LTE technology and LTE test; a deskside chat

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Outline

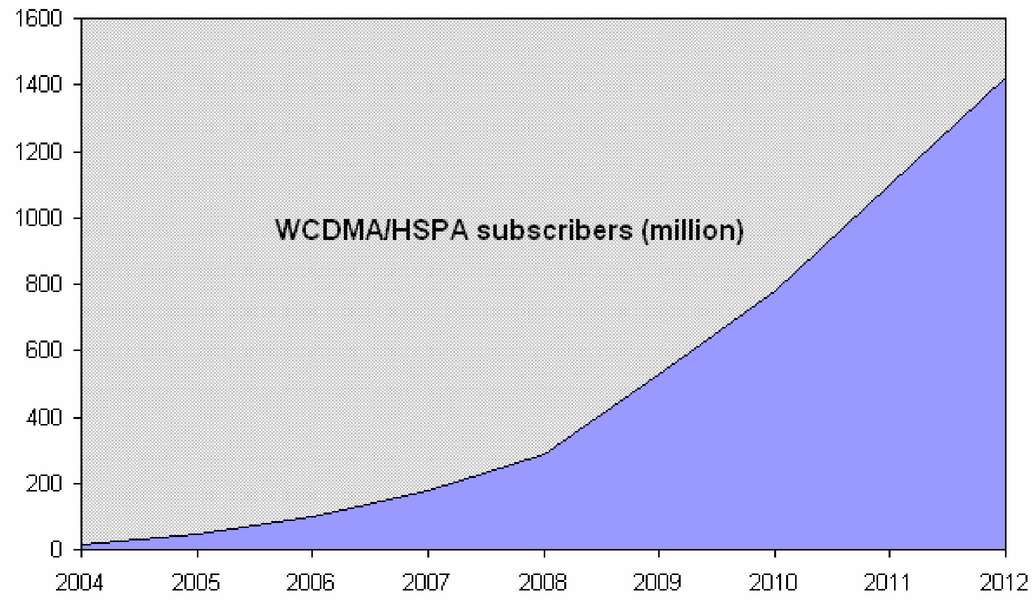
- **Motivation for LTE**
- **LTE technology basics**
  - Key parameters
  - OFDMA and downlink frame structure
  - SC-FDMA and uplink frame structure
  - Network and protocol architecture
  - LTE UE categories
- **Radio procedures**
  - Cell search
  - System information broadcast
  - Random access
  - EPS bearer setup
  - Downlink and uplink data transmission
  - Mobility
  - MIMO
- **LTE test requirements**
  - eNodeB RF testing
  - UE RF testing
  - LTE wireless device testing from R&D up to conformance
  - LTE field trial testing and coverage measurements

MIMO = Multiple Input Multiple Output
EPS = Evolved Packet System
UE = User Equipment
RRM = Radio Resource Management
OFDMA = Orthogonal Frequency Division Multiple Access
SC-FDMA = Single Carrier Frequency Division Multiple Access

Motivation for LTE

LTE market situation
based on HSPA success story

- HSPA growth is based on the uptake of mobile data services worldwide. More than 250 networks worldwide have already commercially launched HSPA.
- Mobile data traffic is growing exponentially, caused by mobile internet offerings and improved user experience with new device types.
- LTE is accepted worldwide as the long term evolution perspective for today's 2G and 3G networks based on WCDMA/HSPA, GSM/EDGE, TD-SCDMA, and CDMA2000 technologies.



Sources: www.gsacom.com, R&S

LTE background story
the early days

- Work on LTE was initiated as a 3GPP release 7 study item “Evolved UTRA and UTRAN” in December 2004:
  - *“With enhancements such as HSDPA and Enhanced Uplink, the 3GPP radio-access technology will be highly competitive for several years. However, to ensure competitiveness in an even longer time frame, i.e. for the next 10 years and beyond, a long-term evolution of the 3GPP radio-access technology needs to be considered.”*
- Basic drivers for LTE have been:
  - Reduced latency
  - Higher user data rates
  - Improved system capacity and coverage
  - Cost-reduction.

Major requirements for LTE
identified during study item phase in 3GPP

- Higher peak data rates: 100 Mbps (downlink) and 50 Mbps (uplink)
- Improved spectrum efficiency: 2-4 times better compared to 3GPP release 6
- Improved latency:
  - Radio access network latency (user plane UE – RNC - UE) below 10 ms
  - Significantly reduced control plane latency
- Support of scalable bandwidth: 1.4, 3, 5, 10, 15, 20 MHz
- Support of paired and unpaired spectrum (FDD and TDD mode)
- Support for interworking with legacy networks
- Cost-efficiency:
  - Reduced **CA**pital and **OP**erational **EX**penditures (CAPEX, OPEX) including backhaul
  - Cost-effective migration from legacy networks
- A detailed summary of requirements has been captured in 3GPP TR 25.913 „Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN)".

Evolution of UMTS FDD and TDD
driven by data rate and latency requirements

FDD evolution	WCDMA	HSDPA/ HSUPA	HSPA+	LTE and HSPA+	LTE-advanced
TDD evolution	TD-SCDMA	TD-HSDPA	TD-HSUPA	TD-LTE and TD-HSPA+	
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

LTE technology basics

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 frequency bands

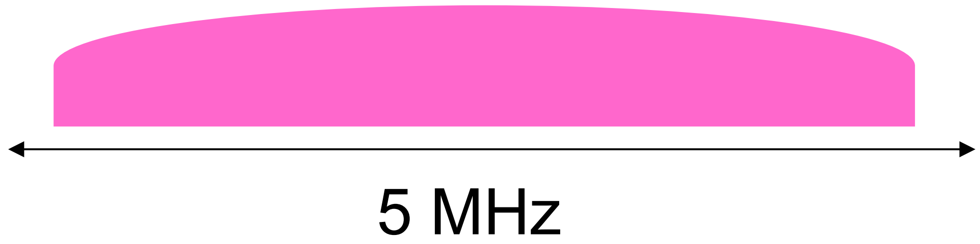
Work on
UMTS/LTE 3500 MHz
ongoing

E-UTRA Band	Uplink (UL) BS receive UE transmit			Downlink (DL) 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
...							
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

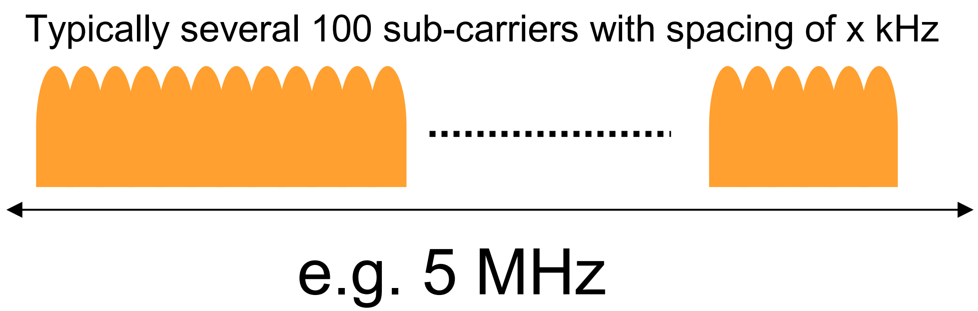
Introduction to OFDMA and downlink frame structure

What is OFDM?

Single Carrier Transmission (e.g. WCDMA)

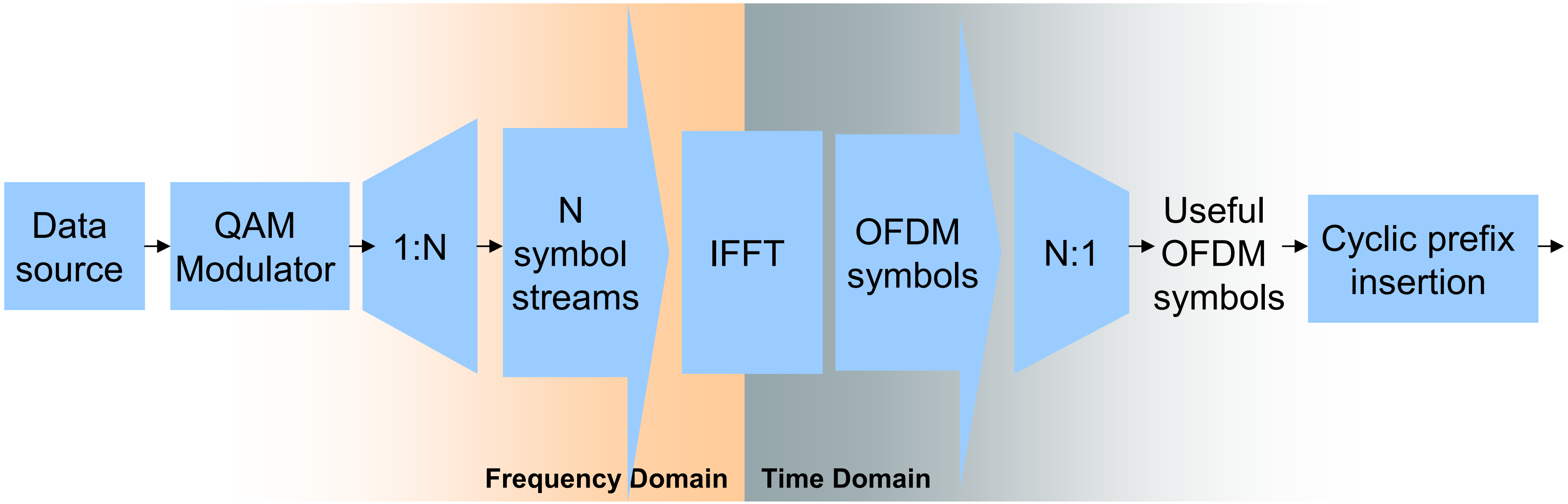


Orthogonal Frequency Division Multiplexing



OFDM signal generation chain

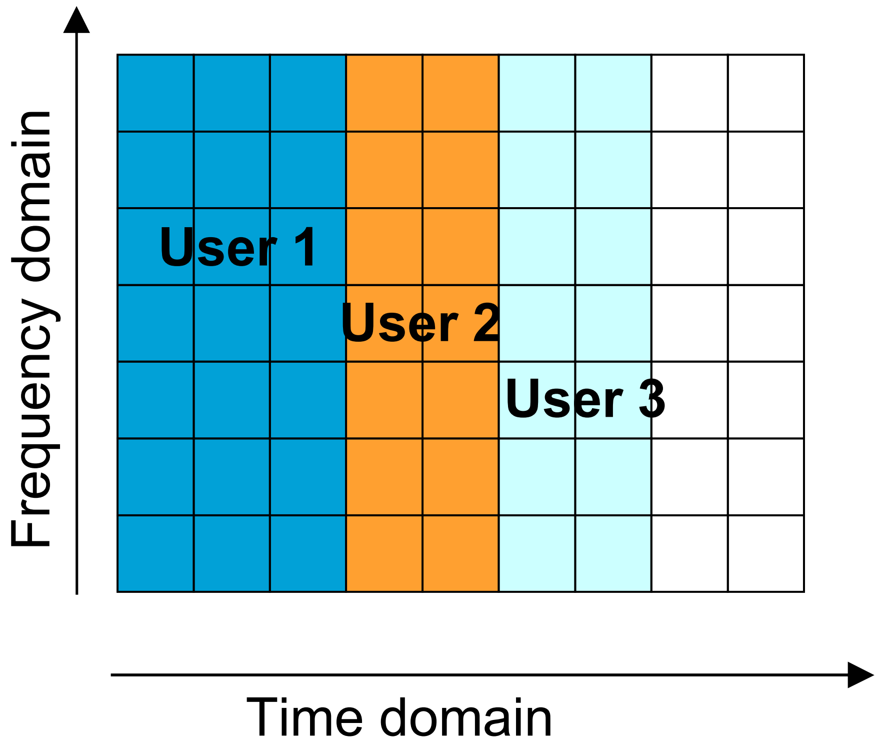
- OFDM signal generation is based on Inverse Fast Fourier Transform (IFFT) operation on transmitter side:



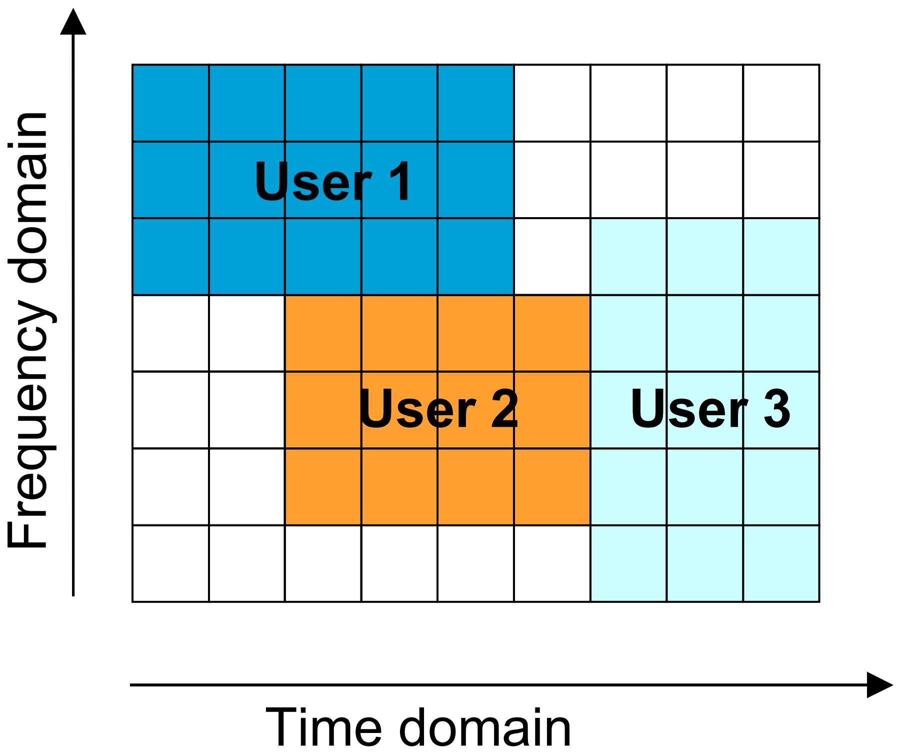
- On receiver side, an FFT operation will be used.

Difference between OFDM and OFDMA

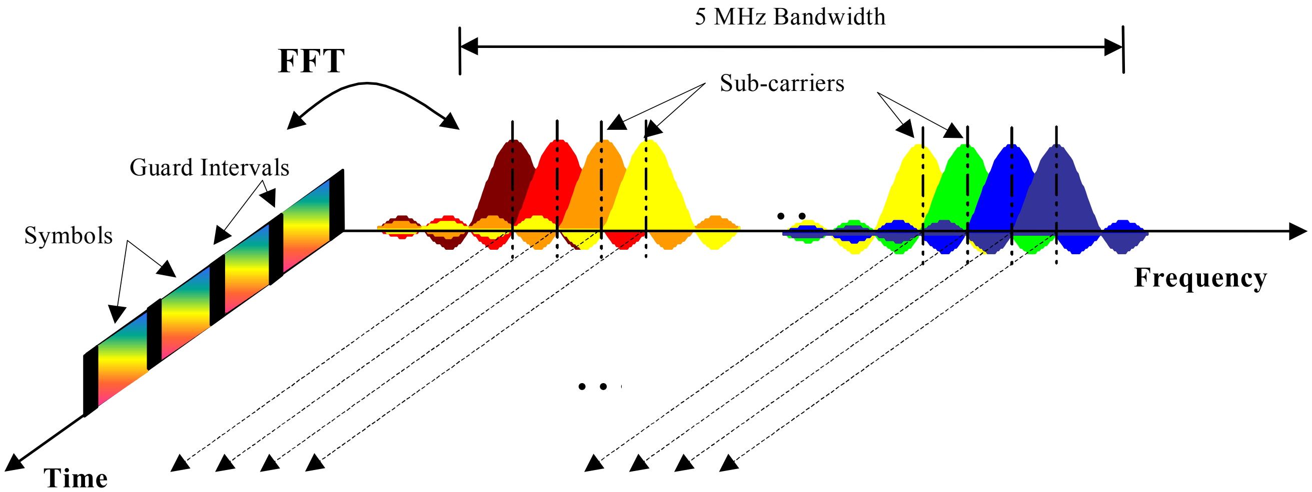
- **OFDM allocates users in time domain only**



- **OFDMA allocates users in time and frequency domain**

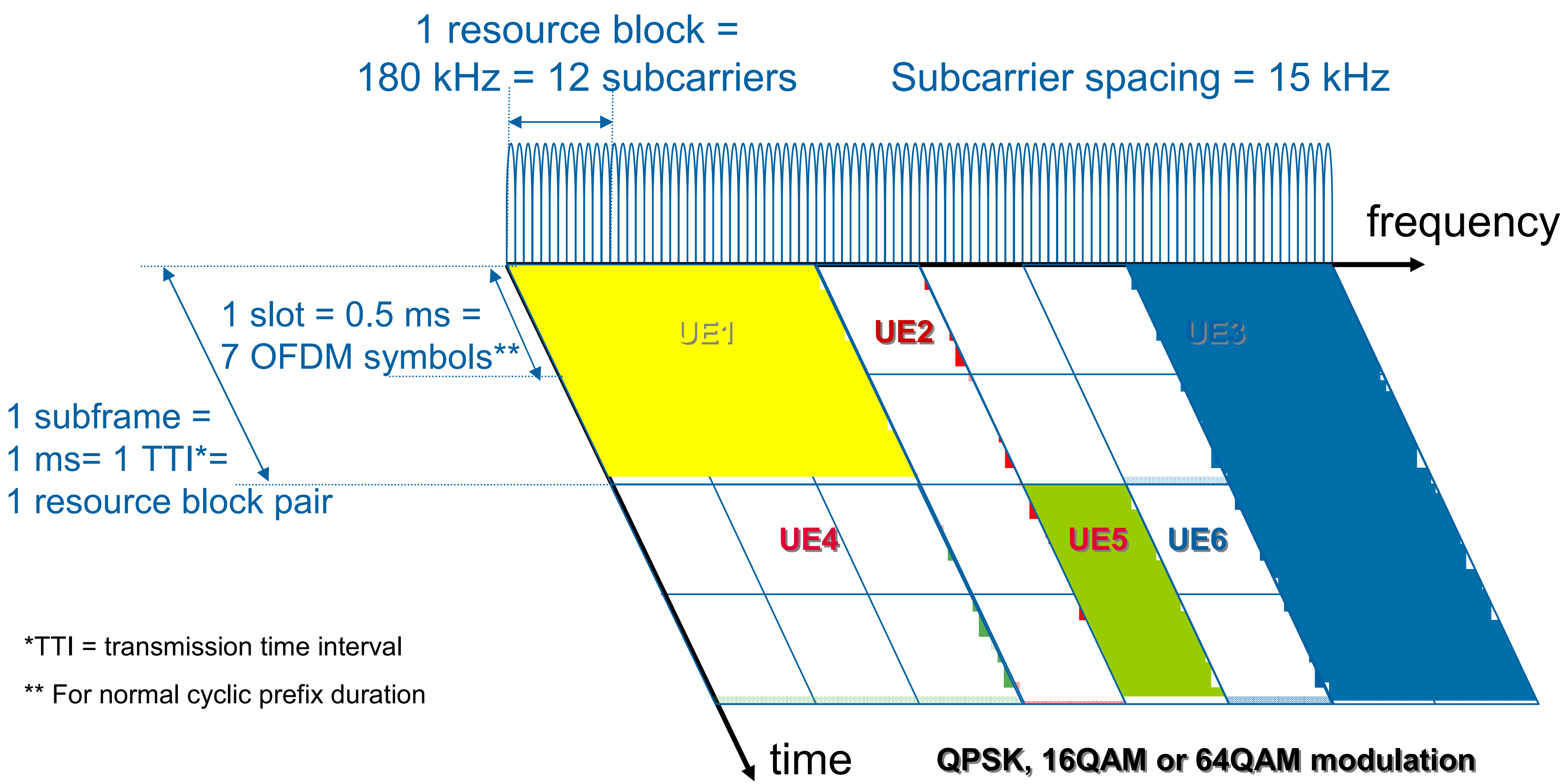


LTE downlink
conventional OFDMA



- LTE provides QPSK, 16QAM, 64QAM as downlink modulation schemes
- Cyclic prefix is used as guard interval, different configurations possible:
  - Normal cyclic prefix with 5.2 µs (first symbol) / 4.7 µs (other symbols)
  - Extended cyclic prefix with 16.7 µs
- 15 kHz subcarrier spacing
- Scalable bandwidth

OFDMA time-frequency multiplexing



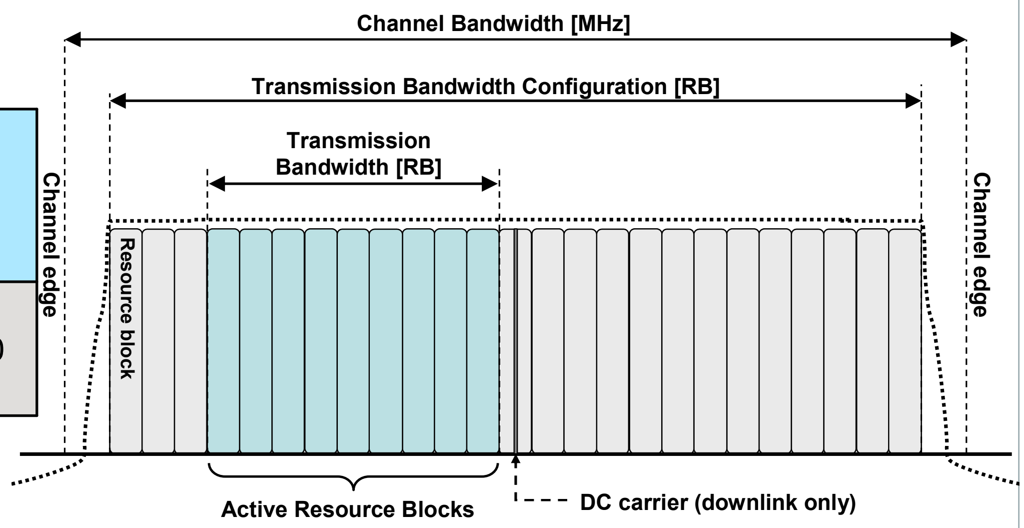
*TTI = transmission time interval

** For normal cyclic prefix duration

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 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
Number of resource blocks	6	15	25	50	75	100



