UMTS Long Term Evolution (LTE)

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75 Years of Driving Innovation

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Overview 3GPP UMTS Evolution
Driven by Data Rate and Latency Requirements

WCDMA	HSDPA/HSUPA	HSPA+	LTE
384 kbps downlink 128 kbps uplink	14 Mbps peak downlink 5.7 Mbps peak uplink	28 Mbps peak downlink 11 Mbps peak uplink	100 Mbps peak downlink 50 Mbps peak uplink
RoundTripTime~150ms	RoundTripTime<100ms	RoundTripTime <50 ms	RoundTripTime~10 ms
3GPP Release 99/4	3GPP Release 5/6	3GPP Release 7	3GPP Release 8
2003/4	2005/6 (HSDPA) 2007/8 (HSUPA)	2008/9	2009/10

Approx. year of specification freezing

Overview 3GPP UMTS evolution

	WCDMA	HSDPA/ HSUPA	HSPA+	LTE and HSPA+	LTE-advanced
3GPP release	3GPP Release 99/4	3GPP Release 5/6	3GPP Release 7	3GPP Release 8	3GPP Study Item initiated
App. year of network rollout	2003/4	2005/6 (HSDPA) 2007/8 (HSUPA)	2008/2009	2010	
Downlink data rate	384 kbps (typ.)	14 Mbps (peak)	28 Mbps (peak)	LTE: 150 Mbps* (peak) HSPA+: 42 Mbps (peak)	100 Mbps high mobility 1 Gbps low mobility
Uplink data rate	128 kbps (typ.)	5.7 Mbps (peak)	11 Mbps (peak)	LTE: 75 Mbps (peak) HSPA+: 11 Mbps (peak)	
Round Trip Time	~ 150 ms	< 100 ms	< 50 ms	LTE: ~10 ms	

*based on 2x2 MIMO and 20 MHz operation

Overview TD-SCDMA evolution towards LTE TDD

	TD-SCDMA	HSDPA	HSUPA	TD-LTE HSPA+
3GPP release	**3GPP Release 4**	**3GPP Release 5**	**3GPP Release 7**	**3GPP Release 8**
Downlink data rate	**384/128 kbps (typ.)**	**2.8 Mbps (peak)**	**2.8 Mbps (peak)***	**LTE:100 Mbps(req.)**
Uplink data rate	**128 kbps (typ.)**	**128 kbps (typ.)**	**2.2 Mbs (peak)***	**LTE: 50 Mbps (req.)**

* Higher data rate with the use of multi carrier possible

Major technical challenges in LTE

New radio transmission schemes (OFDMA / SC-FDMA)	FDD and TDD mode
MIMO multiple antenna schemes	Throughput / data rate requirements
Timing requirements (1 ms transm.time interval)	Multi-RAT requirements (GSM/EDGE, UMTS, CDMA)
Scheduling (shared channels, HARQ, adaptive modulation)	System Architecture Evolution (SAE)

Introduction to UMTS LTE: Key parameters

Frequency Range	**UMTS FDD bands and UMTS TDD bands**					
Channel bandwidth, 1 Resource Block=180 kHz	**1.4 MHz**	**3 MHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
	6 Resource Blocks	15 Resource Blocks	25 Resource Blocks	50 Resource Blocks	75 Resource Blocks	100 Resource Blocks
Modulation Schemes	**Downlink:** QPSK, 16QAM, 64QAM **Uplink:** QPSK, 16QAM, 64QAM (optional for handset)					
Multiple Access	**Downlink:** OFDMA (Orthogonal Frequency Division Multiple Access) **Uplink:** SC-FDMA (Single Carrier Frequency Division Multiple Access)					
MIMO technology	**Downlink:** Wide choice of MIMO configuration options for transmit diversity, spatial multiplexing, and cyclic delay diversity (max. 4 antennas at base station and handset) **Uplink:** Multi user collaborative MIMO					
Peak Data Rate	**Downlink:** 150 Mbps (UE category 4, 2x2 MIMO, 20 MHz) 300 Mbps (UE category 5, 4x4 MIMO, 20 MHz) **Uplink:** 75 Mbps (20 MHz)					

LTE/LTE-A Frequency Bands (FDD)

E–UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1452.9 MHz	1475.9 MHz	–	1500.9 MHz	FDD
12	698 MHz	–	716 MHz	728 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	-	862 MHz	791 MHz	-	821 MHz	FDD
21	1447.9 MHz	-	1462.9 MHz	1495.9 MHz	-	1510.9 MHz	FDD
22	3410 MHz	-	3500 MHz	3510 MHz	-	3600 MHz	FDD

LTE/LTE-A Frequency Bands (TDD)

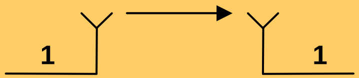
E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	3400 MHz – 3600MHz			3400 MHz – 3600MHz			TDD

MIMO =

Multiple Input Multiple Output Antennas

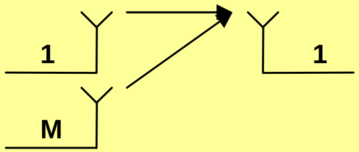
MIMO is defined by the number of Rx / Tx Antennas
and not by the Mode which is supported

Mode



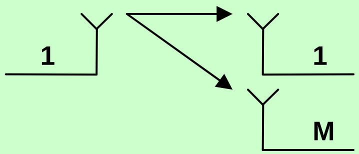
SISO
Single Input Single Output

Typical todays wireless Communication System



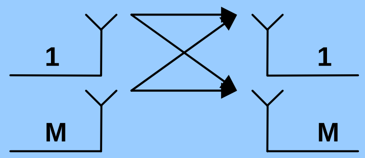
MISO
Multiple Input Single Output

Transmit Diversity
- Maximum Ratio Combining (MRC)
- Matrix A also known as STC
- Space Time / Frequency Coding (STC / SFC)



SIMO
Single Input Multiple Output

Receive Diversity
- Maximum Ratio Combining (MRC)



MIMO
Multiple Input Multiple Output

Definition is seen from Channel
Multiple In = Multiple Transmit Antennas

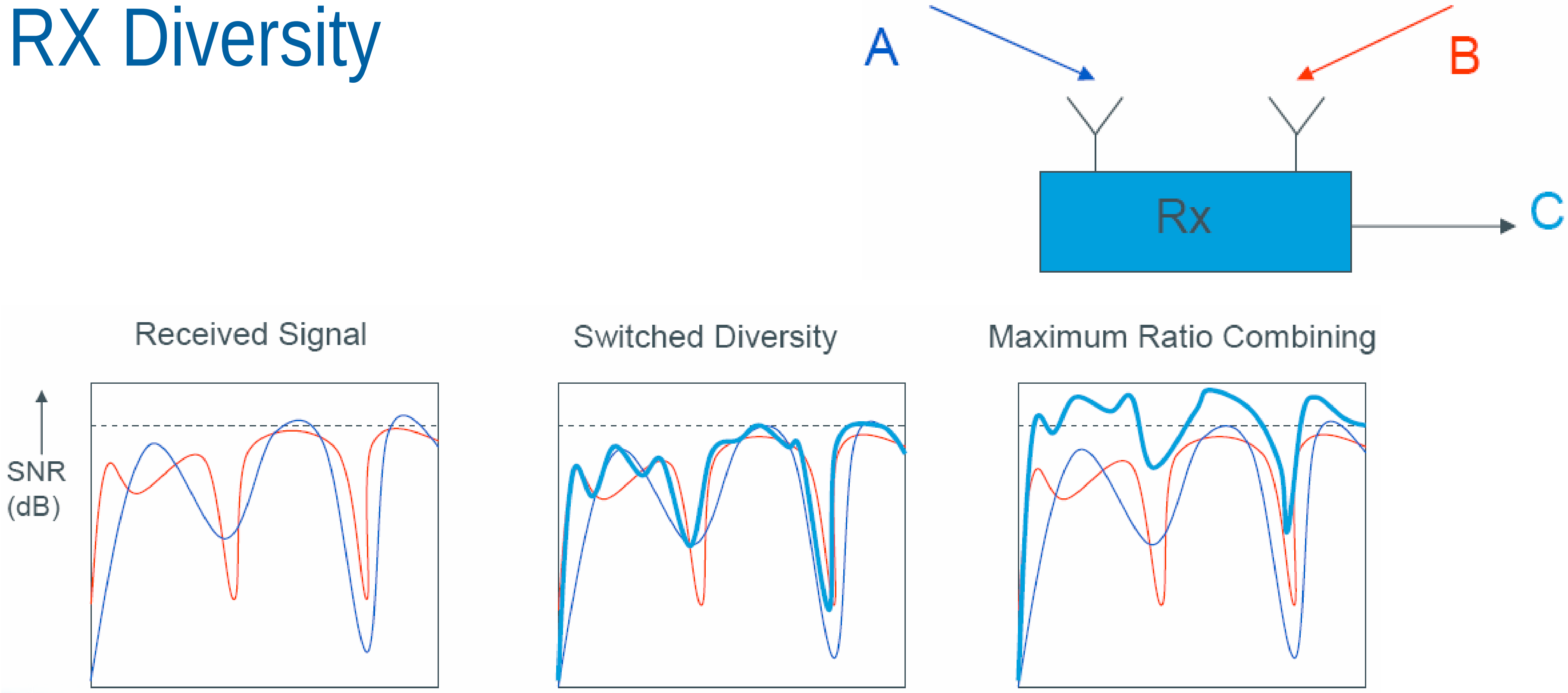
Receive / Transmit Diversity

Spatial Multiplexing (SM) also known as:
- Space Division Multiplex (SDM)
- True MIMO
- Single User MIMO (SU-MIMO)
- Matrix B

Space Division Multiple Access (SDMA) also known as:
- Multi User MIMO (MU MIMO)
- Virtual MIMO
- Collaborative MIMO

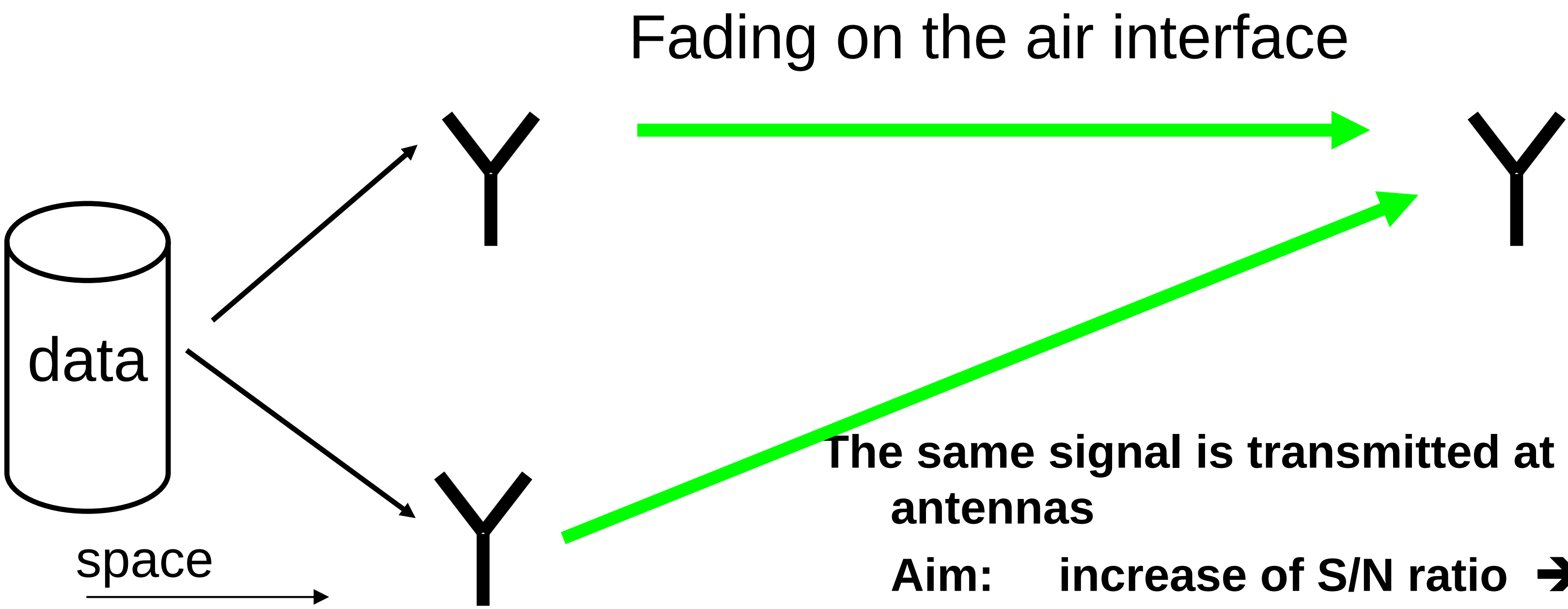
Beamforming

RX Diversity



Maximum Ratio Combining depends on different fading of the two received signals. In other words decorrelated fading channels

TX Diversity: Space Time Coding



space

$$S_2 = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix}$$

time

Alamouti Coding

The same signal is transmitted at differnet antennas

Aim: increase of S/N ratio ➔ increase of throughput

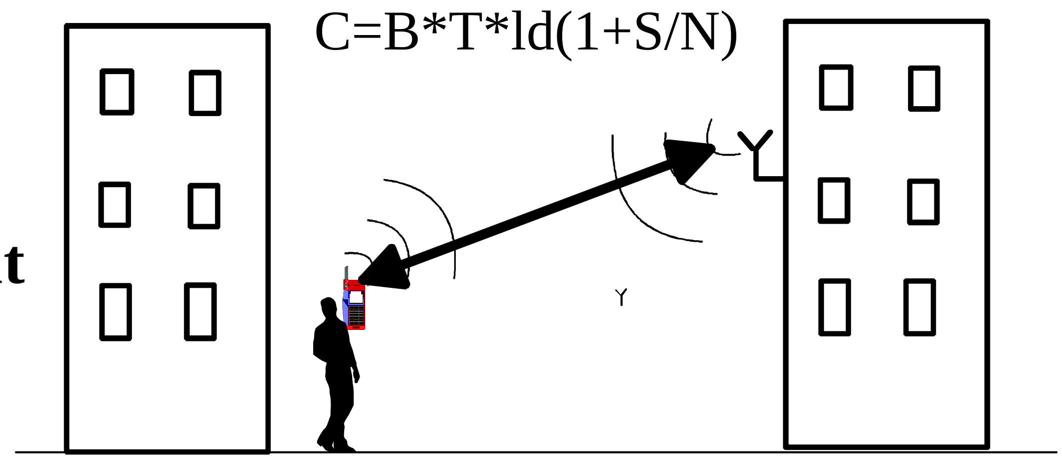
Alamouti Coding = diversity gain approaches

RX diversity gain with MRRC!

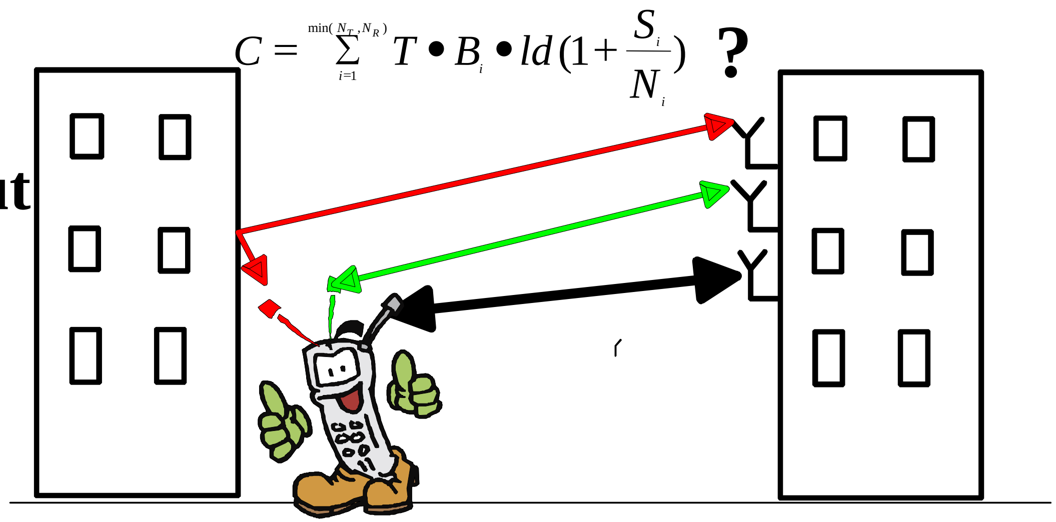
-> benefit for mobile communications

MIMO Spatial Multiplexing

SISO:
Single Input
Single Output



MIMO:
Multiple Input
Multiple Output



Increasing capacity per cell

The MIMO promise

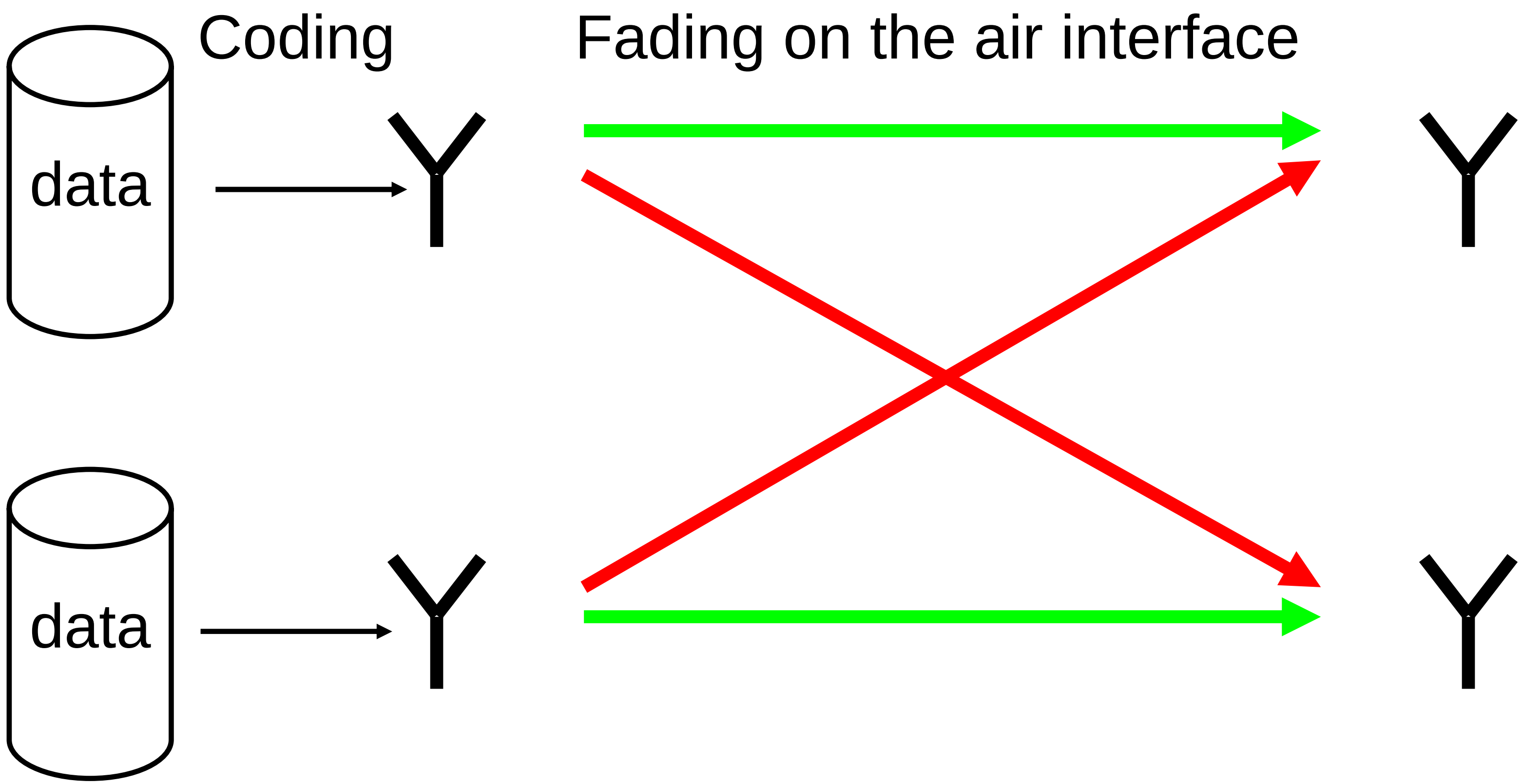
- **Channel capacity grows linearly with antennas ☺**

Max Capacity ~ min(N_{TX}, N_{RX})

- **Assumptions ☹**
  - Perfect channel knowledge
  - Spatially uncorrelated fading

- **Reality 😐**
  - Imperfect channel knowledge
  - Correlation $\neq$ 0 and rather unknown

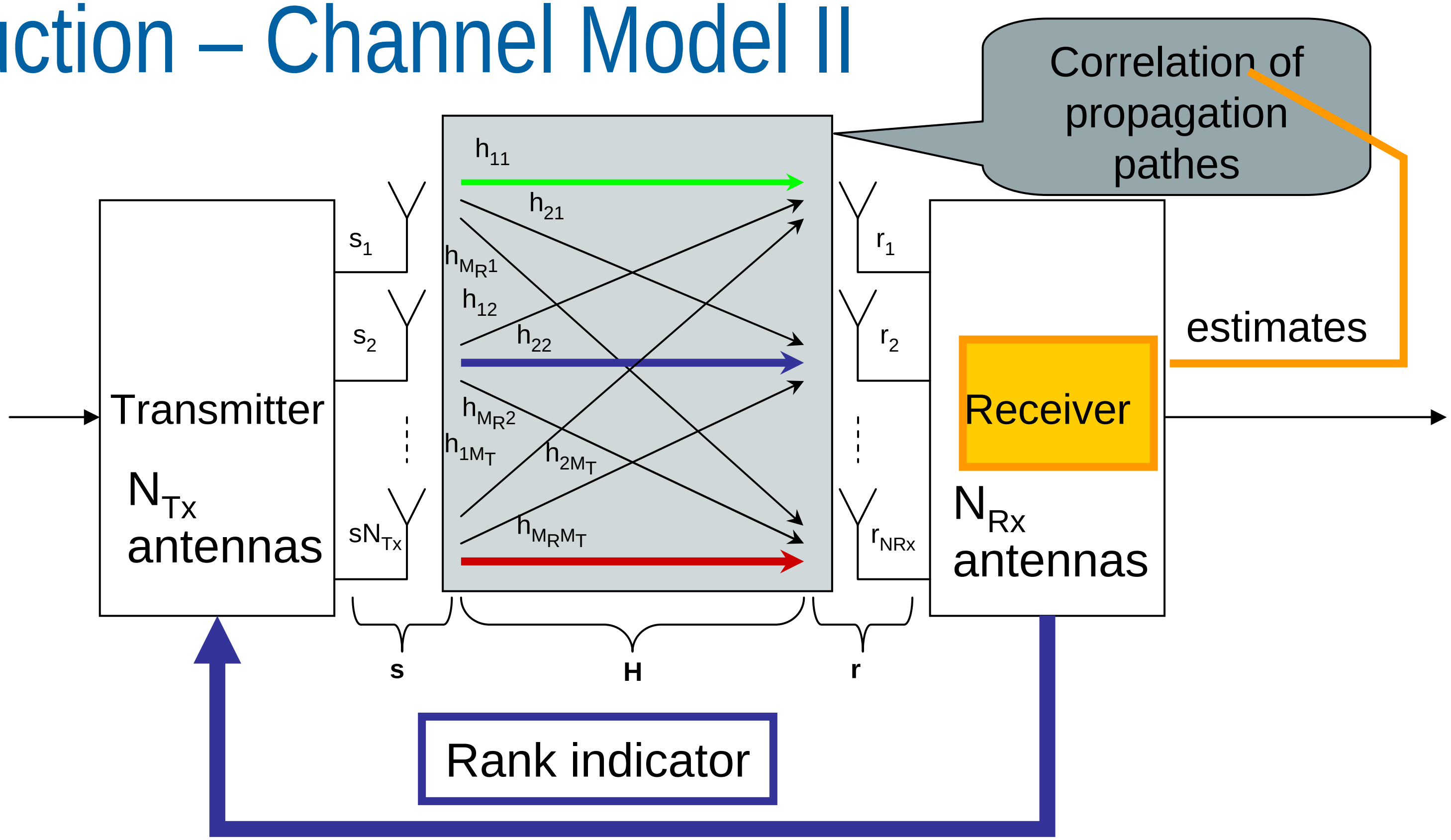
Spatial Multiplexing



Throughput: **<200%**

Spatial Multiplexing: We increase the throughput but we also increase the interference!

Introduction – Channel Model II



Capacity ~ min(N_{TX}, N_{RX}) → max. possible rank!

But effective rank depends on channel, i.e. the correlation situation of H

Spatial Multiplexing prerequisites

Decorrelation is achieved by:

- **Decorrelated data content on each spatial stream**

difficult

- **Large antenna spacing**

Channel condition

- **Environment with a lot of scatters near the antenna (e.g. MS or indoor operation, but not BS)**

Technical assist

- **Precoding**
- **Cyclic Delay Diversity**

But, also possible that decorrelation is not given

MIMO: channel interference + precoding

MIMO channel models: different ways to combat against channel impact:

I.: Receiver cancels impact of channel

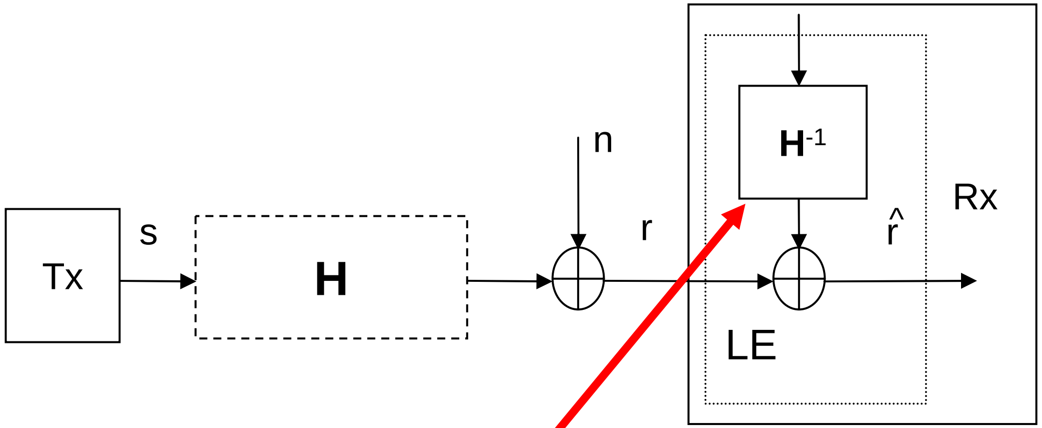
II.: Precoding by using codebook. Transmitter assists receiver in cancellation of channel impact

III.: Precoding at transmitter side to cancel channel impact

MIMO: Principle of linear equalizing

$$\boxed{R = S*H + n}$$

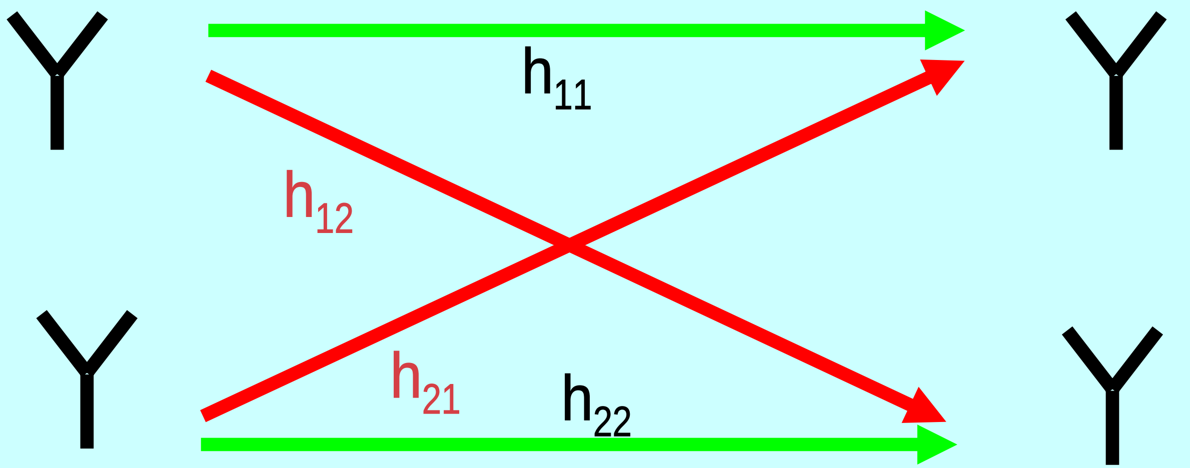
Transmitter will send reference signals or pilot sequence to enable receiver to estimate H.



The receiver multiplies the signal r with the Hermetian conjugate complex of the transmitting function to eliminate the channel influence.

Linear equalization – compute power increase

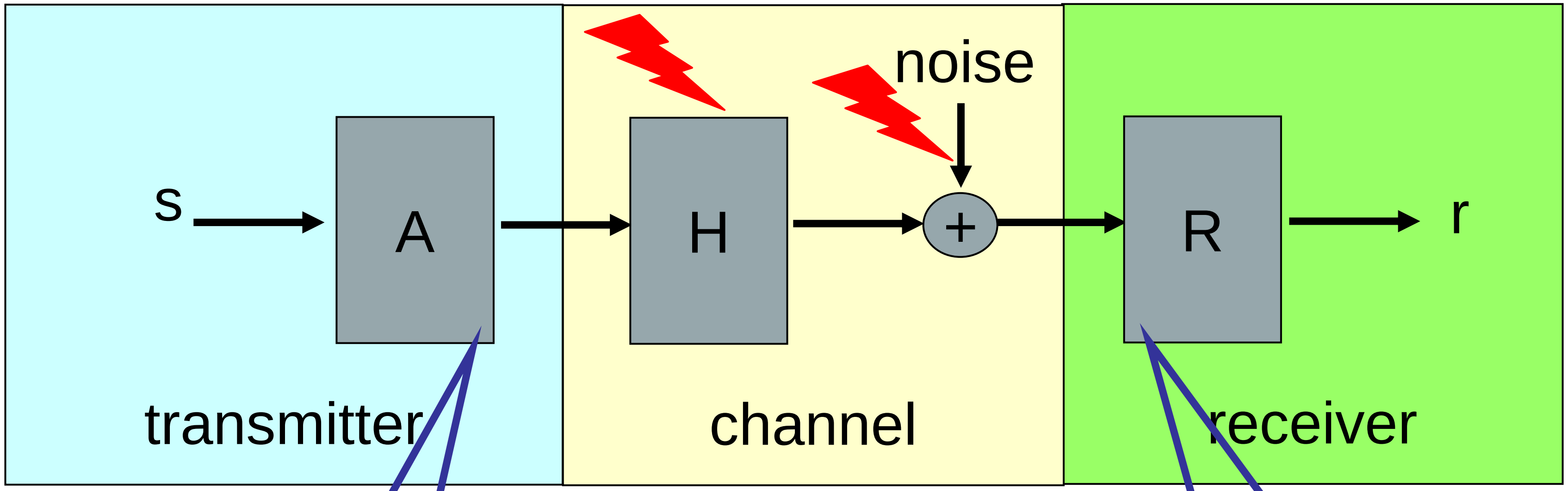
SISO: Equalizer has to estimate 1 channel



$$H = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix}$$

2x2 MIMO: Equalizer has to estimate 4 channels

transmission – reception model

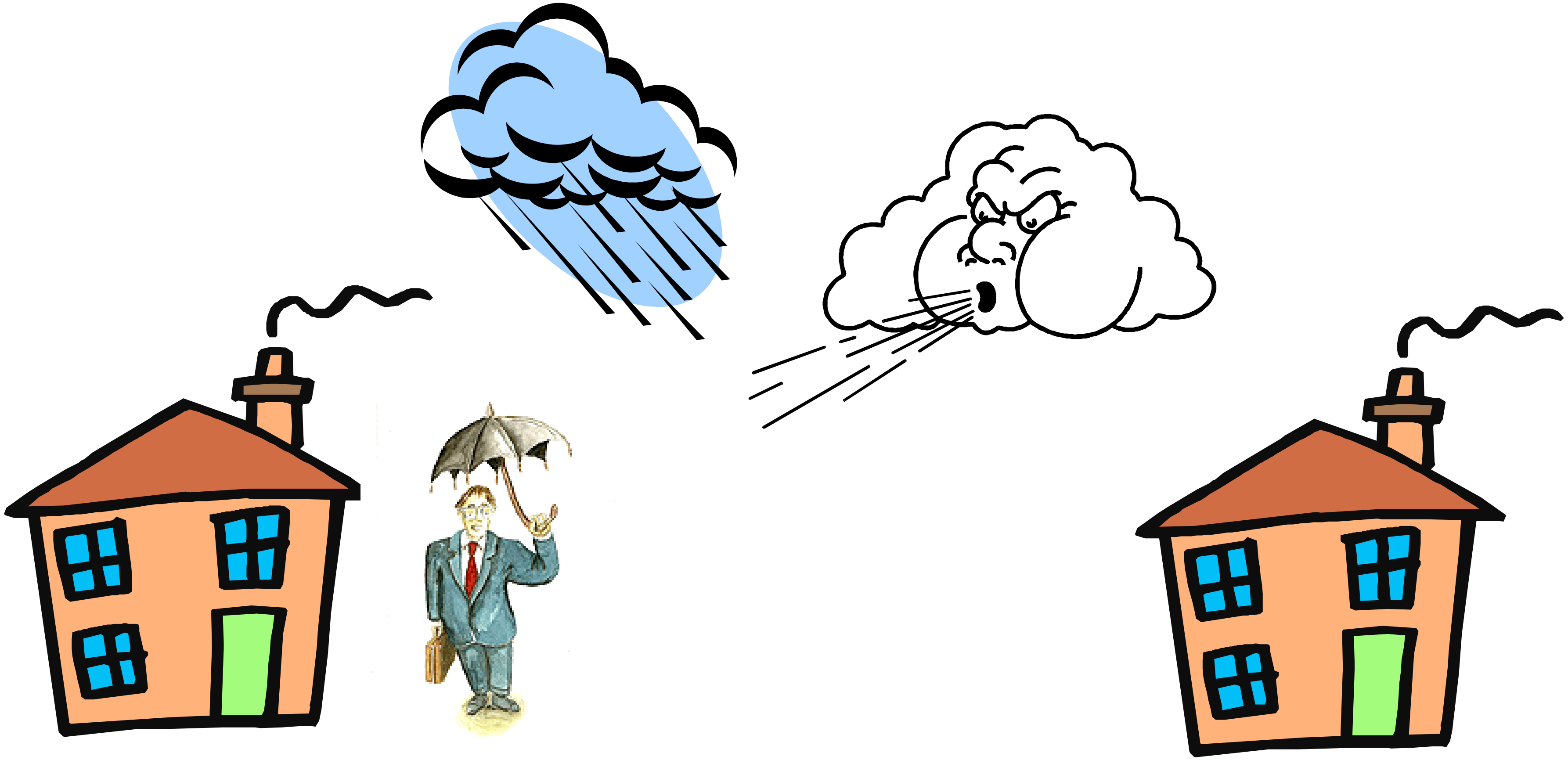


•Modulation,
•Power
•„precoding“,
•etc.

Linear equalization
at receiver is not
very efficient, i.e.
noise can not be cancelled

•detection,
•estimation
•Eliminating channel impact
•etc.

MIMO – work shift to transmitter



Transmitter

Channel

Receiver

MIMO Precoding in LTE (DL)

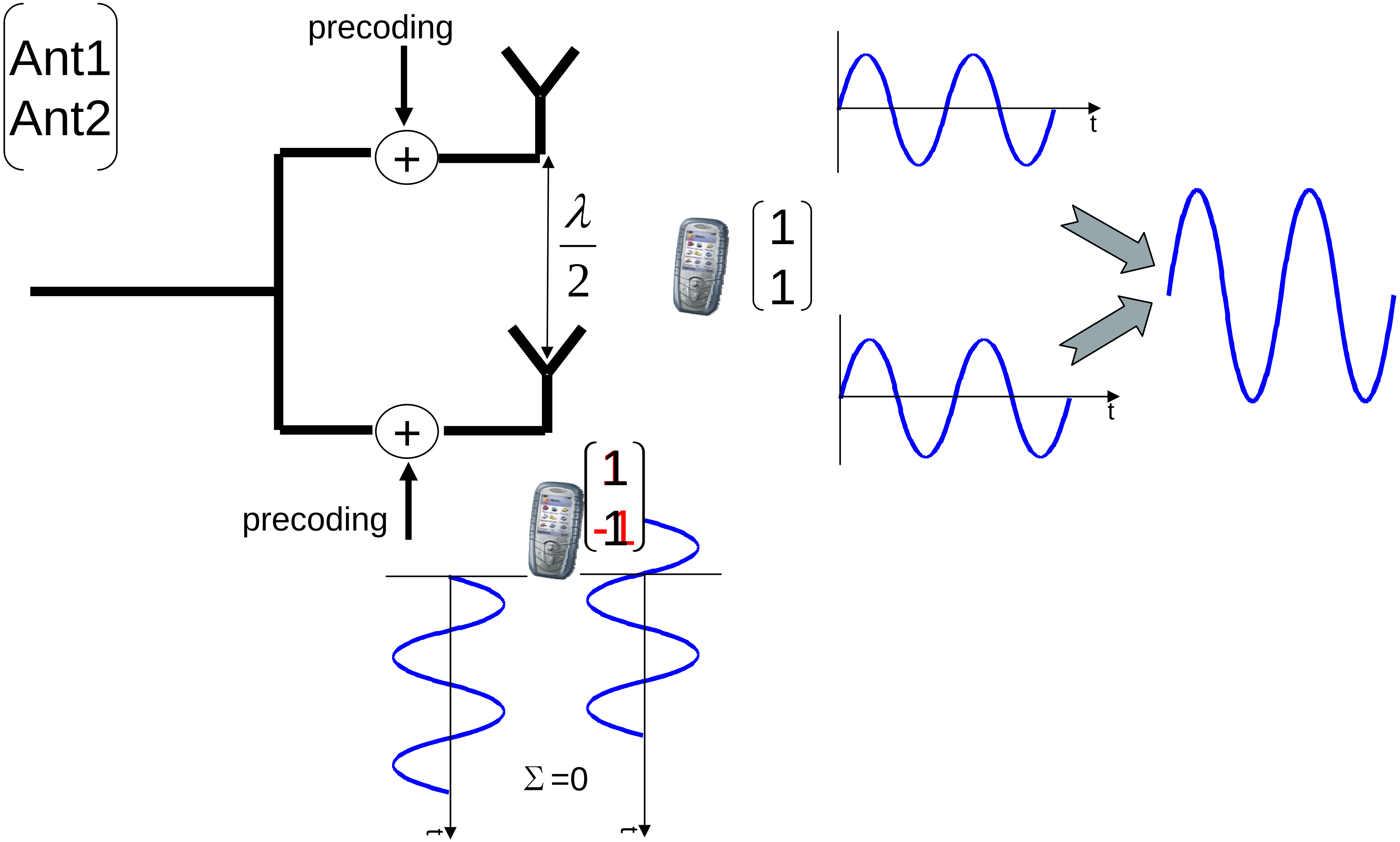
Spatial multiplexing – Code book for precoding

Code book for 2 Tx:

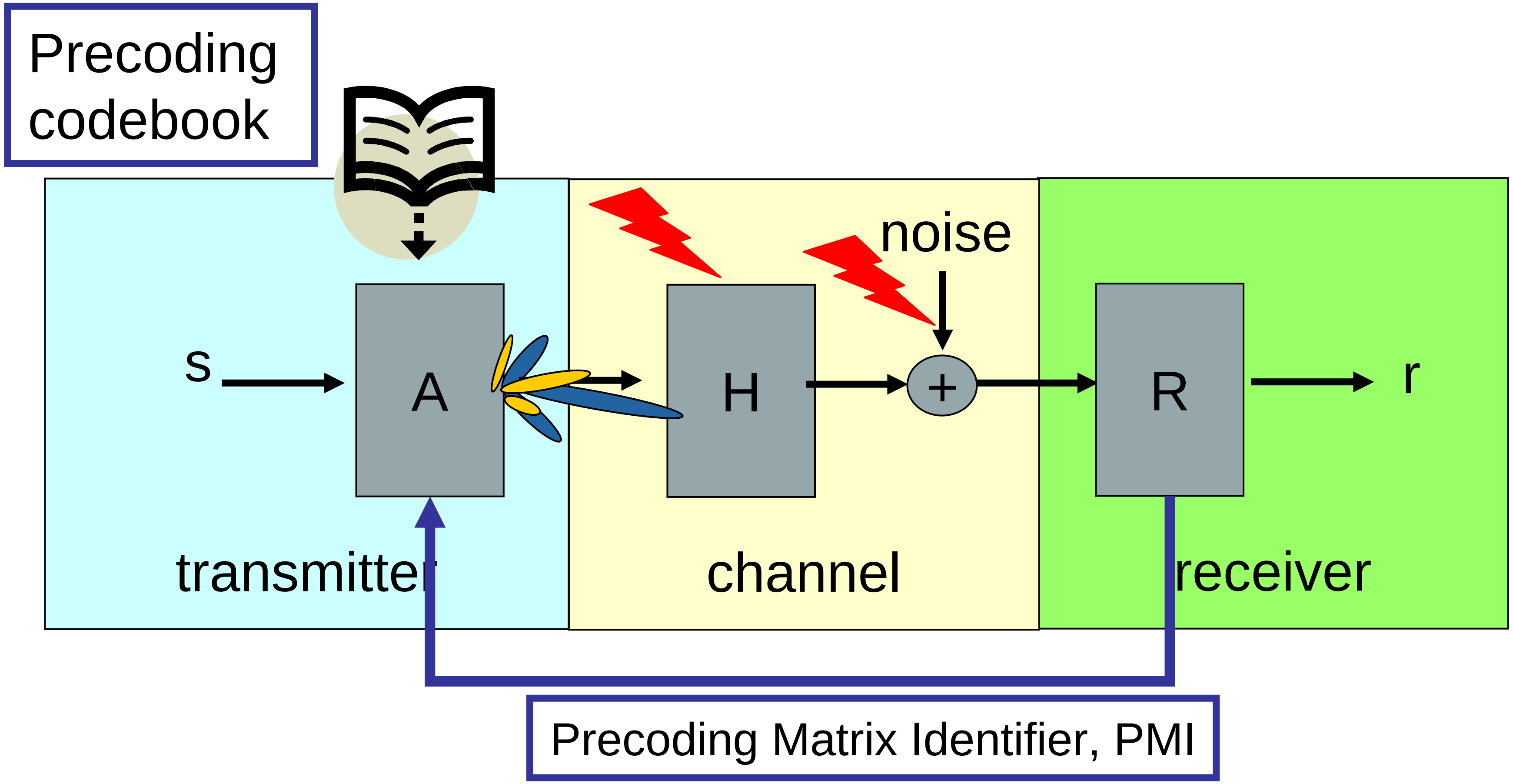
Codebook index	Number of layers υ 1	2
0	$\begin{bmatrix}1\\0\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\begin{bmatrix}0\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	-
4	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	-
5	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Additional multiplication of the layer symbols with codebook entry

MIMO precoding



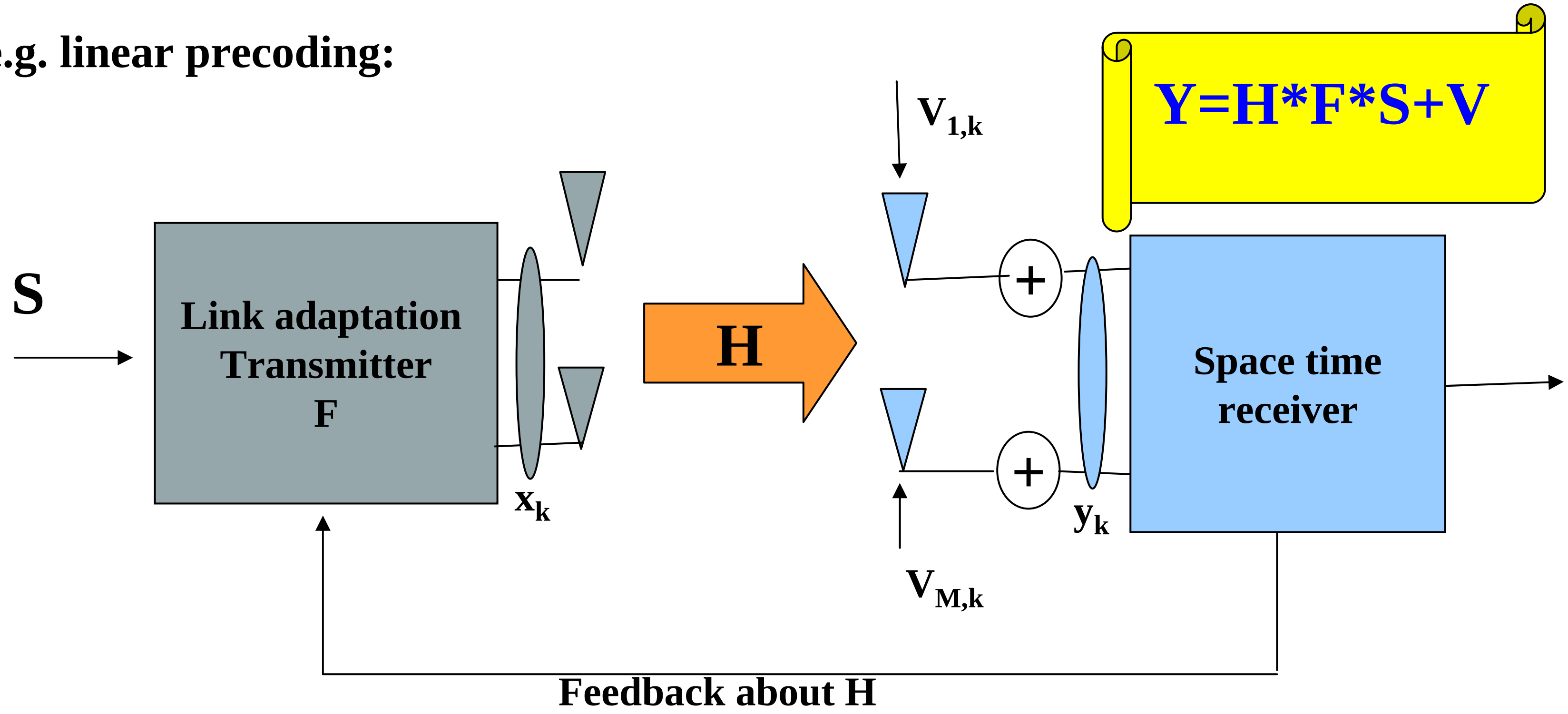
MIMO – codebook based precoding



Codebook based precoding creates some kind of „beamforming light“

MIMO: avoid inter-channel interference

e.g. linear precoding:

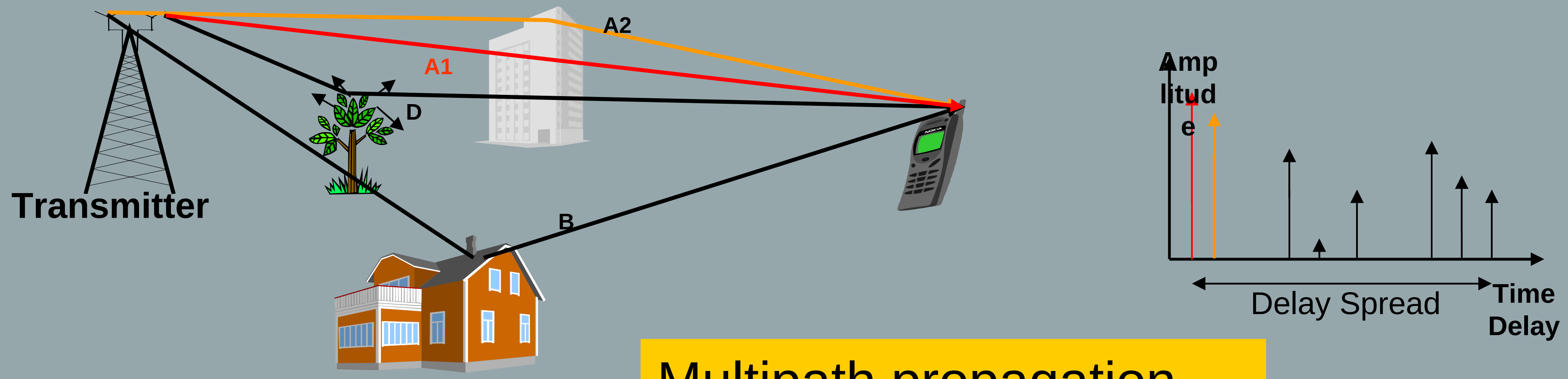


Idea: F adapts transmitted signal to current channel conditions

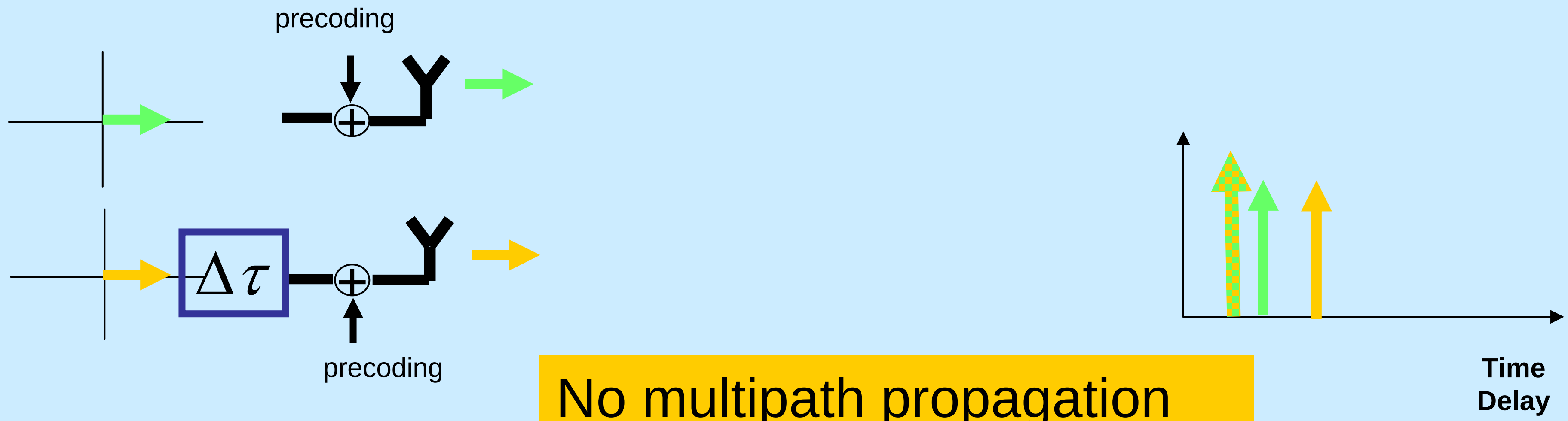
MAS: „Dirty Paper“ Coding

- **Multiple Antenna Signal Processing: „Known Interference“**
  - Is like NO interference
  - Analogy to writing on „dirty paper“ by changing ink color accordingly

Cyclic Delay Diversity, CDD



Multipath propagation

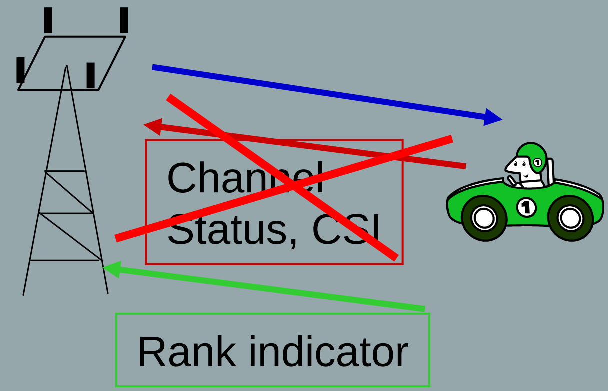


No multipath propagation

„Open loop“ und „closed loop“ MIMO

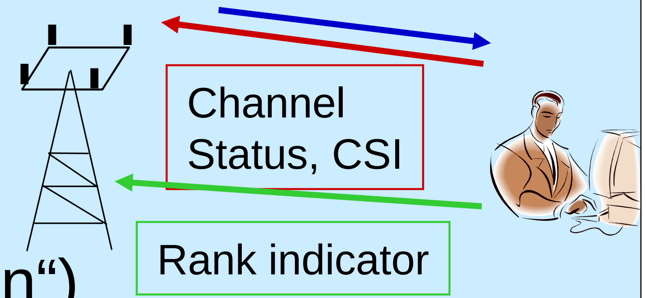
Open loop (No channel knowledge at transmitter)

$$r = Hs + n$$



Closed loop (With channel knowledge at transmitter

$$r = HWs + n$$



Adaptive Precoding matrix („Pre-equalisation“)

Feedback from receiver needed (closed loop)

MIMO transmission modes

7 transmission modes are defined

- Transmission mode1
  SISO
- Transmission mode2
  TX diversity
- Transmission mode3
  Open-loop spatial multiplexing
- Transmission mode4
  Closed-loop spatial multiplexing
- Transmission mode5
  Multi-User MIMO
- Transmission mode6
  Closed-loop spatial multiplexing, using 1 layer
- Transmission mode7
  SISO, port 5
  = beamforming in TDD

Beamforming

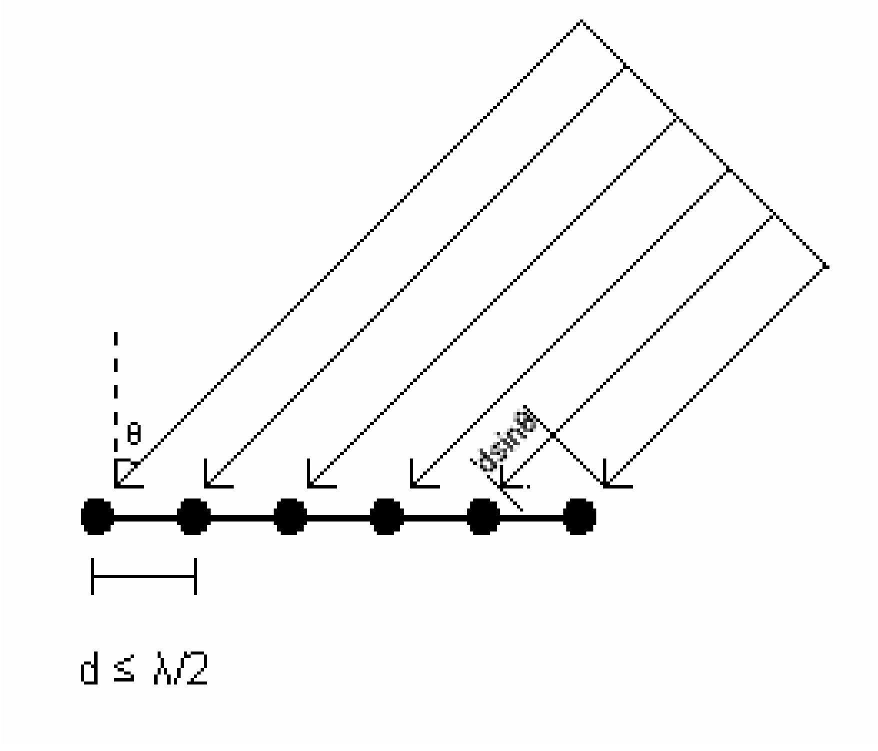
Adaptive Beamforming

Closed loop precoded beamforming

- Classic way
- Antenna weights to adjust beam
- Directional characteristics
- Specific antenna array geometrie
- Dedicated pilots required

- Kind of MISO with channel knowledge at transmitter
- Precoding based on feedback
- No specific antenna array geometrie
- Common pilots are sufficient

Adaptive Beamforming



$$s_0(t) = s(t)$$
$$s_1(t) = s(t-\tau) \approx s(t)e^{-j\theta}$$
$$s_1(t) = s(t-2\tau) \approx s(t)e^{-j2\theta}$$
$$s_1(t) = s(t-3\tau) \approx s(t)e^{-j3\theta}$$
$$\vdots$$
$$s_{M-1}(t) = s(t-(M-1)\tau) \approx s(t)e^{-j(M-1)\theta}$$

Signal at each antenna

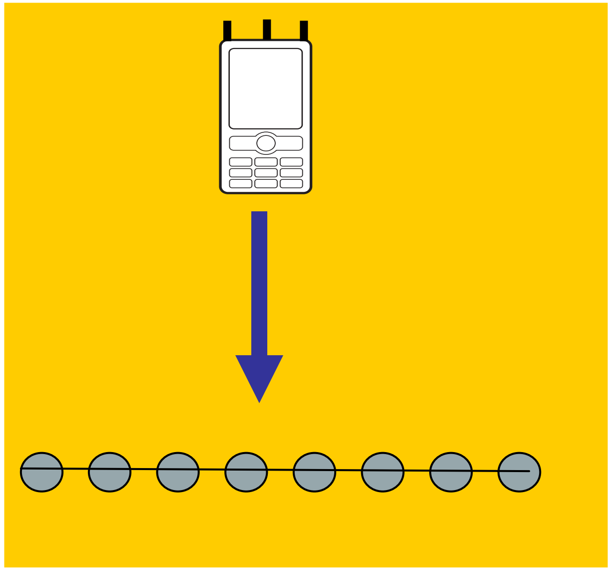
$$\mathbf{d}(t) = \begin{bmatrix} 1 \\ e^{-j\theta} \\ e^{-j2\theta} \\ e^{-j3\theta} \\ \vdots \\ e^{-j(M-1)\theta} \end{bmatrix} \cdot s(t) = \mathbf{a}(\theta) \cdot s(t),$$

Vector format

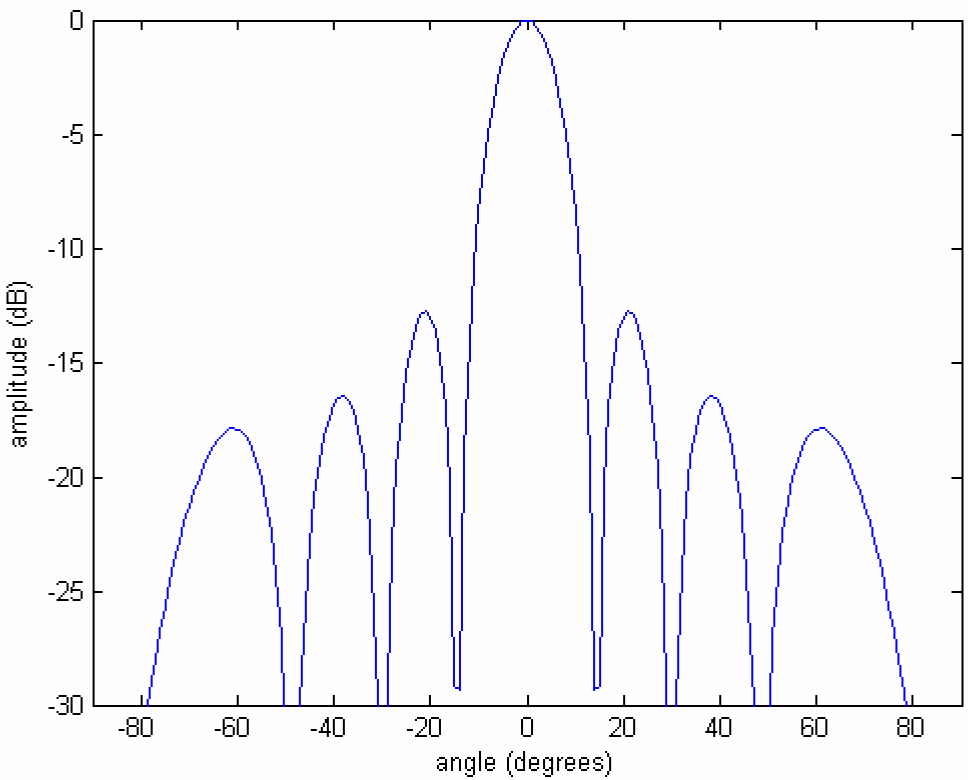
$$\boxed{\tau_i = \frac{(i-1)d\sin\theta}{c} = (i-1)\tau} \longleftarrow \boxed{\tau = \frac{d\sin\theta}{c}}$$

Delay at each antenna

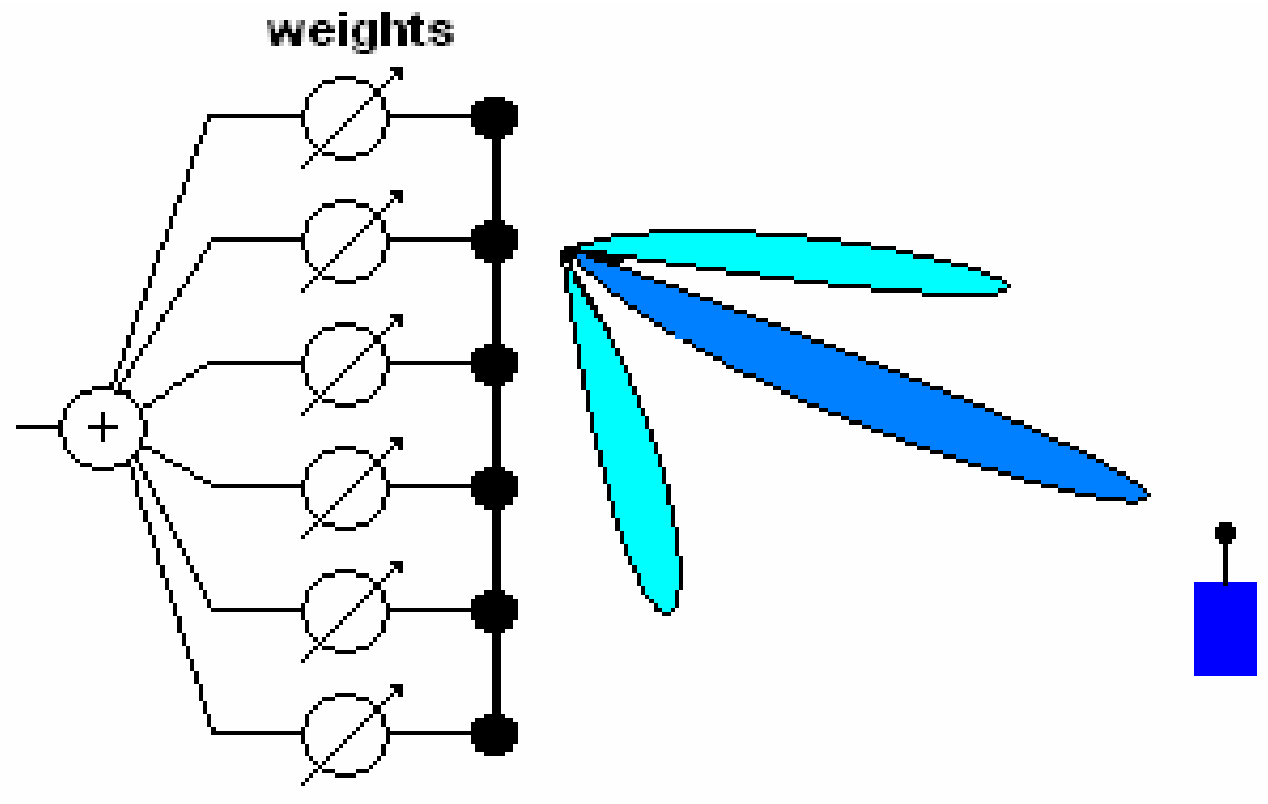
Adaptive Beamforming



Example:
8 antenna ULA,
Uniform antenna
array



Adaptive Beamforming

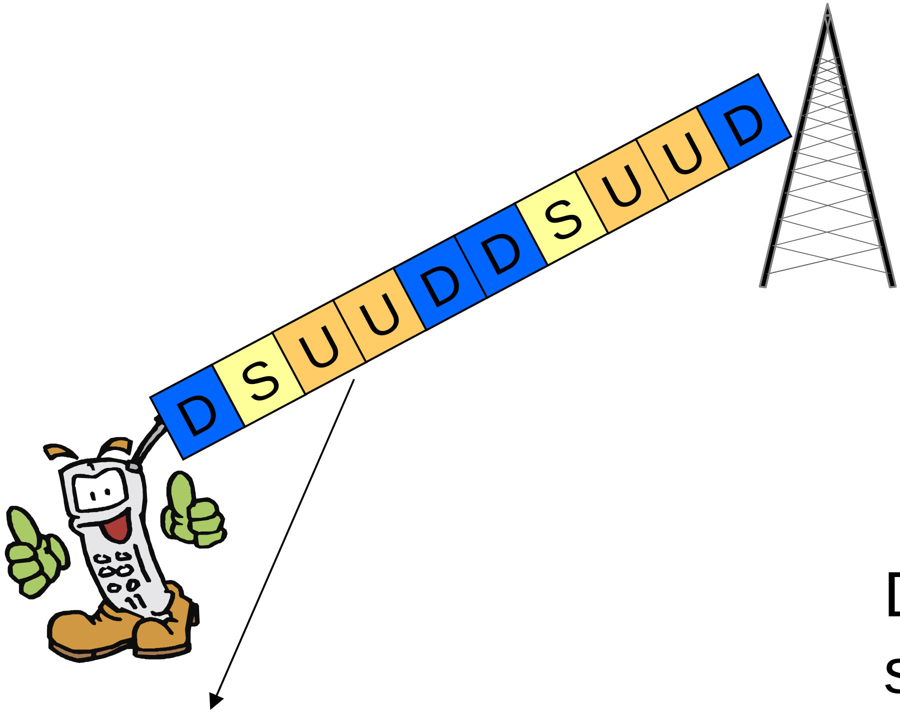


$$y(t) = \mathbf{w}^H \cdot \mathbf{d}(t) = \mathbf{w}^H \cdot \mathbf{a}(q) \cdot s(t),$$

Idea: Adding a weight vector and optimize e.g: $\mathbf{w}^H \cdot \mathbf{a}(q) = 1$

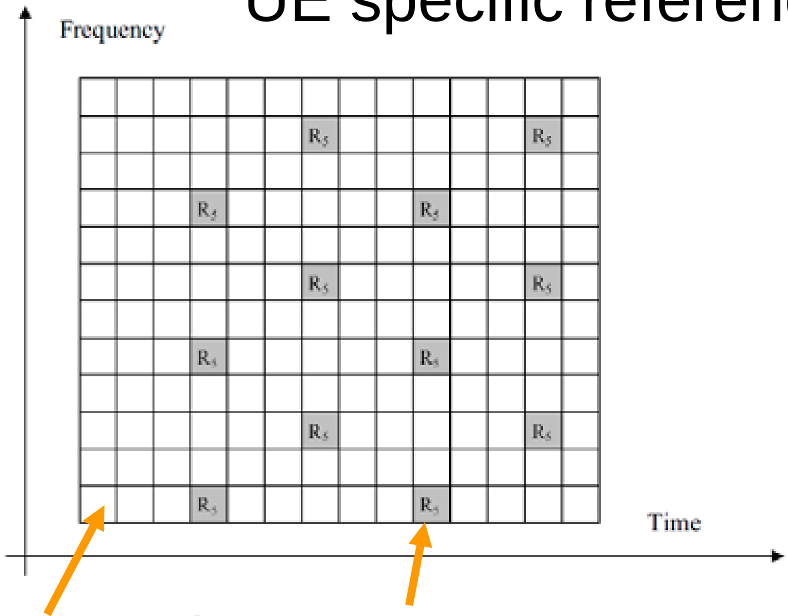
Adaptive beamforming: transmission mode 7

Used only in TD-LTE mode



UL can be used by eNodeB
for Channel Status Information
inquiry

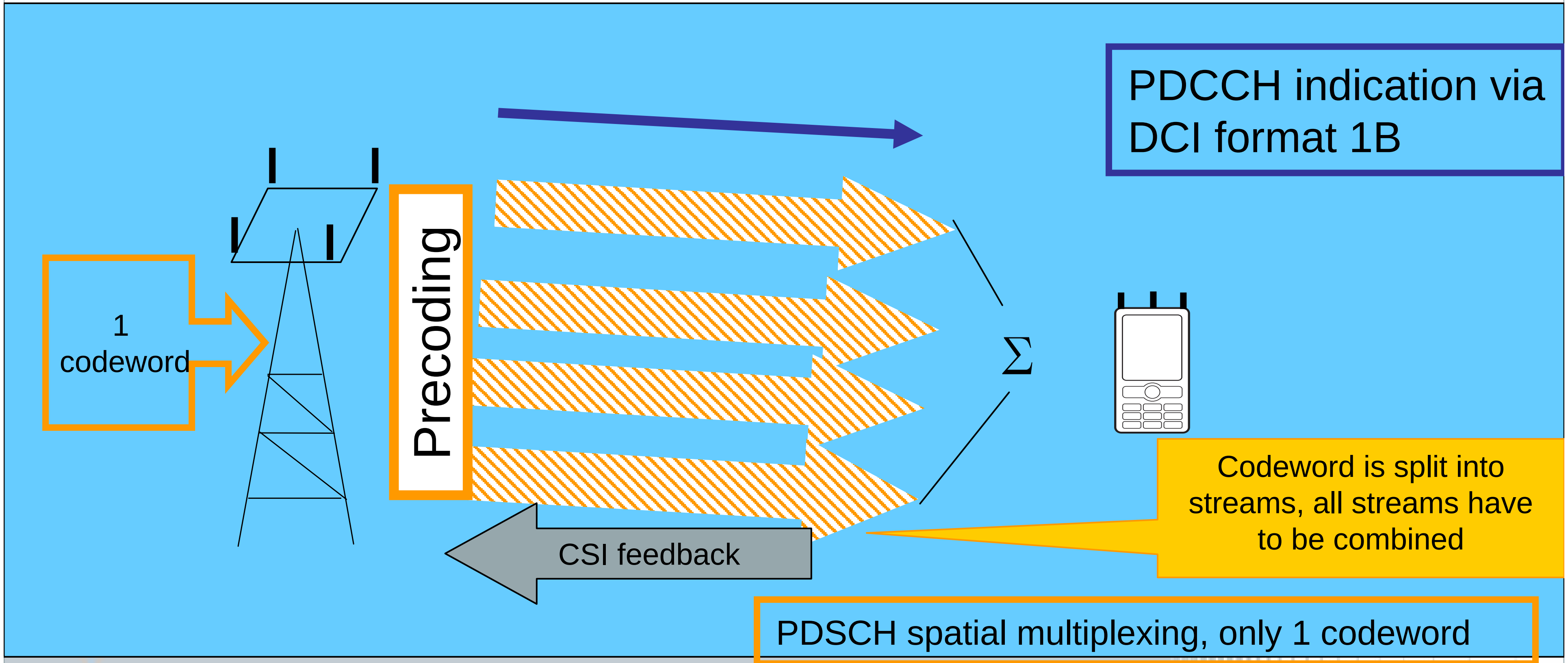
UE specific reference



Data and reference
symbols use the
same precoding

Closed loop precoded beamforming

- UE has to send channel status information as feedback.
- Based on CSI, node B selects appropriate precoding matrix



Closed loop precoded beamforming

Codebook index	Number of layers υ	
	1	2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Possible precoding values for 1- 2 antennas

