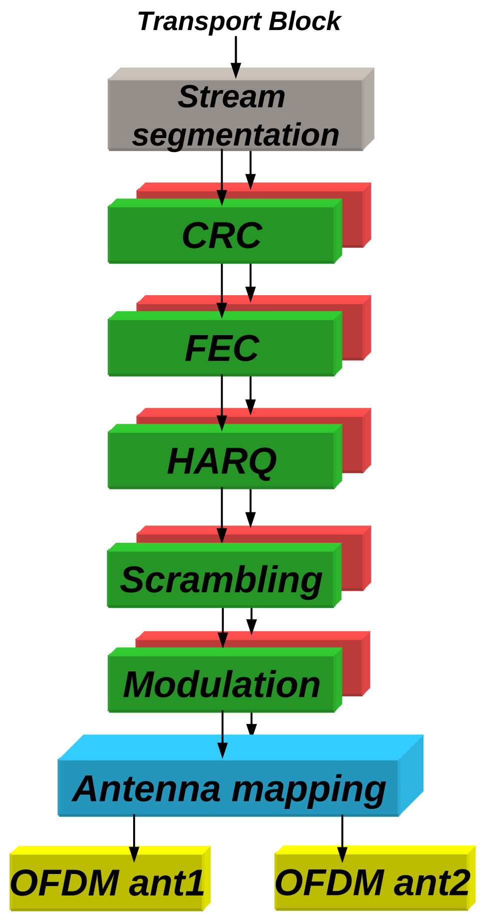
Rel6 Turbo coding

Select sub-set of coded bits as determined by scheduler and HARQ status

Scrambling for inter-cell interference randomization

Modulation as determined by scheduler (QPSK, 16QAM, 64QAM)

OFDM modulation (per antenna)



Downlink phy channels

- Physical Downlink Shared Channel, PDSCH
- Physical Broadcast Channel, PBCH
- Physical Multicast Channel, PMCH
- Physical Control Format Indicator Channel, PCFICH
- Physical Downlink Control Channel, PDCCH
- Physical Hybrid ARQ Indicator Channel, PHICH

Peak to Average Power Ratio

- Extremely high for pure OFDM signals
- Demands high amplifier linearity
- Impacts batter life

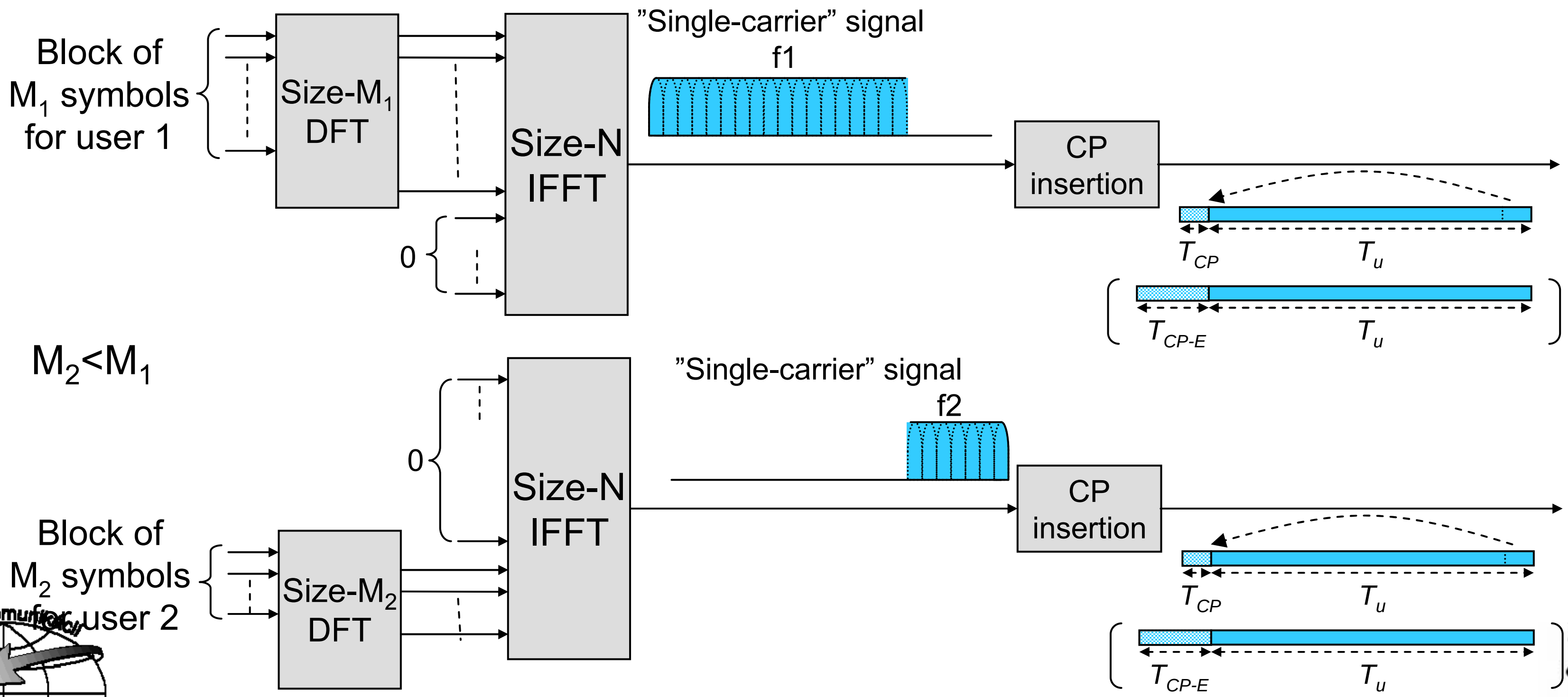
⬇

Not suitable for UL transmission

Uplink transmission scheme
– *DFTS-OFDM*

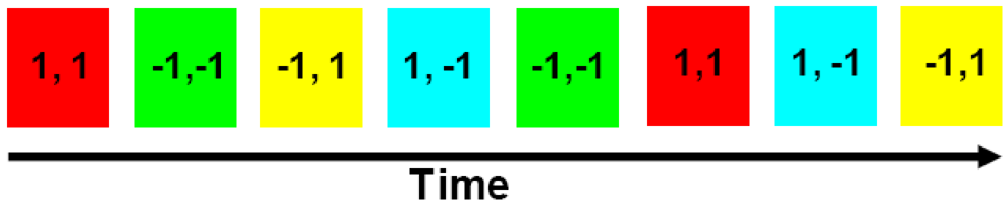
SC-FDMA

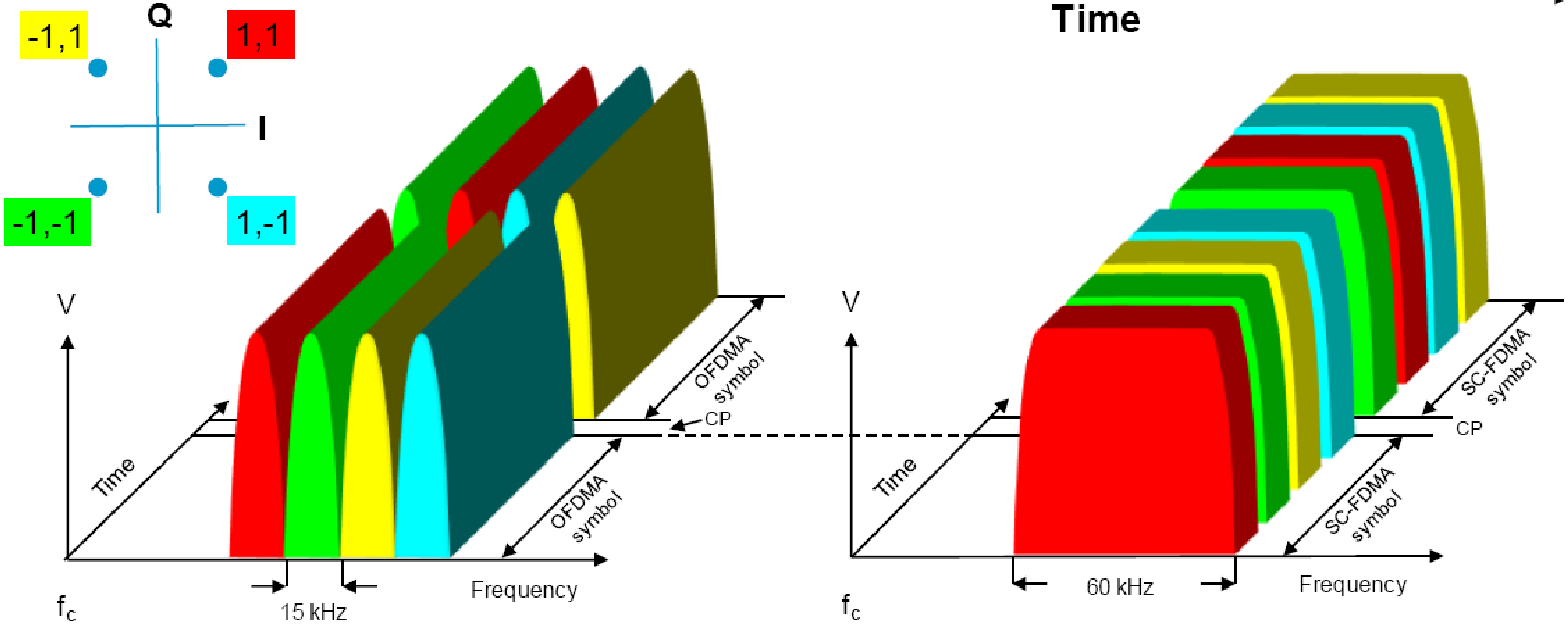
- OFDM with DFT-based pre-coding ⇨ Low PAPR
- Same basic "OFDM" parameters as for downlink
  - Δf = 15 kHz, $T_{CP} \approx 4.7$ / 5.2 μs, $T_{CP\text{-}E} \approx 16.7$ μs
- Orthogonal uplink – no intra cell interference