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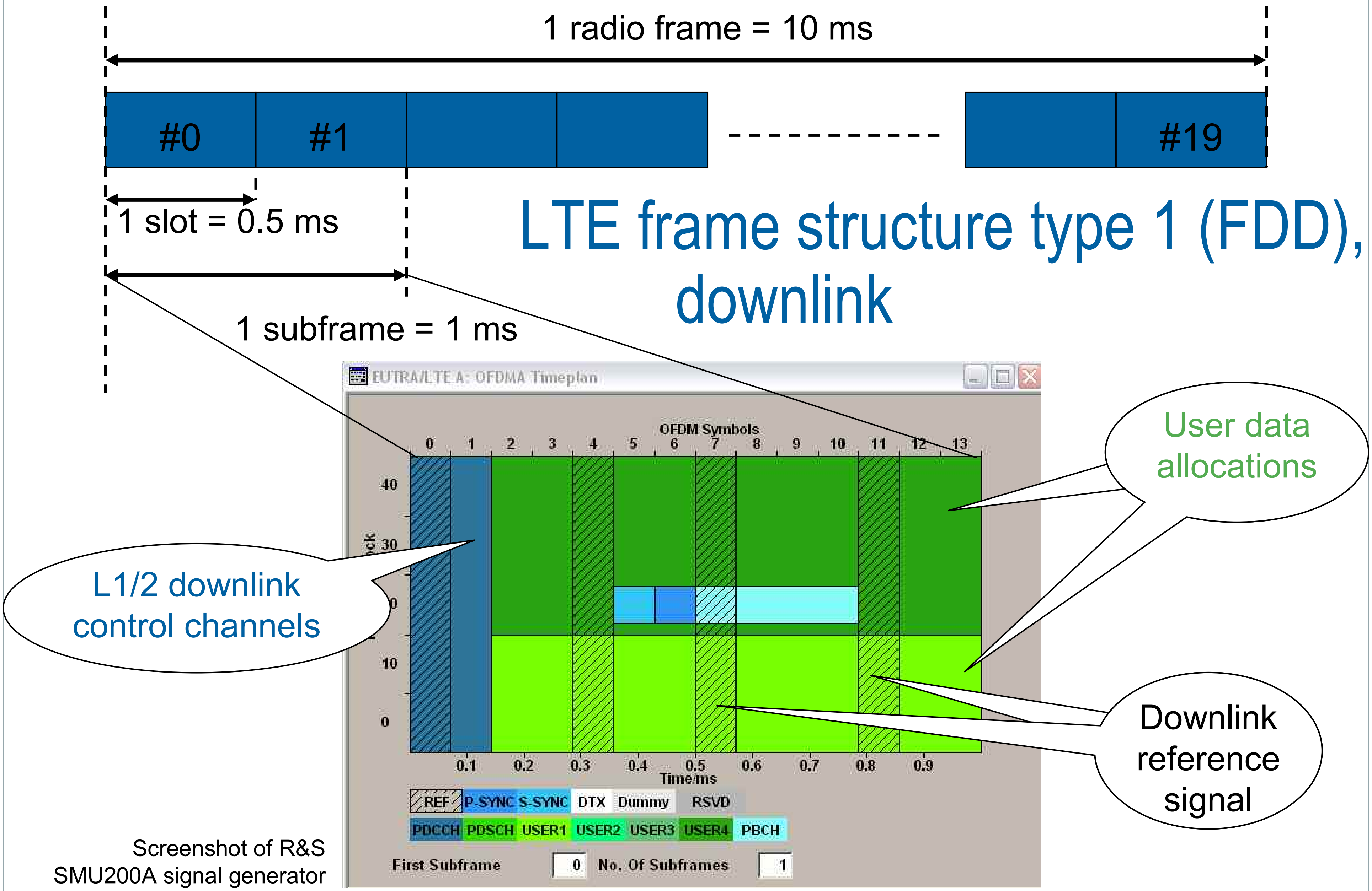
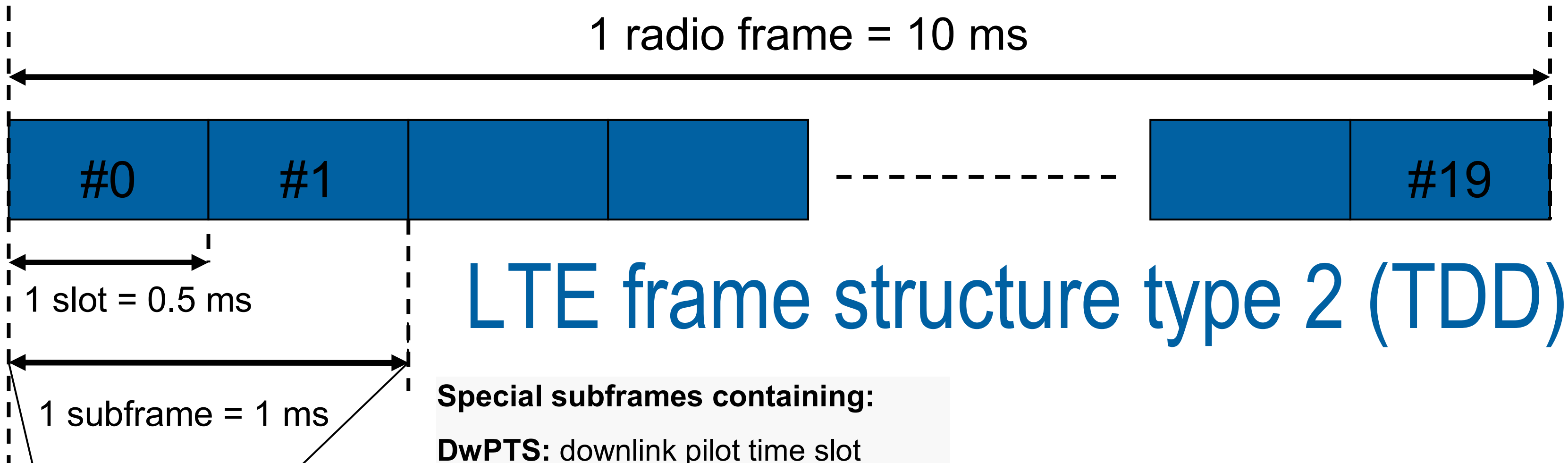
LTE frame structure type 1 (FDD), downlink



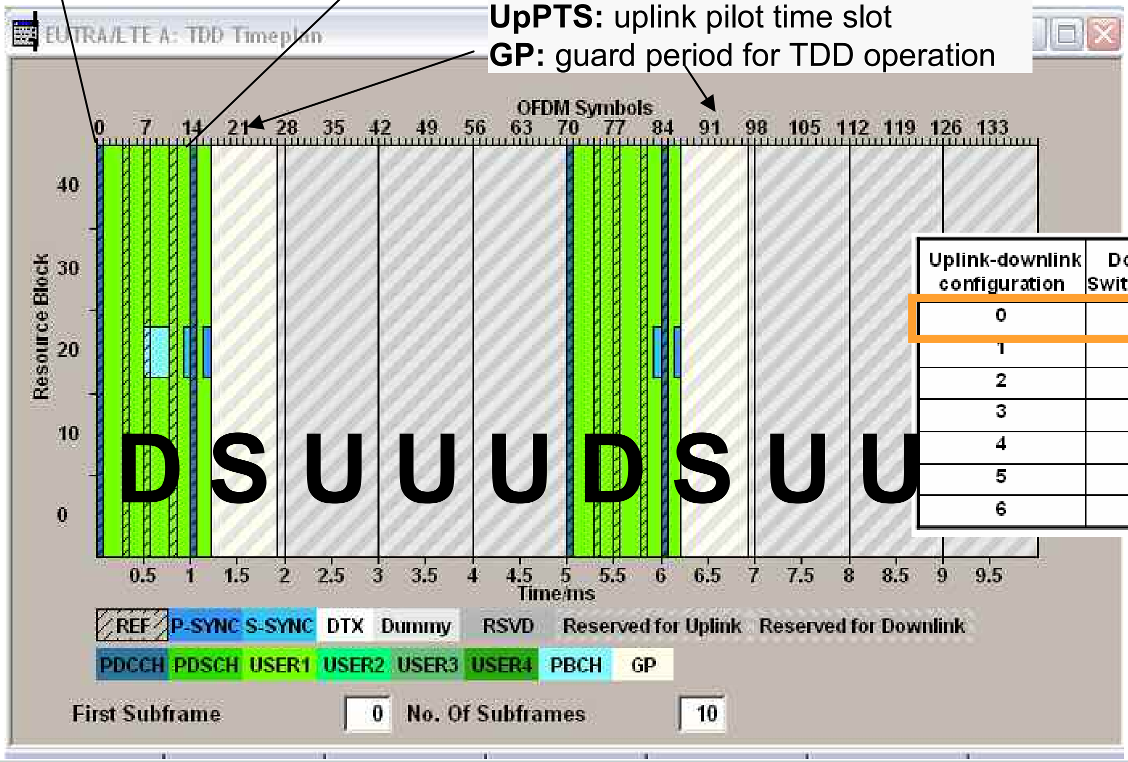
Screenshot of R&S SMU200A signal generator

LTE frame structure type 2 (TDD)



Special subframes containing:

DwPTS: downlink pilot time slot
UpPTS: uplink pilot time slot
GP: guard period for TDD operation



Possible uplink-downlink configurations (D=Downlink, U=Uplink, S=Special Subframe):

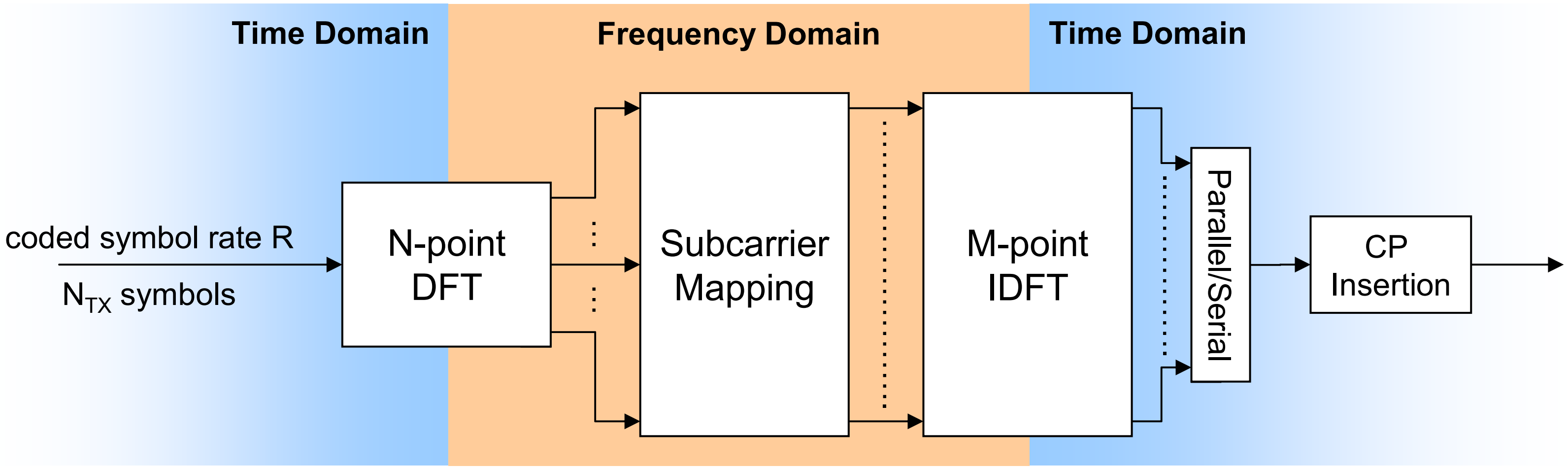
Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

Screenshot of R&S SMU200A signal generator

Introduction to SC-FDMA and uplink frame structure

How to generate SC-FDMA?

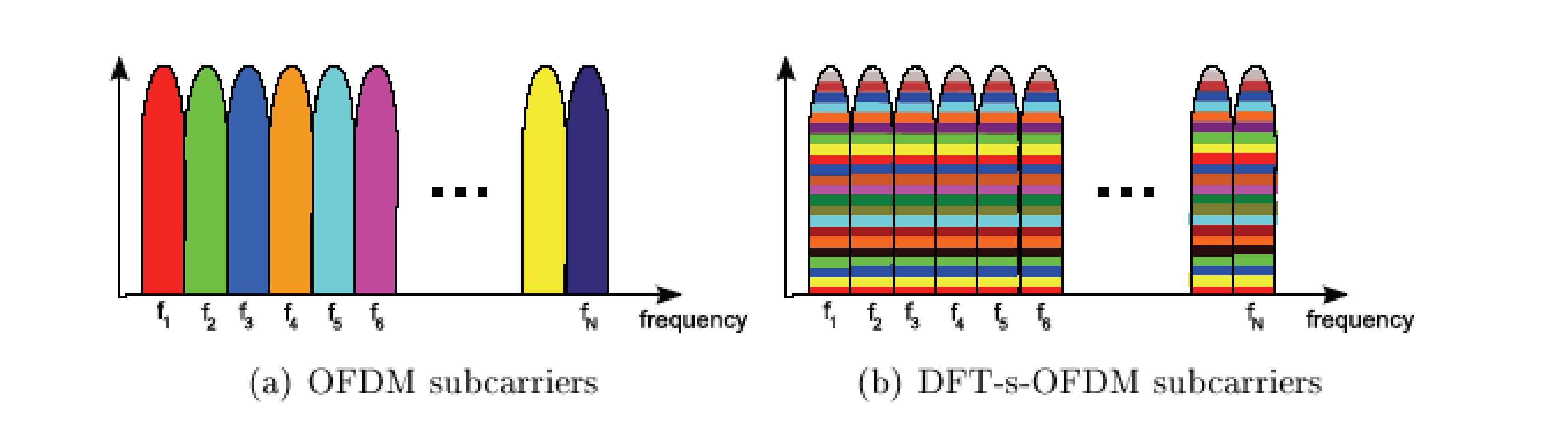
- DFT "pre-coding" is performed on modulated data symbols to transform them into frequency domain,
- Sub-carrier mapping allows flexible allocation of signal to available sub-carriers,
- IFFT and cyclic prefix (CP) insertion as in OFDM,



- Each subcarrier carries a portion of superposed DFT spread data symbols, therefore SC-FDMA is also referred to as DFT-spread-OFDM (DFT-s-OFDM).

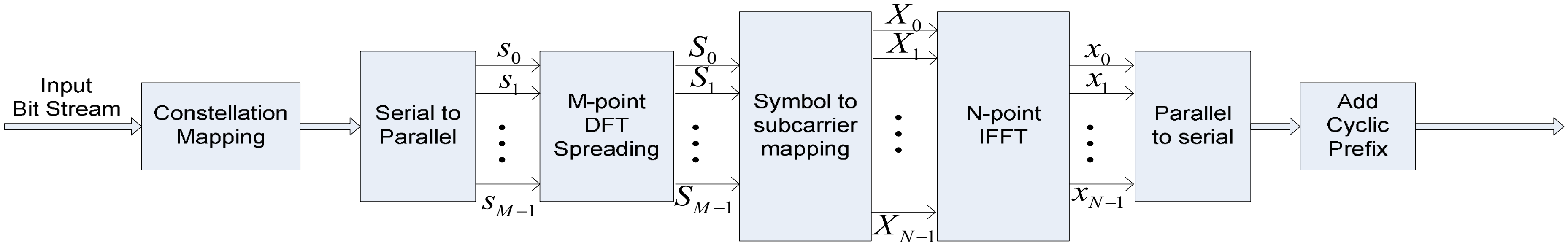
How does a SC-FDMA signal look like?

- **Similar to OFDM signal, but…**
  - …in OFDMA, each sub-carrier only carries information related to one specific symbol,
  - …in SC-FDMA, each sub-carrier contains information of ALL transmitted symbols.

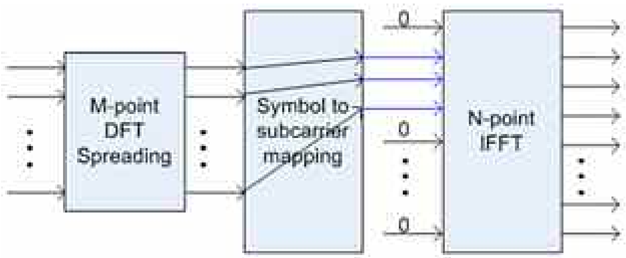


SC-FDMA signal generation

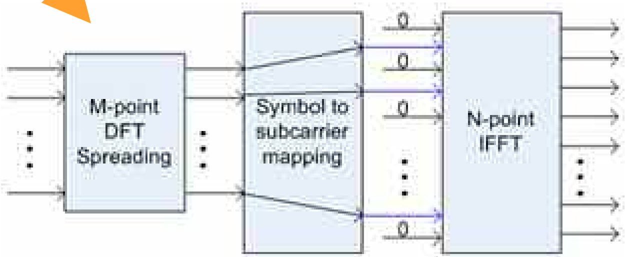
Localized vs. distributed FDMA



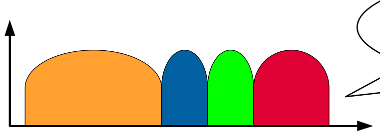
- We have seen that DFT will distribute the time signal over the frequency domain Next question that arises is how is that distribution done: localized or distributed?



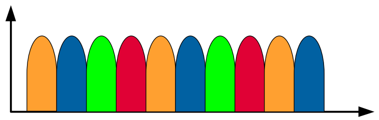
Localized: contiguous subcarriers



Distributed: evenly spaced subcarriers



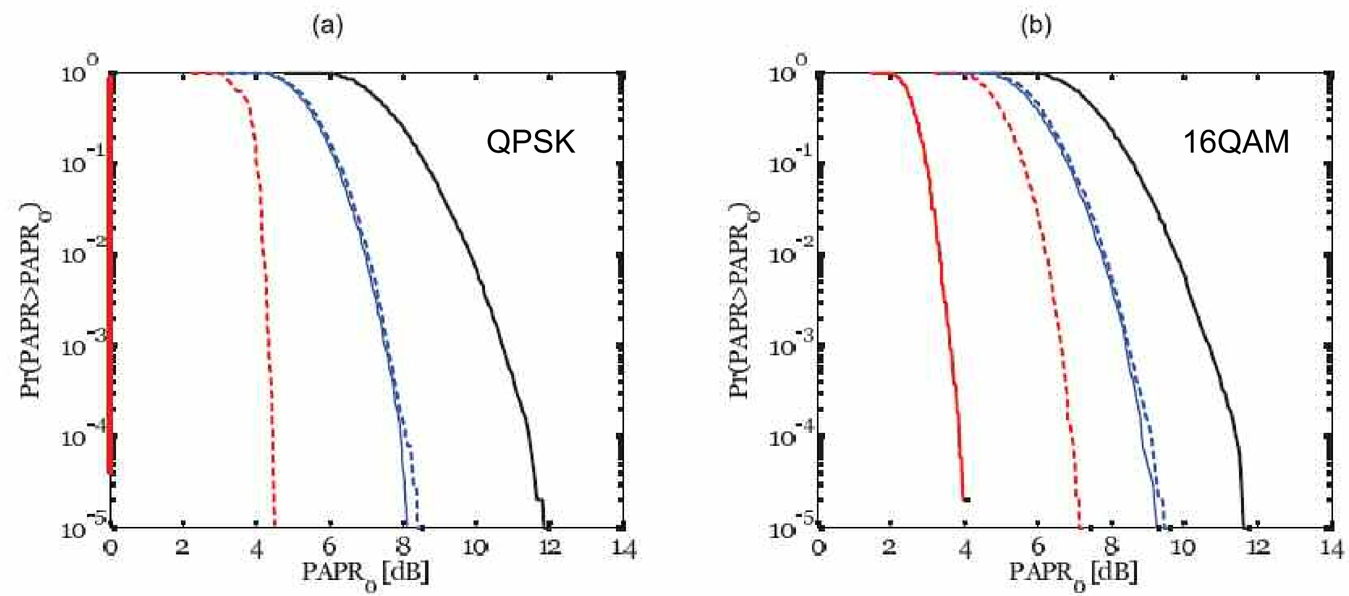
multi-user scheduling gain in frequency domain



robust transmission for control channels and high mobility UE

localized mode is used in LTE

SC-FDMA – Peak-to-average Power Ratio (PAPR)



localized mode (LFDMA) is used in LTE

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.

Source:
H.G. Myung, J.Lim, D.J. Goodman "SC-FDMA for Uplink Wireless Transmission", IEEE VEHICULAR TECHNOLOGY MAGAZINE, SEPTEMBER 2006

IFDMA = "Interleaved FDMA" = Distributed SC-FDMA
LFDMA = "Localized FDMA" = Localized SC-FDMA

SC-FDMA parameterization (FDD and TDD)

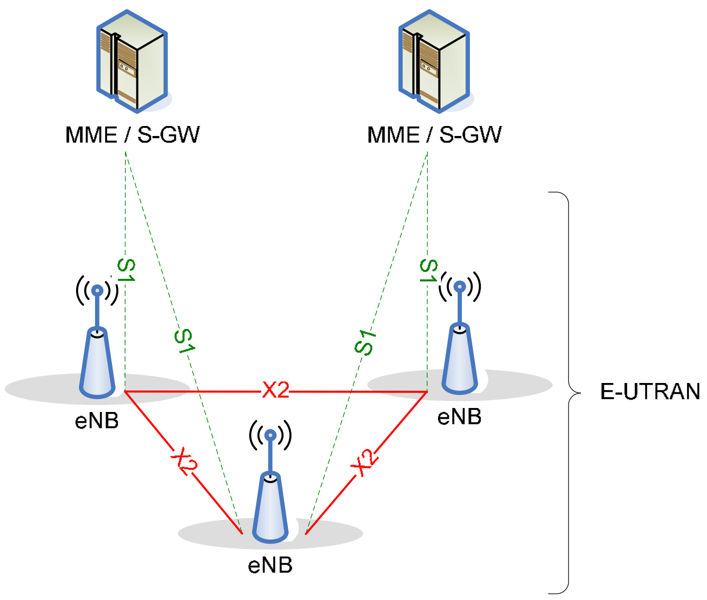
- **LTE FDD**
  - Same as in downlink,

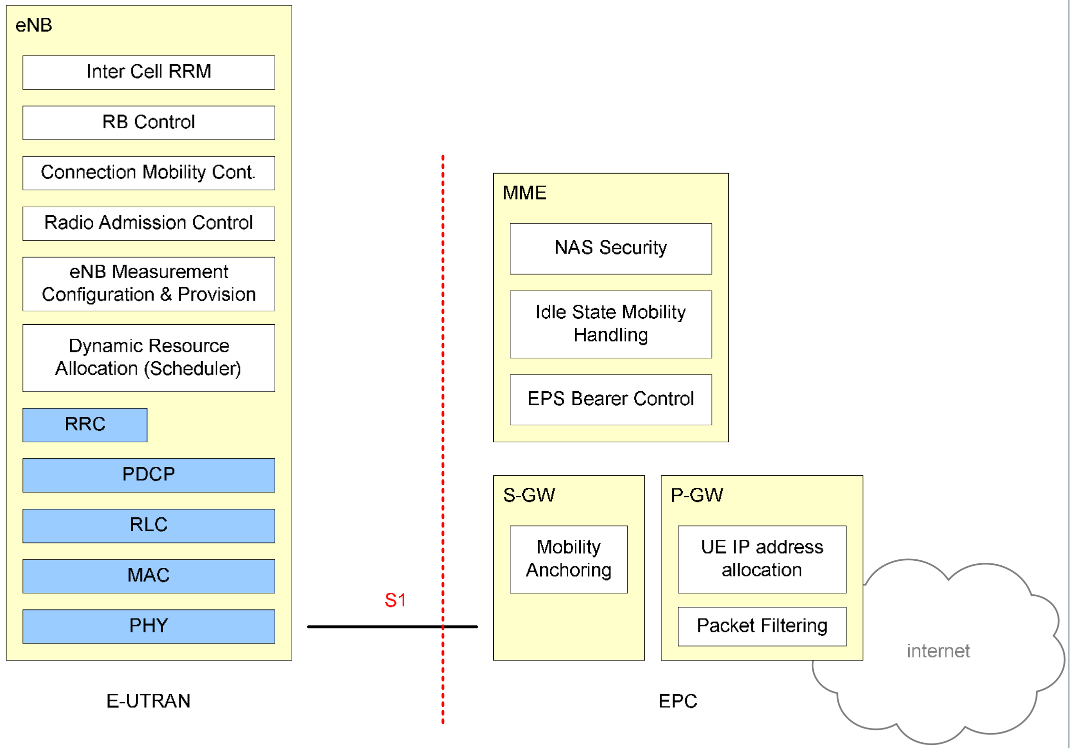
Configuration	Number SC-FDMA Symbols	Number of Subcarrier	Cyclic Prefix Length in Samples	Cyclic Prefix Length in µs
Normal CP Δf = 15 kHz	7	12	160 for 1st symbol 144 for other symbols	5.2 for 1st symbol 4.7 for other symbols
Extended CP Δf = 15 kHz	6		512	16.7

