Outline

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  - System information broadcast
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  - MIMO
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  - UE RF testing
  - LTE wireless device testing from R&D up to conformance
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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

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

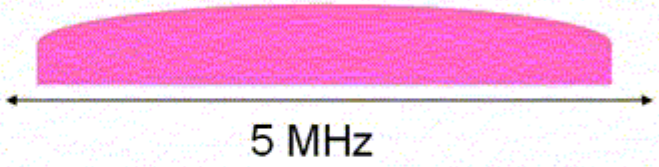
Work on UMTS/LTE 3500 MHz ongoing

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

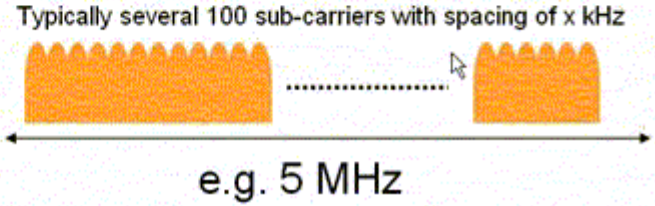
Introduction to OFDMA and downlink frame structure

What is OFDM?

Single Carrier Transmission (e.g. WCDMA)

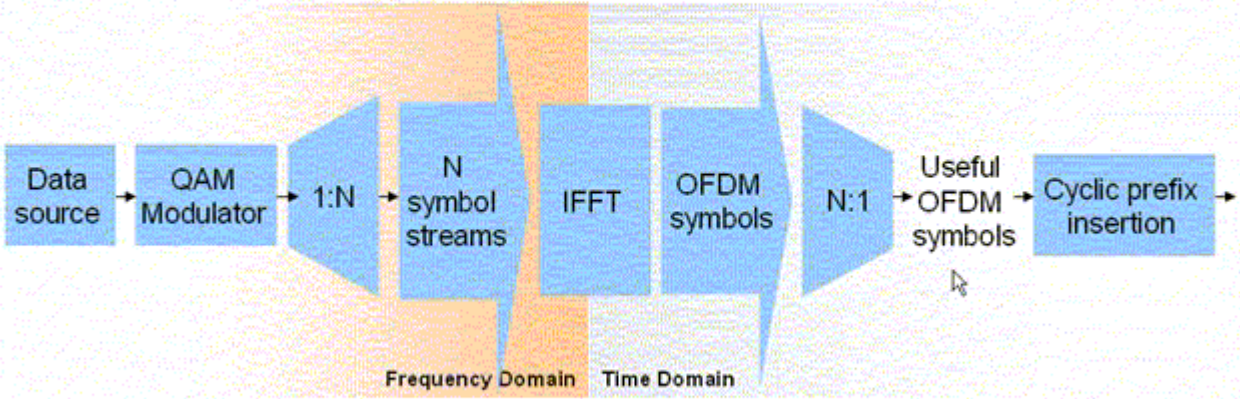


Orthogonal Frequency Division Multiplexing



OFDM signal generation chain

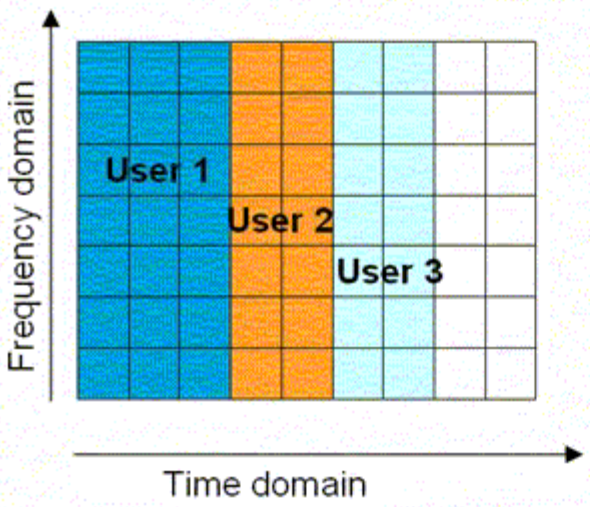
- OFDM signal generation is based on Inverse Fast Fourier Transform (IFFT) operation on transmitter side:



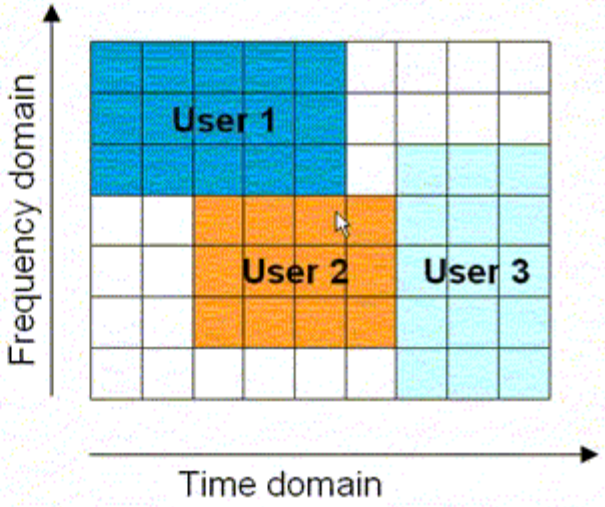
- On receiver side, an FFT operation will be used.

Difference between OFDM and OFDMA

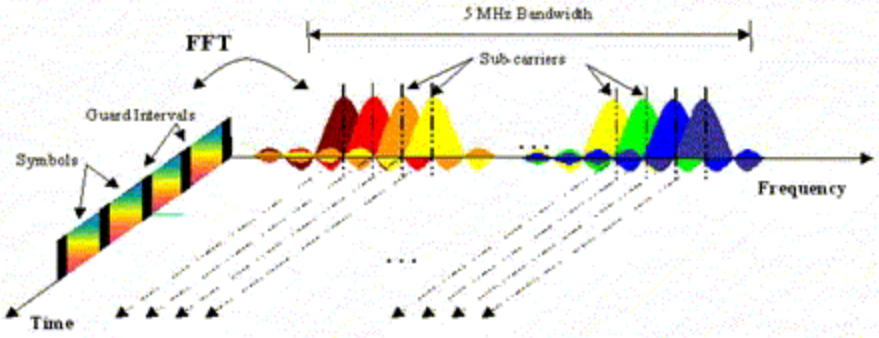
- **OFDM allocates users in time domain only**