QPSK example with 4 subcarriers

The following graphs show how a sequence of eight QPSK symbols is represented in frequency and time





OFDMA

Data symbols occupy 15 kHz for one OFDMA symbol period

SC-FDMA

Data symbols occupy M*15 kHz for 1/M SC-FDMA symbol periods

Uplink Coding Chain

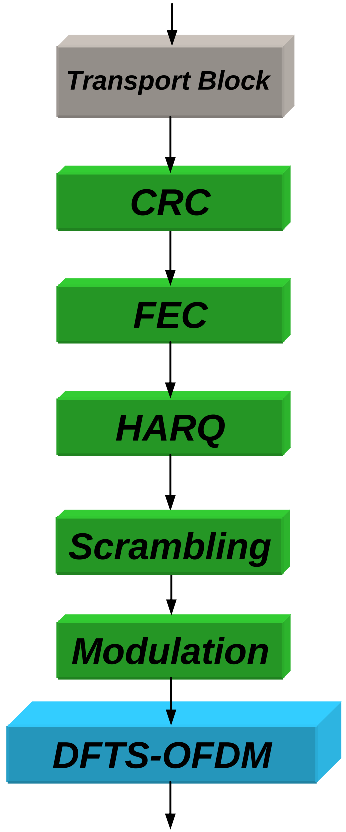
24 bit CRC addition

Rel6 Turbo coding

Select sub-set of coded bits as determined by scheduler and HARQ status

Scrambling for interference randomization

Modulation as determined by scheduler
(QPSK, 16QAM, 64QAM)

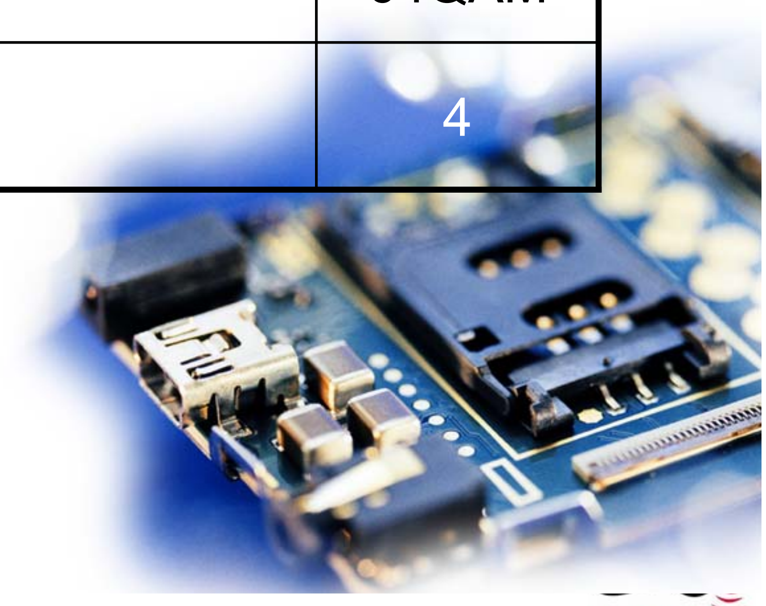


Uplink phy channels

- Physical Uplink Shared Channel, PUSCH
- Physical Uplink Control Channel, PUCCH
- Physical Random Access Channel, PRACH

UE Categories

Category	1	2	3	4	5
DL peak rate	10	50	100	150	300
UL peak rate	5	25	50	50	75
Max DL mod	64QAM				
Max UL mod	16QAM				64QAM
Layers for spatial mux.	1	2			4



Key challenges

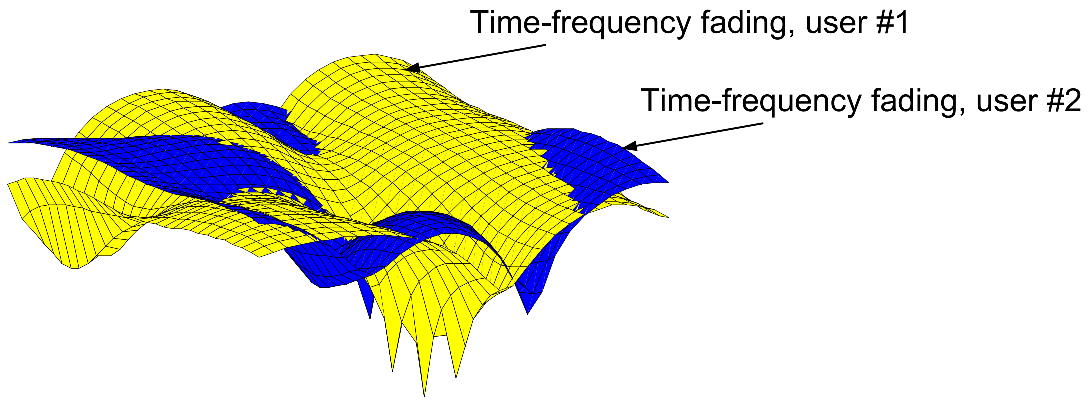
Radio Resource Management

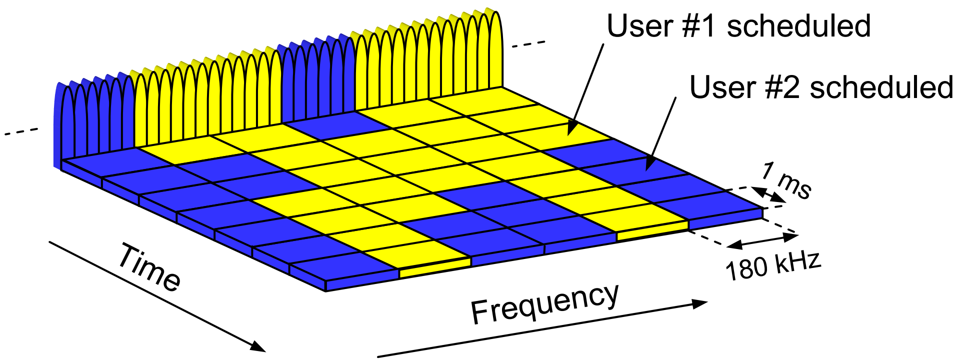
- Not standardized (just RRC messages)

- Intercell Interference Mitigation
- Scheduling & channel estimation
- MIMO operation
- Power control

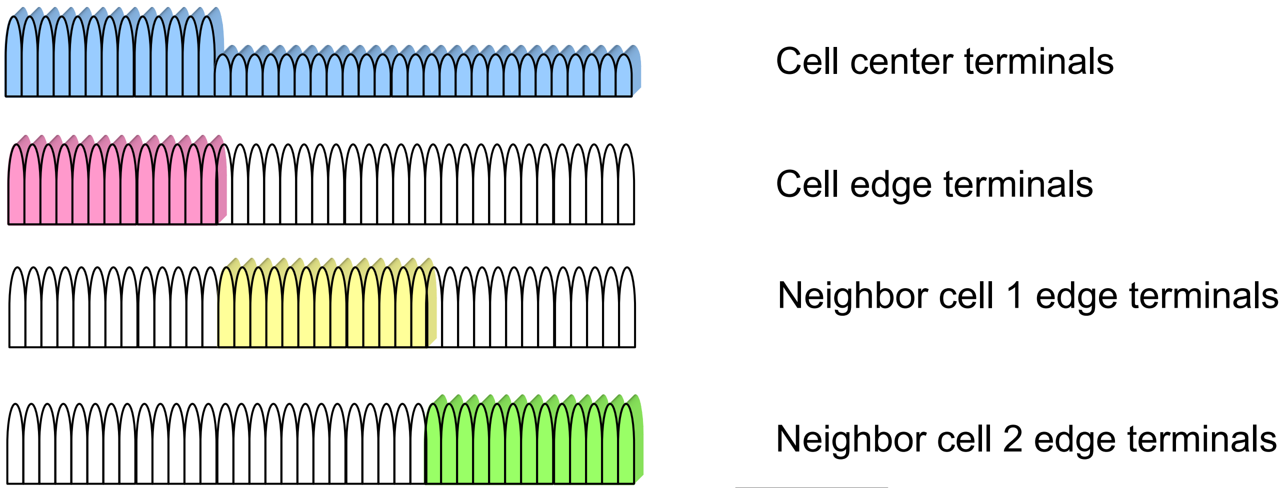
Channel-dependent Scheduling

- HSPA – channel-dependent scheduling in time-domain only
- LTE – channel-dependent scheduling in time *and* frequency domains