- **TD-LTE**
  - Usage of UL depends on the selected UL-DL configuration (1 to 8), each configuration offers a different number of subframes (1ms) for uplink transmission,
  - Parameterization for those subframes, means number of SC-FDMA symbols same as for FDD and depending on CP,

Network and protocol architecture

LTE/SAE network architecture

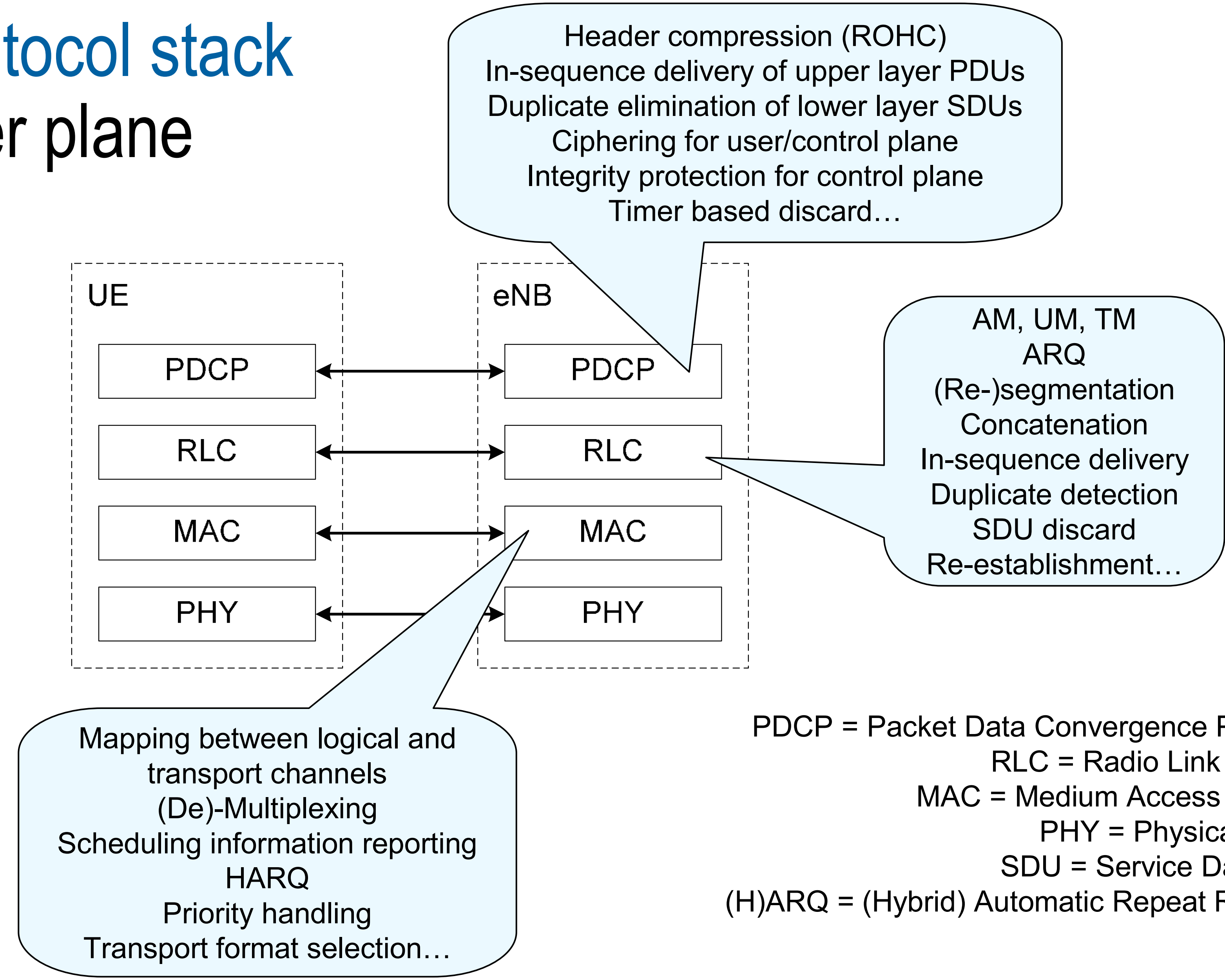




SAE = System Architecture Evolution
eNB = evolved Node B
MME = Mobility Management Entity
E-UTRAN = Evolved UMTS Terrestrial Radio Access Network
S-GW = Serving Gateway

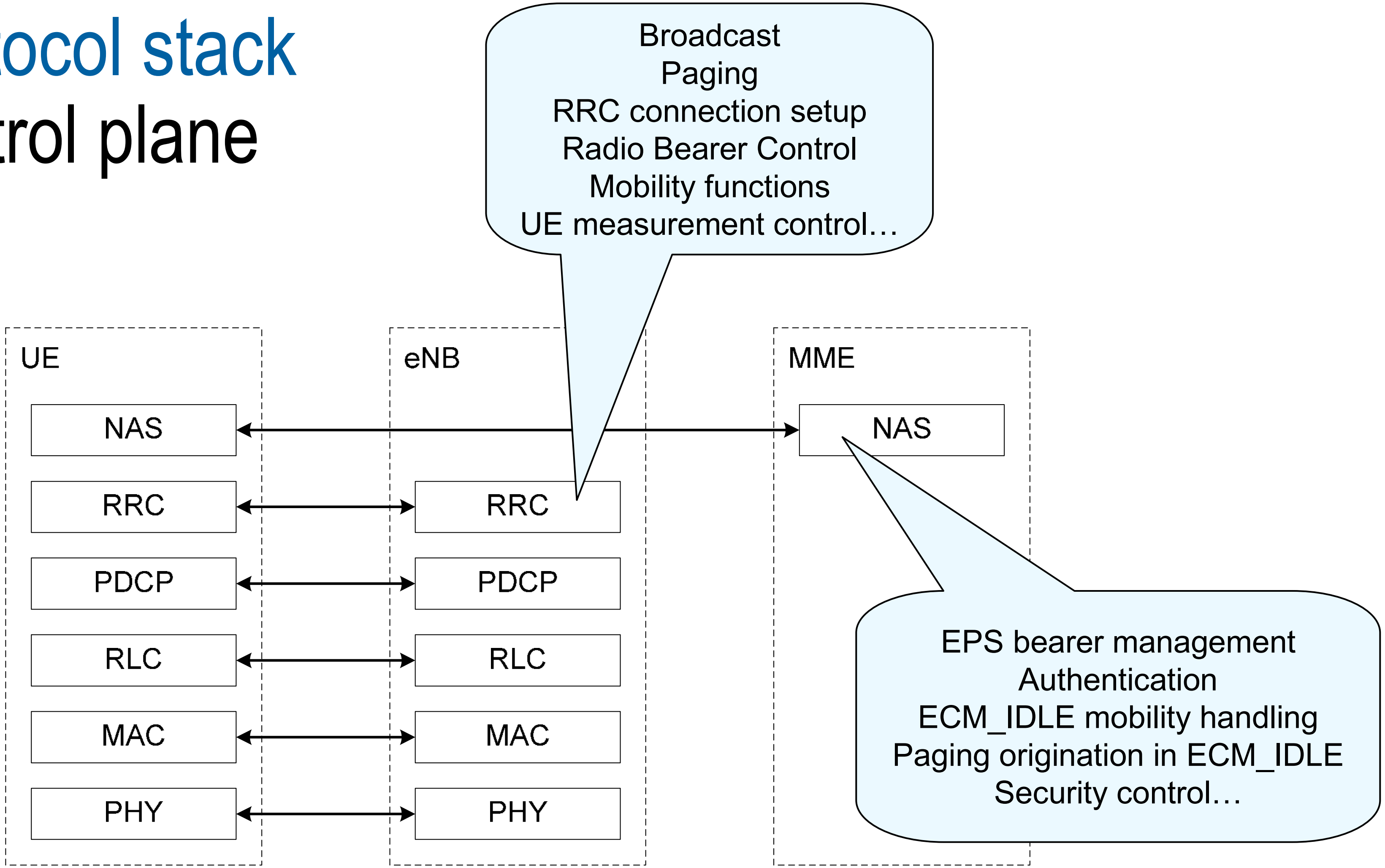
EPS = Evolved Packet System
EPC = Evolved Packet Core
P-GW = Packet Data Network Gateway
NAS = Non Access Stratum
RB = Radio Bearer

Protocol stack
user plane



PDCP = Packet Data Convergence Protocol
RLC = Radio Link Control
MAC = Medium Access Control
PHY = Physical Layer
SDU = Service Data Unit
(H)ARQ = (Hybrid) Automatic Repeat Request

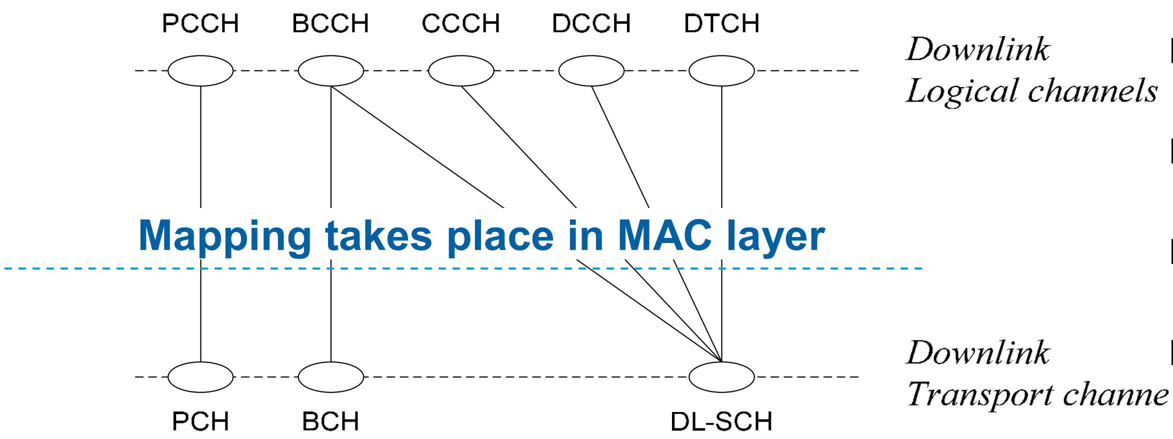
Protocol stack
control plane



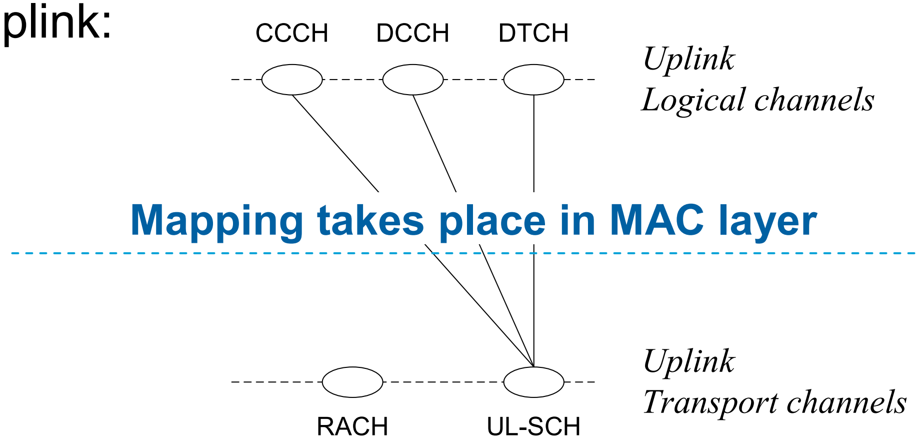
EPS = Evolved packet system
RRC = Radio Resource Control
NAS = Non Access Stratum
ECM = EPS Connection Management

Mapping between logical and transport channels
simplified architecture…

Downlink:



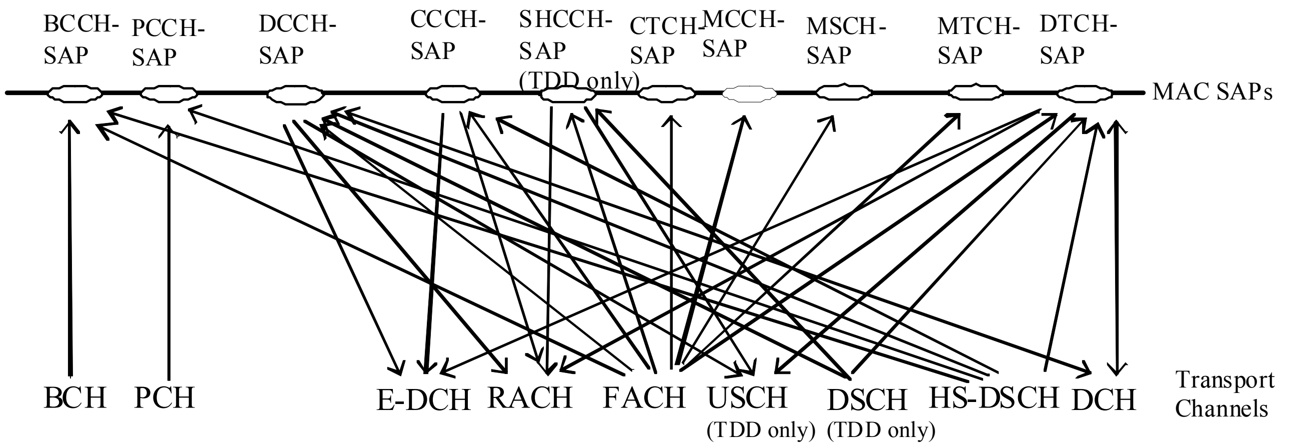
Uplink:



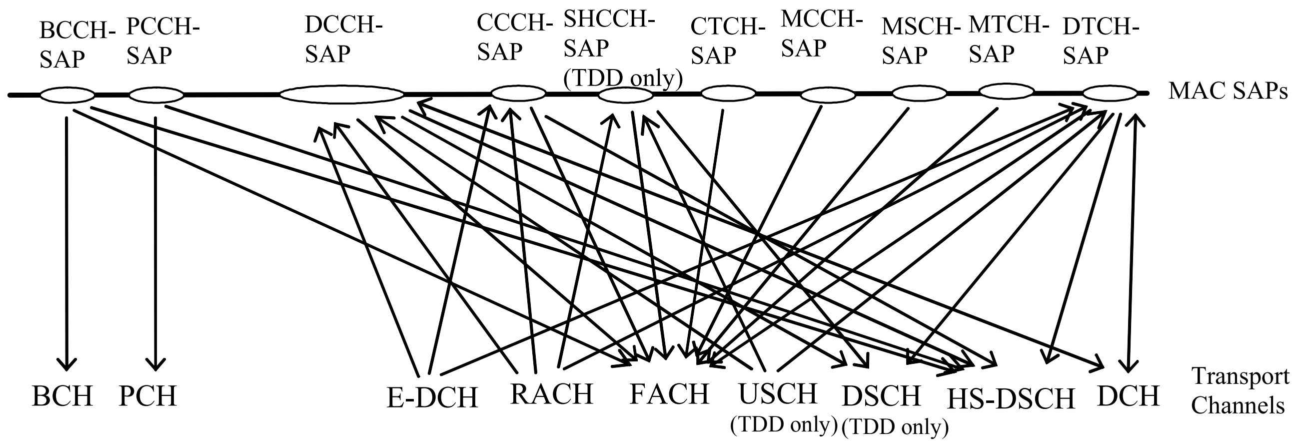
- DTCH:
  Dedicated Traffic Channel
- DCCH:
  Dedicated Control Channel
- CCCH:
  Common Control Channel
- DL-SCH:
  Downlink Shared Channel
- UL-SCH:
  Uplink Shared Channel
- B(C)CH:
  Broadcast (Control) Channel
- P(C)CH:
  Paging (Control) Channel
- RACH: Random Access Channel

...compared to WCDMA/HSPA

Downlink:



Uplink:



LTE UE categories (downlink and uplink)

UE category	Maximum number of DL-SCH transport block bits received within TTI	Maximum number of bits of a DL-SCH transport block received a TTI	Total number of soft channel bits	Maximum number of supported layers for spatial multiplexing in DL
1	10296	10296	250368	1
2	51024	51024	1237248	2
3	102048	75376	1237248	2
4	150752	75376	1827072	2
5	302752	151376	3667200	4

~300 Mbps peak DL data rate for 4x4 MIMO

~150 Mbps peak DL data rate for 2x2 MIMO

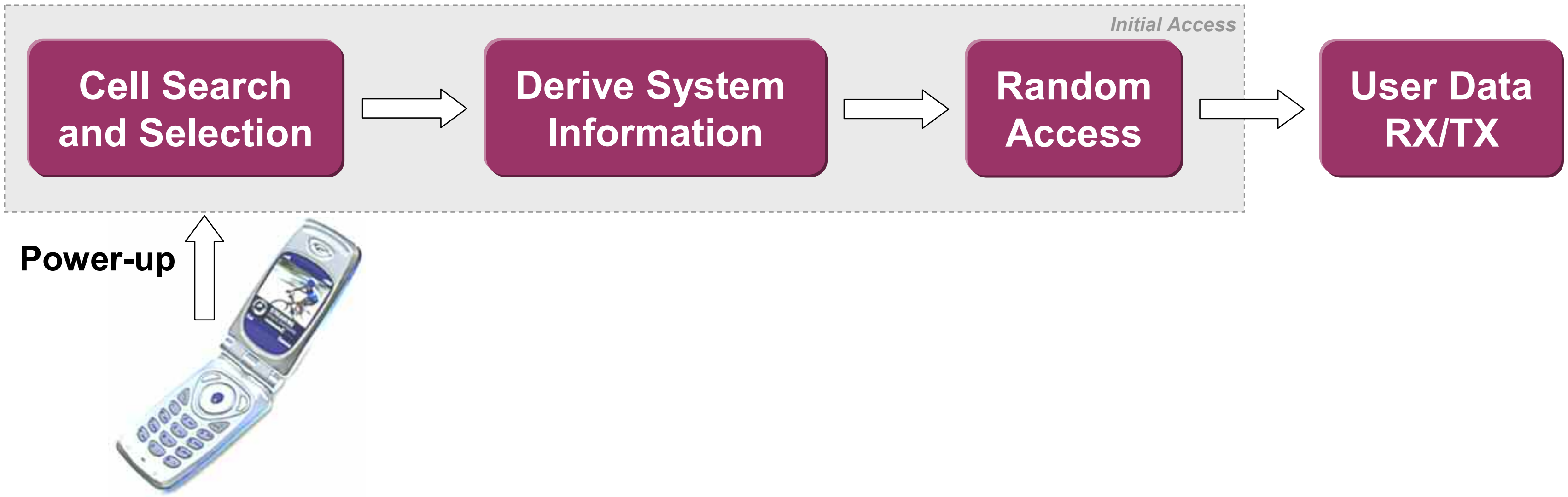
UE category	Maximum number of UL-SCH transport block bits received within TTI	Support 64QAM in UL
1	5160	No
2	25456	No
3	51024	No
4	51024	No
5	75376	Yes

~75 Mbps peak UL data rate

MIMO = Multiple Input Multiple Output
UL-SCH = Uplink Shared Channel
DL-SCH = Downlink Shared Channel
UE = User Equipment
TTI = Transmission Time Interval

Radio procedures

LTE Initial Access



Downlink physical channels and signals

LTE Downlink Physical Signals	
Primary and Secondary Synchronization Signal	Provide acquisition of cell timing and identity during cell search
Downlink Reference Signal	Cell search, initial acquisition, coherent demod., channel estimation

LTE Downlink Physical Channels	
Physical Broadcast Channel (PBCH)	Provides essential system information e.g. system bandwidth

not required for cell search and cell selection

Cell search in LTE

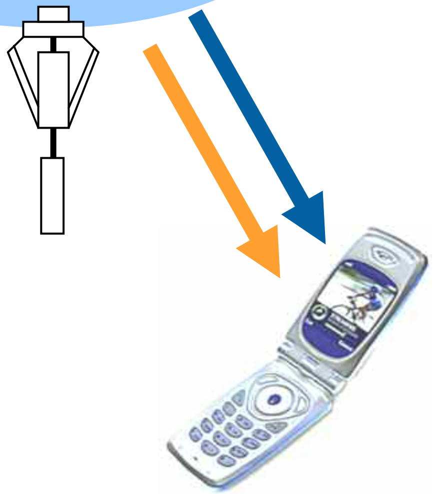
Physical layer cell identity
(1 out of 504)

Identified by…

Physical layer cell identity group

"Smith"	"Johnson"	"Rose"
0	**1**	**167**
0 1 2	0 1 2	0 1 2
"James" "John" "Robert"	"James" "John" "Robert"	"James" "John" "Robert"

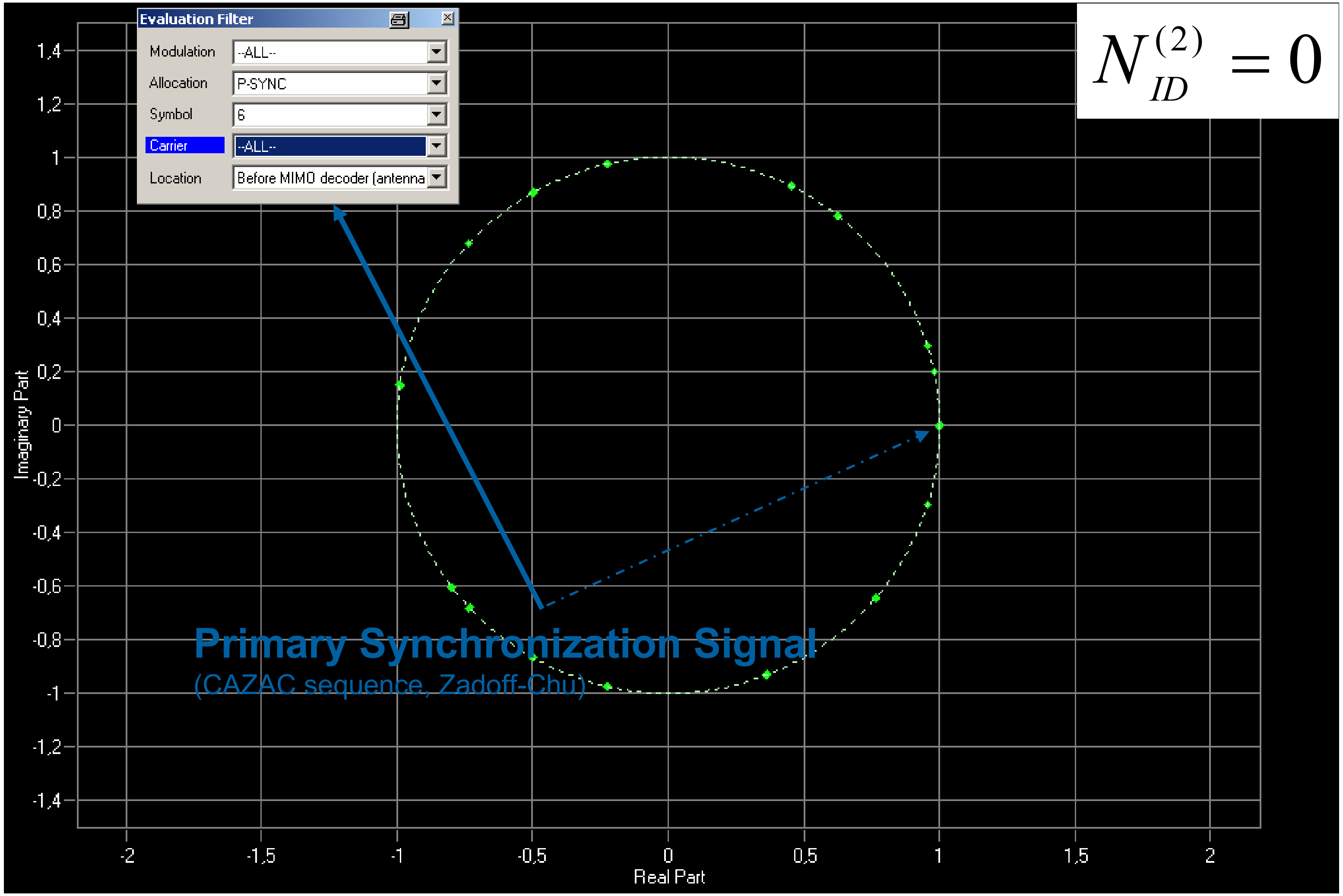
Physical layer identity



1. Primary synchronization signal (PSS)
   – 3 possible sequences to identify the cell's physical layer identity (0, 1, 2),
2. Secondary synchronization signal (SSS)
   – 168 different sequences to identity physical layer cell identity group,

- Hierarchical cell search as in 3G; providing PSS and SSS for assistance,
  – PSS is carrying physical layer identity $N_{ID}^{(2)}$,
  – SSS is carrying physical layer cell identity group $N_{ID}^{(1)}$,
  – Cell Identity is computed as $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$, where $N_{ID}^{(1)} = 0,1,...,167$ and $N_{ID}^{(2)} = 0, 1, 2$
  .