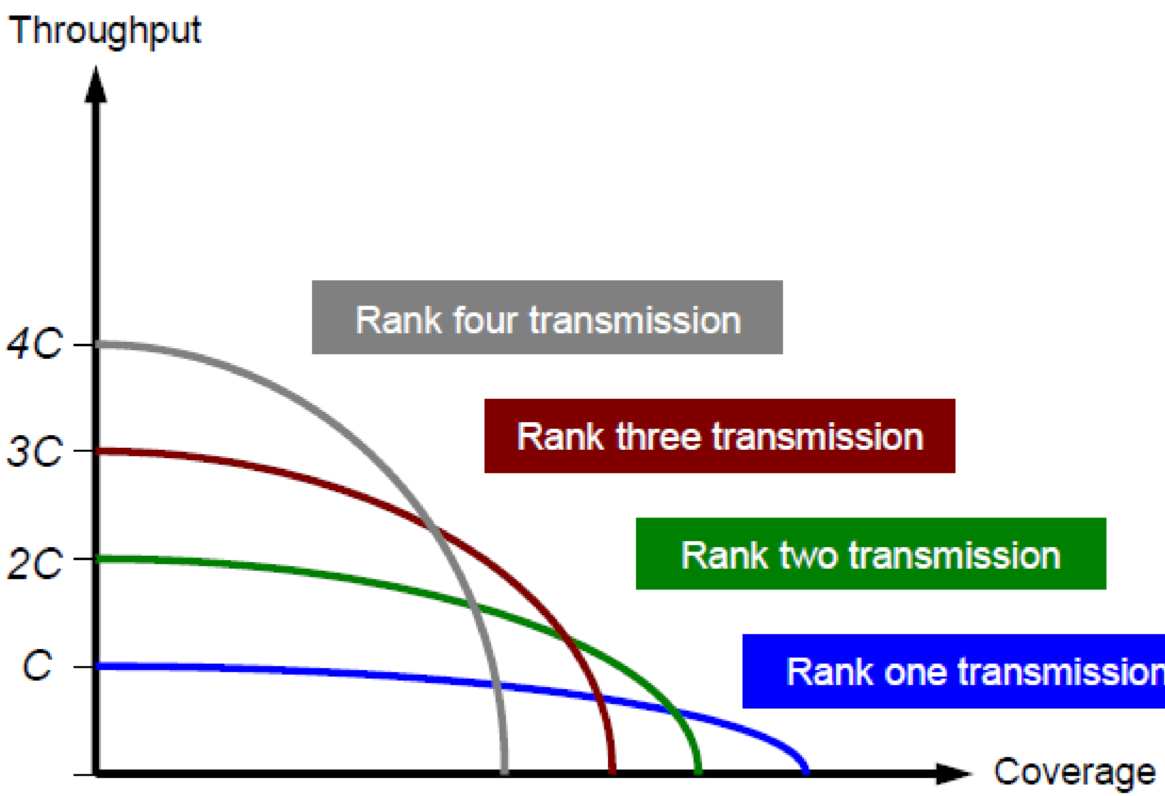
Closed loop precoded beamforming

Codebook index	u_n	Number of layers υ 1	2	3	4
0	$u_0 = [1 \ -1 \ -1 \ -1]^T$	$W_0^{\{1\}}$	$W_0^{\{14\}}/\sqrt{2}$	$W_0^{\{124\}}/\sqrt{3}$	$W_0^{\{1234\}}/2$
1	$u_1 = [1 \ -j \ 1 \ j]^T$	$W_1^{\{1\}}$	$W_1^{\{12\}}/\sqrt{2}$	$W_1^{\{123\}}/\sqrt{3}$	$W_1^{\{1234\}}/2$
2	$u_2 = [1 \ 1 \ -1 \ 1]^T$	$W_2^{\{1\}}$	$W_2^{\{12\}}/\sqrt{2}$	$W_2^{\{123\}}/\sqrt{3}$	$W_2^{\{3214\}}/2$
3	$u_3 = [1 \ j \ 1 \ -j]^T$	$W_3^{\{1\}}$	$W_3^{\{12\}}/\sqrt{2}$	$W_3^{\{123\}}/\sqrt{3}$	$W_3^{\{3214\}}/2$
4	$u_4 = \left[1 \ (-1-j)/\sqrt{2} \ -j \ (1-j)/\sqrt{2}\right]^T$	$W_4^{\{1\}}$	$W_4^{\{14\}}/\sqrt{2}$	$W_4^{\{124\}}/\sqrt{3}$	$W_4^{\{1234\}}/2$
5	$u_5 = \left[1 \ (1-j)/\sqrt{2} \ j \ (-1-j)/\sqrt{2}\right]^T$	$W_5^{\{1\}}$	$W_5^{\{14\}}/\sqrt{2}$	$W_5^{\{124\}}/\sqrt{3}$	$W_5^{\{1234\}}/2$
6	$u_6 = \left[1 \ (1+j)/\sqrt{2} \ -j \ (-1+j)/\sqrt{2}\right]^T$	$W_6^{\{1\}}$	$W_6^{\{13\}}/\sqrt{2}$	$W_6^{\{134\}}/\sqrt{3}$	$W_6^{\{1324\}}/2$
7	$u_7 = \left[1 \ (-1+j)/\sqrt{2} \ j \ (1+j)/\sqrt{2}\right]^T$	$W_7^{\{1\}}$	$W_7^{\{13\}}/\sqrt{2}$	$W_7^{\{134\}}/\sqrt{3}$	$W_7^{\{1324\}}/2$
8	$u_8 = [1 \ -1 \ 1 \ 1]^T$	$W_8^{\{1\}}$	$W_8^{\{12\}}/\sqrt{2}$	$W_8^{\{124\}}/\sqrt{3}$	$W_8^{\{1234\}}/2$
9	$u_9 = [1 \ -j \ -1 \ -j]^T$	$W_9^{\{1\}}$	$W_9^{\{14\}}/\sqrt{2}$	$W_9^{\{134\}}/\sqrt{3}$	$W_9^{\{1234\}}/2$
10	$u_{10} = [1 \ 1 \ 1 \ -1]^T$	$W_{10}^{\{1\}}$	$W_{10}^{\{13\}}/\sqrt{2}$	$W_{10}^{\{123\}}/\sqrt{3}$	$W_{10}^{\{1324\}}/2$
11	$u_{11} = [1 \ j \ -1 \ j]^T$	$W_{11}^{\{1\}}$	$W_{11}^{\{13\}}/\sqrt{2}$	$W_{11}^{\{134\}}/\sqrt{3}$	$W_{11}^{\{1324\}}/2$
12	$u_{12} = [1 \ -1 \ -1 \ 1]^T$	$W_{12}^{\{1\}}$	$W_{12}^{\{12\}}/\sqrt{2}$	$W_{12}^{\{123\}}/\sqrt{3}$	$W_{12}^{\{1234\}}/2$
13	$u_{13} = [1 \ -1 \ 1 \ -1]^T$	$W_{13}^{\{1\}}$	$W_{13}^{\{13\}}/\sqrt{2}$	$W_{13}^{\{123\}}/\sqrt{3}$	$W_{13}^{\{1324\}}/2$
14	$u_{14} = [1 \ 1 \ -1 \ -1]^T$	$W_{14}^{\{1\}}$	$W_{14}^{\{13\}}/\sqrt{2}$	$W_{14}^{\{123\}}/\sqrt{3}$	$W_{14}^{\{3214\}}/2$
15	$u_{15} = [1 \ 1 \ 1 \ 1]^T$	$W_{15}^{\{1\}}$	$W_{15}^{\{12\}}/\sqrt{2}$	$W_{15}^{\{123\}}/\sqrt{3}$	$W_{15}^{\{1234\}}/2$

Possible precoding values for 4 antennas

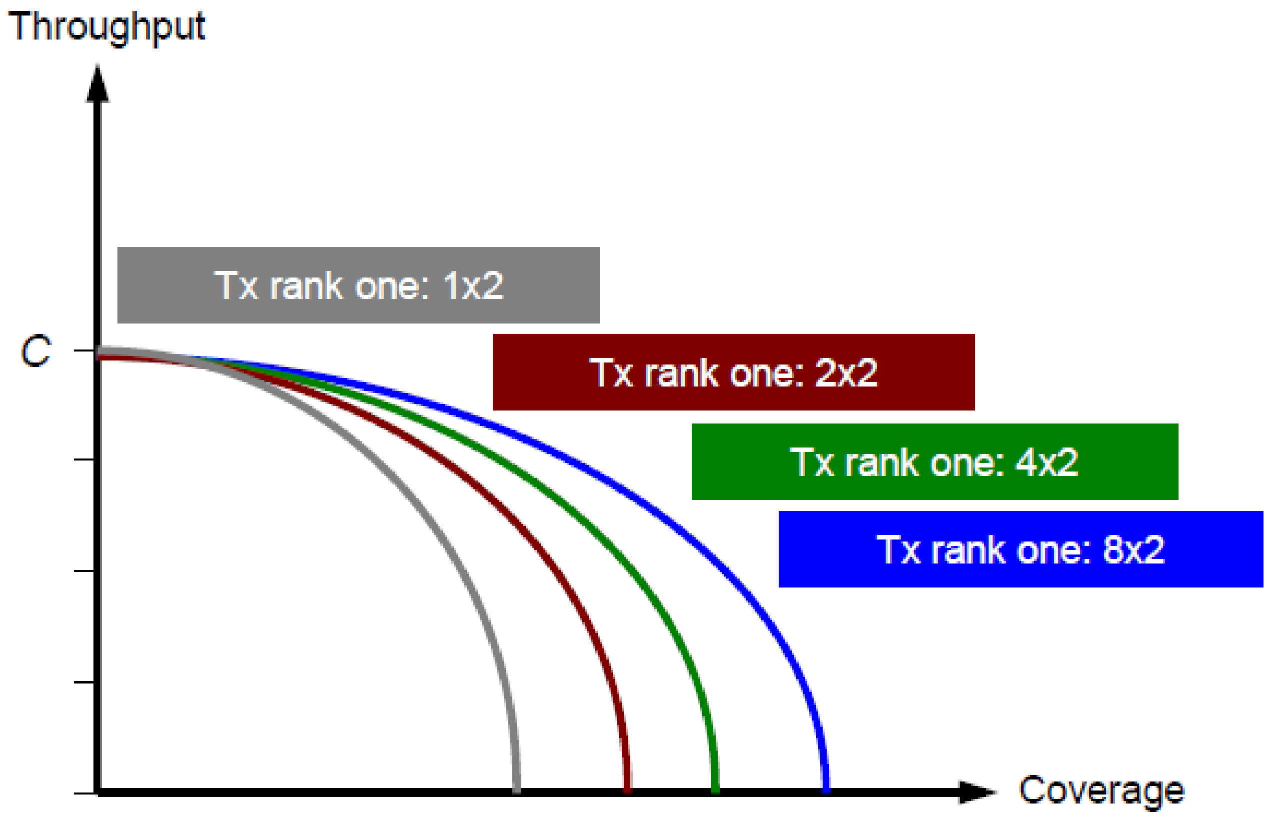
$$W_n = I - 2u_n u_n^H / u_n^H u_n$$

Spatial multiplexing vs beamforming



Spatial multiplexing increases throughput, but looses coverage

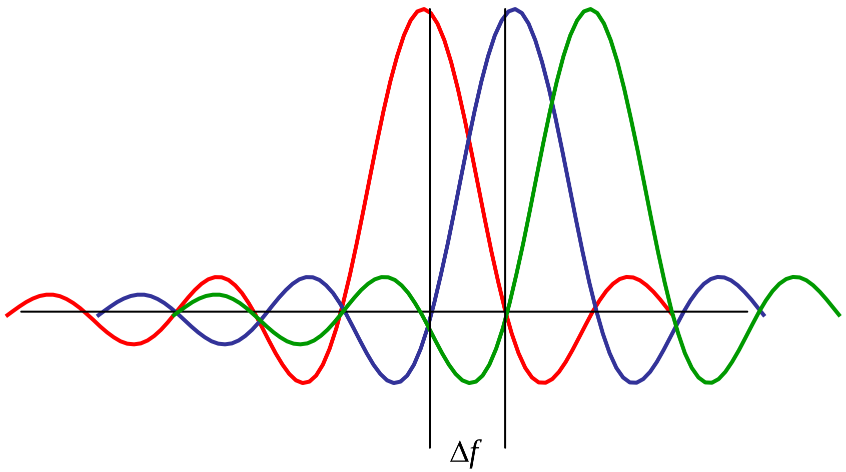
Spatial multiplexing vs beamforming



Beamforming increases coverage

Some technical details of LTE / EUTRA

Basic OFDM parameter



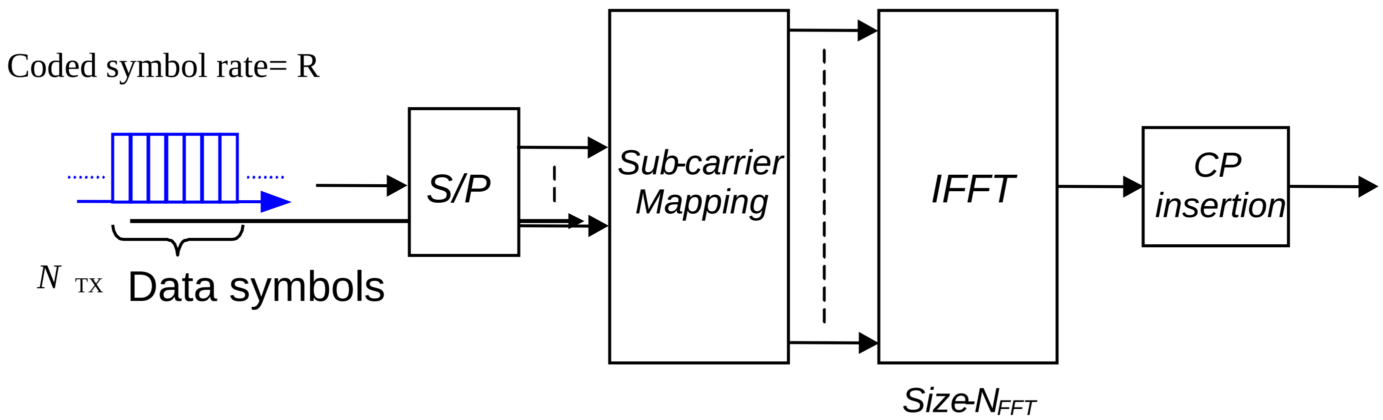
LTE

$$\Delta f = 15\,kHz = \frac{1}{T}$$

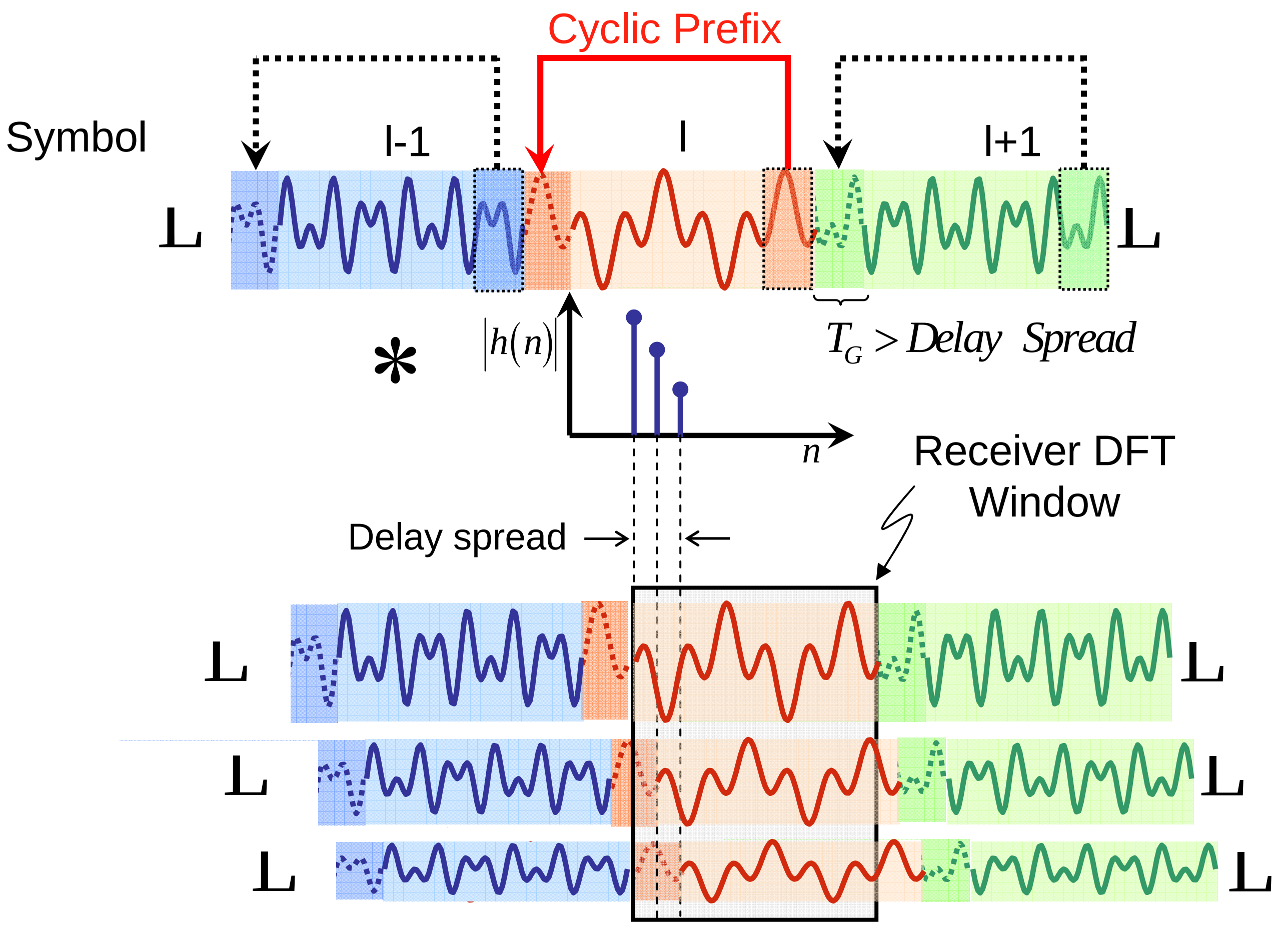
$$F_s = N_{FFT} \cdot \Delta f$$

$$F_s = \frac{N_{FFT}}{256} \cdot 3.84 Mcps$$

$$N_{FFT} = 2048$$



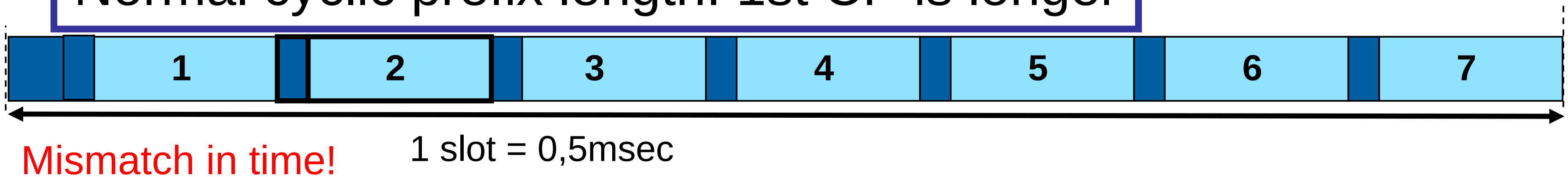
Guard Intervall as Cyclic Prefix



Cyclic Prefix guarantees the supression of ISI and ICI!

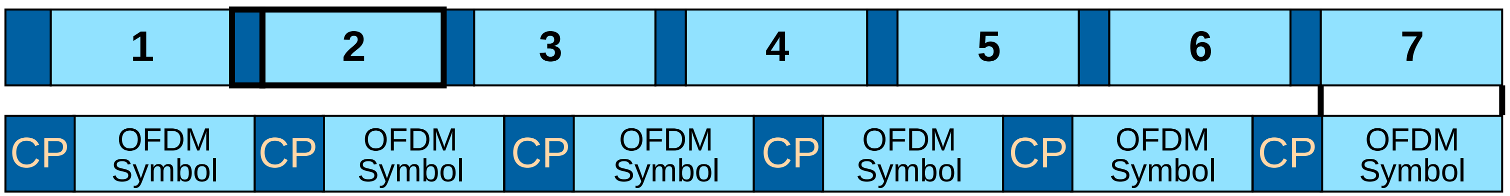
Cyclic prefix length

Normal cyclic prefix length: 1st CP is longer



Mismatch in time!

1st Cyclic prefix is longer



Normal CP

Extended CP

2 different Cyclic prefix lengths are defined

The LTE basic time unit T_s

This time unit is used to specify all timing aspects in LTE, e.g. the length of the cyclic prefix is defined as 144 * T_s

$$T_s = \frac{1}{15kHz \cdot 2048} \approx 32.55 nano\sec$$

LTE time unit T_s is a multiple of the legacy chiprate to alleviate multimode chipsets design

But also the legacy:

WCDMA chiprate = 3.84 MCps

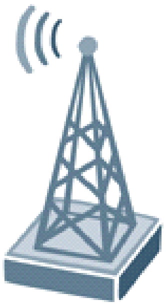
$$T_s = \frac{1}{15kHz \cdot 2048} = \frac{1}{8 * 3.84}$$

CDMA2000 chiprate = 1.2288 MCps

$$T_s = \frac{1}{15kHz \cdot 2048} = \frac{1}{25 * 1.2288}$$

LTE Physical Layer

LTE: new physical channels for data and control



Physical Control Format Indicator Channel PCFICH:
Indicates Format of PDCCH

Physical Downlink Control Channel PDCCH:
Downlink and uplink scheduling decisions

Physical Downlink Shared Channel PDSCH: Downlink data

Physical Hybrid ARQ Indicator Channel PHICH:
ACK/NACK for uplink packets

Physical Uplink Shared Channel PUSCH: Uplink data

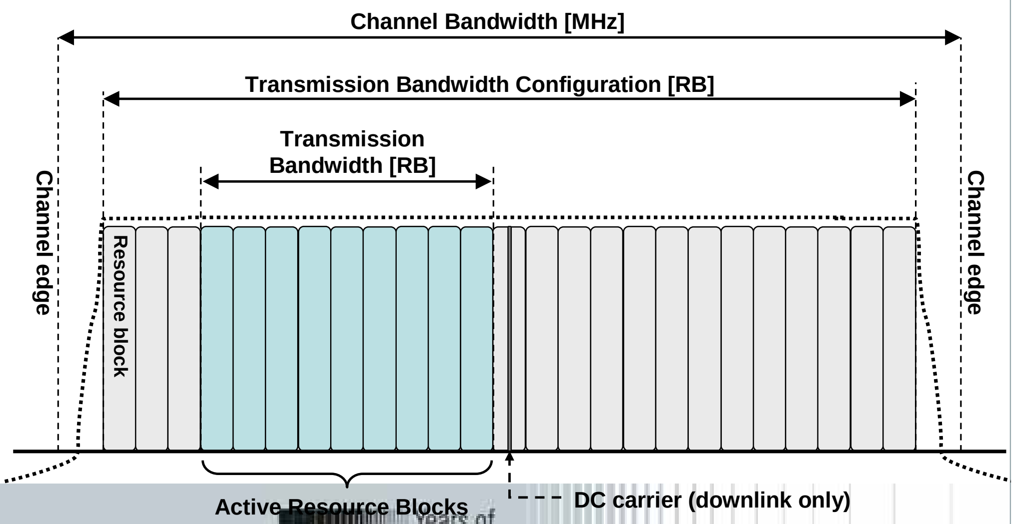
Physical Uplink Control Channel PUCCH:
ACK/NACK for downlink packets, scheduling requests, channel quality info

LTE – spectrum flexibility

- LTE physical layer supports any bandwidth from 1.4 MHz to 20 MHz in steps of 180 kHz (resource block)
- Current LTE specification supports only a subset of 6 different system bandwidths
- All UEs must support the maximum bandwidth of 20 MHz

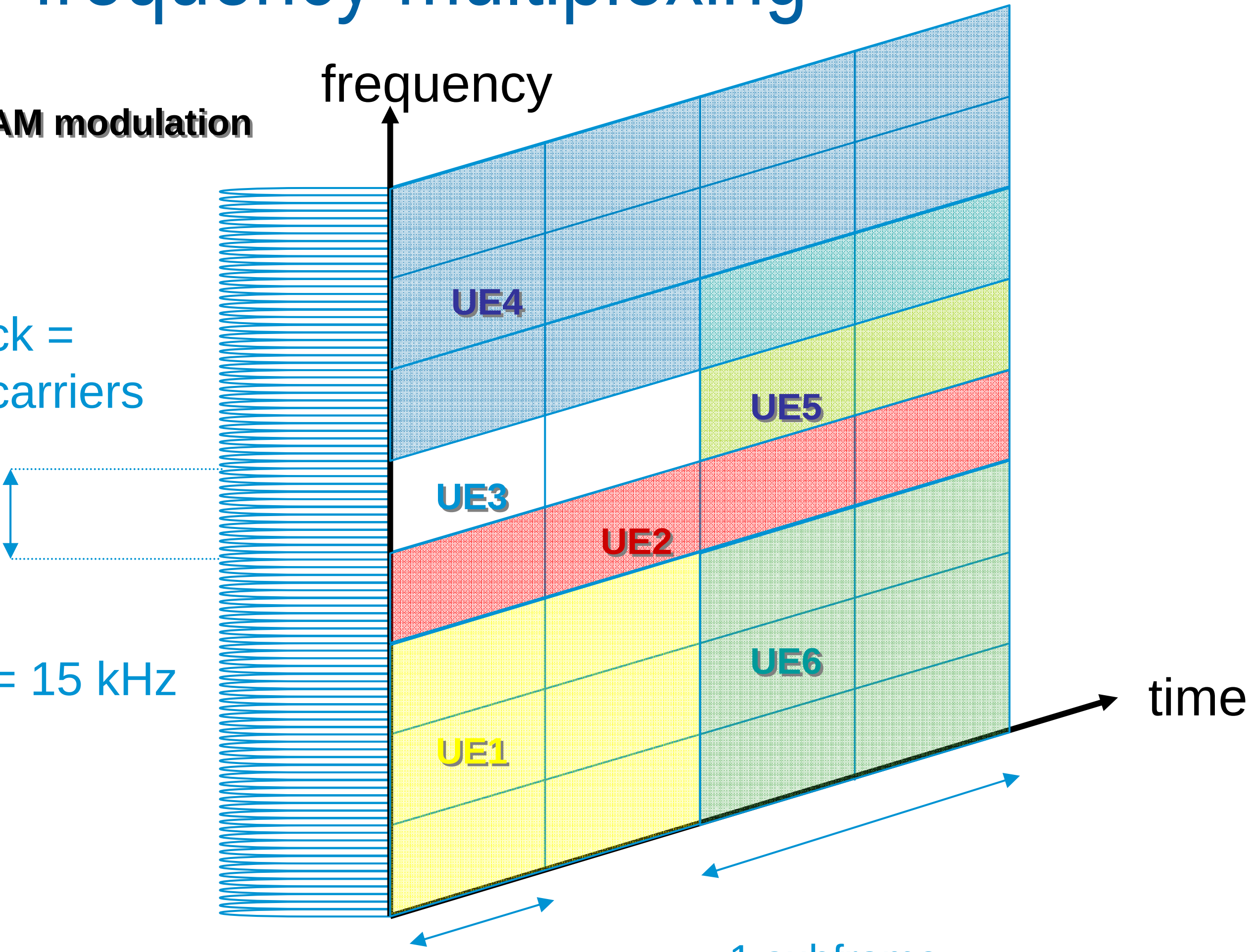
Channel bandwidth $BW_{Channel}$ [MHz]	1.4	3	5	10	15	20
FDD and TDD mode	6	15	25	50	75	100

number of resource blocks



LTE Downlink
OFDMA time-frequency multiplexing

QPSK, 16QAM or 64QAM modulation



1 resource block =
180 kHz = 12 subcarriers

Subcarrier spacing = 15 kHz

1 slot = 0.5 ms =
7 OFDM symbols**

1 subframe =
1 ms= 1 TTI*=
1 resource block pair

*TTI = transmission time interval

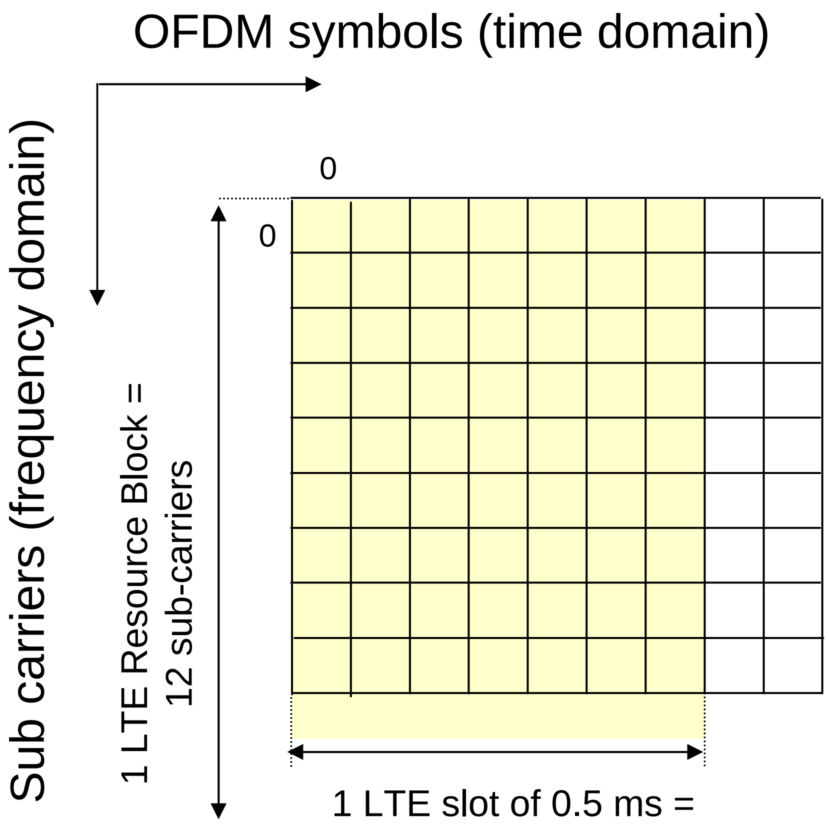
** For normal cyclic prefix duration

LTE Downlink:
OFDMA Time/Frequency Representation

Resource block

- Sub-carrier spacing in **LTE = 15 kHz** (7.5 kHz for MBMS scenarios)
- Data is allocated in multiples of resource blocks
- 1 resource block spans 12 sub-carriers in the frequency domain and 1 slot in the time domain
- Resource block size is identical for all bandwidths

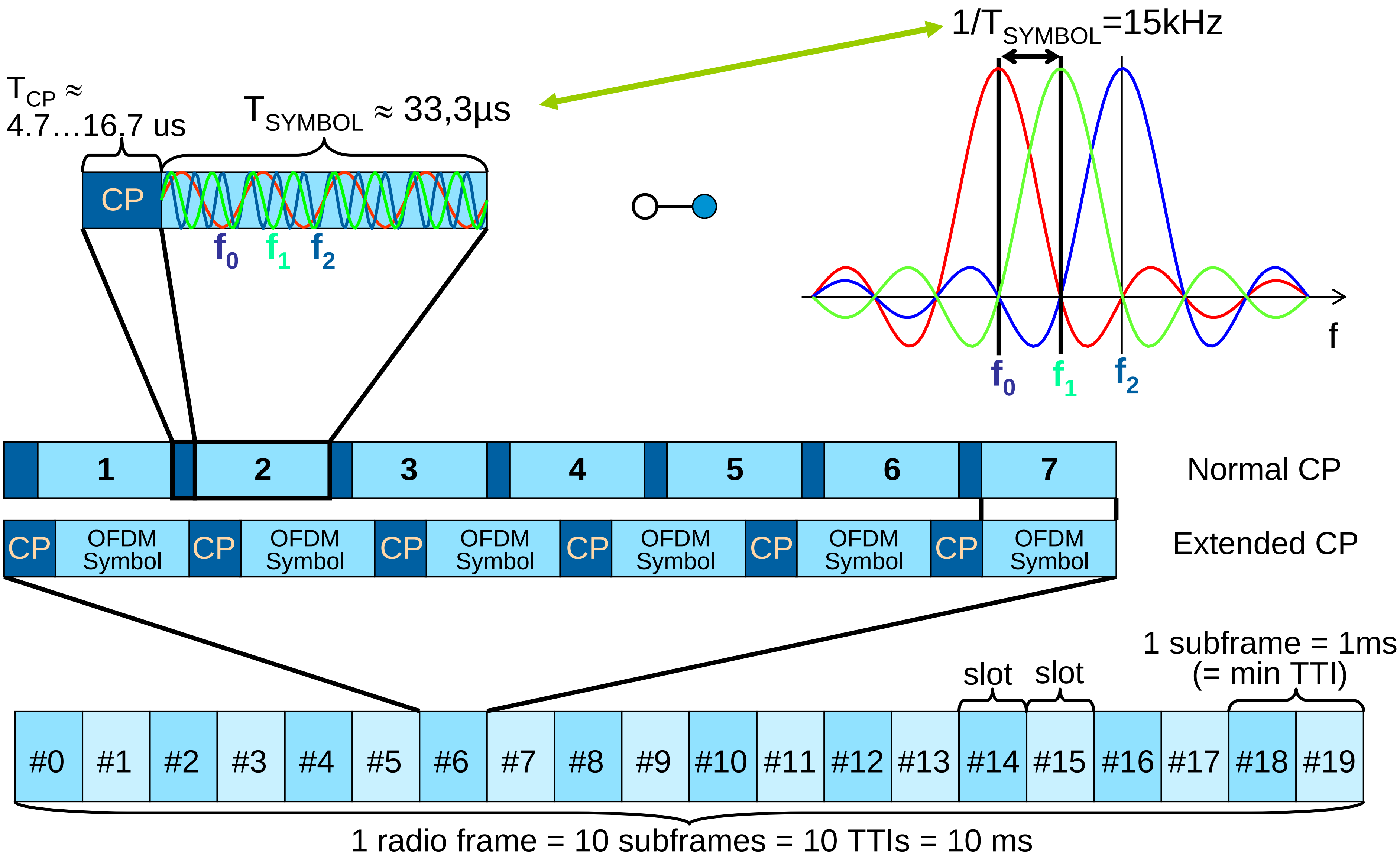
Normal scenario: carrier spacing of 15 kHz
Big cell scenario: 7,5 kHz + extended guard time



6 / 7 OFDM symbols dep. on cyclic prefix length

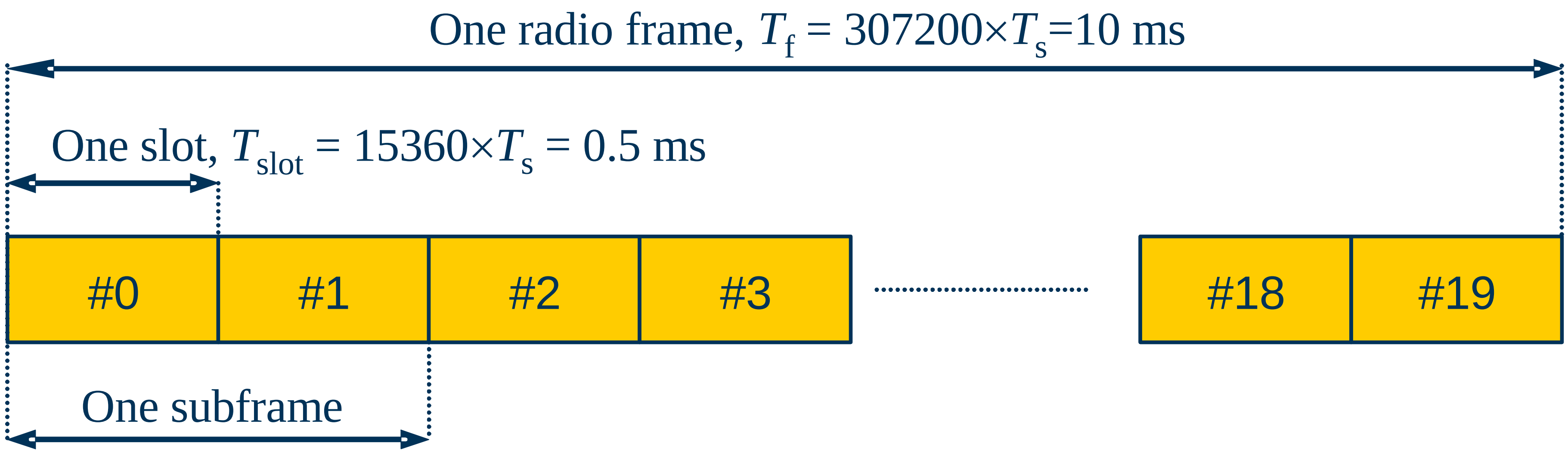
(3 symbols for 7.5 kHz spacing / MBMS scenarios)

Basic Frame Structure – E-UTRA FDD and TDD



LTE Downlink:
Downlink slot and (sub)frame structure

Symbol time, or number of symbols per time slot is not fixed

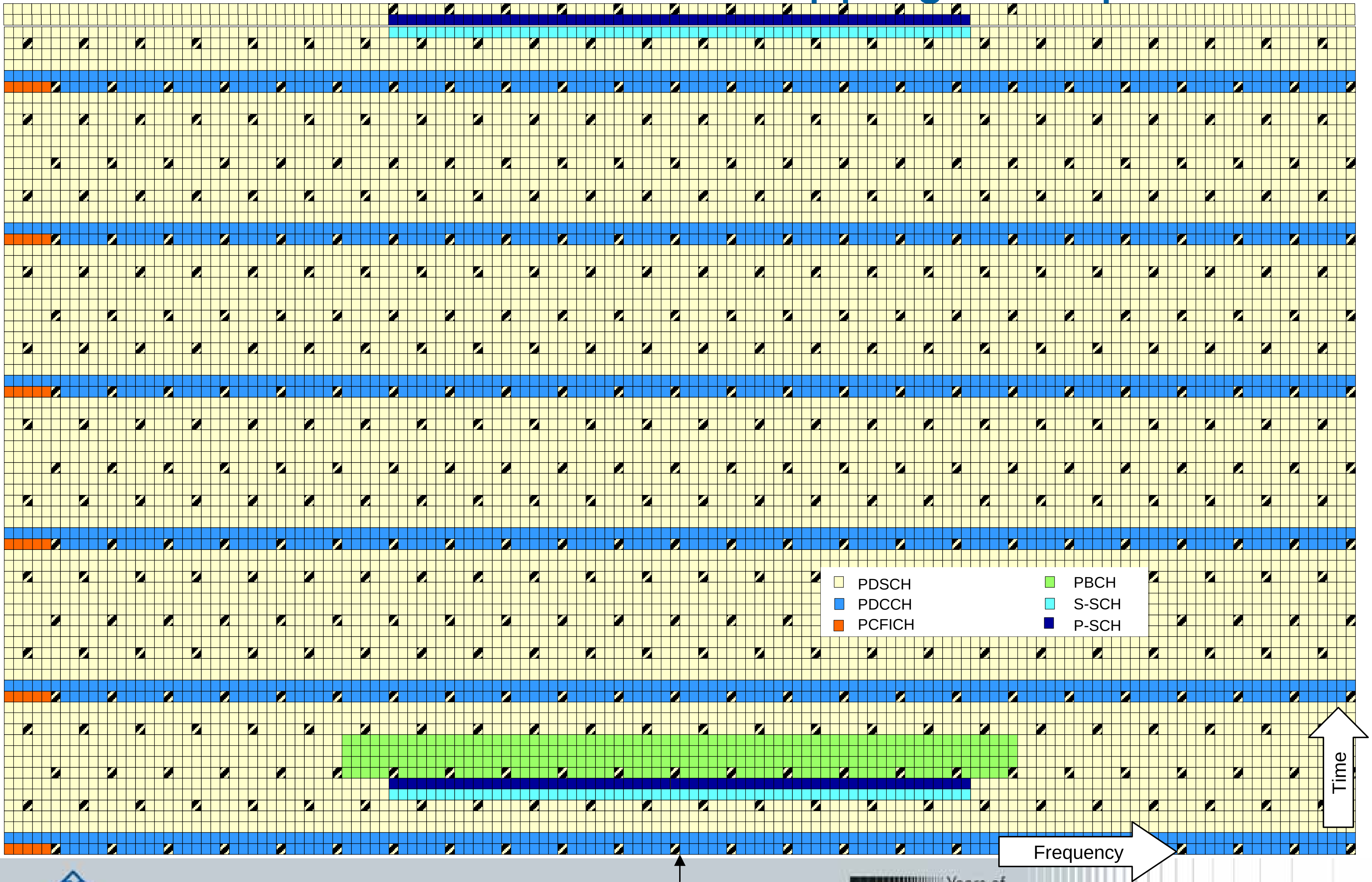


We talk about 1 slot, but the minimum resource is 1 subframe = 2 slots !!!!!

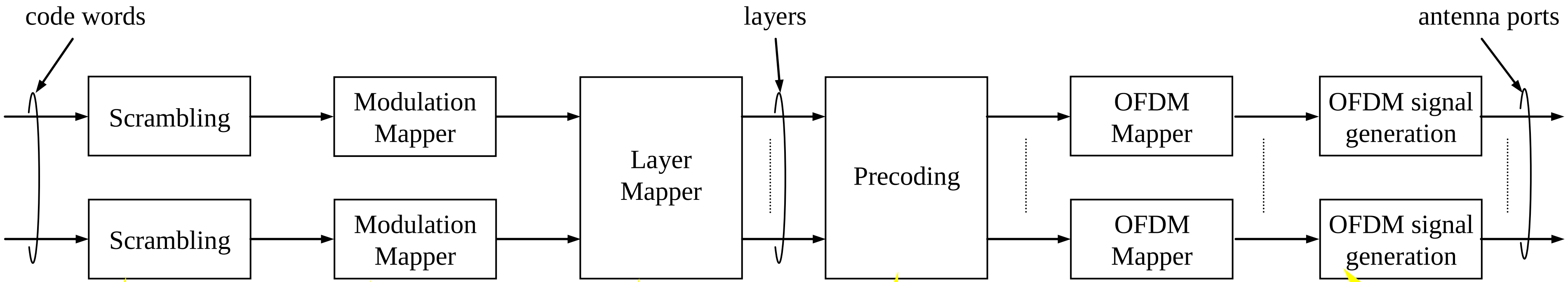
$$T_s = 1/(15000 \times 2048)$$

Ts = 32.522 ns

LTE Downlink: FDD channel mapping example



LTE Downlink: baseband signal generation



Avoid constant sequences

QPSK
16 QAM
64 QAM

For MIMO Split into Several streams if needed

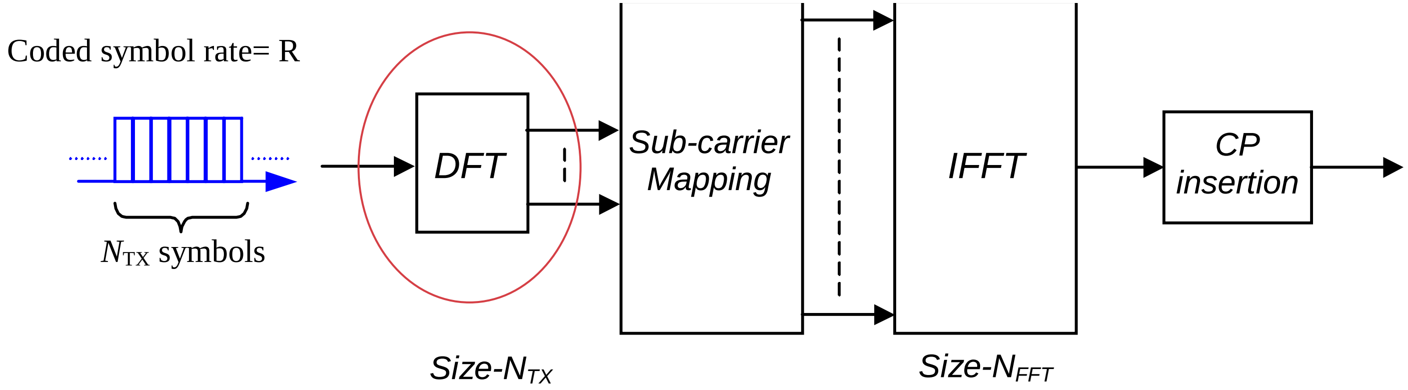
Weighting data streams for MIMO

1 OFDM symbol per stream

1 stream = several subcarriers, based on Physical ressource blocks

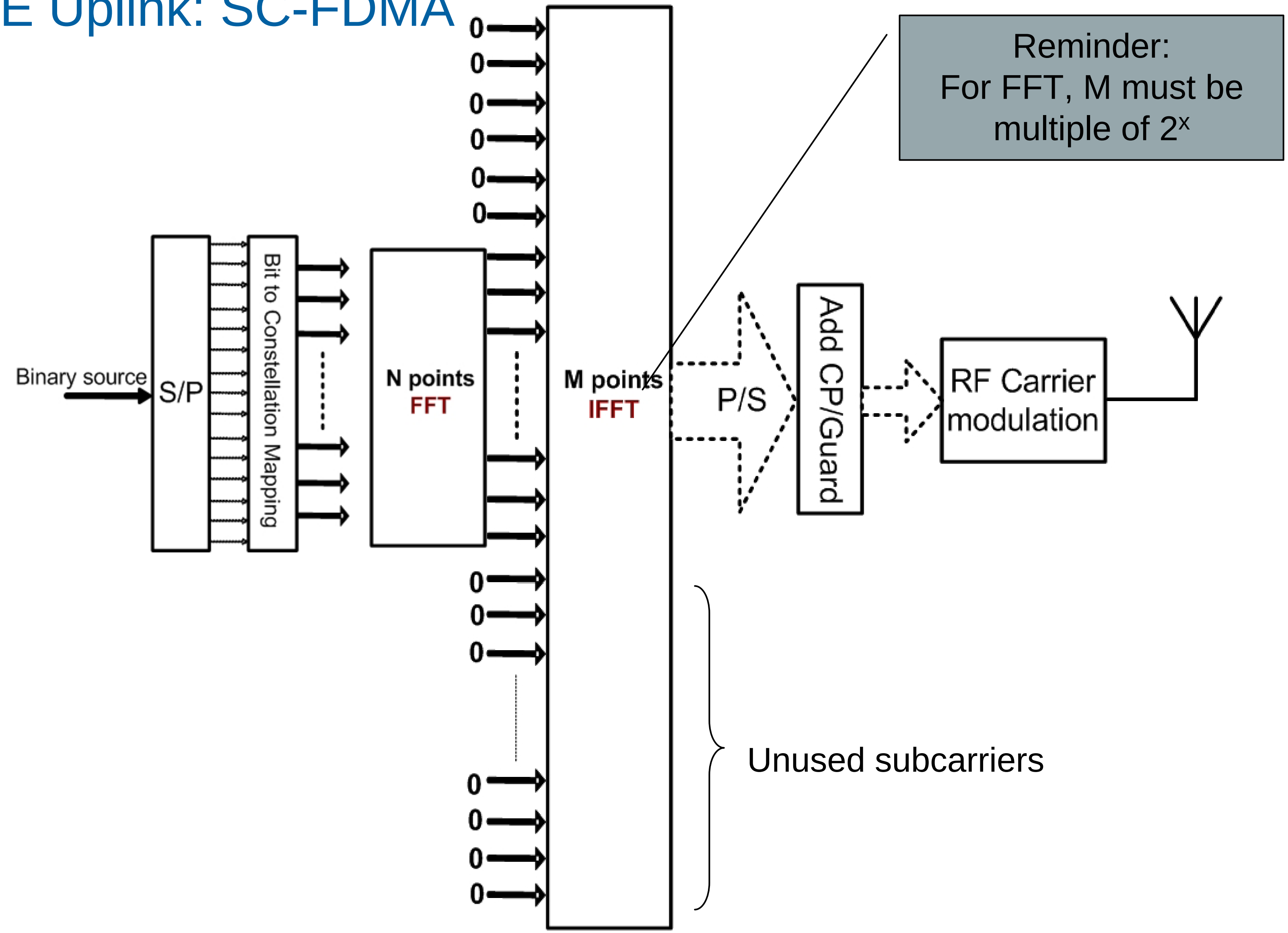
LTE Physical Layer: SC-FDMA in uplink

LTE Uplink:
How to generate an SC-FDMA signal in theory?

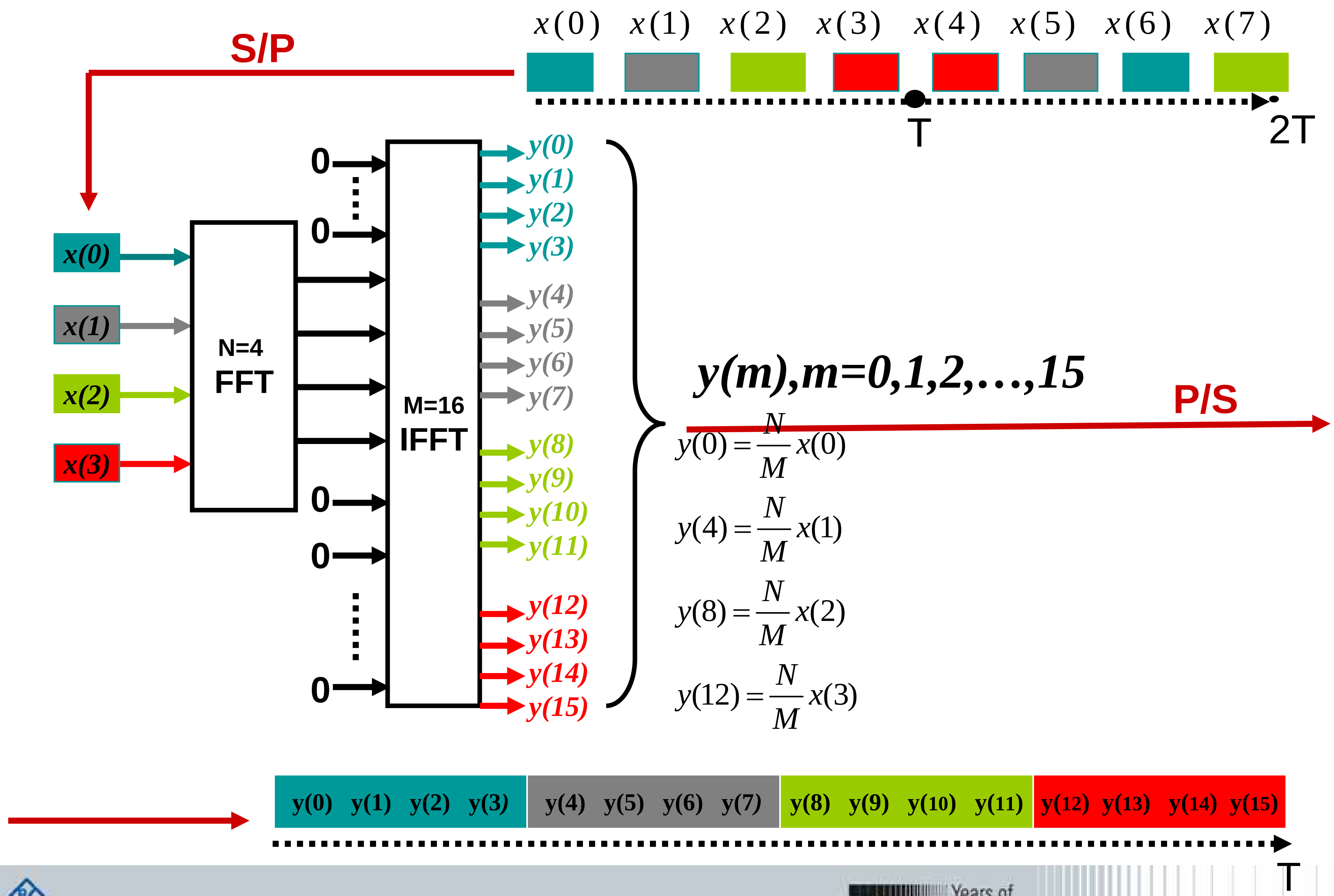


- LTE provides QPSK,16QAM, and 64QAM as uplink modulation schemes
- DFT is first applied to block of N_{TX} modulated data symbols to transform them into frequency domain
- Sub-carrier mapping allows flexible allocation of signal to available sub-carriers
- IFFT and cyclic prefix (CP) insertion as in OFDM
- Each subcarrier carries a portion of superposed DFT spread data symbols
- Can also be seen as "**pre-coded OFDM**" or "**DFT-spread OFDM**"

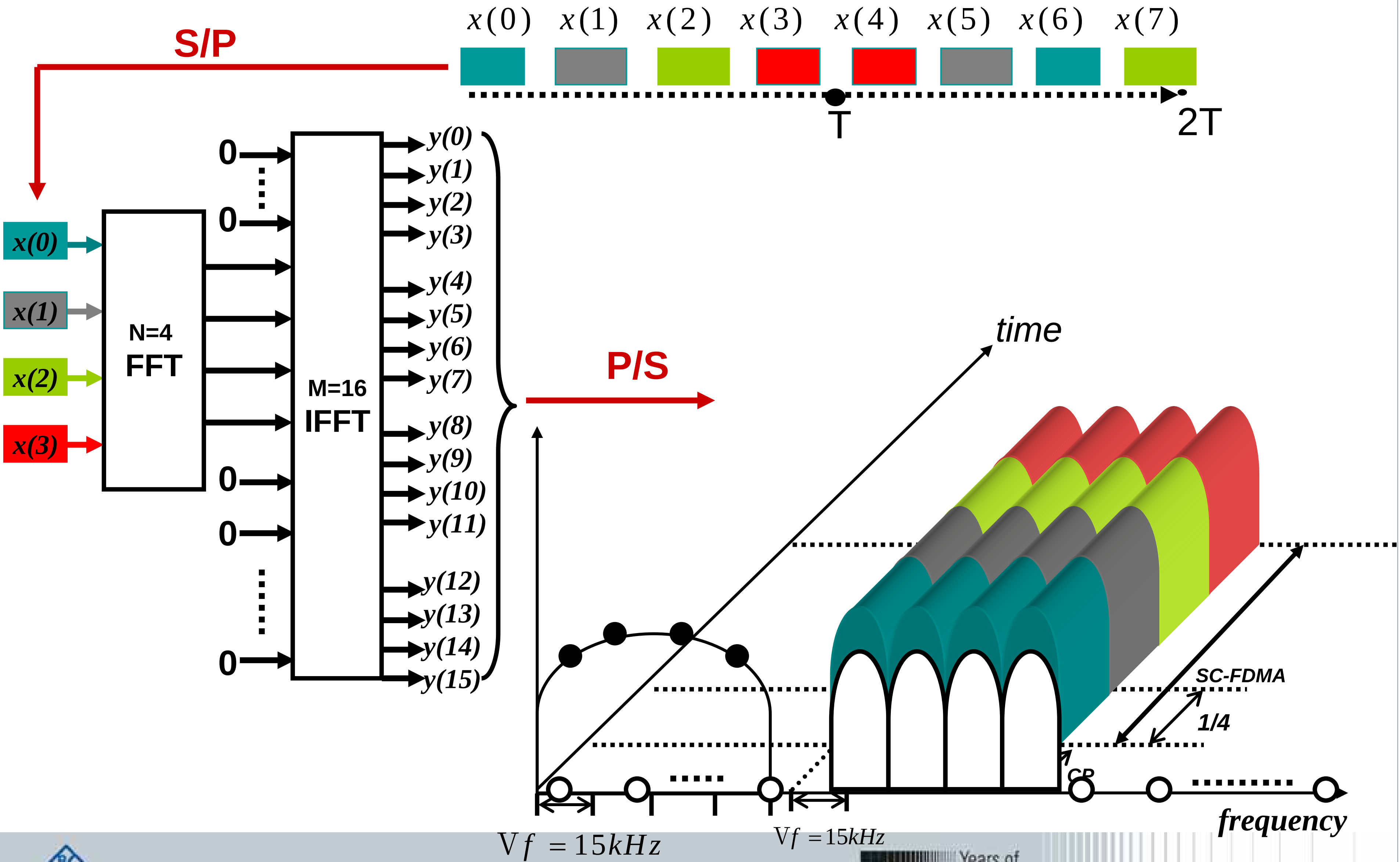
LTE Uplink: SC-FDMA



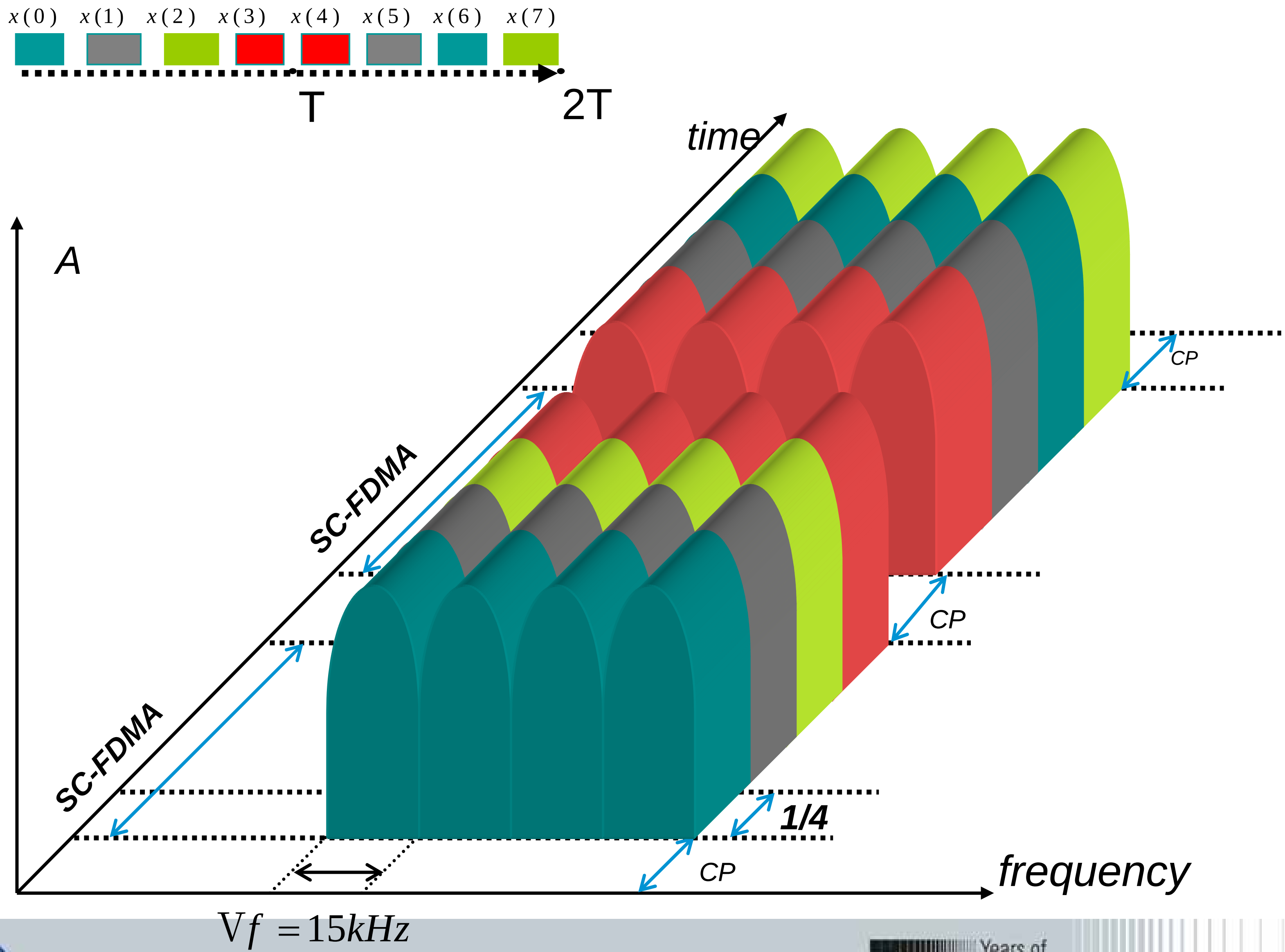
SC-FDMA example



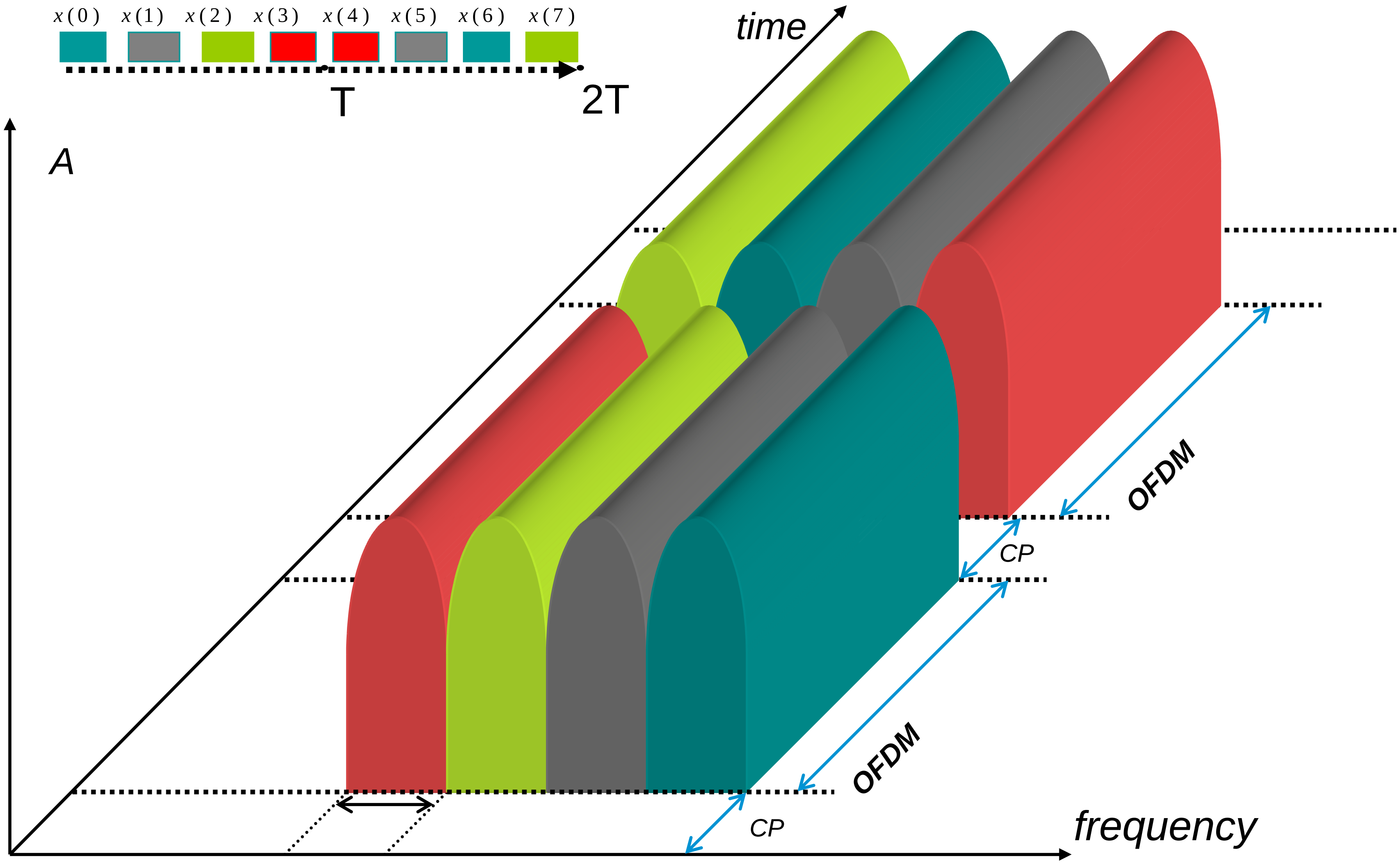
SC-FDMA example



SC-FDMA example



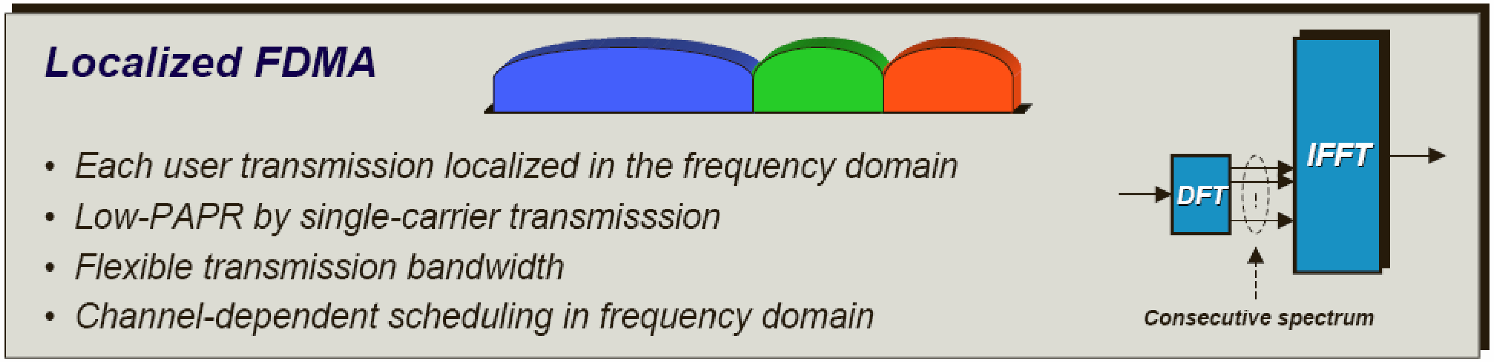
OFDMA example



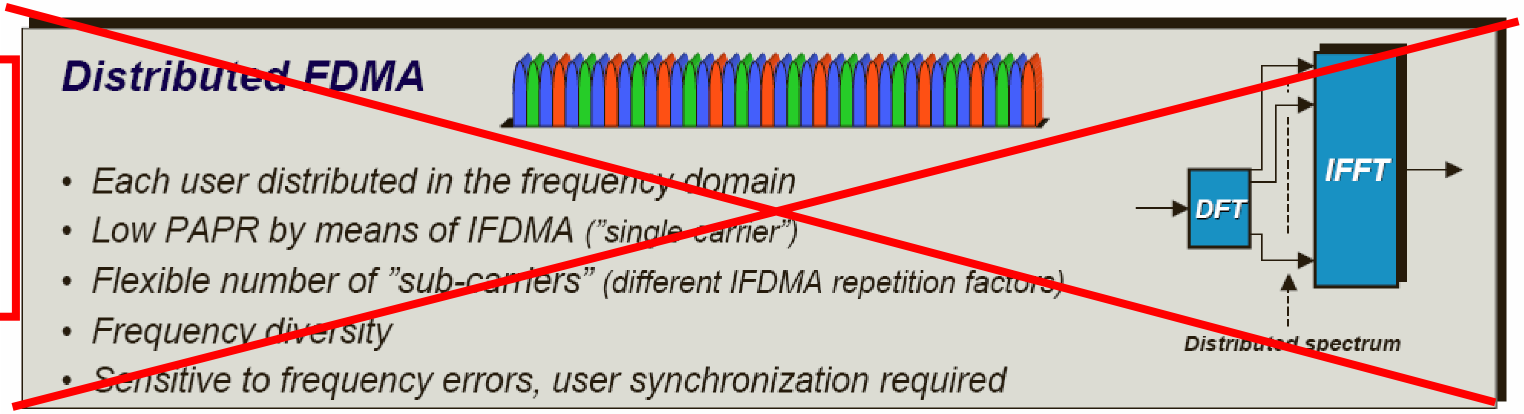
$$\nabla f = 15kHz$$

Localized versus Distributed FDMA

We have seen that DFT will distribute the time signal over the frequency. Next question that arises is: how is that distribution done: localized or distributed?



Not used in LTE



SC-FDMA Peak to average

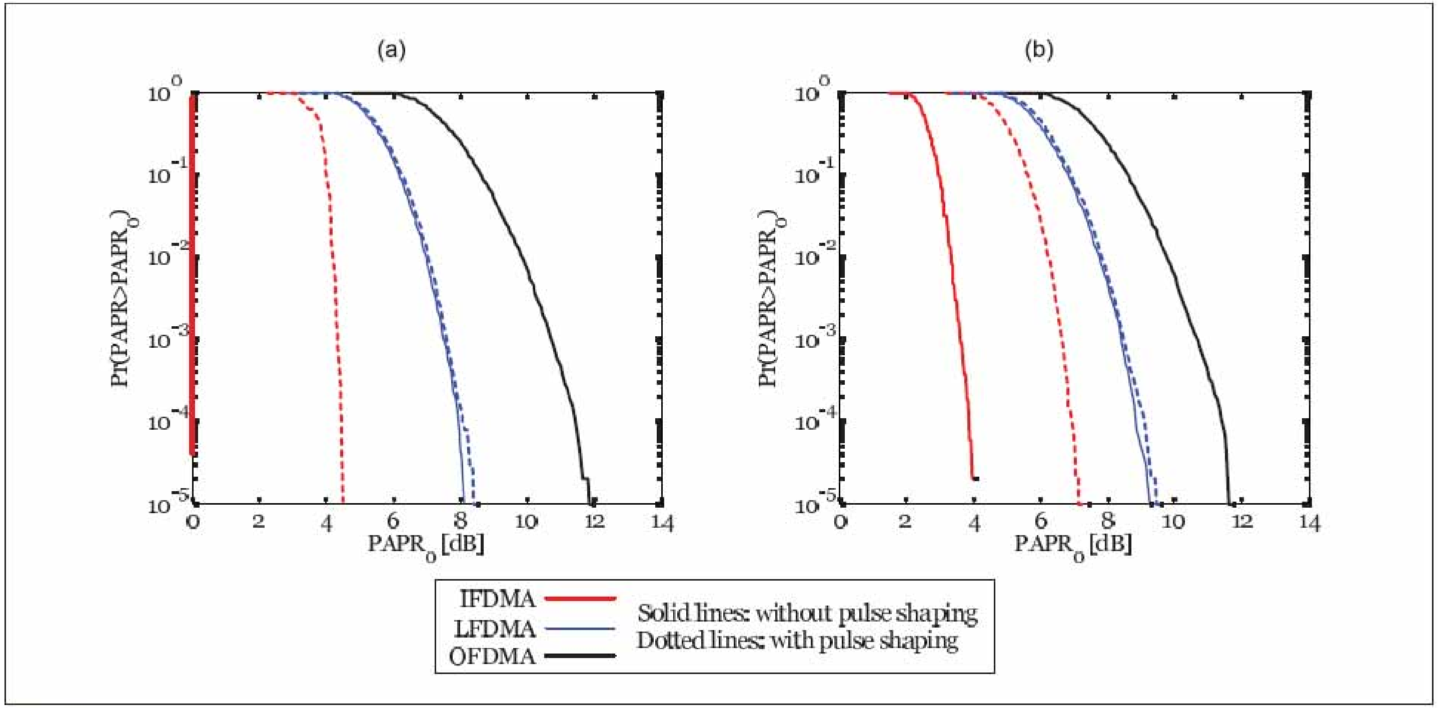
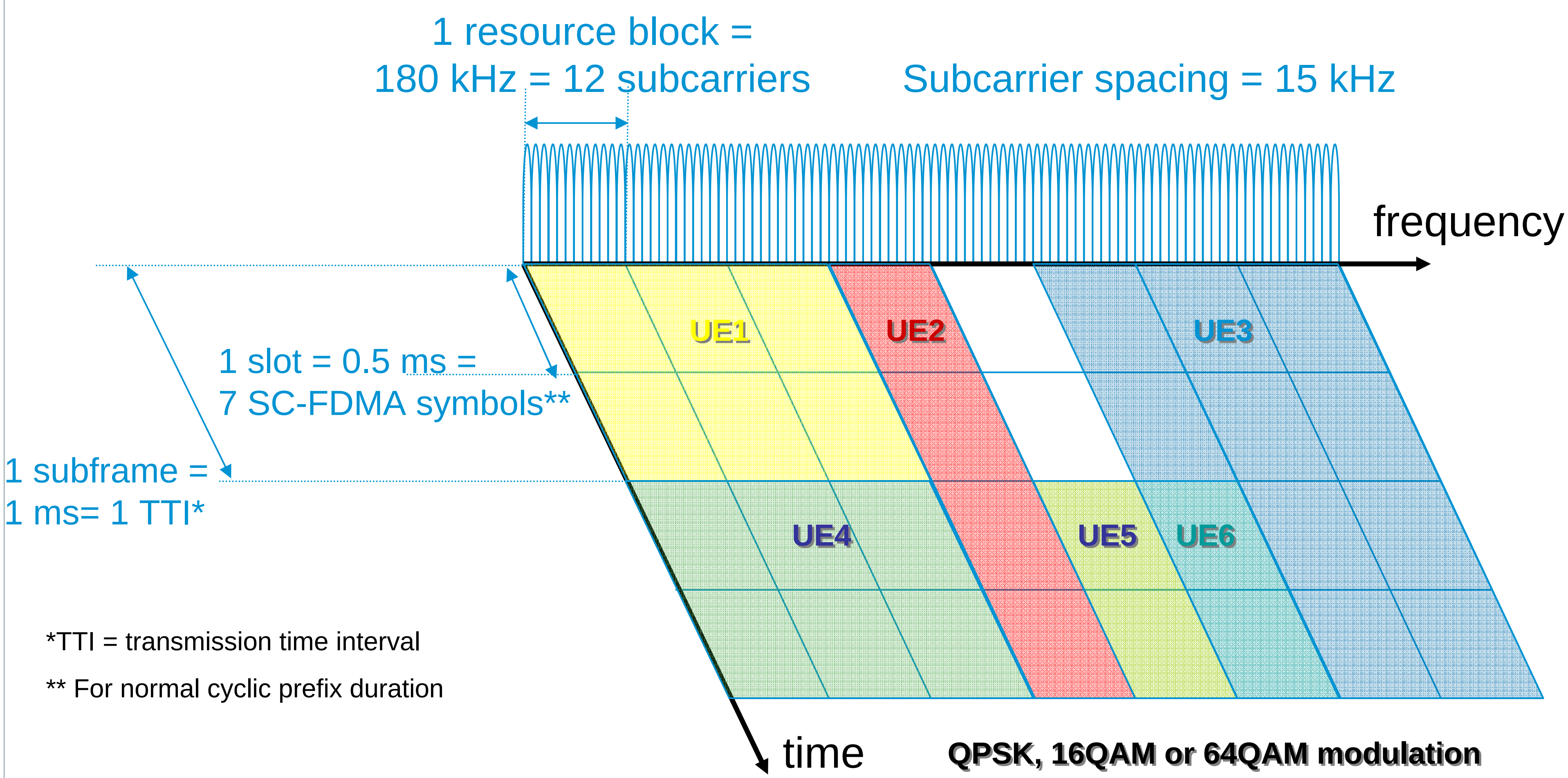


FIGURE 5 Comparison of CCDF of PAPR for IFDMA, LFDMA, and OFDMA with $M = 256$ system subcarriers, $N = 64$ subcarriers per user, and a = 0.5 rolloff factor; (a) QPSK; (b) 16-QAM.