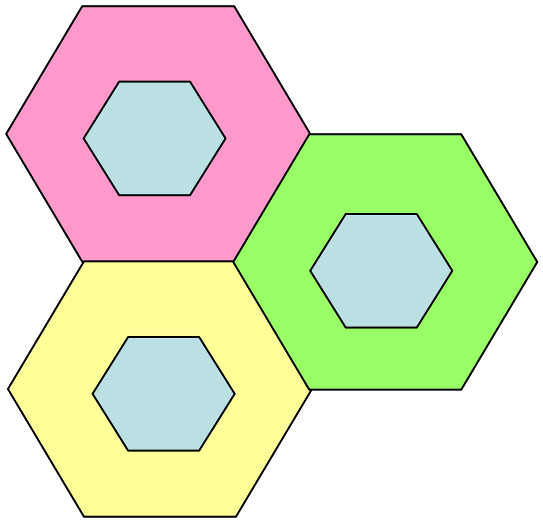




Cell/user separation – example



Coordination over X2 interface

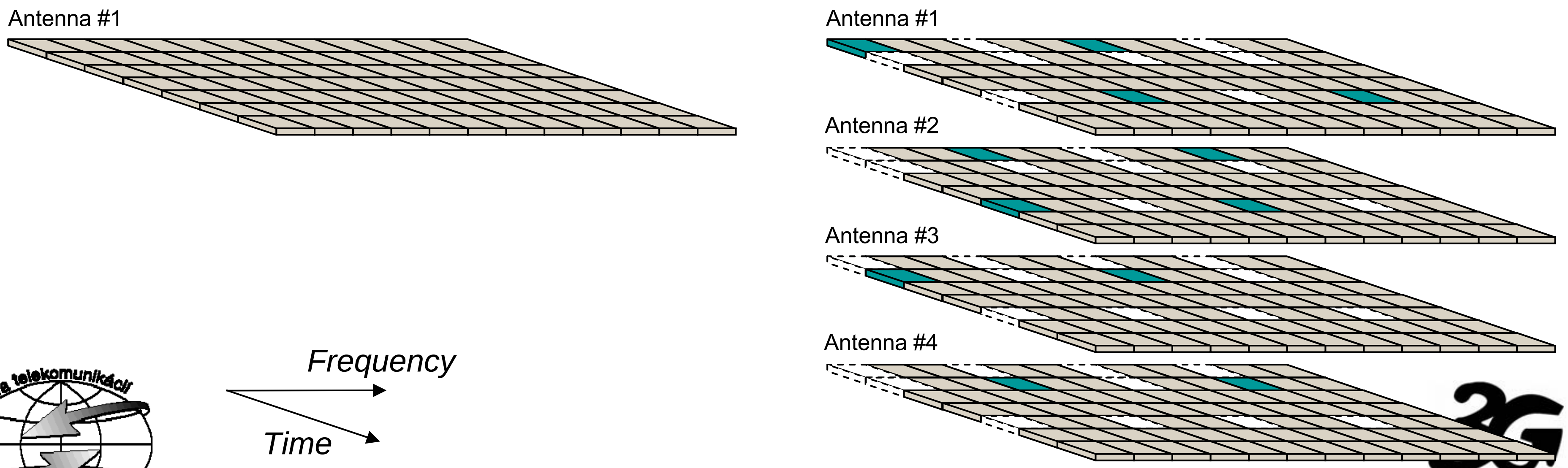


MIMO

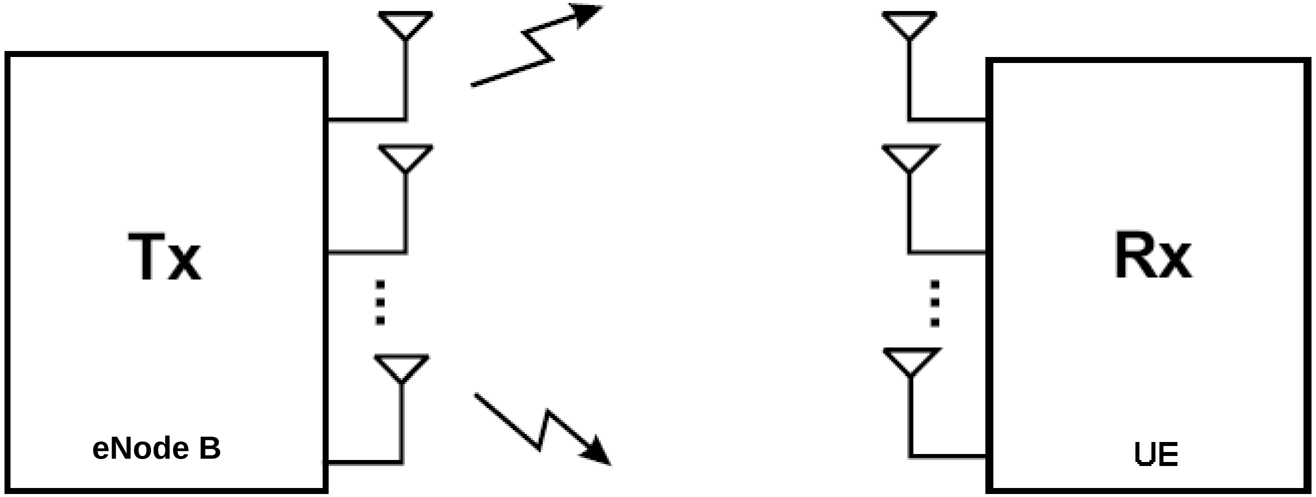
- **Single User MIMO** (DL only)
  - Precoded spatial multiplexing → higher peaks
- **Multi User MIMO** (DL only)
  - Multiple UEs per RB
  - Max one layer per UE
- **Collaborative MIMO** (UL only)
  - Use of CDMA for individual pilots
- **Beamforming** (TDD)
  - Interference suppression

Multi-antenna transmission

- One, two, or four *antenna ports*
- Multiple antenna ports ⇨ Multiple time-frequency grids
- Each antenna port defined by an associated ***Reference Signal***



MIMO basics

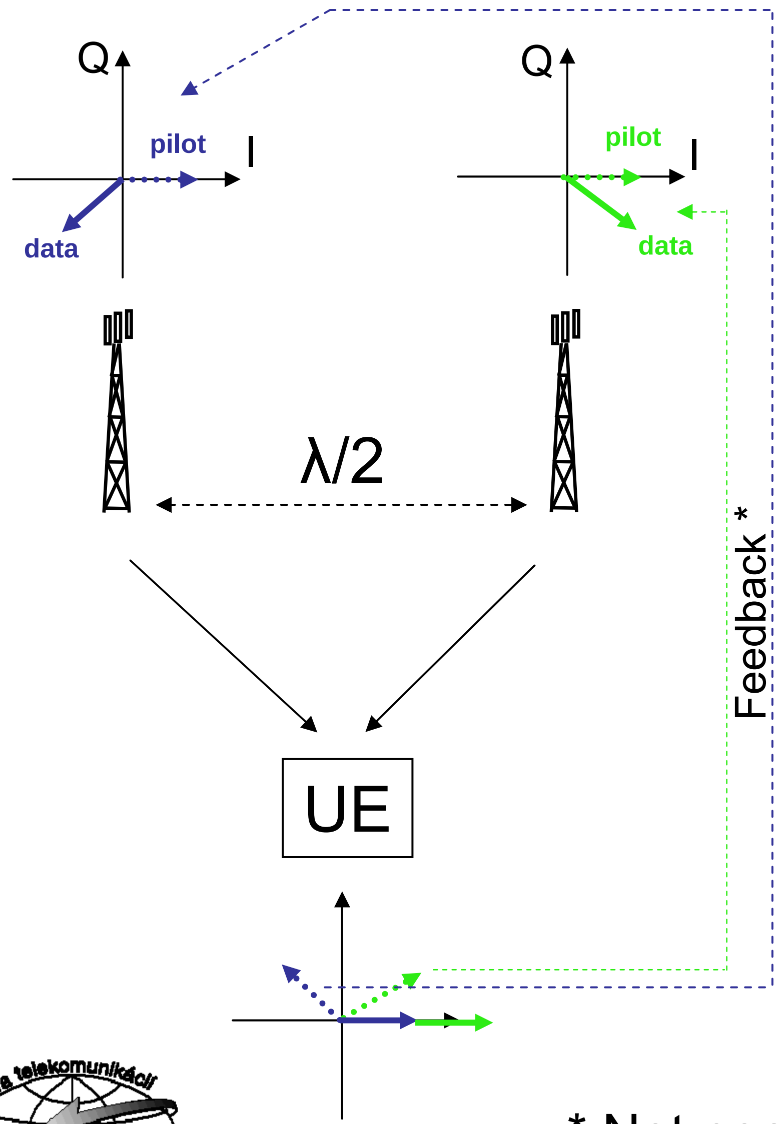


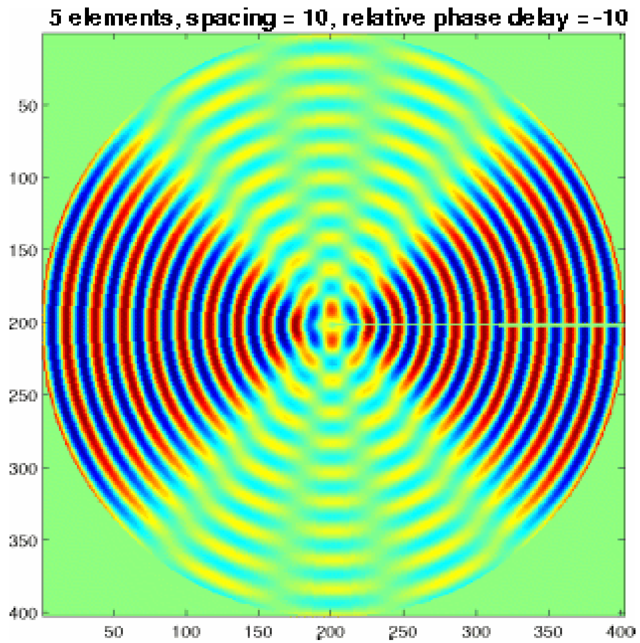
$$R_{x1} = h_{11}T_{x1} + h_{12}T_{x2}$$
$$R_{x2} = h_{21}T_{x1} + h_{22}T_{x2}$$