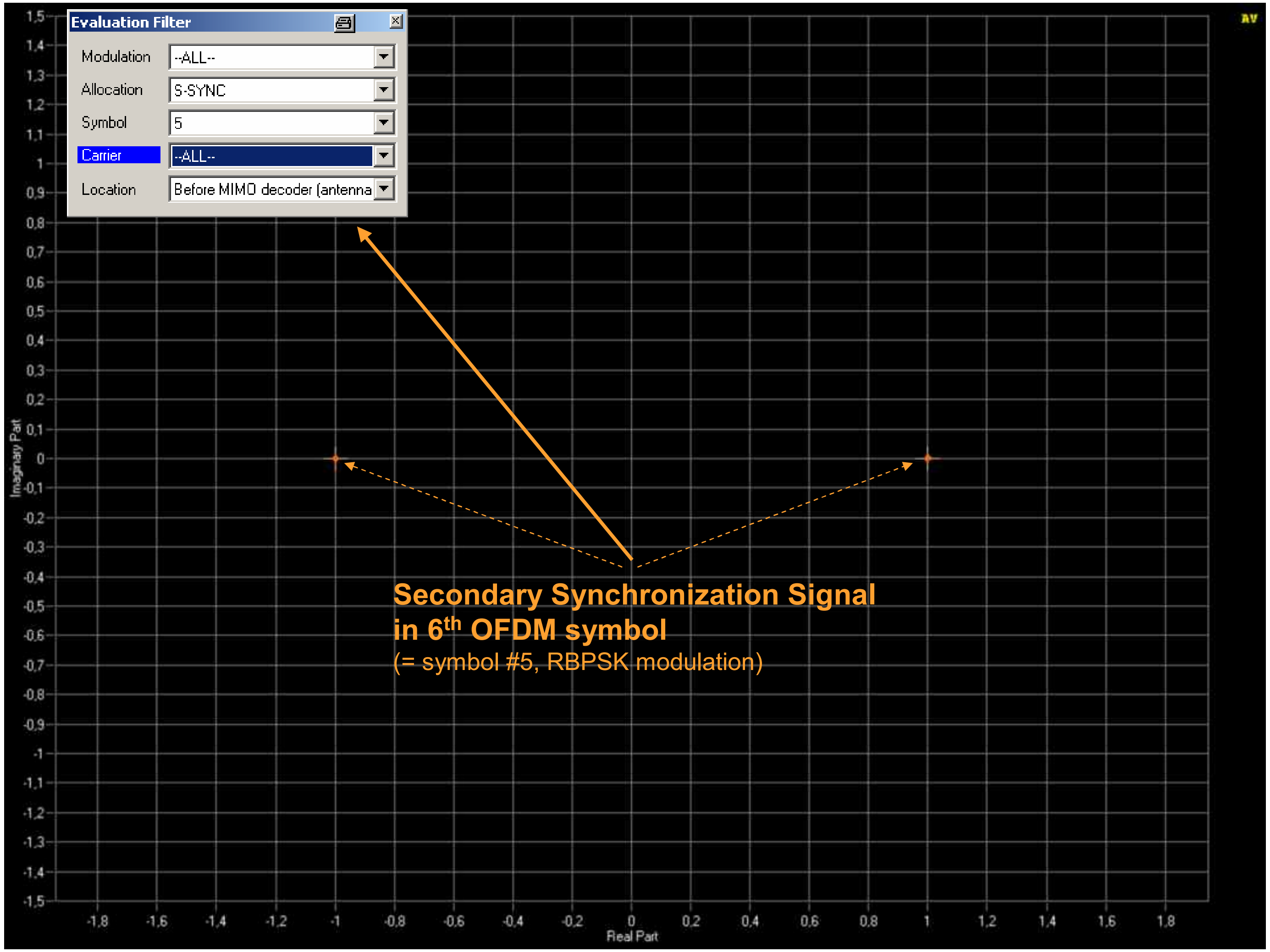
Primary Synchronization Signal



$$N_{ID}^{(2)} = 0$$

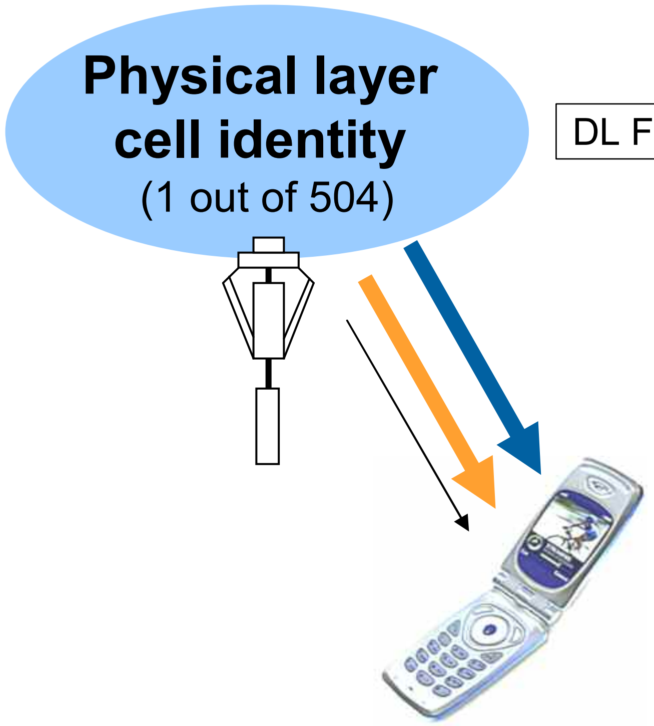
Screenshot taken from R&S® FSQ signal analyzer

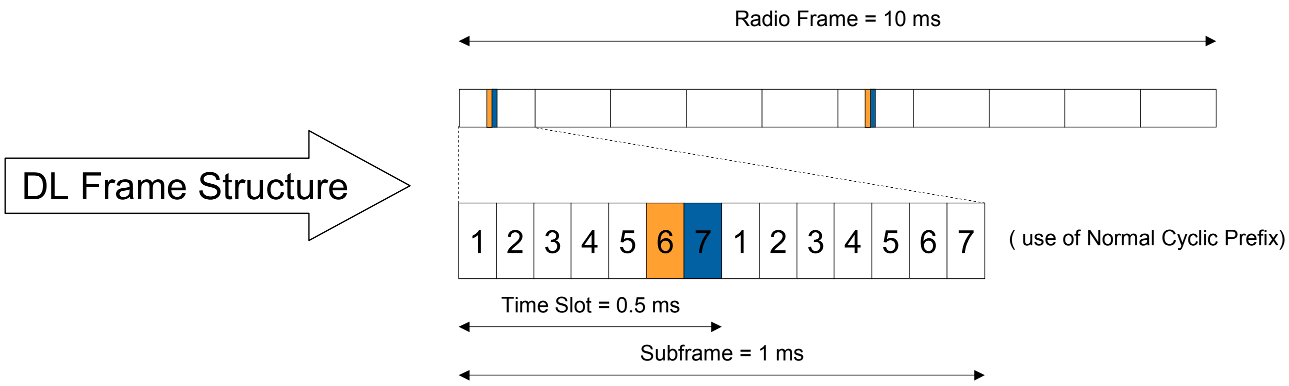
Secondary Synchronization Signal



Screenshot taken from R&S® FSQ signal analyzer

Cell search in LTE, reference signals





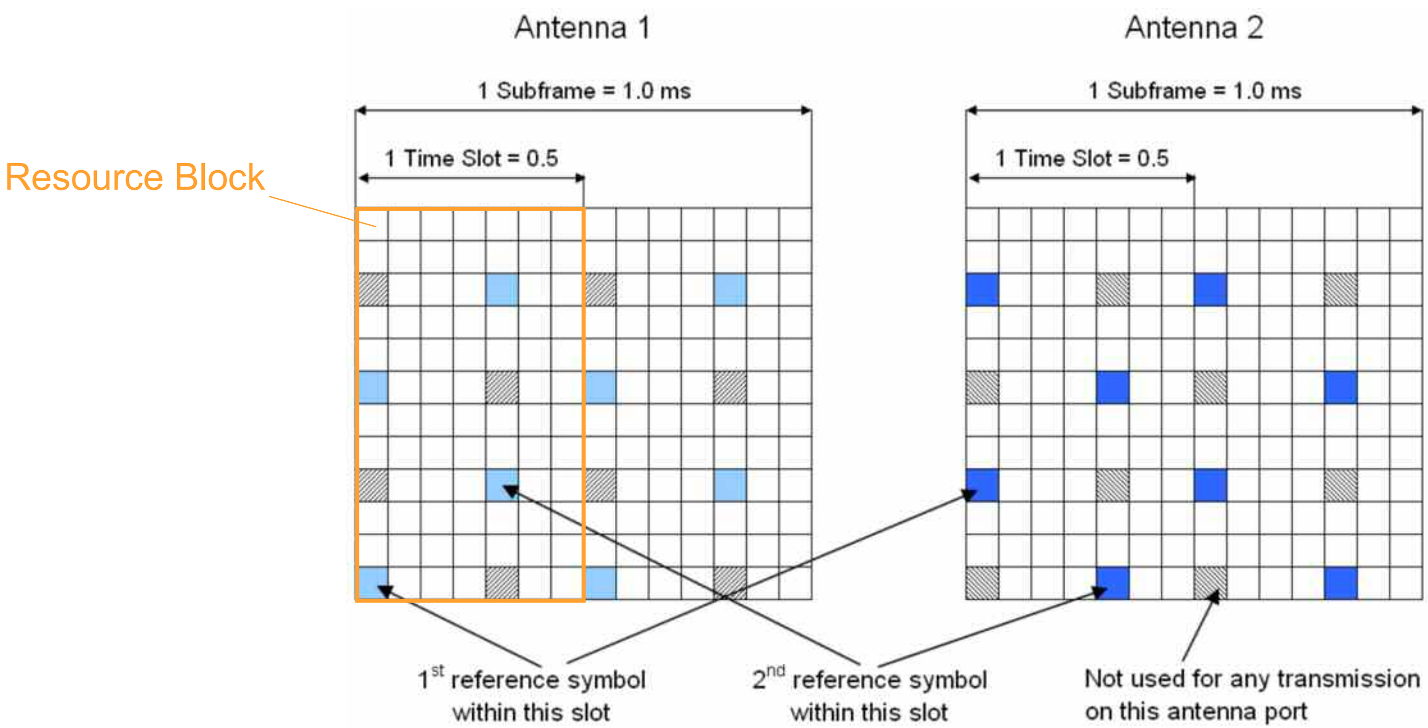
1. Primary synchronization signal (PSS)
   – 3 possible sequences to identify the cell's physical layer identity (0, 1, 2),
2. Secondary synchronization signal (SSS)
   – 168 different sequences to identity physical layer cell identity group,

⇨ Downlink reference signals,

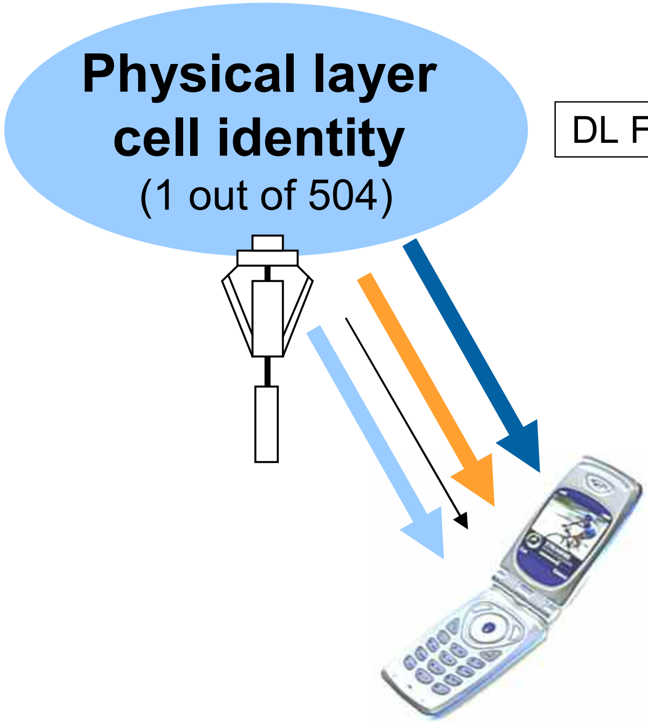
- Cell-specific reference signals are used for…
  – … cell search and initial acquisition,
  – … downlink channel estimation for coherent demodulation/detection at the UE,
  – … downlink channel quality measurements.

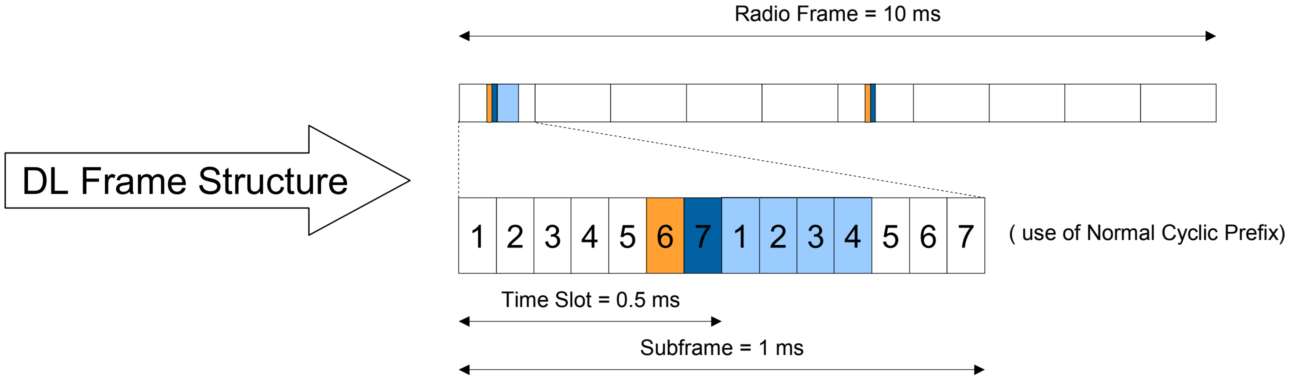
Downlink reference signals

- Each antenna has a specific reference signal pattern, e.g. for 2 antennas,
  - Frequency domain spacing is 6 subcarrier,
  - Time domain spacing is 4 OFDM symbols ⇨ 4 reference signals per resource block,



Cell search in LTE, essential system information



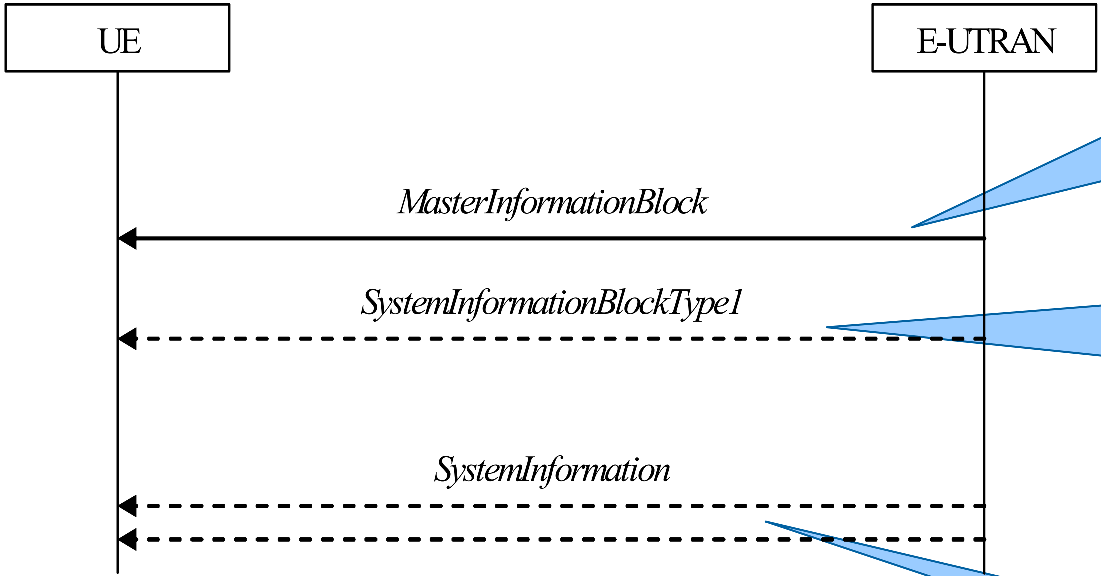


1. Primary synchronization signal (PSS)
   - 3 possible sequences to identify the cell's physical layer identity (0, 1, 2),
2. Secondary synchronization signal (SSS)
   - 168 different sequences to identity physical layer cell identity group,

⇨ Downlink reference signals,

3. Physical Broadcast Channel (PBCH)
   - Carrying broadcast channel (BCH) with Master Information Block (MIB) System bandwidth [4 bit], PHICH configuration [Duration: 1 bit, Resource: 2 bit], System Frame Number [SFN, 8 bit] and indirect about the used Tx antennas,
   - QPSK modulated, cell-specific scrambling
   - Transmitted on 72 subcarriers around the carrier frequency,

System information broadcast in LTE



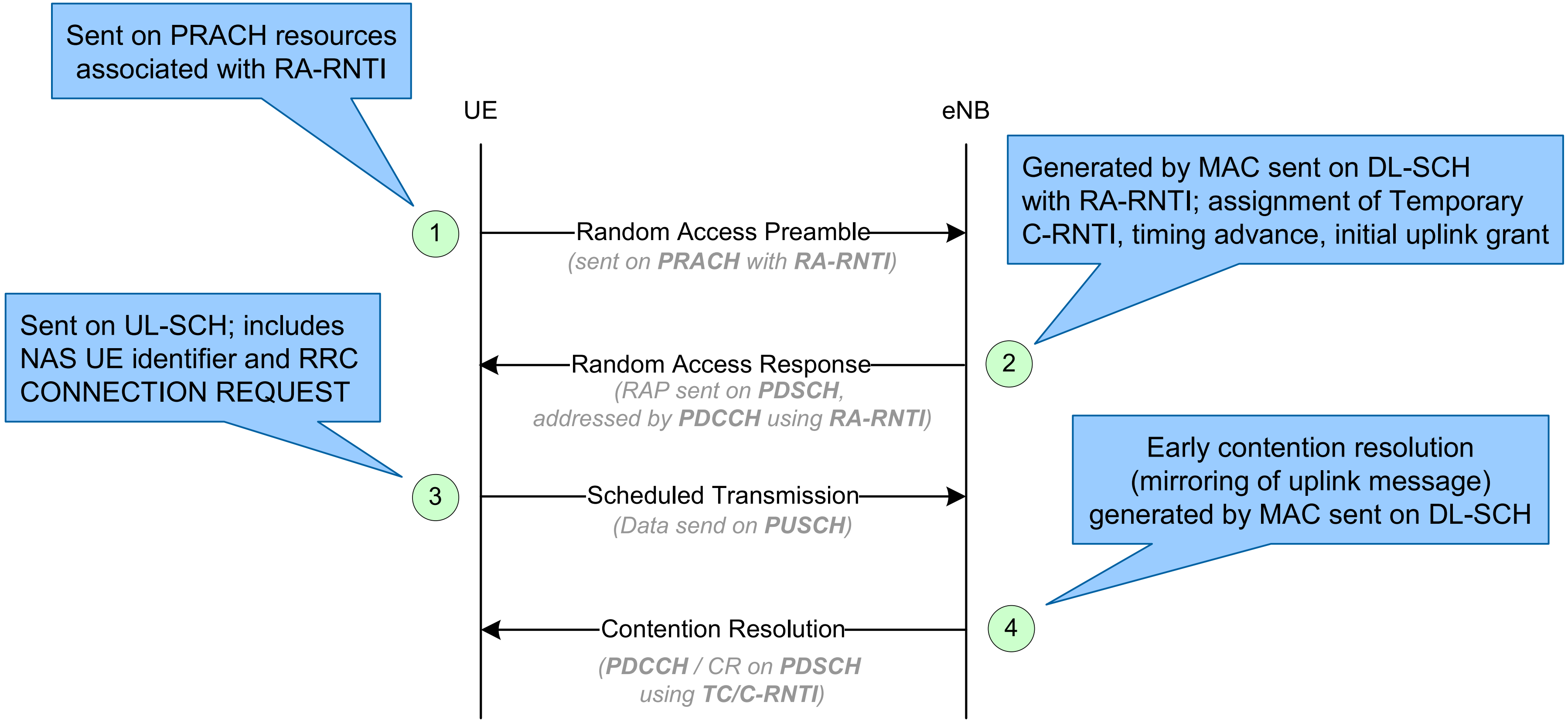
<u>Master Information Block (on BCH), periodicity 40 ms:</u>
System bandwidth, PHICH configuration, SFN number of transmit antennas,

<u>System Information Block Type 1 (on DL-SCH), periodicity 80 ms:</u>
PLMN IDs, Tracking Area Code, Cell identity, Access restrictions, scheduling information,…

System information blocks with same scheduling requirements can be mapped to same SI message (DL-SCH)