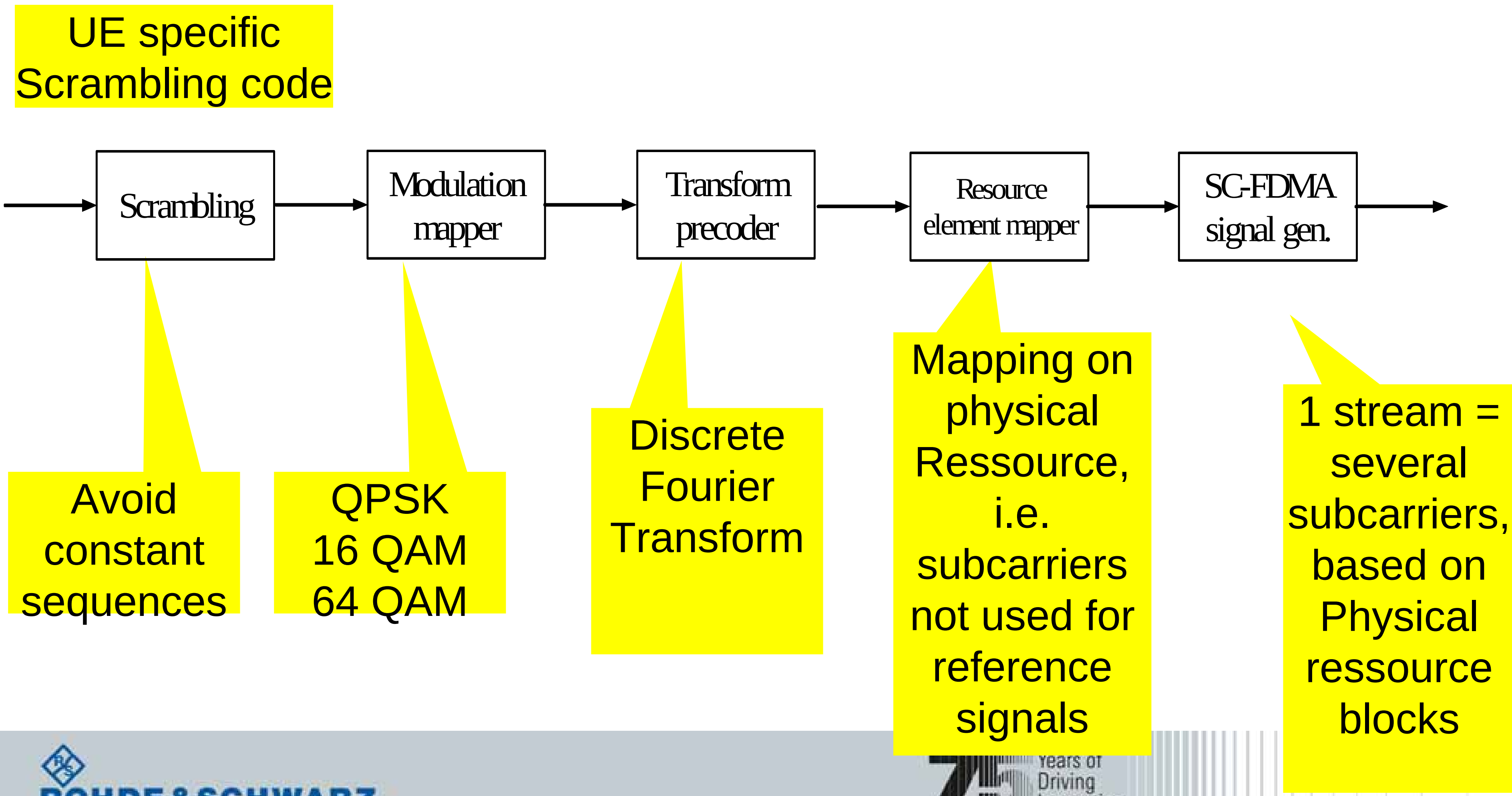
LTE uplink
SC-FDMA time-frequency multiplexing



*TTI = transmission time interval

** For normal cyclic prefix duration

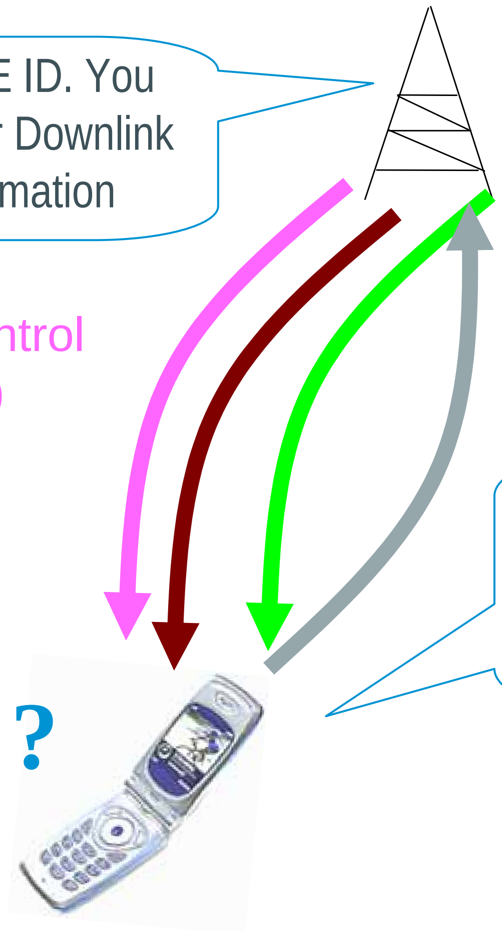
LTE Uplink: baseband signal generation



LTE resource allocation principles

LTE resource allocation
Scheduling of downlink and uplink data

Check PDCCH for your UE ID. You may find here Uplink and/or Downlink resource allocation information



Physical Uplink Shared Channel (PUSCH)

Physical Downlink Control Channel (PDCCH)

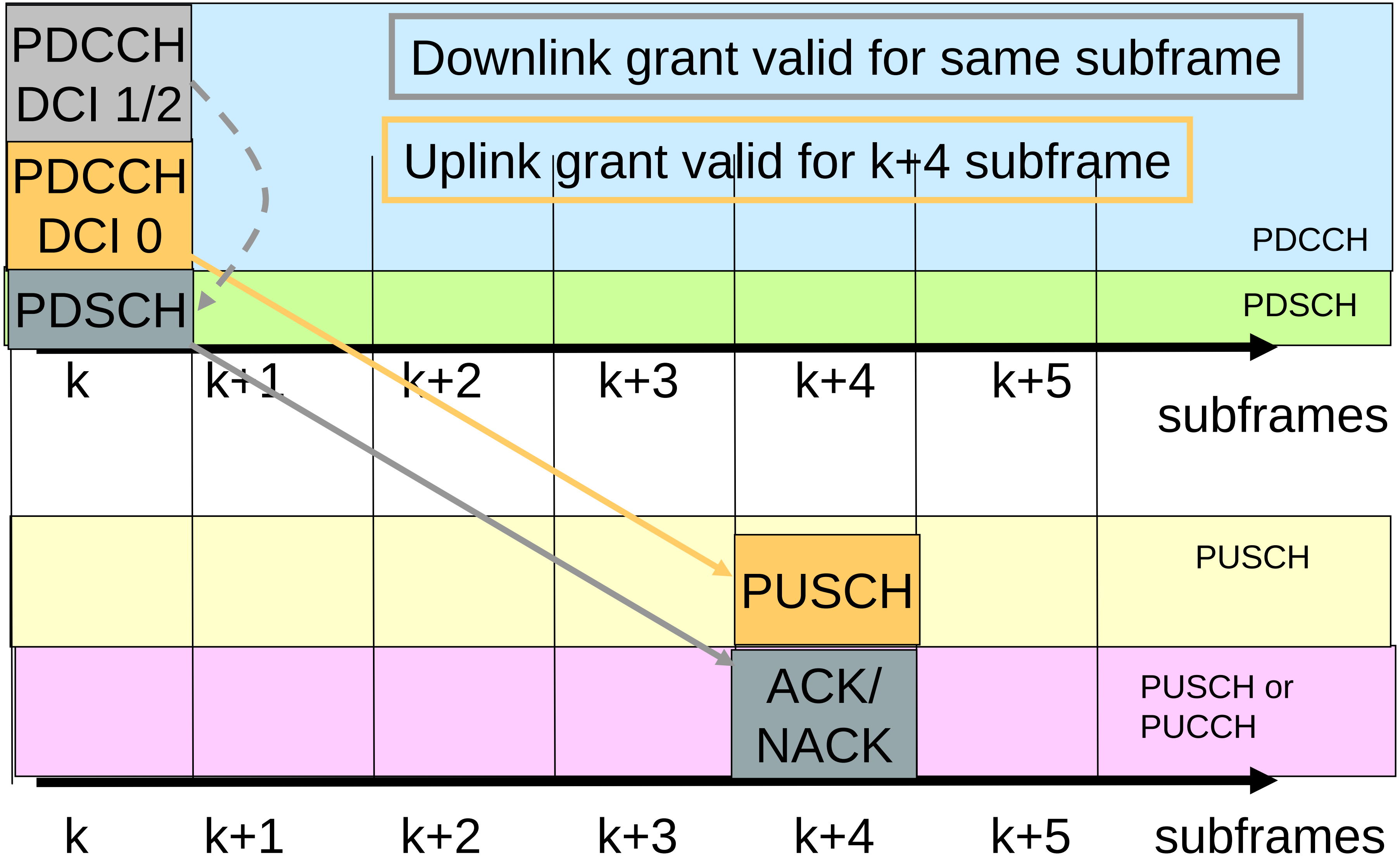
Physical Downlink Shared Channel (PDSCH)

Physical Control Format Indicator Channel (PCFICH),

Info about PDCCH format

I would like to receive data on PDSCH and / or send data on PUSCH

Resource allocation – timing aspects

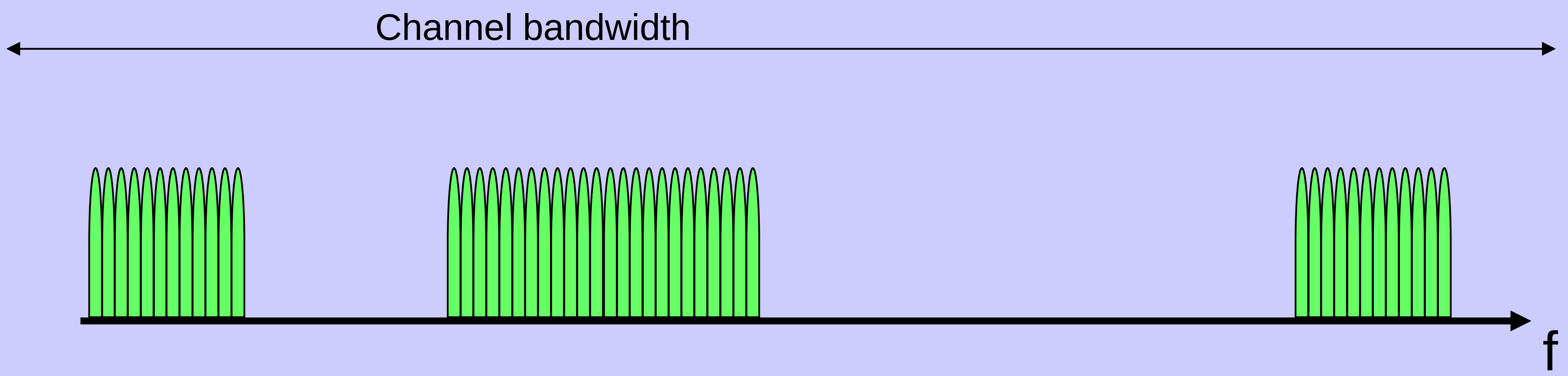


Resource allocation types in LTE

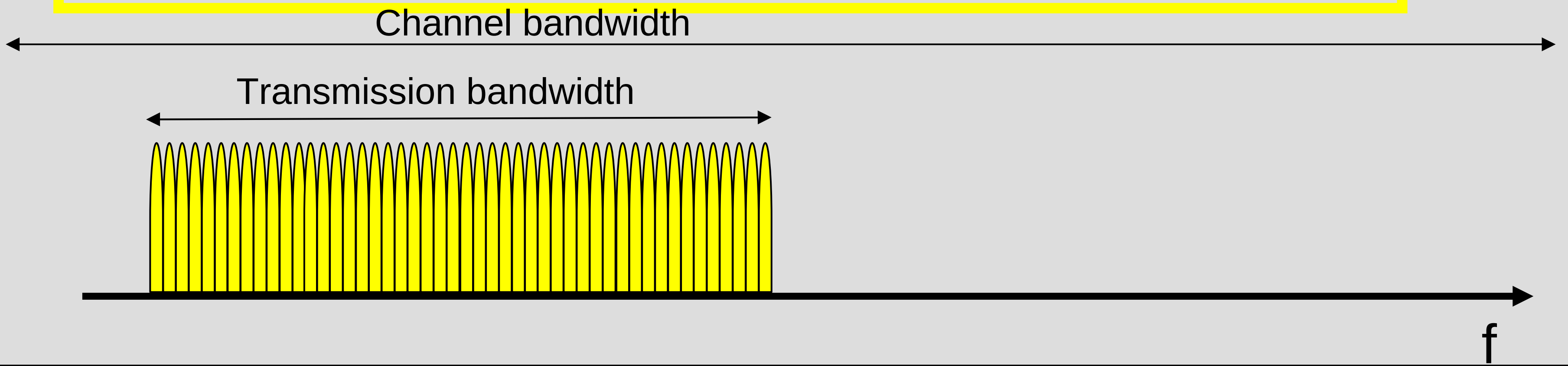
Allocation type	DCI Format	Scheduling Type	Antenna configuration
Type 0 / 1	DCI 1	PDSCH, one codeword	SISO, TxDiversity
	DCI 2A	PDSCH, two codewords	MIMO, open loop
	DCI 2	PDSCH, two codewords	MIMO, closed loop
Type 2	DCI 0	PUSCH	SISO
	DCI 1A	PDSCH, one codeword	SISO, TxDiversity
	DCI 1C	PDSCH, very compact codeword	SISO

Resource allocation types in LTE

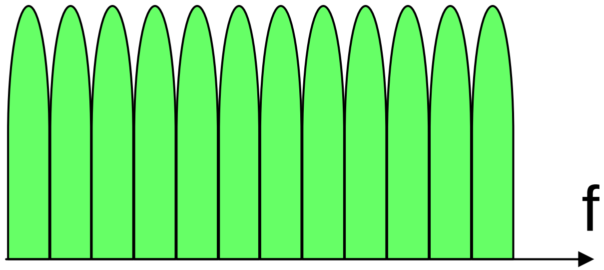
Type 0 and 1 for distributed allocation in frequency domain



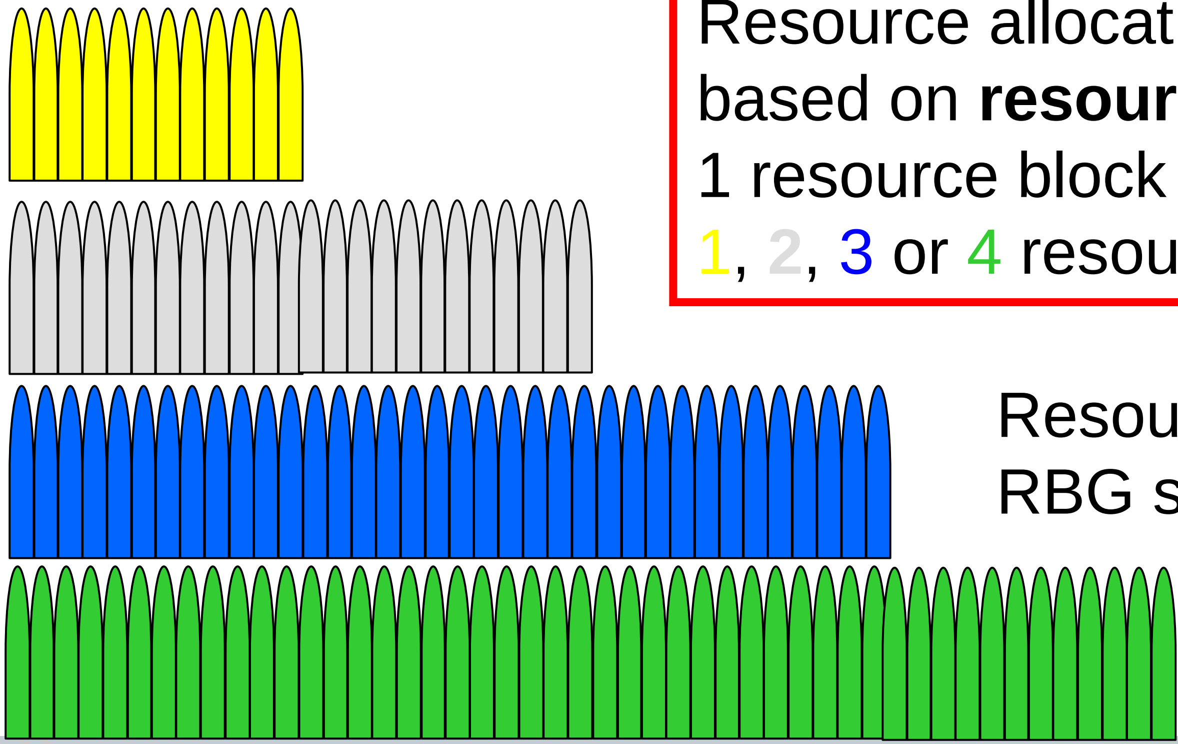
Type 2 for contiguous allocation in frequency domain



Resource Block Group



Reminder: 1 resource block =
12 subcarriers in frequency domain



Resource allocation is performed based on **resource block groups**.
1 resource block group may consist of 1, 2, 3 or 4 resource blocks

Resource block groups, RBG sizes

Resource allocation type 0

Type 0 (for distributed frequency allocation of Downlink resource, SISO and MIMO possible)

- **Bitmap to indicate which resource block groups, RBG are allocated**
- **One RBG consists of 1-4 resource blocks:**

Channel bandwidth	RBG size P
≤10	1
11-26	2
27-63	3
64-110	4

- **Number of resource block groups N_{RBG} is given as:**

$$N_{RBG} = \left\lceil N_{\mathrm{RB}}^{\mathrm{DL}} / P \right\rceil$$

- **Allocation bitmap has same length than N_{RBG}**

Resource allocation type 0 example

Calculation example for type 0:

- **Channel bandwidth = 10MHz**
- **-> 50 resource blocks**
- **-> Resource block group RBG size = 3**
- **-> bitmap size = 17**

if $N_{\mathrm{RB}}^{\mathrm{DL}} \bmod P > 0$ then one of the RBGs is of size $N_{\mathrm{RB}}^{\mathrm{DL}} - P \cdot \lfloor N_{\mathrm{RB}}^{\mathrm{DL}} / P \rfloor$

i.e. here 50 mod 3 = 16, so the last resource block group has the size 2.

-> some allocations are not possible, e.g. here you can allocate 48 or 50 resource blocks, but not 49!

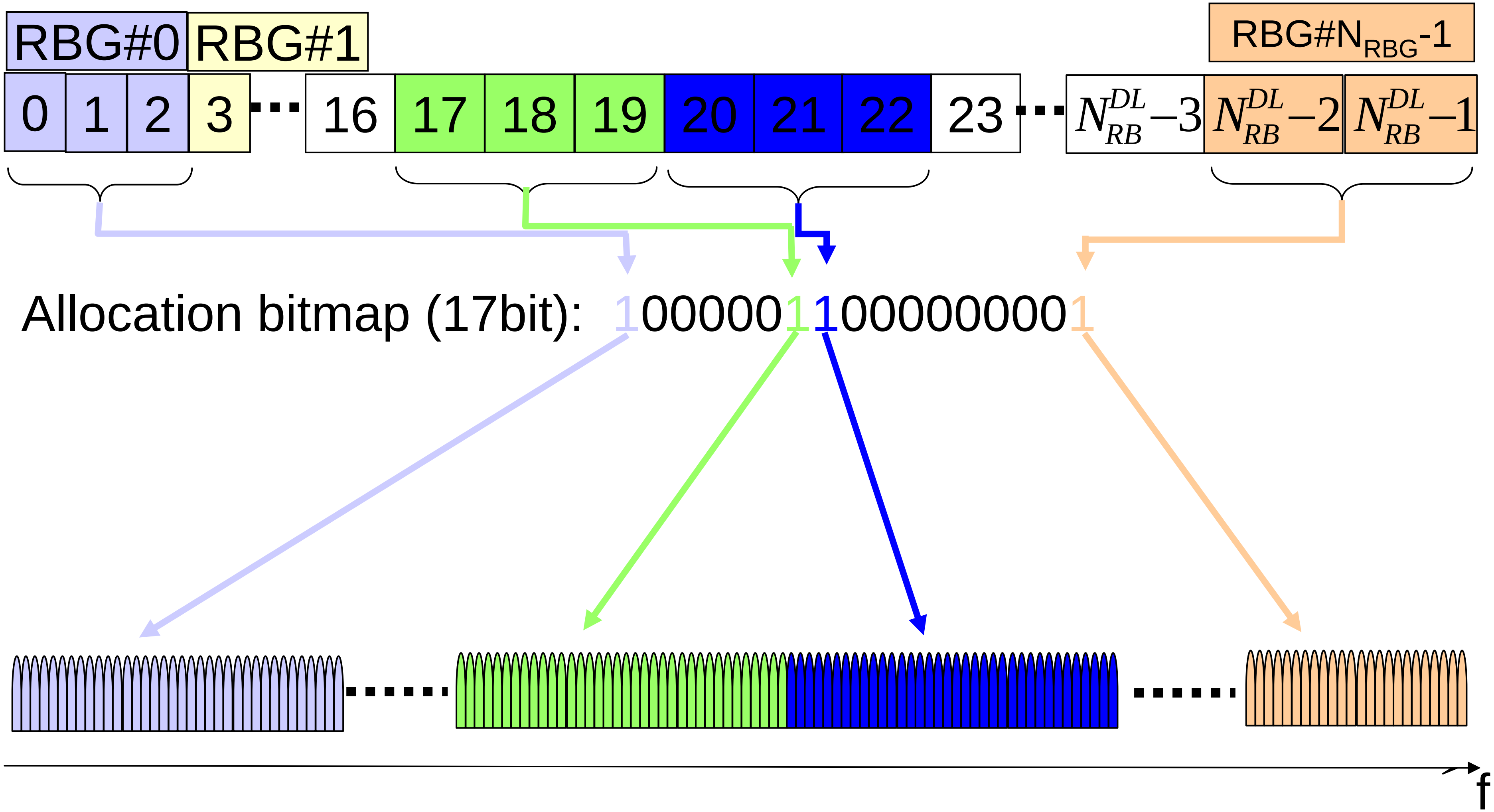
reminder

$N_{RBG} = \lceil N_{\mathrm{RB}}^{\mathrm{DL}} / P \rceil$ = round up, i.e. $\lceil 3.5 \rceil$ = 4

$\lfloor N_{\mathrm{RB}}^{\mathrm{DL}} / P \rfloor$ = round down, i.e. $\lfloor 3.49 \rfloor$ = 3

Resource allocation type 0

Channel bandwidth = 10MHz -> 50 RBs -> RBG size = 3 -> number of RBGs = 17



Resource allocation type 1

Type 1 (for distributed frequency allocation of Downlink resource, SISO and MIMO possible)

- **RBs are divided into $\lceil \log_2(P) \rceil$ RBG subsets**

Channel bandwidth	RBG size P
≤10	1
11-26	2
27-63	3
64-110	4

- **Bitmap indicates RBs inside a RBG subset allocated to the UE**

- **Resource block assignment consists of 3 fields:**
  - Field to indicate the selected RBG
  - Field to indicate a shift of the resource allocation
  - Field to indicate the specific RB within a RBG subset

Resource allocation type 1

Channel bandwidth = 10MHz -> 50 RBs -> RBG size = 3 -> number of RBGs = 17

RBG#0			RBG#1										RBG#N_{RBG}-1	
0	1	2	3	…	16	17	18	19	20	21	22	23	…	$N_{RB}^{DL}-3$	$N_{RB}^{DL}-2$	$N_{RB}^{DL}-1$

RBG subset #0					
RBG#0	RBG#3	RBG#6	RBG#9	RBG#12	RBG#15

RBG subset #1					
RBG#1	RBG#4	RBG#7	RBG#10	RBG#13	RBG#16

RBG subset #2				
RBG#2	RBG#5	RBG#8	RBG#11	RBG#14

P= Number of RBG subsets with length:

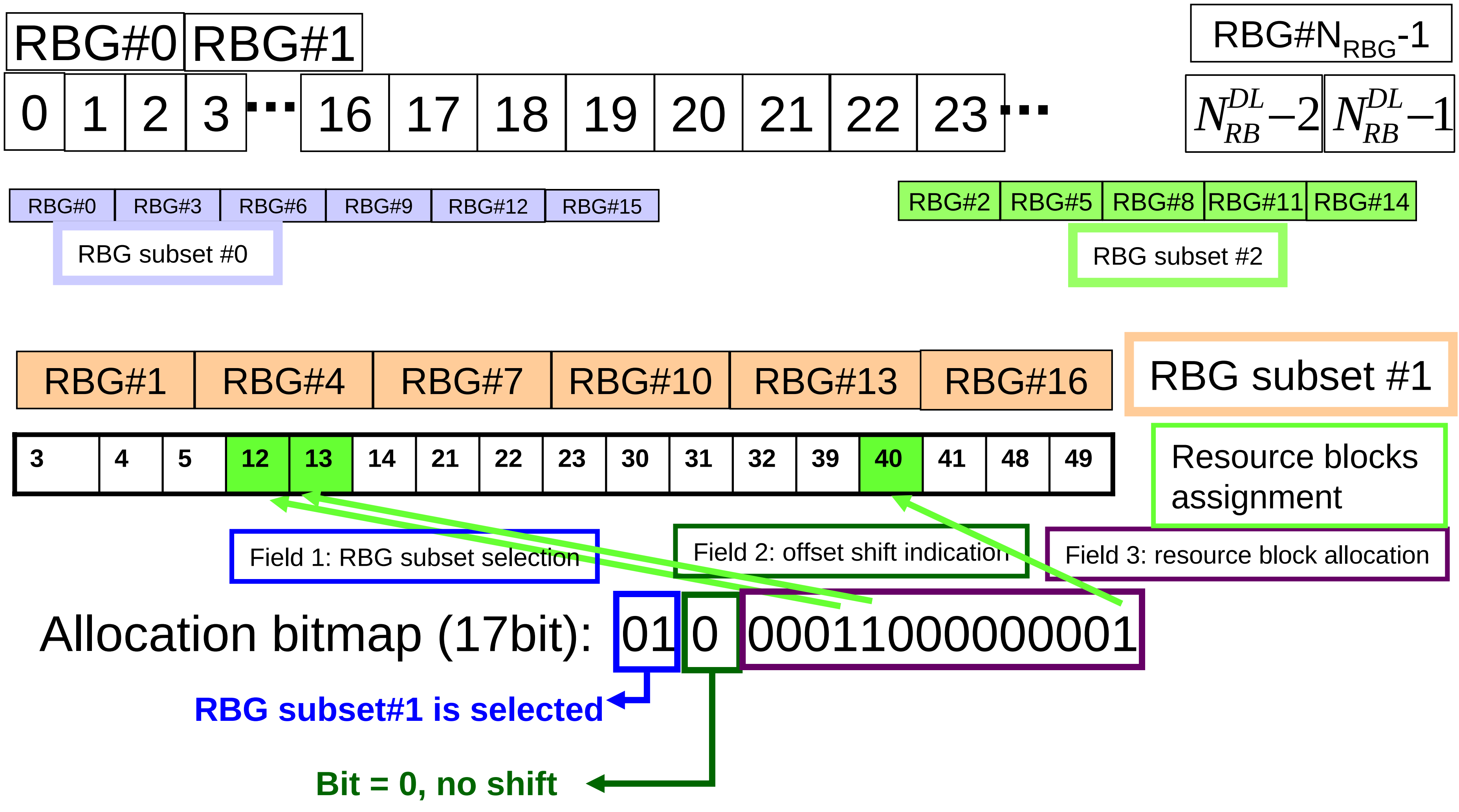
$$N_{RB}^{RBG\,subset}(p) = \begin{cases} \left\lfloor \frac{N_{RB}^{DL}-1}{P^2} \right\rfloor \cdot P + P & , p < \left\lfloor \frac{N_{RB}^{DL}-1}{P} \right\rfloor \bmod P \\ \left\lfloor \frac{N_{RB}^{DL}-1}{P^2} \right\rfloor \cdot P + (N_{RB}^{DL}-1) \bmod P + 1 & , p = \left\lfloor \frac{N_{RB}^{DL}-1}{P} \right\rfloor \bmod P \\ \left\lfloor \frac{N_{RB}^{DL}-1}{P^2} \right\rfloor \cdot P & , p > \left\lfloor \frac{N_{RB}^{DL}-1}{P} \right\rfloor \bmod P \end{cases}$$

$$\lceil \log_2(P) \rceil$$

Number of bits to indicate subset

Resource allocation type 1

Channel bandwidth = 10MHz -> 50 RBs -> RBG size = 3 -> number of RBGs = 17

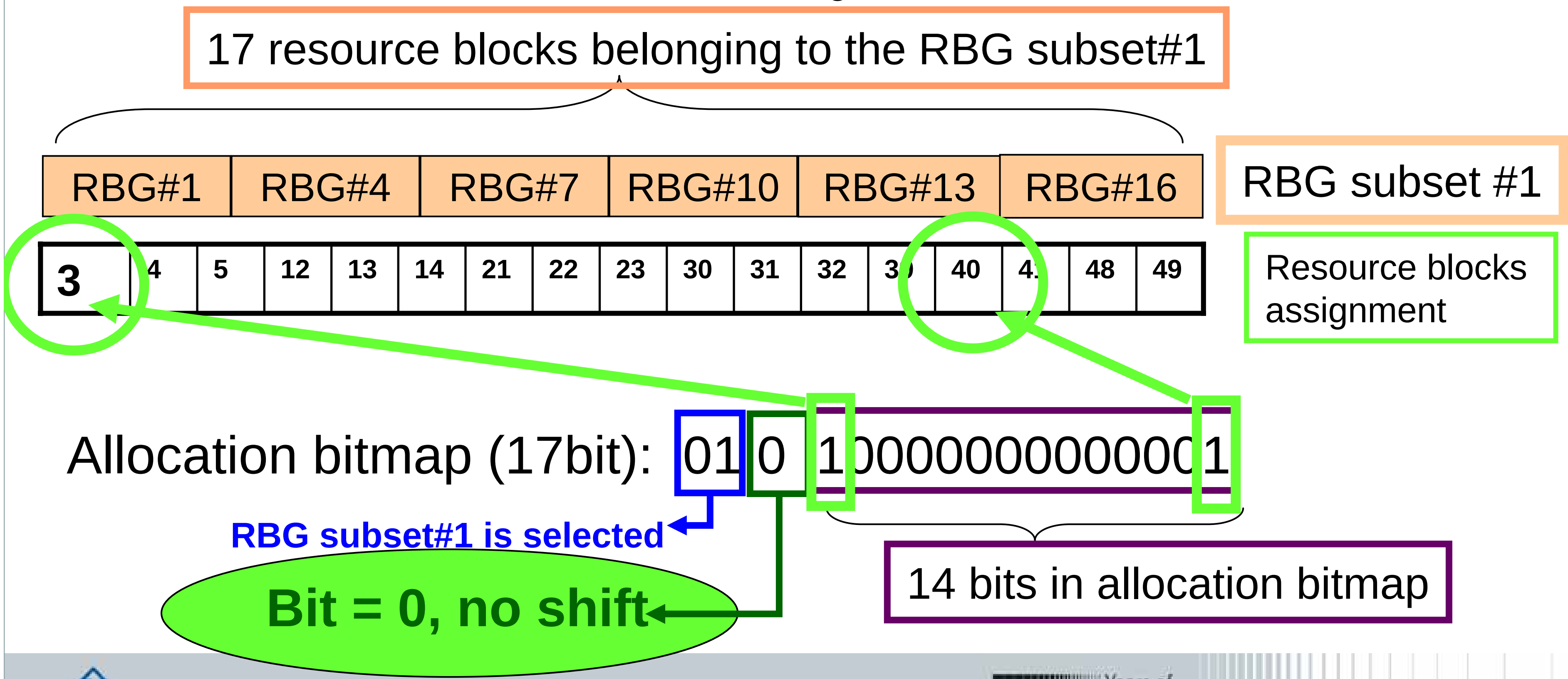


Resource allocation type 1

Channel bandwidth = 10MHz -> 50 RBs -> RBG size = 3 -> number of RBGs = 17

The meaning of the shift offset bit:

Number of resource blocks in one RBG subset is bigger than the allocation bitmap
-> you can not allocate all the available resource blocks
-> offset shift to indicate which RBs are assigned



Resource allocation type 1

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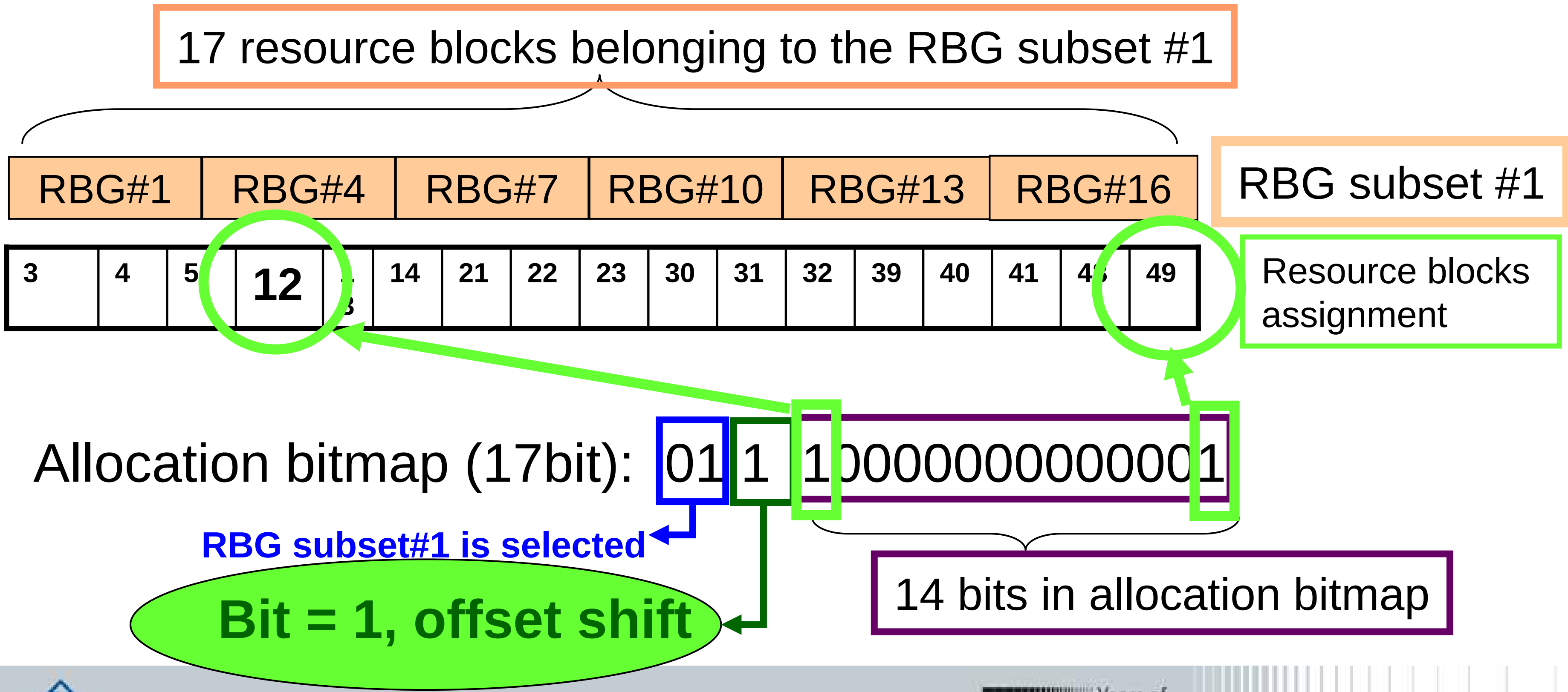
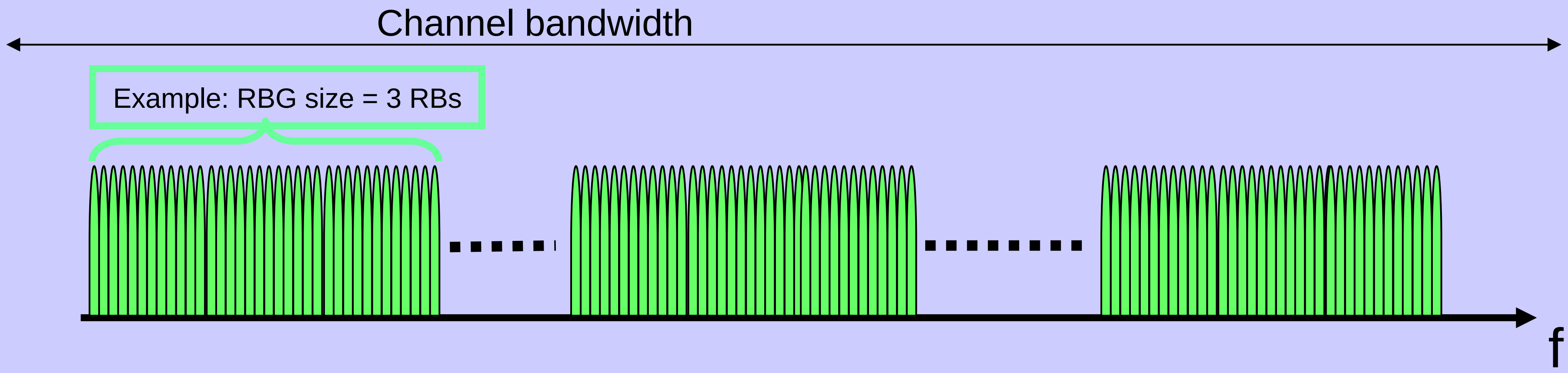
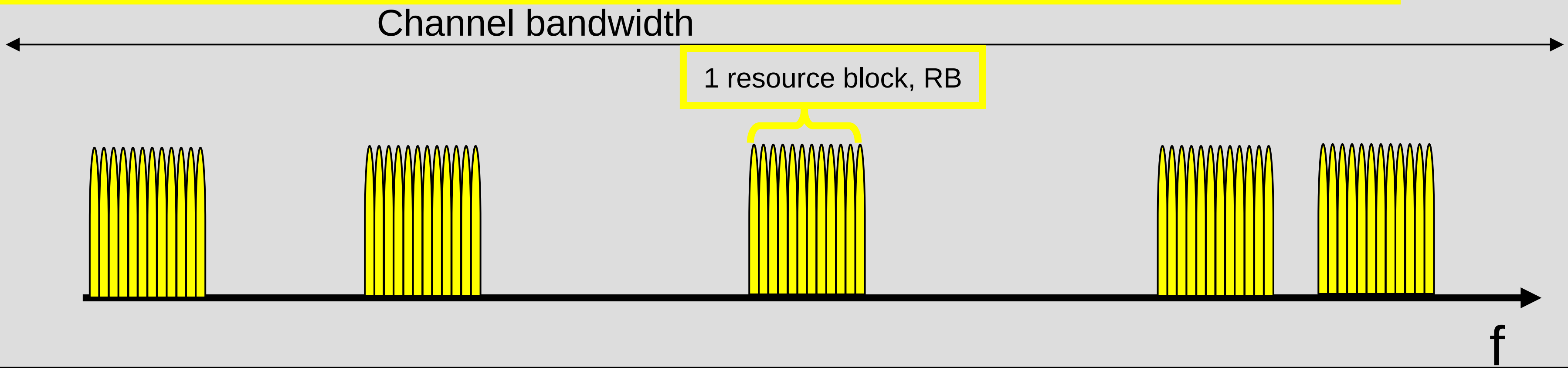


Resource allocation types in LTE

Type 0 allows the allocation based on **resource block groups** granularity

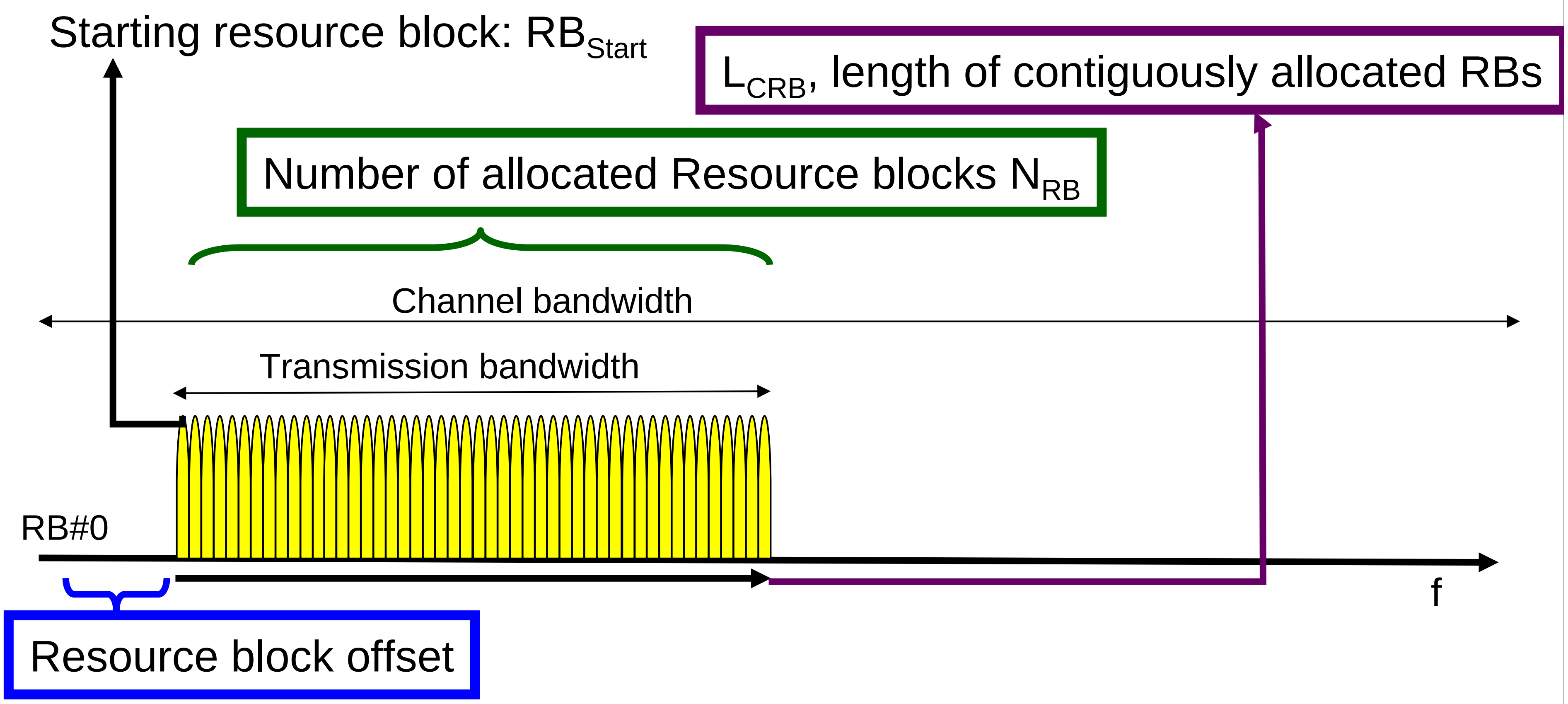


Type 1 allows the allocation based on **resource block** granularity



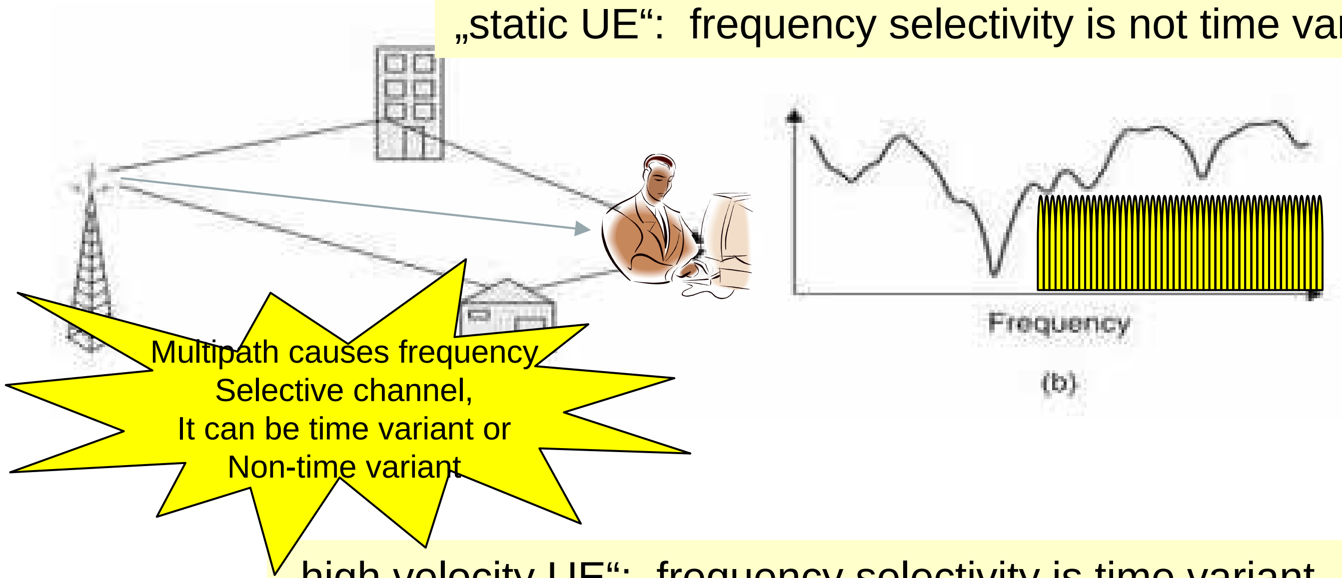
Resource allocation type 2

Localized mode

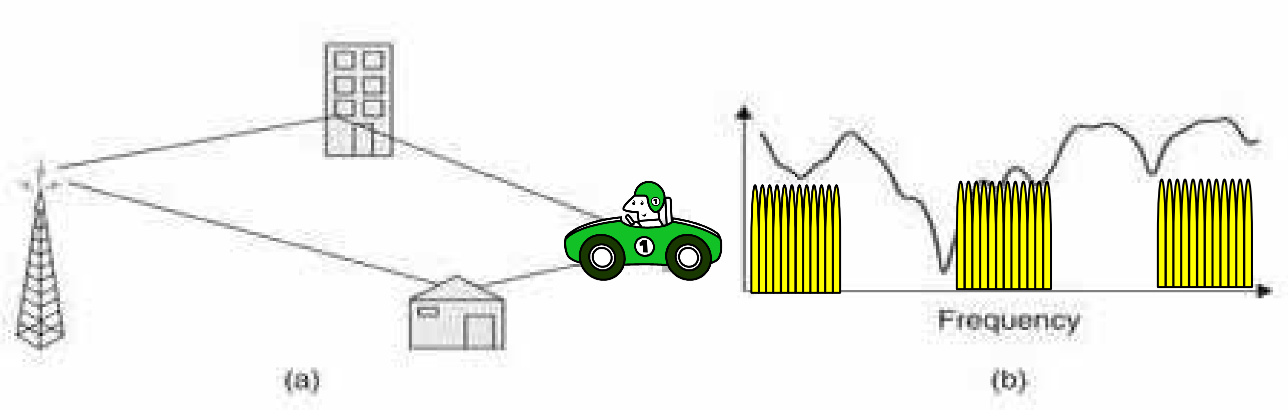


Benefit of localized or distributed mode

„static UE“: frequency selectivity is not time variant -> localized allocation



„high velocity UE“: frequency selectivity is time variant -> distributed allocation



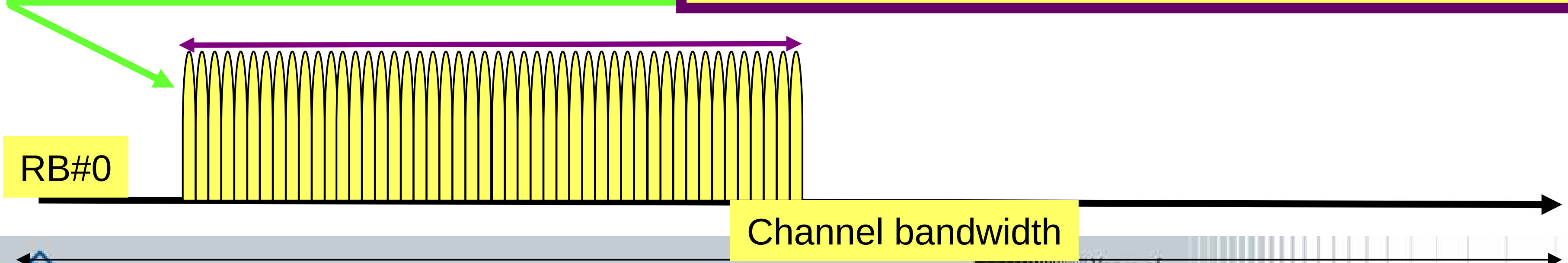
Resource allocation Uplink

Allocation type	DCI Format	Scheduling Type	Antenna configuration
Type 0 / 1	DCI 1	PDSCH, one codeword	SISO, TxDiversity
	DCI 2A	PDSCH, two codewords	MIMO, open loop
	DCI 2	PDSCH, two codewords	MIMO, closed loop
Type 2	**DCI 0**	**PUSCH**	**SISO**
	DCI 1A	PDSCH, one codeword	SISO, TxDiversity
	DCI 1C	PDSCH, very compact codeword	SISO

LTE Uplink uses Type 2 allocation

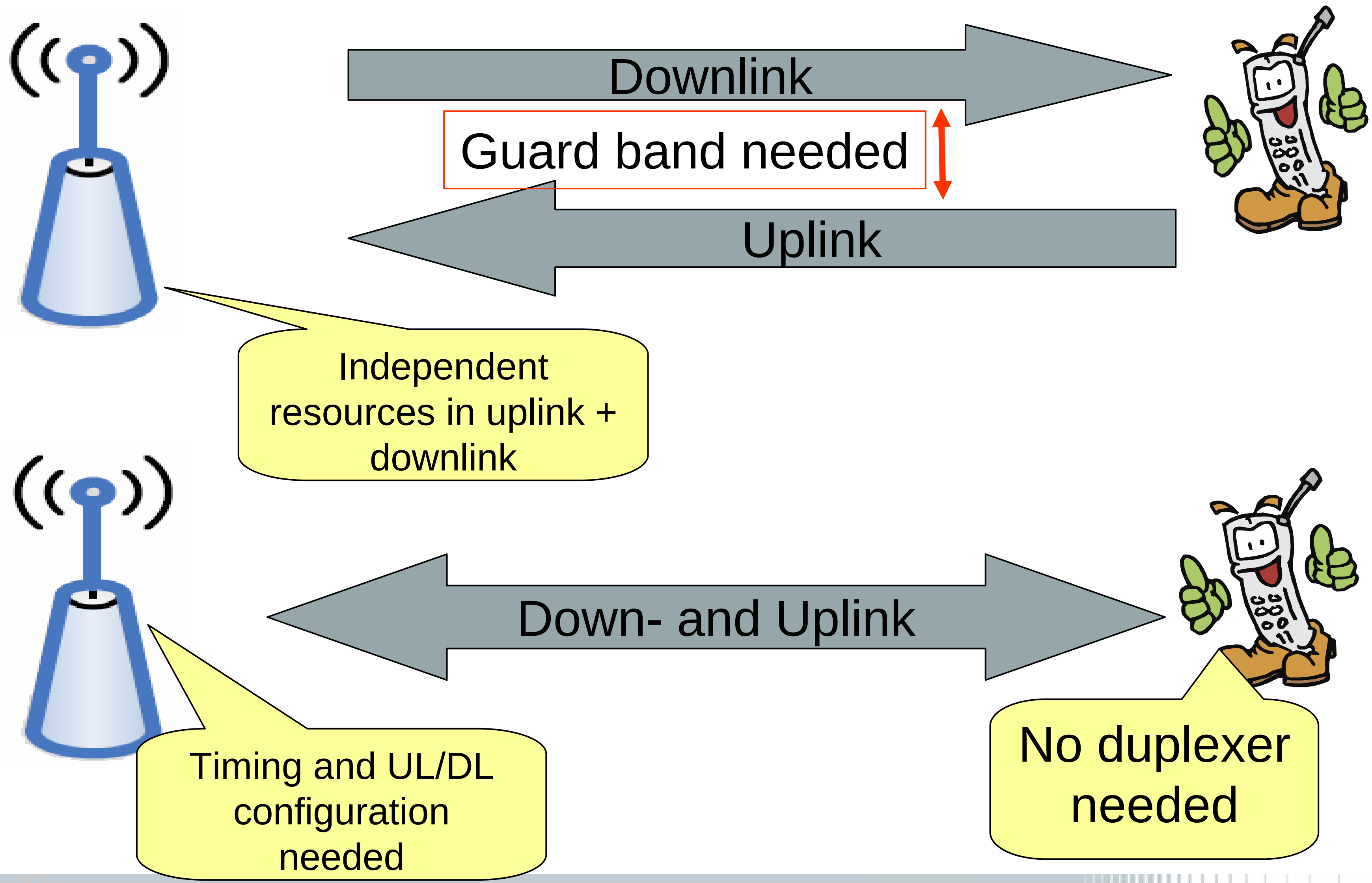
Starting resource block: RB_{Start}

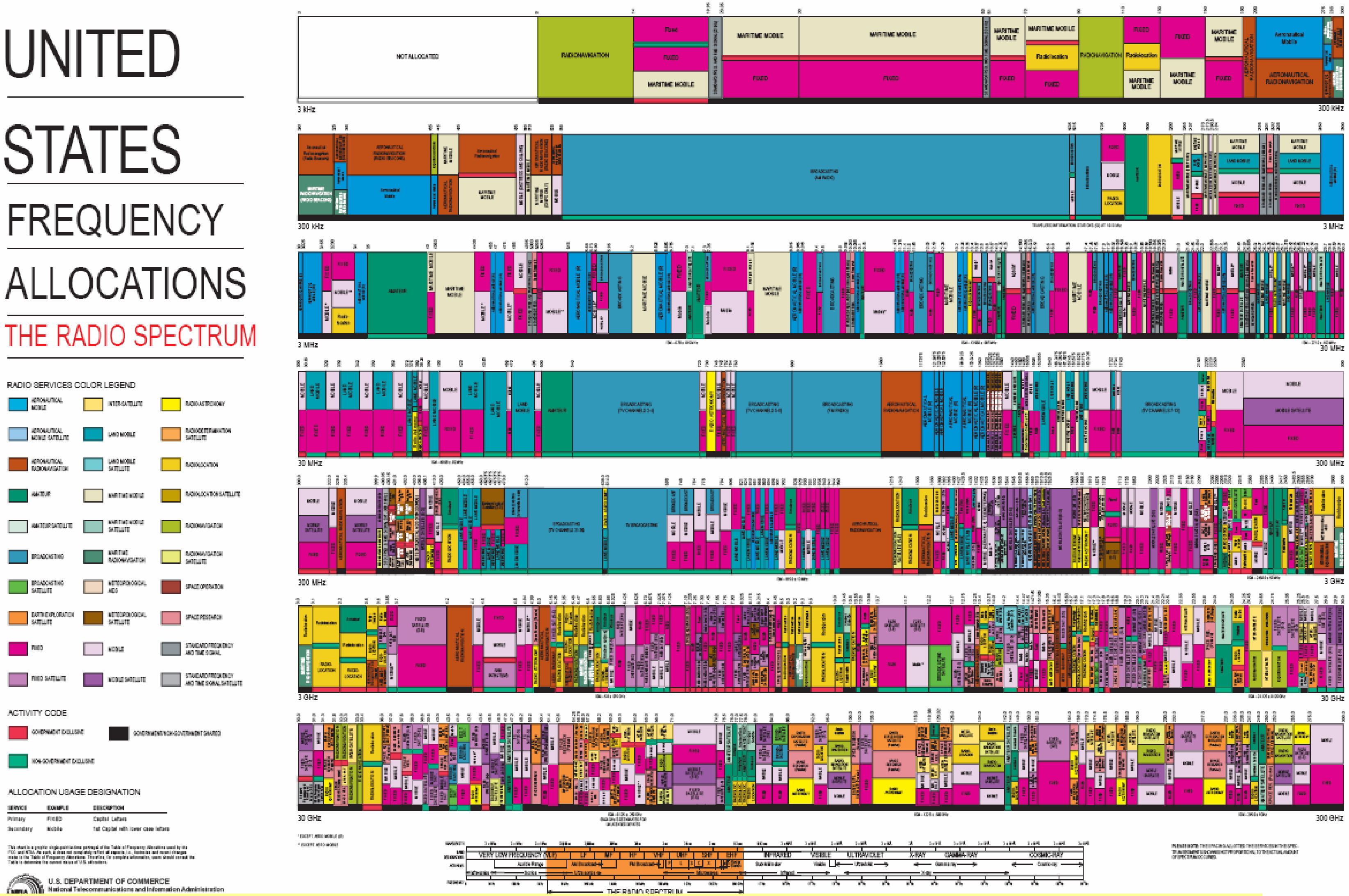
L_{CRB}, length of contiguously allocated RBs



LTE TDD and FDD mode of operation

TDD versus FDD





Paired spectrum not always available -> use TDD mode

General comments

What is called “Advantages of TDD vs. FDD mode”

- **Data traffic,**
  - Asymmetric setting between downlink and uplink possible, depending on the situation,

See interference aspects:
UL – DL and inter-cell

- **Channel estimation,**
  - Channel characteristic for downlink and uplink same,

In principle yes:
•But hardware influence!
•And: Timing delay UL and DL

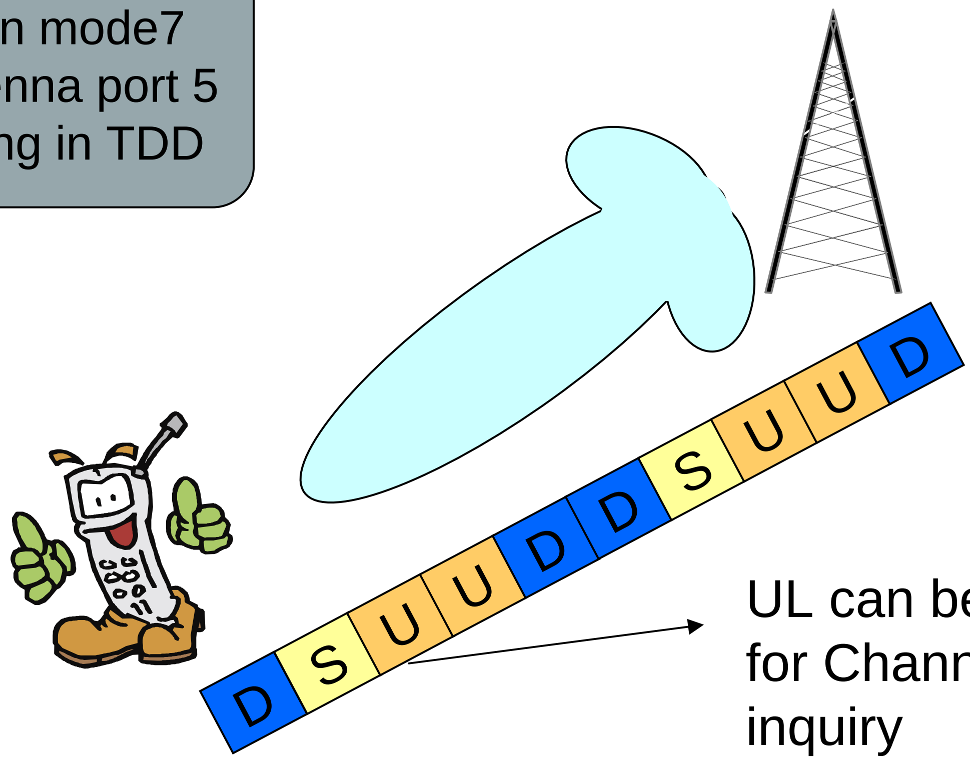
- **Design,**
  - No duplexer required, simplifies RF design and reduce costs.

But most UEs will be dual-mode: FDD and TDD!

Beamforming in LTE TDD

- **Adaptive Beamforming**
  - Beamforming in TDD mode is used via Specific antenna port 5
  - Channel estimation performed at eNodeB based on uplink timeslots

Transmission mode7
SISO, via antenna port 5
= beamforming in TDD



UL can be used by eNodeB for Channel Status information inquiry

Frequency band

- **For TDD mode, uplink and downlink is on the same frequency band**

E-UTRA BAND	Uplink (UL) eNode b receive UE transmit	Downlink (DL) eNode b transmit UE receive
	$F_{UL\_low} – F_{UL\_high}$	$F_{DL\_low} – F_{DL\_high}$
33	1900 MHz–1920 MHz	1900 MHz–1920 MHz
34	2010 MHz–2025 MHz	2010 MHz–2025 MHz
35	1850 MHz – 1910 MHz	1850 MHz – 1910 MHz
36	1930 MHz – 1990 MHz	1930 MHz – 1990 MHz
37	1910 MHz – 1930 MHz	1910 MHz – 1930 MHz
38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz
39	1880 MHz - 1920 MHz	1880 MHz - 1920 MHz
40	2300 MHz - 2400 MHz	2300 MHz - 2400 MHz

- **Bandwidth**

Channel bandwidth [MHz]	1.4	3	5	10	15	20
FDD mode	6	15	25	50	75	100
TDD mode	6	15	25	50	75	100

number of resource blocks

LTE TDD mode - overview

7 different UL/DL configurations are defined

Characteristics + differences of UL/DL configurations:

- •Number of subframes dedicated to Tx and Rx
- •Number of Hybrid Automatic Repeat Request, HARQ processes
- •HARQ process timing: time between first transmission and retransmission
- •Scheduling timing: What is the time between PDCCH and PUSCH?

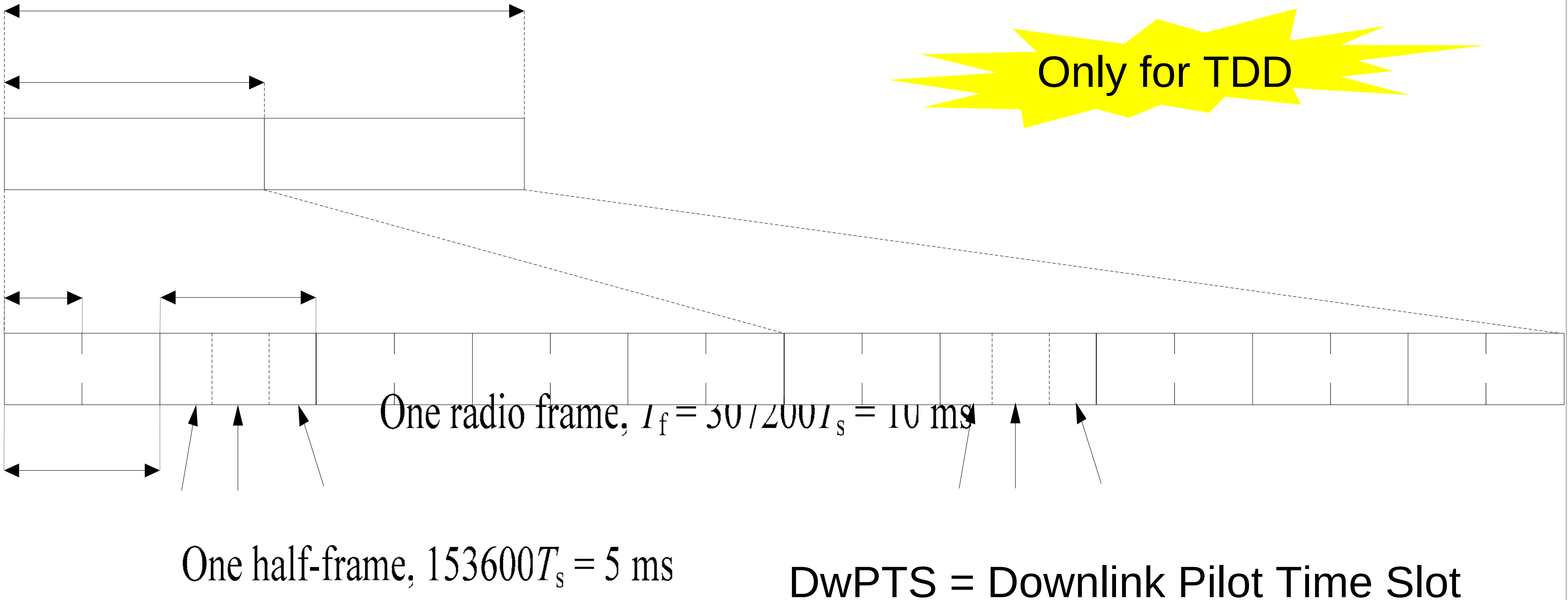
9 different configurations for the „special subframe“ are defined

Definition of how long are the DL and UL pilot signals and how much control information can be sent on it. -> also has an impact on cell size

Differences between Uplink and Downlink in TD-LTE

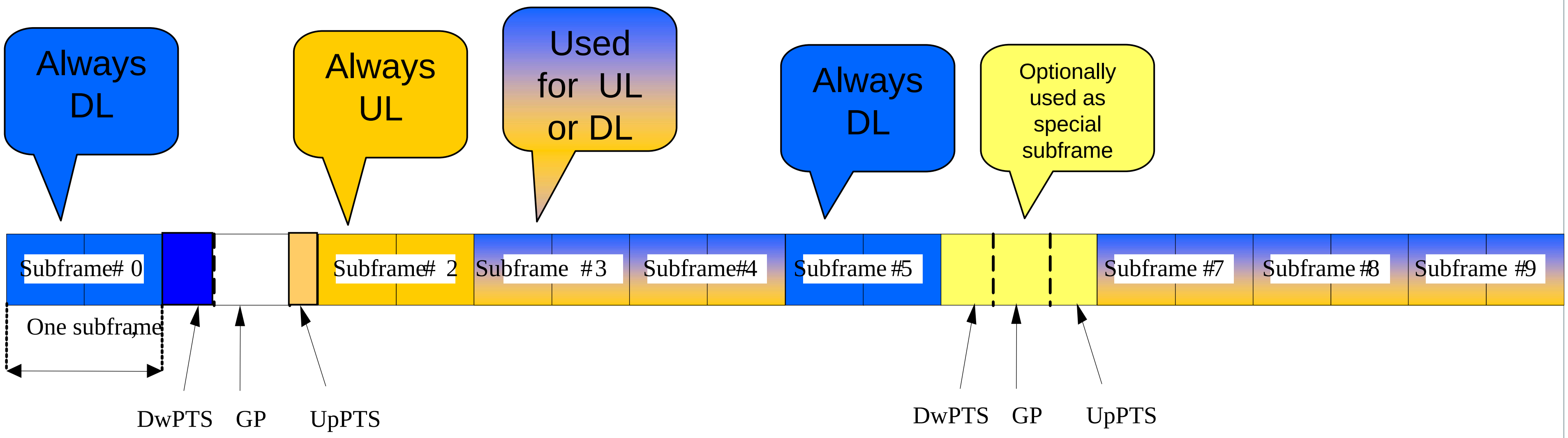
- •Characteristic of HARQ: Synchronuous or asynchronuous
- •Number of Hybrid Automatic Repeat Request, HARQ processes
- •HARQ process timing: time between first transmission and retransmission

LTE Downlink: Downlink slot and frame structure: type 2



DwPTS = Downlink Pilot Time Slot
UpPTS = Uplink Pilot Time Slot

LTE TDD: frame structure type 2



DwPTS = PDCCH, P-Sync, Reference symbol, User Data
GP = main Guard Period for TDD operation
UpPTS = PRACH, sounding reference signal

TD-LTE uplink-downlink configurations

First requirements, that need to be supported…

UL-DL configuration	DL-to-UL switch point periodicity	DL:UL Ratio	Peak data rate		Subframe number									
			DL	UL	0	1	2	3	4	5	6	7	8	9
0	5 ms	1:3	51.5	29.4	D	S	U	U	U	D	S	U	U	U
1	5 ms	2:2	81.4	19.6	D	S	U	U	D	D	S	U	U	D
2	5 ms	3:1	111.6	9.8	D	S	U	D	D	D	S	U	D	D
3	10 ms	6:3	101.0	14.7	D	S	U	U	U	D	D	D	D	D
4	10 ms	7:2	116.1	9.8	D	S	U	U	D	D	D	D	D	D
5	10ms	8:1	131.6	4.9	D	S	U	D	D	D	D	D	D	D
6	5 ms	3:5	66.3	24.5	D	S	U	U	U	D	S	U	U	D

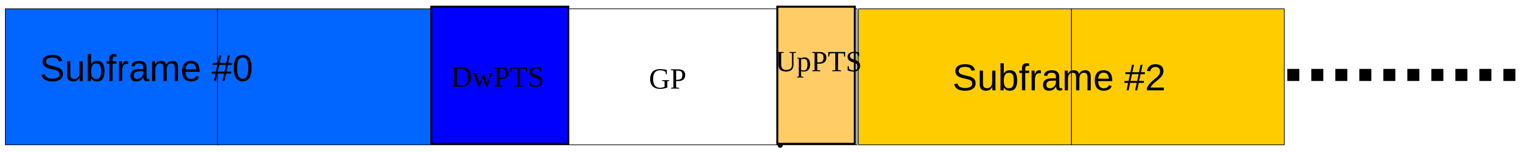
D = the subframe is reserved for downlink transmissions

U = the subframe is reserved for uplink transmissions

S = a special subframe containing DwPTS, GP and UpPTS

LTE TDD: special subframe configurations

Special subframe configuration = maximum cell size



Timing given by:

Example for timing

Number basis = 2192*T_s

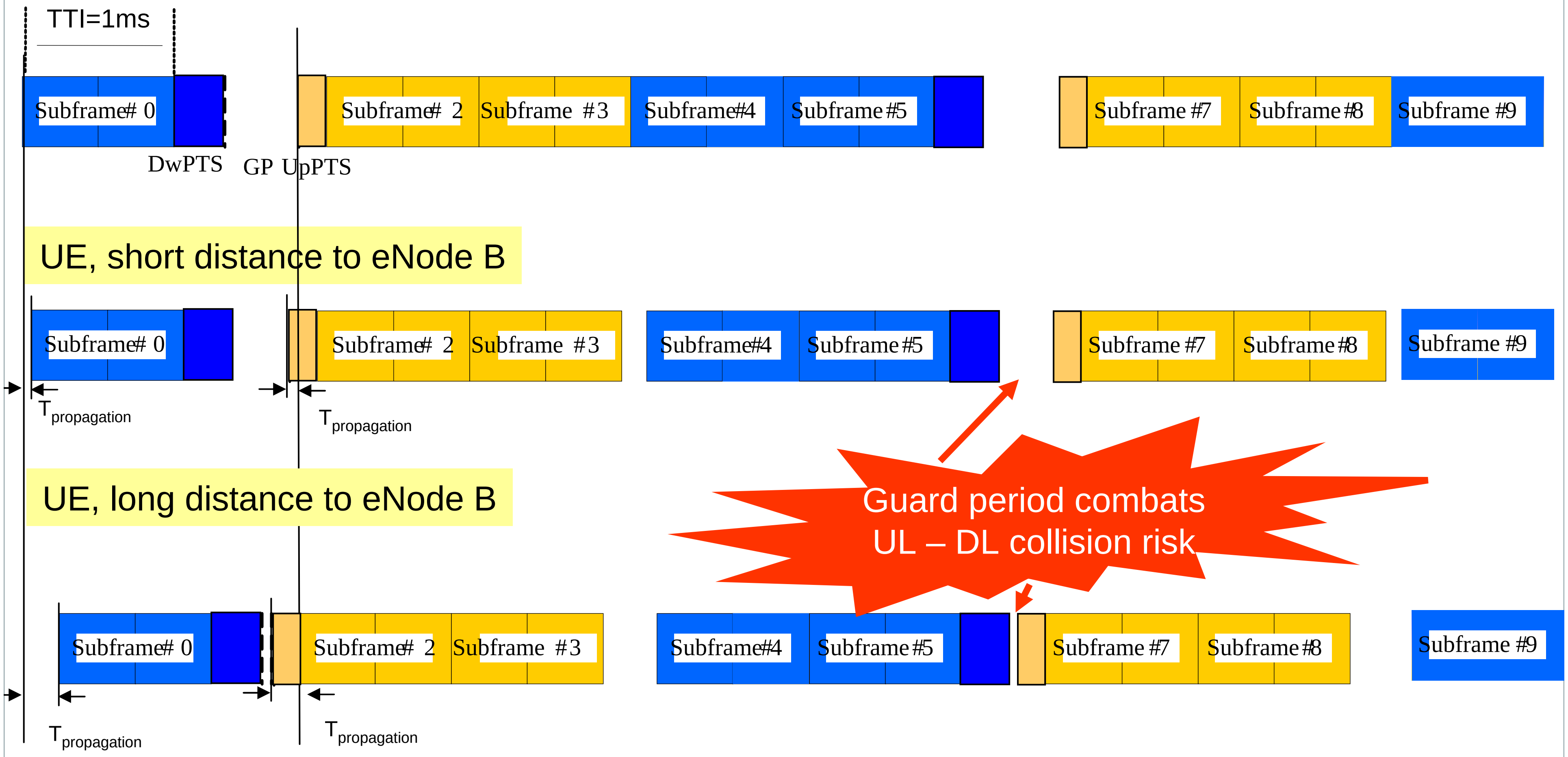
Special subframe configuration	Normal Cyclic prefix in DL and UL			Max Cell size
	DwPTS	Guard Period	UpPTS	
0	3	10	1	100 km
1	9	4	1	40 km
2	10	6	1	60 km
3	11	2	1	20 km
4	12	1	1	10 km
5*	3	9	2	90 km
6	9	3	2	30 km
7*	10	2	2	20 km
8	11	1	2	10 km

*: first requirements

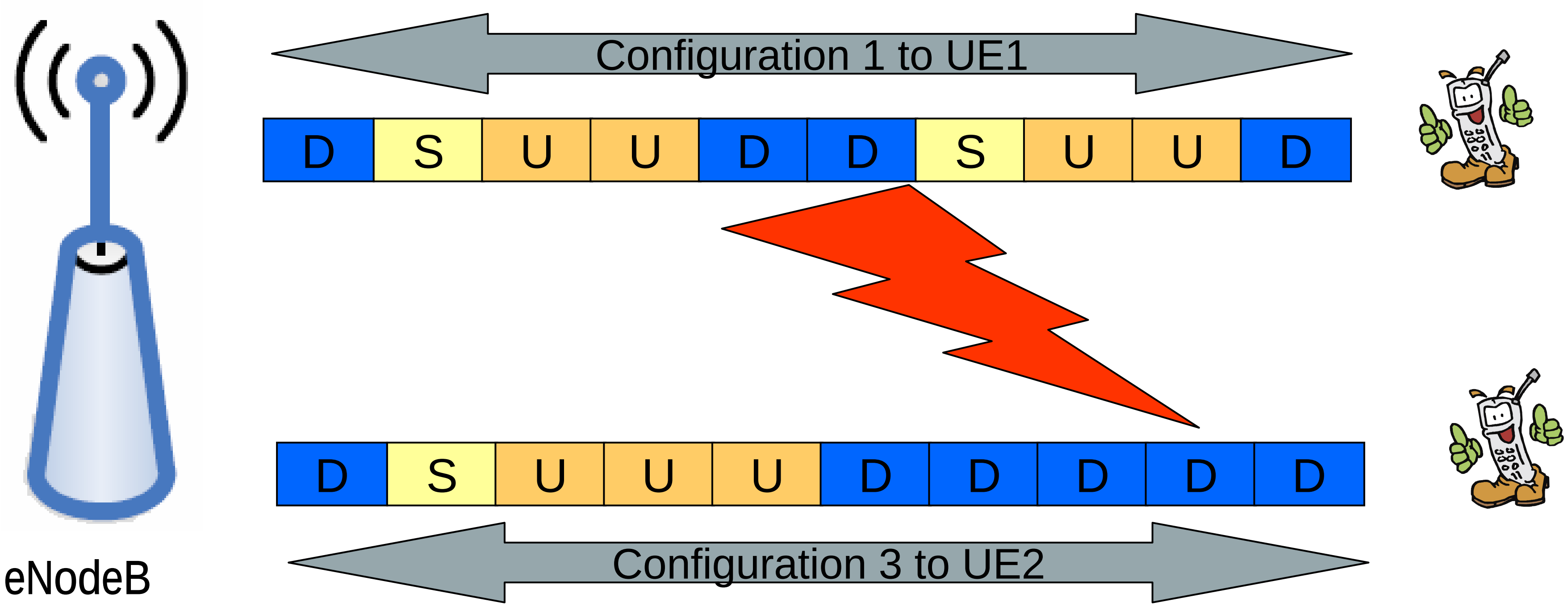
LTE TDD: timing advance and guard period

eNode B

In TDD there is a guard period needed between Transition DL-> UL, because of timing advance