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

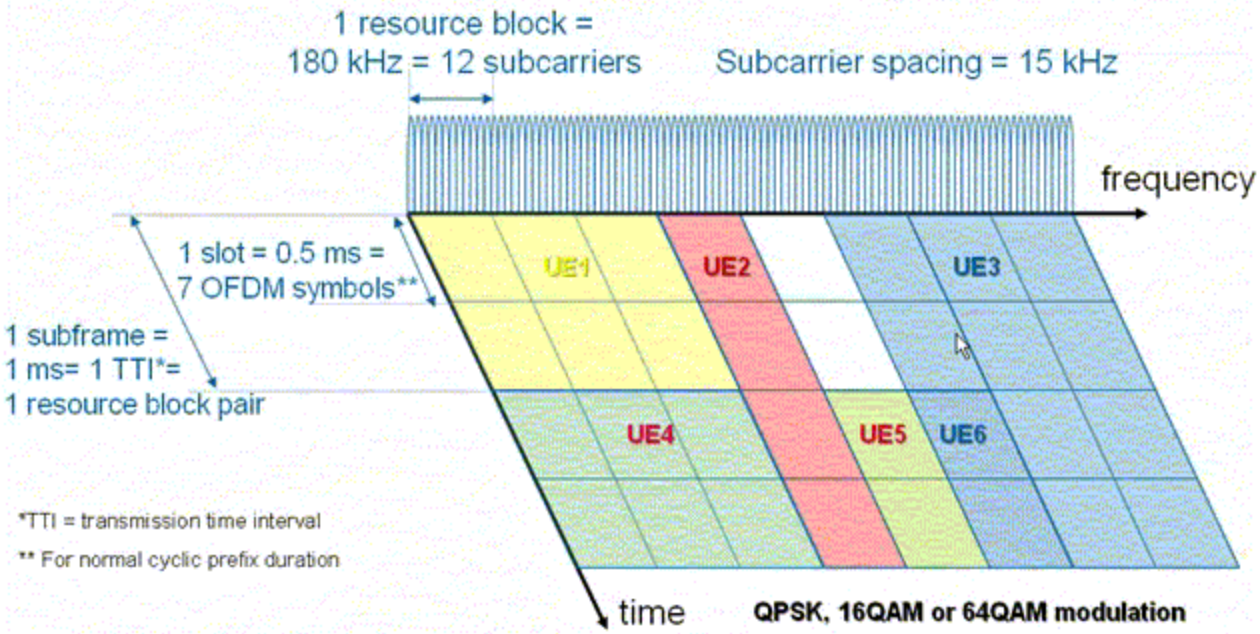


LTE downlink
conventional OFDMA



- 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

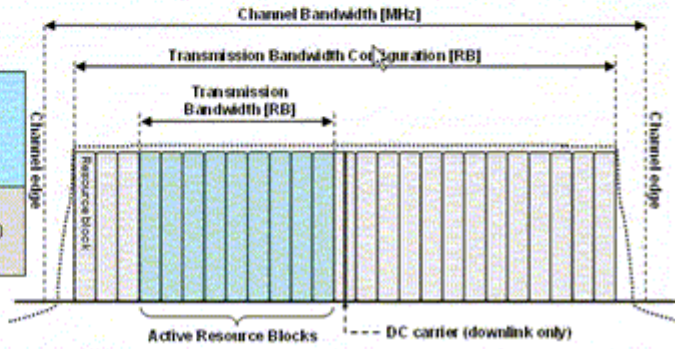
OFDMA time-frequency multiplexing

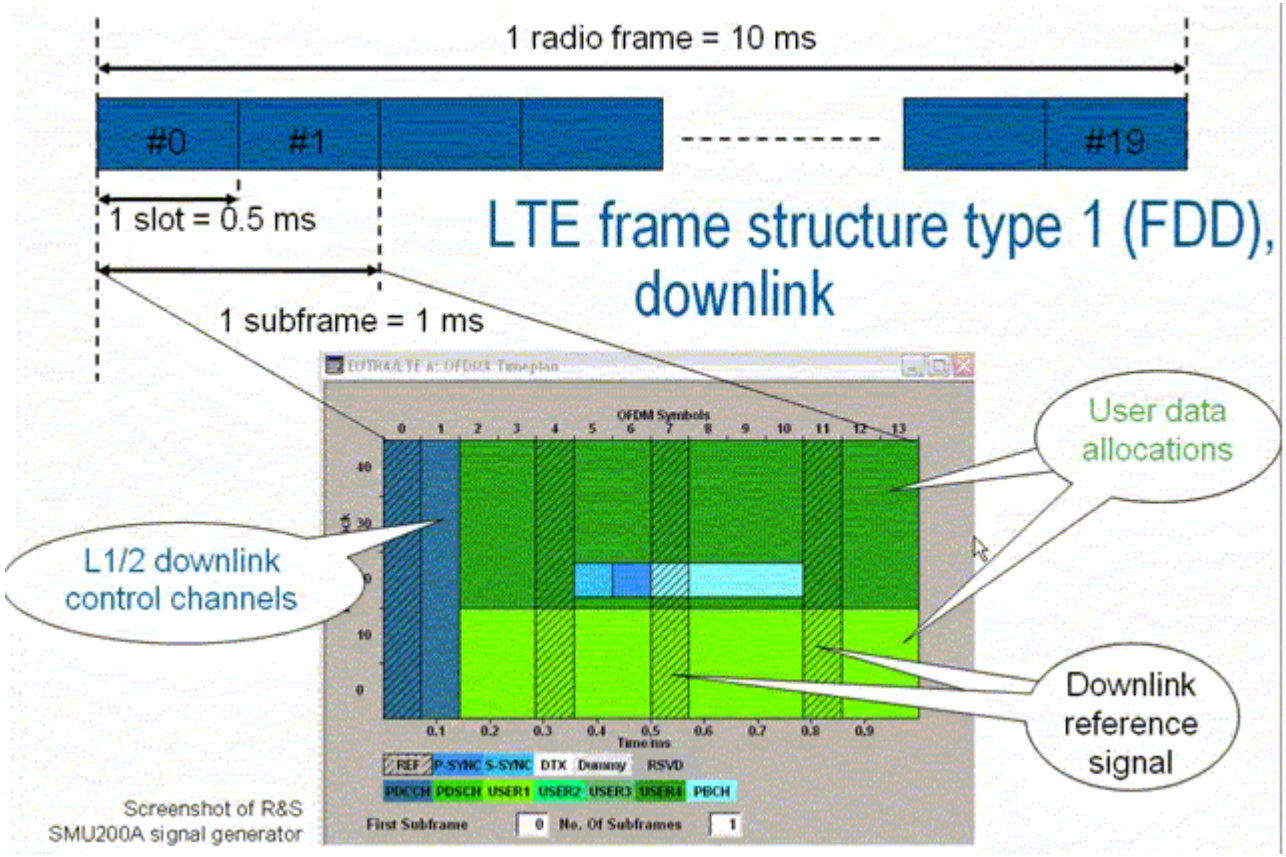


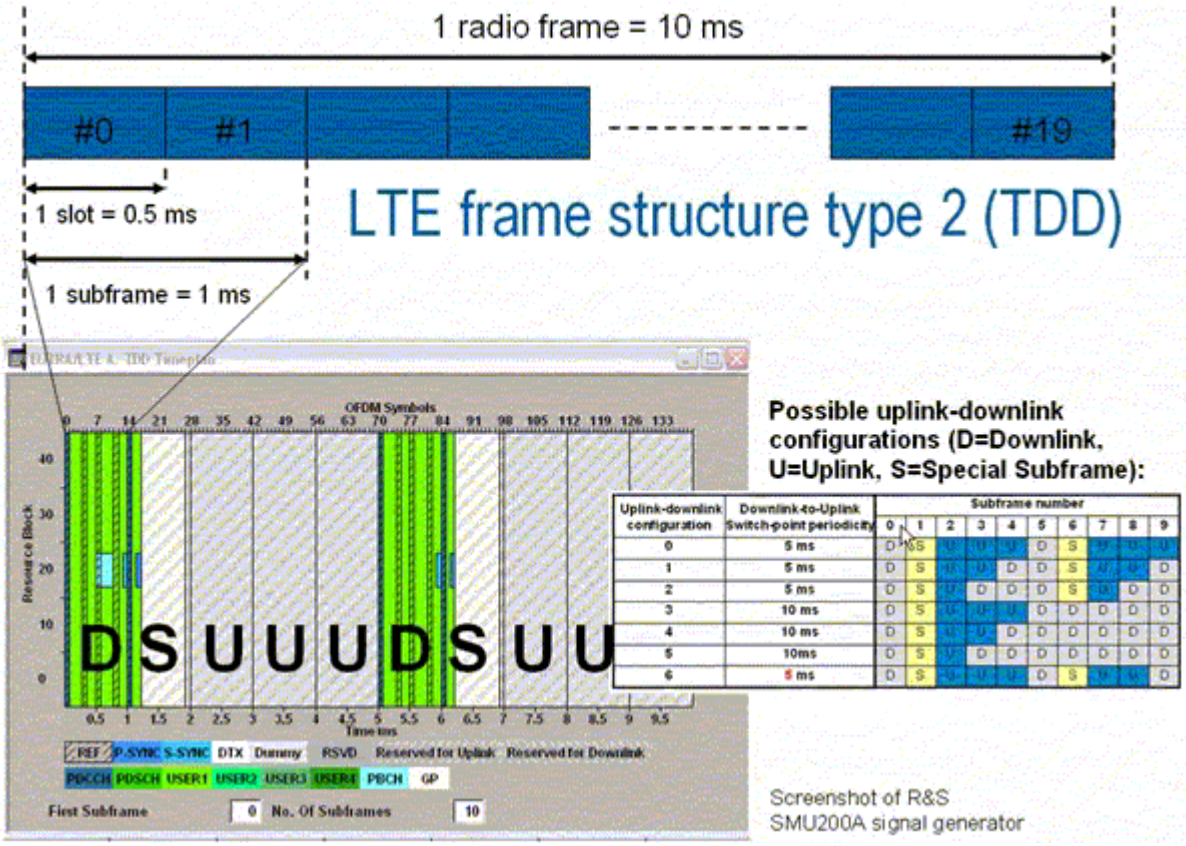
LTE – spectrum flexibility

- 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




1 radio frame = 10 ms
#0
#1
#19
1 slot = 0.5 ms
1 subframe = 1 ms
LTE frame structure type 1 (FDD), downlink