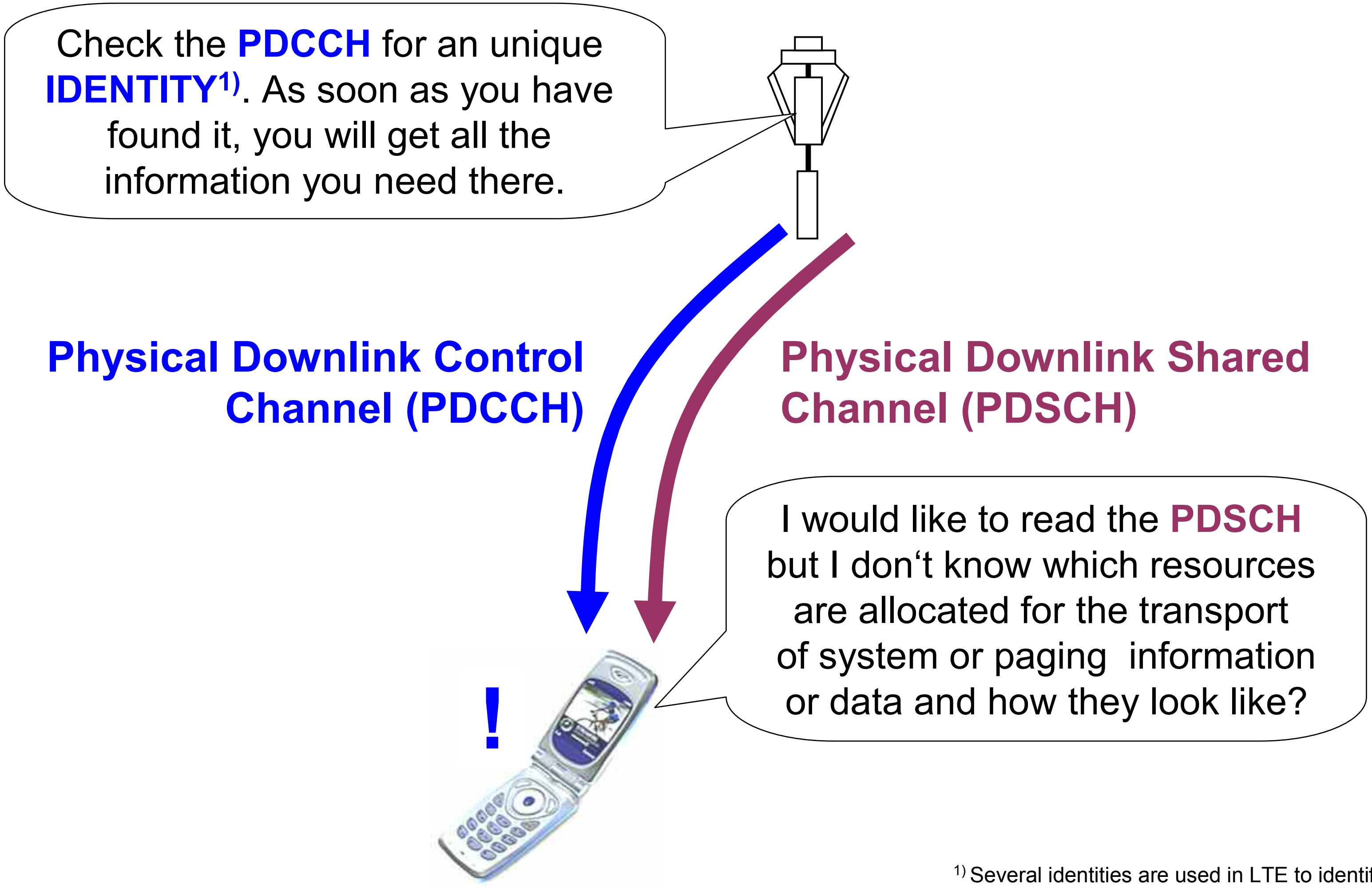
SI-RNTI is used on ***PDCCH*** to address System Information Block Type 1 and SI messages

Random Access Procedure



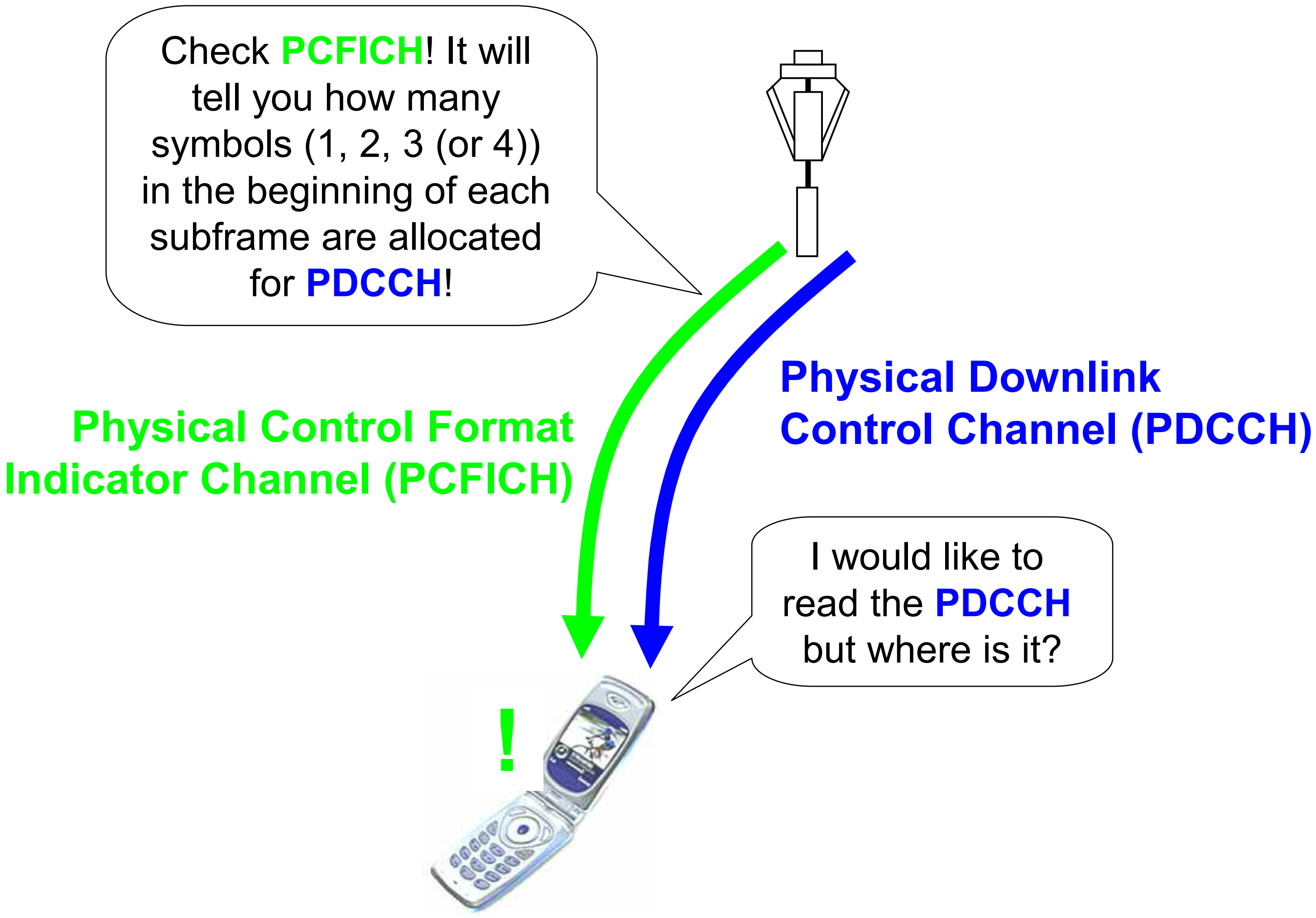
PRACH	Physical Random Access Channel	C-RNTI	Cellular RNTI
RA-RNTI	Random Access Radio Network Temporary Identity	UL-SCH	Uplink Shared Channel
MAC	Medium Access Control (Layer)	CR	Contention Resolution
DL-SCH	Downlink Shared Channel	TC-RNTI	Temporary Cellular RNTI

How to derive information in LTE?



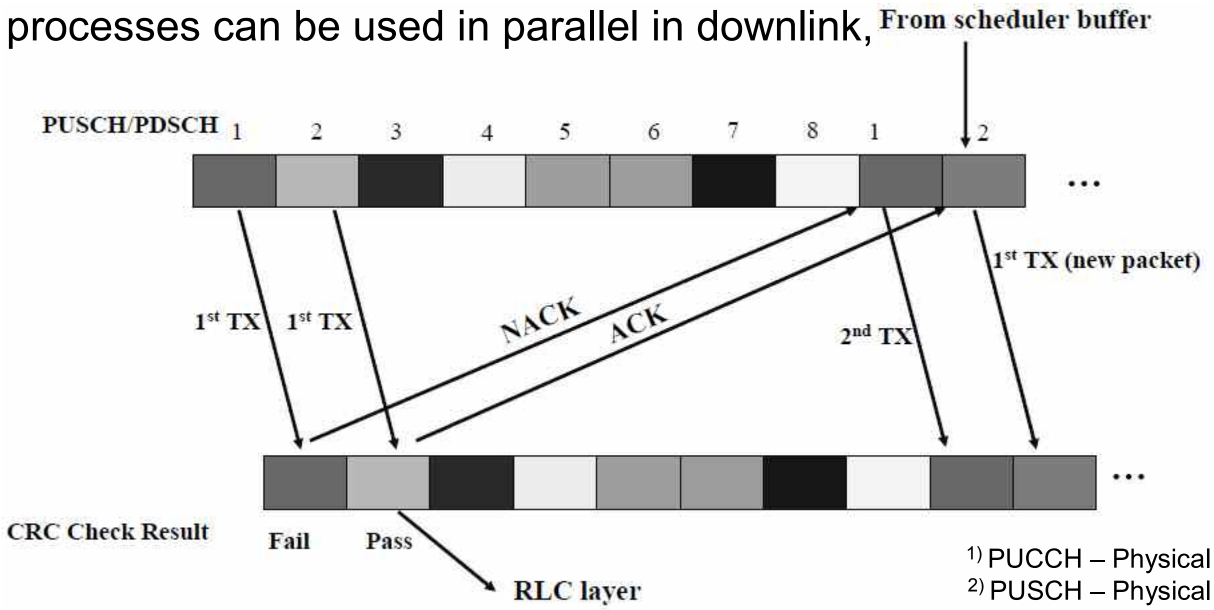
[1] Several identities are used in LTE to identify UE's (e.g. C-RNTI), System Information (SI-RNTI), Paging Information (P-RNTI) or during Random Access Procedure (RA-RNTI), for details see 3GPP TS36.321 V8.5.0 MAC Protocol Specification

Indicating PDCCH format



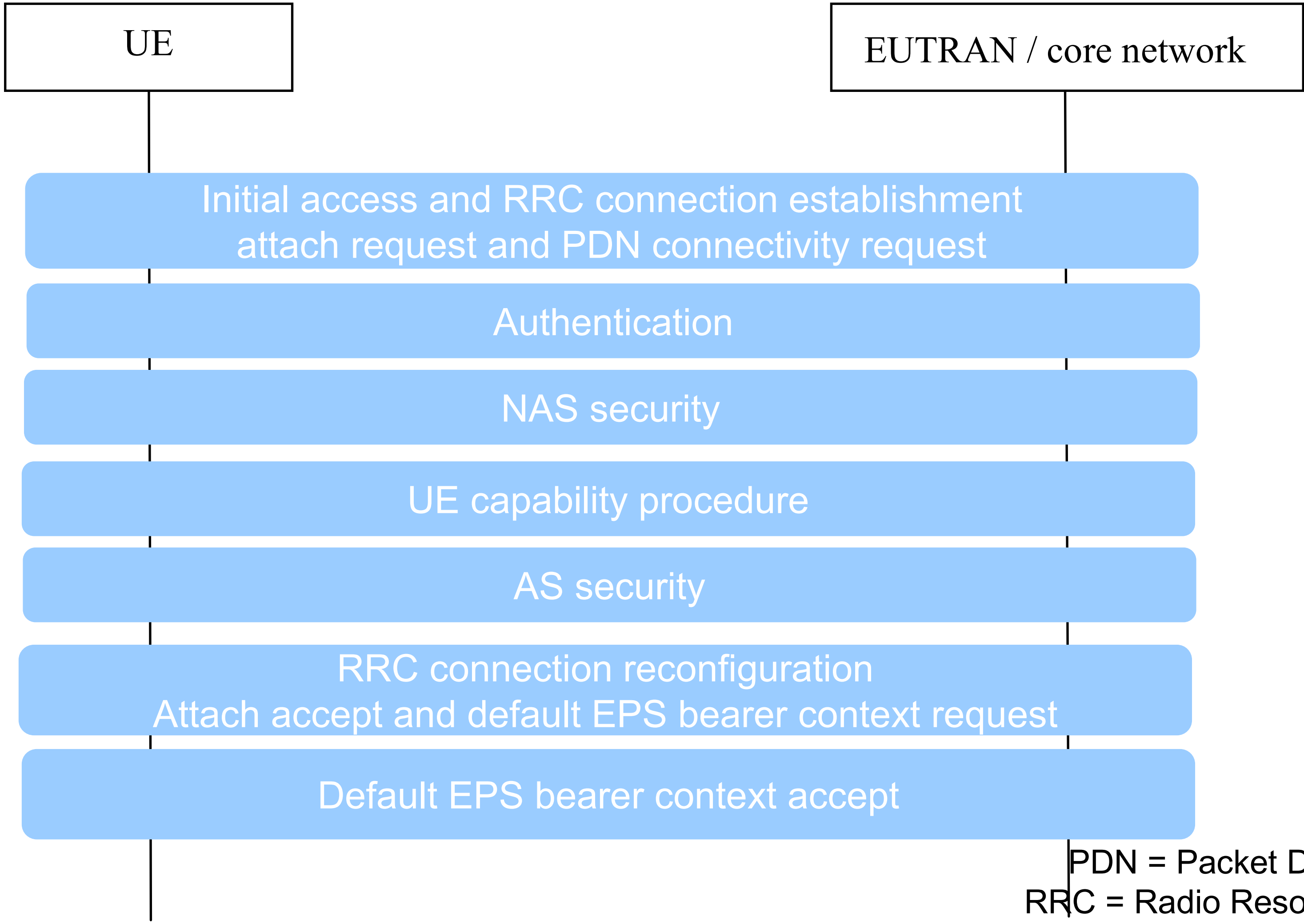
Hybrid ARQ in the downlink

- ACK/NACK for data packets transmitted in the downlink is the same as for HSDPA, where the UE is able to request retransmission of incorrectly received data packets,
  - ACK/NACK is transmitted in UL, either on PUCCH[1)] or multiplexed within PUSCH[2)] (see description of those UL channels for details),
  - ACK/NACK transmission refers to the data packet received four sub-frames (= 4 ms) before,
  - 8 HARQ processes can be used in parallel in downlink,



1) PUCCH – Physical Uplink Control Channel
2) PUSCH – Physical Uplink Shared Channel

Default EPS (Evolved Packet System) bearer setup



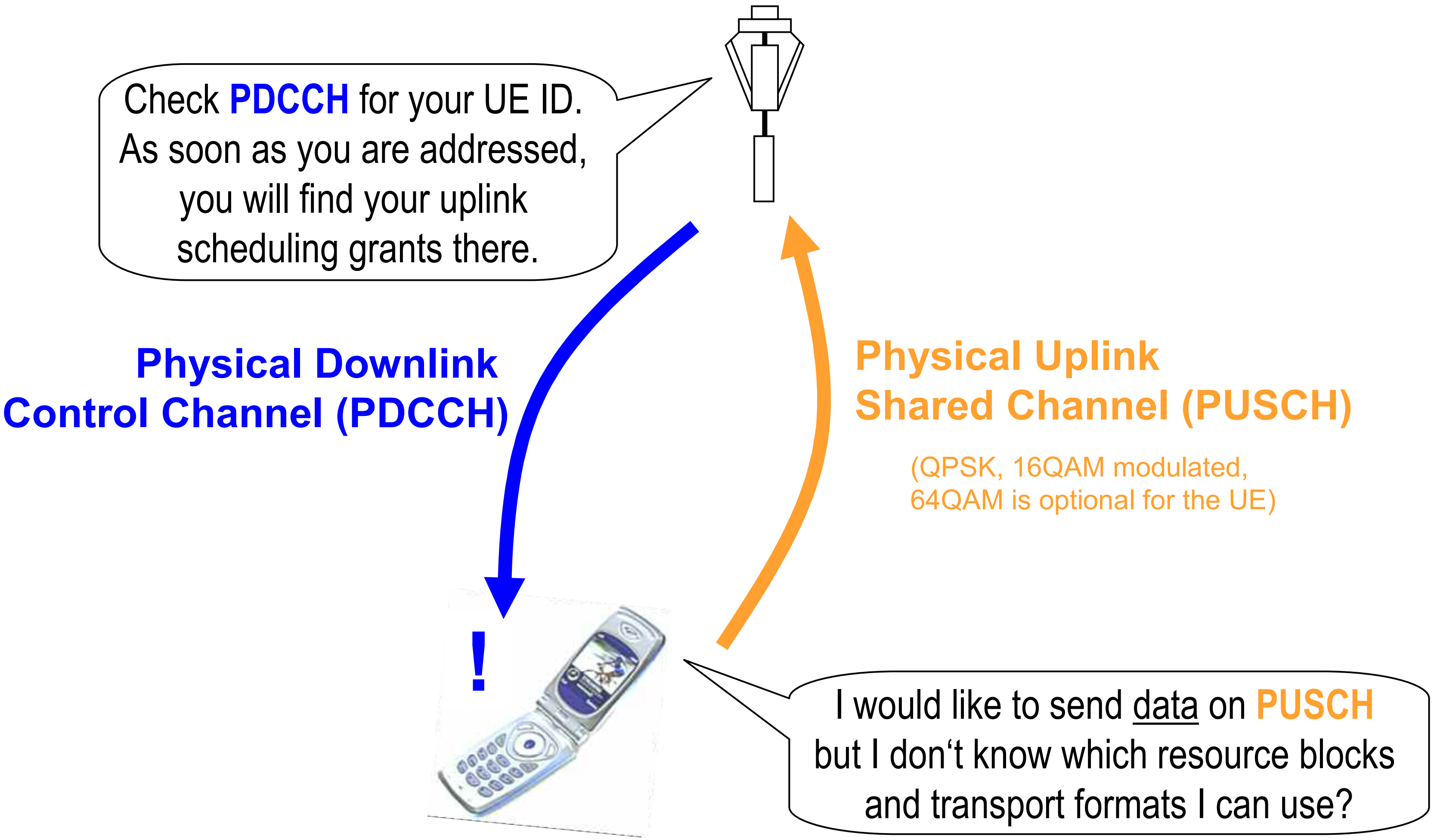
PDN = Packet Data Network
RRC = Radio Resource Control
NAS = Non-Access Stratum
AS = Access Stratum

Uplink physical channels and signals

LTE Uplink Physical Channels	
Physical Uplink Shared Channel (PUSCH)	Carries user data
Physical Uplink Control Channel (PUCCH)	Carries control information (UCI = Uplink Control Information)
Physical Random Access Channel (PRACH)	Preamble transmission for initial access

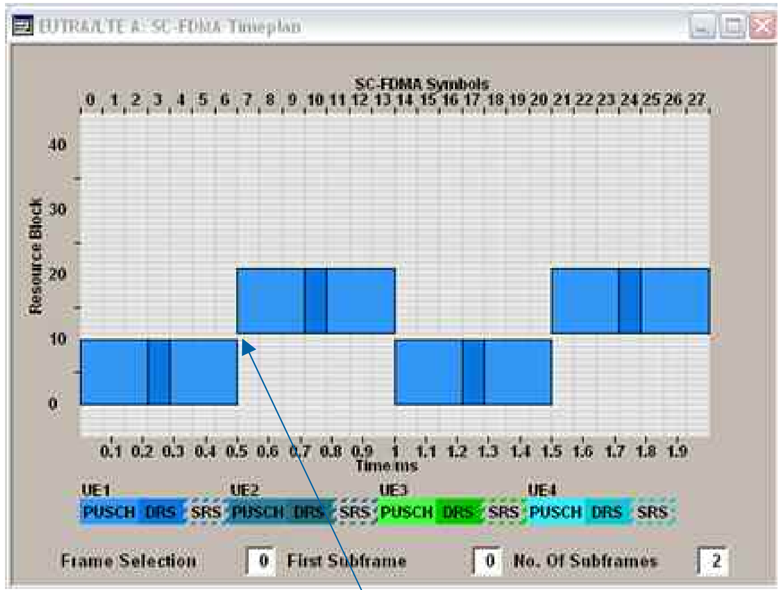
LTE Uplink Physical Signals	
Demodulation Reference Signal (DRS)	Enables channel estimation and data demodulation
Sounding Reference Signal (SRS)	Enables uplink channel quality evaluation

Scheduling of uplink data

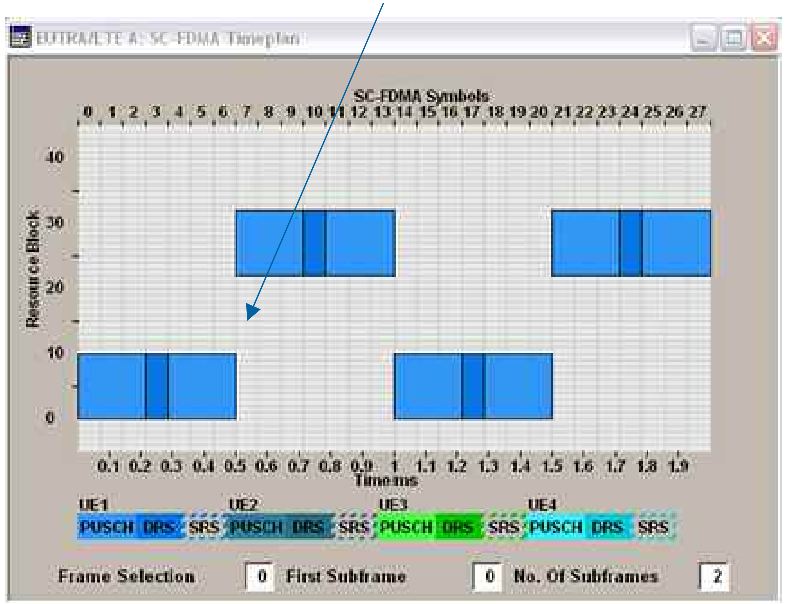


UL frequency hopping

- **Intra- and inter-subframe hopping,**
  - **Intra-subframe hopping.** UE hops to another frequency allocation from one slot to another within one subframe,
  - **Inter-subframe hopping.** Frequency allocation changes from one subframe to another one,
  - **Two types of hopping,**
    - **Type I.** Explicit frequency offset is used in the 2nd slot, can be configured and is indicated to the UE by resource block assignment / hopping resource allocation field in DCI format 0,
    - **Type II.** Use of pre-defined hopping pattern, allocated BW is divided into sub-bands, hopping is done from one sub-band to another from one slot or subframe depending on configured frequency hopping scheme.