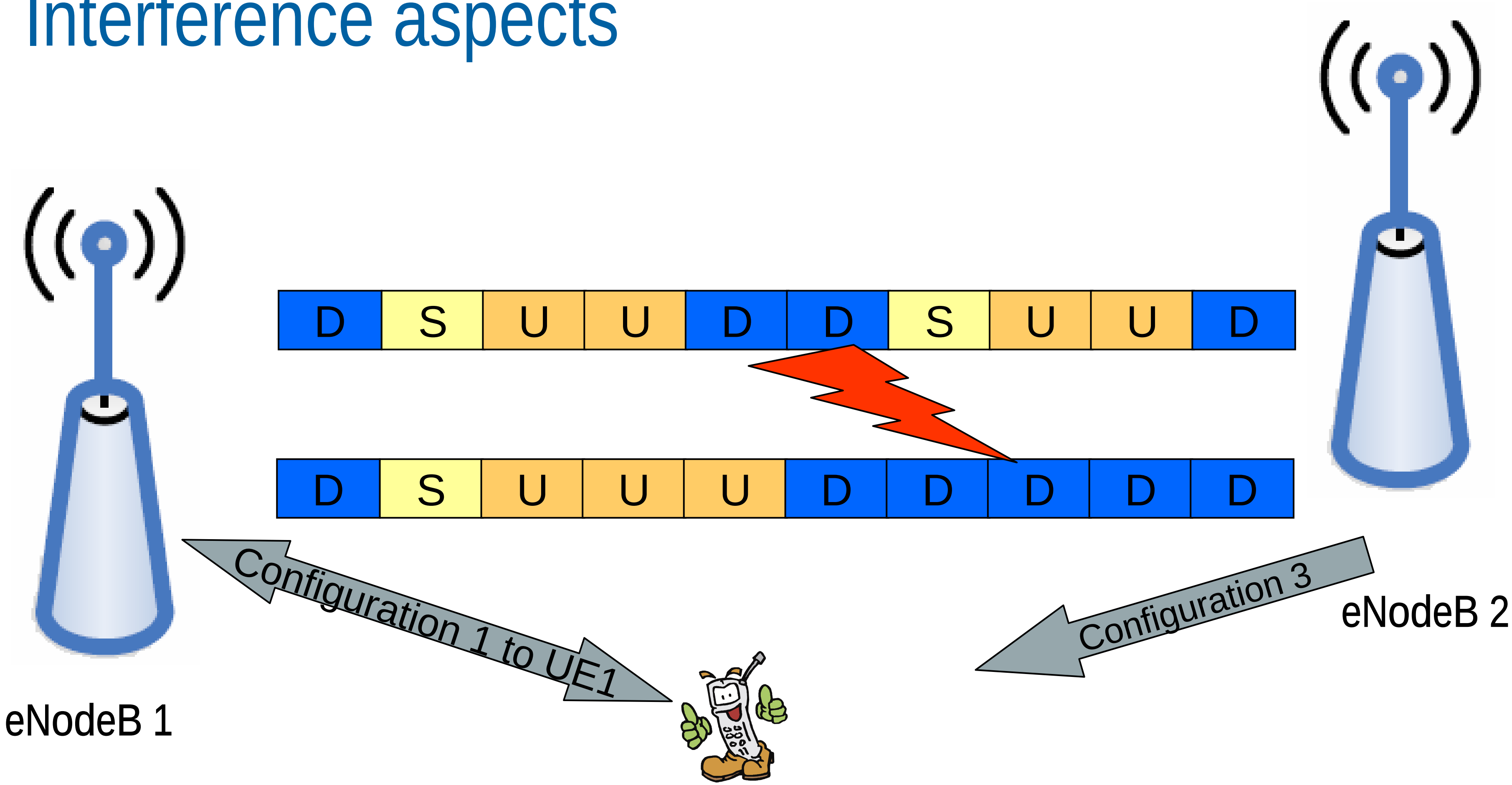


Interference aspects



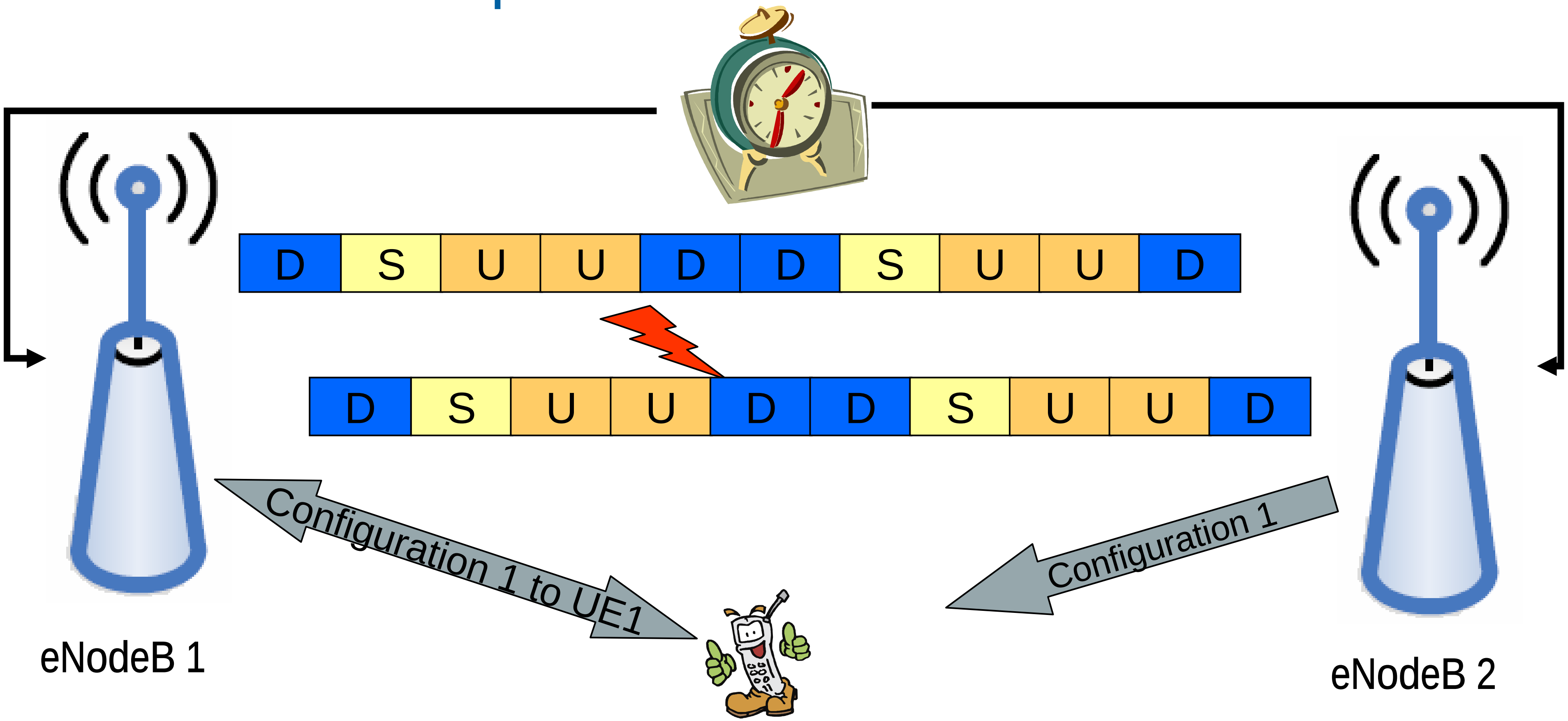
The UL/DL configuration can not vary dynamically between the UEs within a node B

Interference aspects



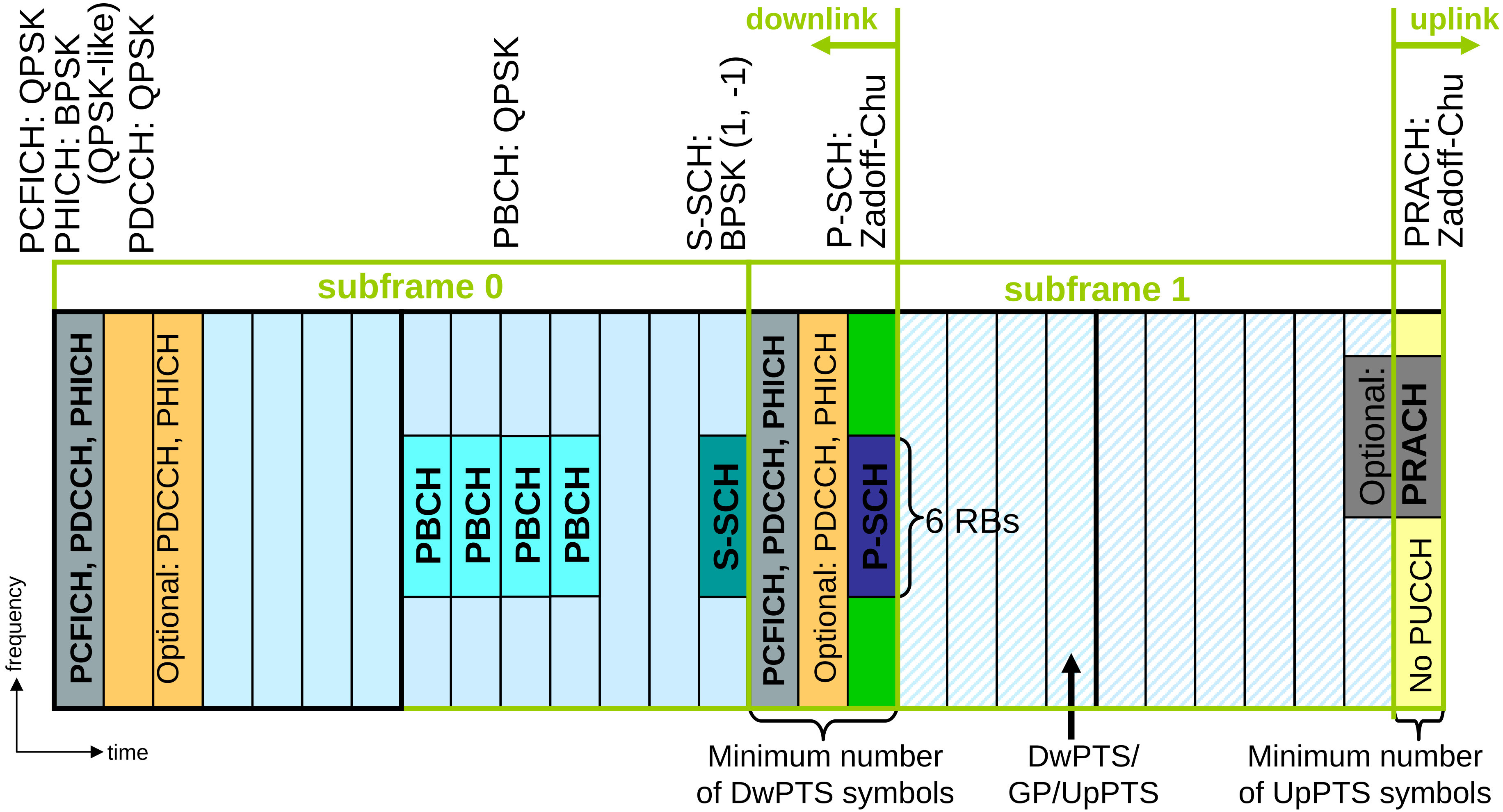
Neighbour cells should have the same UL/DL configurations

Interference aspects



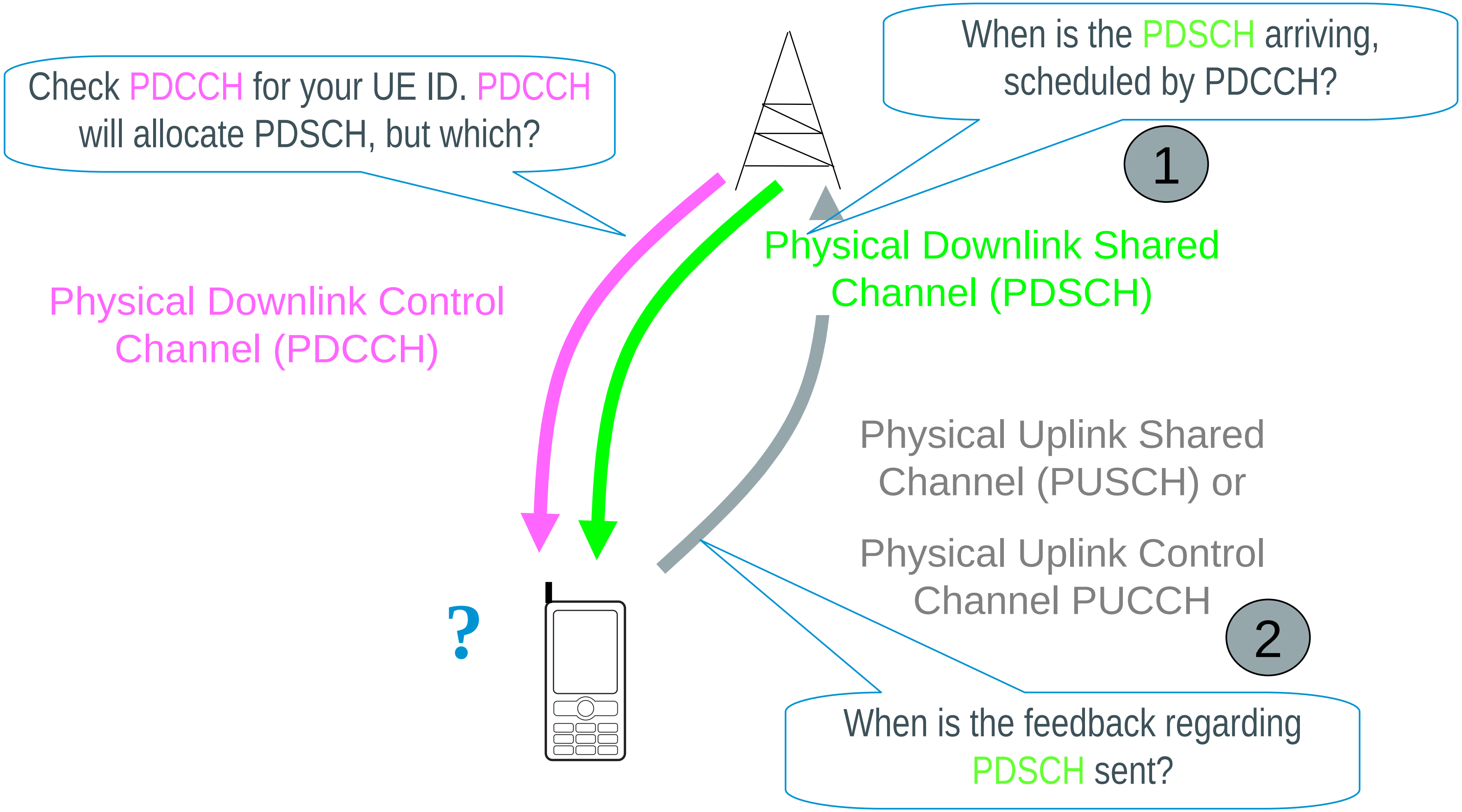
Neighbour cells should have the same Frame timing. Synchronisation required

TDD: First Downlink Subframes

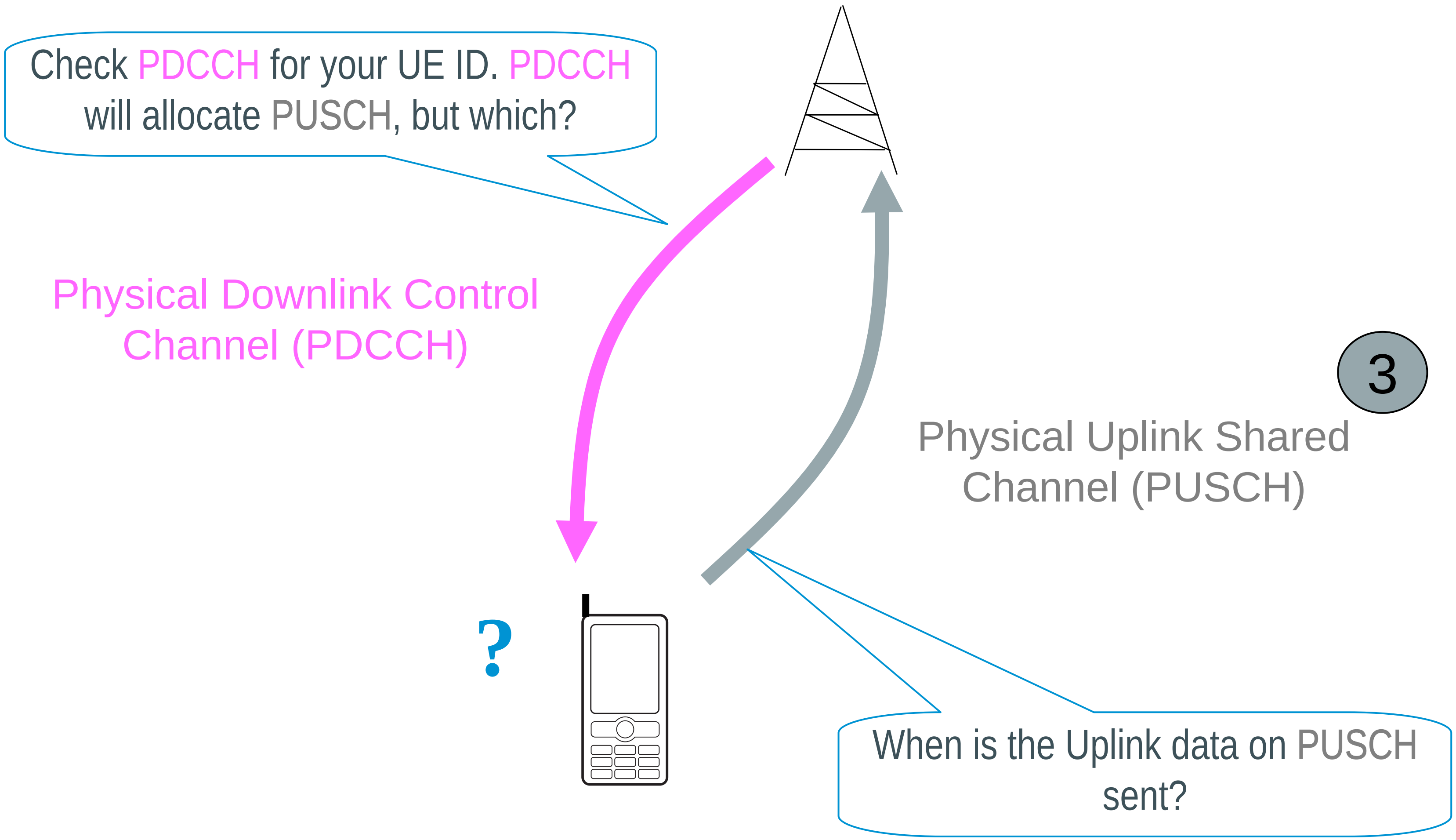


- PCFICH, PDCCH, PHICH, PBCH, Reference Signals are transmitted on all antenna ports.
- Antenna port for P-SCH is not specified. Antenna port of S-SCH is identical to P-SCH.

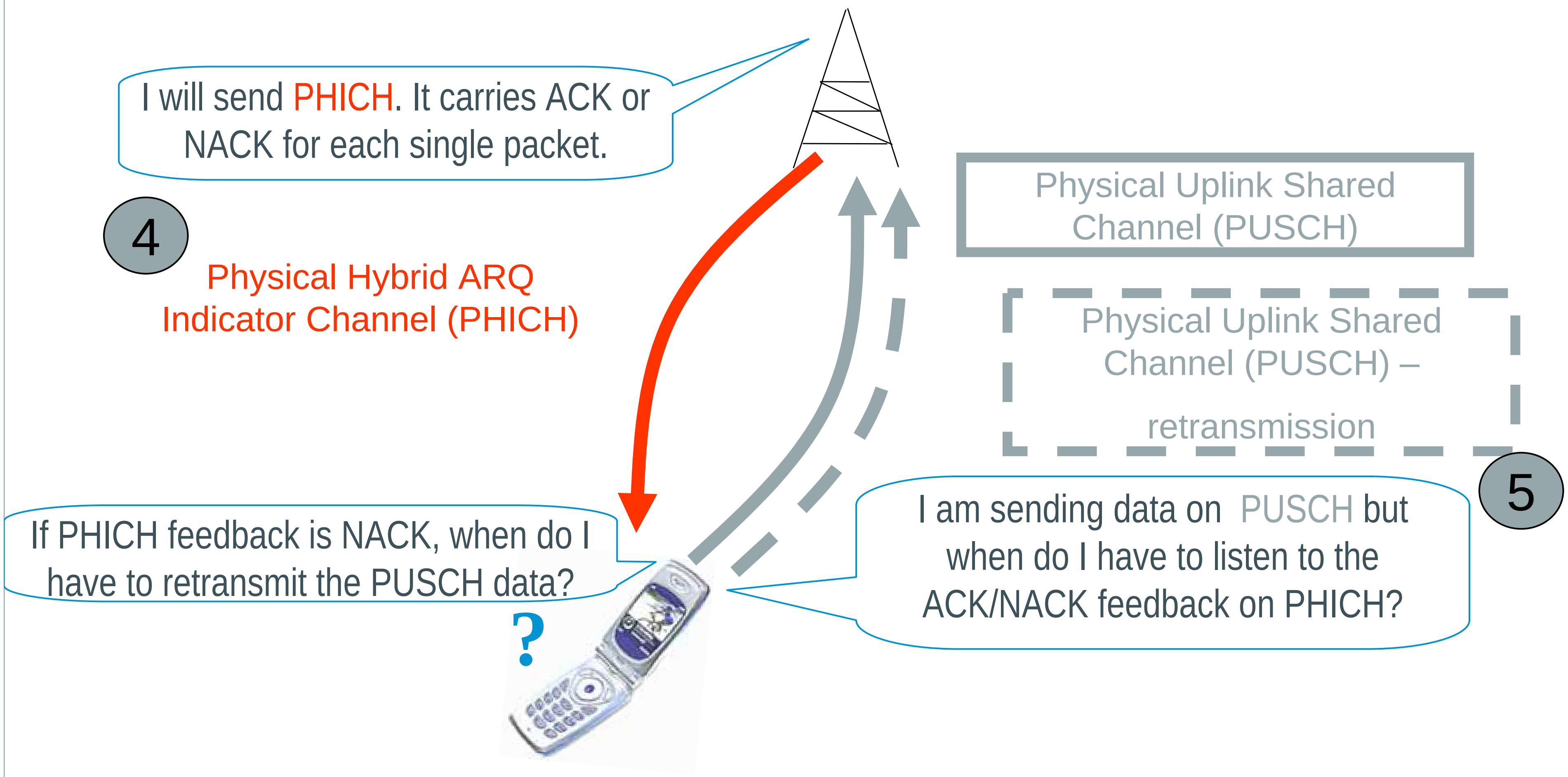
LTE TDD timing aspects: what to consider?



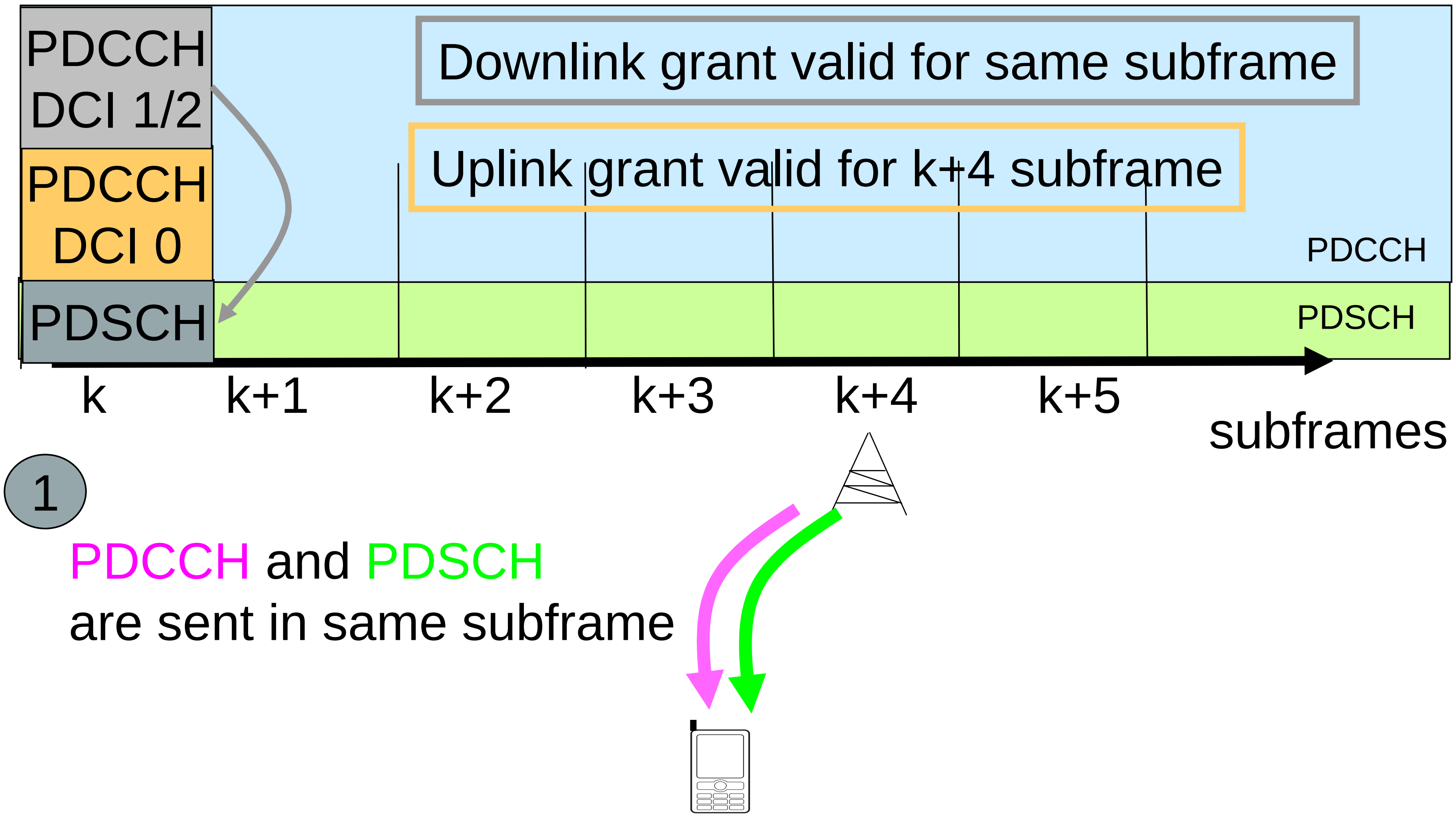
LTE TDD timing aspects: what to consider?



LTE TDD timing aspects: what to consider?



LTE TDD – timing aspects



PUSCH and PDCCH Timing Relation

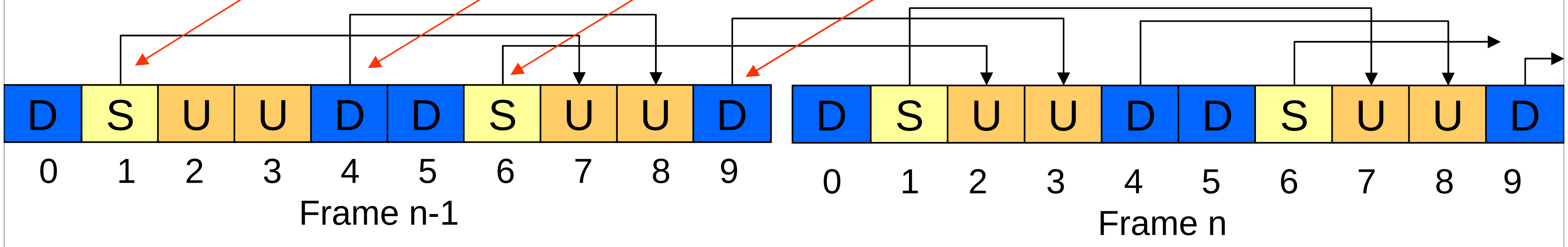
TDD: PUSCH timing relation depends on TDD frame configuration

3

(*)= for UL/DL configuration 0 there is normal HARQ operation and bundling HARQ operation. Latter is described in TS36.213

TDD UL/DL Configuration	Delay K for DL subframe number *n*									
	0	1	2	3	4	5	6	7	8	9
0	$4^{(*)}$	$6^{(*)}$				$4^{(*)}$	$6^{(*)}$			
1		6			4		6			4
2				4					4	
3	4								4	4
4									4	4
5									4	
6	7	7				7	7			5

Example:
Configuration 1



LTE HARQ protocol

- **Downlink:**
  - Asynchronous adaptive protocol
  - Retransmission of data blocks can occur at any time after the initial transmission
  - To identify, the eNode B assigns a HARQ process identifier

- **Uplink**:
  - Synchronous non-adaptive protocol
  - Retransmission occurs at a predefined time after the initial transmission
  - HARQ process number is not assigned. Process can be derived from timing

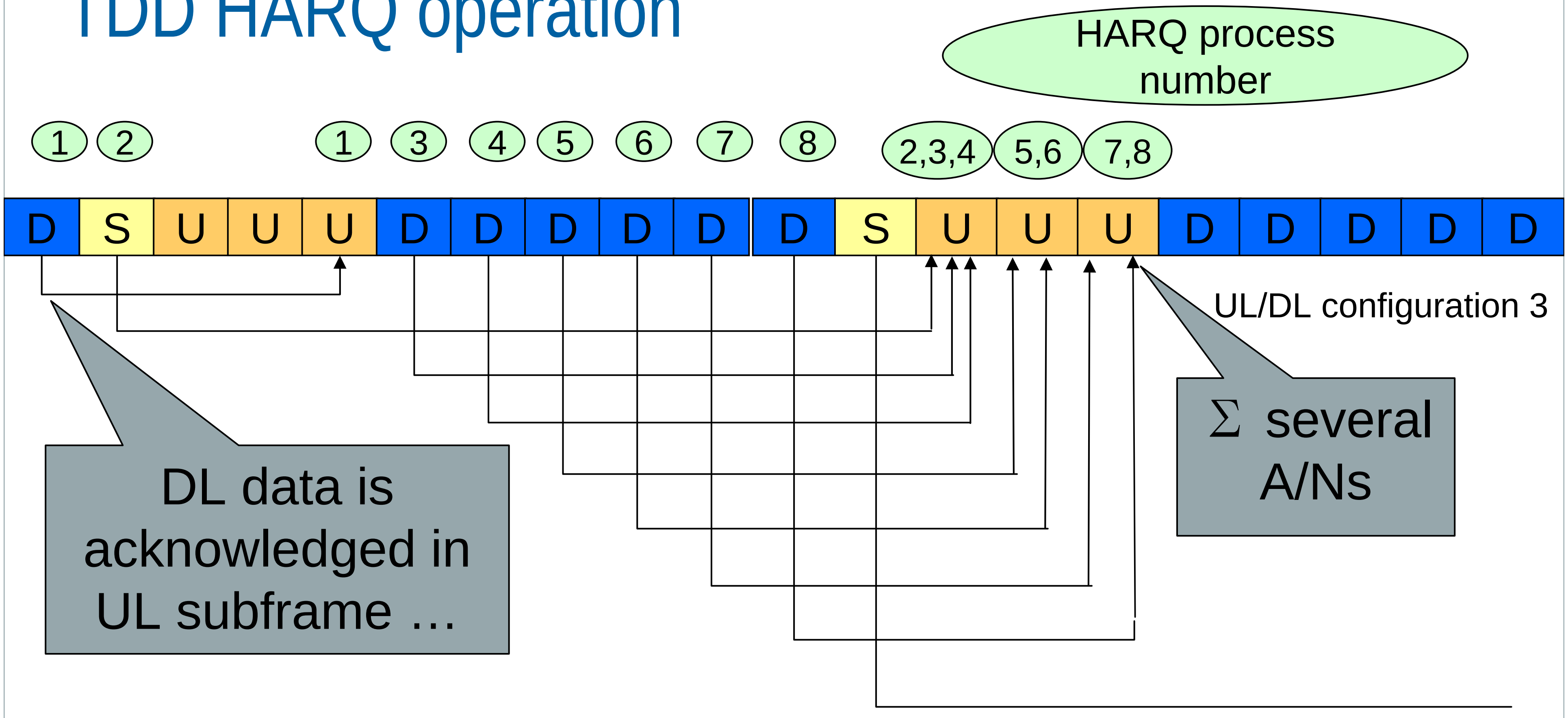
LTE TDD: HARQ processes in UL and DL

UL/DL configuration defines the number of HARQ processes, in configuration 2,3,4 and 5 are more than FDD

TDD UL/DL configuration	Maximum number of HARQ processes in Downlink	Maximum number of HARQ processes in Uplink
0	4	7
1	7	4
2	10	2
3	9	3
4	12	2
5	15	1
6	6	6

FDD=8 HARQ

TDD HARQ operation



Uplink subframe may combine acknowledgement of several Downlink data subframes.
-> different DL – UL timing and roundtrip times

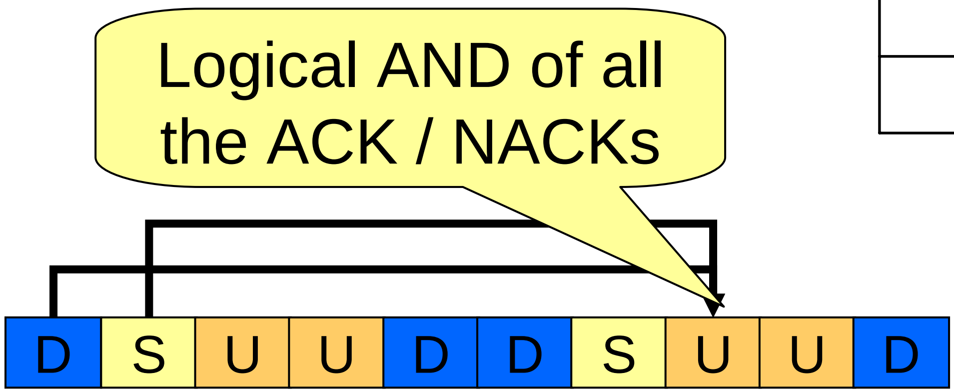
TDD ACK/NACK Bundling and Multiplexing

2 modes for feedback supported

ACK/NACK Bundling
for all UL-DL configurations

ACK/NACK Multiplexing
for all UL-DL configurations,
except configuration 5 (8 DL, 1 UL)

Example:
Configuration 1



HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2)	$n^{(1)}_{\mathrm{PUCCH}}$	$b(0),b(1)$
ACK, ACK, ACK	$n^{(1)}_{\mathrm{PUCCH},0}$	1, 1
ACK, ACK, NACK/DTX	$n^{(1)}_{\mathrm{PUCCH},1}$	1, 1
ACK, NACK/DTX, ACK	$n^{(1)}_{\mathrm{PUCCH},2}$	1, 1

⋮

Those bits are sent on PUCCH resource to indicate ACK/NACK

LTE TDD HARQ processes

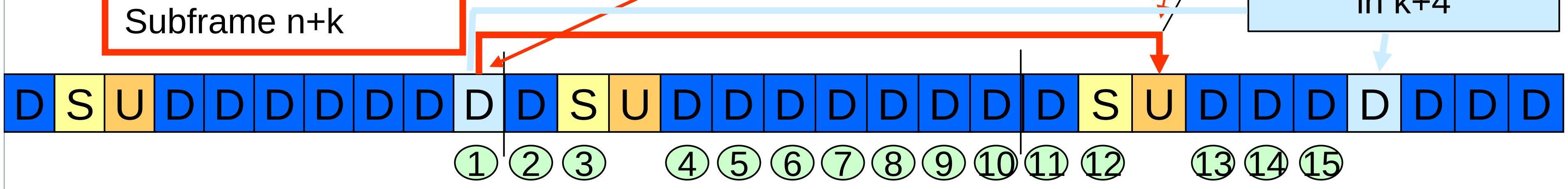
Downlink LTE TDD mode HARQ processes are non-synchronous and therefore they are signaled to the UE

UL/DL configuration	Subframe n									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
5	**12**	**11**	**-**	**9**	**8**	**7**	**6**	**5**	**4**	**13**
6	**7**	**7**	**-**	**-**	**-**	**7**	**7**	**-**	**-**	**5**

Example:
ACK/NACK
timing

PDSCH in Subframe n will be acknowledged in Subframe n+k

e.g. here NACK ->retransmission in k+4



HARQ Info = 4 bits

HARQ process identifier.
Here 15 HARQ processes are needed

LTE TDD: PDSCH-ACK/NACK feedback

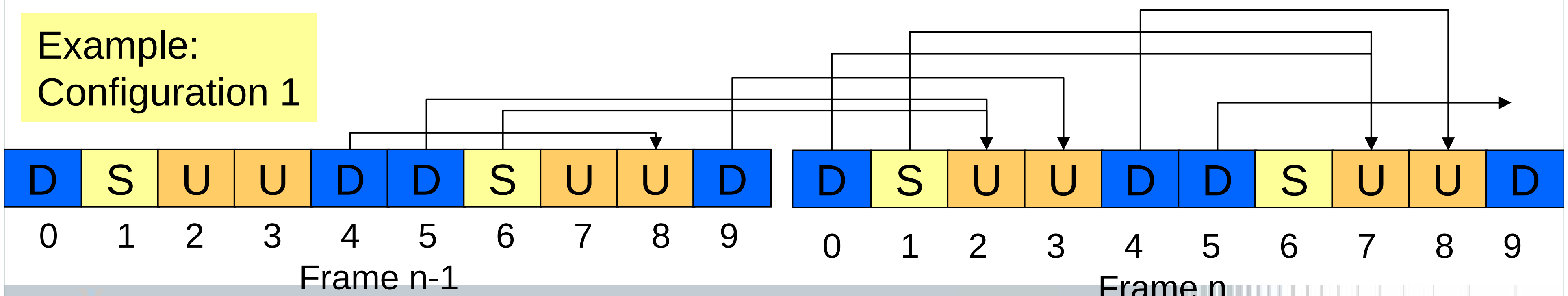
UE receiving data in subframe n-k sends ACK/NACK in subframe n

Value of k given as (TS36.213)

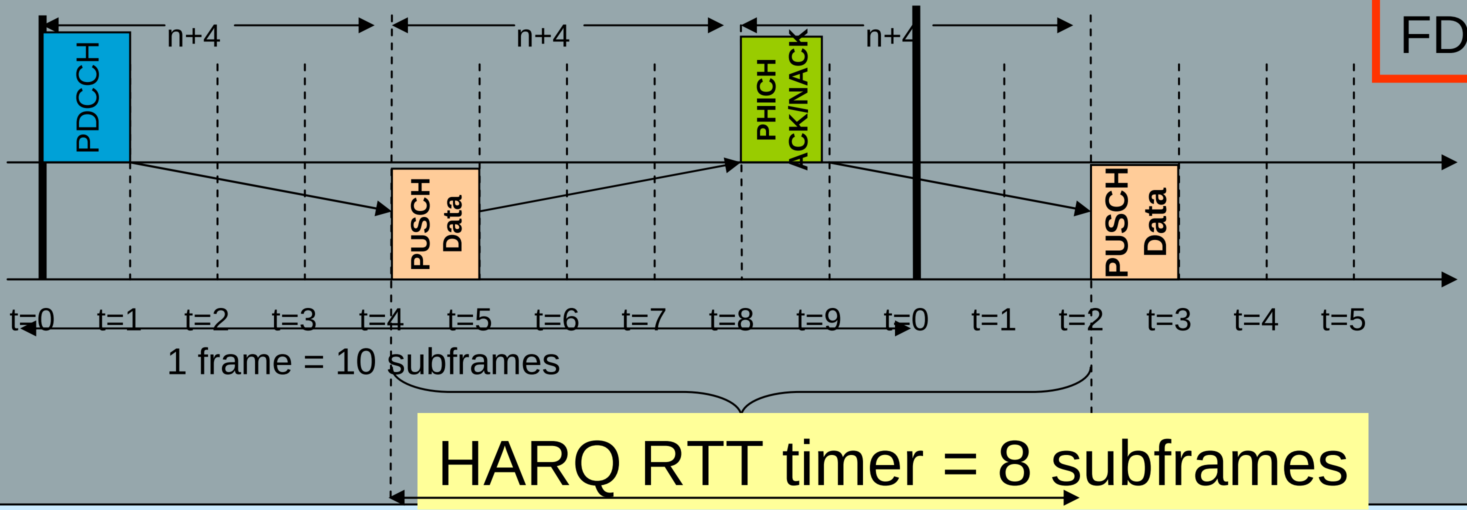
2

UL-DL Configuration	Subframe *n*									
	0	1	2	3	4	5	6	7	8	9
0	-	-	6	-	4	-	-	6	-	4
1	**-**	**-**	**7, 6**	**4**	**-**	**-**	**-**	**7, 6**	**4**	**-**
2	-	-	8, 7, 4, 6	-	-	-	-	8, 7, 4, 6	-	-
3	-	-	7, 6, 11	6, 5	5, 4	-	-	-	-	-
4	-	-	12, 8, 7, 11	6, 5, 4, 7	-	-	-	-	-	-
5	-	-	13, 12, 9, 8, 7, 5, 4, 11, 6	-	-	-	-	-	-	-
6	-	-	7	7	5	-	-	7	7	-

Example:
Configuration 1



HARQ Round Trip Time aspects, RTT timer



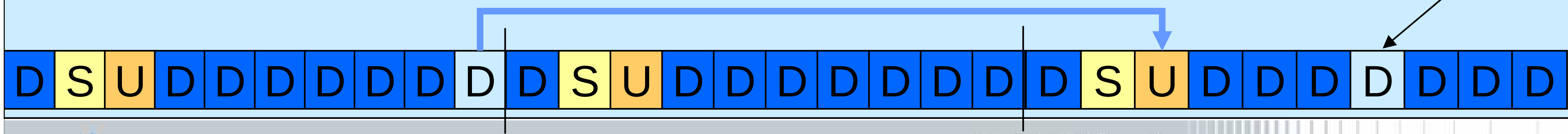
TDD = variable RTT!

PDSCH in Subframe n - k will be acknowledged in Subframe n

UL-DL Configuration	Subframe *n*									
	0	1	2	3	4	5	6	7	8	9
0	-	-	6	-	4	-	-	6	-	4
1	**-**	**-**	**7, 6**	**4**	**-**	**-**	**-**	**7, 6**	**4**	**-**
2	-	-	8, 7, 4, 6	-	-	-	-	8, 7, 4, 6	-	-
3	-	-	7, 6, 11	6, 5	5, 4	-	-	-	-	-
4	-	-	12, 8, 7, 11	6, 5, 4, 7	-	-	-	-	-	-
5	-	-	13, 12, 9, 8, 7, 5, 4, 11, 6	-	-	-	-	-	-	-
6	-	-	7	7	5	-	-	7	7	-

6

HARQ RTT timer = k+4



LTE TDD: PUSCH-ACK/NACK feedback

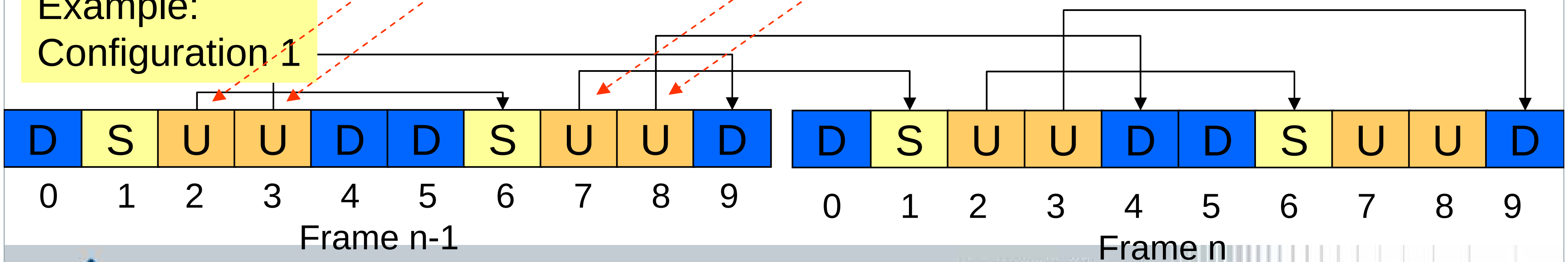
4

UE transmitting data in subframe n listens to PHICH ACK/NACK in subframe n+k

Value of k given as (TS36.213)

TDD UL/DL Configuration	UL subframe index *n*									
	0	1	2	3	4	5	6	7	8	9
0			4	7	6			4	7	6
1			4	6				4	6	
2			6					6		
3			6	6	6					
4			6	6						
5			6							
6			4	6	6			4	7	

Example:
Configuration 1

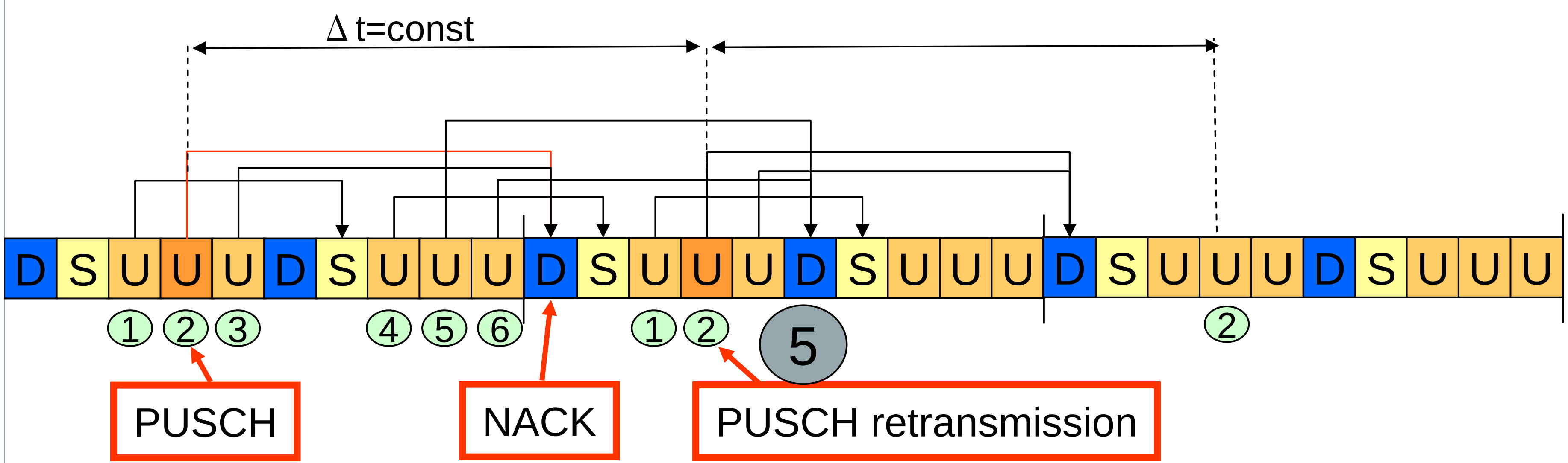


PUSCH-ACK/NACK Timing

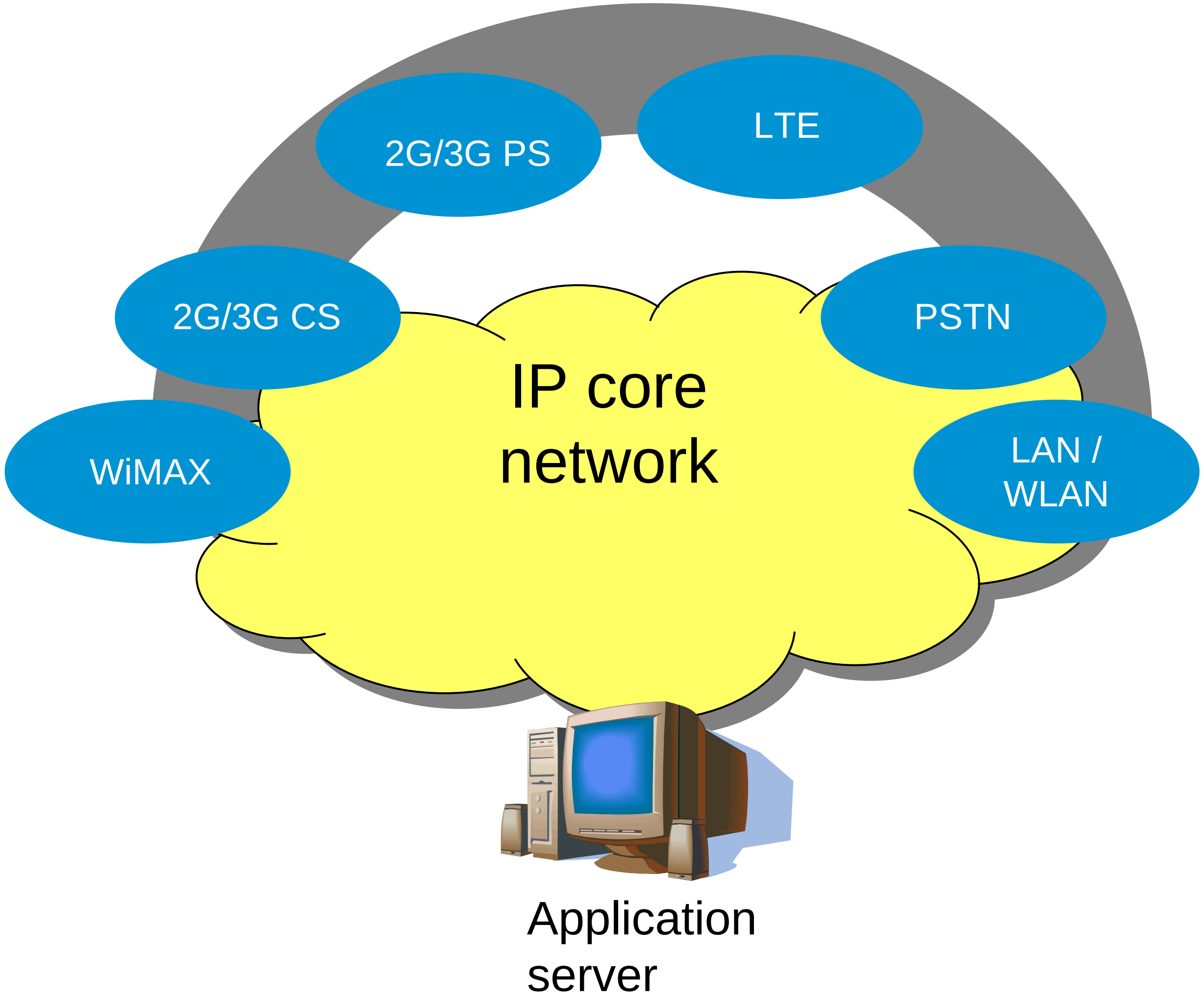
TDD UL/DL Configuration	UL subframe index *n*									
	0	1	2	3	4	5	6	7	8	9
0			4	7	6			4	7	6

4

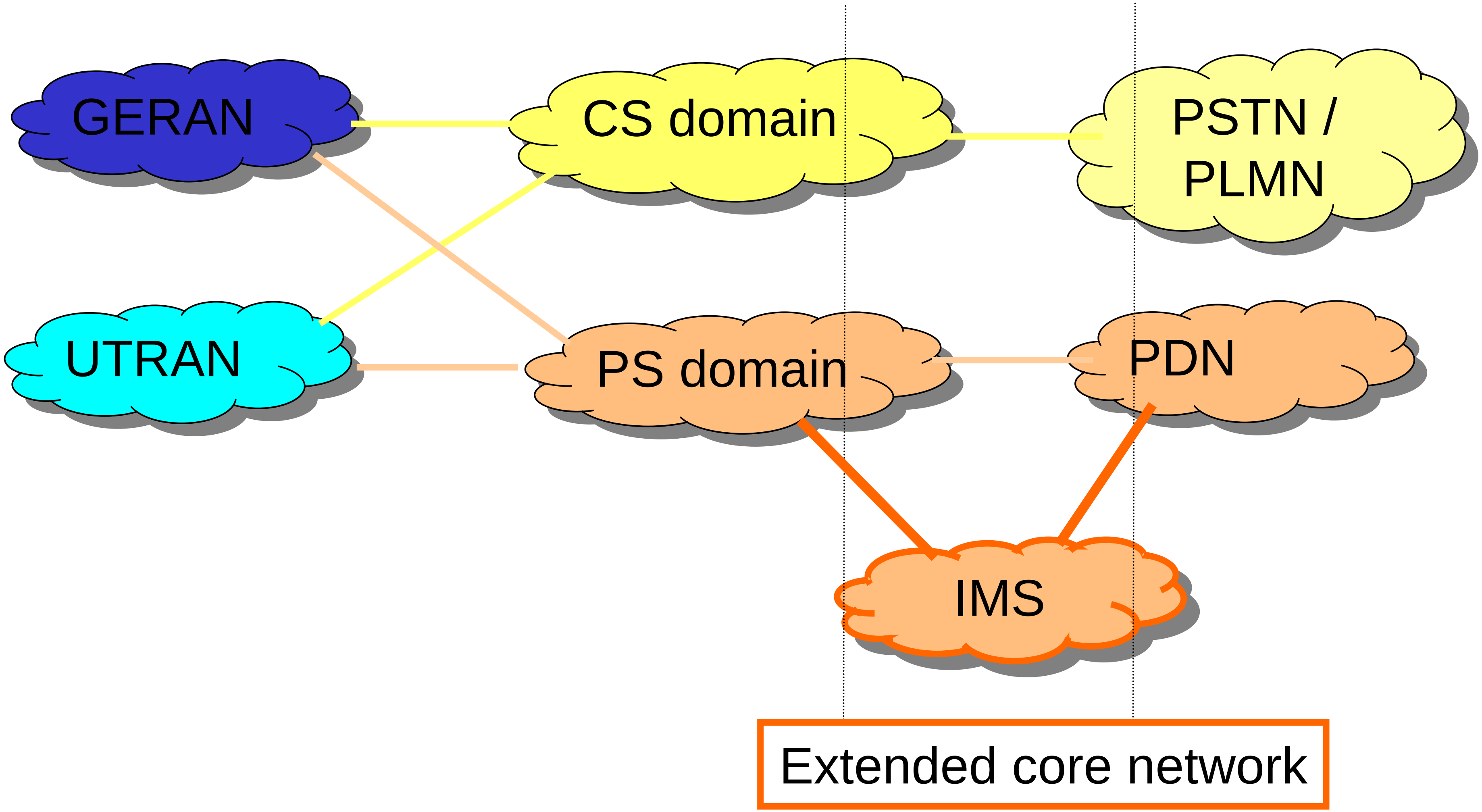
Uplink HARQ processes are synchronuous, no indication needed



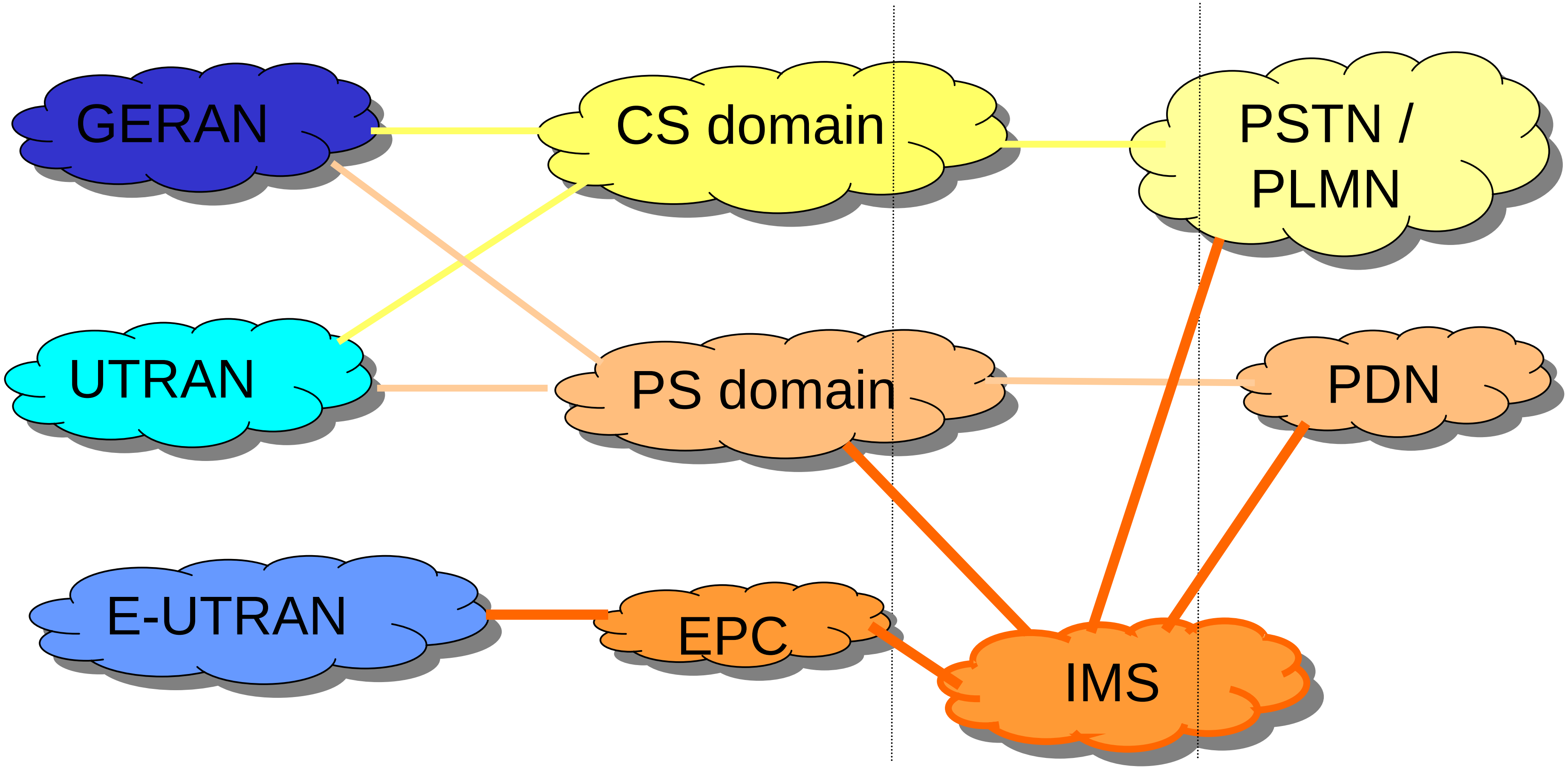
All over IP


2G/3G PS
LTE
2G/3G CS
PSTN
IP core network
WiMAX
LAN / WLAN
Application server

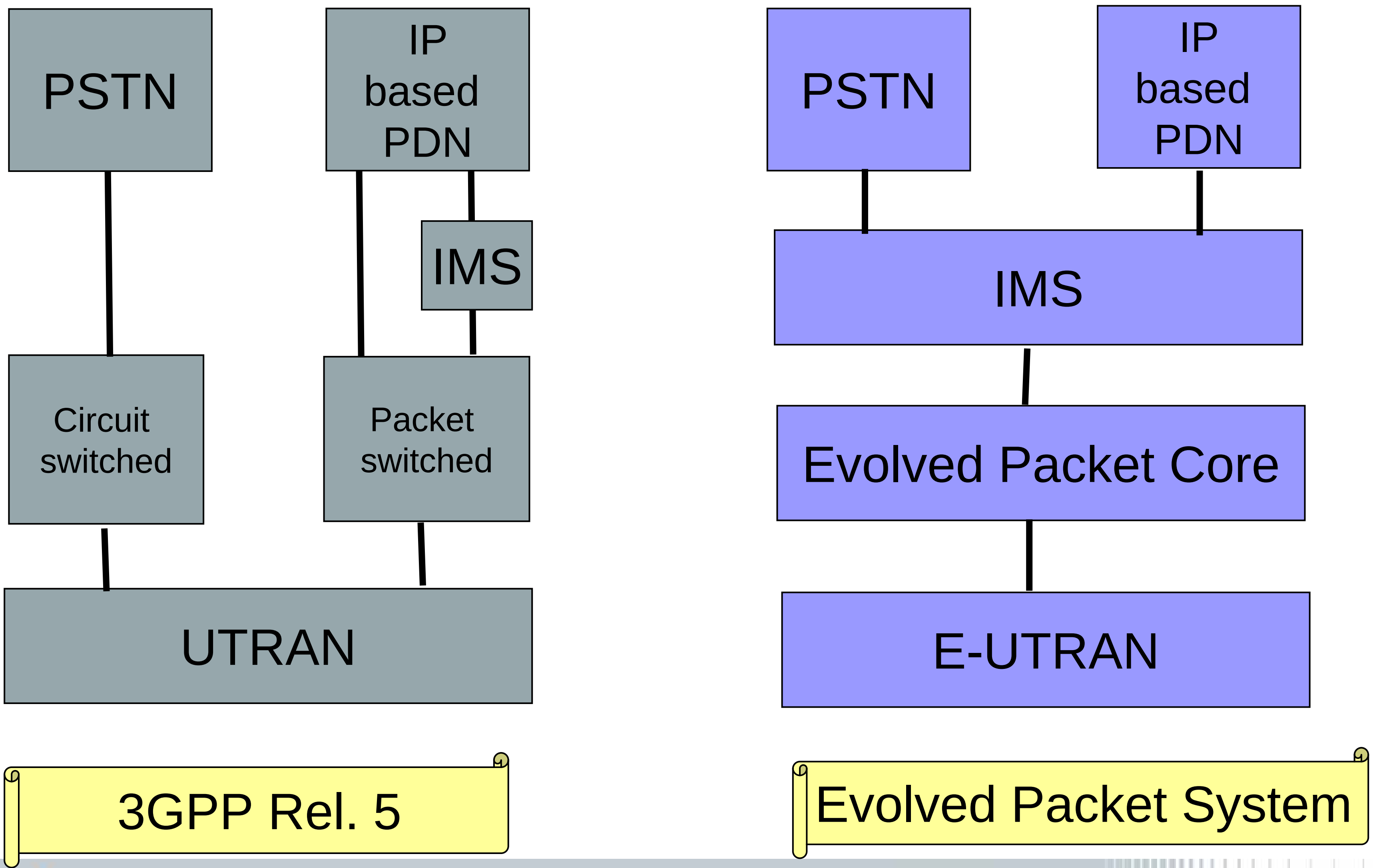
Introduction of IMS in Rel.5



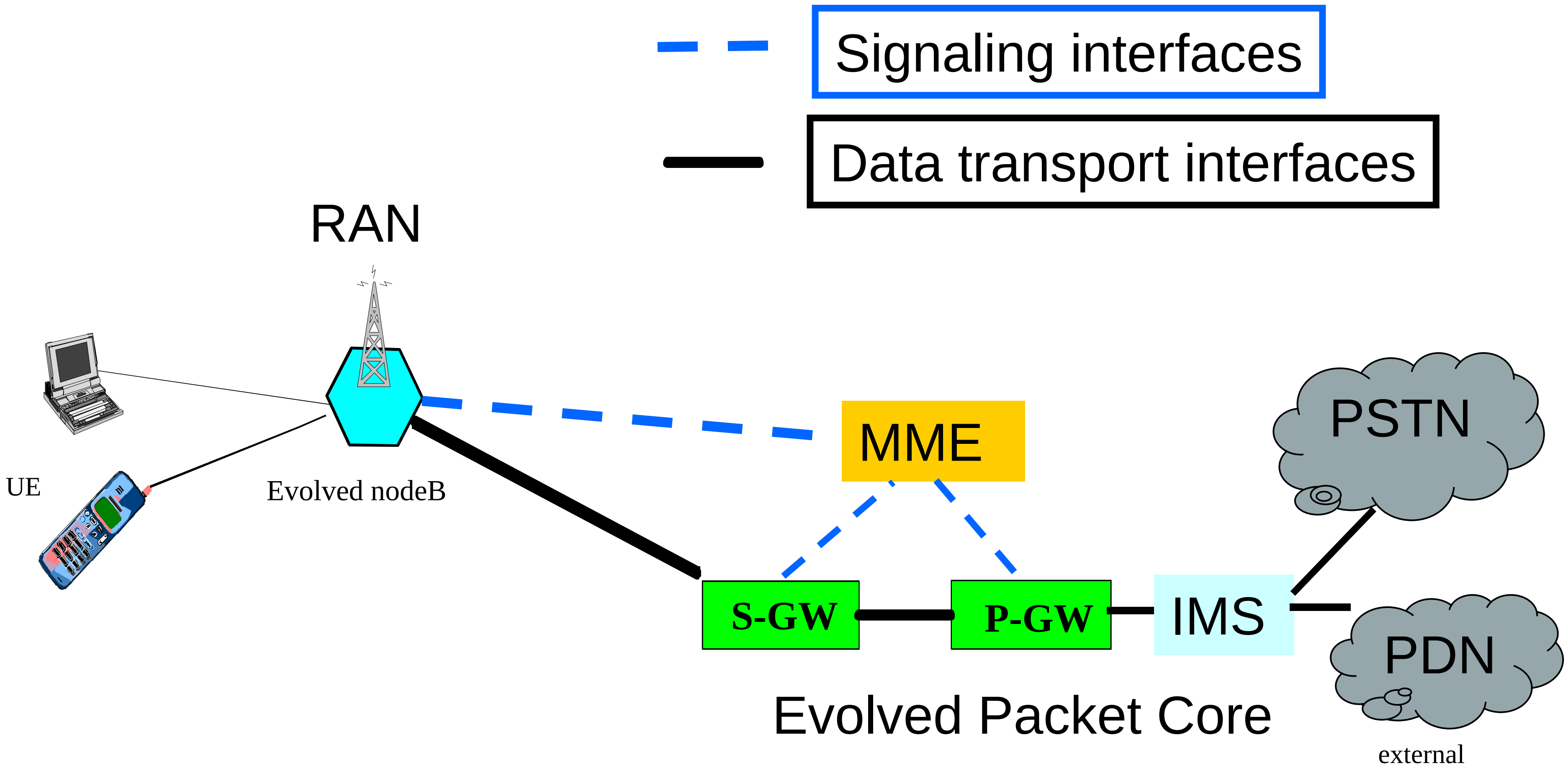
2-4G network structure



Evolution of Network Architecture

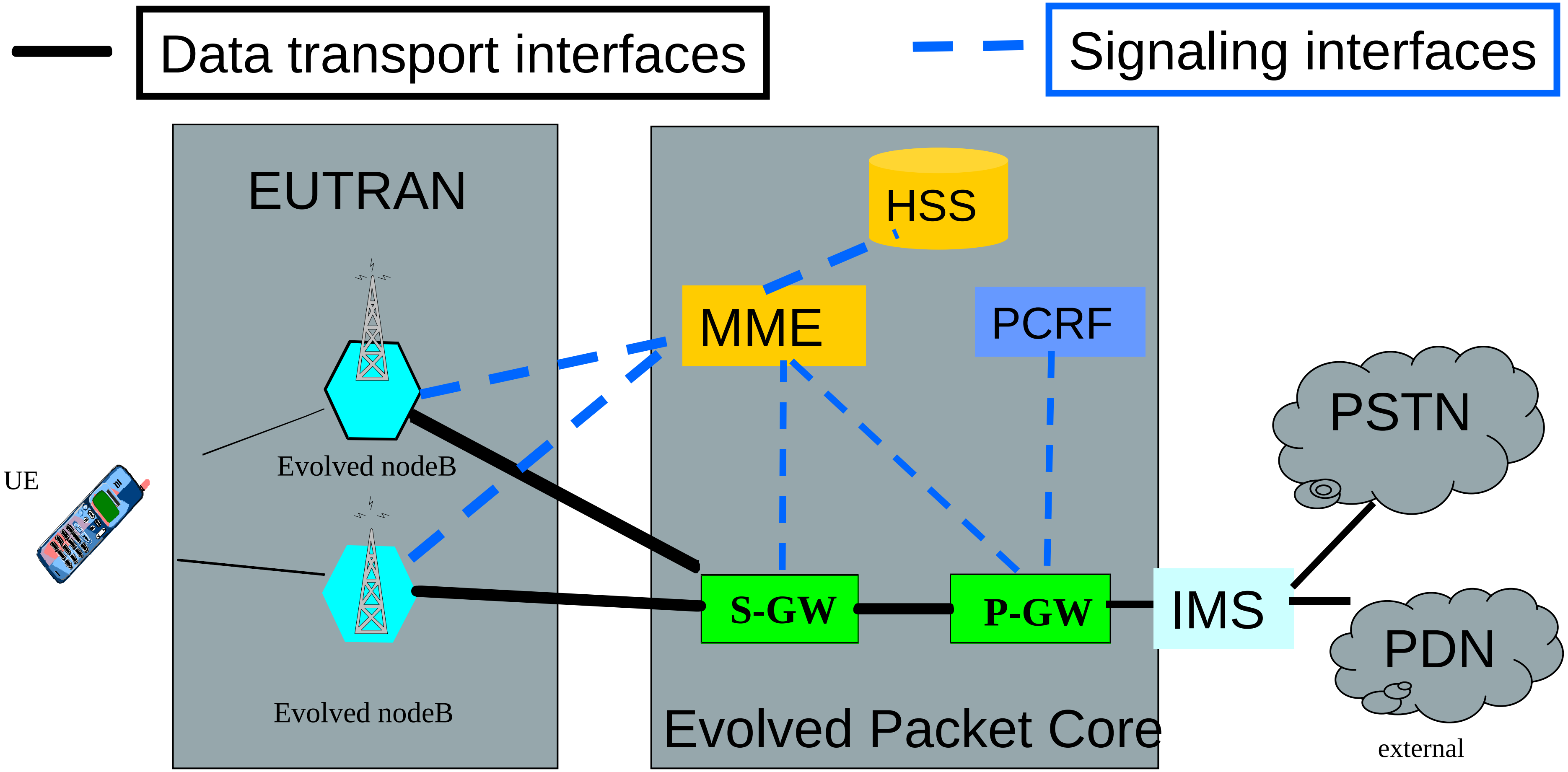


3 GPP System Architecture Evolution



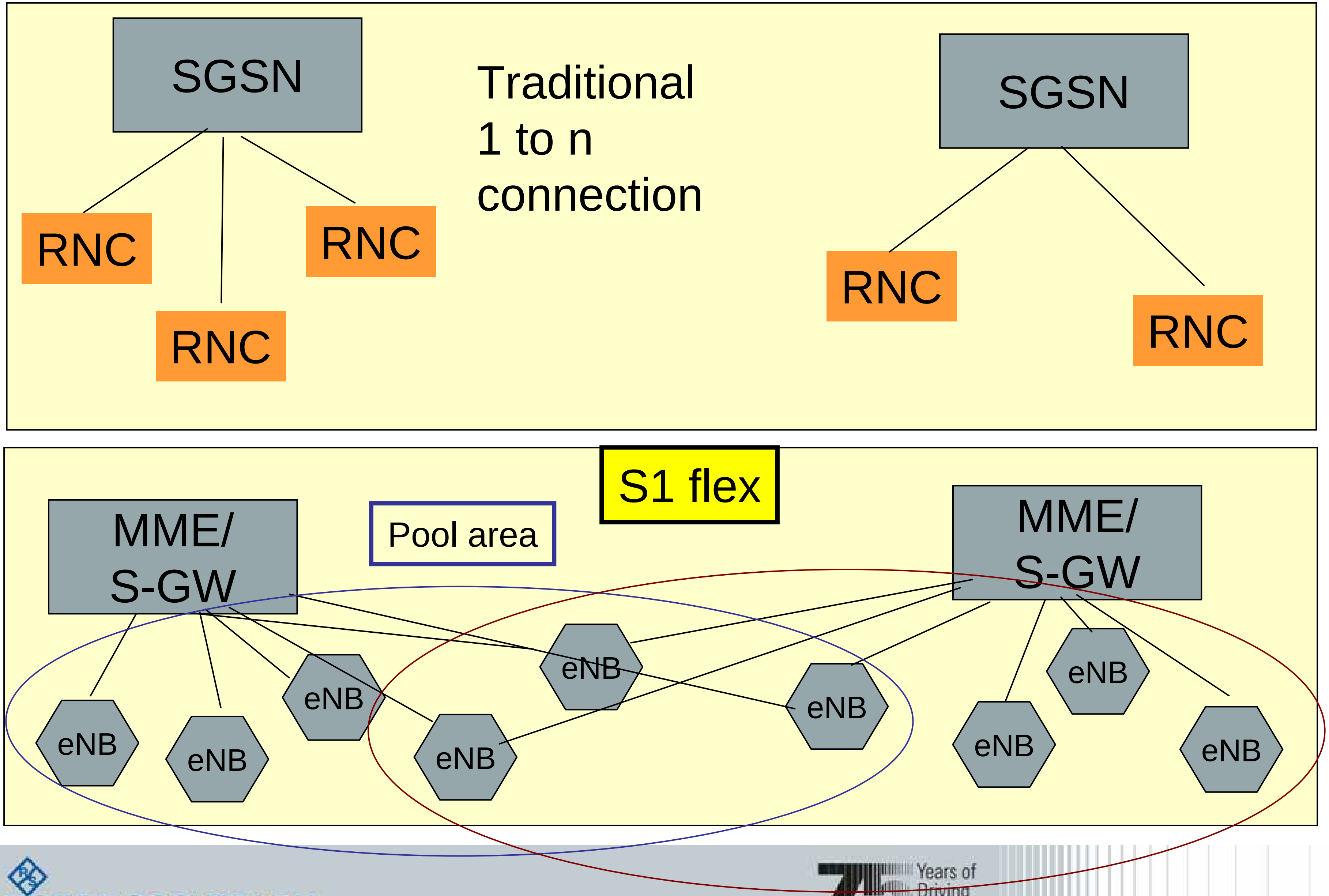
All interfaces are packet switched

EPS, Evolved Packet System - components

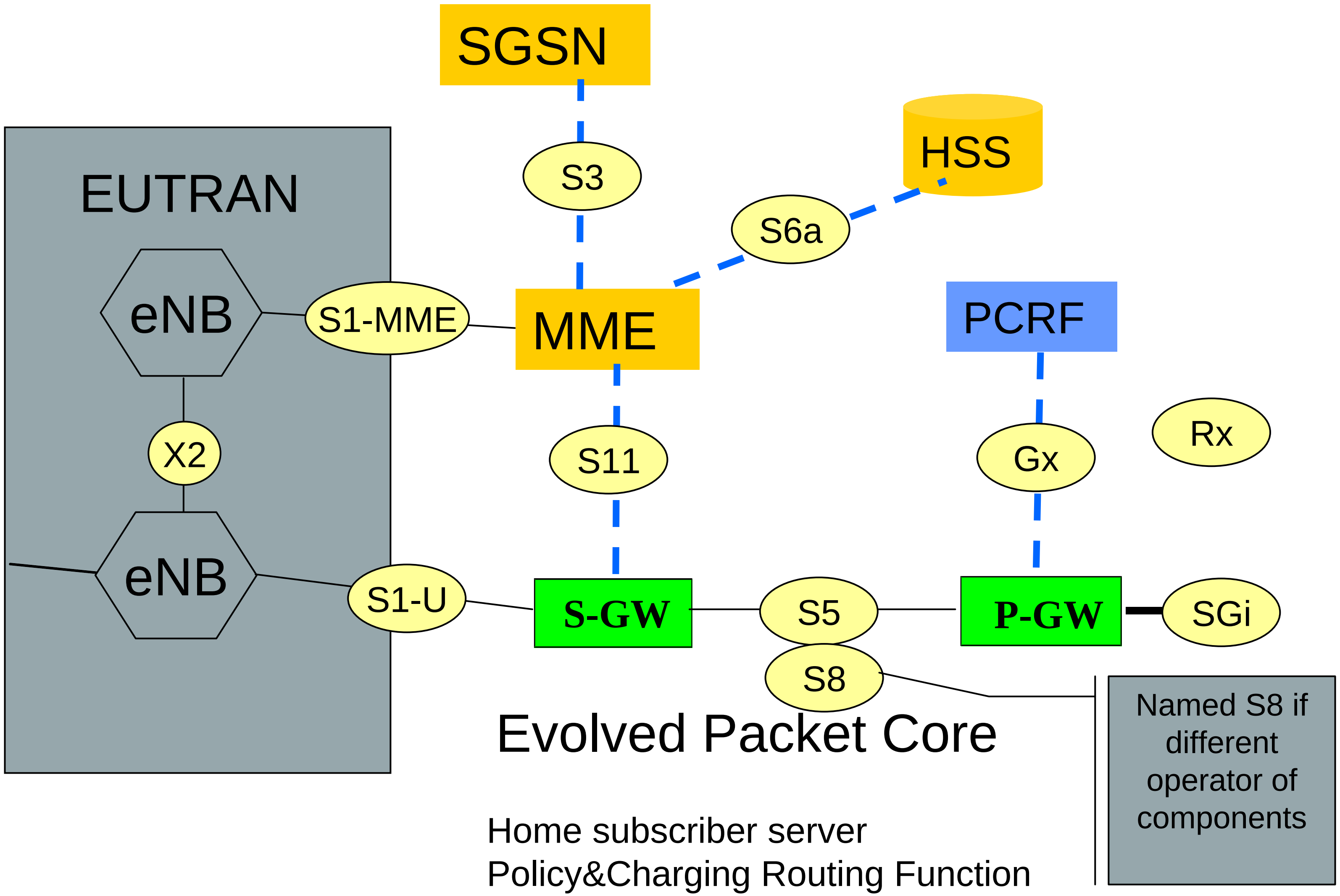


Home subscriber server
Policy&Charging Routing Function
Mobility Management Entitiy