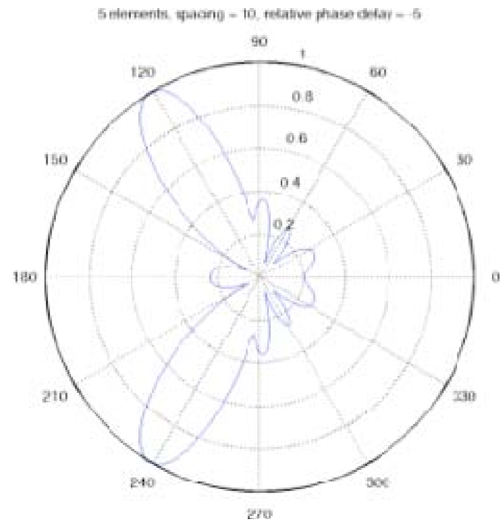
det(H)≠ 0

$$\begin{bmatrix} R_{x1} \\ R_{x2} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} T_{x1} \\ T_{x2} \end{bmatrix} \Rightarrow \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}^{-1} \begin{bmatrix} R_{x1} \\ R_{x2} \end{bmatrix} = \begin{bmatrix} T_{x1} \\ T_{x2} \end{bmatrix}$$

Beamforming

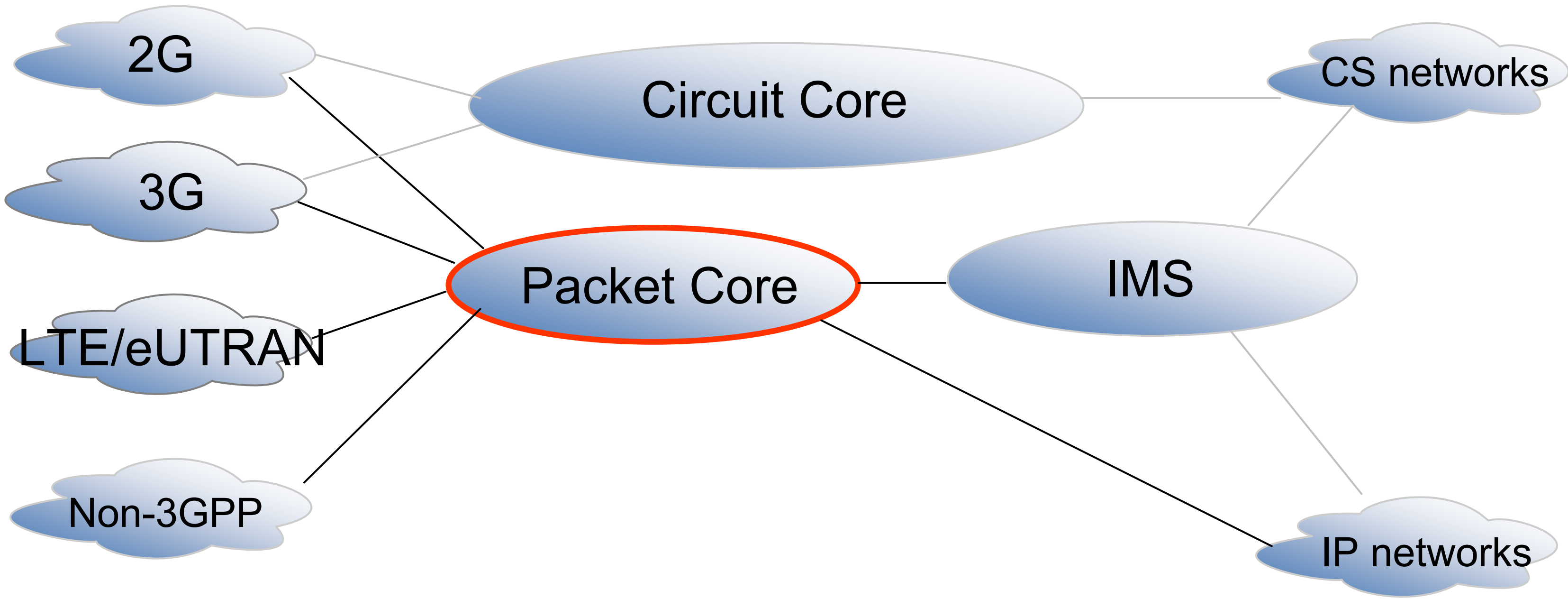




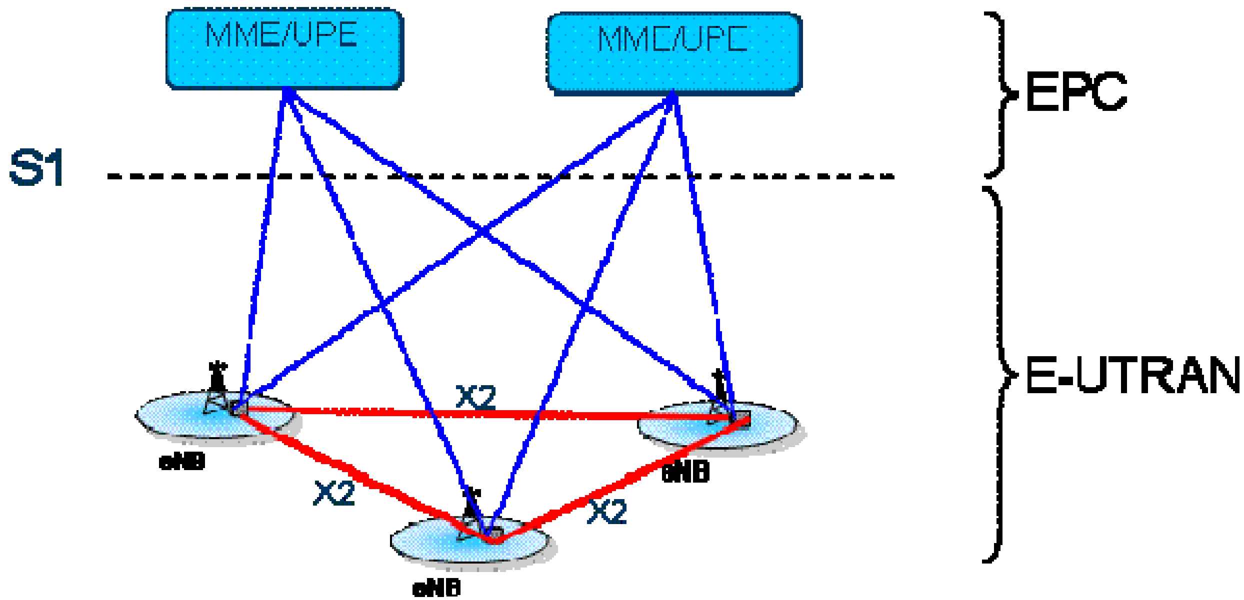


* Not needed for TDD

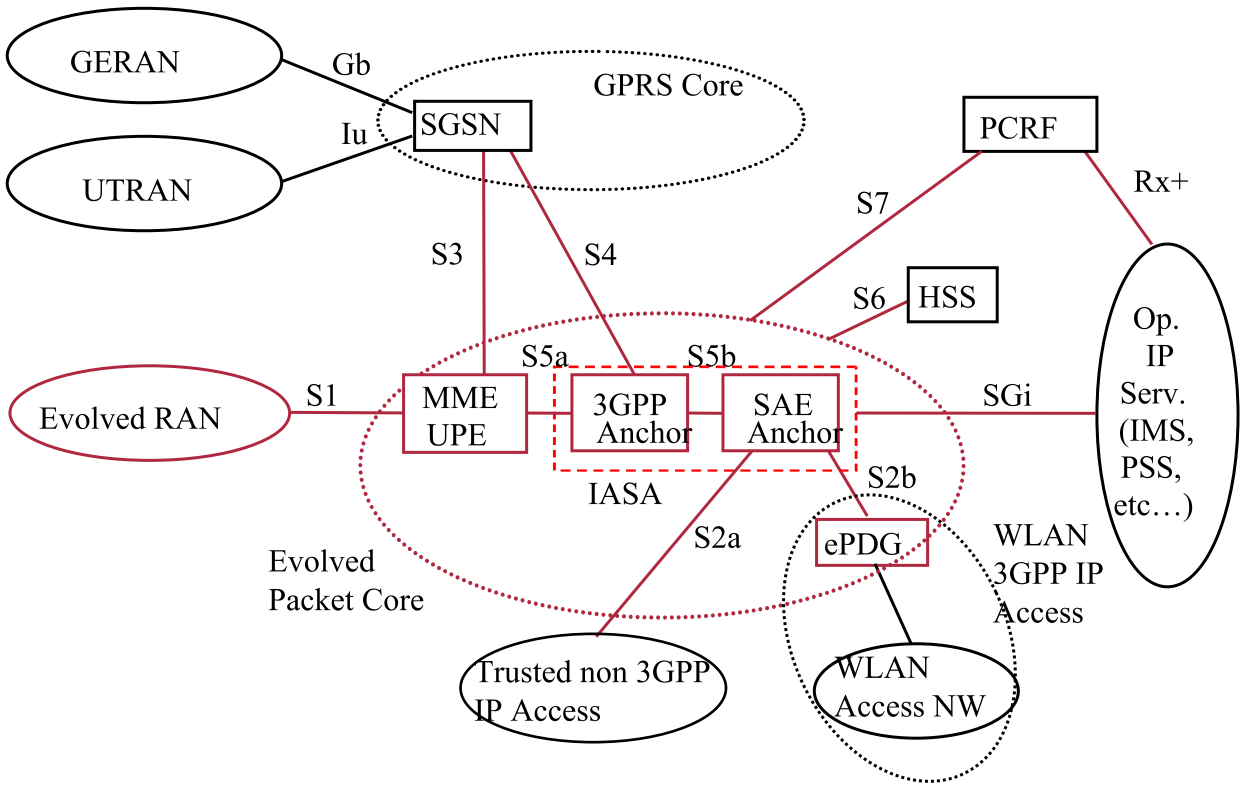
Where is SAE?