Example: Intra-subframe hopping, Type I with different offsets

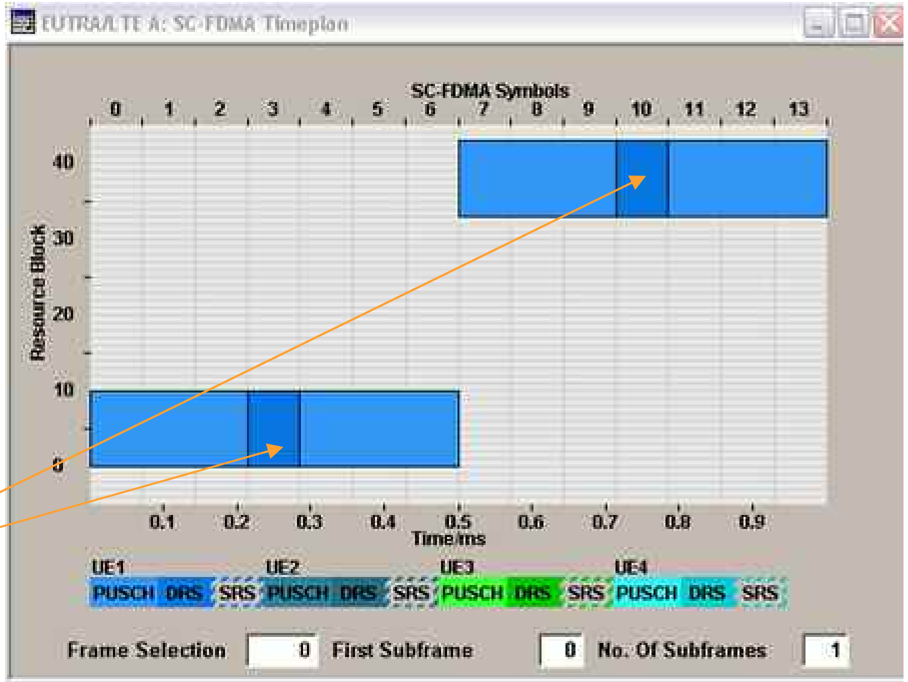


Screenshots of R&S® SMU200A Vector Signal Generator

75 Years of Driving Innovation

Demodulation Reference Signal (DRS) in the UL

- **DRS are used for channel estimation in the eNodeB receiver in order to demodulate data (PUSCH) and control (PUCCH) channels,**
  - **PUSCH.** Located in the 4th SC-FDMA symbol in each slot (symbol #3, #10 for normal CP), spanning the same BW as allocated for user data,
  - **PUCCH.** Different symbols, depending on format (see one of the following slides),

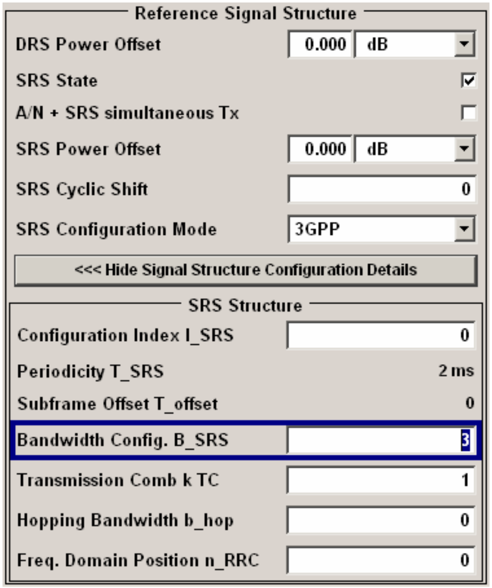


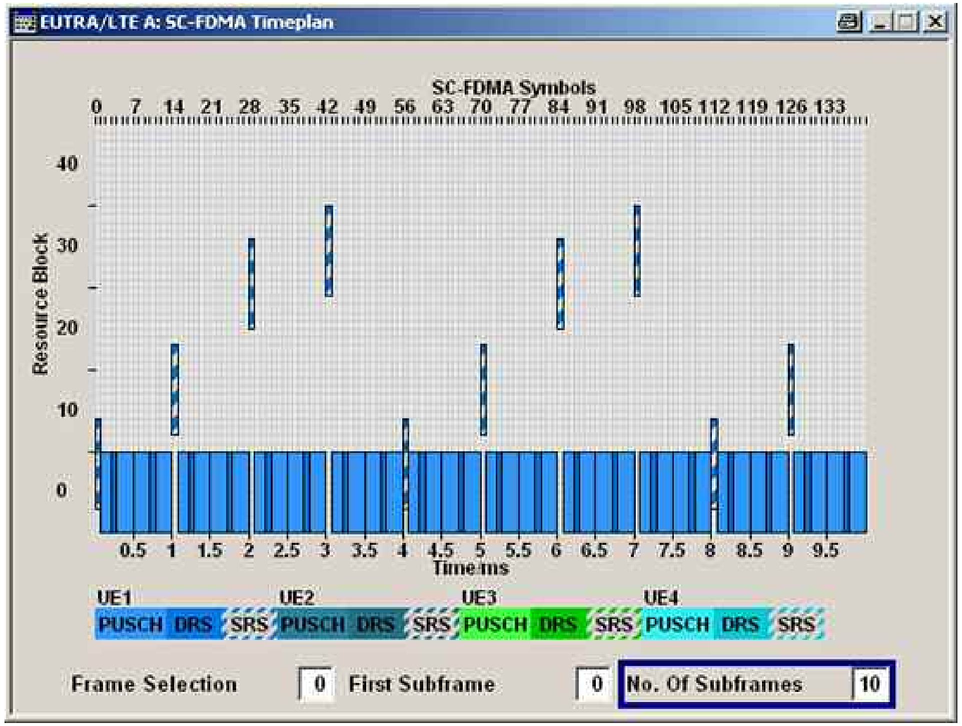
Demodulation Reference Signal (DRS)

Screenshot of R&S® SMU200A Vector Signal Generator

Sounding Reference Signal (SRS) in the UL

- SRS are used to estimate uplink channel quality in other frequency areas as a basis for scheduling decisions,
  - Transmitted in areas, where no user data is transmitted, first or last symbol of subframe is used for transmission,
  - Configuration (e.g. BW, power offset, cyclic shift, duration, periodicity, hopping pattern) is signaled by higher layers,





Screenshot of R&S® SMU200A Vector Signal Generator

PUSCH power control & timing relation

- Power level in dBm to be used for PUSCH transmission is derived using the following formula:

$$P_{\text{PUSCH}}(i) = \min\{P_{\text{MAX}}, 10\log_{10}(M_{\text{PUSCH}}(i)) + P_{\text{O\_PUSCH}}(j) + \alpha \cdot PL + \Delta_{\text{TF}}(TF(i)) + f(i)\}$$

Maximum allowed UE power

Combination of cell-[1] and UE-specific[2] component configured by RRC

PUSCH transport format

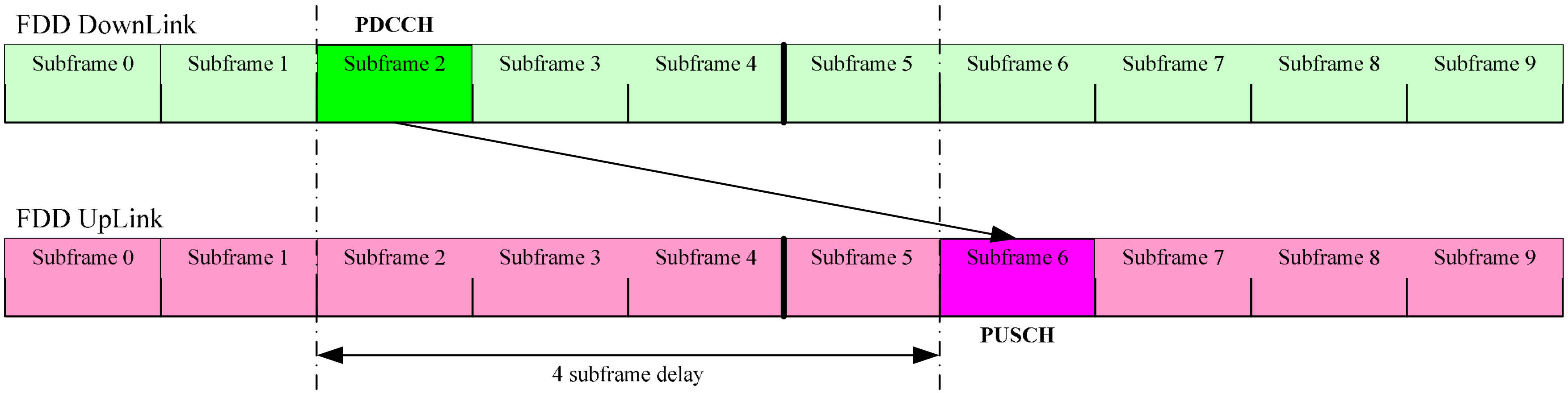
UE PUSCH transmit power in subframe i

Number of PUSCH resource blocks

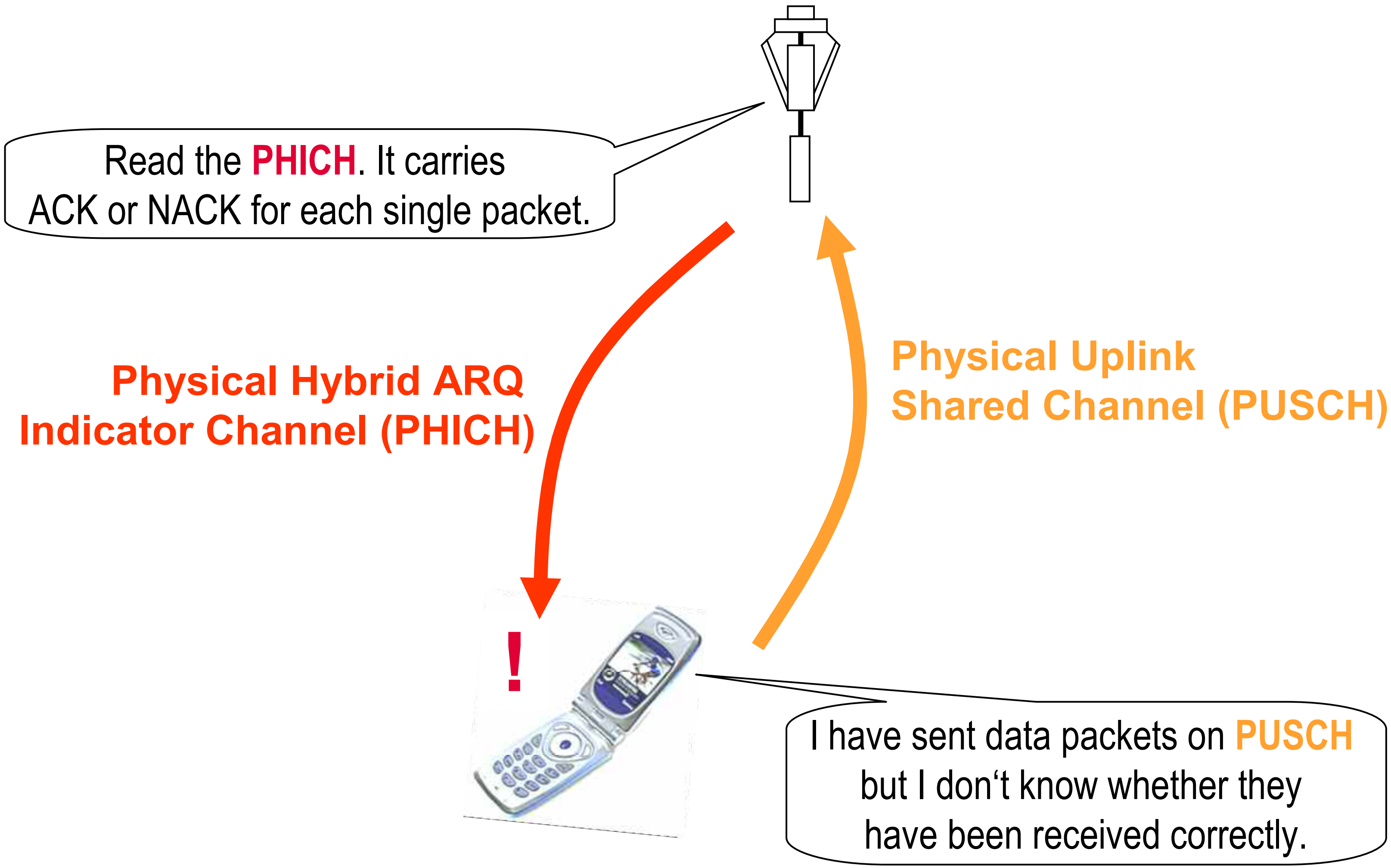
Cell-specific Parameter configured by RRC

Downlink path loss estimate

Power control adjustment derived from TPC command received via DCI format subframe (i-4)



Acknowledging UL data packets on PHICH



Physical Uplink Control Channel

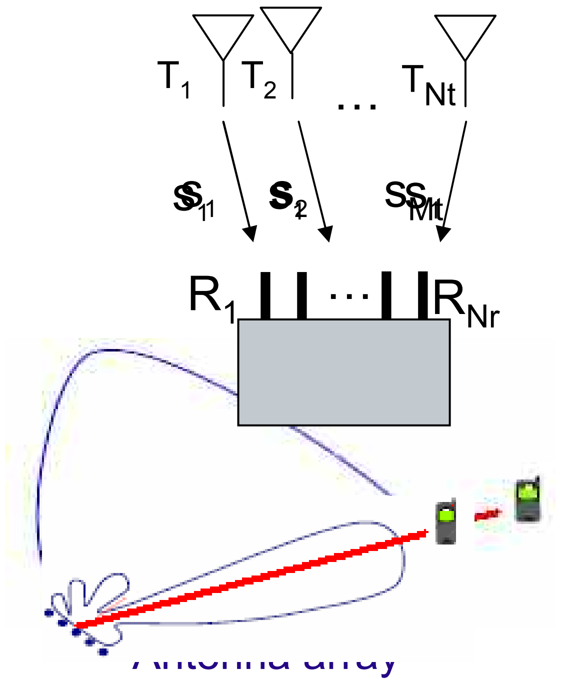
- PUCCH carries Uplink Control Information (UCI), when no PUSCH is available,
  - If PUSCH is available, means resources have been allocated to the UE for data transmission, UCI are multiplexed with user data,
- UCI are Scheduling Requests (SR), ACK/NACK information related to DL data packets, CQI, Pre-coding Matrix Information (PMI) and Rank Indication (RI) for MIMO,
- PUCCH is transmitted on reserved frequency regions, configured by higher layers, which are located at the edge of the available bandwidth
  - Minimizing effects of a possible frequency-selective fading affecting the radio channel,
  - Inter-slot hopping is used on PUCCH,
  - A RB can be configured to support a mix of PUCCH formats (2/2a/2b and 1/1a/1b) or exclusively 2/2a/2b,

PUCCH format	Bits per subframe	Modulation	Contents
1	On/Off	N/A	Scheduling Request (SR)
1a	1	BPSK	ACK/NACK, ACK/NACK+SR
1b	2	QPSK	ACK/NACK, ACK/NACK+SR
2	20	QPSK	CQI/PMI or RI (any CP), (CQI/PMI or RI)+ACK/NACK (ext. CP only)
2a	21	QPSK+BPSK	(CQI/PMI or RI)+ACK/NACK (normal CP only)
2b	22	QPSK+BPSK	(CQI/PMI or RI)+ACK/NACK (normal CP only)

CQI/PMI/RI are only signaled via PUCCH when periodic reporting is requested, scheduled and aperiodic reporting is only done via PUSCH

MIMO

Introduction to MIMO
gains to exploit from multiple antenna usage

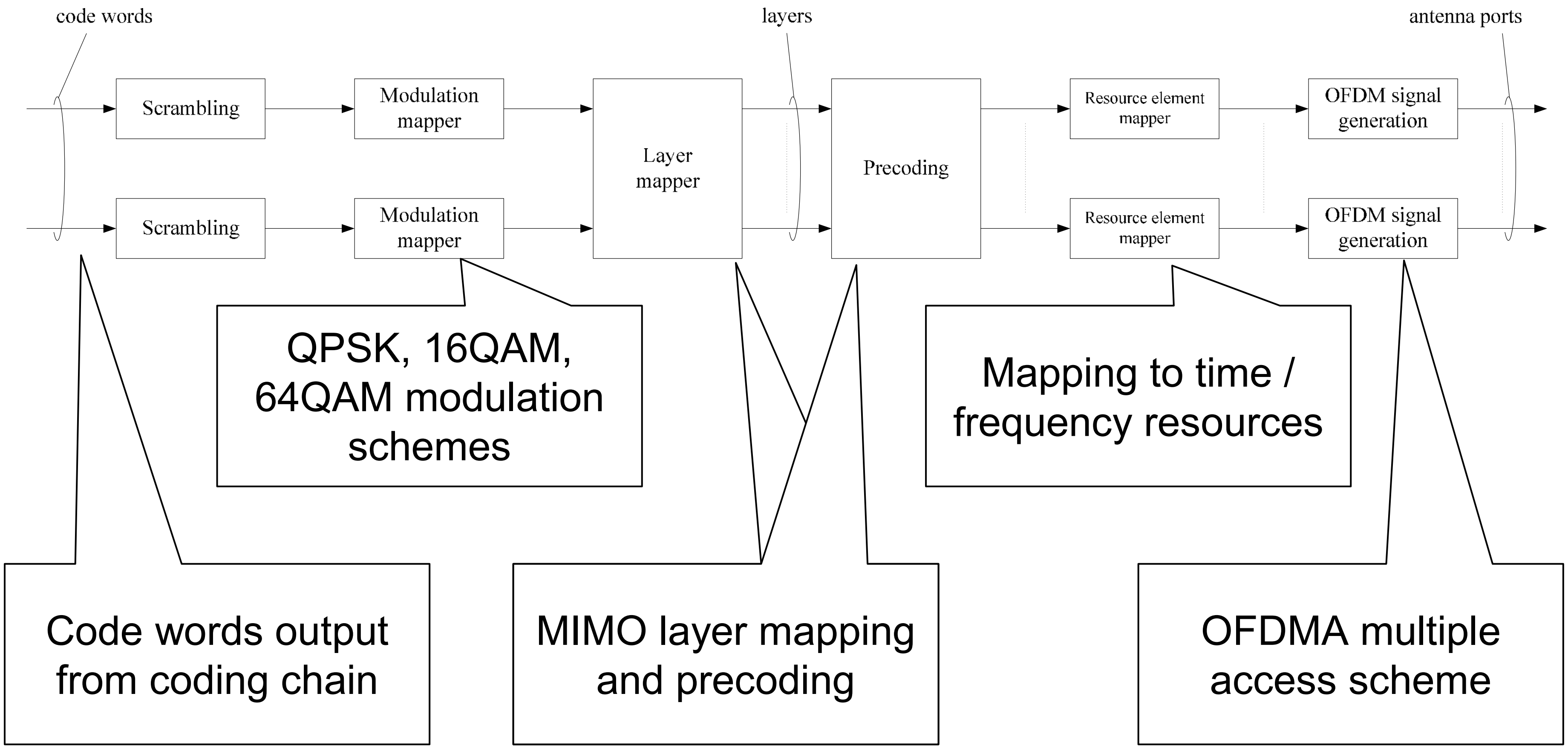


- **Transmit diversity (TxD)**
  - Combat fading
  - Replicas of the same signal sent on several Tx antennas
  - Get a higher SNR at the Rx
- **Spatial multiplexing (SM)**
  - Different data streams sent simultaneously on different antennas
  - Higher data rate
  - No diversity gain
  - Limitation due to path correlation
- **Beamforming**

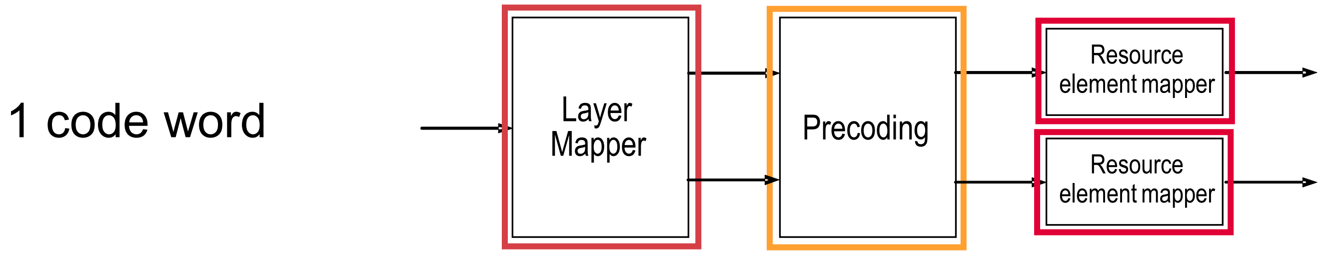
LTE MIMO
downlink modes

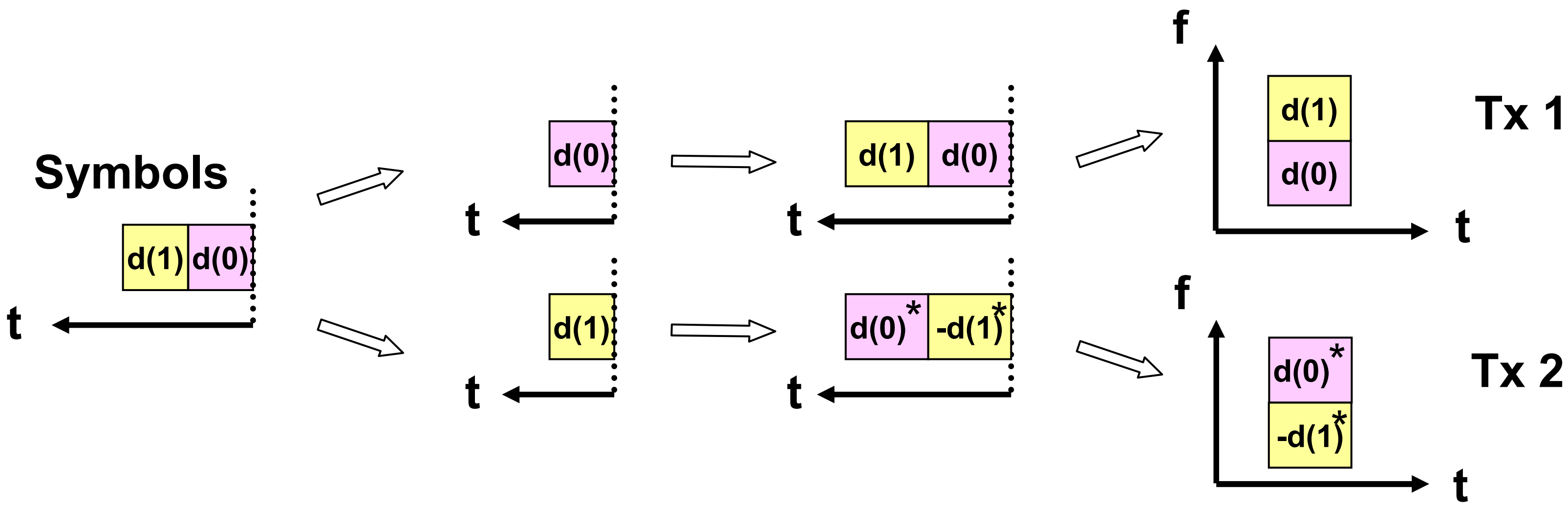
- **Transmit diversity:**
  - Space Frequency Block Coding (SFBC)
  - Increasing robustness of transmission
- **Spatial multiplexing:**
  - Transmission of different data streams simultaneously over multiple spatial layers
  - Codebook based precoding
  - Open loop mode for high mobile speeds possible
- **Cyclic delay diversity (CDD):**
  - Addition of antenna specific cyclic shifts
  - Results in additional multipath / increased frequency diversity

LTE downlink transmitter chain



Downlink transmit diversity
Space-Frequency Block Coding (2 Tx antenna case)