S1 flex versus traditional access to core

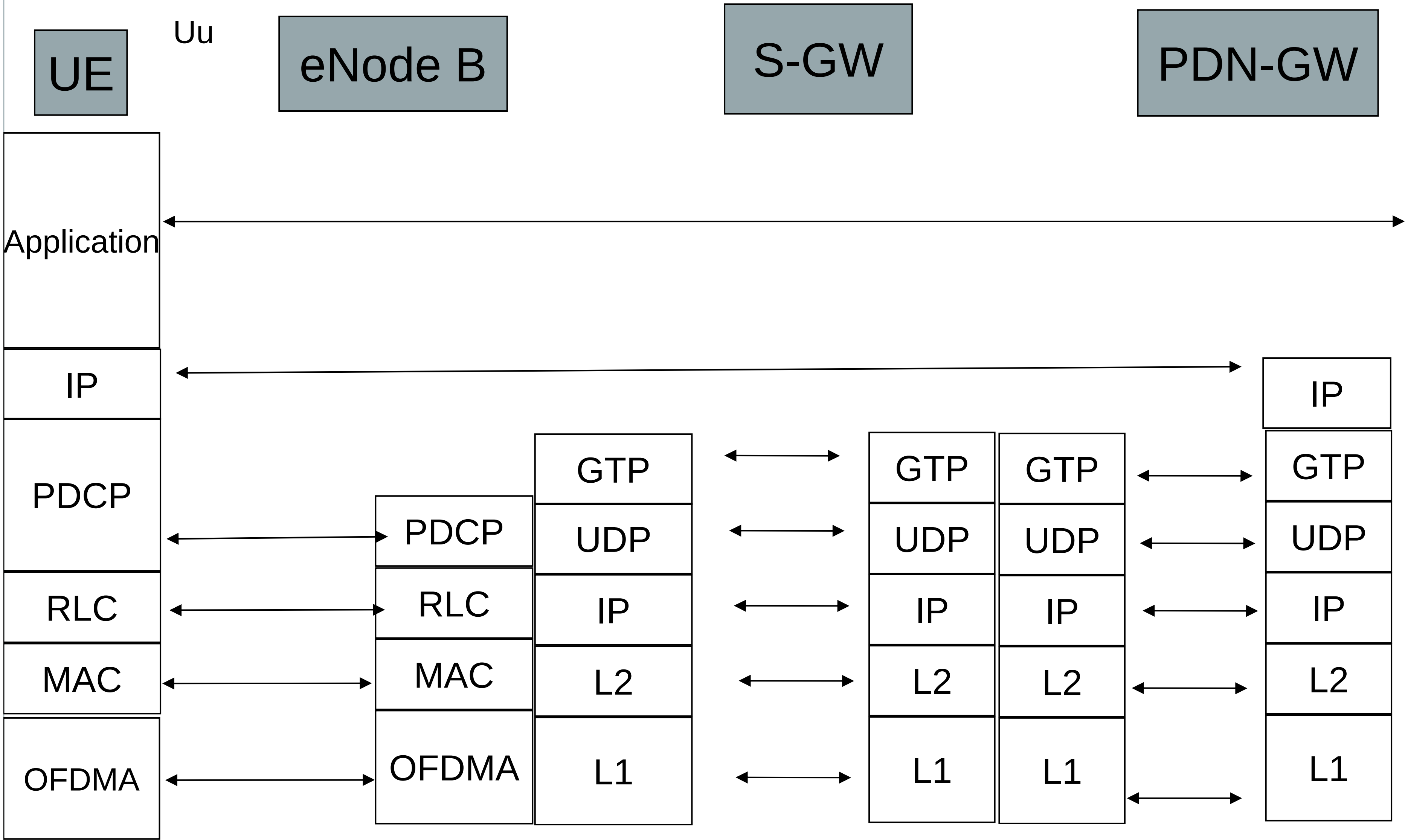


EPS - Interfaces

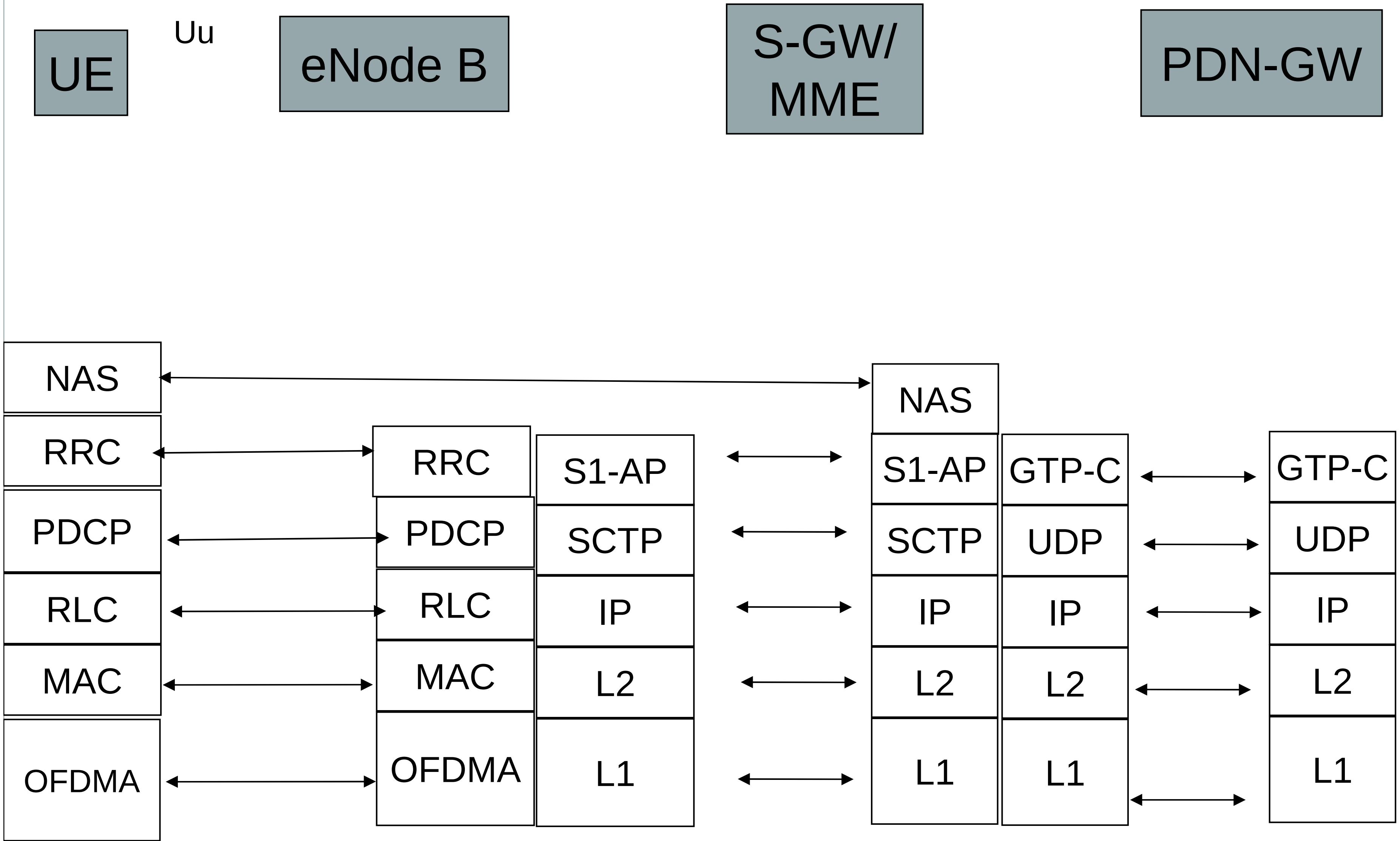


Home subscriber server
Policy&Charging Routing Function
Mobility Management Entitiy

User plane between UE and PDN-GW

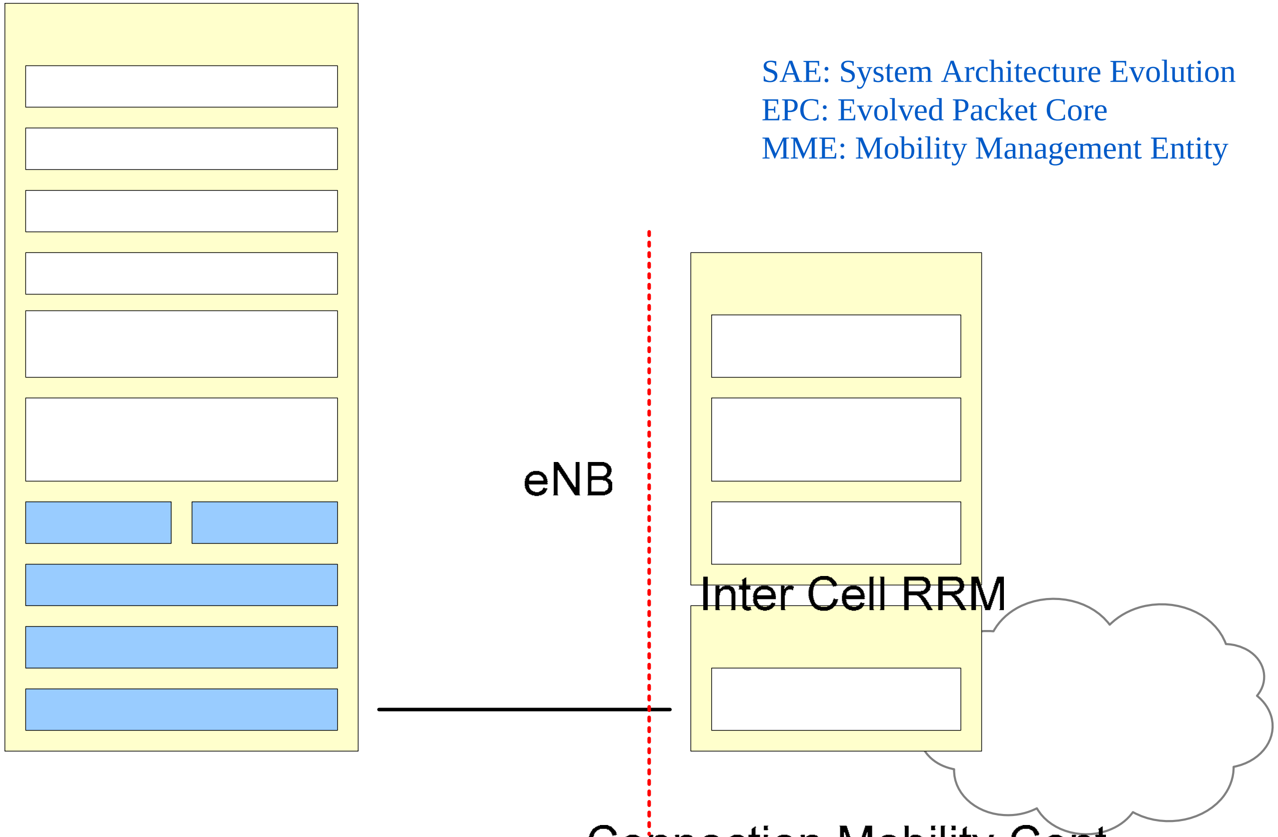


Control plane between UE and PDN-GW



LTE Protocol Architecture
New network elements and functional split

SAE: System Architecture Evolution
EPC: Evolved Packet Core
MME: Mobility Management Entity



LTE Protocol Architecture
New network elements and functional split

eNB functions:

- RRM, Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Scheduling for uplink and downlink
- IP header compression and encryption of user data stream
- Selection of an MME at UE attachment
- Routing of user plane data towards SAE Gateway
- Scheduling and transmissino of paging messages originated from MME
- Scheduling and transmission of broadcast informationoriginated from MME or O&M
- Measurement and measurement reporting configuration

MME functions:

- Distribution of paging messages to eNBs
  - Security Control
- Idle state mobility control
- EPS bearer ccontrol
- Ciphering and integrity protection of NAS Signalling
- Roaming support
- S-GW & PDN-GW selection

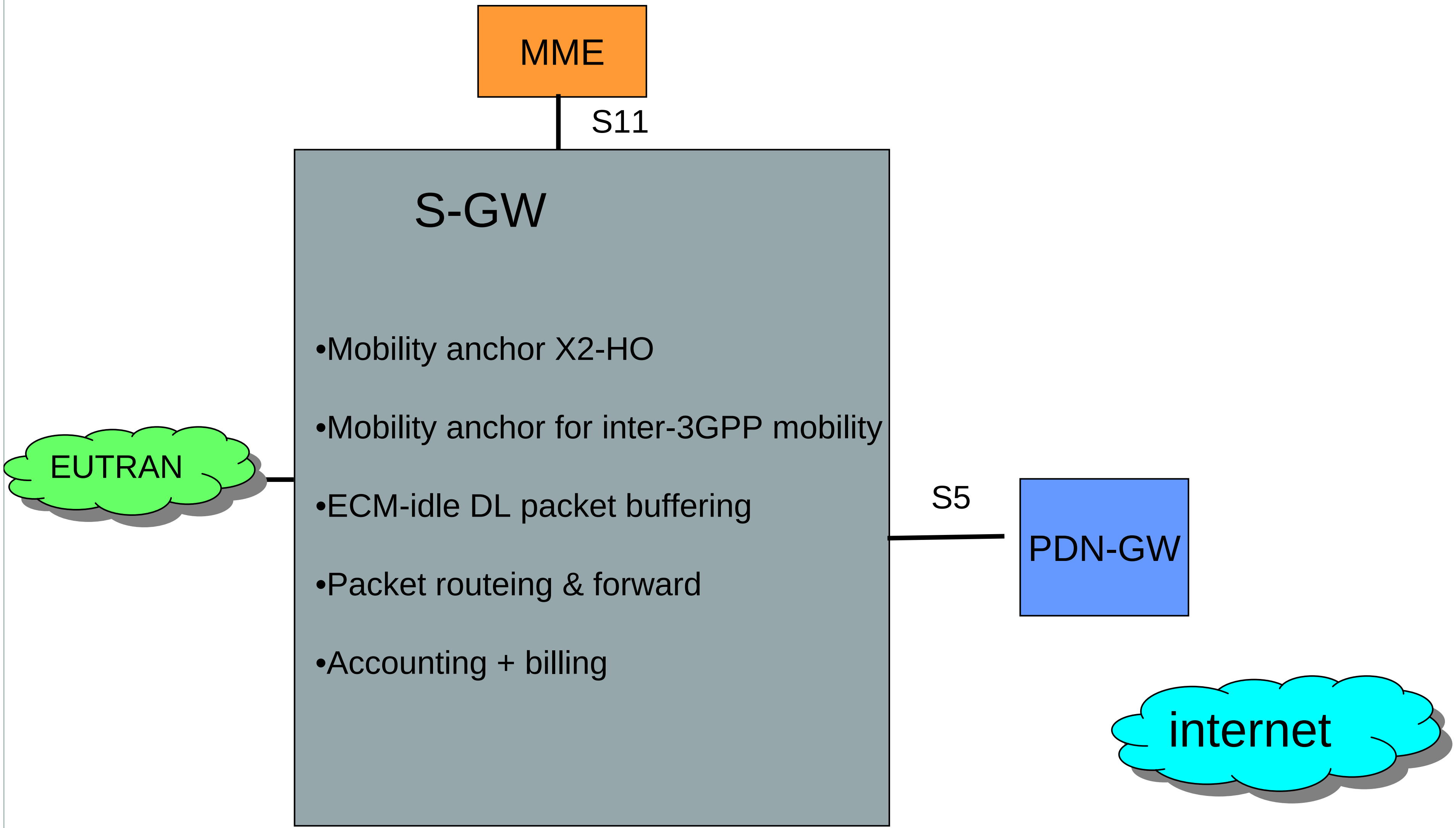
SAE Gateway:

- Termination of user plane packets for paging reasons
- Switching of user plane for support of UE mobility

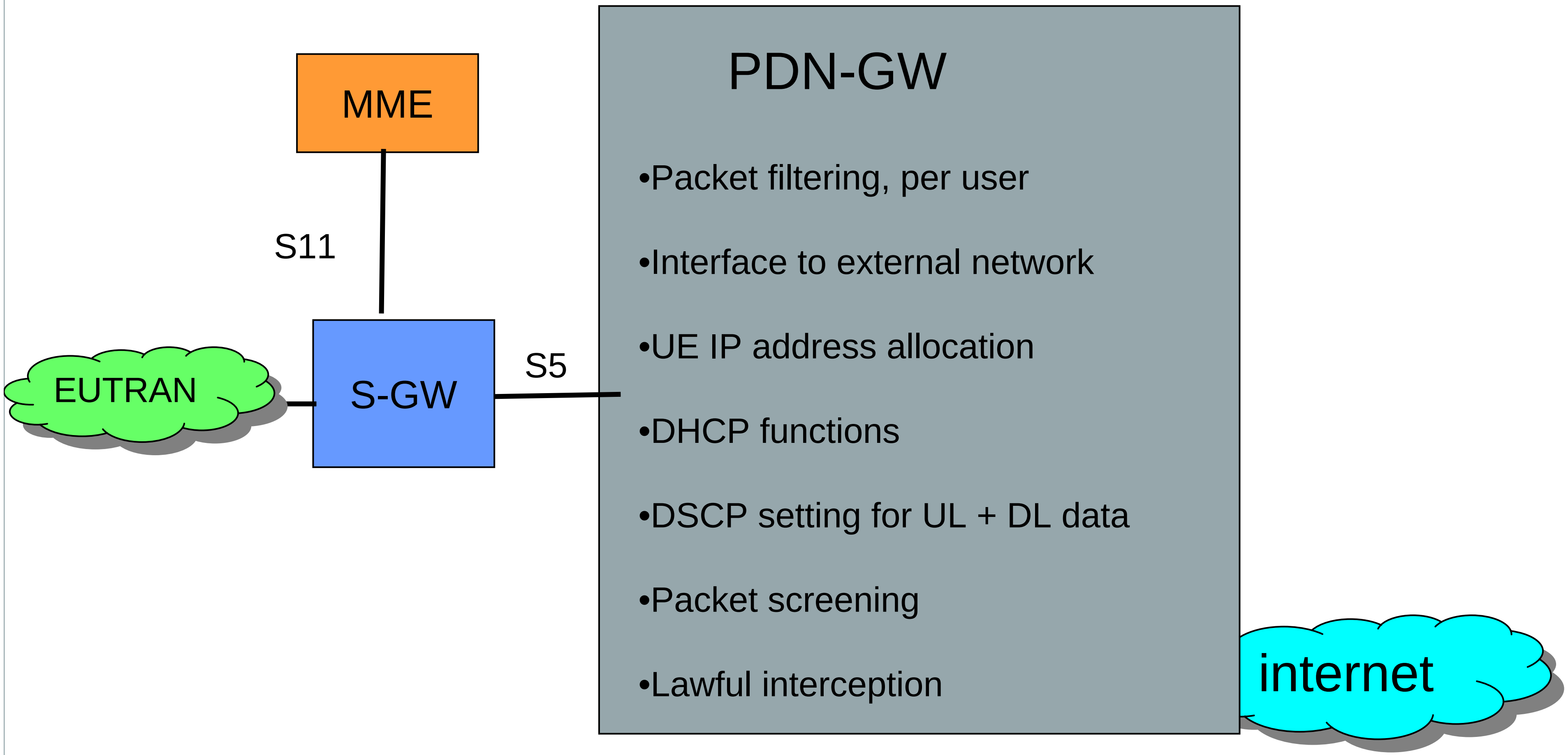
MME – Mobility Management Entity

- **NAS signaling**
- **Inter Core Network signaling for mobility between 3GPP access networks, i.e. via S3 interface contact SGSN**
- **UE reachability in ECM-IDLE state (control and execute paging)**
- **Tracking Area list management**
- **PDN Gateway and Serving GW selection**
- **MME selection for handovers with MME change**
- **SGSN selection for handovers to 2G or 3G access network**
- **Roaming support (contact HLR via S6a interface)**
- **Bearer management functions, establish dedicated bearer on S11**
- **Lawful interception of signaling traffic**

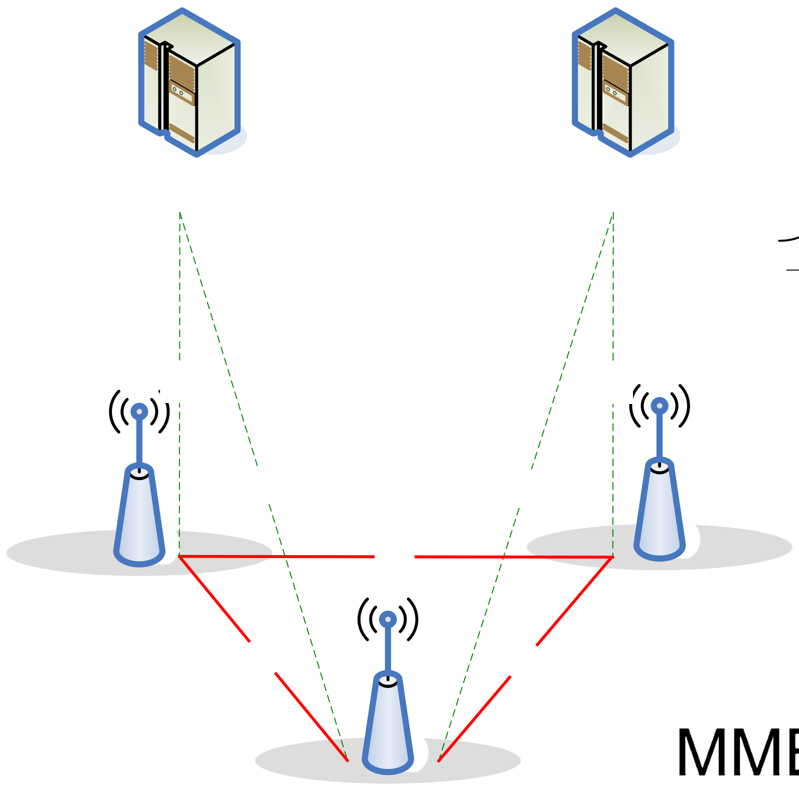
Serving Gateway, S-GW



PDN Gateway, PDN-GW



LTE Protocol Architecture
New network elements and functional split



Evolved Packet Core

MME/SAE Gateway

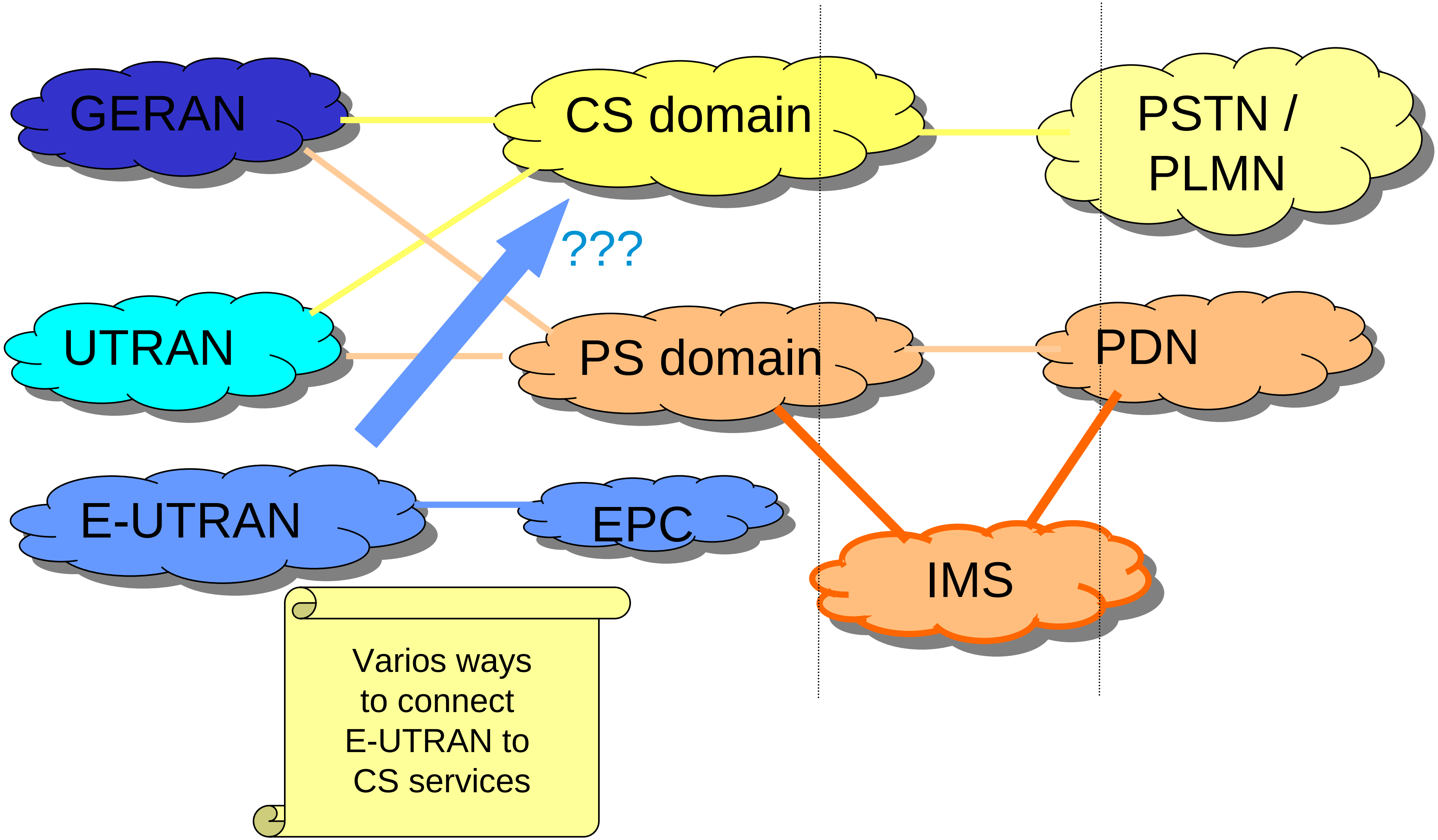
MME

S1

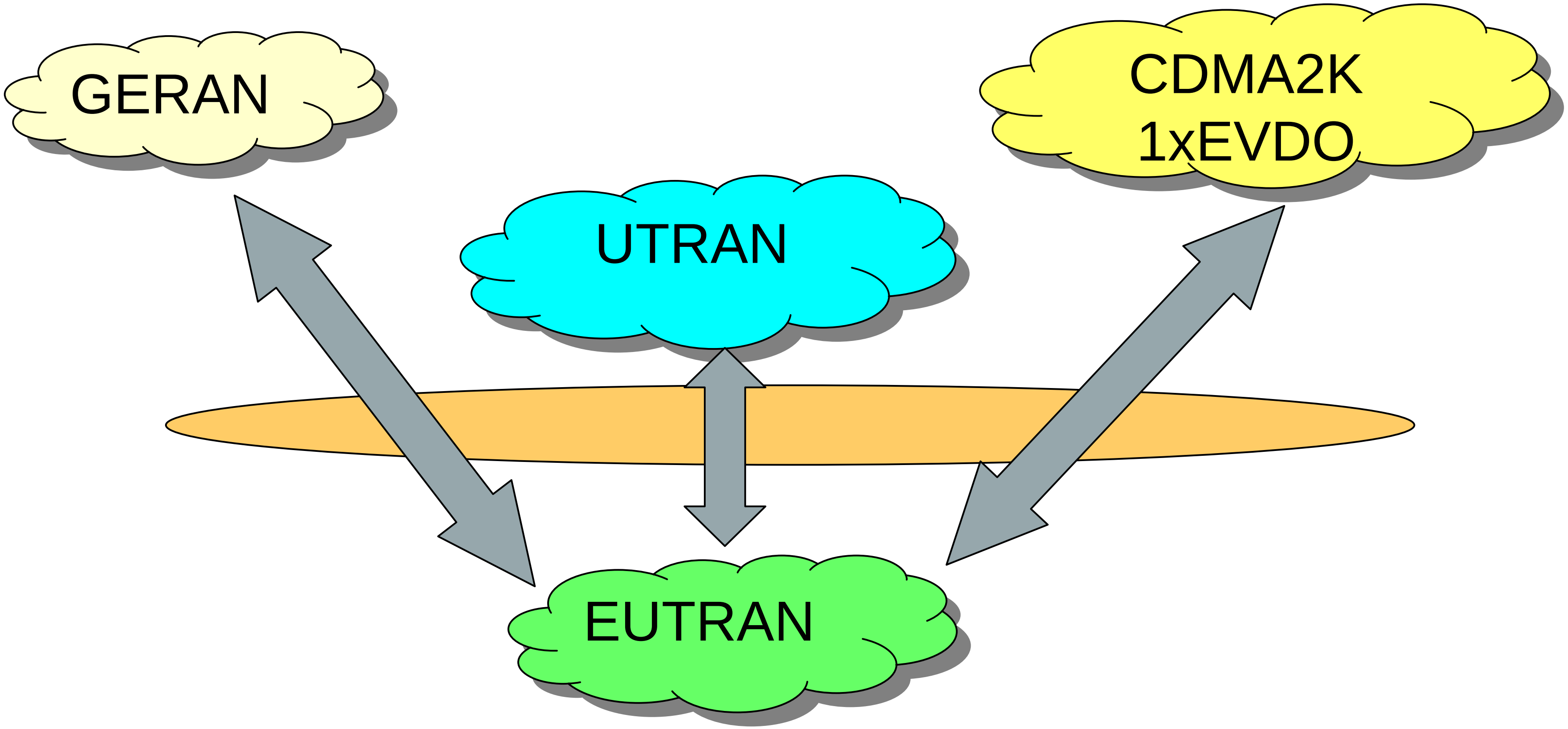
X2 for support of handover

EPC = Evolved Packet Core
MME = Mobility Management Entity
SAE = System Architecture Evolution

CS Service integration into LTE/SAE



Radio Access Technologies today



LTE coverage is not fully up from day one
-> interworking with legacy networks is essential!!!

Background for IMS and relation to LTE?

- **LTE has been designed as a fully packet-orientated, “all-IP”-based, multi-service system with a flat network architecture,**
  - Technical challenges offering circuit-switched services (Voice, SMS) via LTE

- **3GPP has defined IMS as long-term solution providing circuit-switched services, for the short- / mid-term there is no industry-wide consensus, but different approaches,**
  - Short-/mid-term: Circuit-switched fallback (CS fallback),
    - SMS. “SMS over SG”, means SMS via Non-Access Stratum (NAS) signaling,
    - Voice. Fallback to 3G or 2G technology to take the call,
  - VOLGA – Voice over LTE Generic Access
    - Call setup time increases while using CS fallback,
  - OneVoice Initiative formed to push for Voice over LTE (VoLTE) based on IMS.

How to connect E-UTRAN to CS services?

- **Connection via IMS: 3GPP and OneVoice initiative**

First a big mess,
Now it seems to be OneVoice

- ~~***Voice over LTE Generic Access – VoLGA Forum – interim solution***~~
- **CS Fallback CSFB for voice calls to 2G or 3G services – preferred interim solution**
- ***Evolved MSC, eMSC – CS Services via EPS – network operator proposal, interim solution***
- **SRVCC – Single Radio Voice Call Continuity**
- **SV-LTE – simultaneous 1x CDMA2000 and LTE**

Voice calls in LTE

- **There is one common solution: Voice over IMS**
  - -> also named Voice over LTE VoLTE or OneVoice initiative

But….

What if IMS is not available at first rollout?

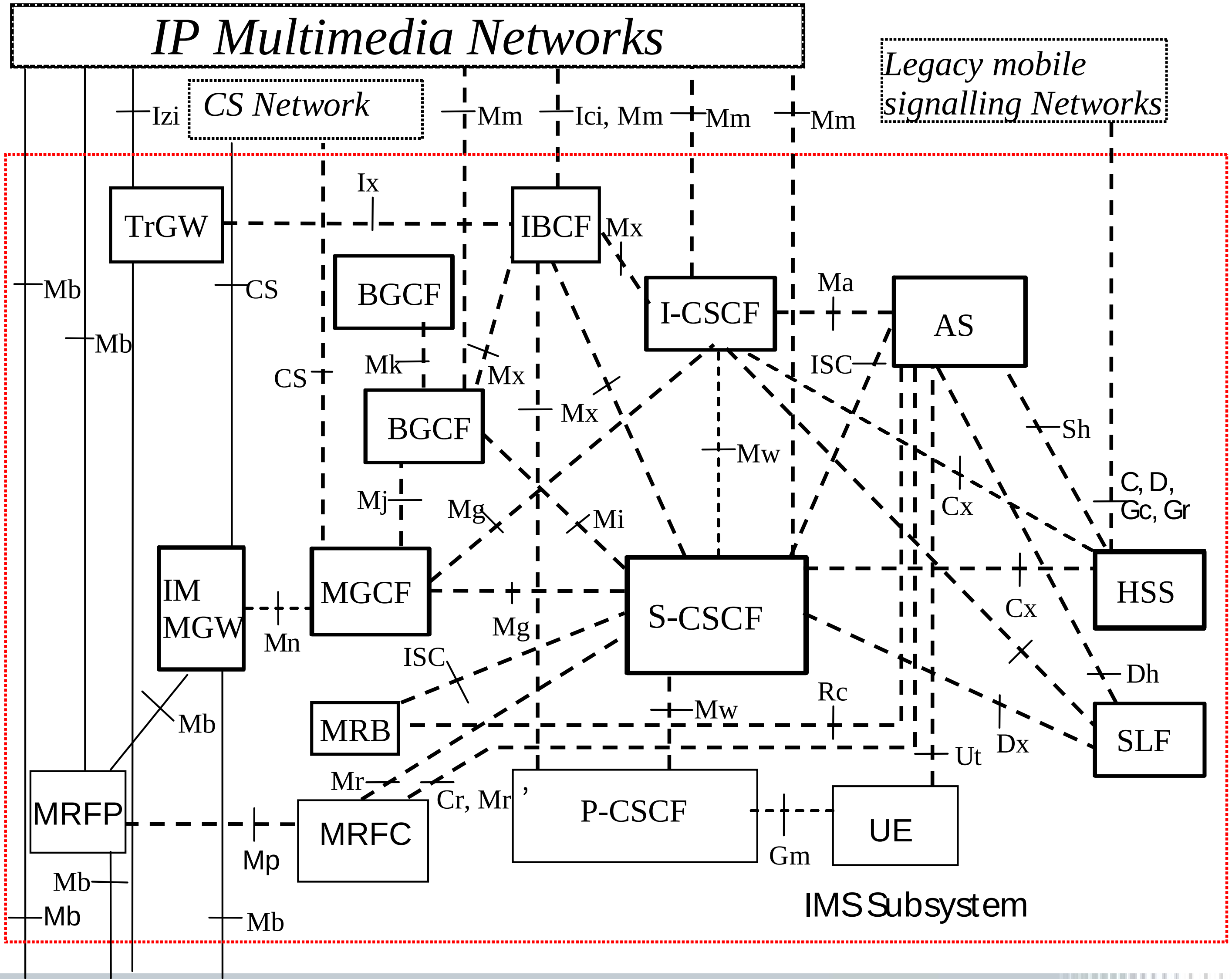
-> interim solution called Circuit Switched Fallback CSFB = handover to 2G/3G

-> or Simultaneous Voice on 1XRTT and LTE, SV-LTE = dual receiver

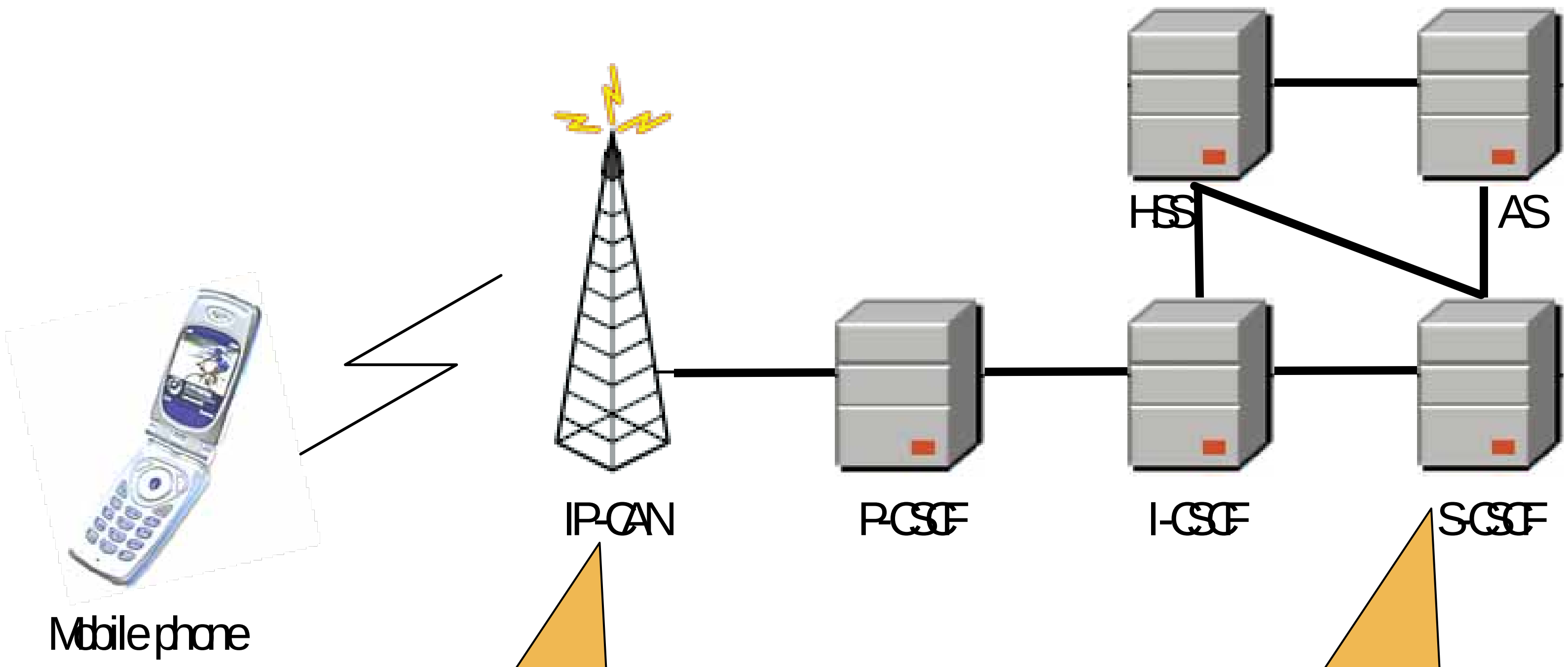
What is if LTE has no full coverage?

-> interworking with existing technologies, Single Radio Voice Call Continuits, SRVCC

Voice over IMS: IMS network structure



Voice over IMS: IMS network structure



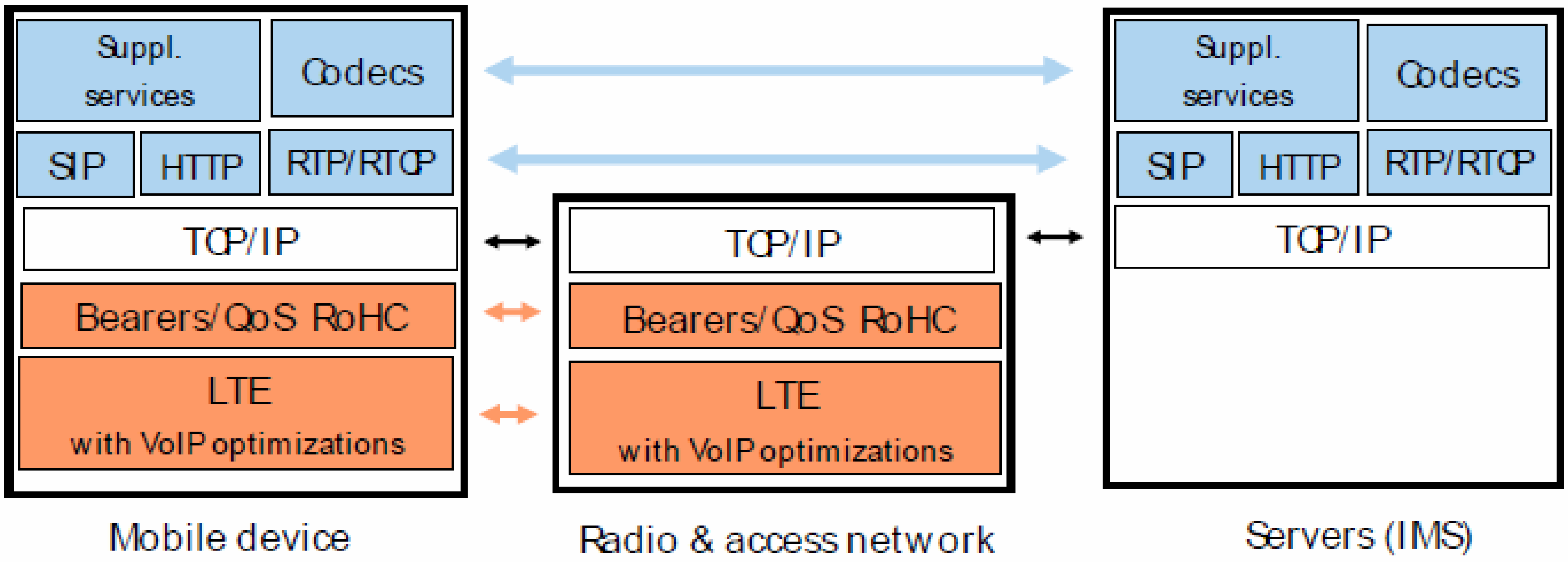
IP connectivity access network = EUTRAN + MME

Serving CSCF will handle IP traffic flow

Voice over IMS: IMS protocol profile

Adaptive Multirate Codecs are used In VoIP over IMS

Codec mode	Source codec bit-rate
AMR_12.20	12,20 kbit/s (GSM EFR)
AMR_10.20	10,20 kbit/s
AMR_7.95	7,95 kbit/s
AMR_7.40	7,40 kbit/s (IS-641)
AMR_6.70	6,70 kbit/s (PDC-EFR)
AMR_5.90	5,90 kbit/s
AMR_5.15	5,15 kbit/s
AMR_4.75	4,75 kbit/s
AMR_SID	1,80 kbit/s (see note 1)



QoS class identifiers QCI

QCI	Resource Type	Priority	Packet Delay Budget	Packet Error Loss Rate	Example Services
1	GBR	2	100 ms	10^{-2}	Conversational Voice
2		4	150 ms	10^{-3}	Conversational Video (Live Streaming)
3		3	50 ms	10^{-3}	Real Time Gaming
4		5	300 ms	10^{-6}	Non-Conversational Video (Buffered Streaming)
5	Non-GBR	1	100 ms	10^{-6}	IMS Signalling
6		6	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		7	100 ms	10^{-3}	Voice, Video (Live Streaming), Interactive Gaming
8		8	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		9			

Voice over LTE – protocol profiles

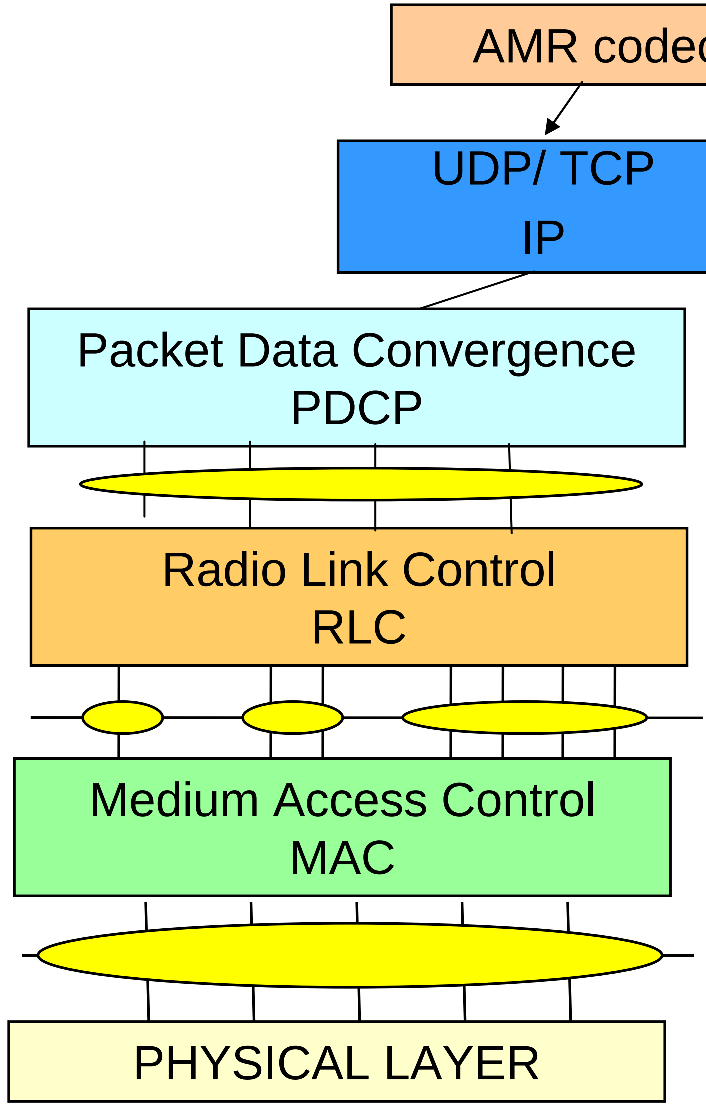
Optimize transmission of
Voice by configuring
Lower layers

Use robust header compression or IP
Short PDCP header is used

Use RLC in UM mode
Small sequence number is used

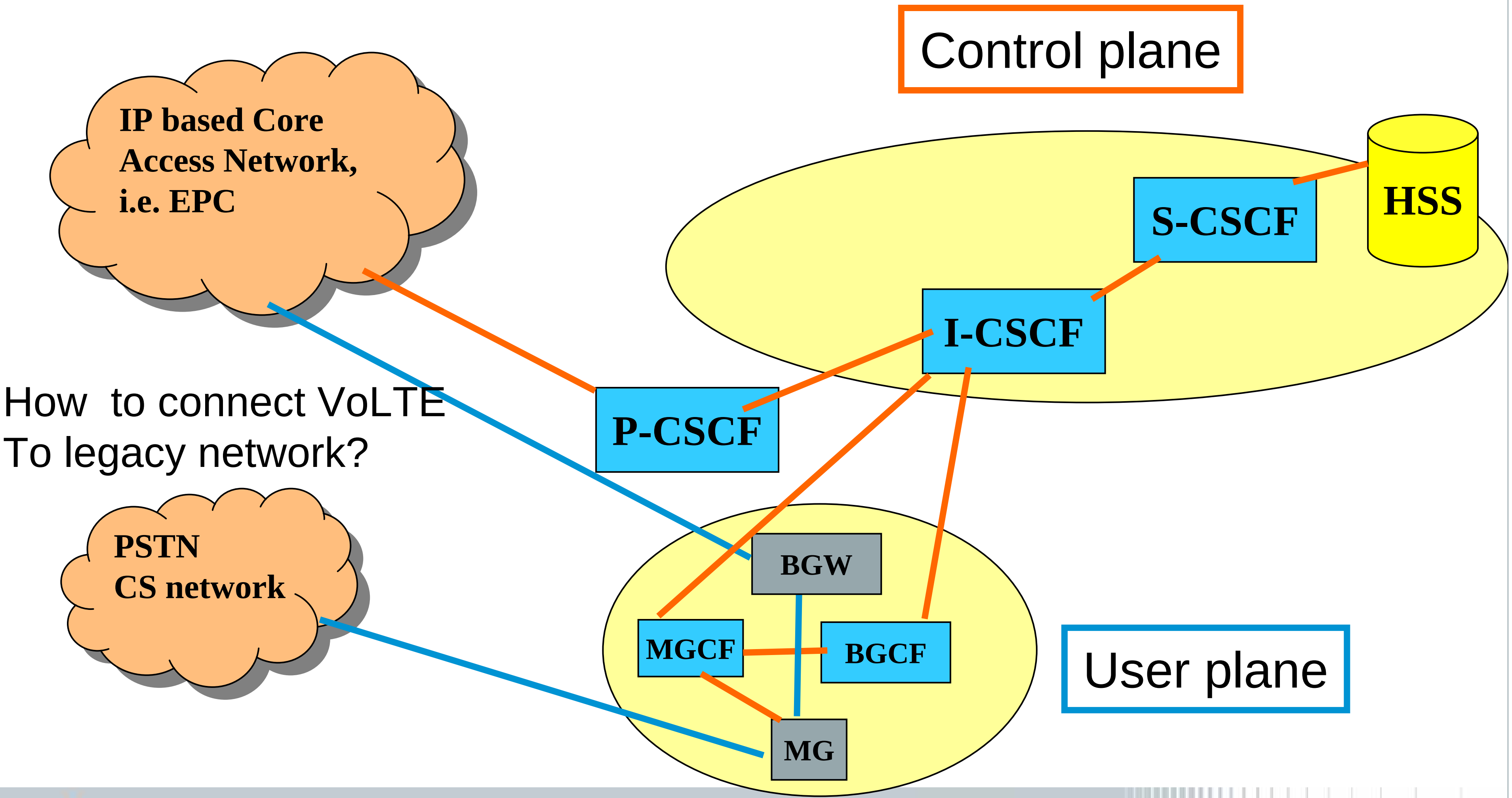
SRB1 and 2 are supported for
DCCH + one AM SRB for SIP signaling

TTI bundling + DRX to reduce PDCCH
Signaling + Semi-persistend scheduling



VoLTE connection to CS via IMS

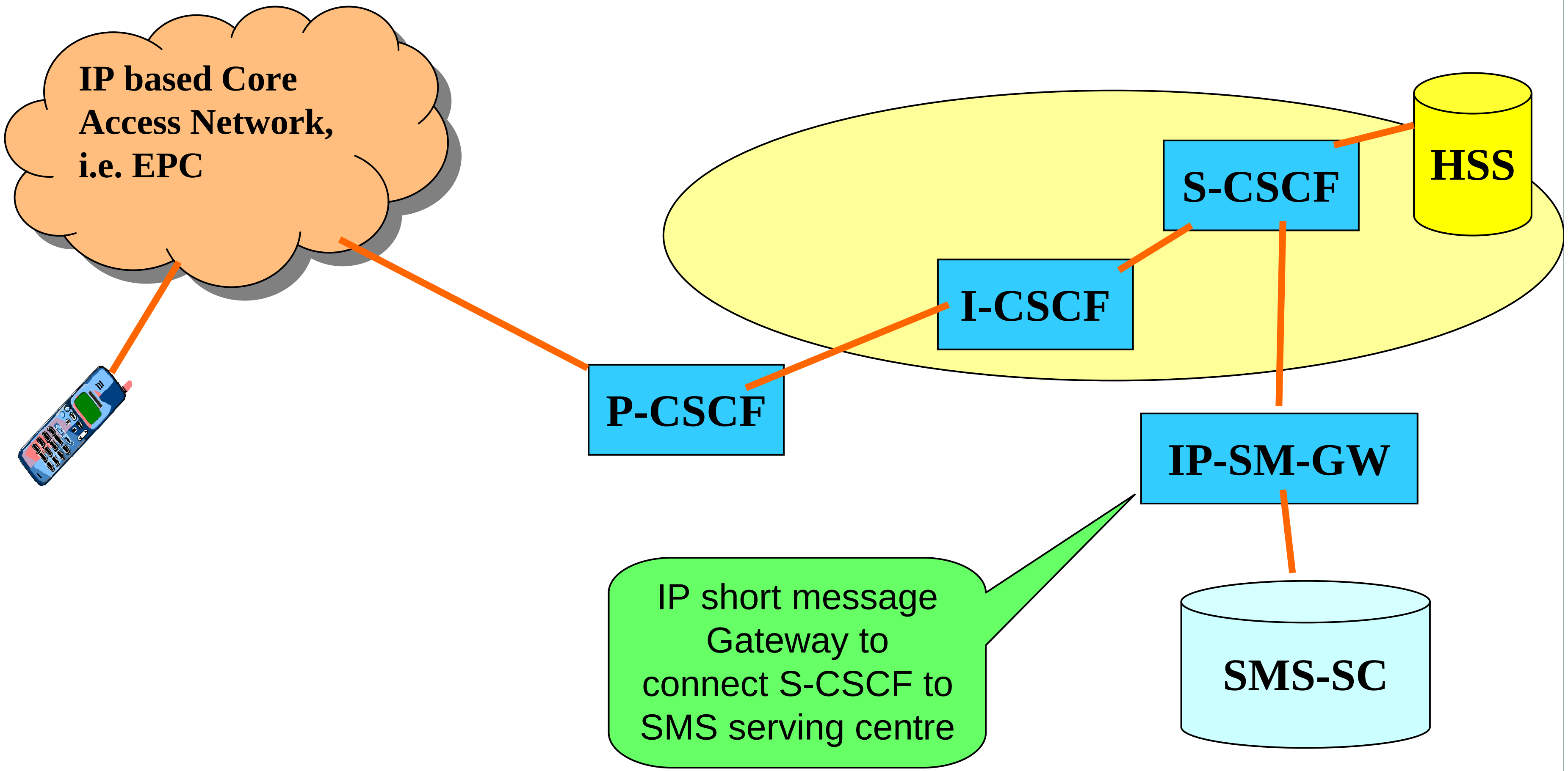
CS Connection via Boarder and Media Gateway of IMS



IMS connection to CS services - arguments

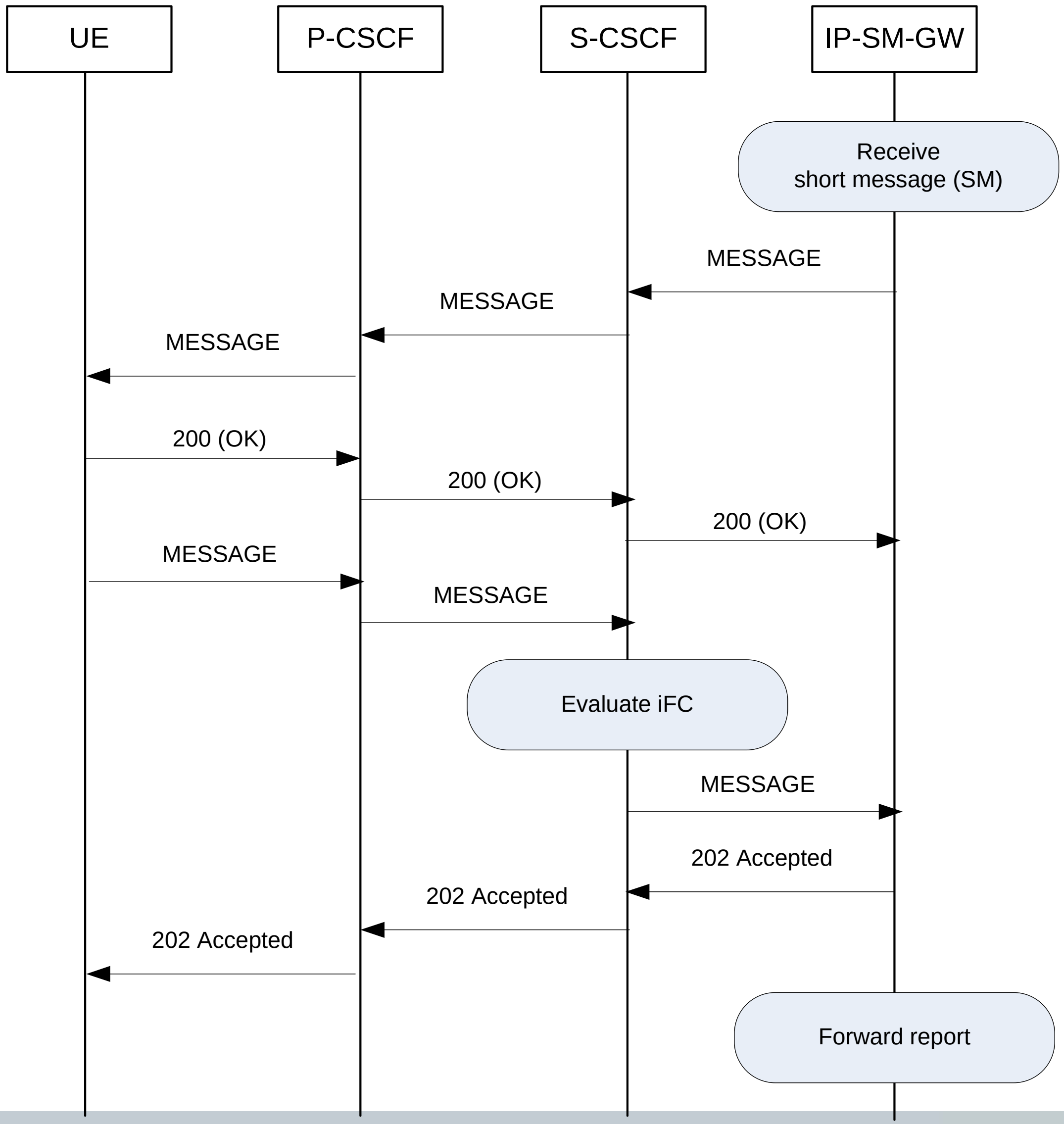
- IMS can provide real end-to-end connection
- IMS defines end-to-end quality of service profiles
- IMS is completely based on Internet Protocol
- Supplementary services can be realized
- Several application servers needed
- Not widely implemented yet – many operators are reluctant
- IMS software client needed on UE side
- What happens under heavy load condition?

SMS over IMS



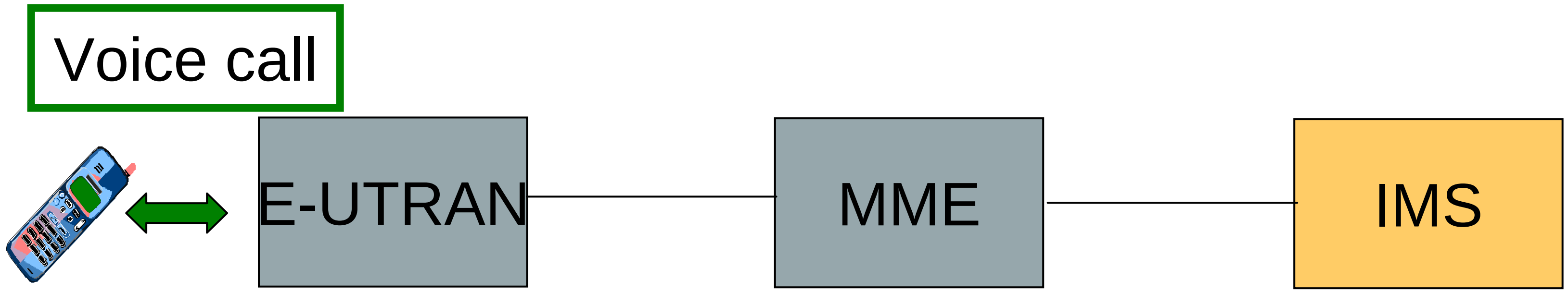
IP based Core Access Network, i.e. EPC
HSS
S-CSCF
I-CSCF
P-CSCF
IP-SM-GW
IP short message Gateway to connect S-CSCF to SMS serving centre
SMS-SC

SMS over IMS



UE
P-CSCF
S-CSCF
IP-SM-GW
Receive
short message (SM)
MESSAGE
MESSAGE
MESSAGE
200 (OK)
200 (OK)
200 (OK)
MESSAGE
MESSAGE
Evaluate iFC
MESSAGE
202 Accepted
202 Accepted
202 Accepted
Forward report

2G or 3G CS fallback

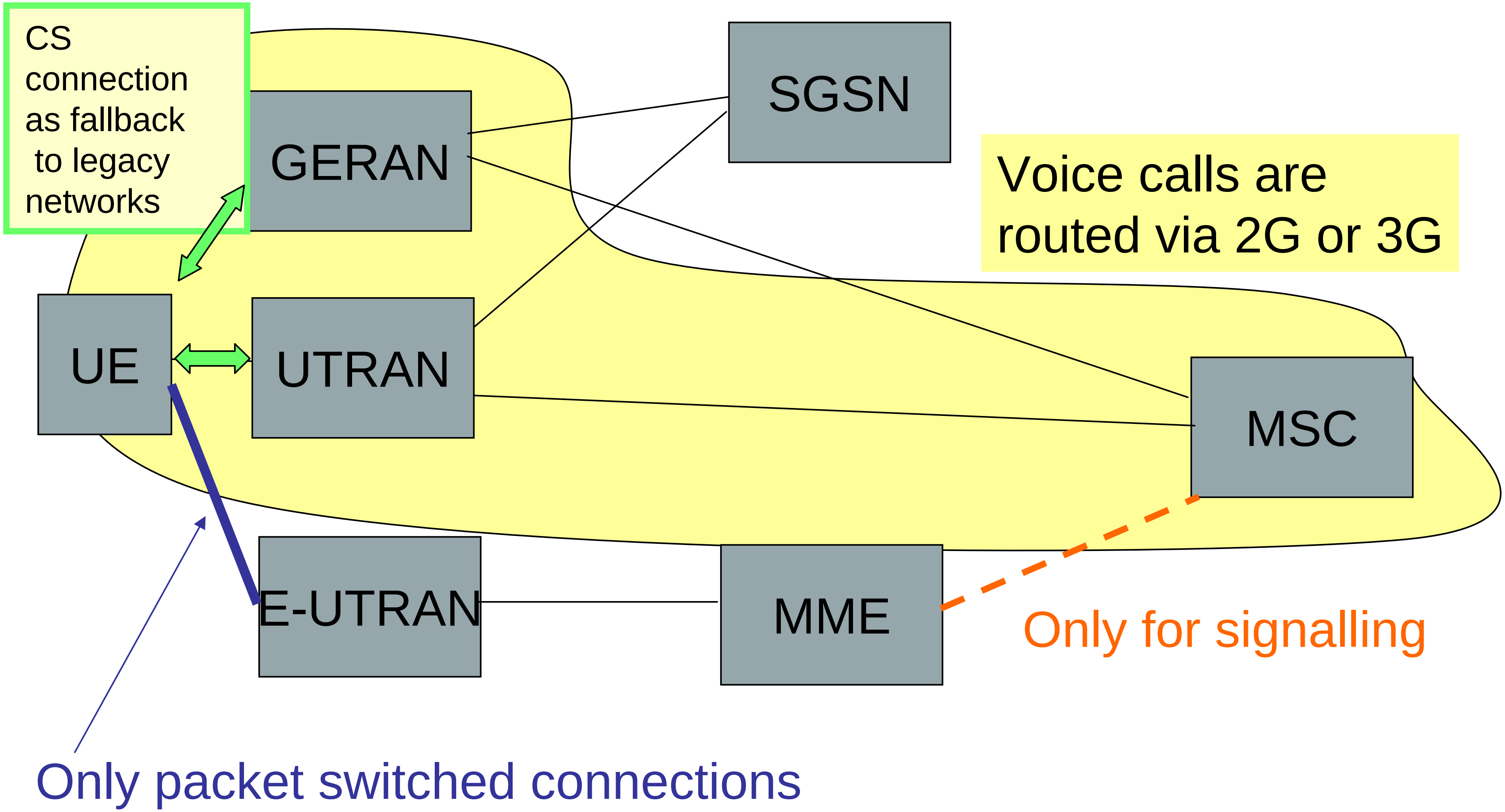


Voice over IMS is the solution,
but IMS is maybe not available in the first network roll-out.

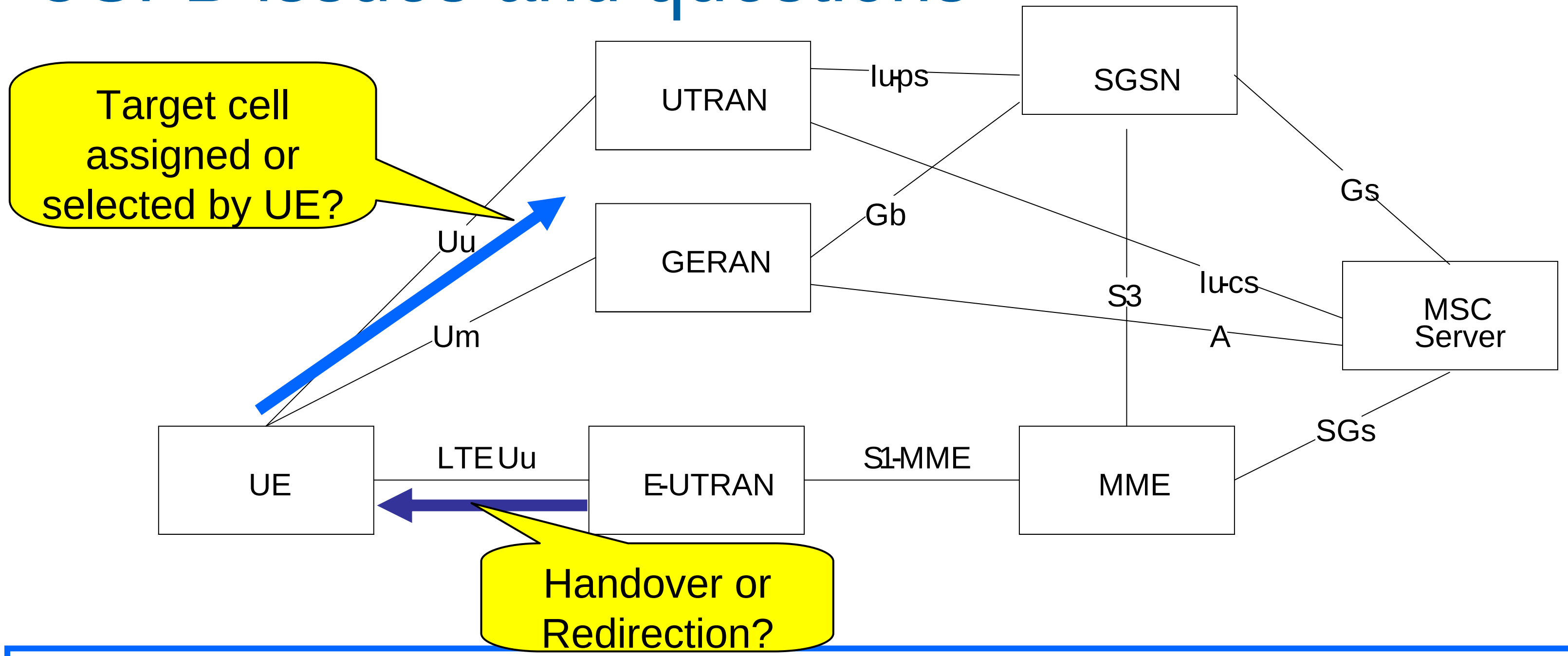
Need for transition solution:

Circuit Switched Fall Back, CSFB move the call to 2G or 3G

2G or 3G CS fallback



CSFB issues and questions



- Is it a handover command or a command to redirect to a new RAN ? i.e. the UE selects the target cell or the EUTRAN commands the target cell
- Is there any information about the target RAN available (SysInfo)?
- Is there a packet data connection PDN active or not?
- Will the PDN be suspended or continued in the target RAN?
- Will the UE re-initiate the PDN or continue?

CS fallback options to UTRAN and GERAN

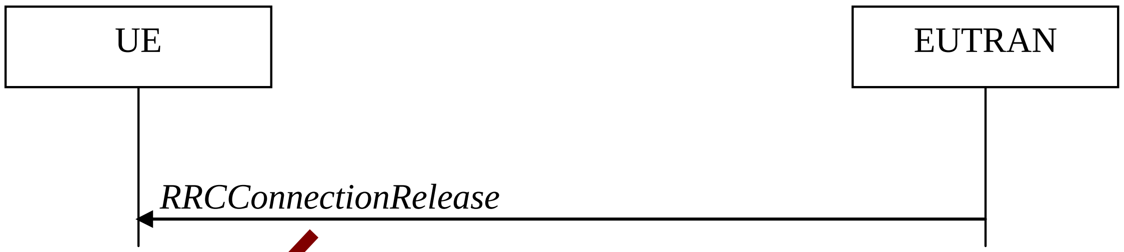
Target RAT	Solutions	Release	UE Capability	FGI Index
CS fallback to UMTS	RRC Connection Release with Redirection without Sys Info	Rel-8	(NOTE 1) Mandatory for UEs supporting CS fallback to UMTS	
	RRC Connection Release with Redirection with Sys Info	Rel-9	(NOTE 1) e-RedirectionUTRA	
	PS handover with DRB(s)	Rel-8	(NOTE 1) Mandatory for UEs supporting CS fallback to UMTS	FGI8, FGI22
CS fallback to GSM	RRC Connection Release with Redirection without Sys Info	Rel-8	(NOTE 2) Mandatory for UEs supporting CS fallback to GSM	
	RRC Connection Release with Redirection with Sys Info	Rel-9	(NOTE 2) e-RedirectionGERAN	
	Cell change order without NACC	Rel-8	(NOTE 2) Mandatory for UEs supporting CS fallback to GSM	FGI10
	Cell change order with NACC	Rel-8	(NOTE 2) Mandatory for UEs supporting CS fallback to GSM	FGI10
	PS handover	Rel-8	(NOTE 2) interRAT-PS-HO-ToGERAN	

NOTE 1: All CS fallback to UMTS capable UE shall indicate that it supports UTRA FDD or TDD and supported band list in the UE capability.

NOTE 2: All CS fallback to GSM capable UE shall indicate that it supports GERAN and supported band list in the UE capability.