2G
3G
LTE/eUTRAN
Non-3GPP
Circuit Core
Packet Core
IMS
CS networks
IP networks

SAE/EPC



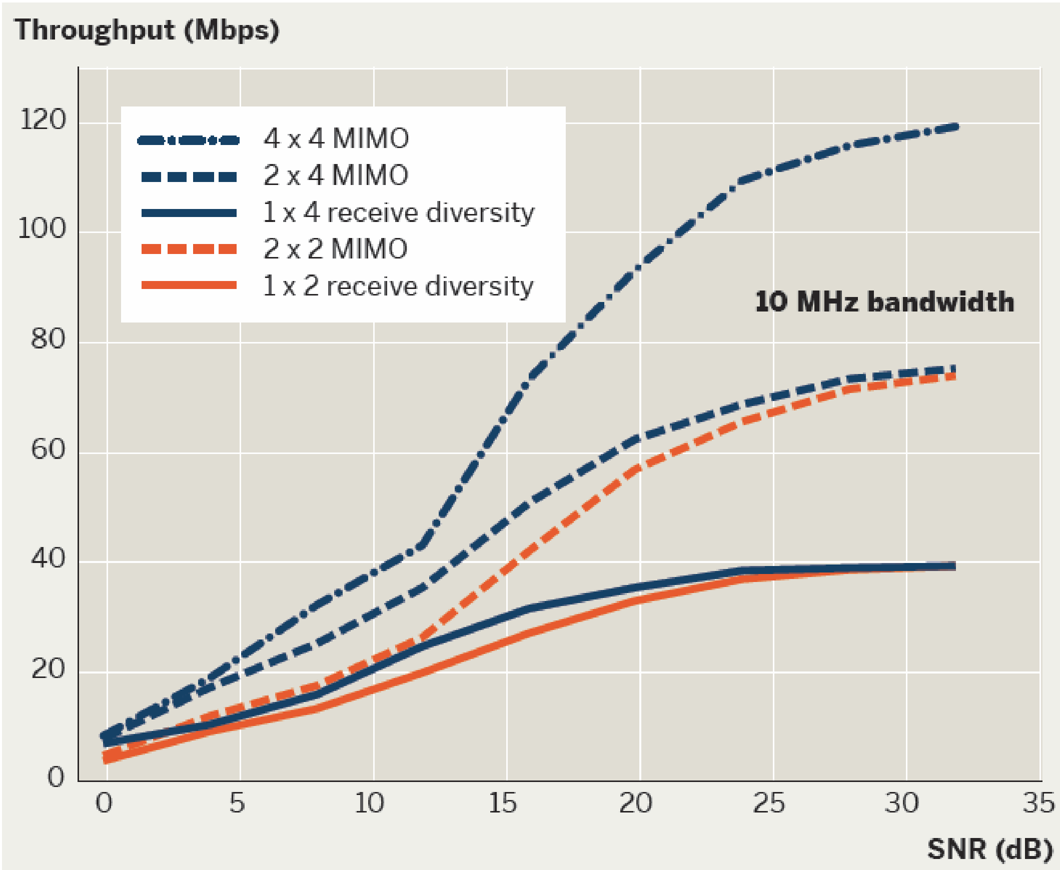
Detailed EPC view



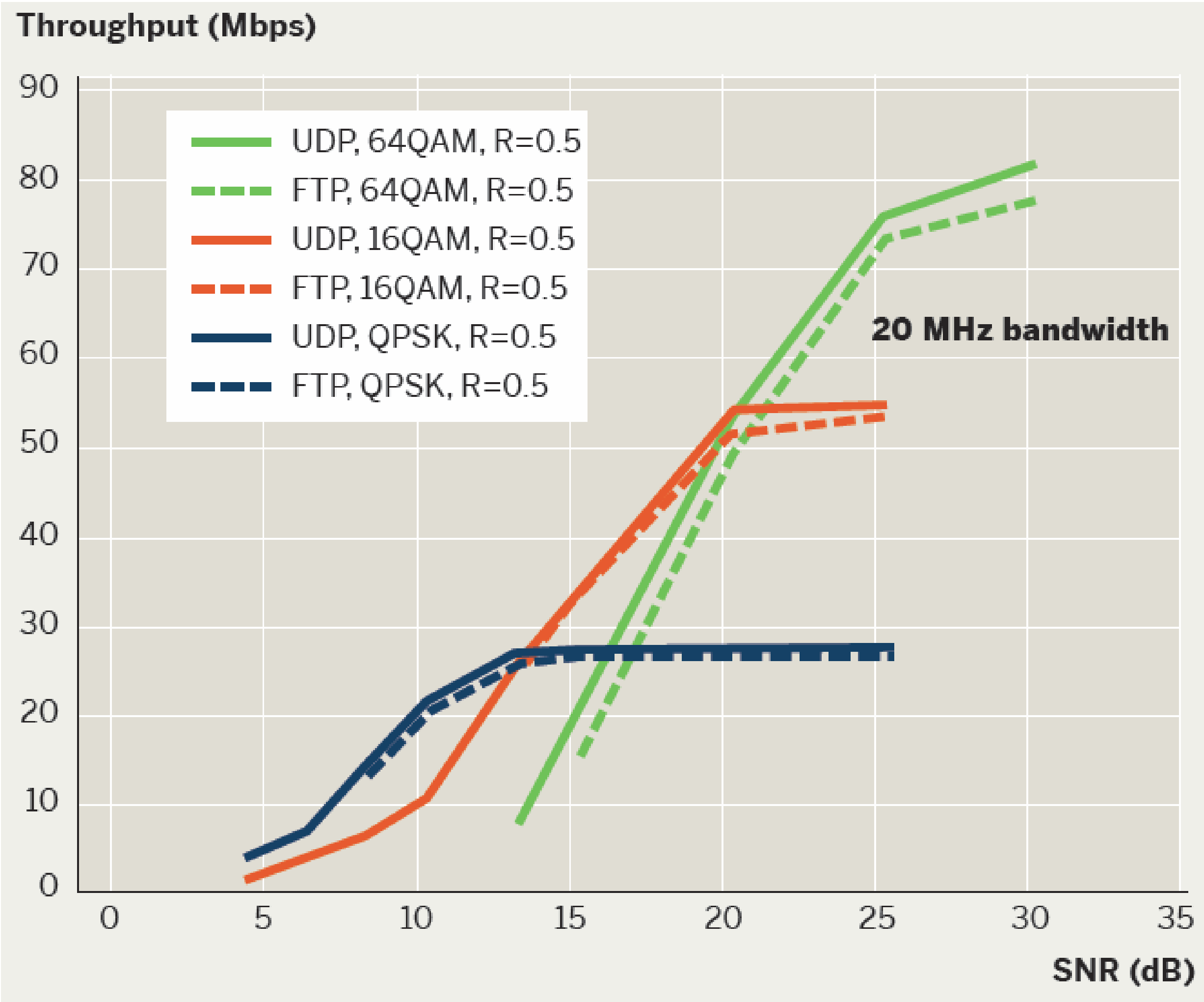
Terminals


ERICSSON
Ericsson Mobile Platforms
1
2 ABC
3 DEF
4 GHI
5 JKL
* a\A
MNO 6
PQRS 7
TUV 8
WXYZ 9
+ 0
_ #
C