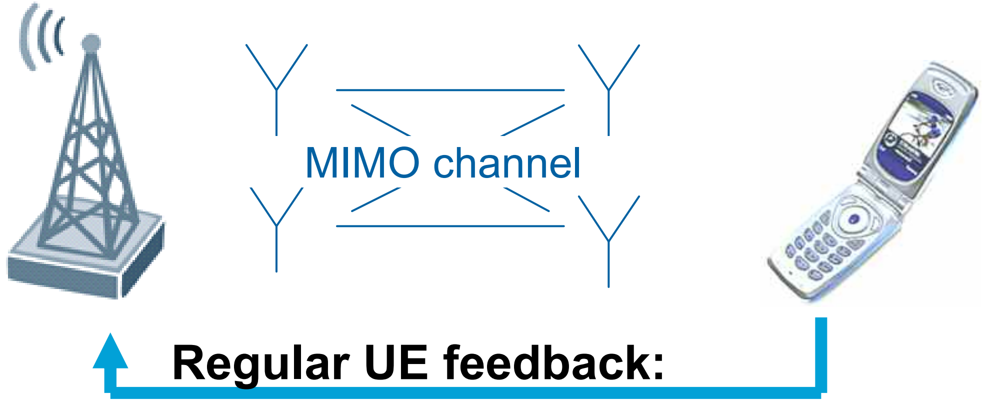


Downlink spatial multiplexing
codebook based precoding

- **The signal is “pre-coded” (i.e. multiplied with a precoding matrix) at eNodeB side before transmission**

Codebook of precoding matrices for 2x2 MIMO:

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	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-



Regular UE feedback:

PMI = Precoding Matrix Indicator

RI = Rank Indication

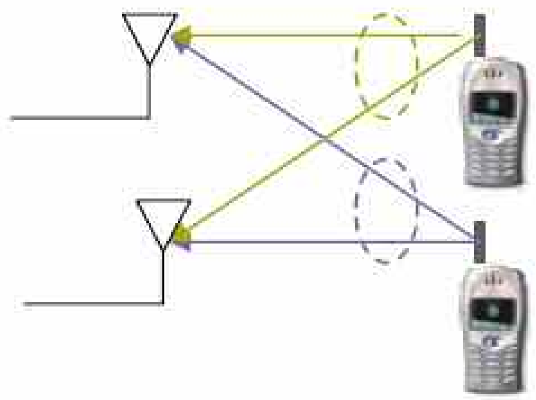
CQI = Channel Quality Indication

- **Optimum precoding matrix is selected from predefined “codebook” known at eNode B and UE side**
- **Selection is based on UE feedback**

LTE MIMO
uplink schemes

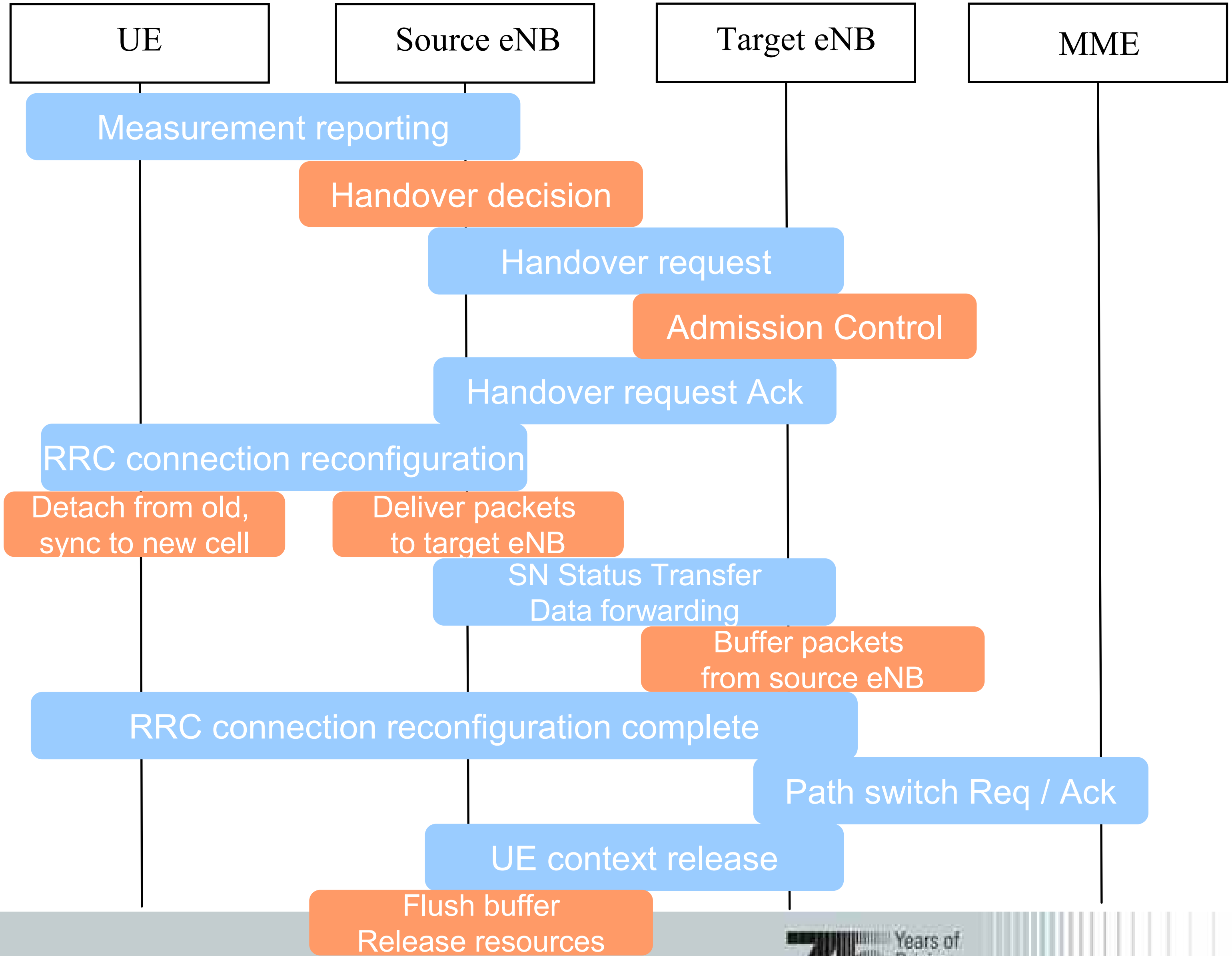
- **Uplink transmit antenna selection:**
  - **1 RF chain, 2 TX antennas at UE side**
  - **Closed loop selection of transmit antenna**
  - **eNodeB signals antenna selection to UE**
  - **Optional for UE to support**

- **Multi-user MIMO / collaborative MIMO:**
  - **Simultaneous transmission from 2 UEs on same time/frequency resource**
  - **Each UE with single transmit antenna**
  - **eNodeB selects UEs with close-to orthogonal radio channels**

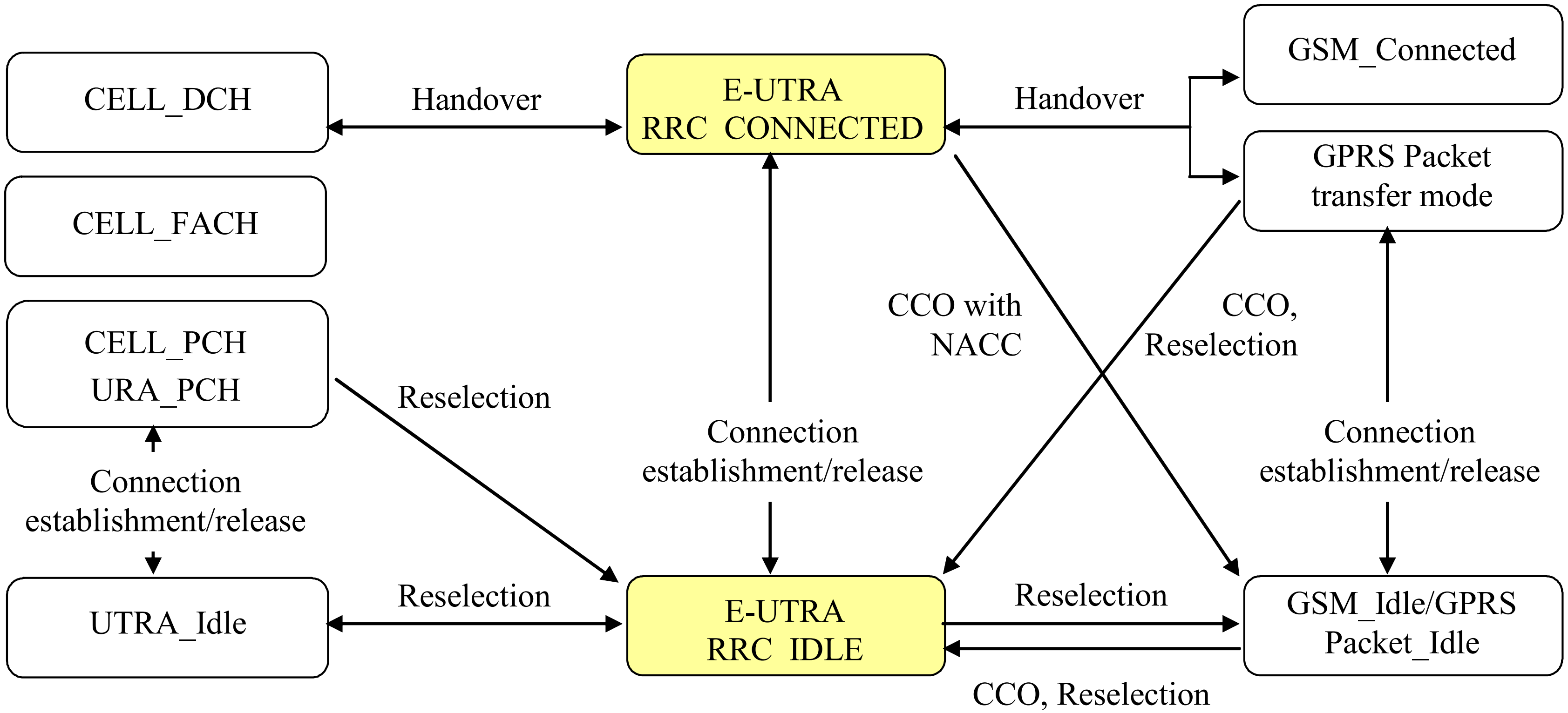


LTE mobility

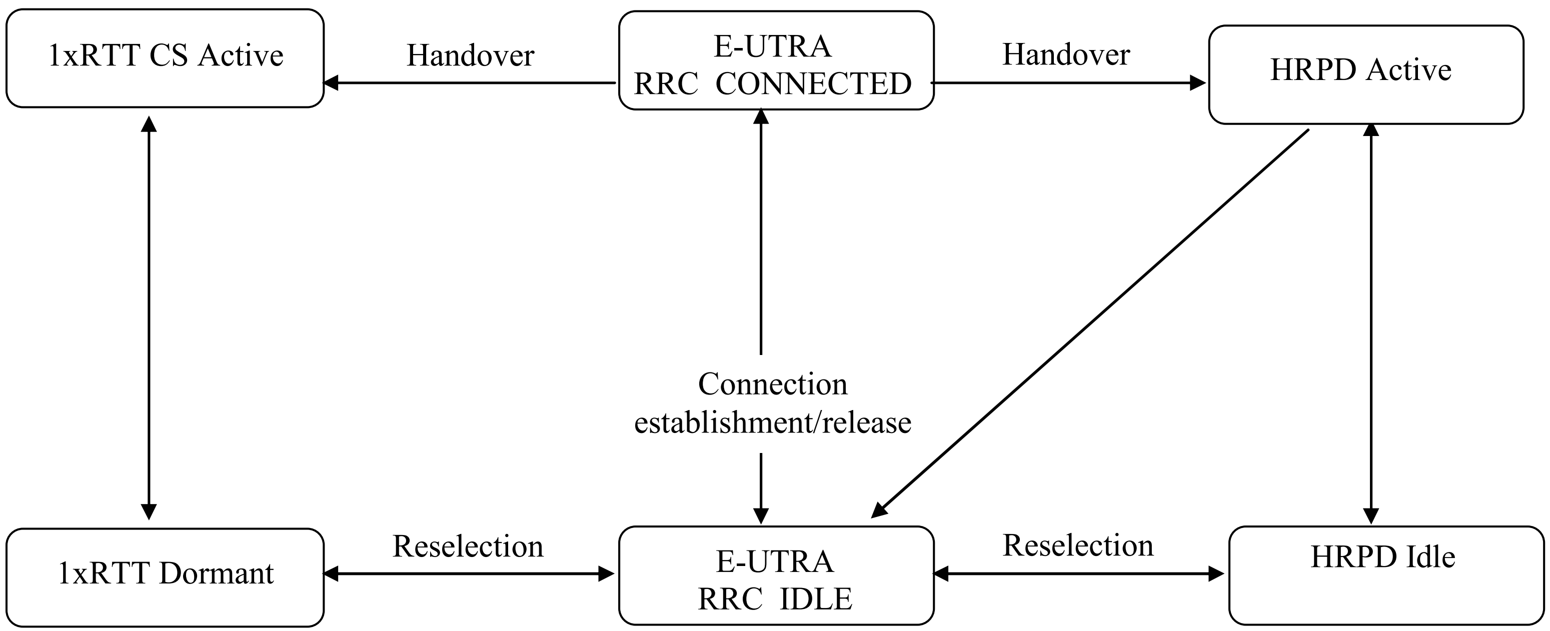
Handover (Intra-MME/Serving Gateway)



LTE Interworking with 2G/3G
Two RRC states: CONNECTED & IDLE

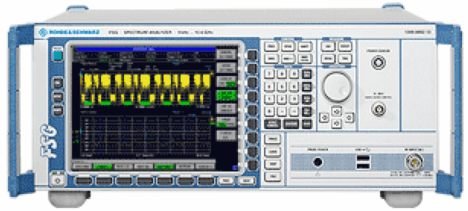


LTE Interworking with CDMA2000 1xRTT and HRPD (High Rate Packet Data)



LTE test requirements

eNodeB RF testing



LTE RF Testing Aspects

Base station (eNodeB) according to 3GPP

- **Measurements are performed using Fixed Reference Channels (FRC) and EUTRA Test Models (E-TM),**
- **Tx characteristic (= Downlink)**
  - Base station output power
  - Output power dynamics,
    - RE Power Control dynamic range, total power dynamic range,
  - Transmit ON/OFF power,
    - Transmitter OFF power, transmitter transient period,
  - Transmitted signal quality
    - Frequency Error, Error Vector Magnitude (EVM), Time alignment between transmitter antennas, DL RS power, etc. …
  - Unwanted emissions,
    - Occupied Bandwidth, Adjacent Channel Leakage Power Ratio (ACLR), Operating band unwanted emissions, etc. …
  - Transmitter spurious emissions and intermodulation,
- **Rx characteristics (= Uplink)**
  - Reference sensitivity level, Dynamic range, In-channel selectivity, Adjacent channel selectivity (ACS) and narrow-band blocking, Blocking, Receiver spurious emissions, Receiver intermodulation
- **Performance requirements,**
  - …for PUSCH,
    - Fading conditions, UL timing adjustment, high-speed train, HARQ-ACK multiplexed in PUSCH,
  - …for PUCCH,
    - DTX to ACK performance, ACK missed detection PUCCH format 1a (single user), CQI missed detection for PUCCH format 2, ACK missed detection PUCCH format 1a (multiple user)
  - PRACH performance,
    - FALSE detection probability, detection requirements,

Captured in TS 36.104: Base Station (BS) radio transmission and reception

eNB modulation quality measurements

- Frequency error,
  - If frequency error is larger than a few subcarrier, demodulation at the UE might not work properly and cause network interference,
  - Quick test: OBW, Limit for frequency error after demodulation 0.05 ppm + 12 Hz (1ms),
- Error Vector Magnitude (EVM),
  - Amount of distortion effecting the receiver to demodulate the signal properly,
  - Limit changes for modulation schemes QPSK (17.5%), 16QAM (12.5%), 64QAM (8%),
- Time alignment,
  - Only TX test defined for multiple antennas, measurement is to measure the time delay between the signals for the two transmitting antennas, delay shall not exceed 65 ns,
- DL RS power
  - “Comparable” to WCDMA measurement CPICH RSCP; absolute DL RS power is indicated on SIB Type 2, measured DL RS power shall be in the range of ±2.1 dB,

ACLR in DL (FDD)

No filter definition in LTE!

Screenshot taken from R&S® FSQ Signal Analyzer

E-UTRA transmitted signal channel bandwidth $BW_{Channel}$ [MHz]	BS adjacent channel centre frequency offset below the first or above the last carrier centre frequency transmitted	Assumed adjacent channel carrier (informative)	Filter on the adjacent channel frequency and corresponding filter bandwidth	ACLR limit
1.4, 3.0, 5, 10, 15, 20	$BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	44.2 dB
	2 x $BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	44.2 dB
	$BW_{Channel}$ /2 + 2.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	44.2 dB
	$BW_{Channel}$ /2 + 7.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	44.2 dB

NOTE 1: $BW_{Channel}$ and BW_{Config} are the channel bandwidth and transmission bandwidth configuration of the E-UTRA transmitted signal on the assigned channel frequency.

NOTE 2: The RRC filter shall be equivalent to the transmit pulse shape filter defined in [15], with a chip rate as defined in this table.

eNB performance requirements
PRACH and preamble testing I

- **PRACH testing is one of the performance requirements defined in 3GPP TS 36.141 E-UTRA BS conformance testing,**
  - Total probability of FALSE detection of preamble (Pfa 0.1% or less),
  - Probability of detection of preamble (Pd = 99% at defined SNR),
  - Two modes of testing: normal and high-speed mode,
    - Different SNR and fading profiles are used (table shows settings for normal mode),

Number of RX antennas	Propagation conditions (Annex B)	Frequency offset	SNR [dB]				
			Burst format 0	Burst format 1	Burst format 2	Burst format 3	Burst format 4
2	AWGN	0	-14.2	-14.2	-16.4	-16.5	-7.2
	ETU 70	270 Hz	-8.0	-7.8	-10.0	-10.1	-0.1
4	AWGN	0	-16.9	-16.7	-19.0	-18.8	-9.8
	ETU 70	270 Hz	-12.1	-11.7	-14.1	-13.9	-5.1

- Depending on the mode different preambles are used to check detection probability (table shows preamble to be used for normal mode),

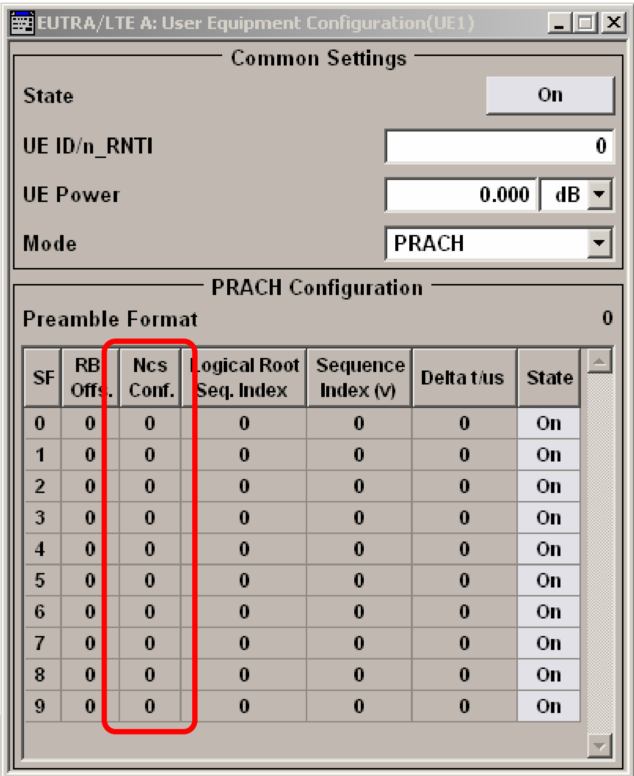
Burst format	N_{cs}	Logical sequence index	v
0	13	22	32
1	167	22	2
2	167	22	0
3	0	22	0
4	10	0	0

eNB performance requirements

PRACH and preamble testing II

- **According to 3GPP TS 36.211 the N_{CS} value is not set directly instead it is translated to a N_{CS} configuration value,**
  - This value is set in the signal generator R&S® SMx or R&S® AMU,

N_{CS} Configuration	N_{CS} value	
	Unrestricted set	Restricted set
0	0	15
1	13	18
2	15	22
3	18	26
4	22	32
5	26	38
6	32	46
7	38	55
8	46	68
9	59	82
10	76	100
11	93	128
12	119	158
13	167	202
14	279	237
15	419	-



Screenshot taken from R&S® SMU200A Vector Signal Generator

R&S®SMx signal generators and
R&S® FSx signal analyzers

R&S®TS8980 LTE RF test system

UE RF testing

R&S®CMW500 wideband radio
communication tester

R&S®SMU200A signal generator and
fading simulator including MIMO

LTE RF Testing Aspects
User Equipment (UE) according to 3GPP

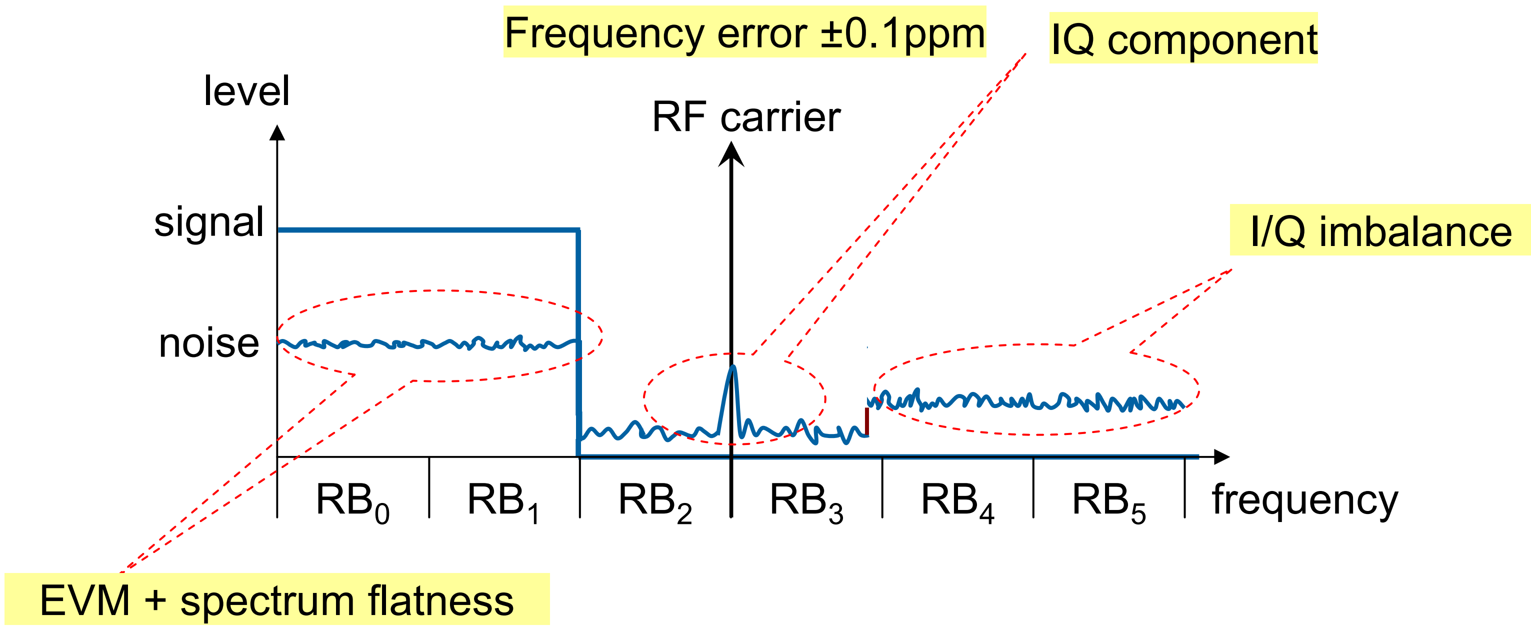
- **Tx characteristic**
  - Transmit power,
  - Output power dynamics,
  - Transmit Signal Quality,
    - Frequency error, EVM vs. subcarrier, EVM vs. symbol, LO leakage, IQ imbalance, In-band emission, spectrum flatness,
  - Output RF spectrum emissions,
    - Occupied bandwidth, Spectrum Emission Mask (SEM), Adjacent Channel Leakage Power Ratio (ACLR),
  - Spurious Emission,
  - Transmit Intermodulation,

- **Rx characteristics**
  - Reference sensitivity level,
  - UE maximum input level,
  - Adjacent channel selectivity,
  - Blocking characteristics,
  - Intermodulation characteristics,
  - Spurious emissions,

- **Performance requirements**
  - Demodulation FDD PDSCH (FRC),
  - Demodulation FDD PCFICH/PDCCH (FRC)

Captured in TS 36.101: User Equipment (UE) radio transmission and reception

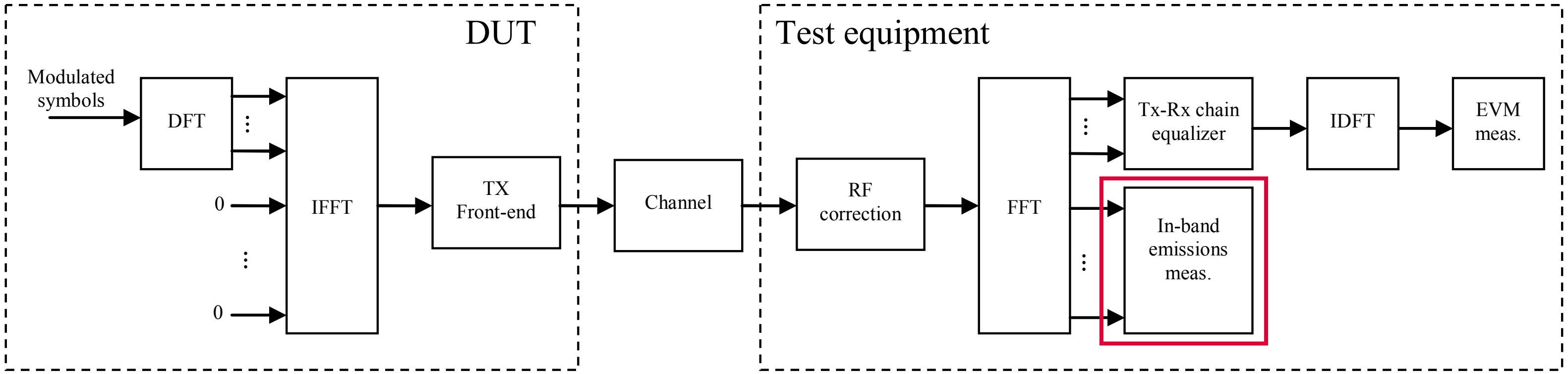
Transmit modulation



According to 3GPP specification LO leakage (or IQ origin offset) is removed from evaluated signal before calculating EVM and in-band emission.