Feature group index, UE indicates CSFB support

CS fallback – initiation by RRC layer



Contains this information element when Falling back to legacy networks

```
RedirectedCarrierInfo ::=                          CHOICE {
        eutra                          ARFCN-ValueEUTRA,
        geran                          CarrierFreqsGERAN,
        utra-FDD                       ARFCN-ValueUTRA,
        utra-TDD                       ARFCN-ValueUTRA,
        cdma2000-HRPD                  CarrierFreqCDMA2000,
        cdma2000-1xRTT                 CarrierFreqCDMA2000,
        ...
}
```

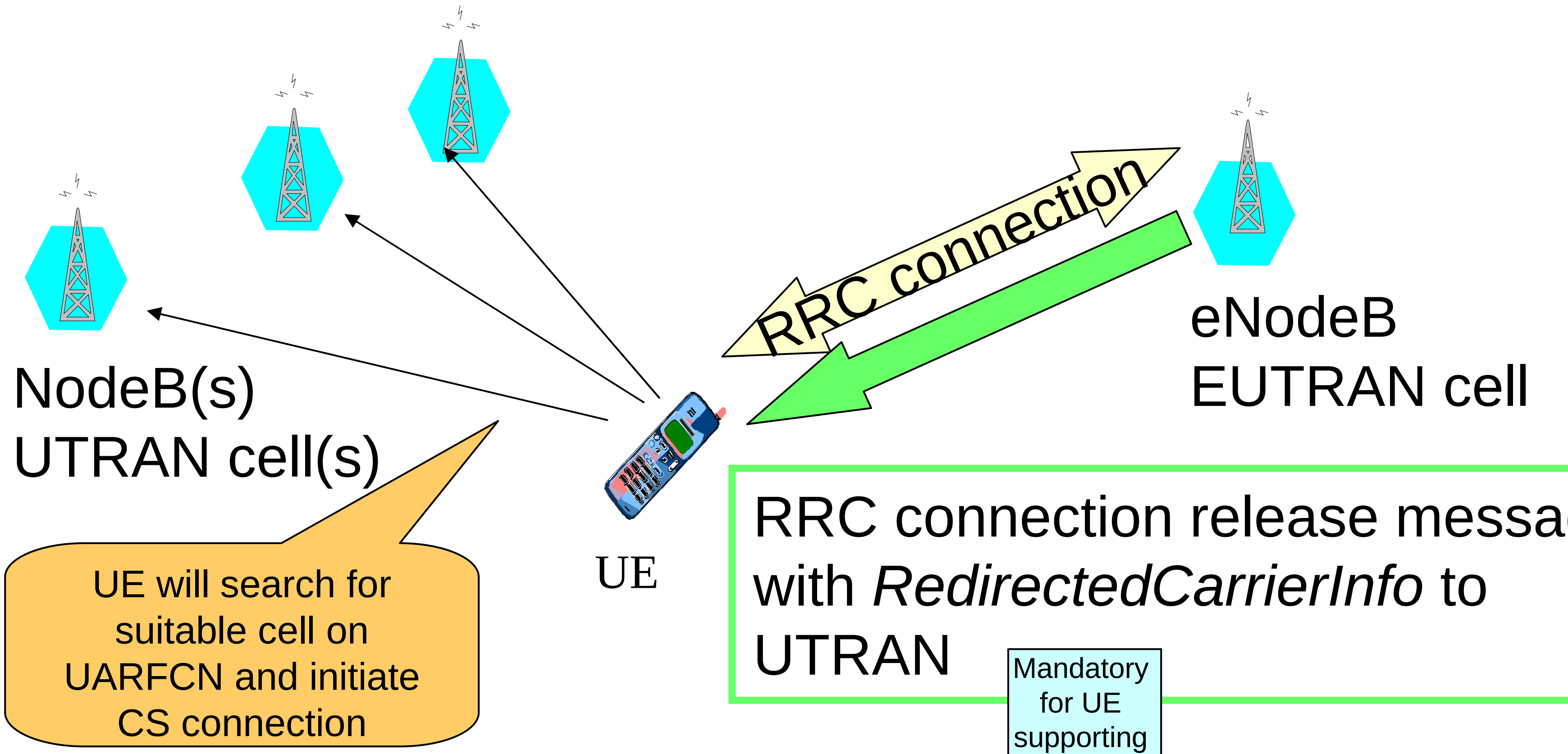
CS fallback to UTRAN

- **RRC connection release with redirection = Rel.6 and Rel.8, i.e. the UE selects a target cell**

- **Deferred measurement control reading = Rel.7, the UE defers the reading of SIB11, 11a and 12 -> handover is faster**

- **RRC connection release with redirection now also includes system information = Rel.9, the redirection contains system information**

CS fallback to UMTS

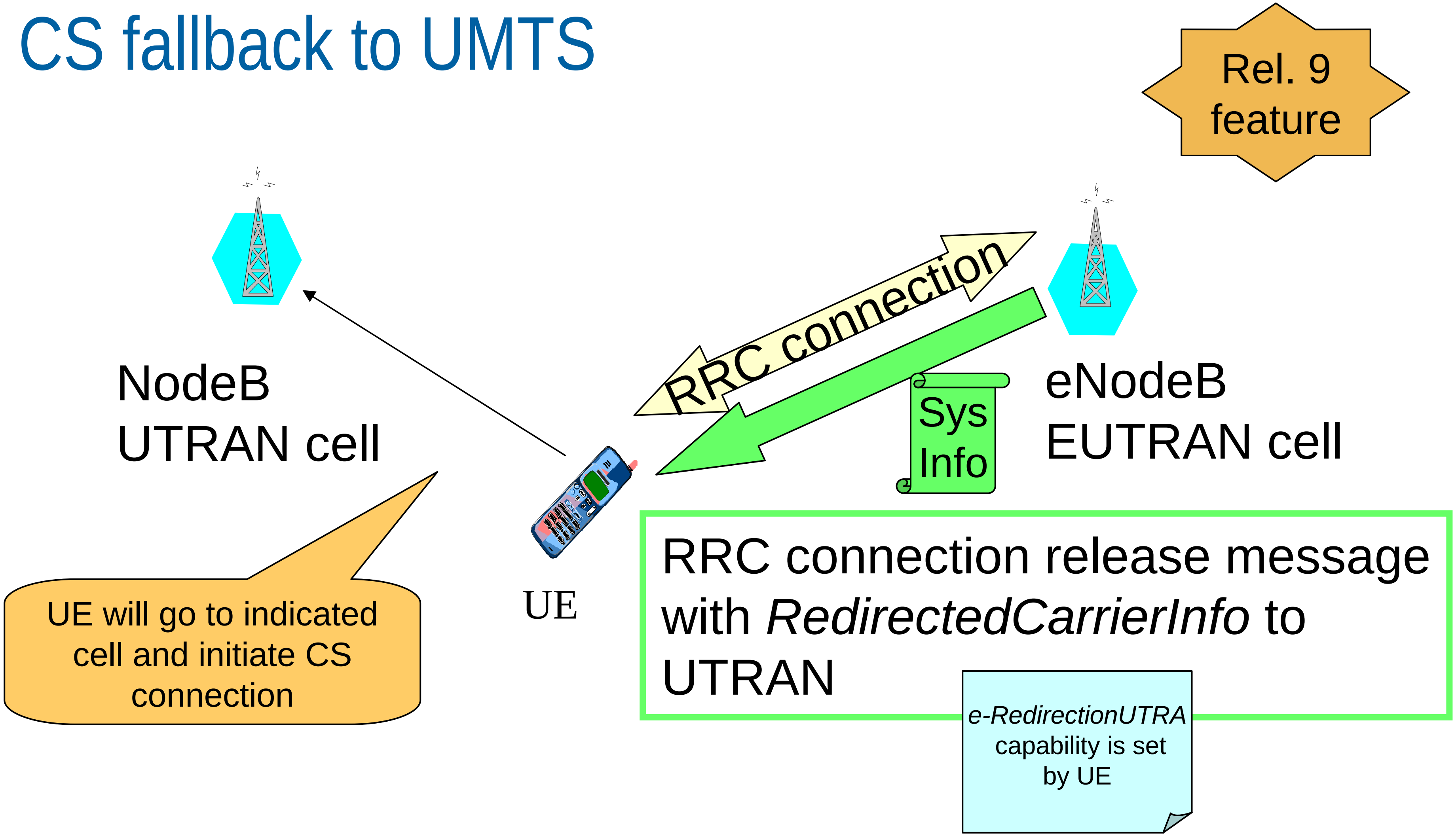


RRC connection release message with *RedirectedCarrierInfo* to UTRAN

Mandatory for UE supporting CSFB

RRC connection release with redirection without SysInfo

CS fallback to UMTS



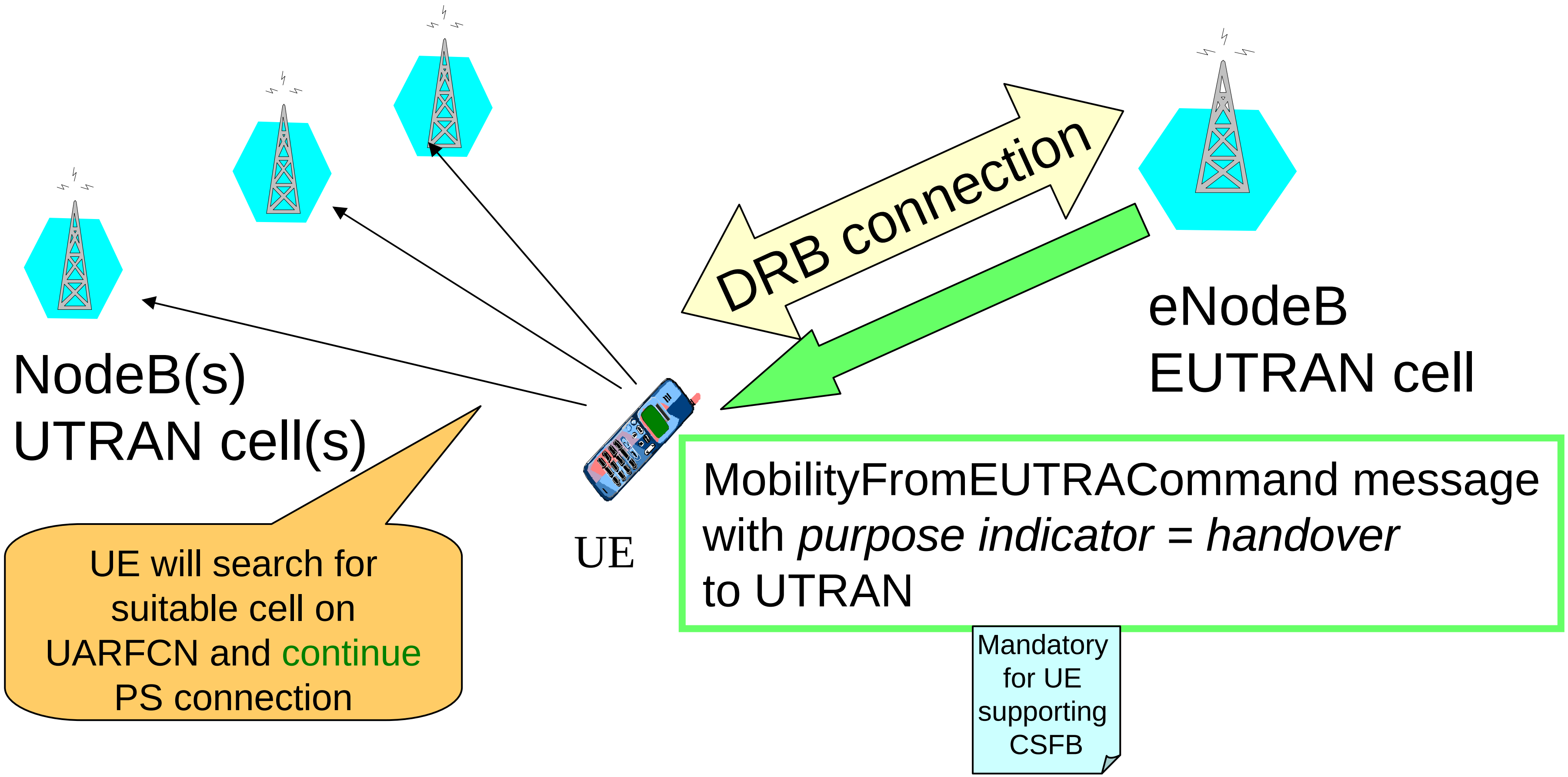
RRC connection release with redirection with SysInfo

CS fallback – Packet Switched handover

Contains this information element when Falling back to legacy networks

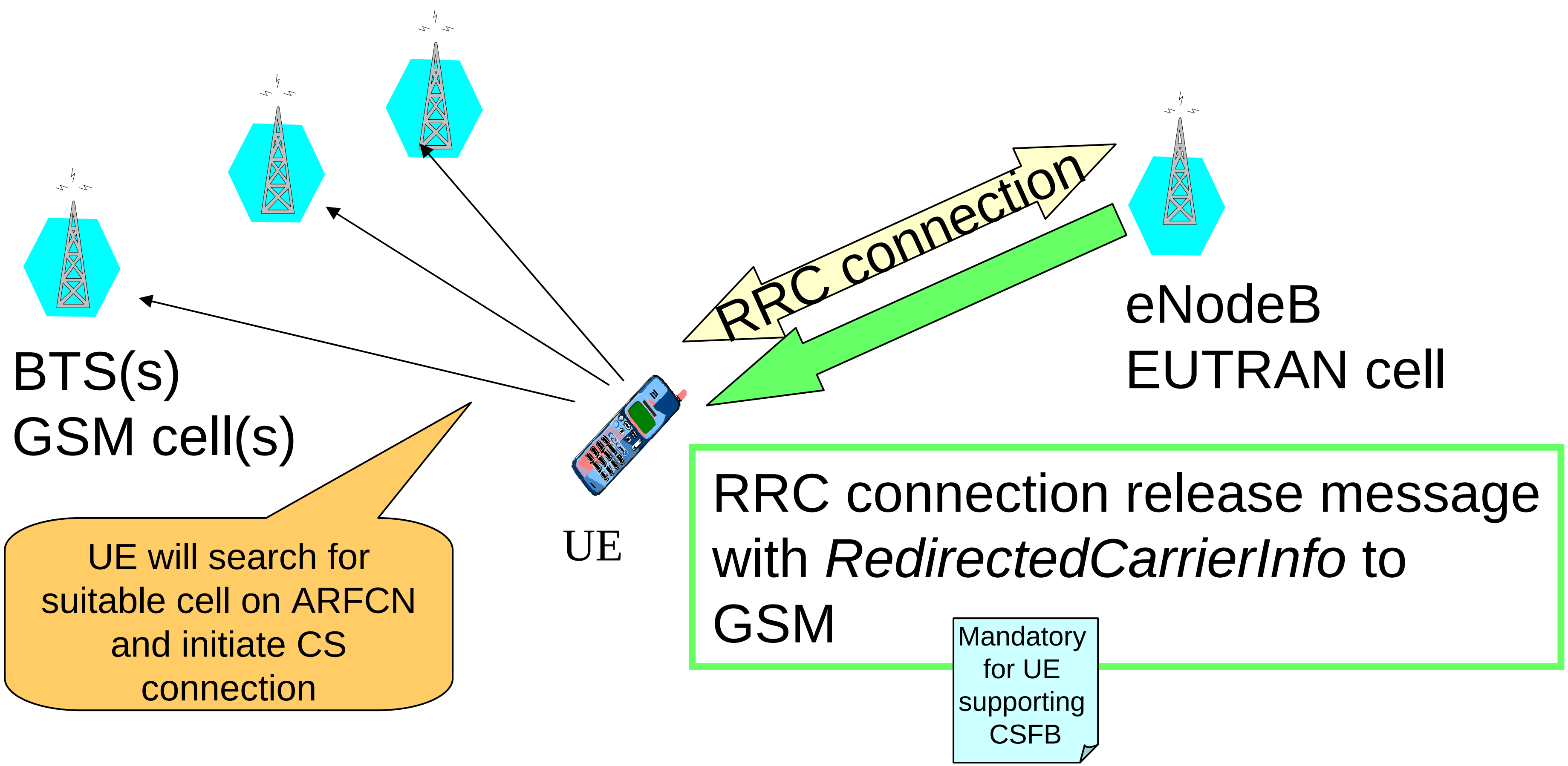
```
MobilityFromEUTRACommand ::=                SEQUENCE {
        rrc-TransactionIdentifier           RRC-TransactionIdentifier,
        criticalExtensions                  CHOICE {
                c1                          CHOICE{
                mobilityFromEUTRACommand-r8               MobilityFromEUTRACommand-r8-IEs,
                mobilityFromEUTRACommand-r9               MobilityFromEUTRACommand-r9-IEs,
                spare2 NULL, spare1         NULL
                },
                criticalExtensionsFuture                            SEQUENCE {}
        }
}
```

CS fallback to UMTS: Packet switched handover



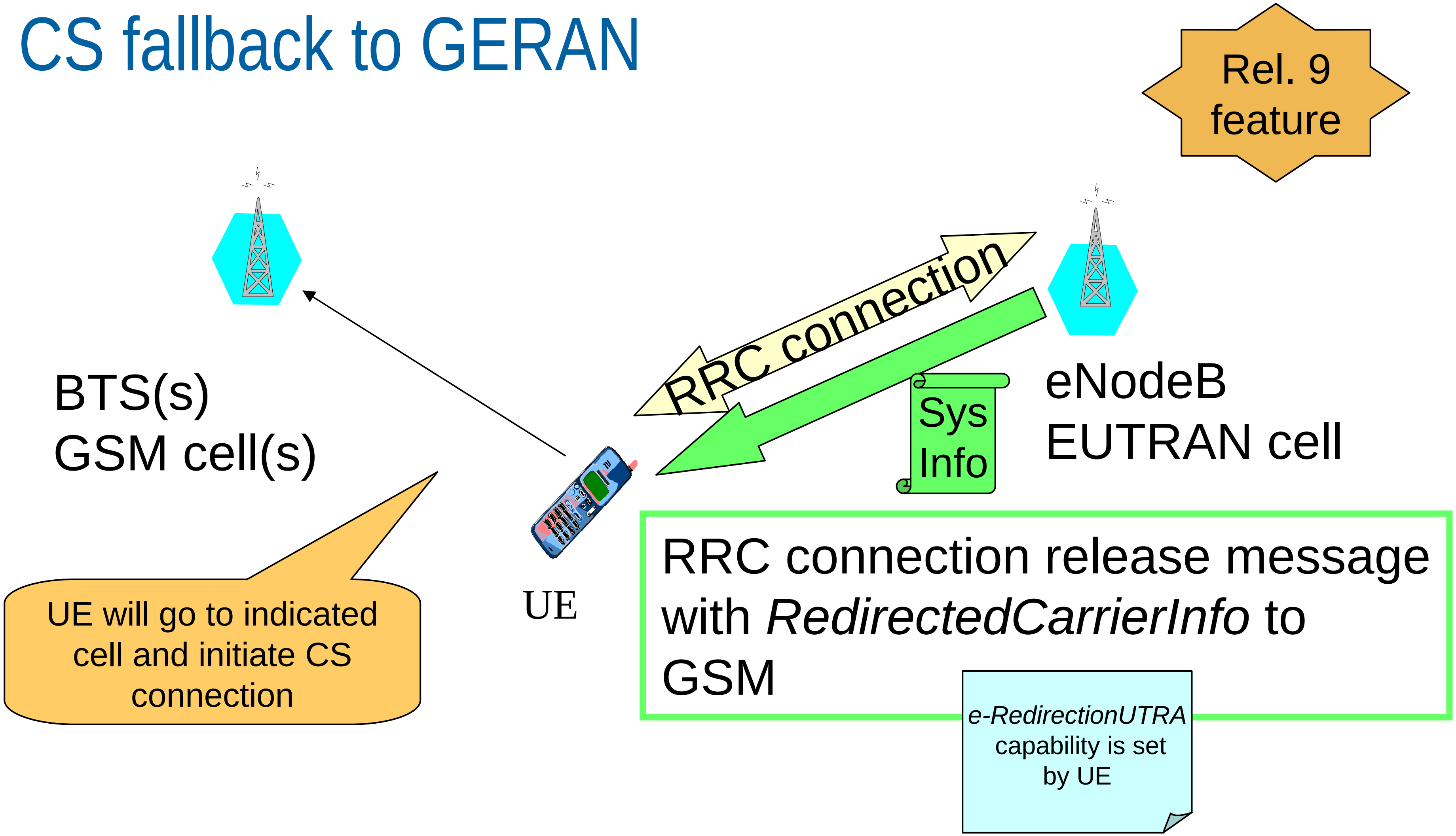
Packet Switched handover to UTRAN without SysInfo

CS fallback to GERAN



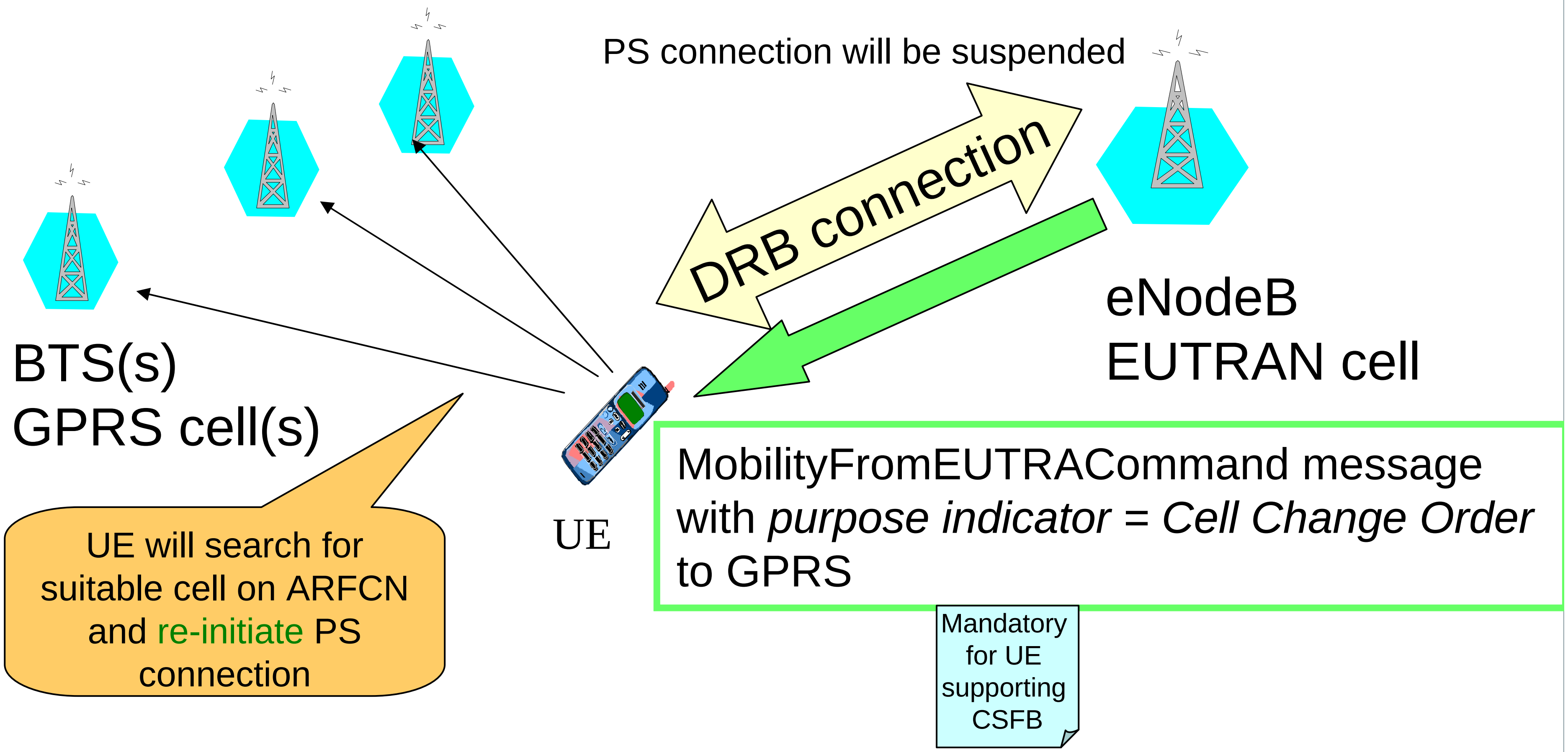
RRC connection release with redirection without SysInfo

CS fallback to GERAN



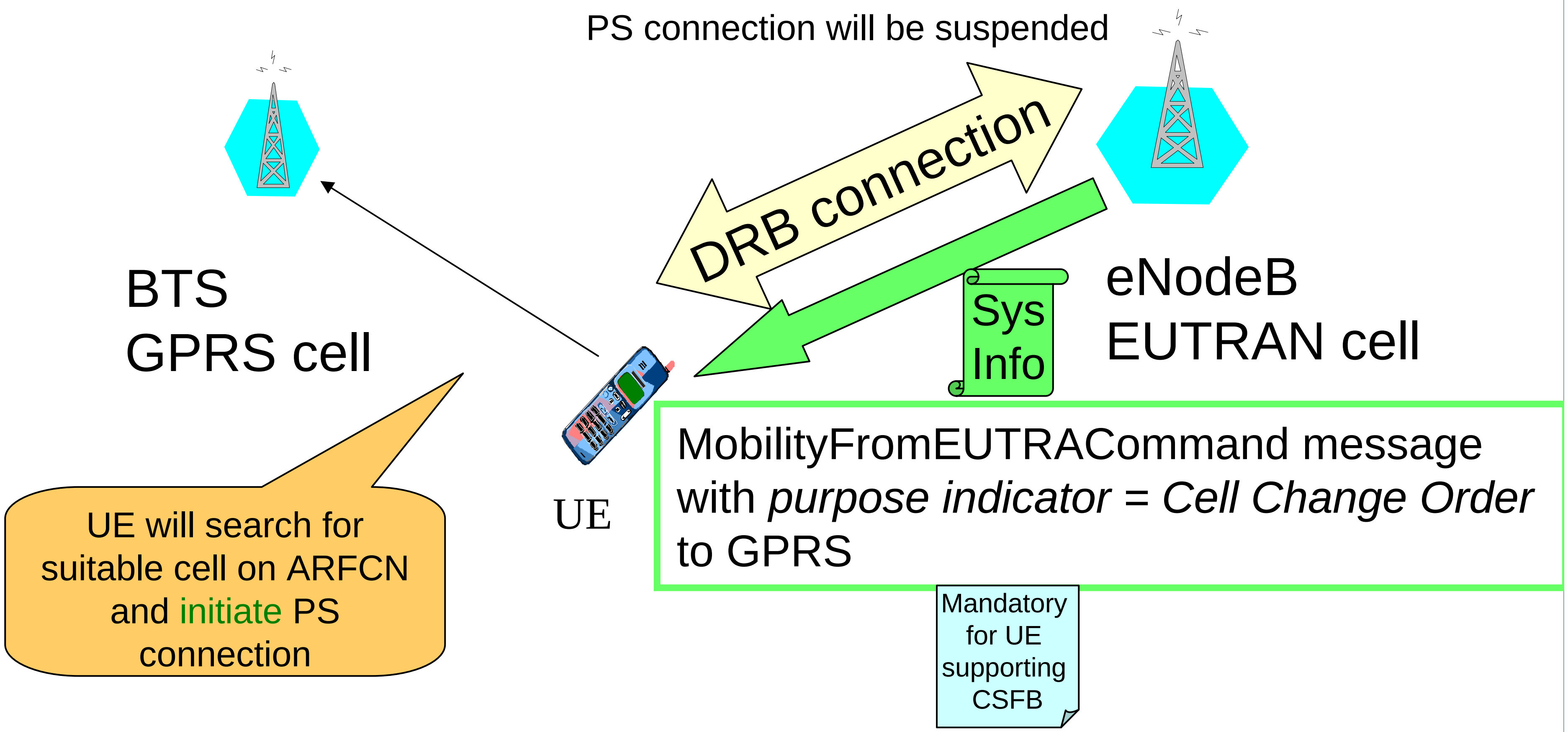
RRC connection release with redirection with SysInfo

CS fallback to GSM: Packet switched handover



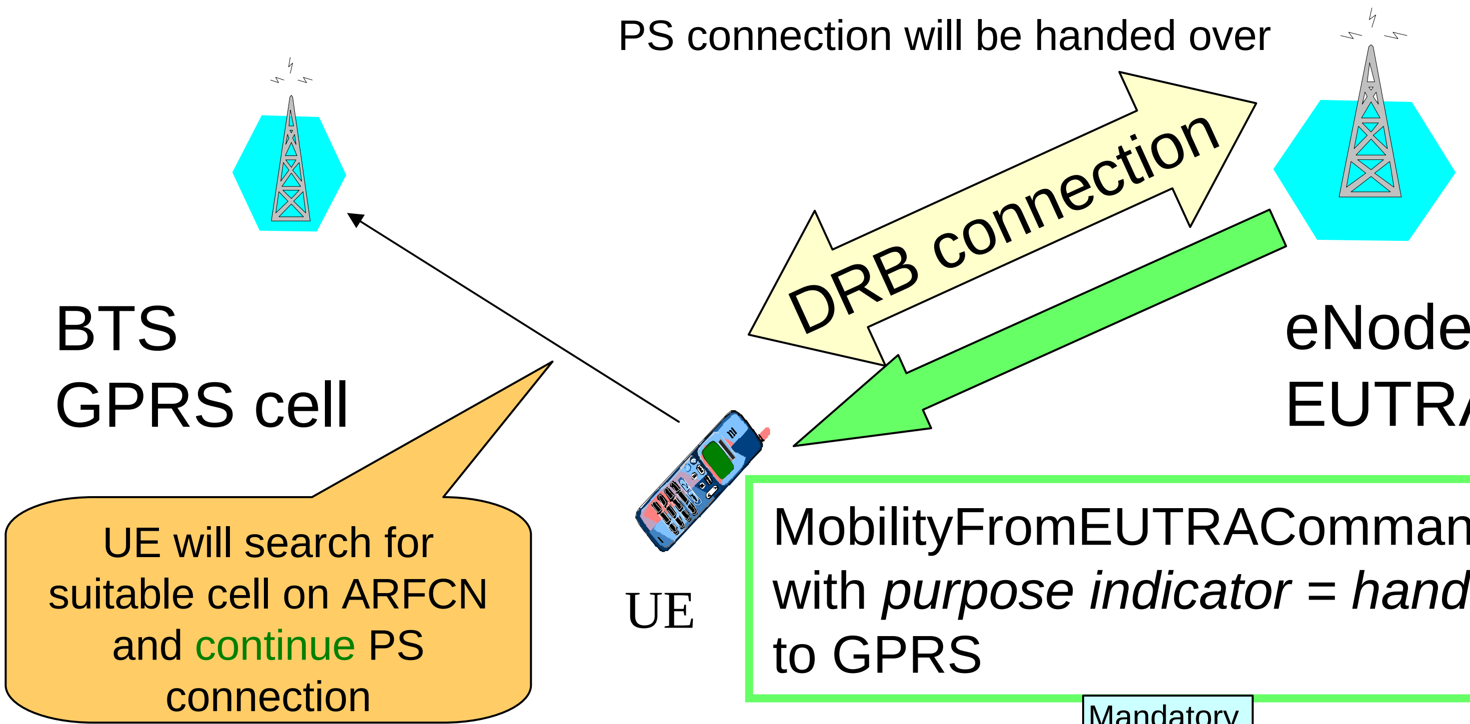
Packet Switched cell change order to GPRS without NACC (network assisted cell change)

CS fallback to GSM: Packet switched handover



Packet Switched cell change order to GPRS with NACC
(network assisted cell change)

CS fallback to GSM: Packet switched handover

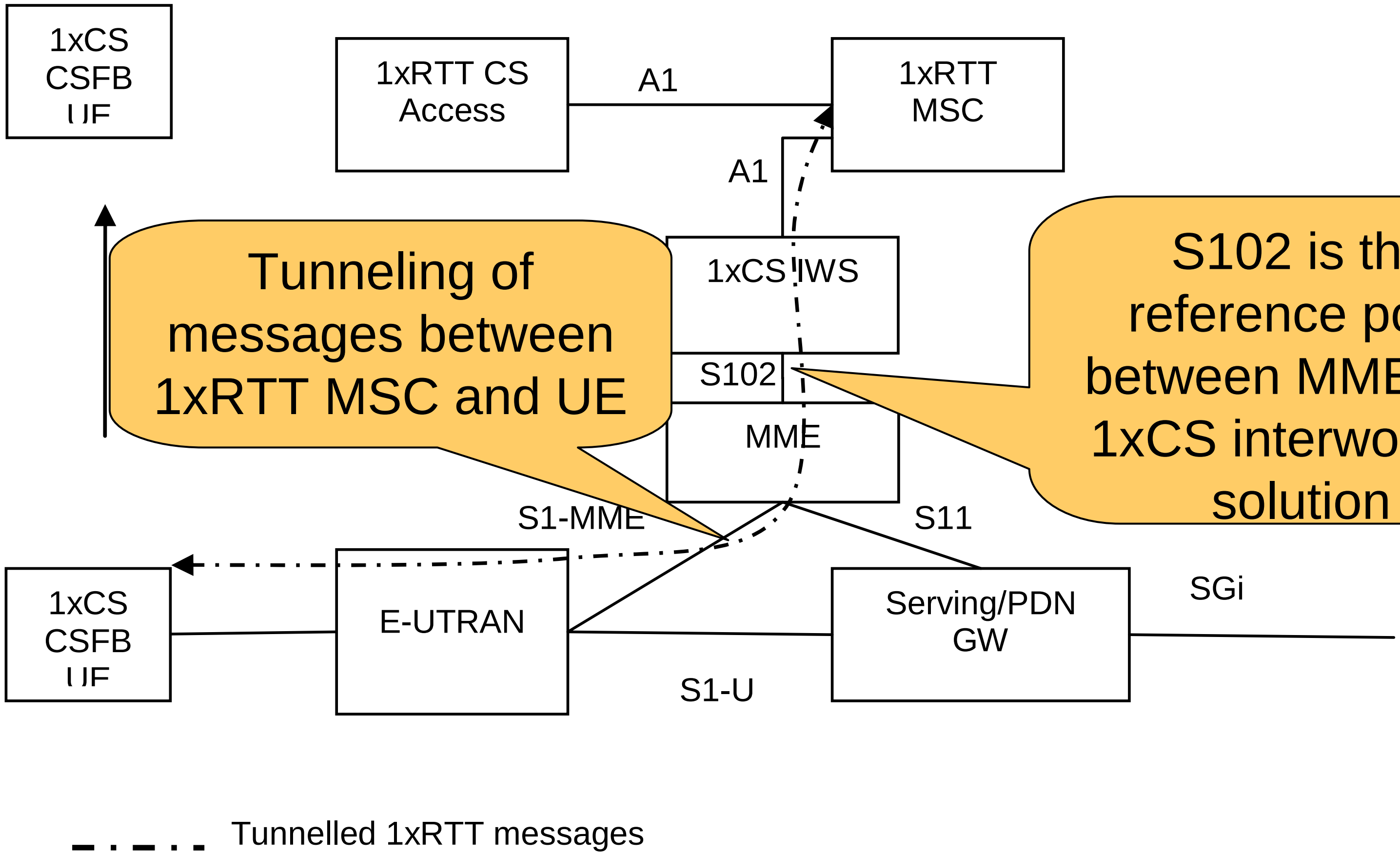


MobilityFromEUTRACommand message with *purpose indicator = handover* to GPRS

Mandatory for UE supporting CSFB

Packet Switched handover to GPRS

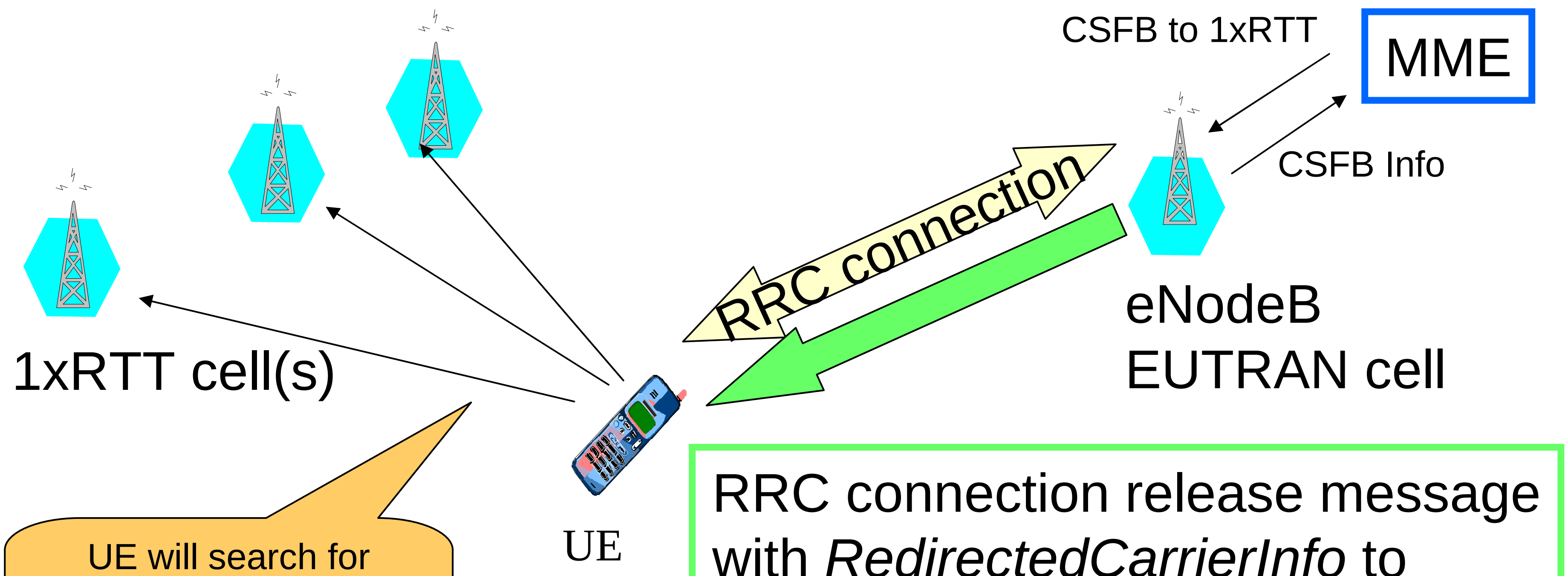
CS fallback to 1xRTT



CS fallback to 1xRTT

Target RAT	Solutions	Release	UE Capability	FGI Index
CS fallback to 1xRTT	RRC Connection Release with Redirection	Rel-8	(NOTE 1) Mandatory for UEs supporting CS fallback to 1xRTT	
	enhanced 1xCSFB	Rel-9	(NOTE 1) e-CSFB-1XRTT	
	enhanced 1xCSFB with concurrent HRPD handover	Rel-9	(NOTE 1) e-CSFB-ConcPS-Mob1XRTT, Support of HRPD, supportedBandListHRPD	FGI12, FGI26
	dual receiver 1xCSFB (RRC Connection Release without Redirection)	Rel-9	(NOTE 1) rx-Config1XRTT (set to 'dual')	
NOTE 1: All CS fallback to 1xRTT capable UE shall indicate that it supports 1xRTT and supported band list in the UE capability.				

CS fallback to 1xRTT



UE will search for suitable cell on UARFCN and initiate CS connection

RRC connection release message with *RedirectedCarrierInfo* to 1xRTT

Mandatory for UE supporting CSFB to 1xRTT

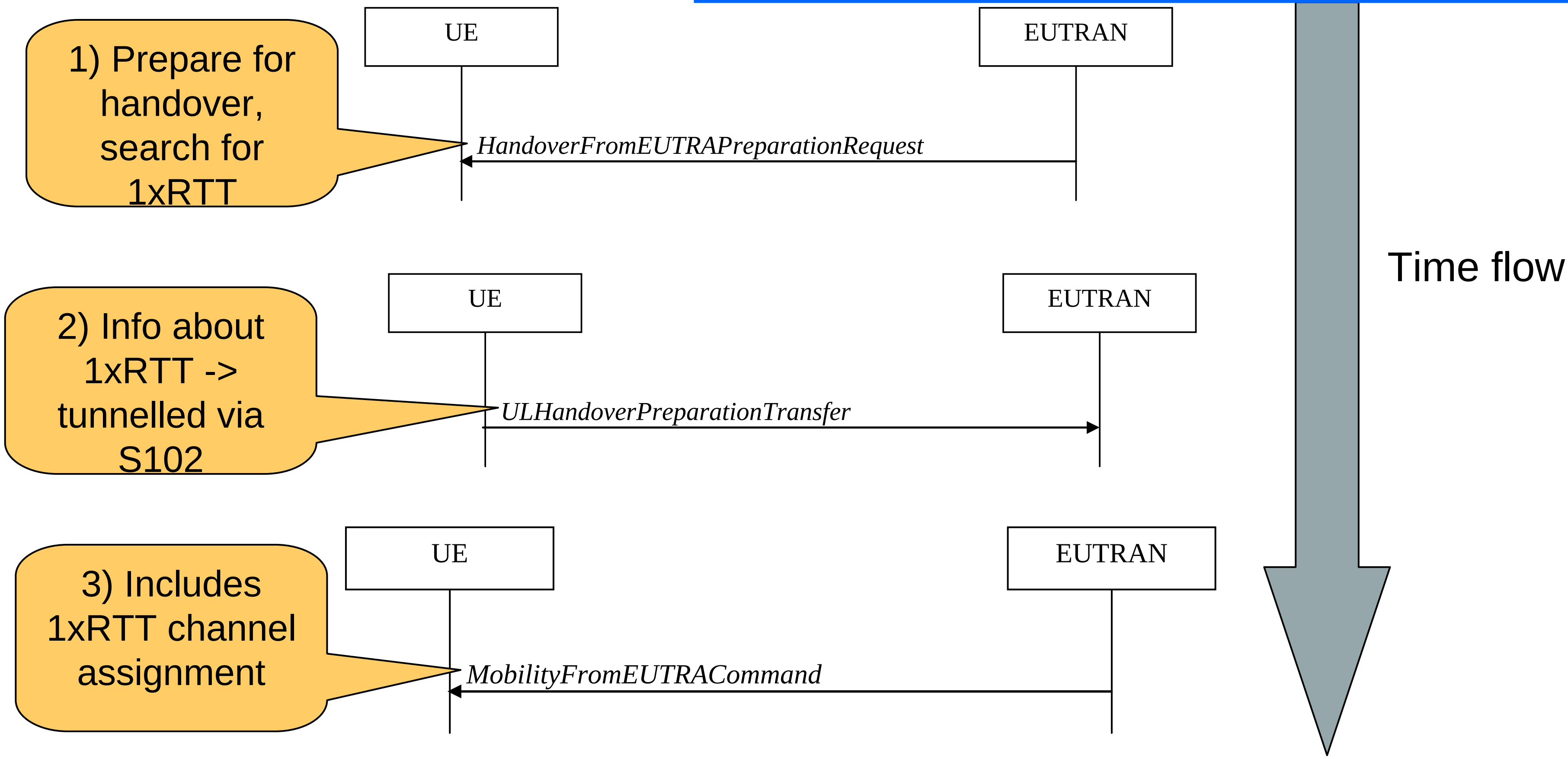
Enhancement: UE can pre-register in 1xRTT network

RRC connection release with redirection without SysInfo

CS fallback to 1xRTT

enhanced 1xCSFB (e1xCSFB)

Enhancement: UE can pre-register in 1xRTT network



CS fallback to 1xRTT

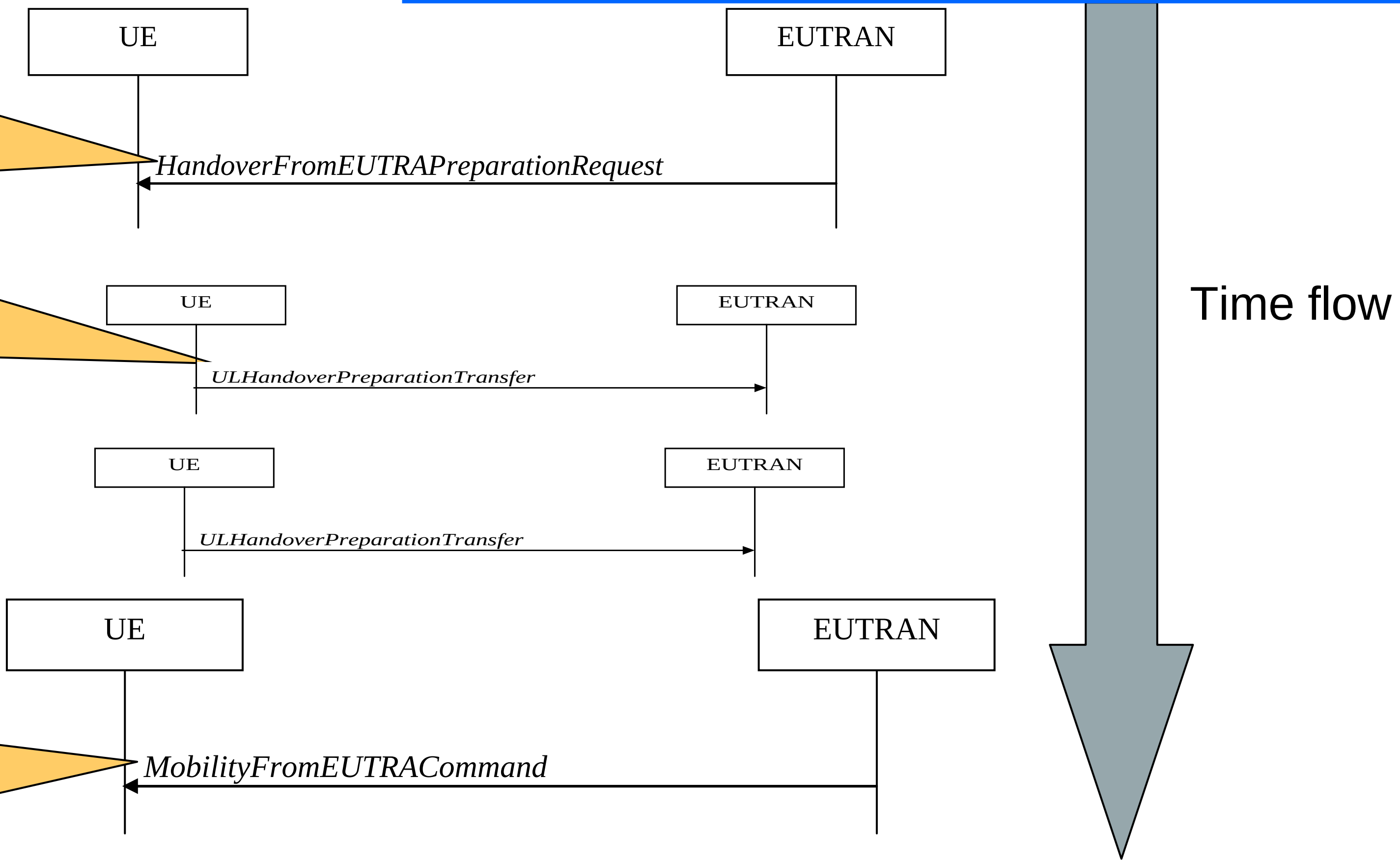
enhanced 1xCSFB (e1xCSFB) + concurrent HRPD handover

Enhancement: UE can pre-register in 1xRTT network

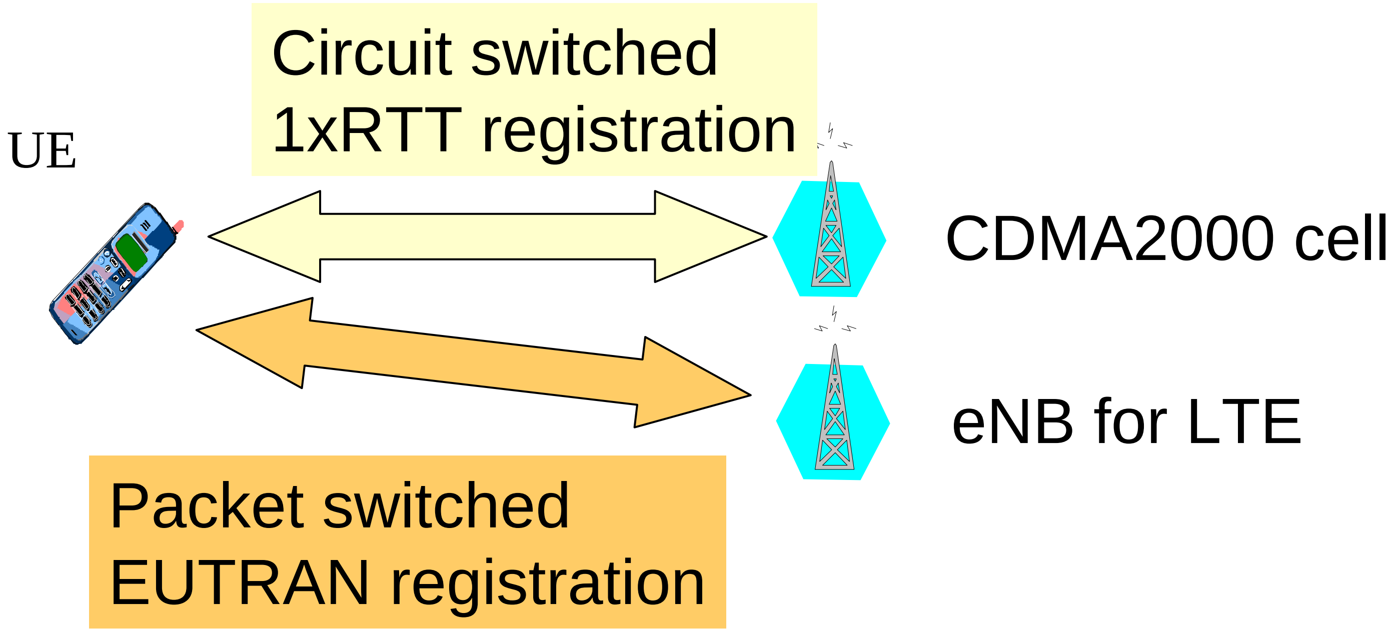
1) Prepare for handover, search for 1xRTT + HRPD

2) Trigger 2 messages with info about 1xRTT + HRPD

3) Redirection to 1xRTT and handover to HRPD

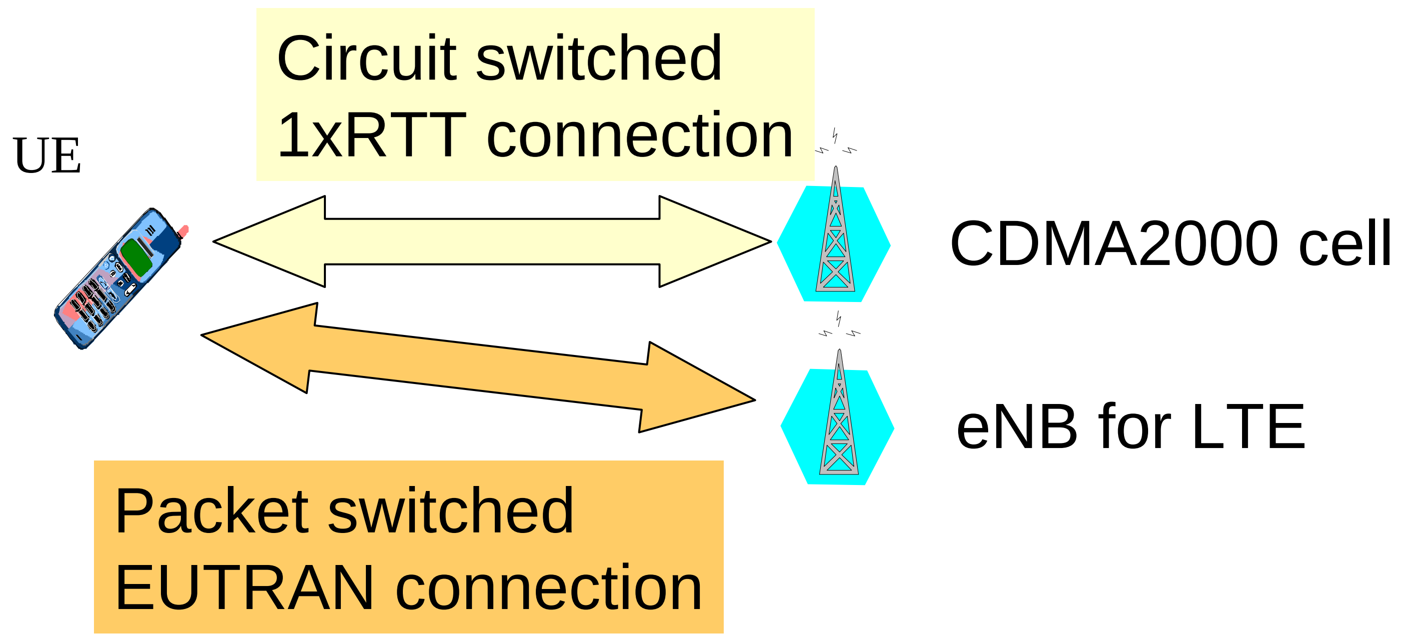


Dual receiver 1xCSFB



Dual receiver 1xCSFB UEs can handle separate mobility and registration procedures 2 radio links at the same time. UE is registered t, no coordination required. When CS connection in 1xRTT, dual receiver UE leaves EUTRAN!

SV-LTE: Simultaneous CDMA200 + LTE



Simultaneous Voice UEs can handle 2 radio links at the same time. UE is registered to MME and CDMA2K independently

CS fallback - arguments

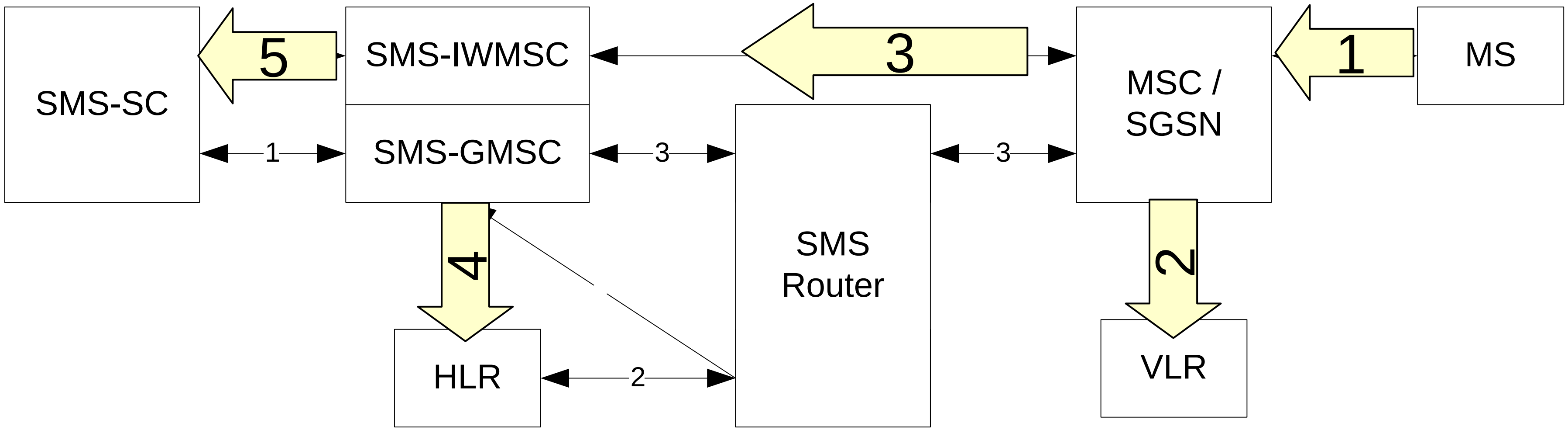
- **E-UTRAN and GERAN/UTRAN coverage must overlap**
- **No E-UTRAN usage for voice**
- **No changes on EPS network required**
- **Gs interface MSC-SGSN not widely implemented**
- **Increased call setup time**
- **No simultaneous voice + data if 2G network/UE does not support DTM**
- **SMS can be used without CS fallback, via E-UTRAN**

Why not CSFB?

- **Call setup delay**
- **Call drop due to handover**
  - Blind hand-over is used for CSFB
- **Data applications are interupted**
- **Legacy RAN coverage needed**

SMS transfer in LTE

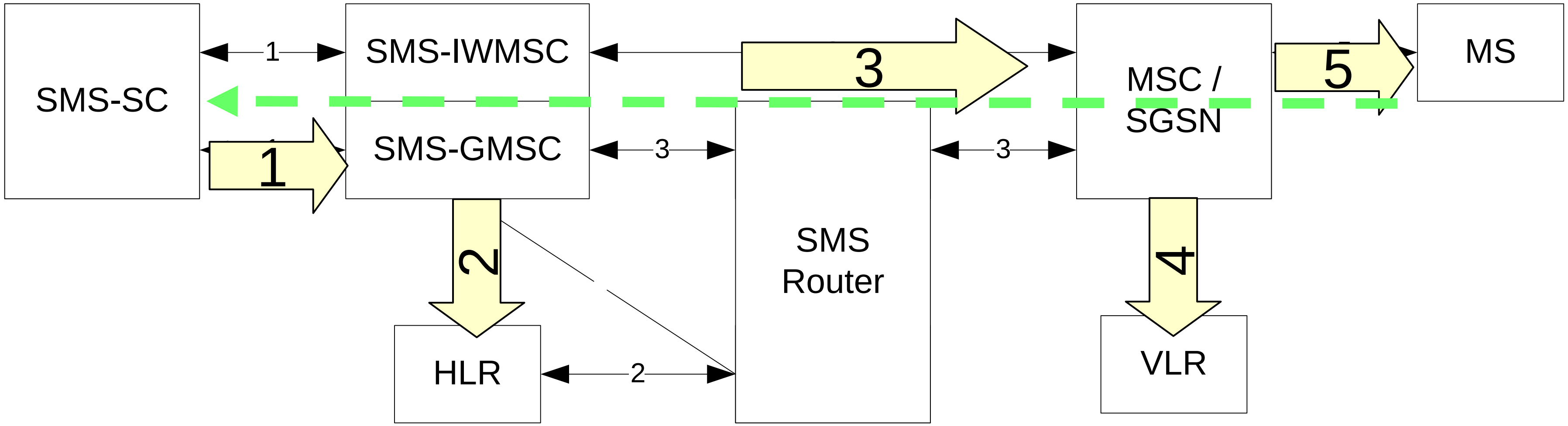
Mobile originated SMS transfer in Circuit Switched mode



1) Mobile sends SMS to MSC
2) MSC contacts VLR for user profile
3) MSC sends SMS to Interworking MSC
4) SMS-IWMSC contacts HLR for receiver mobile information
5) SMS-IWMSC sends SMS to SMS-SC

SMS transfer in LTE

Mobile terminated SMS transfer in Circuit Switched mode

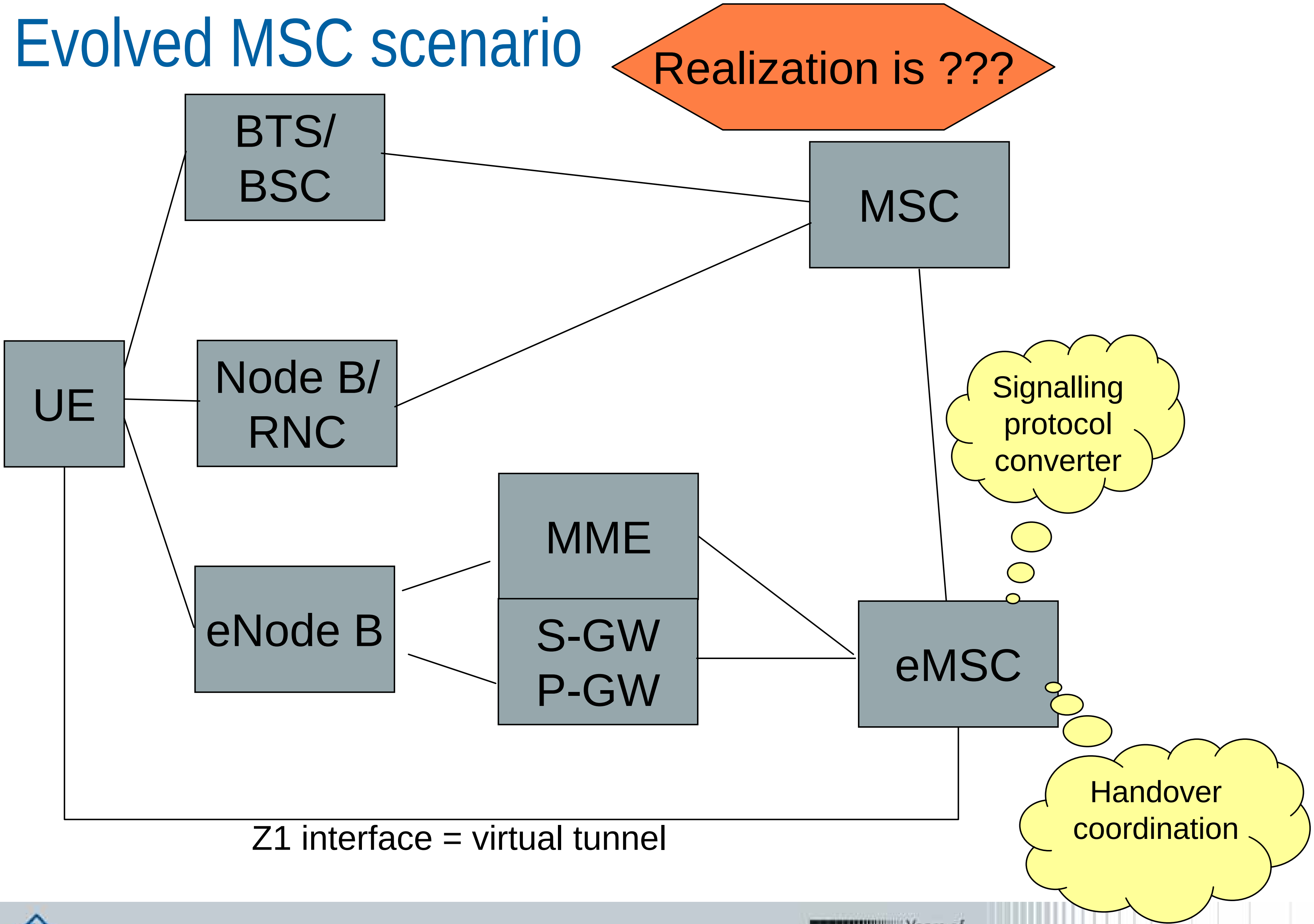


1) SMS-SC sends SMS to Gateway MSC
2) GMSC contacts HLR for receiver mobile information
3) GMSC sends SMS to MSC
4) MSC contacts VLR for receiver mobile profile
5) MSC sends SMS to mobile
6) On request, mobile will generate acknowledgement and send it to SMS-SC

CSFB circuit switched fallback – SMS transfer

- **SMS can be transferred in the signaling messages -> so no real circuit switched fallback**
- **CSFB ready at LTE launch? CSFB needs SGs interface between MME and MSC**
- **Roaming: no guarantee that CSFB is supported worldwide**
- **Specification issues: Not clear what happens if SMS transfer occurs at ongoing CSFB procedure**
- **Test scenarios: No CSFB SMS test scenarios defined yet**

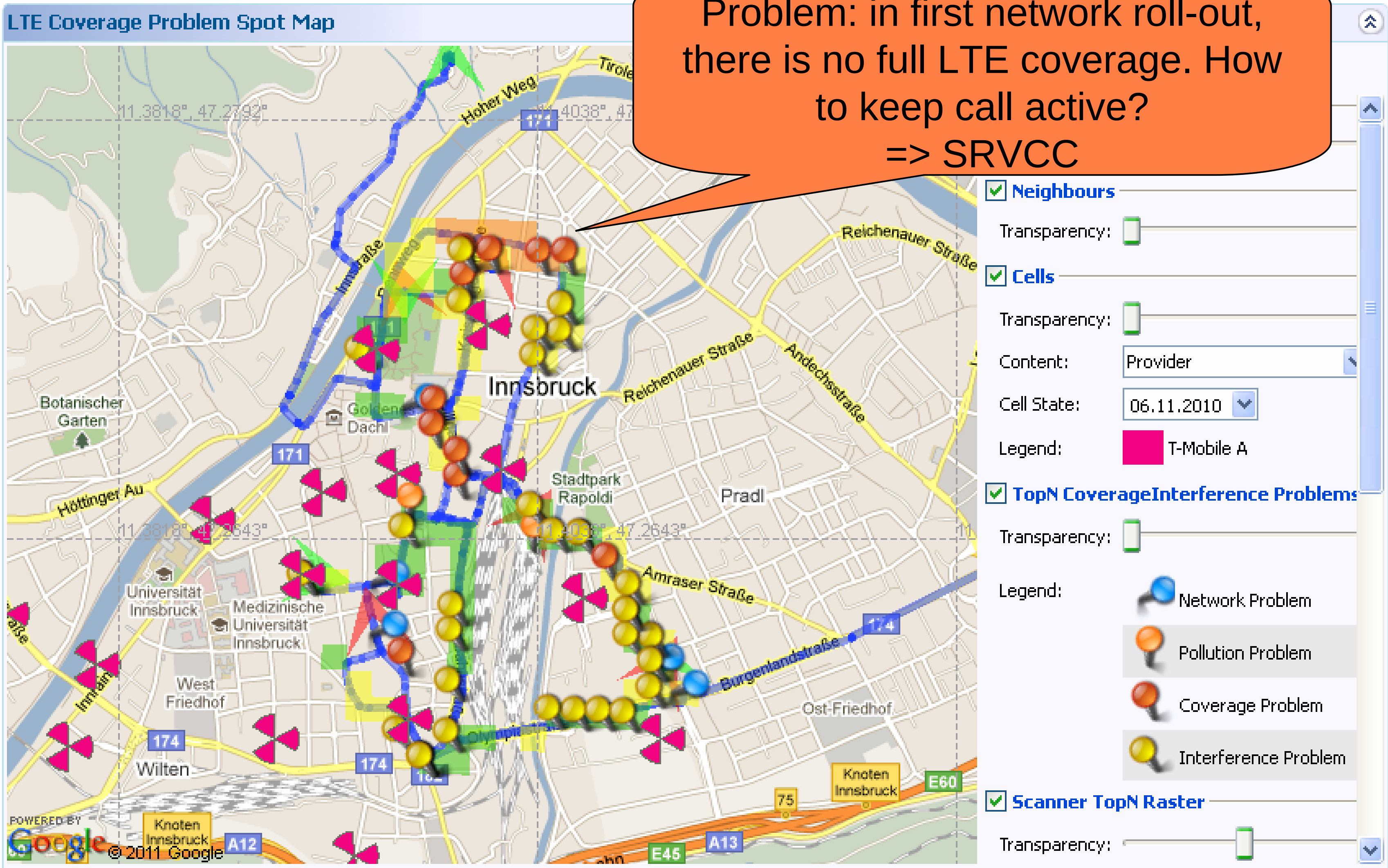
Evolved MSC scenario



CS services via eMSC - arguments

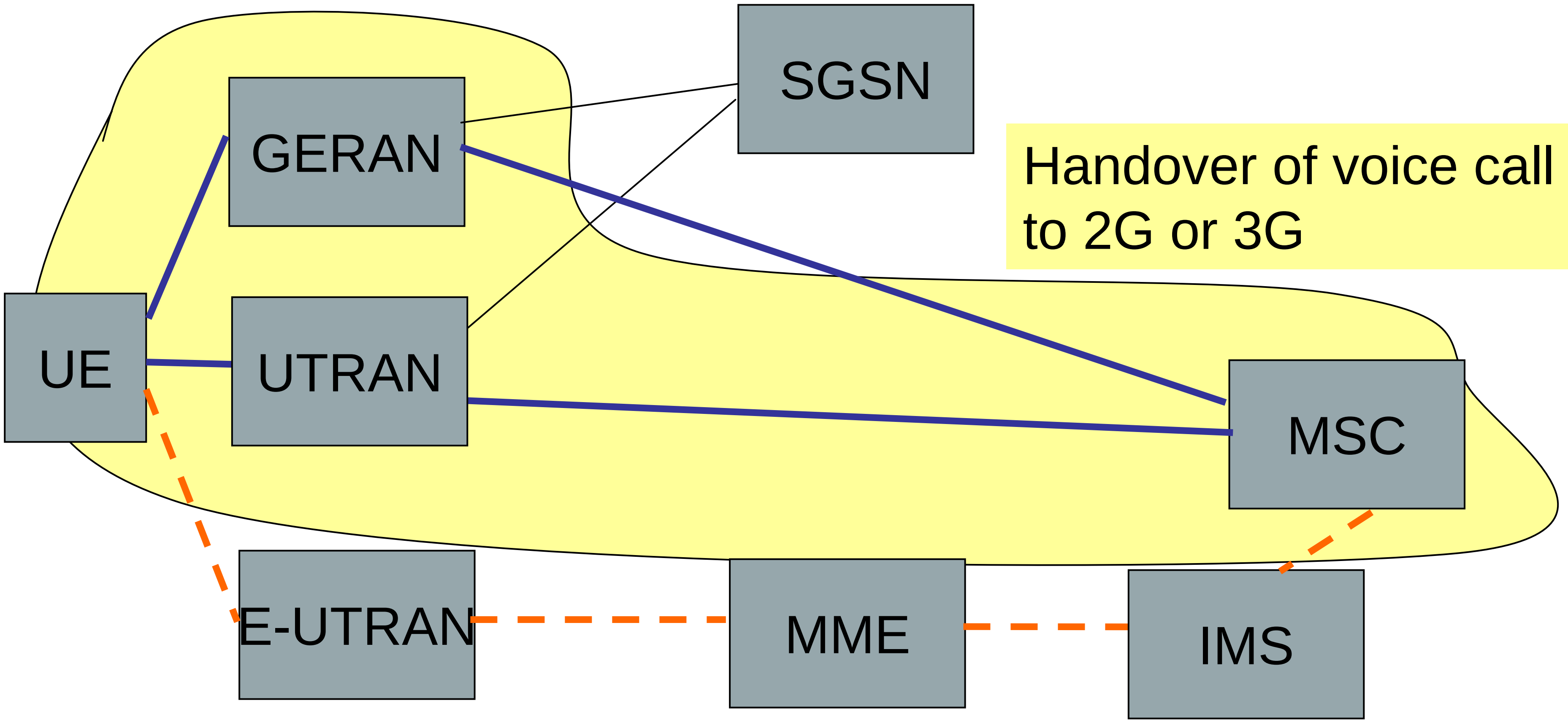
- eMSC is currently Rel.-9 study item
- eMSC acts as a signaling protocol converter
- Only voice services for eMSC
- No instant messaging services
- Necessary changes: UE must support handover for 2G,3G and 4G
- eNB must forward CS handover to UE transparently
- MME must communicate to eMSC for handover purposes
- MSC must communicate via DTAP over IP to perform 2G/3G to 4G Handover

Single Radio Voice Call Continuity



Problem: in first network roll-out, there is no full LTE coverage. How to keep call active?
=> SRVCC

SRVCC – Single Radio Voice Call Continuity

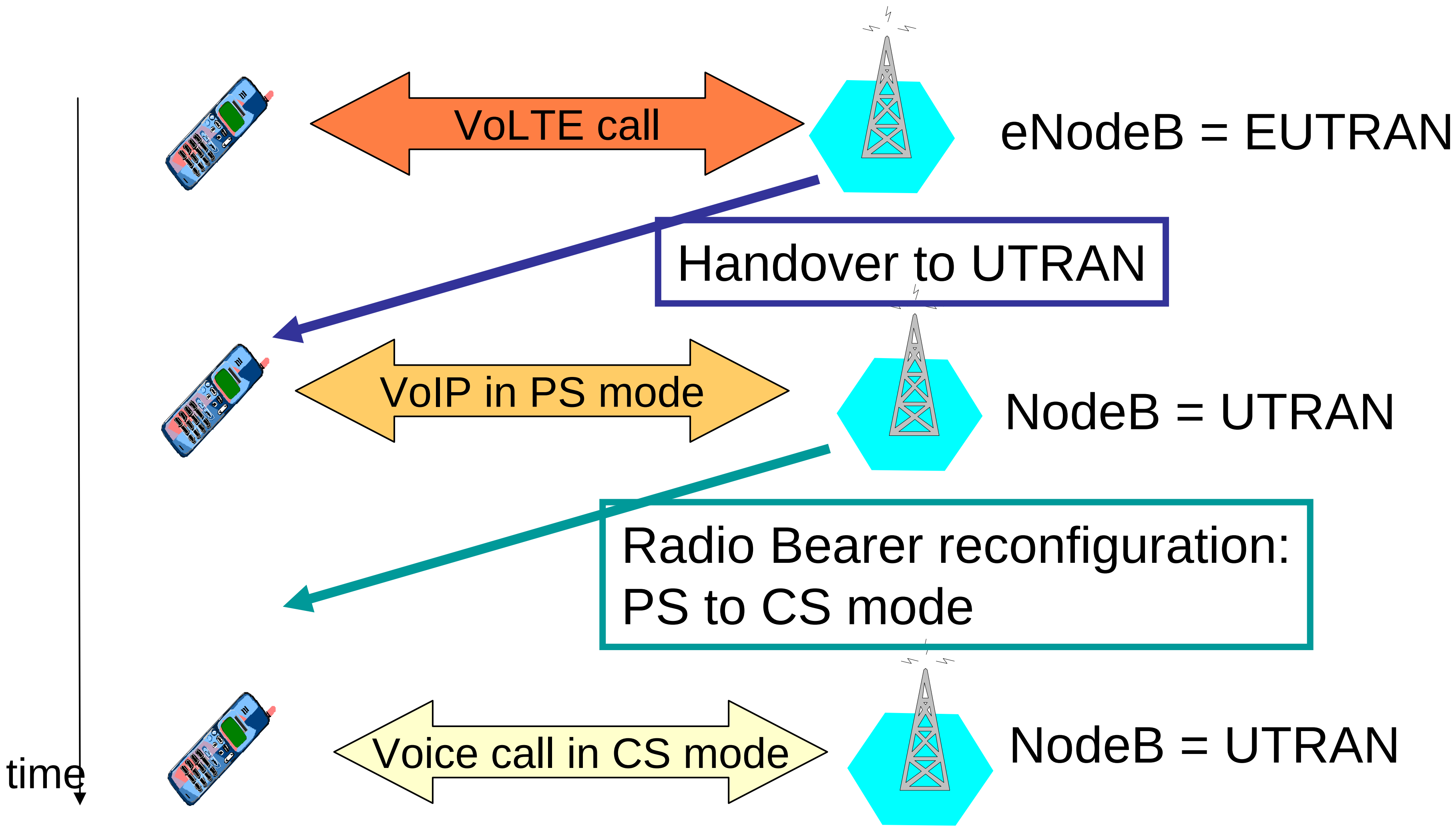


User plane after handover

User plane before handover

SRVCC is handover from EUTRAN to 2G/3G if no LTE coverage

Single Radio Voice Call Continuity



IMS
IP Multimedia Subsystem

Reiner Stuhlfauth

Years of Driving Innovation

ROHDE&SCHWARZ

What is IMS?
A high level summary

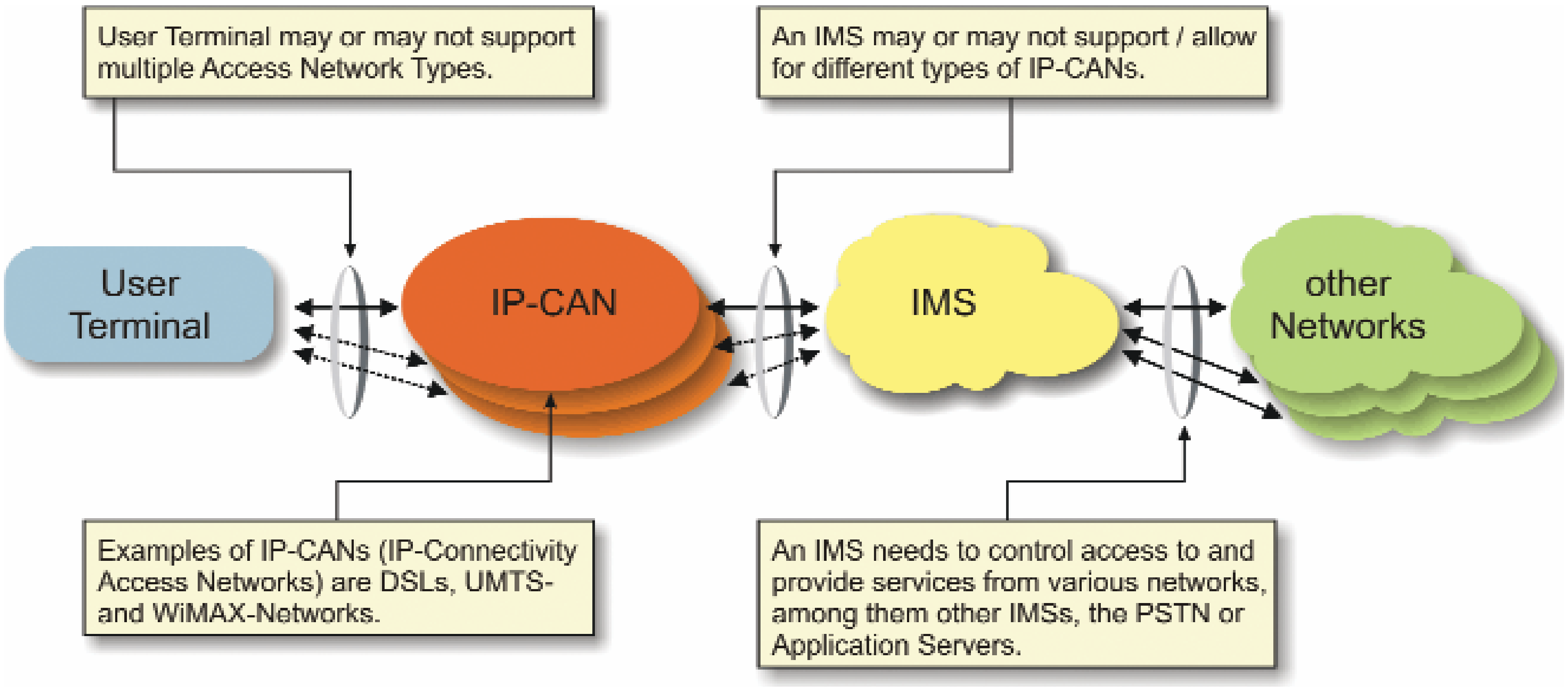
- **The success of the internet, using the Internet Protocol (IP) for providing voice, data and media has been the catalyst for the convergence of industries, services, networks and business models,**
  - IP provides a platform for network convergence enabling a service provider to offer seamless access to any services, anytime, anywhere, and with any device,
  - 3GPP has taken these developments into account with specification of IMS,
- **IMS stands for *I*P *M*ultimedia *S*ubsystem,**
  - IMS is a global ***access-independent*** and standard-based ***IP connectivity*** and service control ***architecture*** that enables various types of multimedia services to end-users using common internet-based protocols,
  - Defines an architecture for the convergence of audio, video, data and fixed and mobile networks.