User data allocations
L1/2 downlink control channels
Downlink reference signal
OFDM Symbols
Time ms
REF
P-SYNC
S-SYNC
DTX
Dummy
RSVD
PDCCH
PDSCH
USER1
USER2
USER3
USER4
PBCH
First Subframe
No. Of Subframes
Screenshot of R&S SMU200A signal generator



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

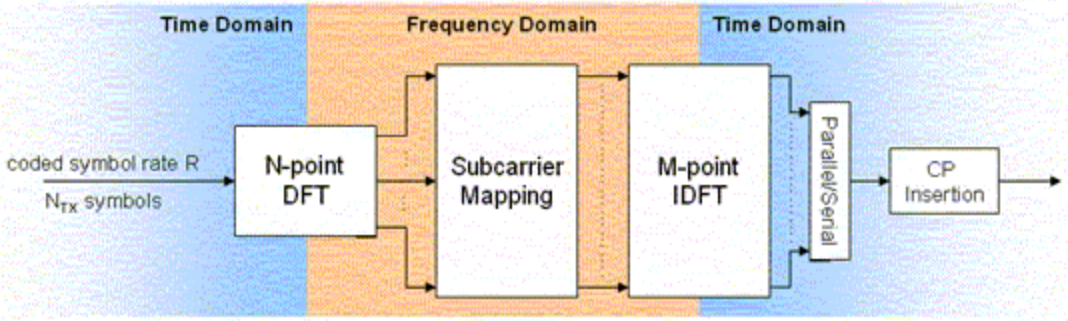
Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U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

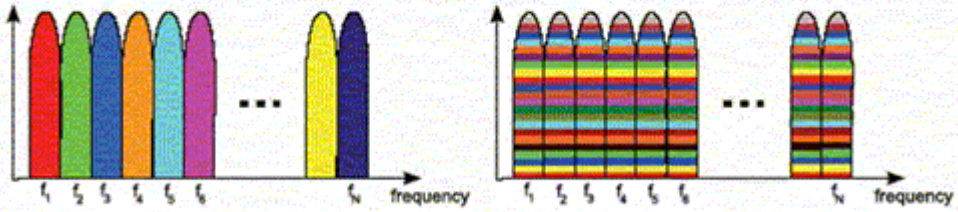