In-band emission

- Estimate the interference to non-allocated resource blocks, as the UE shares transmission bandwidth with other UE's,
  - In-band emission are measured in frequency domain are measured right after FFT, before equalization filter,
  - Measurement is defined as average across 12 subcarriers and as a function of RB offset from the edge of the allocated bandwidth,
  - Minimum requirement $\max\left[-25, (20 \cdot \log_{10} EVM) - 3 - 10 \cdot (\Delta_{RB} - 1) / N_{RB})\right]$

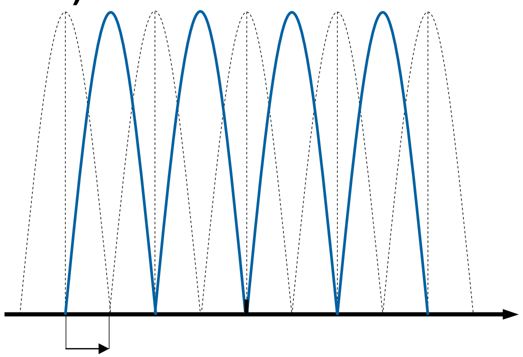


IQ component

- Also known is LO leakage, IQ offset, etc.,
- Measure of carrier feedthrough present in the signal,
- Removed from measured waveform, before calculating EVM and in-band emission (3GPP TS 36.101 V8.3.0, Annex F),
- In difference to DL the DC subcarrier in UL is used for transmission, but subcarriers are shifted half of subcarrier spacing (= 7.5 kHz) to be symmetric around DC carrier,
- Due to this frequency shift energy of the LO falls into the two central subcarrier,

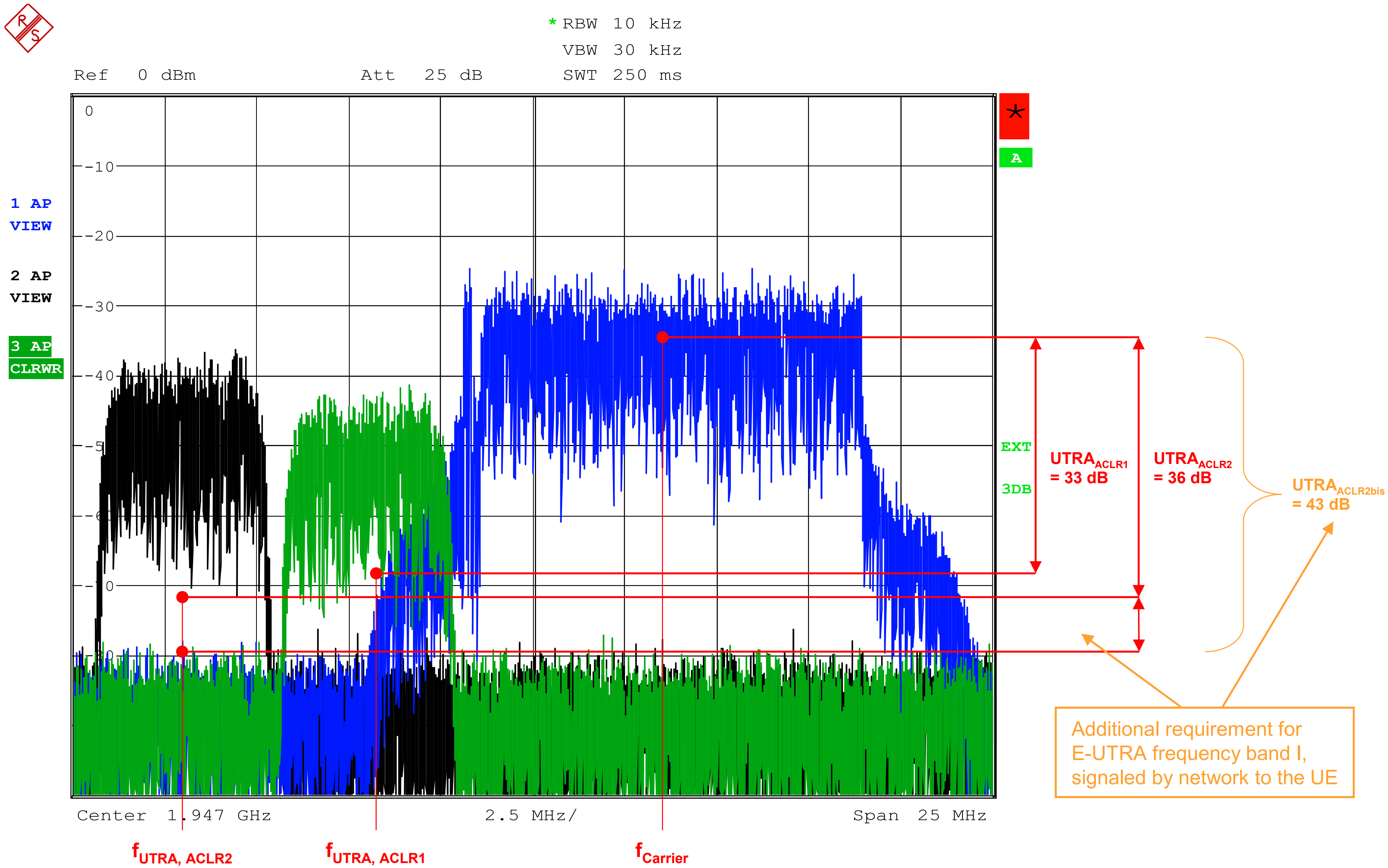
	Parameters	Relative Limit (dBc)
LO leakage	Output power > 0 dBm	-25
	-30 dBm ≤ output power ≤ 0 dBm	-20
	-40 dBm ≤ output power < -30 dBm	-10

Uplink (SC-FDMA)



Δf = 7.5 kHz
frequency shift

ACLR measurement I



Receiver characteristics

- **Throughput shall be >95% for…**
  - Reference Sensitivity Level,
  - Adjacent Channel Selectivity,
  - Blocking Characteristics,
- **…using the well-defined DL reference channels according to 3GPP specification,**

R&S®SMx signal generators and
R&S® FSx signal analyzers

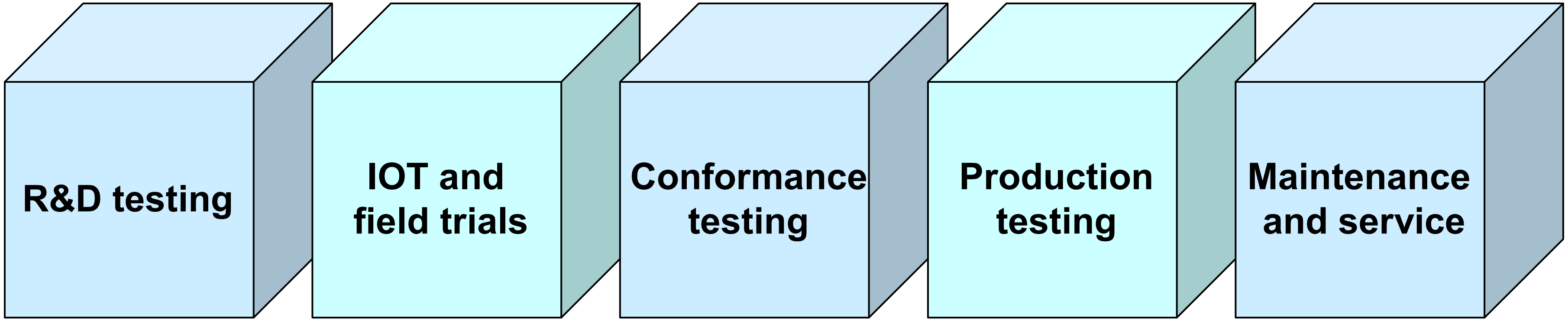
R&S®TS8980 LTE RF test system

LTE wireless device testing from R&D up to conformance

R&S®CMW500 wideband radio
communication tester

R&S®AMU200A signal generator
and fading simulator incl. MIMO

Stages of LTE terminal testing



Complementary test approaches for verifying:

Functionality and performance (RF, layer 1, protocol stack, application)	Interoperability between features and implemen-tations	Standard compliance (basis for terminal certification)	Final functional test and alignment	Basic functions and parameter test

LTE terminal interoperability testing
motivation

- **Interoperability testing is used to verify**
  - Connectivity of the UE with the real network (by means of base station simulators)
  - Service quality, end-to-end performance
  - Different LTE features and parametrizations
  - Interworking between LTE and legacy technologies
- **The complete UE protocol stack is tested.**
- **IOT test scenarios are based on requirements from real network operation and typical use cases.**

R&S®CMW500 wideband radio communication tester (base station simulator)

LTE terminal interoperability testing
example test scenarios

- **Registration**
- **UE initiated detach**
- **Network initiated detach**
- **Mobile originated EPS bearer establishment**
- **Mobile terminated EPS bearer establishment**
- **Cell (re-)selection**
- **GUTI reallocation**
- **Tracking are update**
- **…**
- **Plus: end-to-end scenarios (video streaming, VoIP, …)**
- **Plus: intra-LTE mobility, inter-RAT mobility**

Test scenarios for LTE terminal IOT
different sources for maximum test coverage

Rohde & Schwarz

Basic procedures and bearer verification (registration, bearer setup, VoIP call, …)

LSTI forum

LSTI
LTE/SAE Trial Initiative

„Common Test Descriptions“ agreed in LSTI IO(D)T activity

IOT test coverage

Network operators

Network-specific IOT requirements for terminal acceptance

LTE conformance testing
motivation

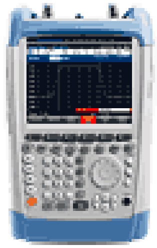
- **Verifying compliance of terminals to 3GPP LTE standard**
  - by validated test cases implemented on registered test platforms
  - in order to ensure worldwide interoperability of the terminal within every mobile network
- **3GPP RAN5 defines conformance test specifications for**
  - RF
  - Radio Resource Management (RRM)
  - Signalling
- **Certification organizations (e.g. GCF) define certification criteria based on RAN5 test specifications.**

R&S®CMW500 wideband radio communication tester

R&S®TS8980 LTE RF test system

LTE terminal certification
success factors

- Terminal certification as quality gateway
- Ensuring global interoperability of terminals
- Increasing reliability and performance
- Partnership between network operators, device manufacturers and test industry
- Close liaison between standardization fora and certification groups
- Harmonized processes for LTE FDD and TDD, e.g. work item structure
- LTE alignment team founded within CCF



R&S®FSH4/8 handheld
spectrum analyzer

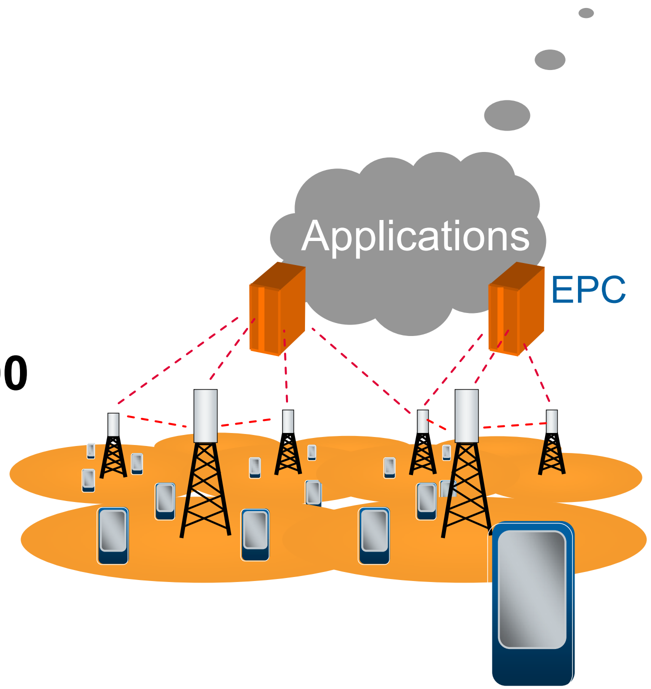
R&S®ROMES drive test software

LTE field trial testing and coverage measurements

R&S®TSMW Universal Radio
Network Analyzer

LTE field trials
requirements from different deployment scenarios

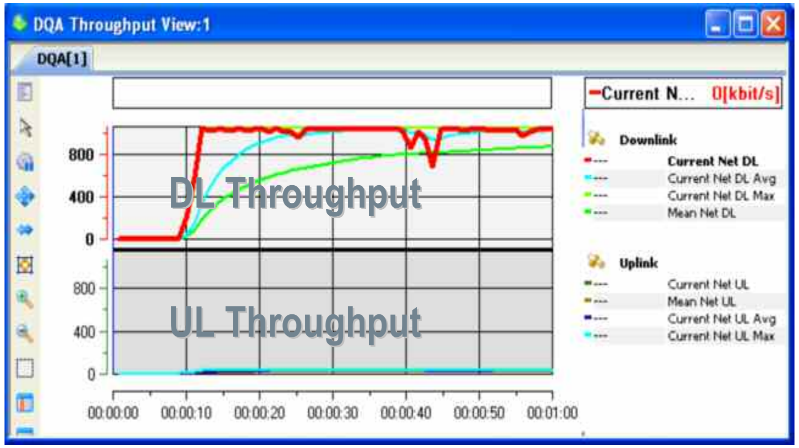
- Bandwidths from 1.4 MHz to 20 MHz
- Different LTE FDD and TDD frequency bands
- Combination with legacy technologies (GSM/EDGE, WCDMA/HSPA, CDMA2000 1xEV-DO)
- Spectrum clearance and refarming scenarios
- Femto cell / Home eNB scenarios



LTE field trials
scope of test tools

- **Field trials provide input for:**
  - Calibration and verification of planning tools for different deployment scenarios
  - Network optimization (capacity and quality)
  - Quality of service verification
  - Definition of Key Performance Indicators (KPIs) and verification, also from subscriber's point of view
- **Parallel use of scanners / measurement receivers for comparison with UE and base station behaviour**
- **Support of IOT activities**

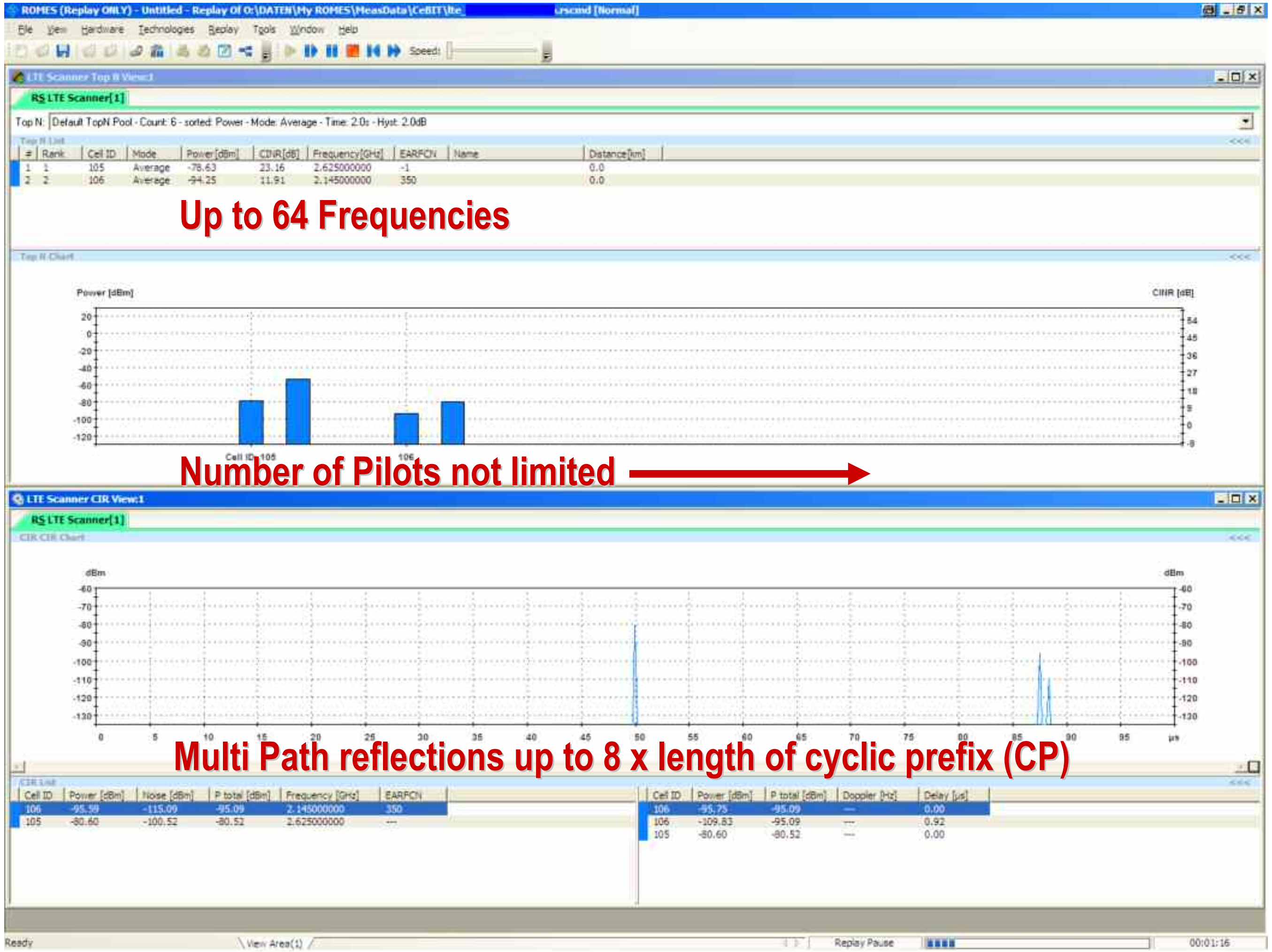
R&S®TSMW Network Scanner and ROMES Drive Test Software



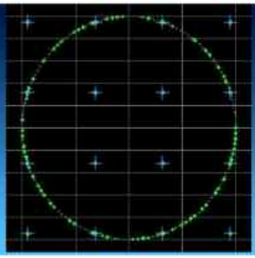
Example result from the field
scanner measurements for LTE

TopN list of all pilots
with Power and SINR

Channel Impulse Response
for Multi Path Reflections and check of Cyclic Prefix



Would you like to know more?



Rohde & Schwarz Products: FSQ, FSG, FSV, FSQ-K100, FSV-K100, FSQ-K101, FSV-K101, FSQ-K102, SMU200A, SMU-K55, SMU-K255, SMATE200A, SMATE-K55, SMJ100A, SMJ-K55, SMJ-K255, WinIQSIM2, AFQ100A/B, AFQ-K255, AMU200A, AMU-K55, AMU-K255, CMW500, TS8980

UMTS Long Term Evolution (LTE)
Technology Introduction

Application Note 1MA111

Even with the introduction of HSPA, evolution of UMTS has not reached its end. To ensure the competitiveness of UMTS for the next 10 years and beyond, UMTS Long Term Evolution (LTE) has been introduced in 3GPP release 8. LTE, which is also known as Evolved UTRA and Evolved UTRAN, provides new physical layer concepts and protocol architecture for UMTS. This application note introduces LTE FDD and TDD technology and testing aspects.

ROHDE&SCHWARZ

RF chipset verification for UMTS LTE (FDD) with R&S®SMU200A and R&S®FSQ
Application Note

Products:
- R&S®SMU200A
- R&S®SMU-K55
- R&S®EX-IQ-Box
- R&S®FSQ
- R&S®FSQ-K100
- R&S®FSQ-K101

This application note describes how to verify and validate a LTE (FDD) RF chipset using R&S®SMU200A vector signal generator, R&S®FSQ signal analyzer and R&S®EX-IQ Box. The related signal generation as well as signal analysis is described.

ROHDE&SCHWARZ

Easy LTE/E-UTRA Base Station Testing acc. to 3GPP TS 36.141
Application Note

Products:
- R&S®FSV
- R&S®FSQ
- R&S®SMU
- R&S®SMJ
- R&S®SMBV
- R&S®SMATE
- R&S®K100
- R&S®K101

This application note describes a simple method for performing basic LTE/E-UTRA base station transmitter and - receiver tests according to 3GPP TS 36.141. Transmitter tests are performed with R&S®FSV or FSQ and the R&S®E-UTRA/LTE Analysis Test Software R&S®K100/101. Test signals for both receiver testing and simulation of a E-UTRA base station output signal are generated by R&S®SMU, SMJ, SMATE or SMBV. The enclosed E-UTRA BS test software provides all the SCPI control sequences for the R&S instruments and the R&S®E- UTRA/LTE Analysis Test Software R&S®K100/101 ready to run.

ROHDE&SCHWARZ

LTE application notes from Rohde & Schwarz