What is IMS?

A high level summary, cont'd.

- **IMS is specified by 3GPP, describing an overall architecture and the interaction with Radio Access Networks (RAN); based on Internet Engineering Task Force (IETF) defined standards,**
  - Session Internet Protocol (SIP), used for registration, subscription, notification and session initiations,
  - Session Description Protocol (SDP), parameters (codec, BW, IP add., ports),
- **Applied concepts,**
  - User registers with IMS network, subscribes for services, receives information about events, establish sessions to other users and/or application servers,
- **IMS concept requires direct message/content flow from UE to UE,**
  - Today: UE are assigned with private IP addresses, traffic is routed by the NW,
  - Problem: UE are not addressable from outside the wireless network.
  - Solution: Introduction of IPv6, to assign every network node with an IP address.
- **Introduction of "All-IP" architecture requires IPsec to ensure secured communication.**

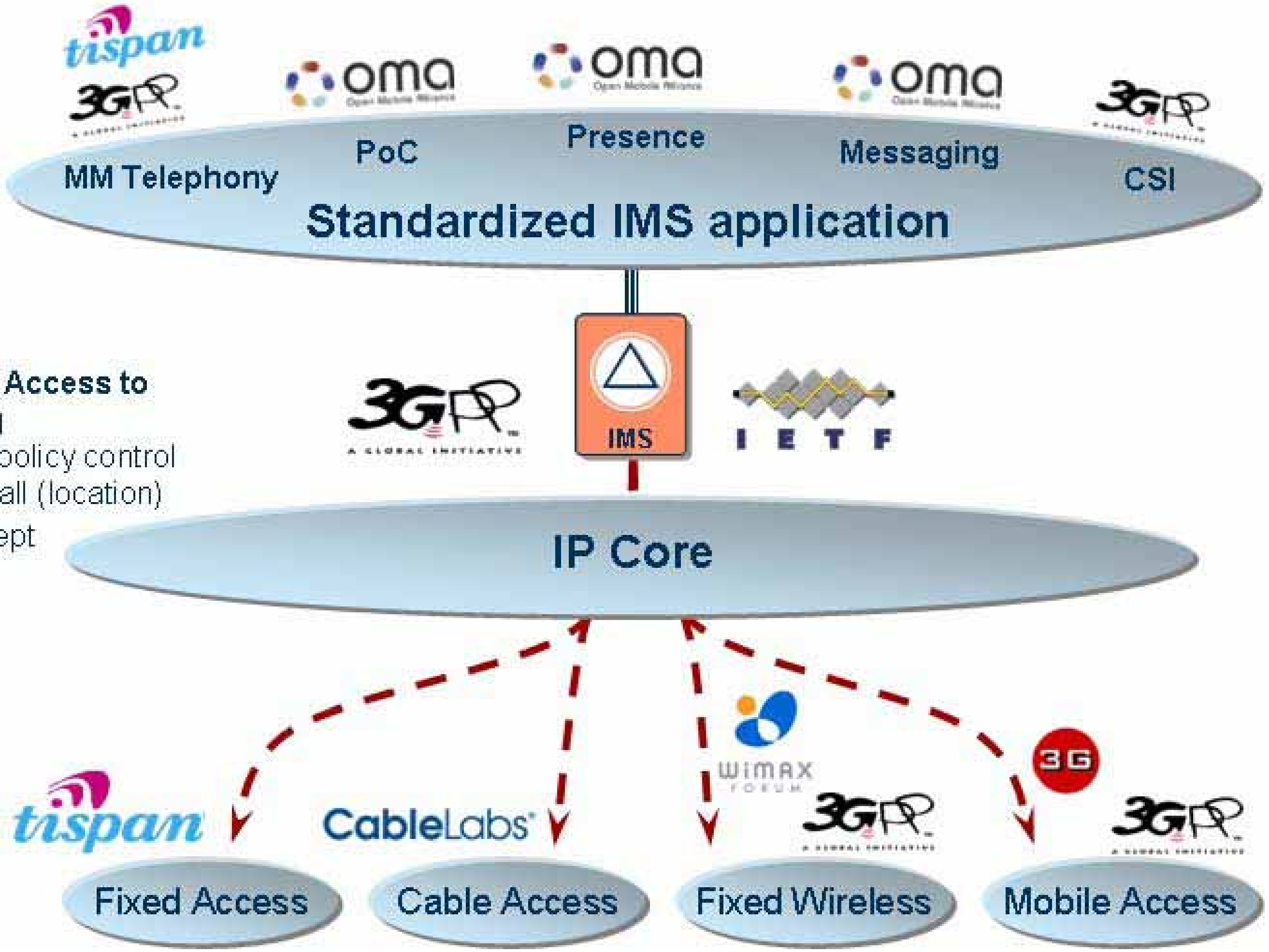
IMS simplified structure



IMS feature overview

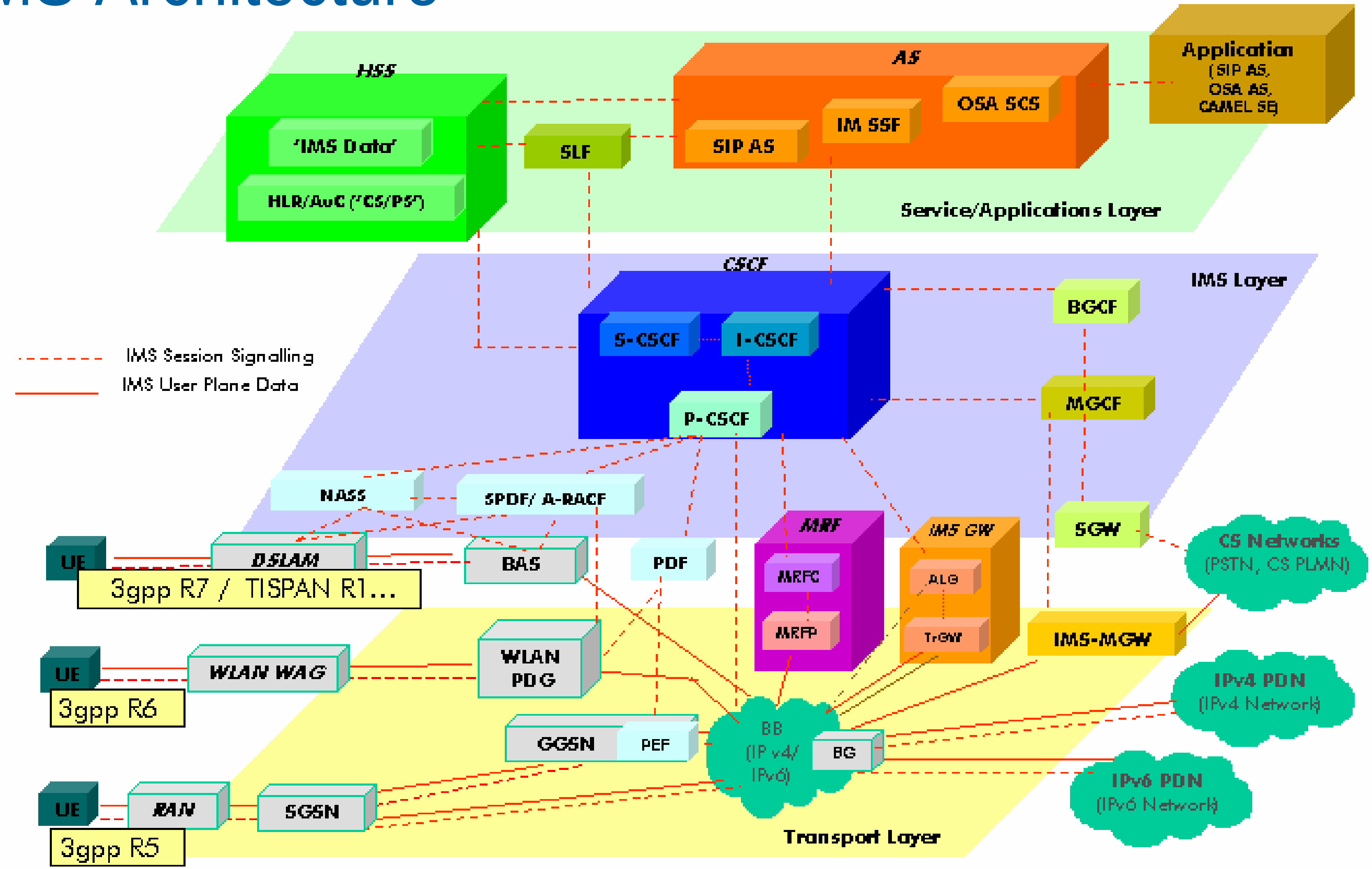
- **Services can be billed (☹ or ☺?)**
- **New services can be added, open interface ISC between Open Architecture-Service Capability Server and CSCF**
- **Fixed mobile convergence becomes reality -> seamless transition between different IP-CANs**

Introduction IMS – IP Multimedia Subsystem
Definition



Standardized Access to IMS providing
- Access QoS policy control
- Emergency call (location)
- Lawful Intercept

IMS Architecture



What is IMS?

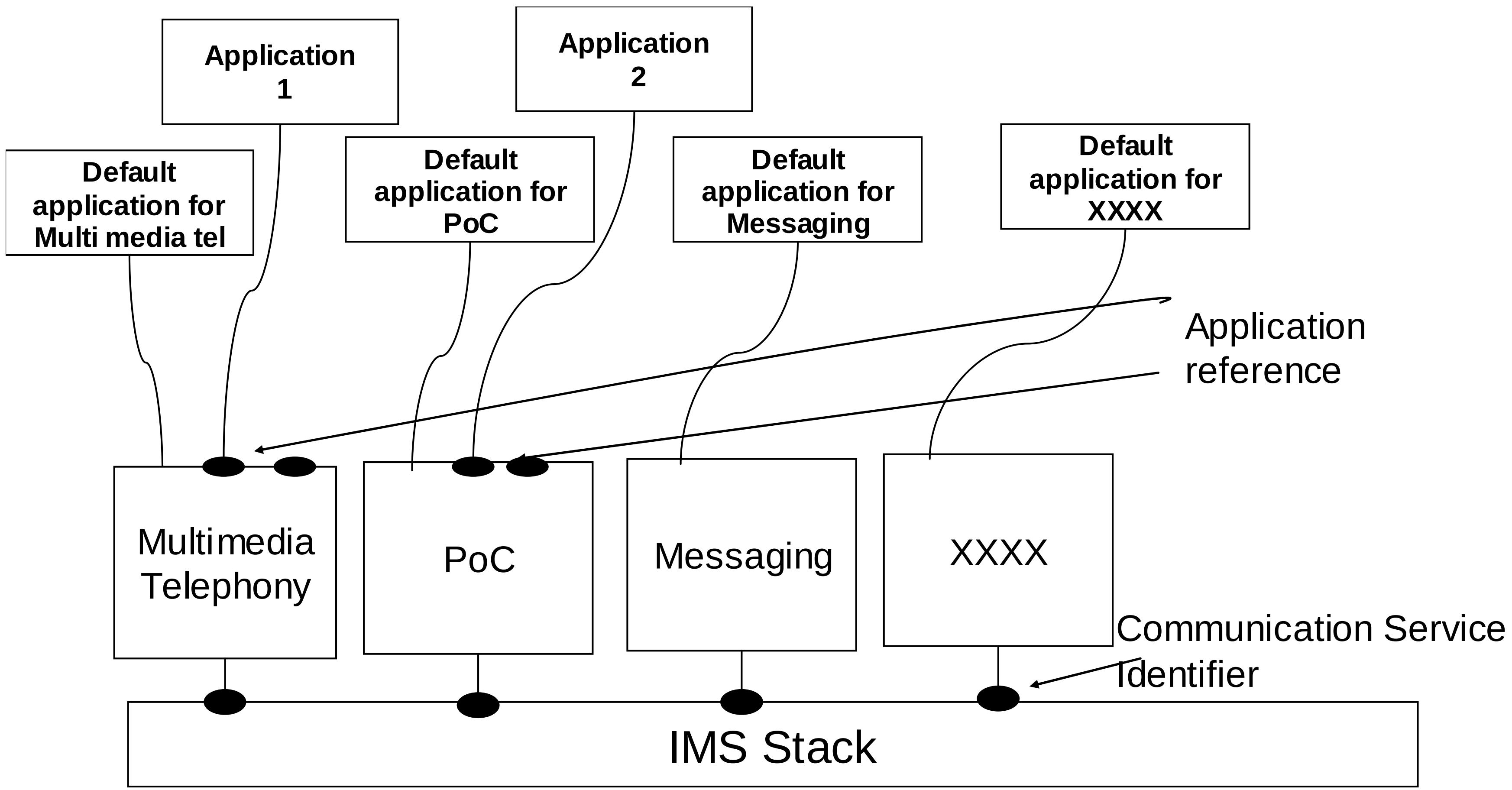
CSCF's

- **CSCF stands Call Session Control Function, there are 3 different types of CSCF,**
  - **Proxy-CSCF.** First point of contact for user, SIP signaling is sent from UE to network and vice versa. SIP (as well as SDP) is text-based, large headers, header parameters, compression required.

```
REGISTER sip:registrar.biloxi.com SIP/2.0
Via: SIP/2.0/UDP bobspc.biloxi.com:5060;branch=z9hG
Max-Forwards: 70
To: Bob <sip:bob@biloxi.com>
From: Bob <sip:bob@biloxi.com>;tag=456248
Call-ID: 843817637684230@998sdasdh09
CSeq: 1826 REGISTER
Contact: <sip:bob@192.0.2.4>
Expires: 7200
Content-Length: 0
```

  - **Interrogating-CSCF.** Contact within an operators network for all connections destined to a subscriber.
  - **Serving-CSCF.** Handling registration process, making routing decisions, maintaining sessions, and storing service profiles.

Applications in IMS



IMS architecture

- **Multimedia resource function MRF:**
- **Divided into MRFC and MRFP**
- **Announcements transmission**
- **Media stream mixing**
- **Providing virtual chatrooms and conference rooms**

- **Depending on the IMS implementation, it is possible that MRF is not implemented, services will be substituted by Application Servers!**

IMS: Architecture + functions

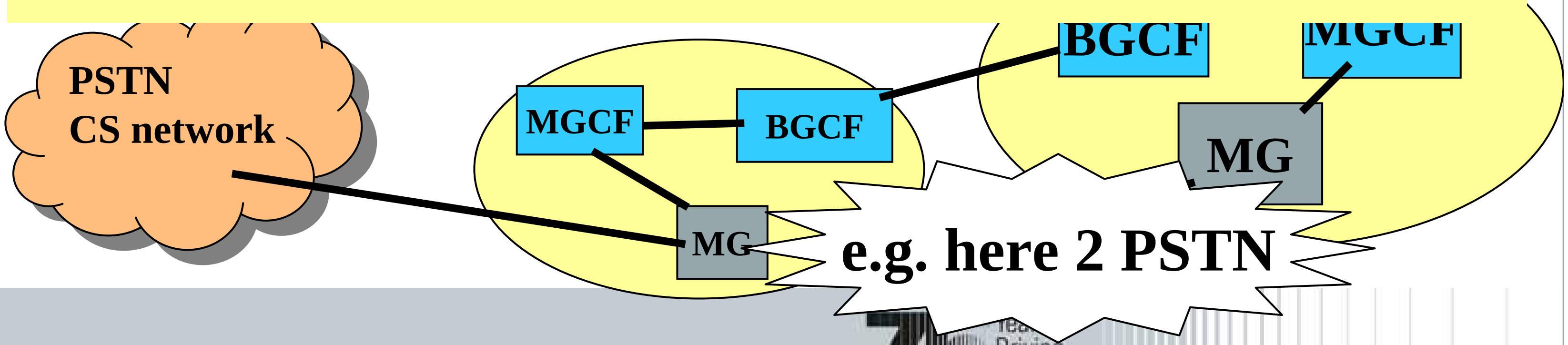
Multimedia Resource Function

Breakout Gateway Control Function, BGCF

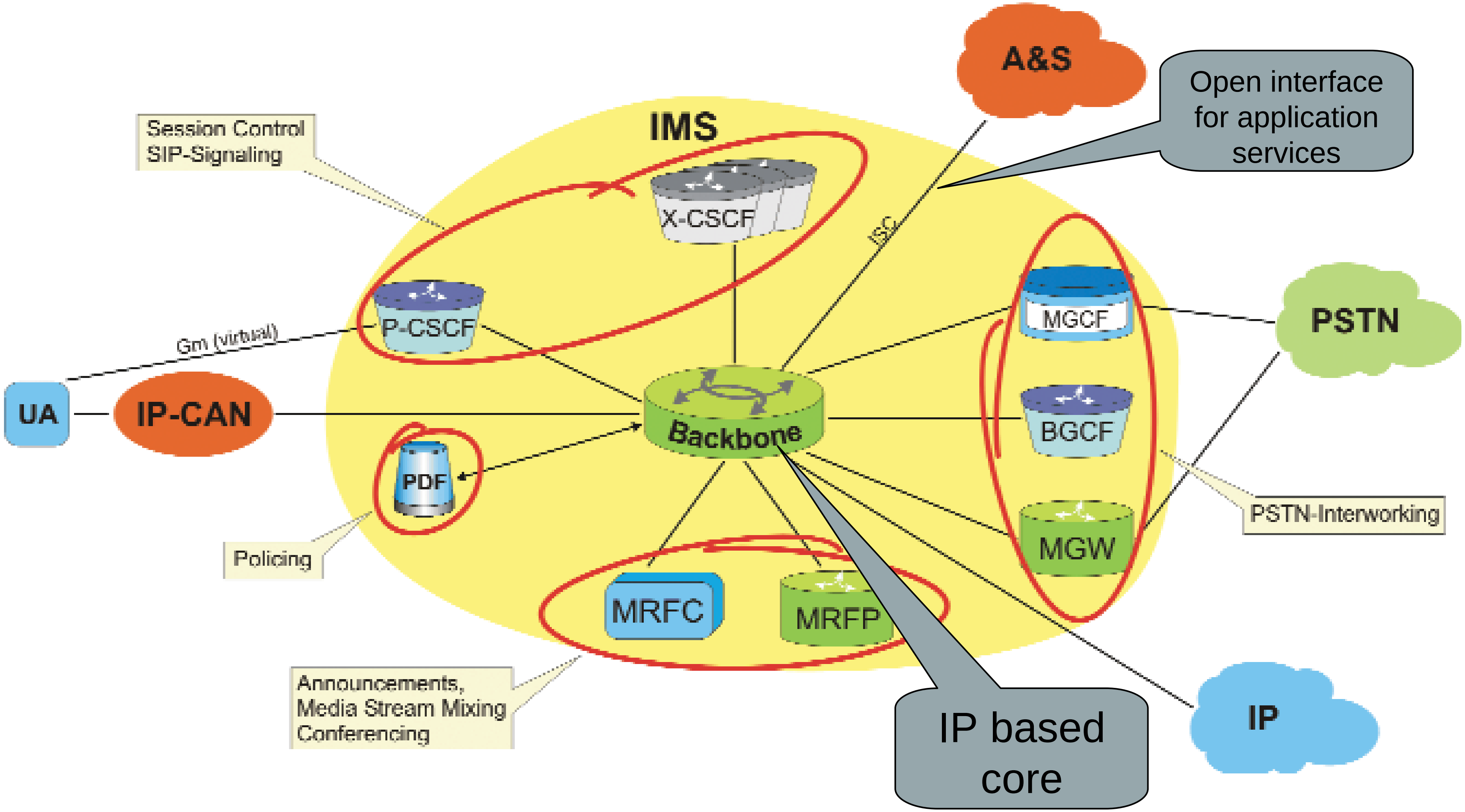
- •The Breakout Gateway control function (BGCF) selects the network in which PSTN/CS Domain breakout is to occur
- •selects a MGCF which will be responsible for the interworking with the PSTN/CS Domain
- •forward this session signalling to another BGCF
- •Generation of CDRs

Media Gateway Control Function, MGCF

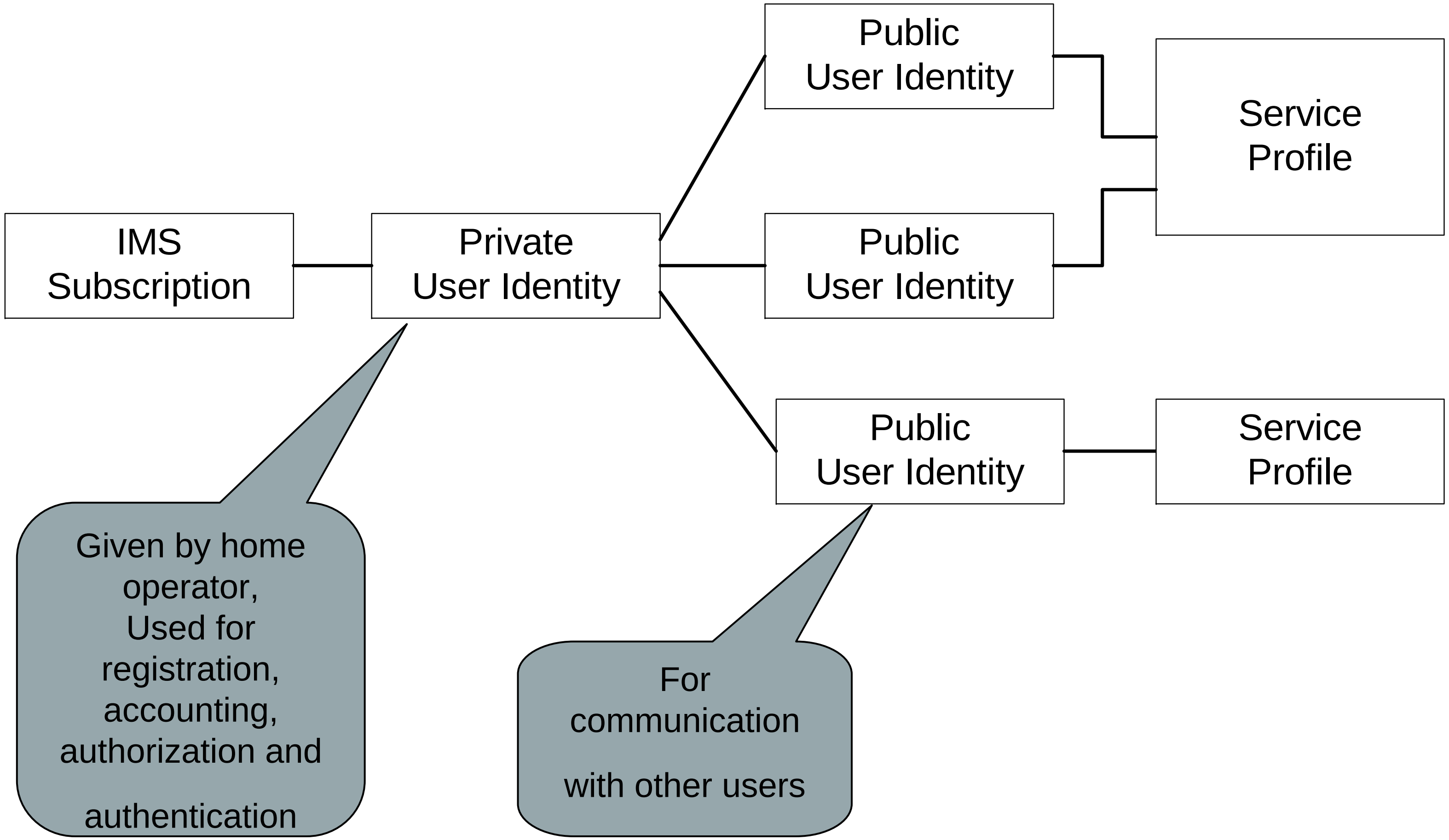
enables interwork with the CS networks, PSTN
codinng between IMS capabilities and PSTN
send or receive DTMF tone indications using the bearer, i.e. inband signalling



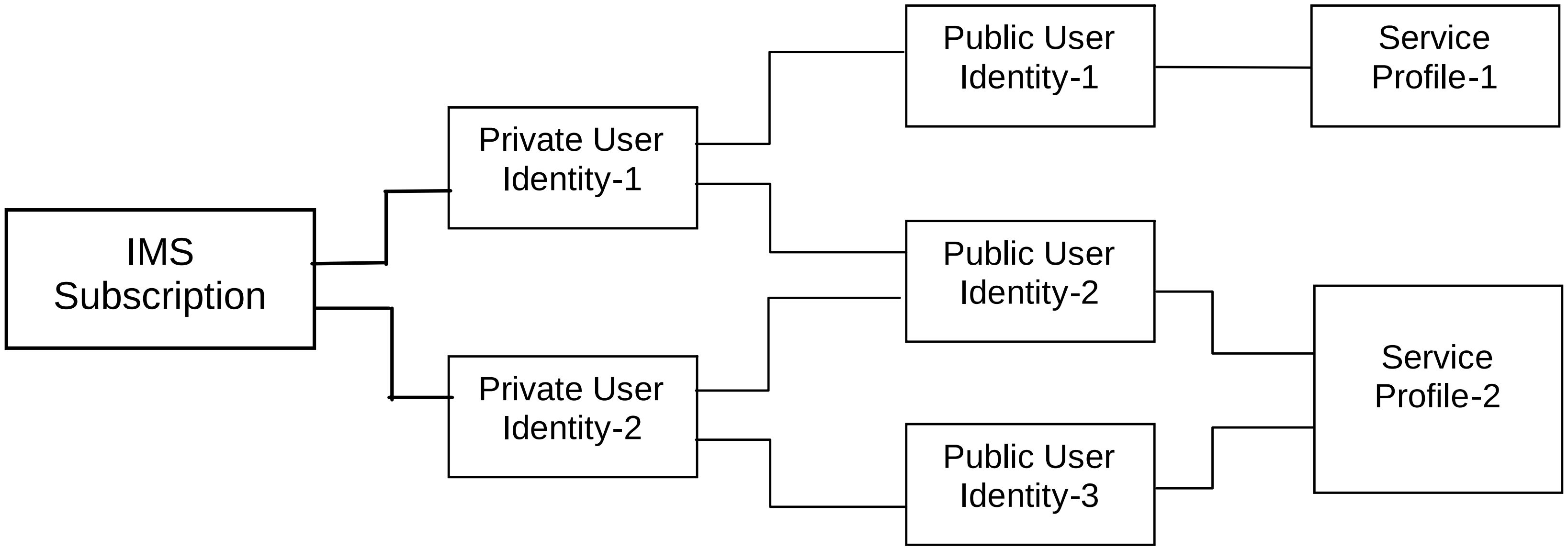
IMS structure and functions



IMS identities

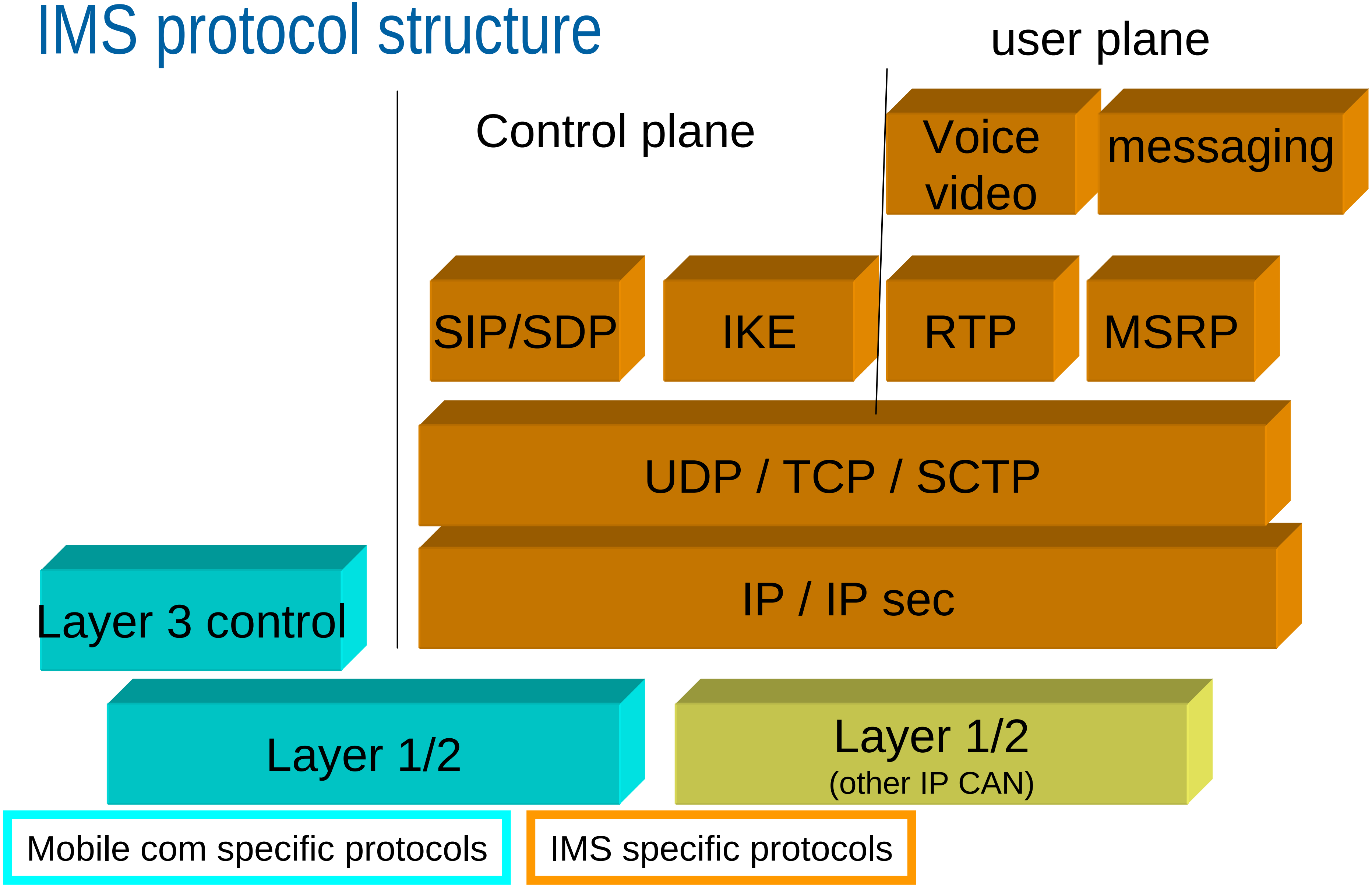


Shared identities



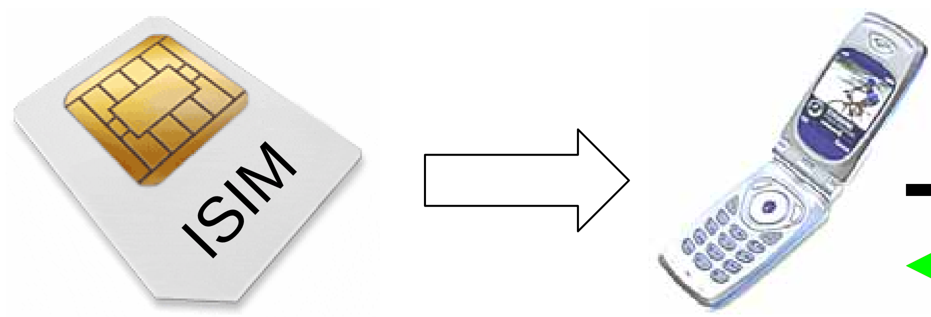
i.e. this allows a user to share identities, a paging call will
Be routed to a fixed telephone and to a
mobile device at same time

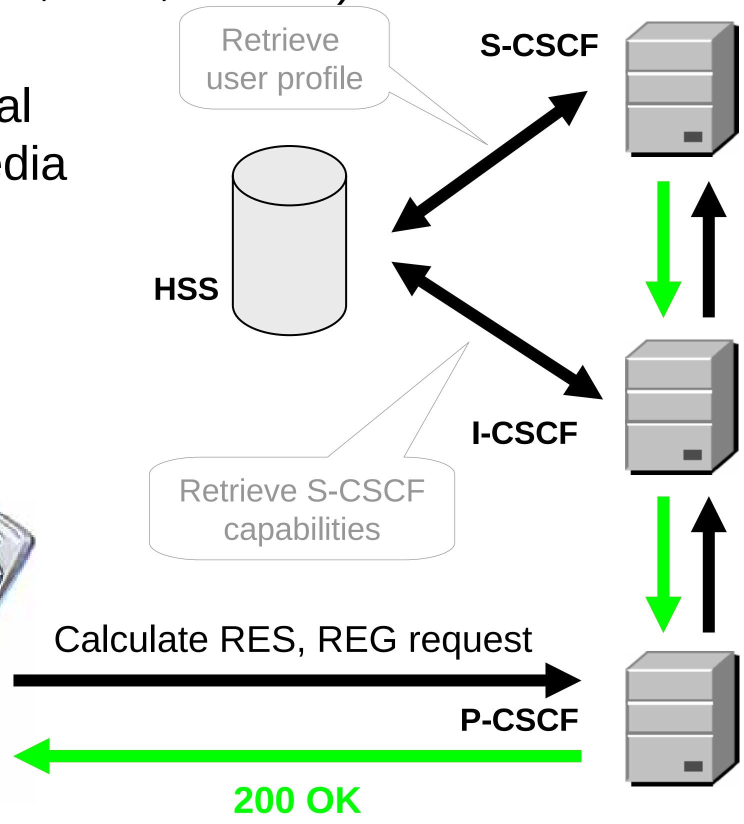
IMS protocol structure



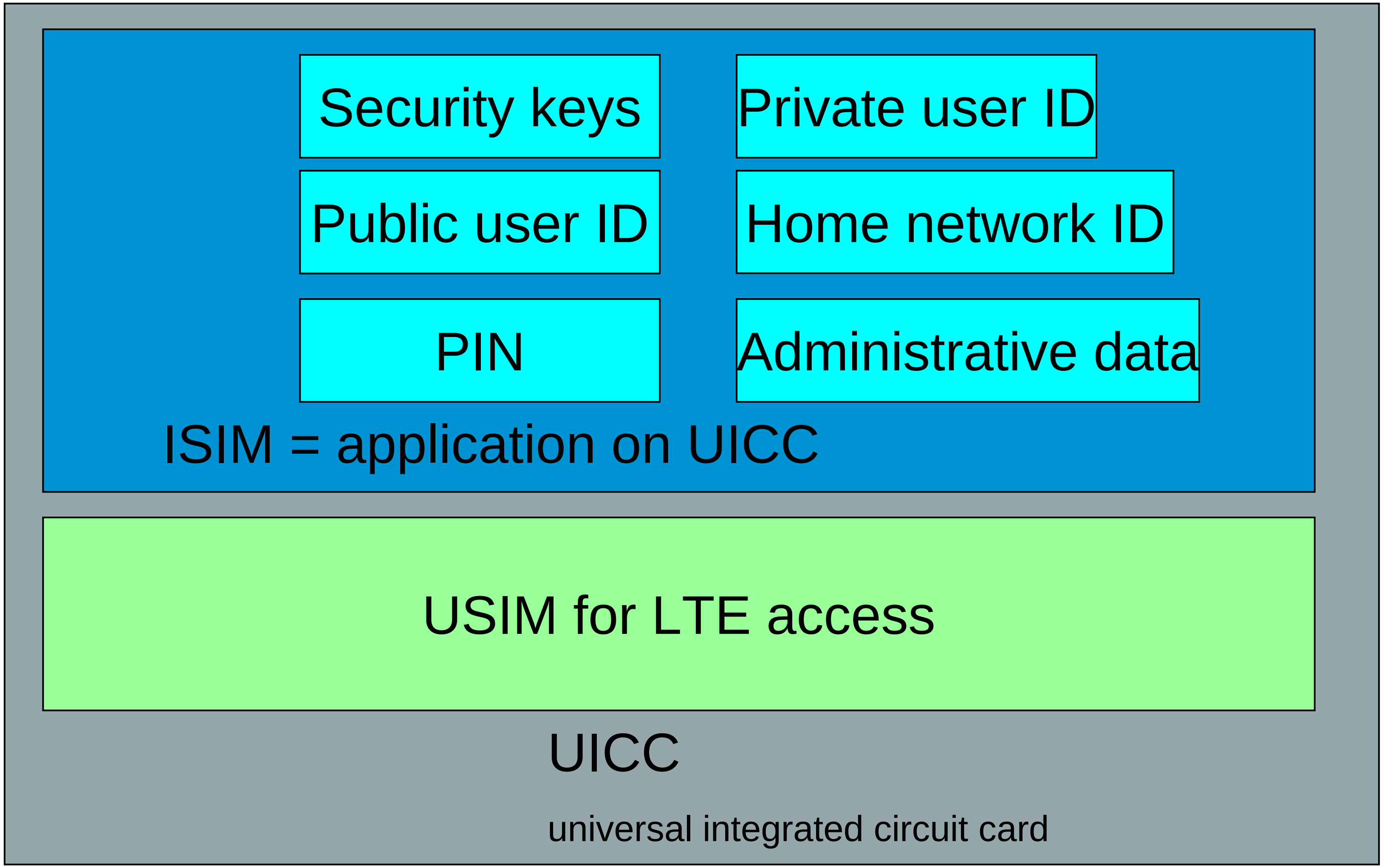
What is IMS?
Registration with IMS

- Prior to IMS registration the UE must discover an IMS entry point (i.e. P-CSCF), which is done through an activation of a PDP context for SIP signaling over 2G (GPRS) or 3G (WCDMA, C2K, EV-DO).
- First, there was SIM (Subscriber Identity Module)…than there was USIM (Universal SIM)…and now there is ISIM (IP Multimedia Service Module),
  – Public User Identity (identify a user),
  – Private User Identity (users subscription),

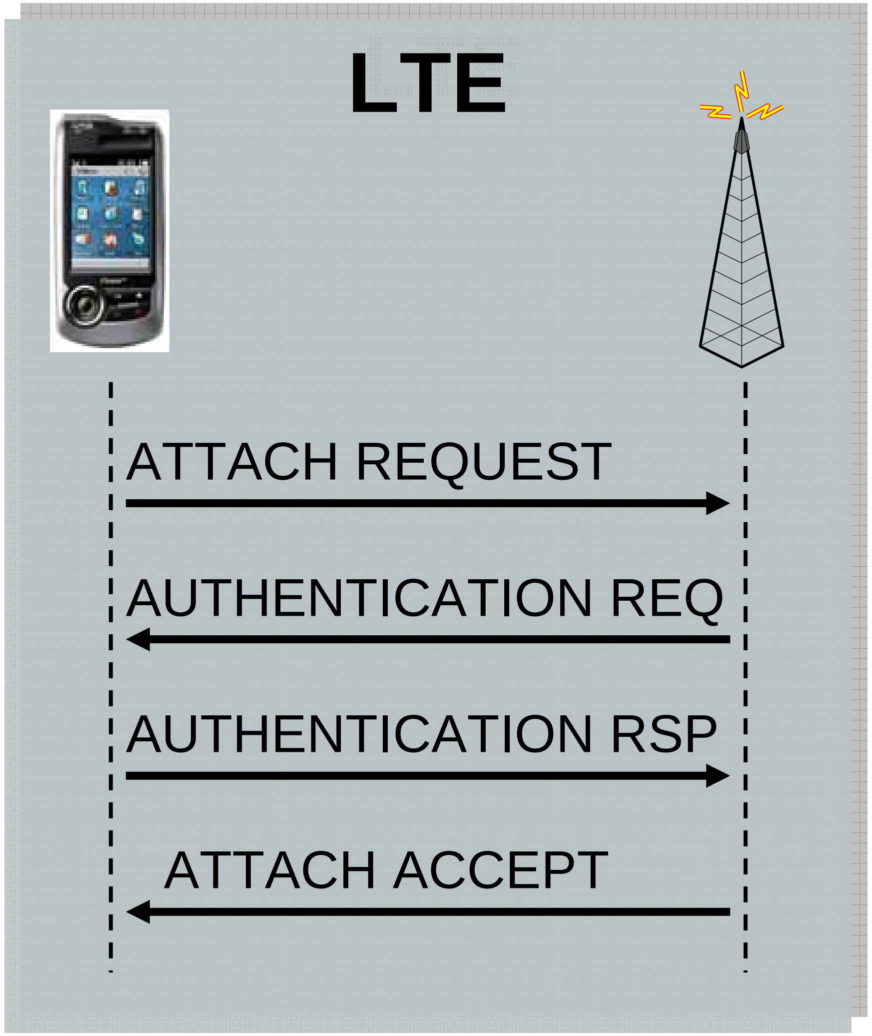


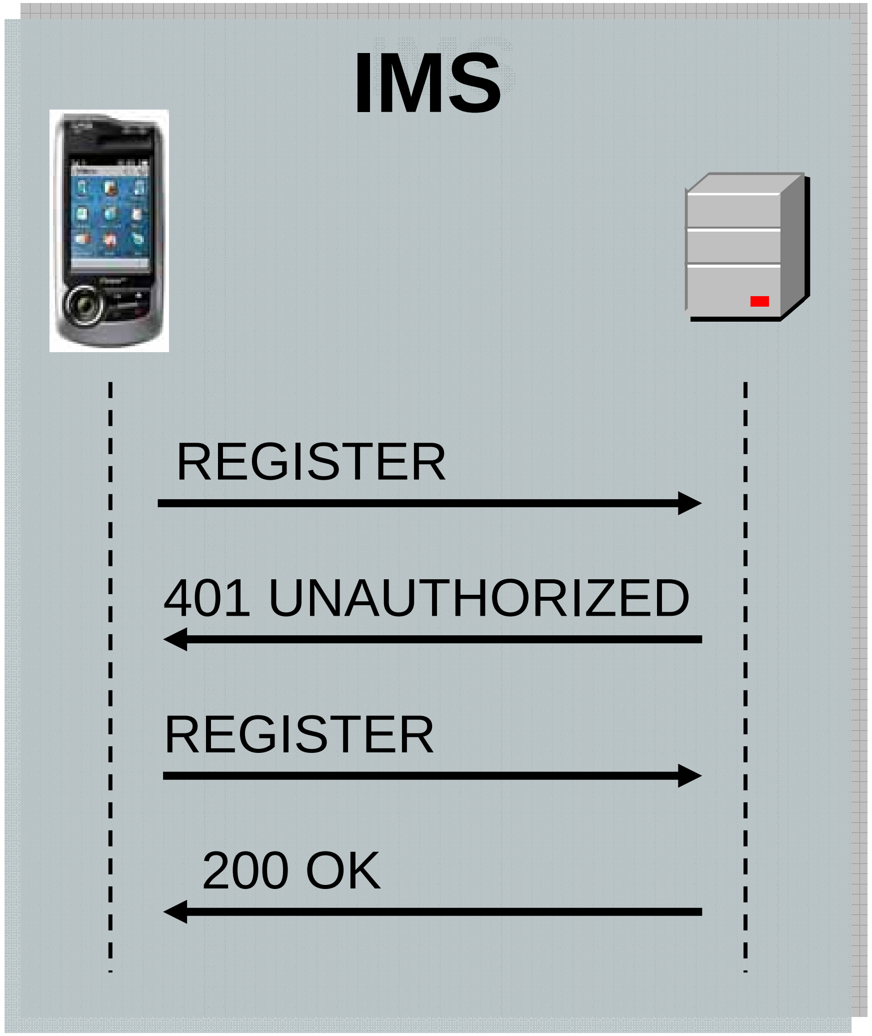


ISIM: IMS SIM


Security keys
Private user ID
Public user ID
Home network ID
PIN
Administrative data
ISIM = application on UICC
USIM for LTE access
UICC
universal integrated circuit card

IMS Registration and Authentication
Comparison with LTE





Architecture
P-CSCF discovery

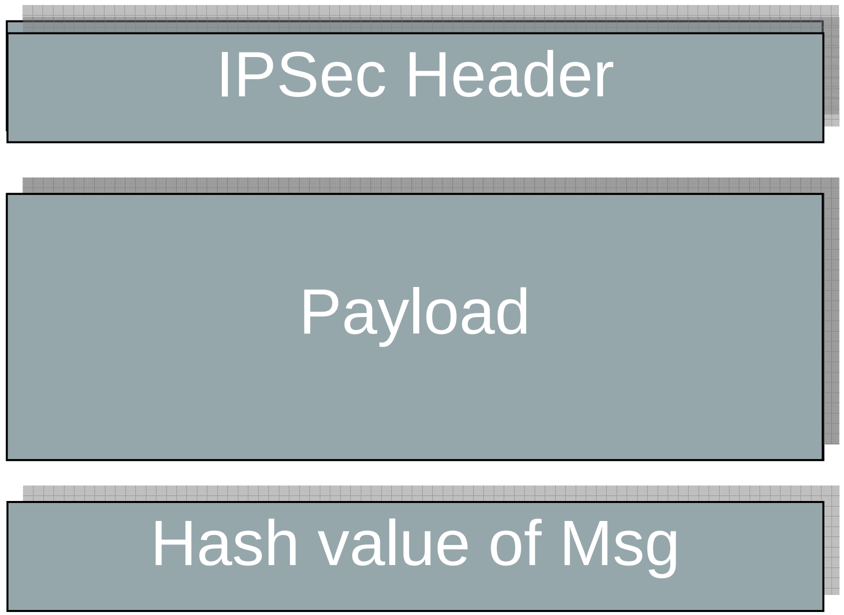
- **PDP Context**
  - The UE requests in the ActivatePDPContextRequest message via special IE the P-CSCF address
  - The network transmitts then in ActivatePDPContextAccept the address
- **DHCP / DNS**
  - UE sends special DHCP DISCOVER message and DHCP server returns either the hostname or IP address of the P-CSCF
  - In case a host name is returned by the DHCP hostname a DNS lookup follows
- **ISIM**
  - P-CSCF is stored in the ISIM (IMS SIM)

Architecture
IPv6

- **Currently operators can provide private IP addresses to UEs and route them via NAT in the internet**
  - Problem: UE is not addressable from the internet
- **IMS requires that media flows directly from UE to UE**
  - both UEs must be addressable from outside the operator network
- **To address every network node directly with an unique IP Address IPv6 is needed**

Architecture
IPSec

- **To enable authentication, integrity (R5) and confidentiality (>=R6) between UE and network IPSec is needed**
- **IPSec provides**
  - Integrety (Hash)
  - Confidentiality (Encyption)
  - Authentication (Hash)
- **IPSec Keys are based on shared secrets (SIM + HSS)**



IMS Applications
Videosharing

- **IMS Video sharing is a standard defined by GSMNA**
- **Parallel to a CS voice call an unidirectional IMS video session can be established**
- **The use case is to send live video to the other call participant**
- **Video sessions can be established in both directions and started and stopped several times during a call**
- **First IMS service in a live network**

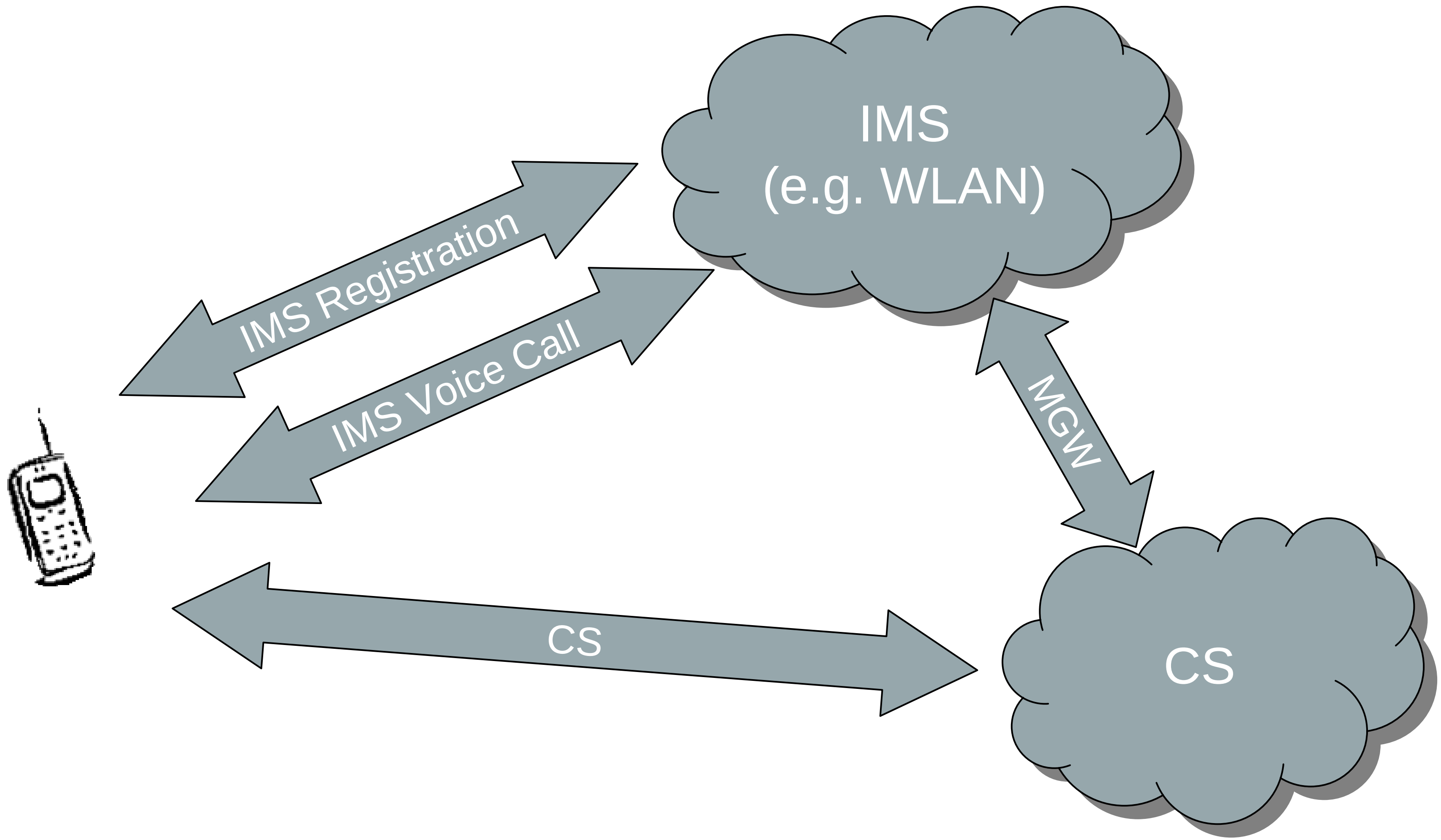
IMS Applications
MTSI – Multimedia Telephony Services for IMS

- **Release 7 introduces MTSI**
- **MTSI includes**
  - Supplementary Services (Call Hold, Call Barring, …)
  - More specific codec requirements for voice, video and text sessions
  - Dynamic multimedia session handling
    - E.g. start with a voice call and add video session later

IMS Applications
Voice Call Continuity - VCC

- **VCC is specified by 3GPP (Rel7)**
- **VCC describes the hand-over of a CS voice call between CS domain and PS domain.**
- **First Use case is the handover between 2G/3G to WLAN.**
- **VCC is specified as handover between 2G/3G and LTE.**
- **VCC is an Application Server in the IMS network.**
- **Hand-over is only triggered by the UE**

IMS Applications
Voice Call Continuity - VCC



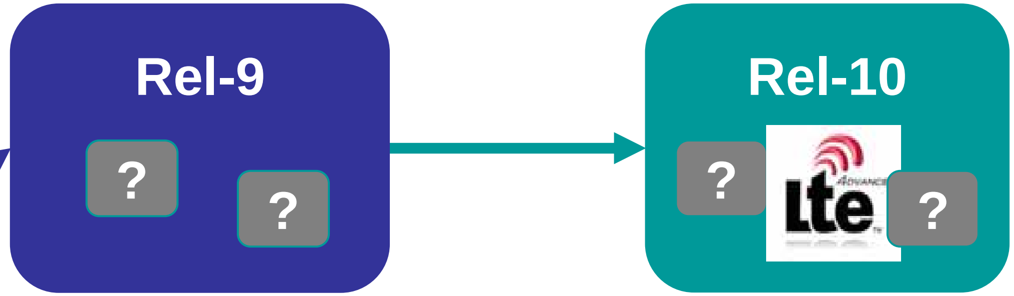
IMS emergency call

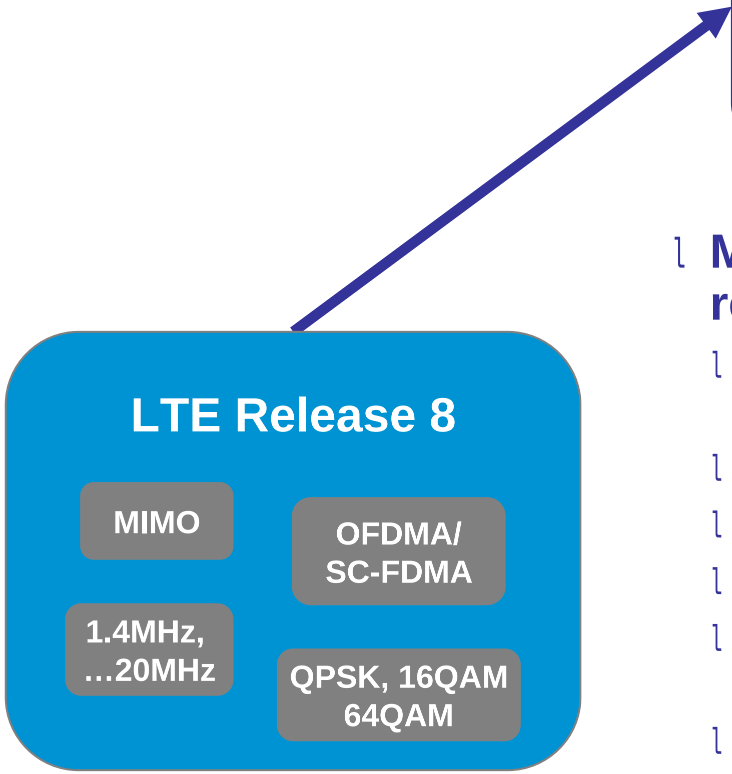
- UE can select to perform emergency call on CS or IMS network
- UE performs emergency registration: REGISTER message contains emergency public user ID
- UE establishes session with INVITE message, containing emergency number and public UE identity
- If available, UE includes location information in the INVITE message
- Anonymous emergency session is possible, without pre-registration

IMS Applications

- **OMA is defining several IMS-based applications**
  - Push to Talk over Cellular
  - Instant Messaging
  - Presence
  - Converged IP Messaging (CPM)
- **SMS-over-IP**
  - In a pure PS domain (WLAN or LTE) Short messages can't be delivered
  - To reduce transcoding effort the binary encoded SMS is transmitted in the body of SIP messages

The LTE evolution path





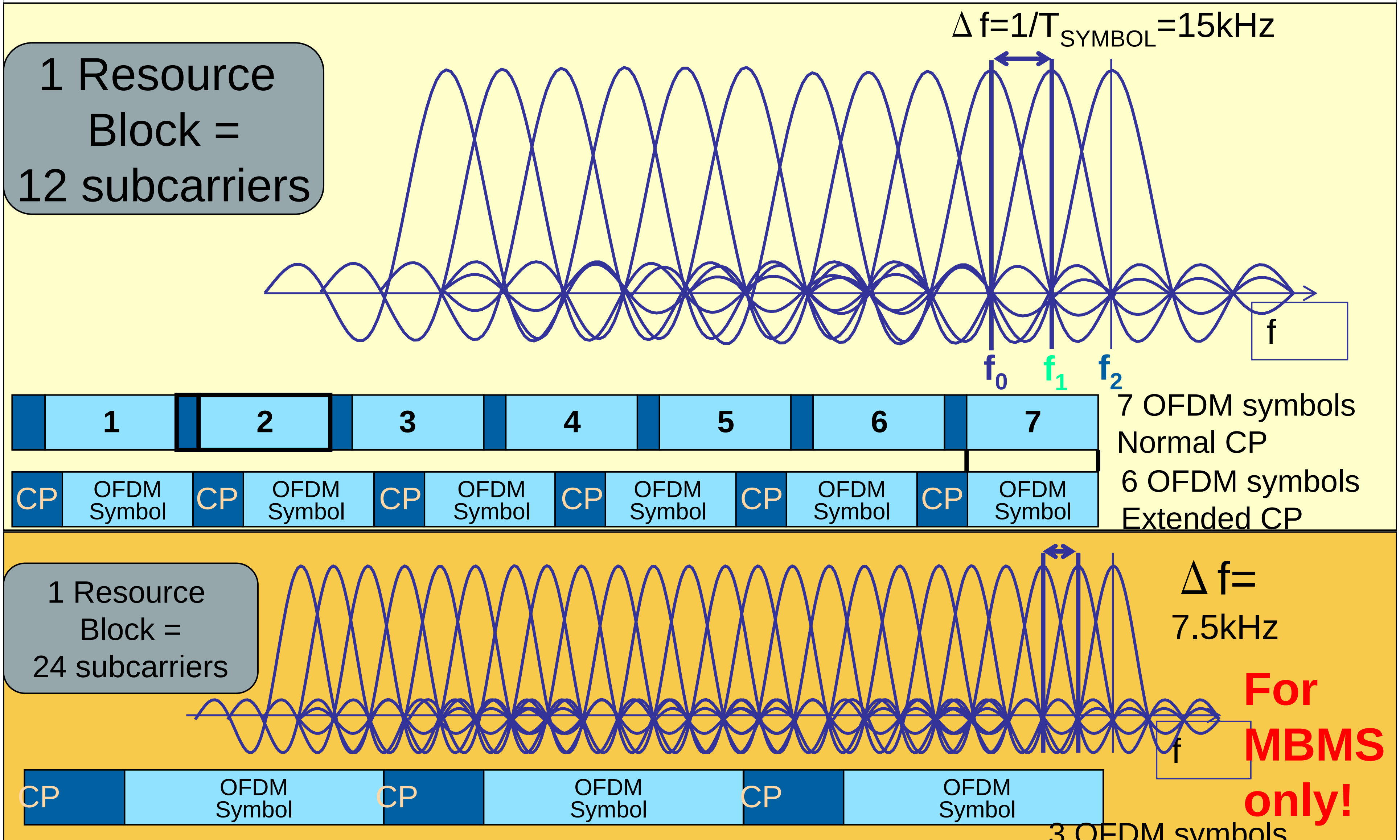
- **Mainly the following 3GPP Release 9 features related to the air interface,**
  - Multimedia Broadcast Multicast Services (MBMS) for LTE,
  - LTE MIMO: dual-layer beamforming,
  - LTE positioning
  - PWS (Public Warning System)
  - RF requirements for multi-carrier and multi-RAT base stations,
  - Home eNodeB specification (femto-cell),
  - Self–Organizing Networks (SON).

LTE Release 9

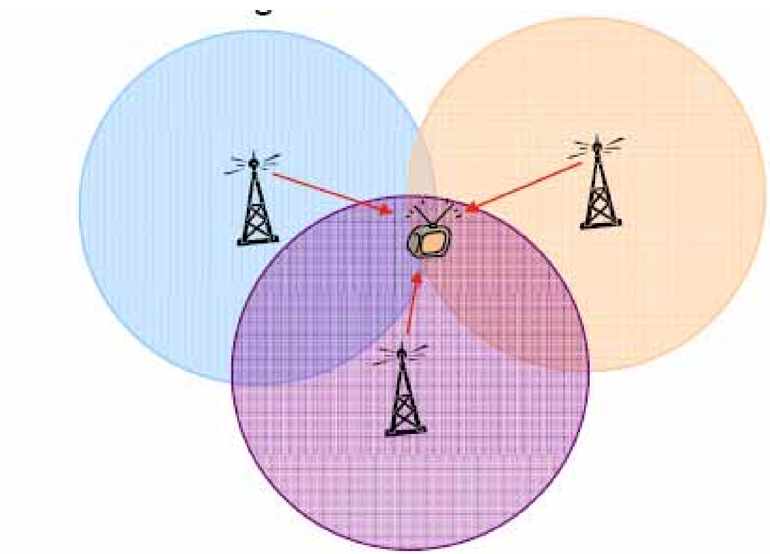
Enhanced Multimedia Broadcast Multicast Services

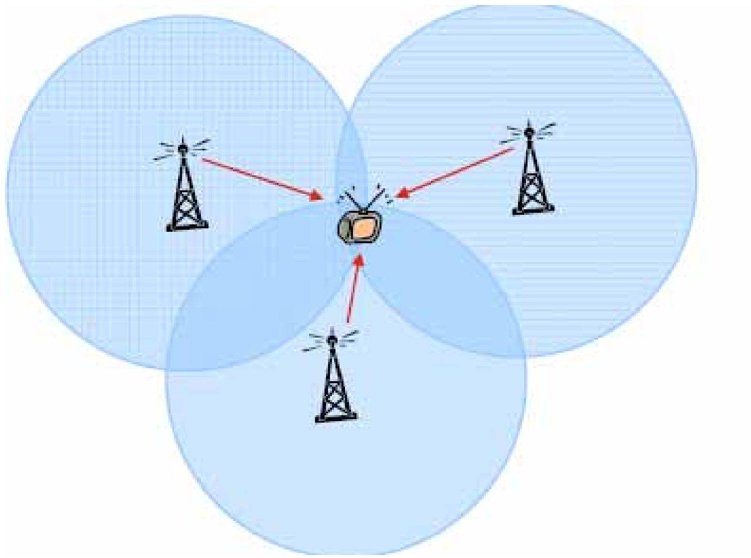
- **MBMS is not new, it has been first specified with 3GPP Release 6,**
  - Optimized transmission of broadcast / point-to-multipoint services,
  - MBSFN – Multimedia Broadcast multicast service Single Frequency Network is set up; all cells belonging to that area transmit time-synchronized → base station (eNBs) need to be time synchronized,
- **Mix of unicast / point-to-point transmissions and MBSFN transmissions; scheduling under network responsibility,**
- **Impact on PHY layer, already available with 3GPP Release 8, higher layer and architectural aspects now with 3GPP Release 9,**
  - Subcarrier spacing Δf = 7.5 kHz,
  - Cyclic prefix = 33.3 µs (1024 samples),
  - 3 OFDM symbols per slot,
  - MBSFN subframes are divided into a MBSFN and non-MBSFN region,
  - Physical Multicast Channel (PMCH) carries MBMS user and control data,
  - Modified reference signal structure compared to common PDSCH transmissions.

Resource block definition for LTE and LTE$_{\text{-MBMS}}$



MBSFN – MBMS Single Frequency Network

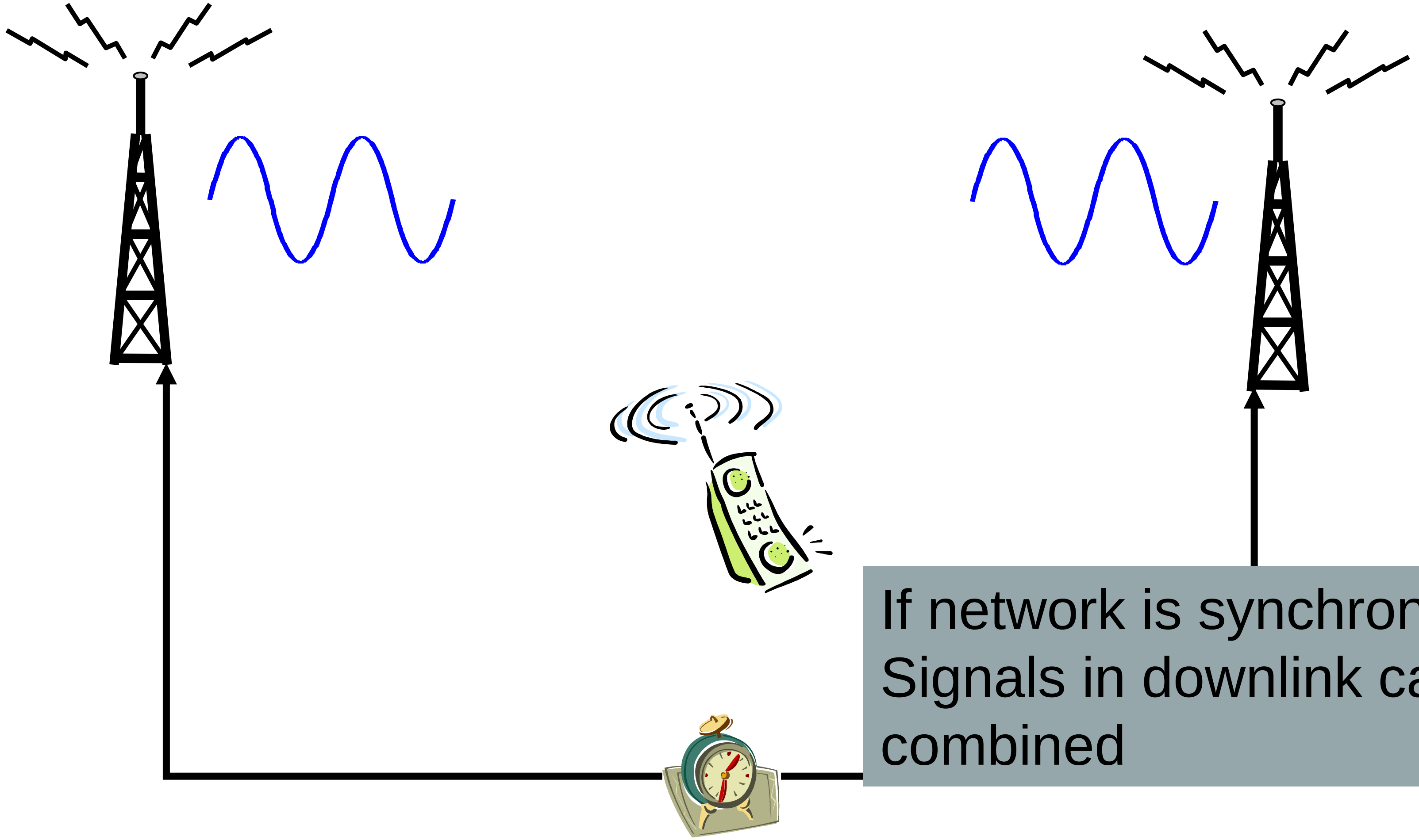




Mobile communication network each eNode B sends individual signals

Single Frequency Network each eNode B sends identical signals

MBSFN



If network is synchronised, Signals in downlink can be combined

LTE Release 9
Dual-layer beamforming

- **3GPP Rel-8 – Transmission Mode 7 = beamforming without UE feedback, using UE-specific reference signal pattern,**
  - Estimate the position of the UE (Direction of Arrival, DoA),
  - Pre-code digital baseband to direct beam at direction of arrival,
  - ***BUT*** single-layer beamforming, only one codeword (TB),

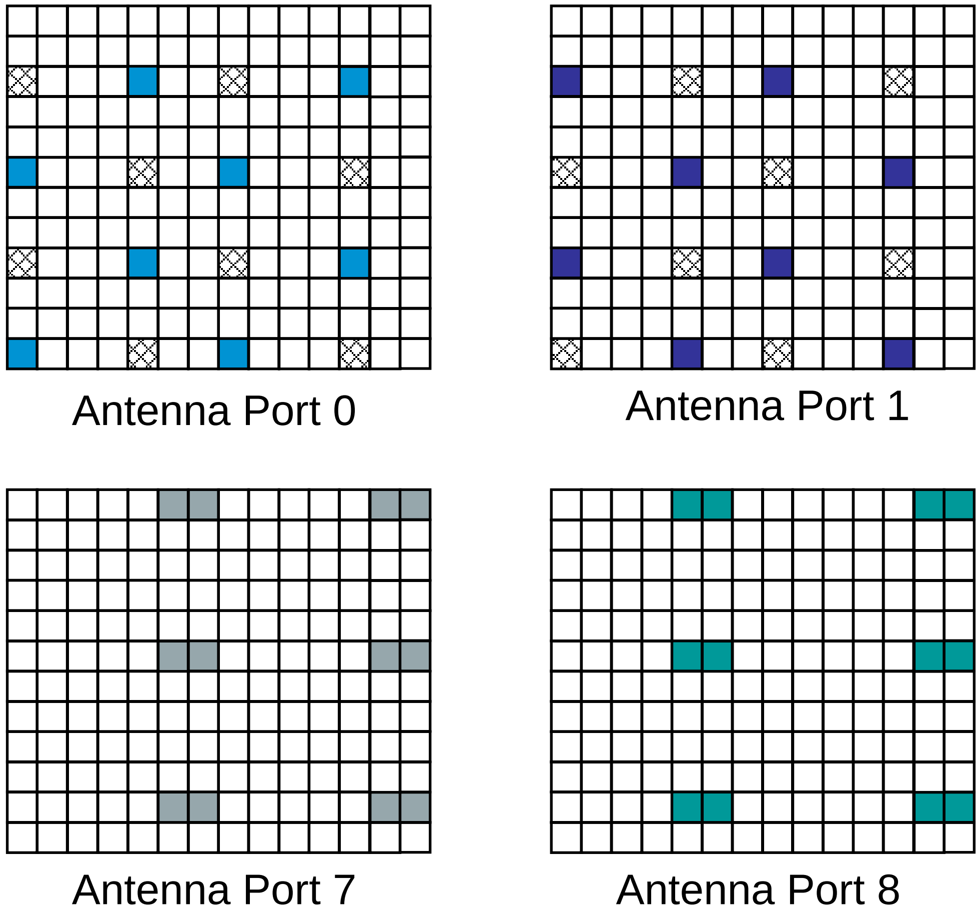
- **3GPP Rel-9 – Transmission Mode 8 = beamforming with or without UE feedback (PMI/RI) using UE-specific reference signal pattern, *but* dual-layer,**
  - Mandatory for TDD, optional for FDD,
  - 2 (new) reference signal pattern for two new antenna ports 7 and 8,
  - New DCI format 2B to schedule transmission mode 8,
  - Performance test in 3GPP TS 36.521 Part 1 (Rel-9) are adopted to support testing of transmission mode 8.