Lab – AWGN, 10 MHz



Lab - PB3 channel, 20 MHz, 2x2

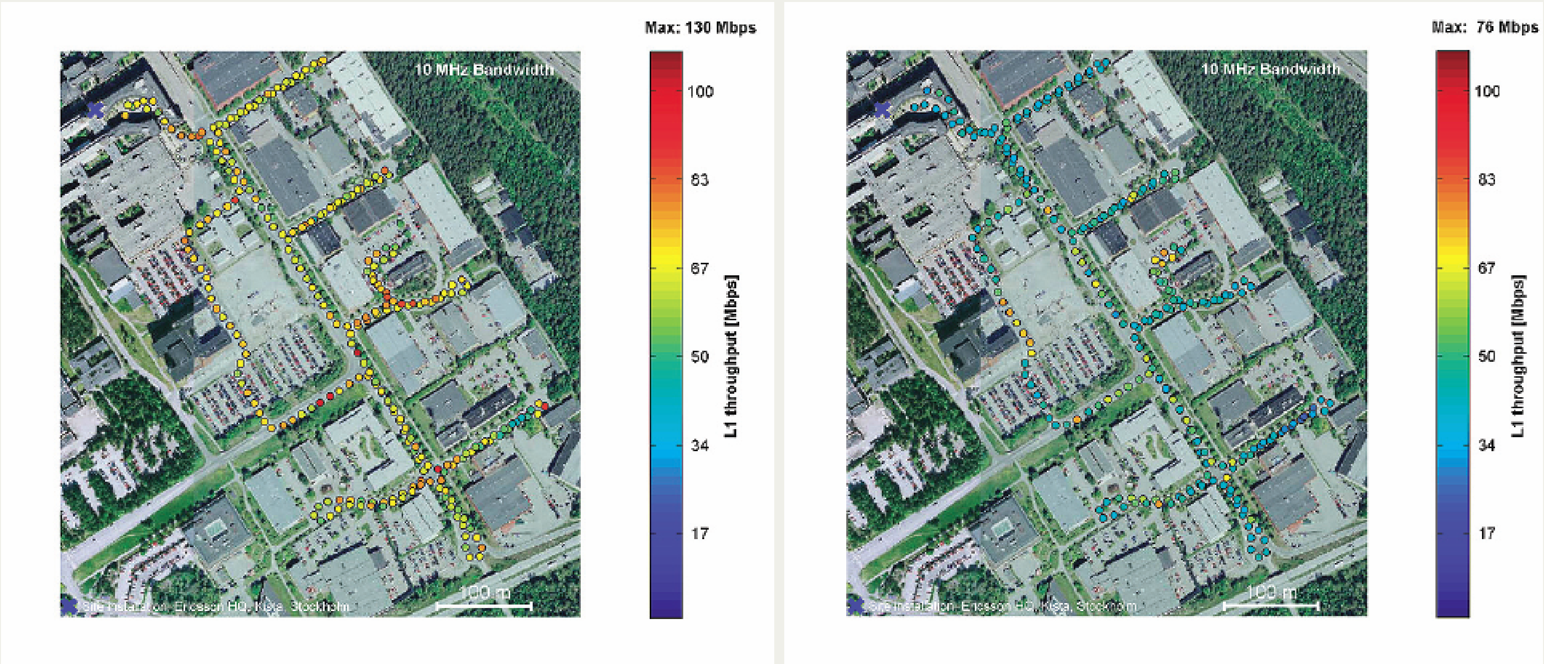


Field results

Field results

Field

Left: Throughput relative to location for a 4x4 MIMO setup using 10 MHz bandwidth and dual-polarized antennas. Right: Throughput relative to location for a 2x2 MIMO setup using 10 MHz bandwidth and dual-polarized antennas. Base station located at X in both plots.



Comparison – 5 MHz, 64 QAM, 4x4 MIMO

HSDPA	E-UTRAN
14,4 x 1,5 (64QAM) x 4 (MIMO) = **86,4 Mbps** Peak spectral efficiency: 86,4 Mbps / 5 MHz = **17,28 bps/Hz**	5 MHz = 25 Resource Blocks 1 RB = 12 carriers (180 kHz) 1 carrier = 6 bits (64QAM) Symbol = (66,67 + 4,7) μs # pilots = 12 out of 84 in 1 symbol # L1 signaling = 8 out of 168 12 x 6 / 71,37 = 1,01 Mbps in 5 MHz + MIMO = 25 x 1,01 x 4 x Pilot OH x L1 sig. OH = 82,45 Mbps Peak spectral efficiency: **16,49 bps/Hz**

LTE DL peak rate
64 QAM and 20 MHz and 4x4 MIMO

- 14 OFDM symbols per 1.0 ms subframe
- 64QAM - 6 bits per symbol
- 6 x 14 = 84 bits per 1.0 ms subframe
- 84bits/1.0ms = 84kbps per subcarrier
- 12 x 84kbps = 1.008Mbps per Resource Block

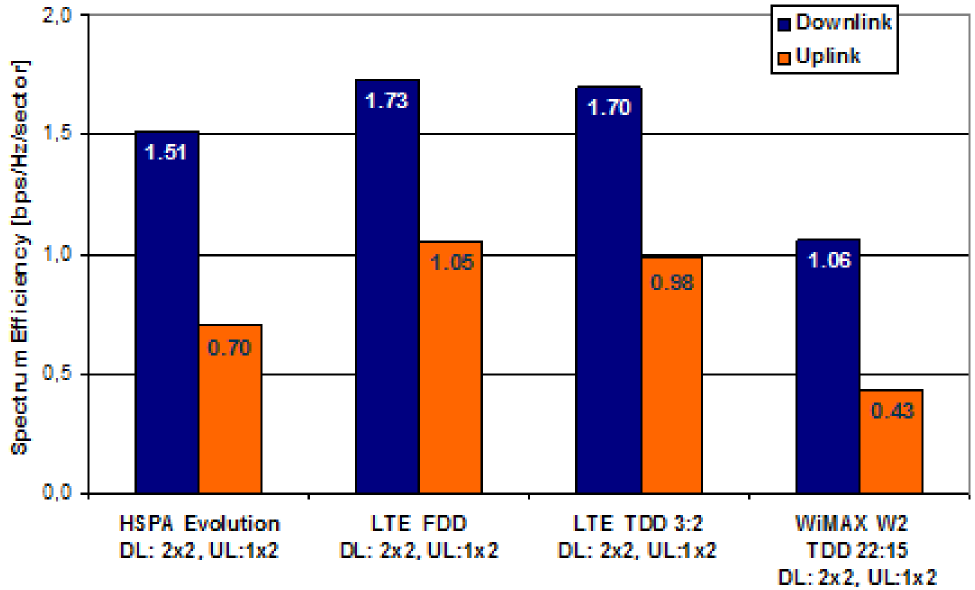
- 100 resource blocks in 20MHz
- 100 x 1.008Mbps = 100.8Mbps per antenna
- 4 x 4 MIMO: 403.2Mbps !!

- no overhead calculated in this example!

Peak vs. Sustainable SE

Spectral Efficiency Urban Macro (TU-similar)

HSPA DL, LTE and WIMAX: Ericsson's input to **NGMN MS 2**. Urban macro 3km/h, ISD=500 m, indoor UE:s
HSPA UL, 3GPP 25.814 case1 (SCM Radio channel model – 3GPP TR 25 996). Similar set up.



3G vs 4G

- WiMAX, LTE are not **4G**!
- 4G = IMT-Advanced by ITU-T
  - 3GPP LTE-Advanced
  - IEEE 802.16m

…specifications in **2010** and beyond

LTE-A targets / requirements

- **1 Gbps** in DL peak
- **500 Mbps** in UL peak
- **100 MHz** channel bandwidth
- 10 ms U-plane latency
- 50 ms C-plane latency
- 30 bps/Hz in DL peak
- 15 bps/Hz in UL peak
- 300 VoIP UE per 5 MHz

LTE-Advanced

- simplified radio network operation
- multiple antenna solutions
  - to 8x8
  - for UL as well
- active interference management
- coordinated multipoint Tx/Rx
- relaying
- direct UE-to-UE communication
- network coding

Key challenges for LTE

- What to do?
  - Physical layer close to Shannon bound
  - Channel quality variations utilized in many ways
  - Interference ’out of control’
- Inter-cell interference
- Throughput increase
- Spectrum flexibility

IMT-Advanced and LTE-Advanced
Requirements and targets

	IMT-Advanced (DL/UL)	LTE release 8 (DL/UL)	LTE-Advanced (DL/UL)
Maximum bandwidth	**min 40 MHz**	**20 MHz**	**100 MHz**
Peak data rates [*Mbps*]	–	**300 / 75**	**1000 / 500**
Peak spectral efficiency [*bps/Hz*]	**15 / 6.75**	**15 / 3.75**	**30 / 15**
Average spectral efficiency [*bps/Hz/cell*]	**2.2 / 1.4**	**2.05 / 1.5**	**2.6 / 2.0**
Cell-edge user spectral efficiency [*bps/user/Hz/cell*]	**0.06 / 0.03**	**0.06 / 0.07**	**0.09 / 0.07**

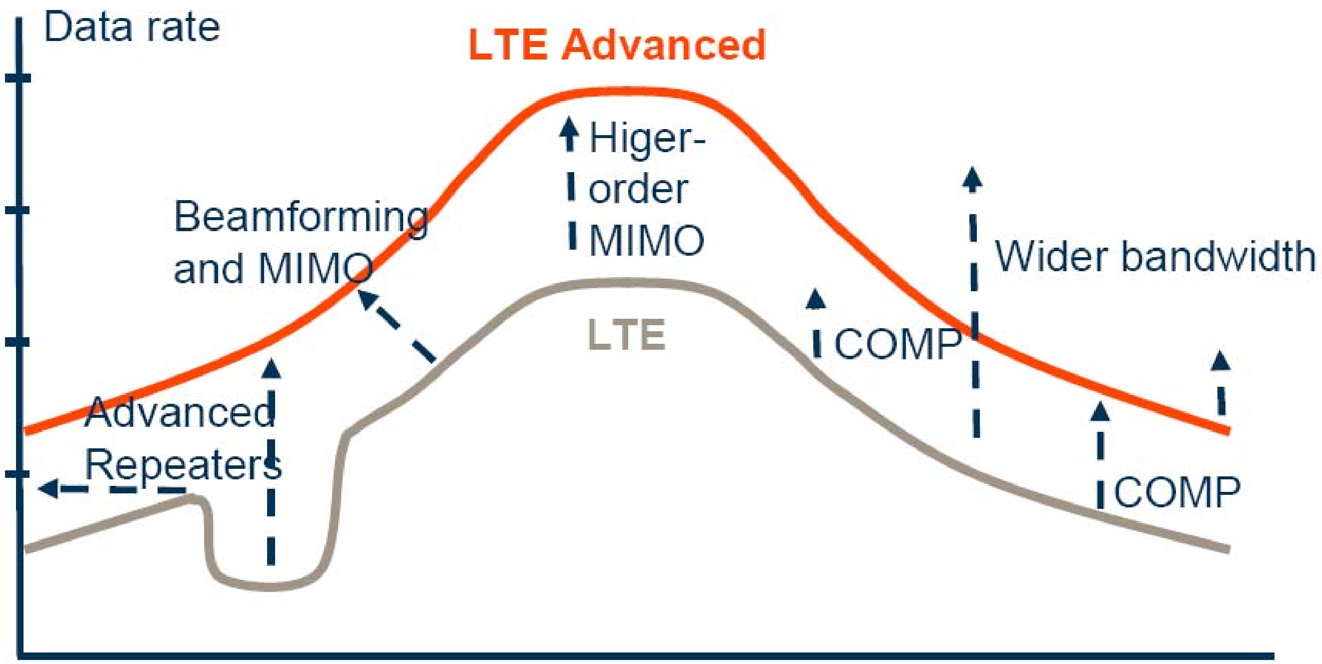
Scenario: IMT-Advanced: Base coverage Urban / LTE & LTE-Advanced: 3GPP Case 1
Antenna conflguration: DL: 4x2 / UL: 2x4 (1x4 for LTE)

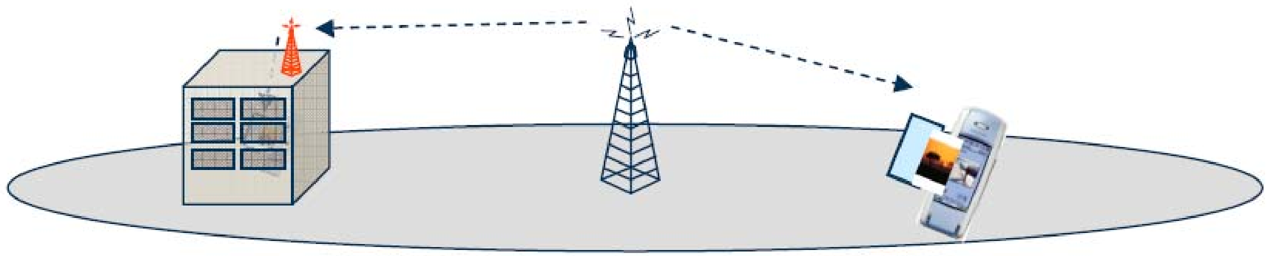
- Already first release of LTE fulfills many of the IMT-Advanced requirements
- LTE-Advanced targets beyond IMT-Advanced

LTE-Advanced – *Technology components*

- Bandwidth extension / Carrier aggregation
- Spectrum aggregation
- Extended multi-antenna transmission
- Relaying functionality
- Coordinated multipoint transmission/reception

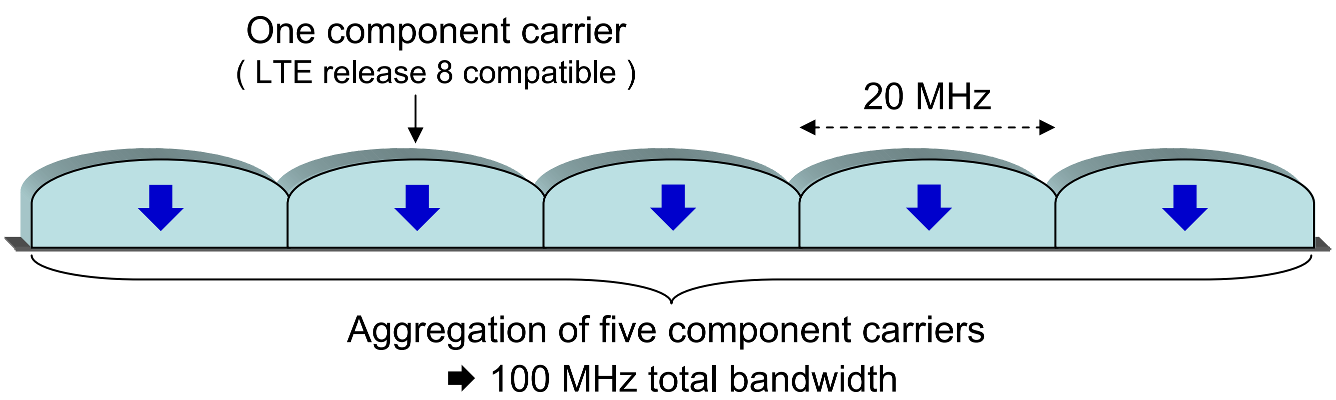
LTE-Advanced





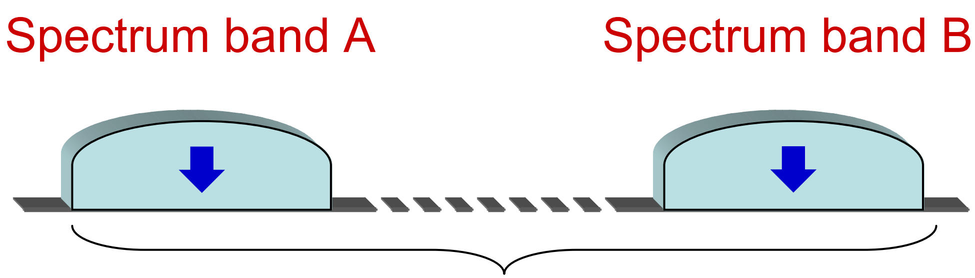
Carrier aggregation

- Aggregation of a set of *component carriers*
- Each component carrier compatible with LTE release 8
  ➡ *Accessible by LTE release 8 UEs*
- LTE-Advanced UE can access set of aggregated carriers
  ➡ *Benefit from overall wider bandwidth*



Spectrum aggregation

- Aggregation of non-contiguous component carriers including carriers in separate spectrum
- Wider overall bandwidth without large contiguous spectrum
  ➡ *Efficient utilization of available spectrum*
- Impact on UE complexity
  ➡ *Supported by high-end mobile devices*



Aggregation of two frequency-disperse component carriers
➡ 40 MHz total bandwidth

Extended multi-antenna transmission

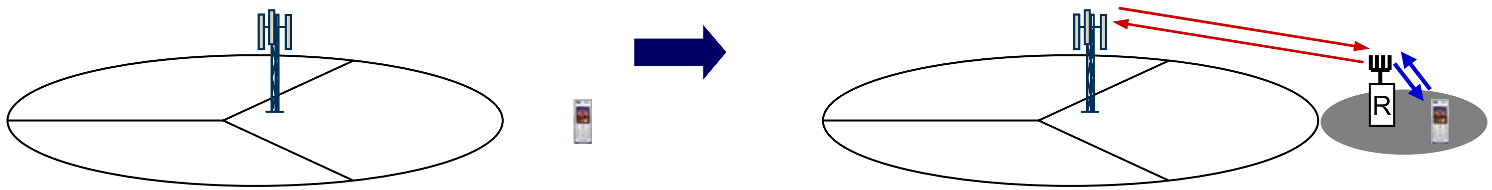
- Multi-antenna support in LTE release 8
  - Downlink transmit diversity – Up to 4 antennas
  - Downlink spatial multiplexing – Up to 4 antennas / layers

- Extended multi-antenna support for LTE-Advanced
  - Uplink spatial multiplexing – Up to 4 layers
  - Extended downlink spatial multiplexing – Up to 8 layers

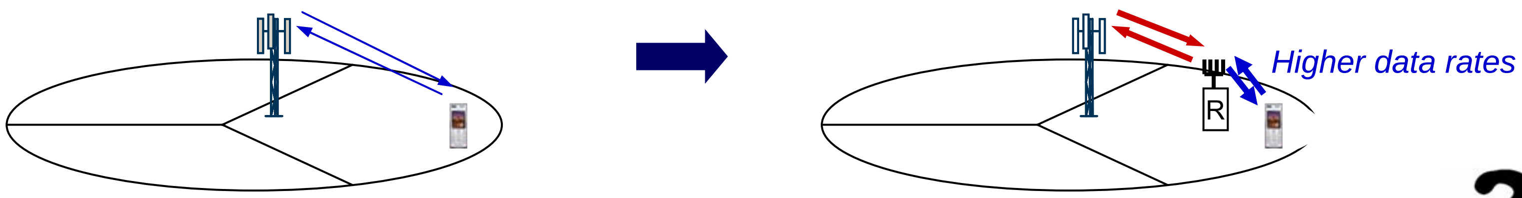
➡ *Higher peak data rates and improved system efficiency*