LTE Release 9

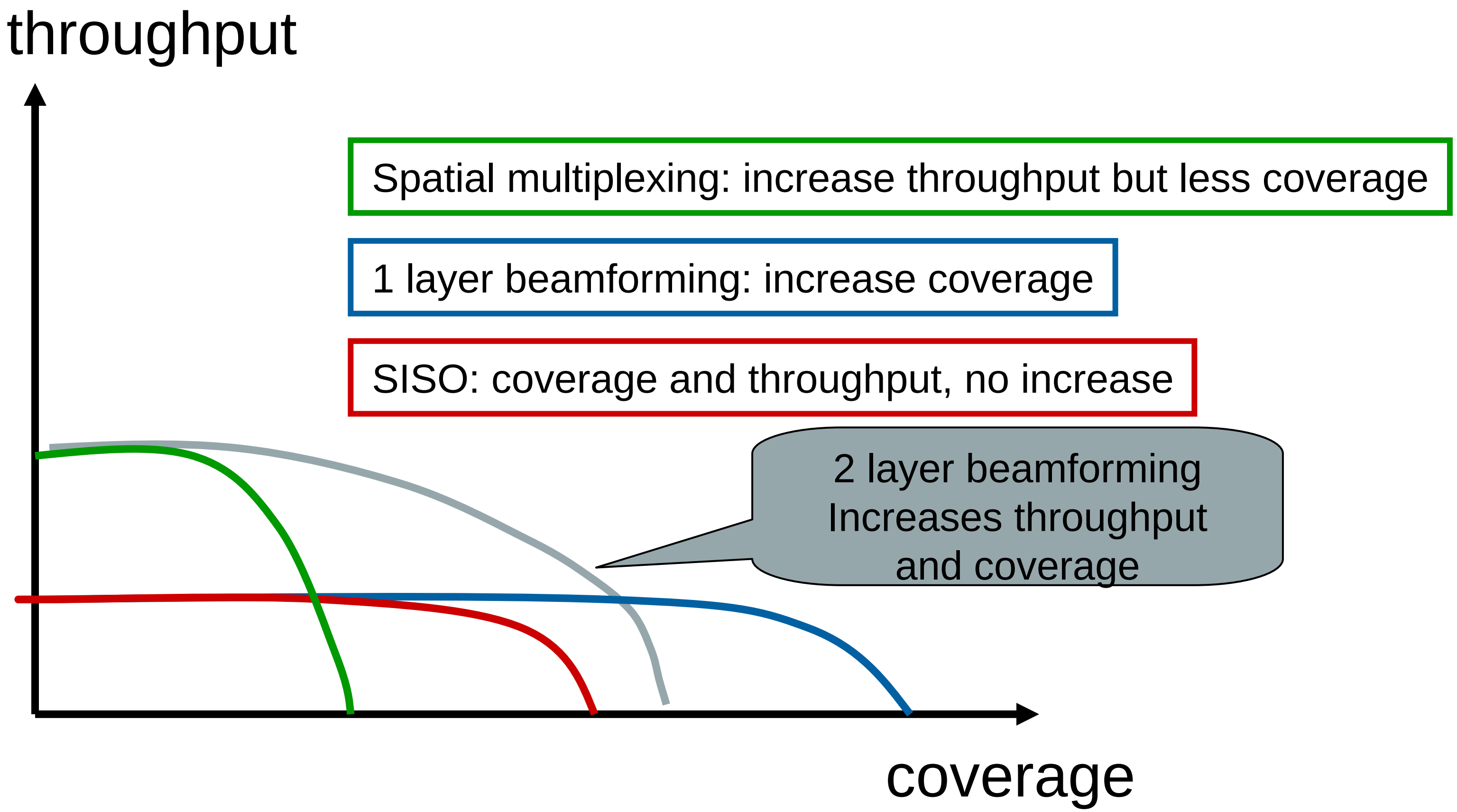
Dual-layer beamforming – Reference Symbol Details

- **Cell specific antenna port 0 and antenna port 1 reference symbols**

- **UE specific antenna port 7 and antenna port 8 reference symbols**



2 layer beamforming

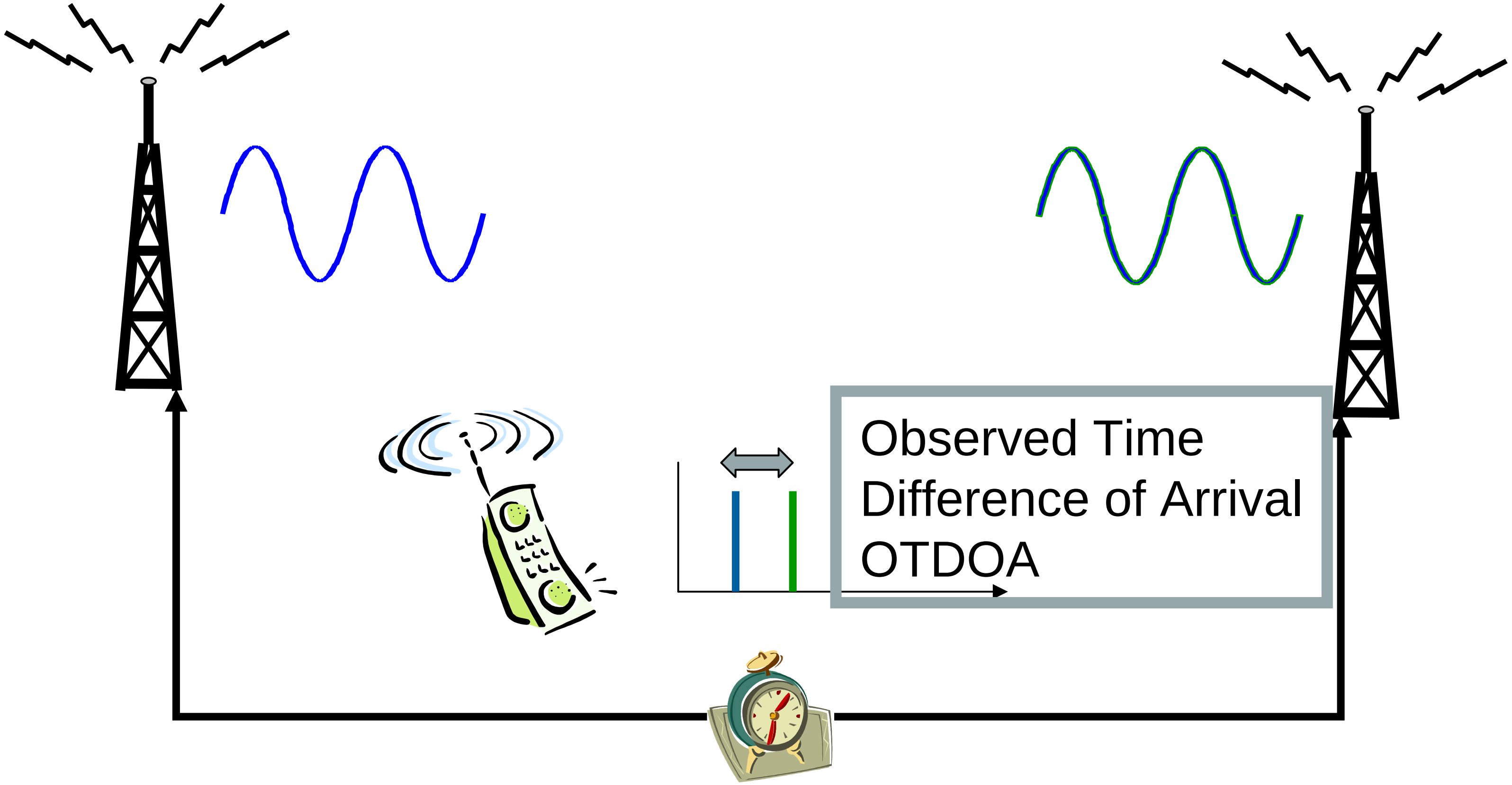


Spatial multiplexing increases throughput, but looses coverage

LTE Release 9
LTE positioning

- **The standard positioning methods supported for E-UTRAN access are:**
  - network-assisted GNSS (Global Navigation Satellite System) methods
    - These methods make use of UEs that are equipped with radio receivers capable of receiving GNSS signals, e.g. GPS.
  - downlink positioning
    - The downlink (OTDOA – Observed Time Difference Of Arrival) positioning method makes use of the measured timing of downlink signals received from multiple eNode Bs at the UE. The UE measures the timing of the received signals using assistance data received from the positioning server, and the resulting measurements are used to locate the UE in relation to the neighbouring eNode Bs.
  - enhanced cell ID method
    - In the Cell ID (CID) positioning method, the position of an UE is estimated with the knowledge of its serving eNode B and cell. The information about the serving eNode B and cell may be obtained by paging, tracking area update, or other methods.

Observed Time difference



If network is synchronised,
UE can measure time difference

LTE Release 9

LTE Positioning - General

- **Positioning using a method based on time measurements requires that the timing of at least three geographically dispersed base stations is measured.**
  - In practice it is favorable to be able to measure, say, five base stations, since the three strongest sites don’t necessarily provide a good geometry for position determination

- **RAN1 concluded that available reference symbols are not sufficient to provide require accuracy of positioning**
  - Hence, new positioning reference signals (PRS) are defined

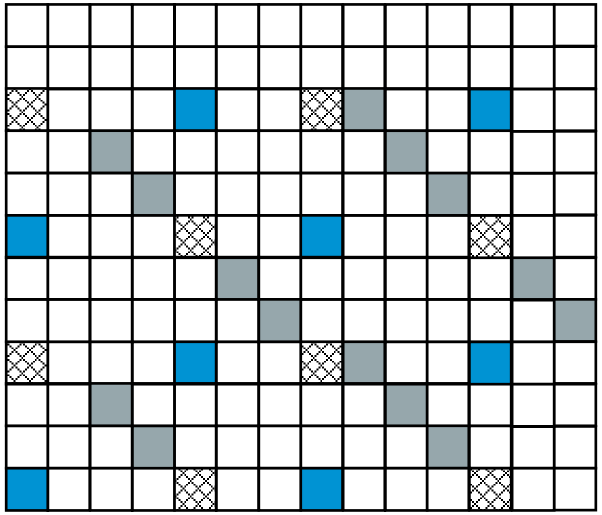
- **New measurements have been specified to support positioning**

- **A new LTE Positioning Protocol (LPP) has been specified (RAN2)**

LTE Release 9

UE positioning – Reference Symbol Details

- **PRS is a pseudo-random QPSK sequence similar to CRS**
- **PRS pattern (baseline for further discussion and CR drafting):**
  - **Diagonal pattern with time varying frequency shift,**
  - **PRS mapped around CRS (to avoid collisions)**

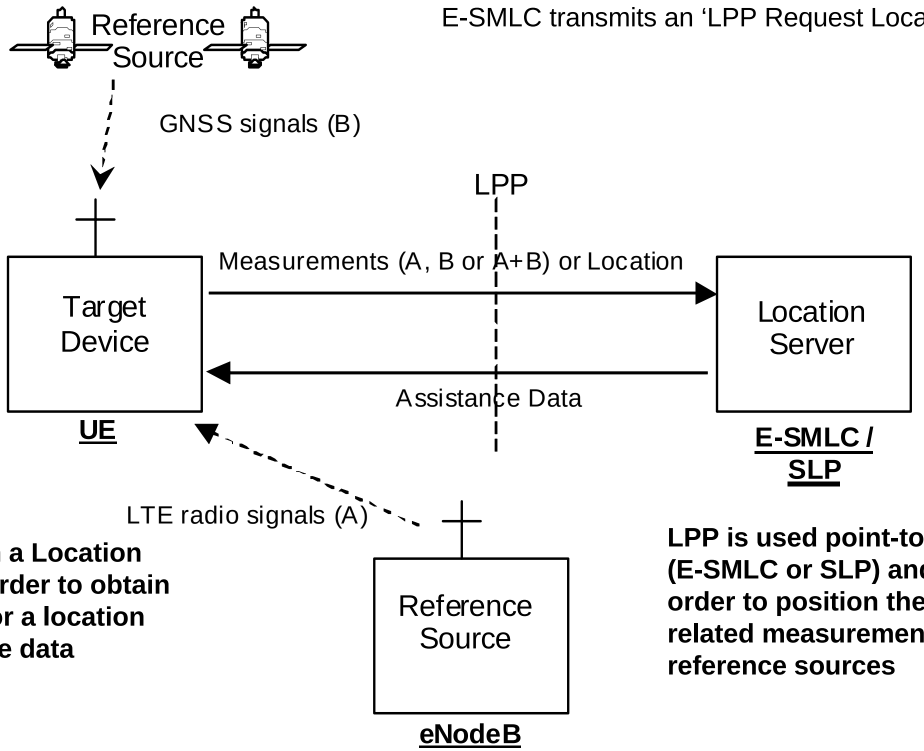


Antenna Port 0

LTE Release 9

Positioning support for LTE - Architecture

E-SMLC transmits an ‘LPP Request Location Information message’ to UE



An LPP session is used between a Location Server and the target device in order to obtain location related measurements or a location estimate or to transfer assistance data

LPP is used point-to-point between a location server (E-SMLC or SLP) and a target device (UE or SET) in order to position the target device using position-related measurements obtained by one or more reference sources

OTDOA, A-GNSS, and E-CID positioning methods

LTE Release 9

LTE positioning – New Measurements

- **UE measurements**
  - Reference signal time difference (RSTD) - relative timing difference between cells
  - UE GNSS Timing of Cell Frames for UE positioning - the timing between a cell and a GNSS-specific reference time for a given GNSS (e.g. GPS/Galileo/… system time)
  - UE GNSS code measurements - The GNSS code phase (integer and fractional parts) of the spreading code of the GNSS satellite signal
  - UE Rx – Tx time difference – UE UL/DL time difference

- **eNodeB measurements**
  - Timing Advance (T_{ADV})
  - eNB Rx – Tx time difference
  - E-UTRAN GNSS Timing of Cell Frames for UE positioning - the time of the occurrence of a specified LTE event according to a GNSS-specific reference time for a given GNSS (e.g., GPS/Galileo/…). The specified LTE event is the beginning of the transmission of a particular frame (identified through its SFN) in the cell.
  - Angle of Arrival (AOA)

LTE Release 9

RF requirements for multi-carrier and multi-RAT base stations

- **Multi-carrier and Multi-Standard Radio (MSR) base stations natural consequence of the multitude of cellular deployment scenarios,**
- **New specification (3GPP TS 37.104) to clarify which RF requirements have to be supported by these base stations,**
  - E-UTRA, UTRA and GSM/EDGE standards are addressed,
  - Operating bands have been categorized,
    - Category 1 – E-UTRA FDD and UTRA FDD,
    - Category 2 – E-UTRA FDD, UTRA FDD, GSM/EDGE,
    - Category 3 – E-UTRA TDD, UTRA-TDD,


3GPP TS 37.104 V9.1.0 (2010-03)

Technical Specification

3rd Generation Partnership Project;
Technical Specification Group Radio Access Networks;
E-UTRA, UTRA and GSM/EDGE;
Multi-Standard Radio (MSR) Base Station (BS) radio
transmission and reception
(Release 9)

LTE Release 9

Public Warning System (PWS)

- **Extend the Warning System support of the E-UTRA/E-UTRAN beyond that introduced in the Release 8 ETWS (Earthquake and Tsunami Warning System) by providing**
  - **E-UTRA/E-UTRAN support for multiple parallel Warning Notifications**
  - **E-UTRAN support for replacing and canceling a Warning Notification**
  - **E-UTRAN support for repeating the Warning Notification with a repetition period as short as 2 seconds and as long as 24 hours**
  - **E-UTRA support for more generic "PWS" indication in the Paging Indication**

- **The requirement is to extend the UE RRC ETWS broadcast reception mechanism and the associated paging mechanism to accommodate reception of CMAS (Commercial Mobile Alert System) alerts contained in a CBS message.**

- **New: TS 22.268 Public Warning System (PWS) Requirements (Release 9)**

LTE Release 9

Home eNodeB specification (femto-cell)

- **Prime objectives,**
  - Improve indoor coverage and increased data rates,
- **Challenge – Think about 1000+ femto-cells switched ON at one point in time,**
  - Typically associated with uncoordinated and large scale deployment, thus requiring specific thoughts on interference protection of macro deployments,
- **Specification of different base station classes (wide area, local area, home BS), basically providing RF requirements for FDD and TDD,**
  - Transmitter: BS output power, unwanted emissions, frequency error, intermodulation, protection of E-UTRA and UTRA operation in adjacent channels,
  - Receiver: Sensitivity, dynamic range, in-channel and adjacent channel selectivity, blocking, intermodulation,

LTE Release 9

Self–Organizing Networks (SON)

- **Complexity in network deployment and operation has increased**
  - Multi-technology environments (LTE, CDMA2000/1xEV-DO, WCDMA/HSPA),
  - Advanced radio interface features and high number of different parameters
  - High number of new network elements due to expected Home eNB roll-out,
  - Tight spectrum usage,

- **GOAL? Decrease CAPEX & OPEX!**
  - Three different use cases,
    - **Self-Configuration.** Automatic recognition and configuration of a new base station. The base station will automatically set its basic parameters, identify its neighbors and establish a relation to them.
    - **Self-Optimization.** Continuous optimization and fine tuning of network (i.e. adjusting neighbor cell lists and handover parameter); measurement of terminals and base stations are evaluated,
    - **Self-Healing.** Algorithms to detect and correct faults automatically, i.e. cell outage.

LTE Release 9

Self–Organizing Networks (SON) in LTE Rel8 and Rel9

- **LTE Rel8**
  - The use cases for release 8 are mainly for Self Configuration. Here, configuration is meant for initial configuration before the RF is switched on.
    - Automated Configuration of Physical Cell Identity
    - Automatic Neighbour Relation Function

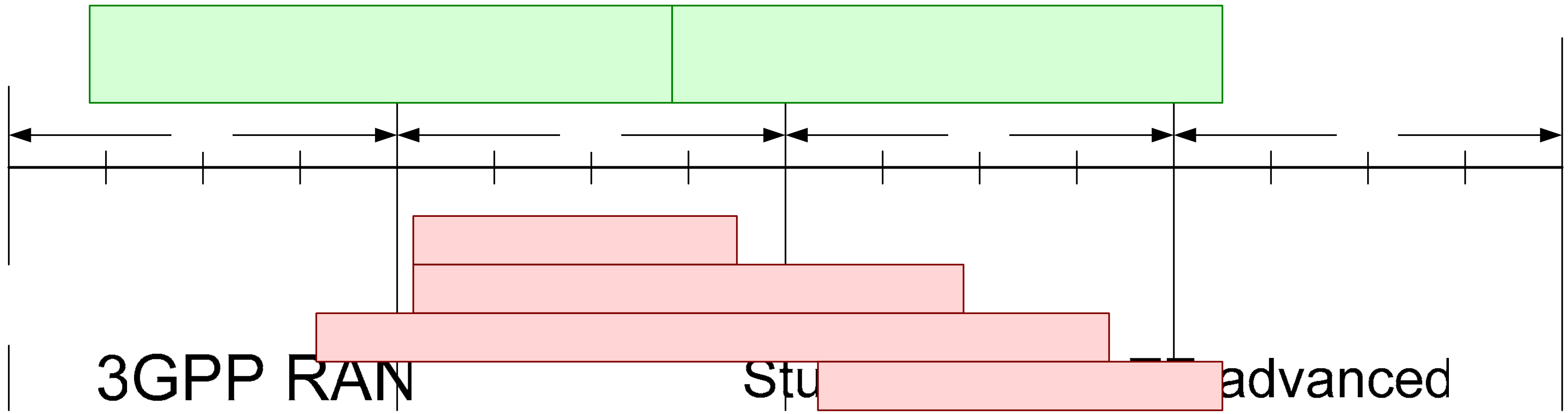
- **LTE Rel9**
  - Whereas the use cases for release 8 was concentrating on the self configuration, there is support for the self optimization in release 9.
    - Mobility Robustness Optimization
    - Mobility Load Balancing Optimization
    - RACH Optimization

IMT-Advanced Requirements

- **A high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner,**
- **Compatibility of services within IMT and with fixed networks,**
- **Capability of interworking with other radio access systems,**
- **High quality mobile services,**
- **User equipment suitable for worldwide use,**
- **User-friendly applications, services and equipment,**
- **Worldwide roaming capability; and**
- **Enhanced peak data rates to support advanced services and applications,**
  - 100 Mbit/s for high and
  - 1 Gbit/s for low mobility

were established as targets for research,

Schedule study/work item for LTE-Advanced



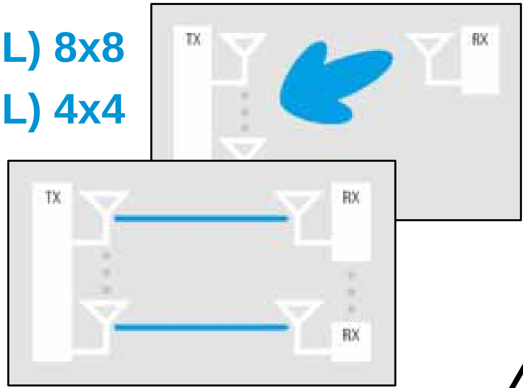
- An “Early Proposal” submission was sent to ITU-R at RAN #41 (9-12 September 2008)
- A “Complete Technology” submission was sent to ITU-R at RAN #44 (26-29 May 2009)
- A “Final” submission to incorporate updates, additional specific details or feature additions, *and* the required self-evaluation was sent to ITU-R at RAN #45 (22-25 September 2009)
- ITU-R Confers IMT-Advanced (4G) Status to 3GPP LTE (Oct. 2010)

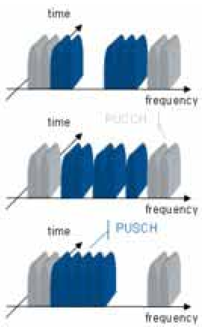
LTE-Advanced

Feature overview

MIMO (DL) 8x8

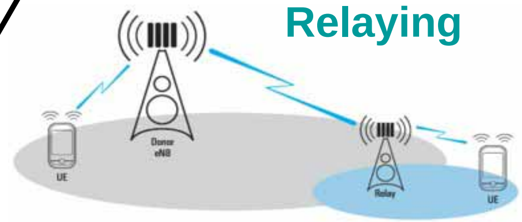
MIMO (UL) 4x4



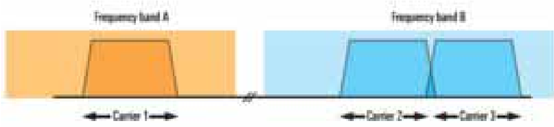


Enhanced SC-FDMA

Relaying



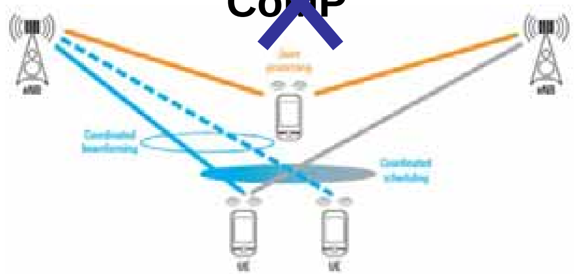
Carrier Aggregation



ICIC

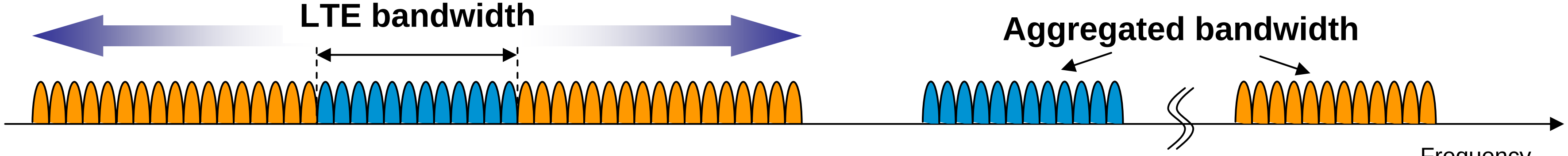
InterCell
Interference
Coordination

~~CoMP~~



LTE-Advanced
Carrier Aggregation

- Two or more component carriers are aggregated in LTE-Advanced in order to support wider bandwidths of up to 100 MHz,
  - Support for contiguous and non-contiguous component carriers,

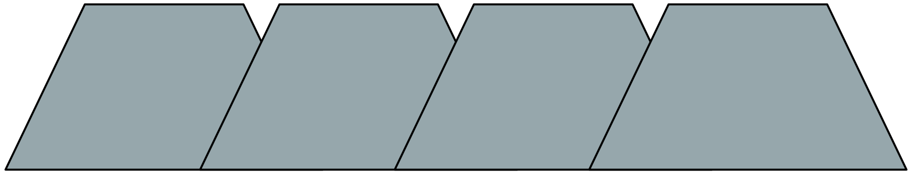


  - Each component carrier limited to a maximum of 100 RB (20 MHz) using the 3GPP Release 8 numerology (means at maximum 5 carriers, each 20 MHz),
  - The following carrier aggregation scenarios shall be considered when appraising the feasibility of the RF scenarios and parameters:
    - Intra- and Inter-band with contiguous and non-contiguous component carrier operation,

- Challenges for a “100-MHz terminal”,
  - Commercially available RF filter for 100 MHz bandwidth,
  - Commercially available ADC in terms of sampling rates and quantization rates,
  - Channel decoding and soft buffer size,

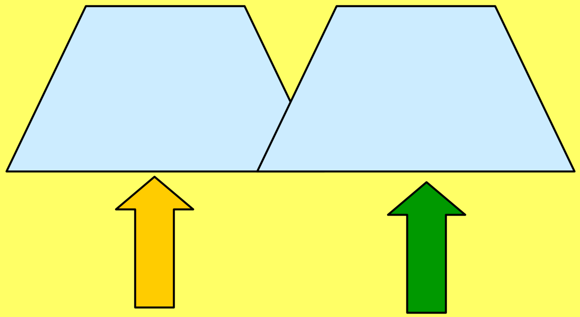
Component Carrier – RACH configuration

Downlink

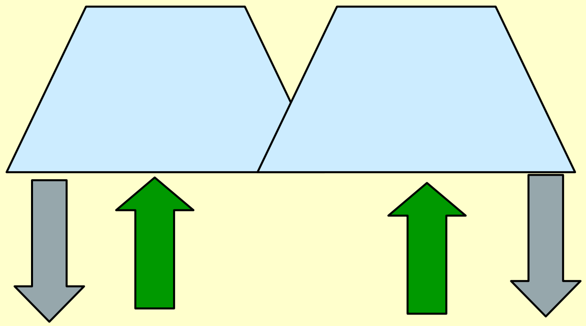


Asymmetric carrier
Aggregation possible,
e.g. DL more CC than UL

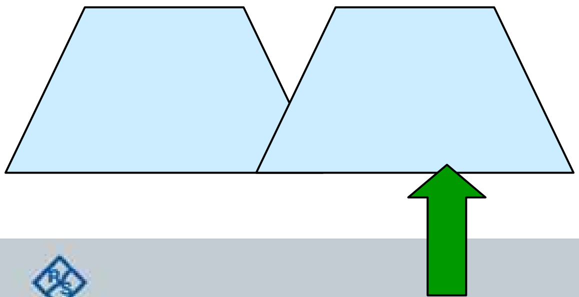
Uplink



Each CC has its own RACH



All CC use same RACH preamble
Network responds on all CCs



Only 1 CC contains RACH

LTE-Advanced
Carrier Aggregation – Initial Deployment

- **Initial LTE-Advanced deployments will likely be limited to the use of two component carrier.**
- **The table summarizes focus scenarios for different regions proposed by network operators.**

Intra-band contiguous carrier aggregation	
FDD	UL/DL: 40 MHz in Band 1/3/7
TDD	UL/DL: 40/50 MHz in Band 38/40
Inter-band non-contiguous carrier aggregation	
Region 1 (Europe)	UL/DL: 40 MHz; 20 MHz CC (Band 7) and 20 MHz CC (Band 20)
	UL/DL: 40 MHz; 20 MHz CC (Band 3) and 20 MHz CC (Band 20)
	UL/DL: 40 MHz; 20 MHz CC (Band 7) and 20 MHz CC (Band 3)
Region 2 (US)	UL/DL: 20 MHz; 10 MHz CC (Band 5) and 10 MHz CC (Band 12)
	UL/DL: 10 MHz; 5 MHz CC (Band 17) and 5 MHz CC (Band 4)
	UL/DL: 20 MHz; 10 MHz CC (Band 13) and 10 MHz CC (Band 4)
	UL/DL: 20 MHz; 10 MHz CC (Band 13) and 10 MHz CC (Band 12)
	UL/DL: 20 MHz; 10 MHz CC (Band 2) and 10 MHz CC (Band 4)
	UL/DL: 10 MHz; 5 MHz CC (Band 18) and 5 MHz CC (Band 2)
Region 3 (Asia)	UL/DL: 20 MHz; 10 MHz CC (Band 1) and 10 MHz CC (Band 19)
	UL/DL: 20 MHz; 10 MHz CC (Band 11) and 10 MHz CC (Band 18)
	UL/DL: 40 MHz; 20 MHz CC (Band 38) and 20 MHz CC (Band 40)
	UL/DL: 20 MHz; 10 MHz CC (Band 3) and 10 MHz CC (Band 5 or 8)
	UL/DL: 20 MHz; 10 MHz CC (Band 1) and 10 MHz CC (Band 5)
	UL/DL: 15 MHz; 5 MHz CC (Band 1) and 10 MHz CC (Band 8)

LTE-Advanced

Carrier Aggregation – Initial Specification Work

- Due to time constraints within 3GPP standardization (RAN4 being the responsible working group) the following scenarios will be worked on first,
- Intra band is prioritized over inter band,
- Additional scenarios may be added at a later stage (release independent).

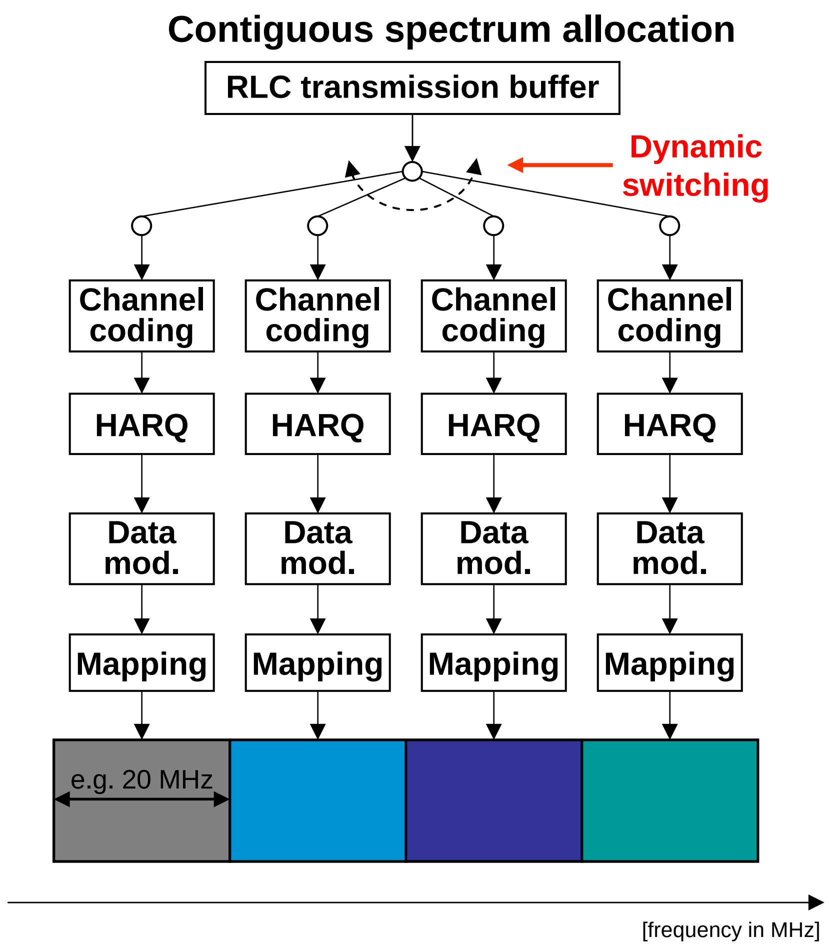
Intra band CA operating bands				
E-UTRA CA Band	E-UTRA Band	Uplink (UL) operating band	Downlink (DL) operating band	Duplex Mode
CA_1	1	1920 – 1980 MHz	2110 – 2170 MHz	FDD
CA_40	40	2300 – 2400 MHz	2300 – 2400 MHz	TDD

Inter band CA operating bands				
E-UTRA CA Band	E-UTRA Band	Uplink (UL) operating band	Downlink (DL) operating band	Duplex Mode
CA_1-5	1	1920 – 1980 MHz	2110 – 2170 MHz	FDD
	5	824 – 849 MHz	869 – 894 MHz	

LTE-Advanced

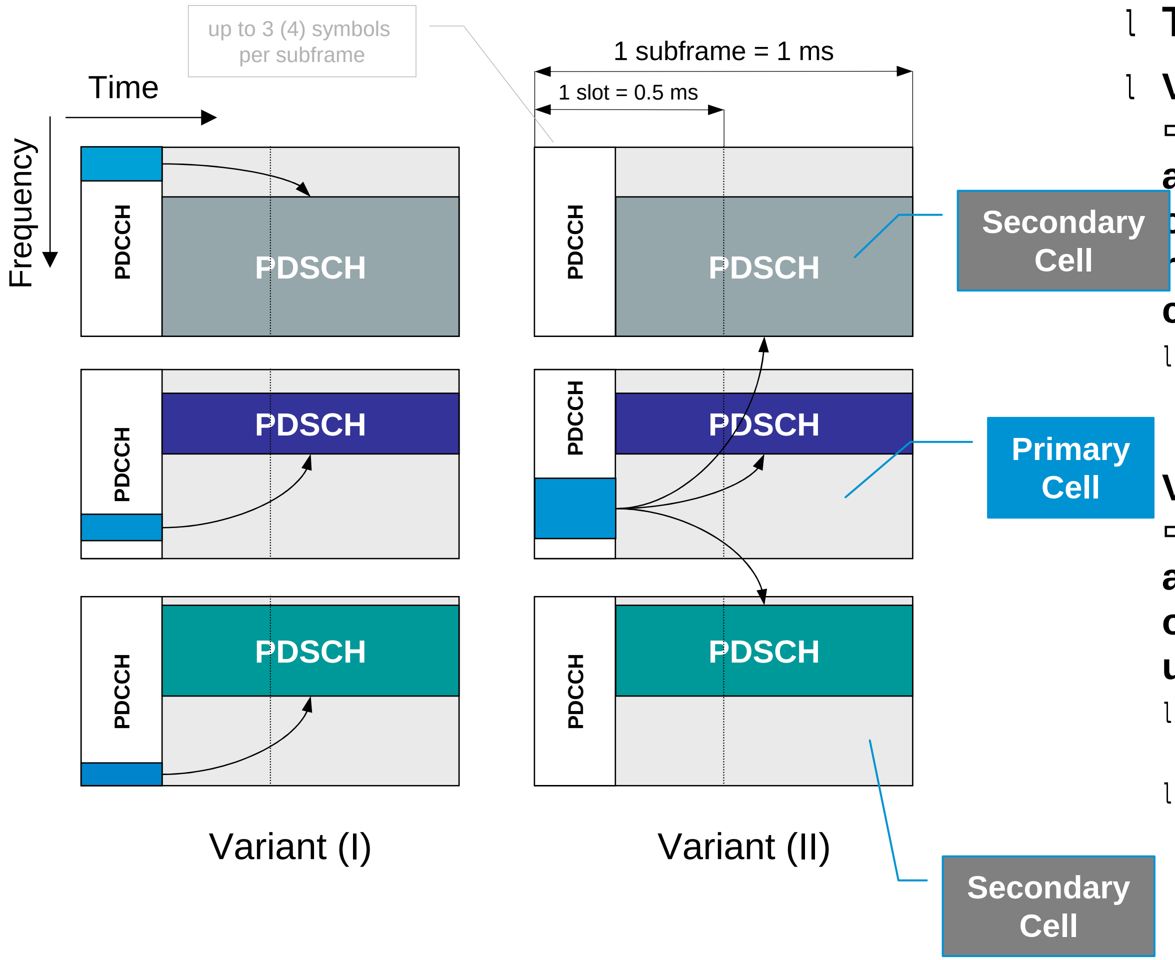
Carrier Aggregation – Scheduling

- **There is one transport block (in absence of spatial multiplexing) and one HARQ entity per scheduled component carrier (from the UE perspective),**
- **A UE may receive multiple component carriers simultaneously,**
- **Two different approaches are discussed how to inform the UE about the scheduling for each band,**
  - Separate PDCCH for each carrier,
  - Common PDCCH for multiple carrier,



LTE-Advanced

Carrier Aggregation – Common and Separate PDCCH?



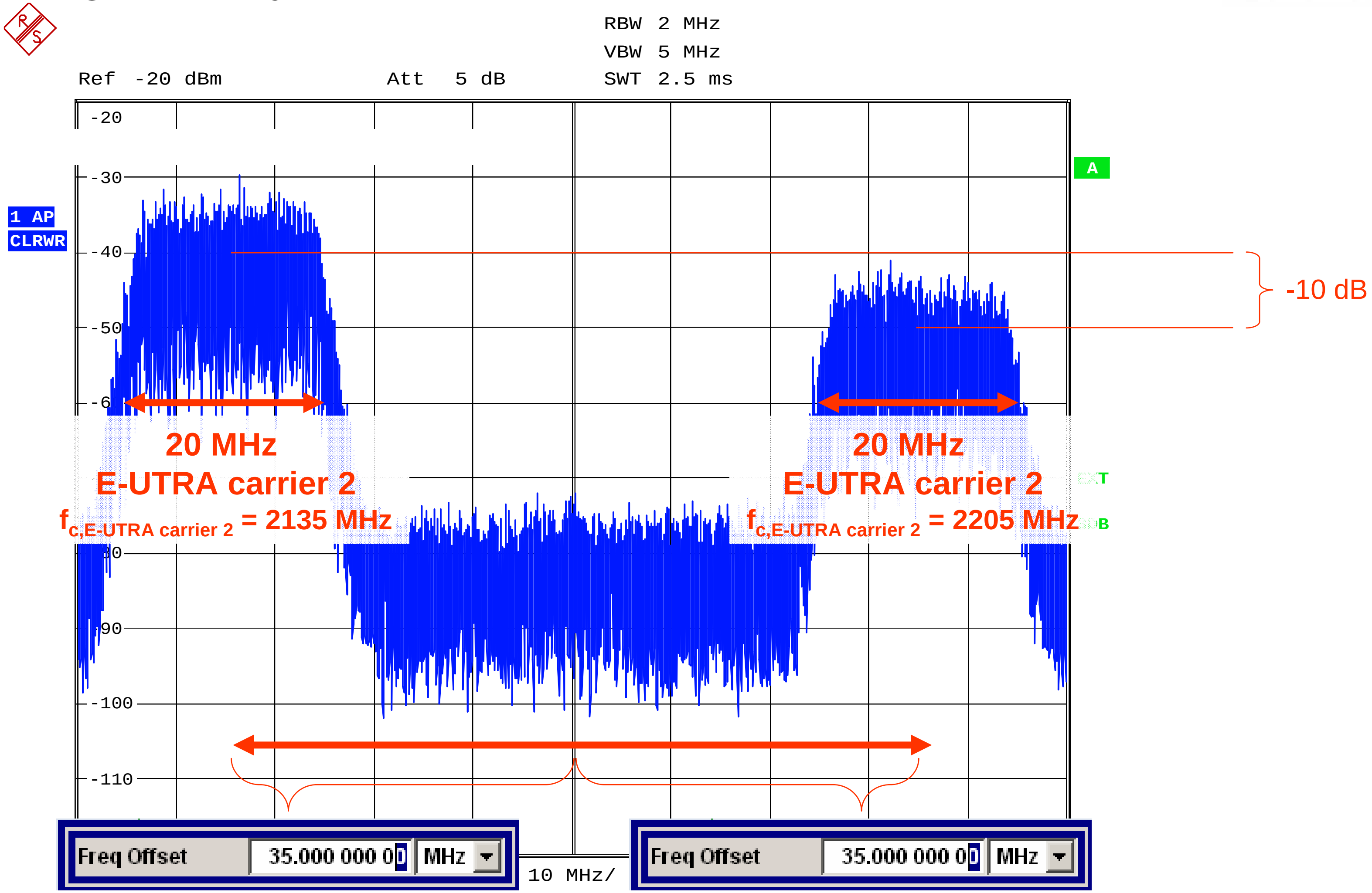
- **Two methods are possible**
- **Variant I (no cross-carrier scheduling) ⇨ PDCCH on a component carrier assigns PDSCH resources on the same component carrier (and PUSCH resources on a single linked UL component carrier)**
  - No carrier indicator field, i.e. Rel-8 PDCCH structure (same coding, same CCE-based resource mapping) and DCI formats

Variant II (cross-carrier scheduling) ⇨ PDCCH on a component carrier can assign PDSCH or PUSCH resources in one of multiple component carriers using the carrier indicator field

  - Rel-8 DCI formats extended with 1 to 3 bit carrier indicator field
  - Reusing Rel-8 PDCCH structure (same coding, same CCE-based resource mapping)

LTE–Advanced solutions from R&S

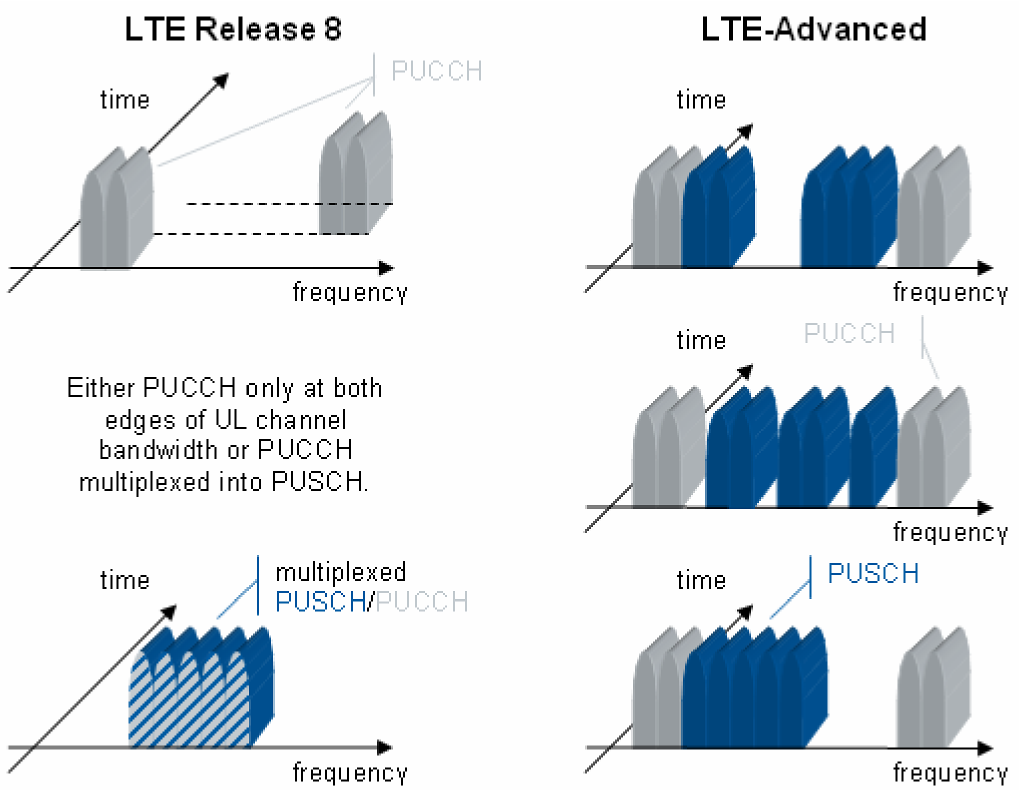
R&S® FSQ Signal Analyzer



LTE-Advanced

Enhanced uplink SC-FDMA

- **The uplink transmission scheme remains SC-FDMA.**
- **The transmission of the physical uplink shared channel (PUSCH) uses DFT precoding.**
- **Two enhancements:**
  - Control-data decoupling
  - Non-contiguous data transmission



LTE-Advanced
Enhanced uplink SC-FDMA

- **UL access scheme stays with SC-FDMA (DFT-precoded OFDMA) for LTE-Advanced, PUSCH transmission (non-MIMO <u>and</u> MIMO) uses DFT-precoding,**
- **One DFT per component carrier,**
- **One each component carrier both, contiguous and non-contiguous resource allocation is supported,**
- **Simultaneous transmission of control and data is supported by two mechanisms,**
  - Control signaling us multiplexed with data on PUSCH as in LTE REl-8,
  - Control signaling transmitted simultaneously with data on PUSCH,

LTE-Advanced
Enhanced MIMO Schemes

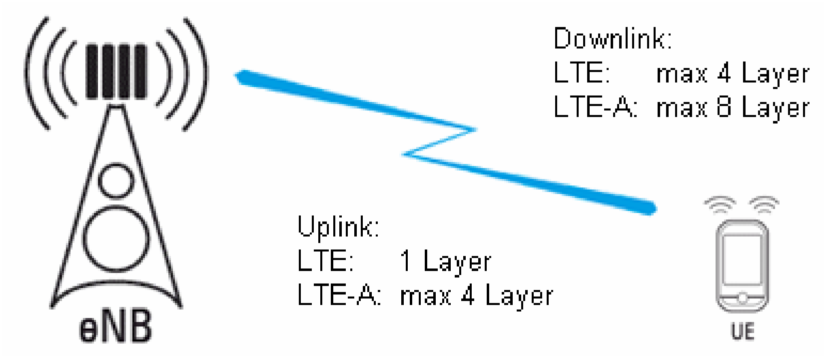
- **Two candidates to considerably improve spectral efficiency,**
  - Higher-Order Modulation,
  - Spatial Multiplexing,

System Aspect	Alt 1: 8x8 SM + 64QAM	Alt 2: 4x4 SM + 1024QAM
Throughput gain over 4x4 SM + 64QAM	- Gain in average spectral efficiency: multiplexing - Gain in cell-edge throughput: diversity - Lower SNR needed to achieve peak rate	- No gain in average spectral efficiency - No gain in cell-edge throughput - Higher SNR needed to achieve peak rate
UE complexity	- Form factor limitation (antenna design) especially for lower frequency bands - Main cost due to higher-order MIMO receiver	- Main cost due to higher receiver sensitivity
EVM requirement	Tend to be lower	Tend to be higher

- **RAN1 decided to focus on spatial multiplexing, i.e. increasing the number of TX/RX antennas (8x8 MIMO).**

LTE-Advanced
Enhanced MIMO Schemes

- **Up to 8x8 MIMO in downlink**
- **Up to 4x4 MIMO in uplink**



- **In addition the downlink reference signal structure has been enhanced compared with LTE Release 8 by**
  - reference signals targeting PDSCH demodulation
    - UE specific, i.e. an extension to multiple layers of the concept of Release 8 UE-specific reference signals used for beamforming
  - reference signals targeting channel state information (CSI) estimation for CQI/PMI/RI/etc reporting when needed
    - cell specific, sparse in the frequency and time domain and punctured into the data region of normal subframes

DL MIMO
Extension up to 8x8

- **Max number of transport blocks: 2**
- **Number of MCS fields**
  - one for each transport block
- **ACK/NACK feedback**
  - 1 bit per transport block for evaluation as a baseline
- **Closed-loop precoding supported**
  - Rely on precoded dedicated demodulation RS (decision on DL RS)
- **Conclusion on the codeword-to-layer mapping:**
  - DL spatial multiplexing of up to eight layers is considered for LTE-Advanced,
  - Up to 4 layers, reuse LTE codeword-to-layer mapping,
  - Above 4 layers mapping – see table
- **Discussion on control signaling details ongoing**

Codeword to layer mapping for spatial multiplexing

Number of layers	Number of code words	Codeword-to-layer mapping $i = 0,1,\ldots, M_{symb}^{layer} - 1$	
5	2	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$ $x^{(2)}(i) = d^{(1)}(3i)$ $x^{(3)}(i) = d^{(1)}(3i+1)$ $x^{(4)}(i) = d^{(1)}(3i+2)$	$M_{symb}^{layer} = M_{symb}^{(0)}/2 = M_{symb}^{(1)}/3$
6	2	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $x^{(3)}(i) = d^{(1)}(3i)$ $x^{(4)}(i) = d^{(1)}(3i+1)$ $x^{(5)}(i) = d^{(1)}(3i+2)$	$M_{symb}^{layer} = M_{symb}^{(0)}/3 = M_{symb}^{(1)}/3$
7	2	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $x^{(3)}(i) = d^{(1)}(4i)$ $x^{(4)}(i) = d^{(1)}(4i+1)$ $x^{(5)}(i) = d^{(1)}(4i+2)$ $x^{(6)}(i) = d^{(1)}(4i+3)$	$M_{symb}^{layer} = M_{symb}^{(0)}/3 = M_{symb}^{(1)}/4$
8	2	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$ $x^{(4)}(i) = d^{(1)}(4i)$ $x^{(5)}(i) = d^{(1)}(4i+1)$ $x^{(6)}(i) = d^{(1)}(4i+2)$ $x^{(7)}(i) = d^{(1)}(4i+3)$	$M_{symb}^{layer} = M_{symb}^{(0)}/4 = M_{symb}^{(1)}/4$

Downlink reference signals in LTE-Advanced

- **Define two types of RS,**
  - RS targeting PDSCH demodulation,
  - RS targeting CSI generation (for CQI/PMI/RI/etc reporting when needed),
- **RS targeting PDSCH demodulation (for LTE-Advanced operation) are**
  - UE specific
    - Transmitted only in scheduled RBs and the corresponding layers
    - Different layers can target the same or different UEs
    - Design principle is an extension of the concept of Rel-8 UE-specific RS (used for beamforming) to multiple layersDetails on UE-specific RS pattern, location, etc are FFS
  - RS on different layers are mutually orthogonal,
  - RS and data are subject to the same pre-coding operation,
  - complementary use of Rel-8 CRS by the UE is not precluded,
- **RS targeting CSI generation (for LTE-A operation) are**
  - Cell specific and sparse in frequency and time
- **Rel-8 transmission schemes using Rel-8 cell-specific and/or UE-specific RS still supported,**

Downlink reference signals in LTE-Advanced

- **Possibility to configure the periodicity of CSI RS transmissions in terms of an integer number of subframes,**
- **Allow transmissions of PDSCH to Rel-10 UEs in MBSFN (LTE-Advanced) subframes,**
  - Possible to configure CSI RS for transmission in LTE-Advanced subframes,
- **Possible to use LTE-Advanced features without any LTE-Advanced subframes,**
  - Cell specific CSI RS possible to transmit in normal, Rel-8, subframes,
- **Strive for same CSI RS and DM-RS patterns regardless of subframe type (DL Rel-8 or DL LTE-A subframes),**
- **DM-RS in support of up-to 8 transmission layers will need to be defined,**

Uplink MIMO
Extension up to 4x4

- **Rel-8 LTE,**
  - UEs must have 2 antennas for reception,
  - But only 1 amplifier for transmission is available (costs/complexity),
  - UL MIMO only as antenna switching mode (switched diversity),
- **Different schemes for spatial multiplexing and diversity are under discussion (for data and control),**
- **4x4 UL SU-MIMO is needed to fulfill UL peak data rate requirement of 15 bps/Hz,**
- **Schemes are very similar to DL MIMO modes,**
  - UL spatial multiplexing of up to 4 layers is considered for LTE-Advanced,
  - SRS enables link and SU-MIMO adaptation,
- **Number of receive antennas are receiver-implementation specific,**
  - At least two receive antennas is assumed on the terminal side,

Uplink MIMO, cont'd.

Extension up to 4x4

- Codebook-based pre-coding is supported for FDD
  - Single TPMI per UL component carrier (frequency non-selective in a component carrier) is supported,
    - Frequency-selective pre-coding (multiple TPMIs) in a component carrier FFS,
  - Size-1 codebook with identity pre-coding for full-rank transmission,
  - Dynamic rank (TRI) adaptation,
- Pre-coding for TDD,
  - Discussion about codebook-based vs. non-codebook still ongoing,
- Same layer mapping as DL LTE Rel-8 (see table)
  - Maximum of 2 code words (transport blocks),
- Spatial bundling of HARQ parameters desirable:
  - Single shared downlink ACK/NACK (PHICH); single shared NDI, RV,
  - Impact on performance (including overhead) to be verified,
- Number of MCS fields: 2,

Precoding codebook for uplink spatial multiplexing (4 Tx antennas)

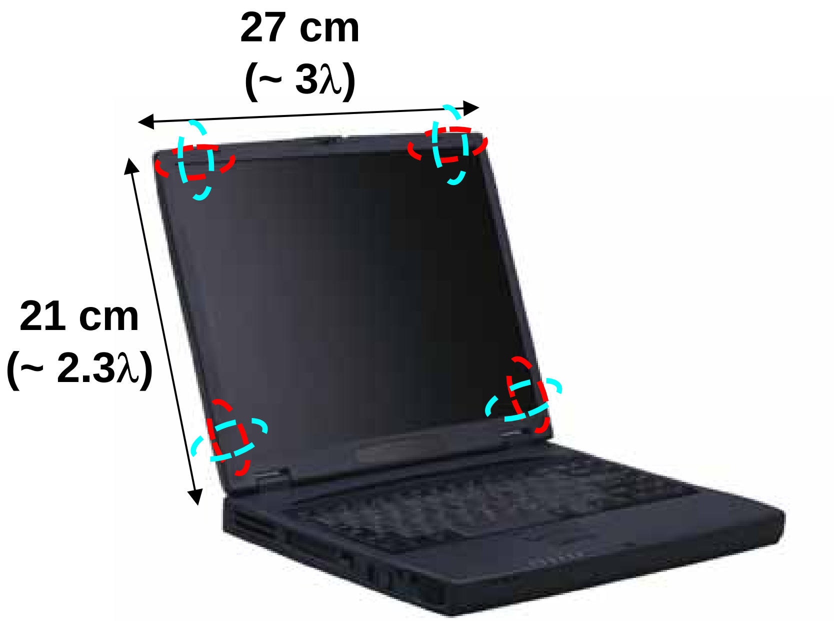
Two layer trasmission

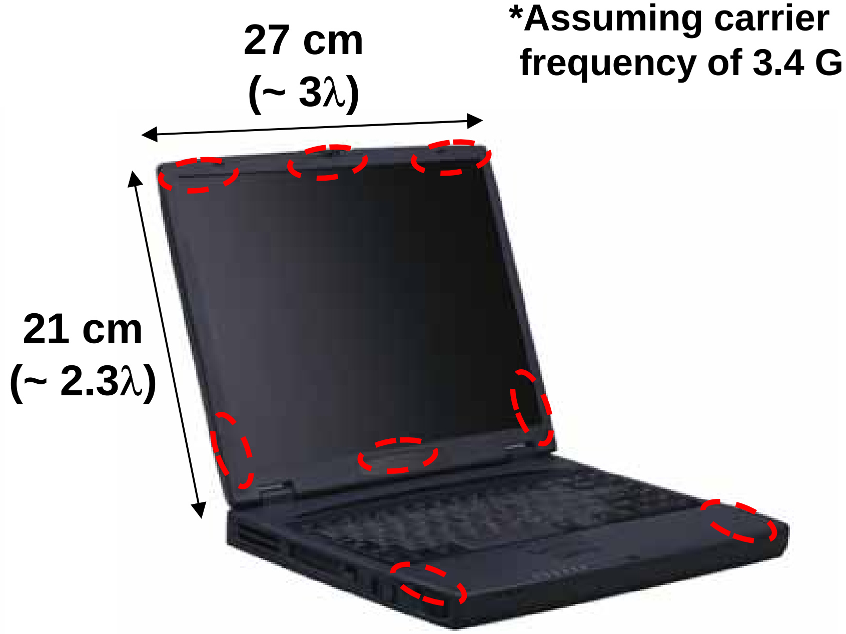
Index	0	1	2	3	4	5	6	7
	$\frac{1}{2}\begin{bmatrix}1&0\\1&0\\0&1\\0&-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\1&0\\0&1\\0&j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\-j&0\\0&1\\0&1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\-j&0\\0&1\\0&-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\-1&0\\0&1\\0&-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\-1&0\\0&1\\0&j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\j&0\\0&1\\0&1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\j&0\\0&1\\0&-1\end{bmatrix}$
Index	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\1&0\\0&1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\1&0\\0&-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\-1&0\\0&1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\-1&0\\0&-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&1\\1&0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&-1\\1&0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&1\\-1&0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&-1\\-1&0\end{bmatrix}$

Uplink MIMO, cont'd.

Possible antenna configurations on the UE side

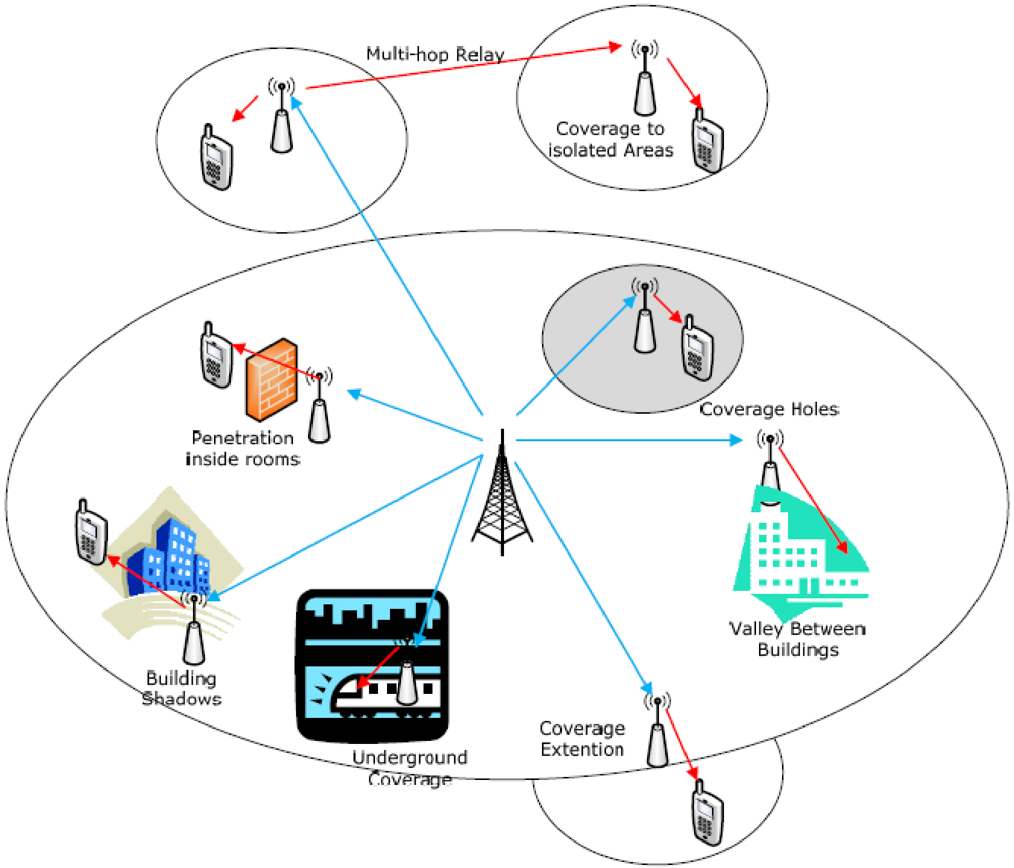
- Four antennas can be implemented in relatively small laptop PCs,
  – Moreover, 8 antenna configuration is possible (see example),
- Polarized antenna is beneficial to save implementation space,
- Sufficiently low antenna correlation is achieved when antenna separation is greater than 0.5λ,





*Assuming carrier frequency of 3.4 GHz

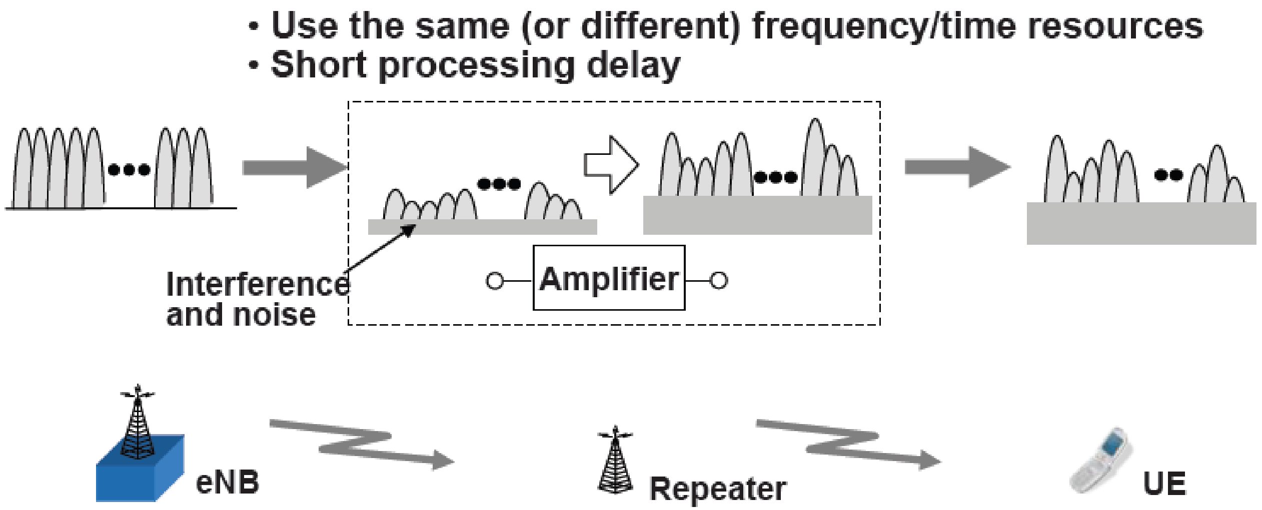
Significant step towards 4G: Relaying ?



Source: TTA's workshop for the future of IMT-Advanced technologies, June 2008

Radio Relaying approach

- **Relays using radio**
- **L1 relays with non-regenerative transmission, i.e., repeaters**
  - ✓ **Since delay is shorter than cyclic prefix duration, no additional change to radio interface is necessary**
  - ✓ **Repeaters are effective in improving coverage in existing cells**
  - ✓ **Should be used as well as in 2G/3G networks**

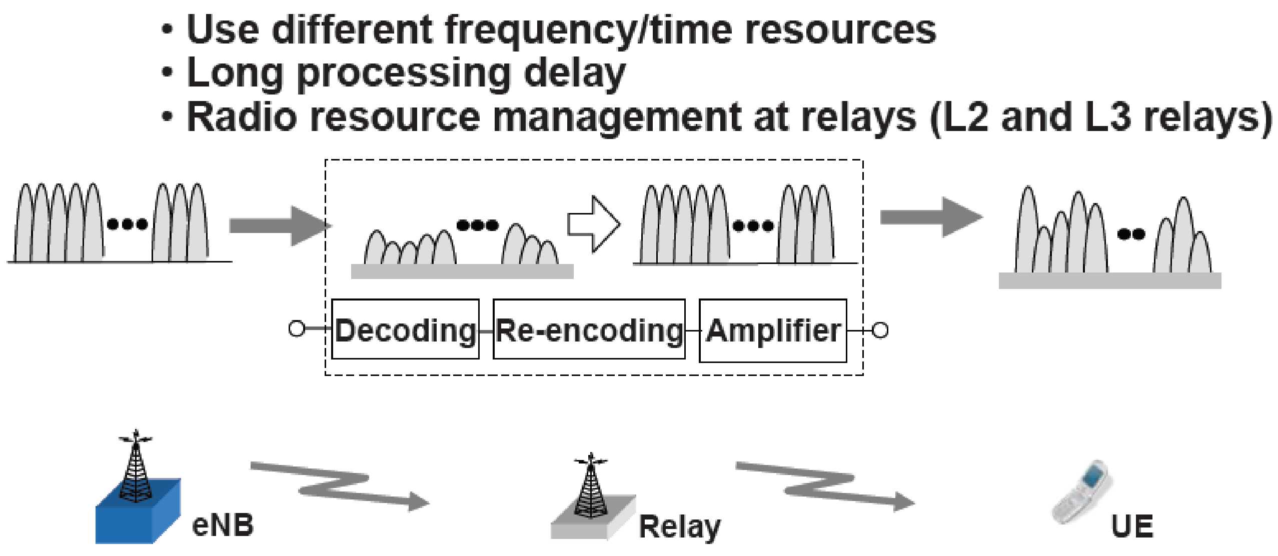


No Improvement of SNR resp. CINR

Source: TTA's workshop for the future of IMT-Advanced technologies, June 2008

L1/L2 Relaying approach

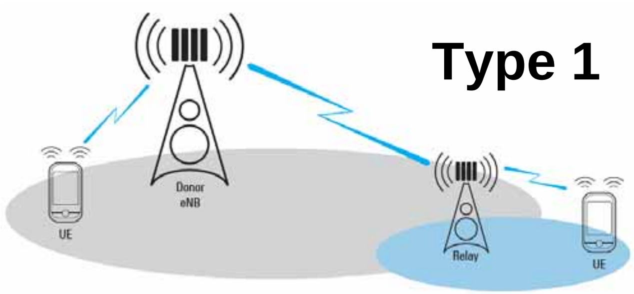
- **Relays using radio**
- **L2 and L3 relays**
  - ✓ **L2 and L3 relays can achieve wide coverage extension via increase in SNR**
  - ✓ **Problems to be solved are efficient radio resource assignment to signals to/from relay station, delay due to relay, etc.**

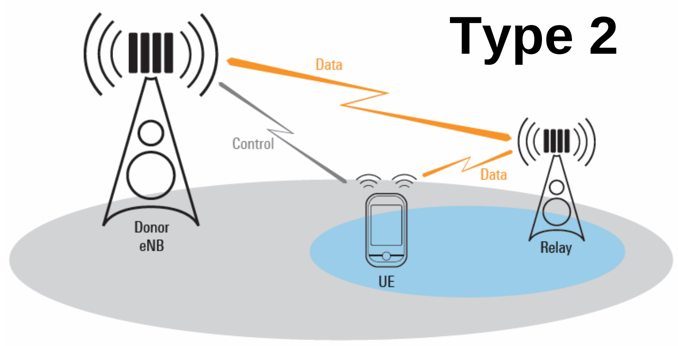


Source: TTA's workshop for the future of IMT-Advanced technologies, June 2008

LTE-Advanced
Relaying

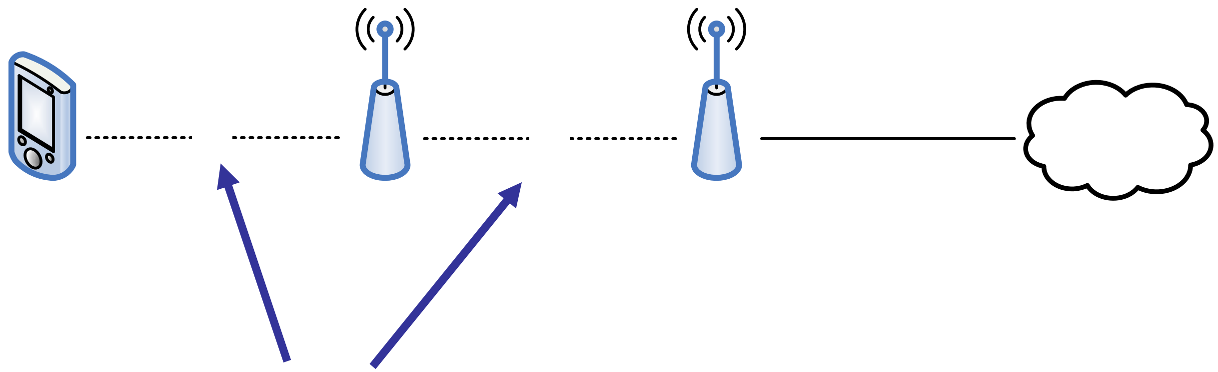
- **LTE-Advanced extends LTE Release 8 with support for relaying in order to enhance coverage and capacity**
- **Classification of relays based on**
  - implemented protocol knowledge…
    - Layer 1 (repeater)
    - Higher Layer (decode and forward or even mobility management, session set-up, handover)
  - … and whether the relay has its own cell identity
    - Type 1 relay effectively creates its own cell (own ID and own synchronization and reference channels
    - Type 2 relay will not have its own Cell_ID





LTE-Advanced: Relaying

The relay node (RN) is wirelessly connected to a *donor cell* of a *donor eNB* via the Un interface, and UEs connect to the RN via the Uu interface

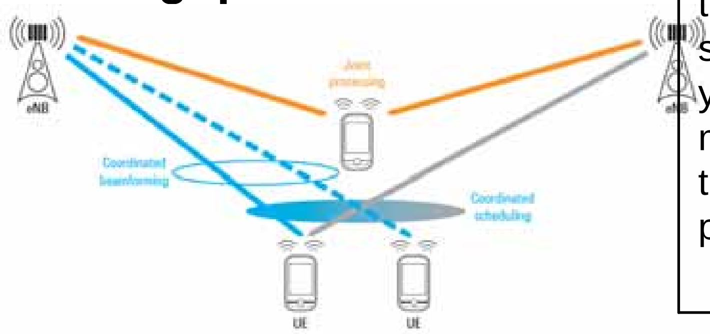


Inband: 2 links operate in the same frequency
Outband: 2 links operate in different frequencies

LTE-Advanced

Coordinated multiple point transmission and reception (CoMP)

- **Coordinated multi-point (CoMP) transmission / reception was considered for LTE-Advanced as a tool to improve the coverage of high data rates, the cell-edge throughput and to increase system throughput.**

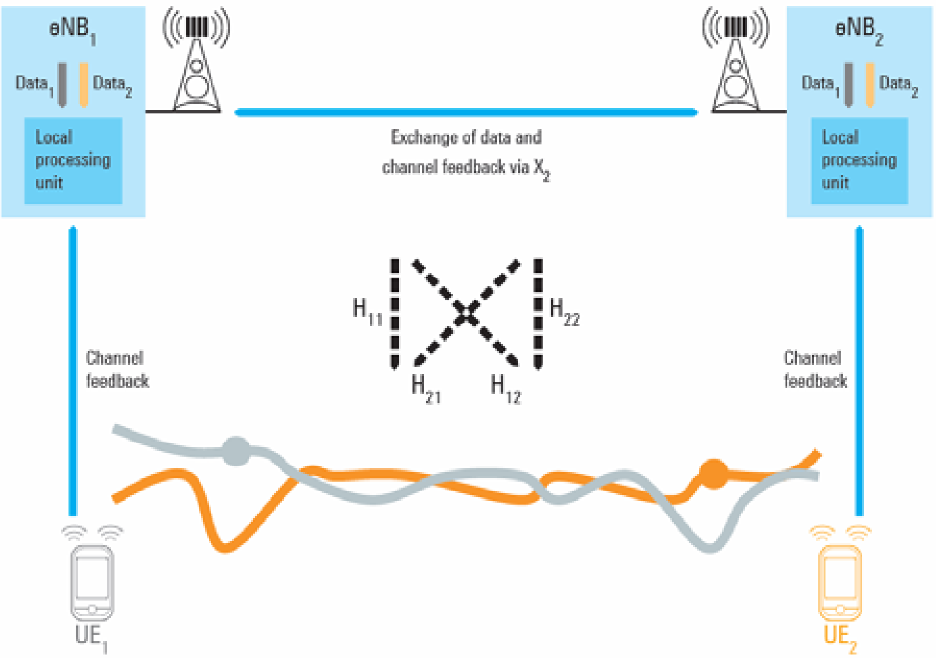


CoMP – transmission (downlink)		
Joint Processing		**Coordinated Scheduling / Beamforming**
Joint transmission	**Dynamic cell selection**	
Data available at each transmission point		Data available at serving cell only
Data transmitted simultaneously from multiple transmission points	Data transmitted from one transmission point at a time	Data transmitted from one transmission point but user scheduling / beamforming decisions are made with coordination among cells

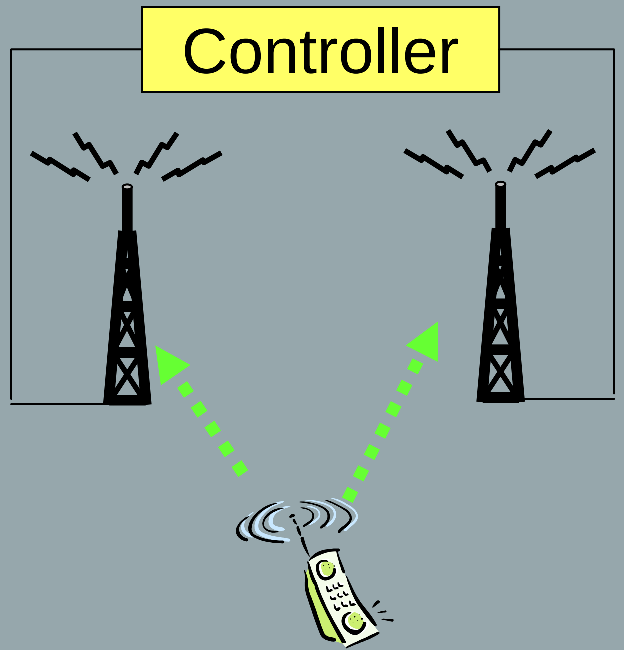
LTE-Advanced

CoMP – Distributed Cooperation Approach

- **In this two eNodeB example the goal is to crosswise eliminate the interference between the two cells**
- **Modifications required on top of LTE Release 8**
  - Clock synchronization between eNodeBs
  - Synchronous data exchange
  - Cell specific pilots
  - Channel feedback / Channel state information
  - Precoded Pilots

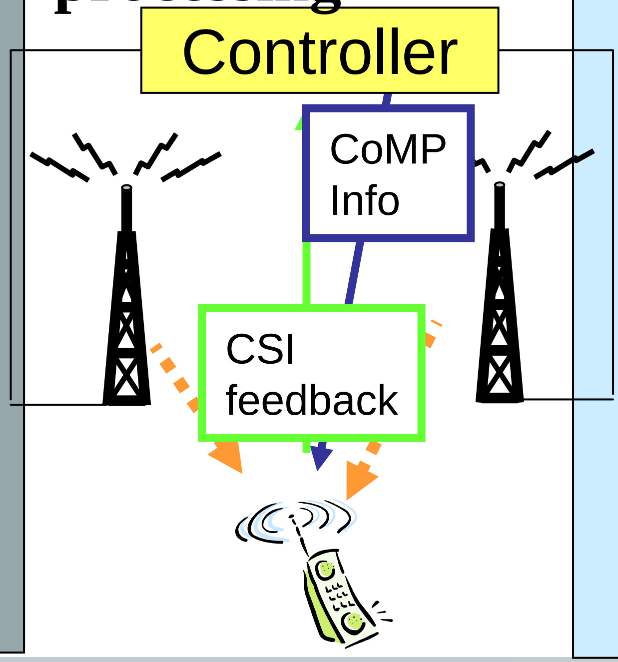


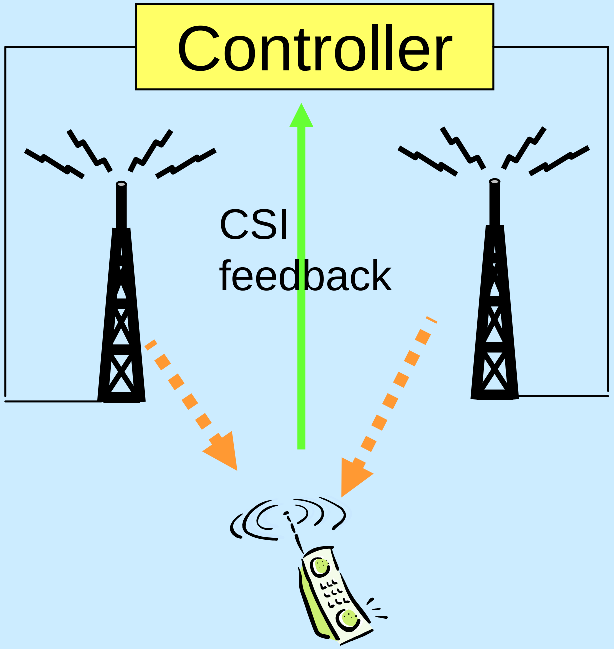
Coordinated Multipoint, CoMP



Each eNB
Estimates Uplink

UE estimates
Various DL
+ feedback
Info about CoMP,
UE perform signal
processing





UE estimates various
Downlink + feedback
No info about CoMP
at UE

LTE-Advanced
Summary

- **LTE-Advanced features deliver different performance gains and will have different impacts on the system complexity / cost.**

	Peak Rate	Capacity	Cell Edge Performance	Coverage	Complexity
Carrier Aggregation	✓ ✓	-	✓	-	Medium
Enhanced UL Schemes	-	✓	✓	-	Low
CoMP	-	✓	✓ ✓	✓	High
Enhanced MIMO	✓ ✓	✓	✓	-	High
Relaying	-	-	✓	✓ ✓	Medium

- **LTE Release 8 / LTE-Advanced will be the innovation platform for the cellular industry for the next decade.**

There will be enough topics

for future trainings ☺

Thank you for your attention!

Comments and questions welcome!