Relaying functionality

- ***Coverage-area extension***, i.e. extend coverage to areas where there currently is no coverage

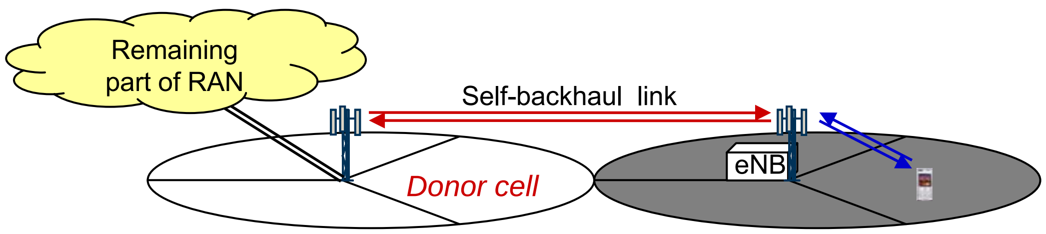


- ***Data-rate extension***, i.e. provide higher data rates in areas where there already is lower-rate coverage



Relaying functionality

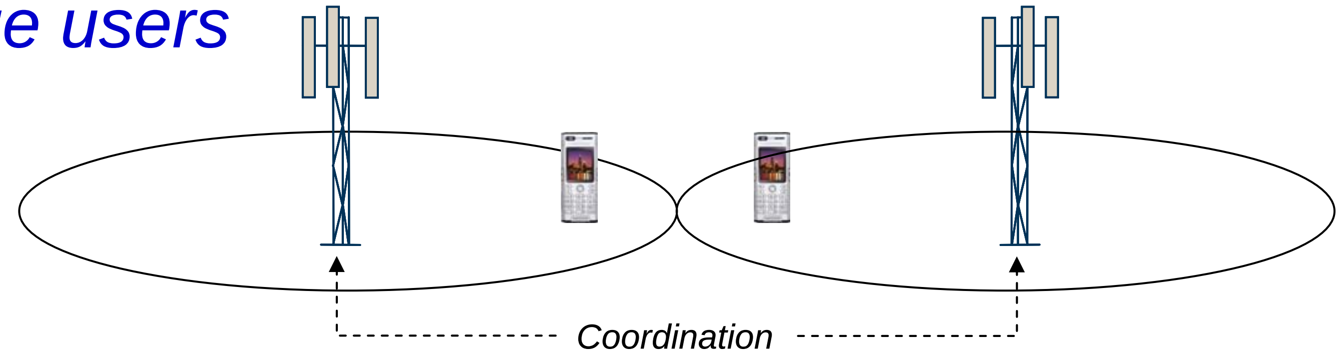
- Repeater (”amplify-and-forward”)
  - Low delay, limited standard impact
  - Sufficient in many cases
- Higher-layer relaying (”decode-and-forward”)
  - User-plane forwarding on layer 2 or layer 3?
  - Location of different control-plane functionalities?
  - Relay has full eNB functionality ➡ ”Self-backhauling”



Coordinated Multipoint transmission / reception (CoMP)

- Dynamic coordination in the transmission and/or reception between different cell sites
- What to achieve?
  - Reduced/controlled inter-cell interference
  - Improved signal strength in downlink and uplink

➡ *Enhanced service provisioning, especially for cell-edge users*



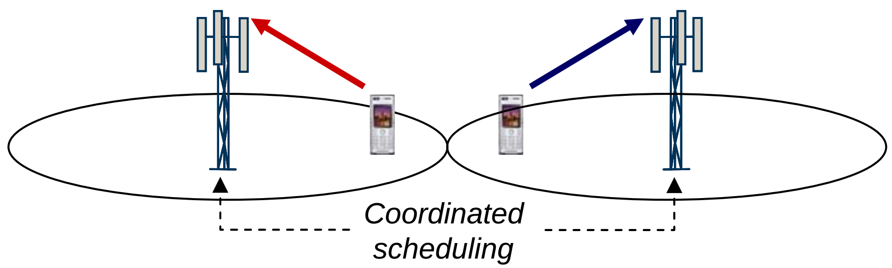
Coordinated multipoint reception

Uplink CoMP

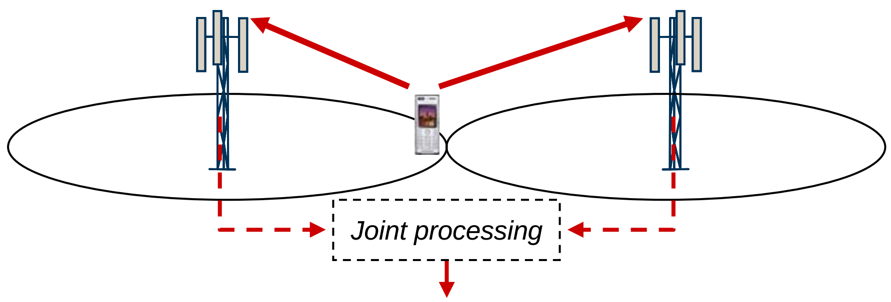
- Dynamic coordination in uplink scheduling between cell sites

- Reception and joint processing of signals received at multiple geographically separated points

Scheduling coordination



Joint processing

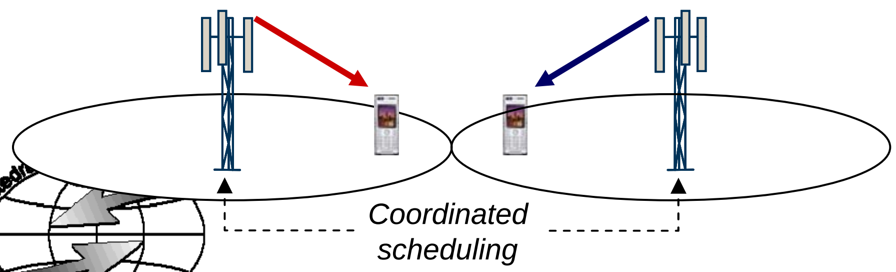


Coordinated multipoint transmission

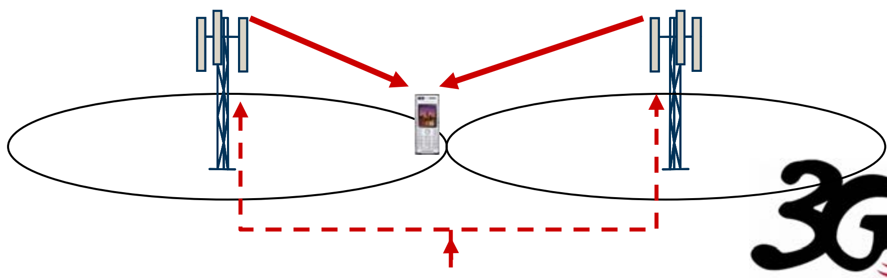
Downlink CoMP

- Dynamic coordination in downlink scheduling between cell sites
- Joint transmission from multiple geographically separated points
  - Non-coherent transmission ➡ Power boost at the cell border
  - Coherent transmission ➡ Multi-cell beam-forming

Scheduling coordination

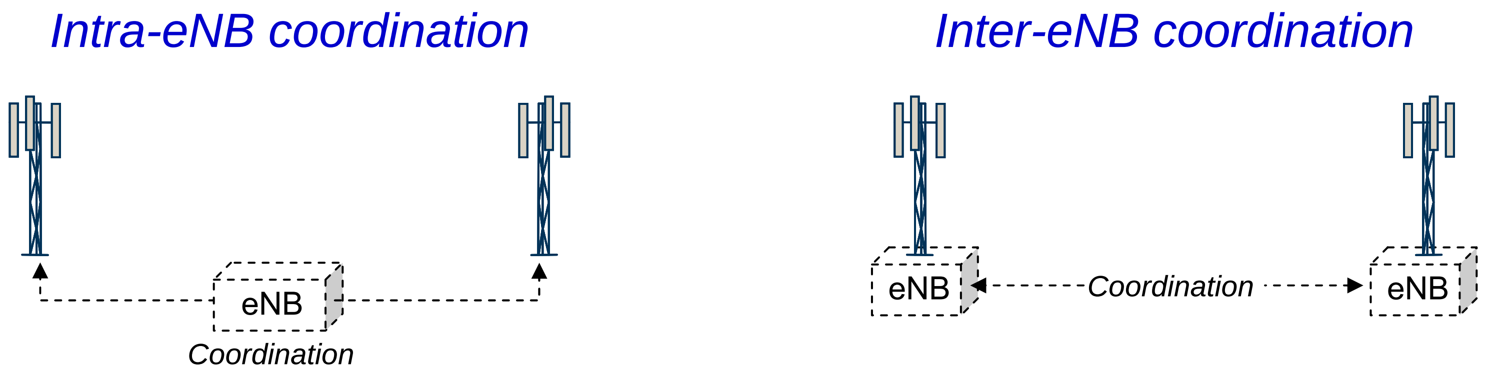


Joint transmission



Architectural impact

- Coordination may be limited to cells of the same eNB or also possible between cells of different eNB
  - Intra-eNB coordination ➪ No impact on RAN-internal interfaces
  - Inter-eNB coordination ➪ Impact on RAN-internal interfaces



- *"Baseline CoMP" between eNB (e.g. only dynamic scheduling coordination)*
- *"Extended CoMP" within eNB (e.g. joint processing/transmission)*

“It is dangerous to put limits on wireless” – G. Marconi, 1932