- DFT "pre-coding" is performed on modulated data symbols to transform them into frequency domain,
- Sub-carrier mapping allows flexible allocation of signal to available sub-carriers,
- IFFT and cyclic prefix (CP) insertion as in OFDM,



- 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?

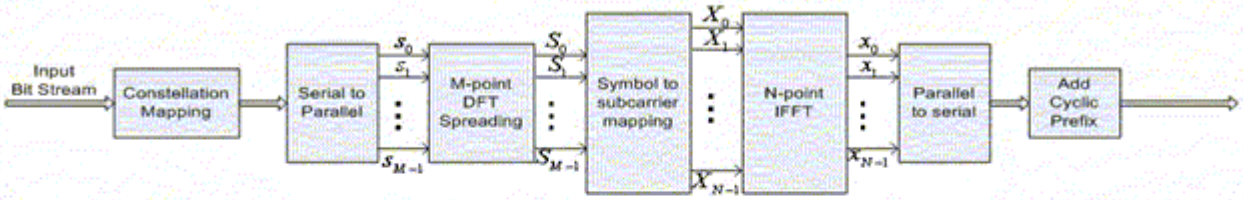
- **Similar to OFDM signal, but…**
  - …in OFDMA, each sub-carrier only carries information related to one specific symbol.
  - …in SC-FDMA, each sub-carrier contains information of ALL transmitted symbols.



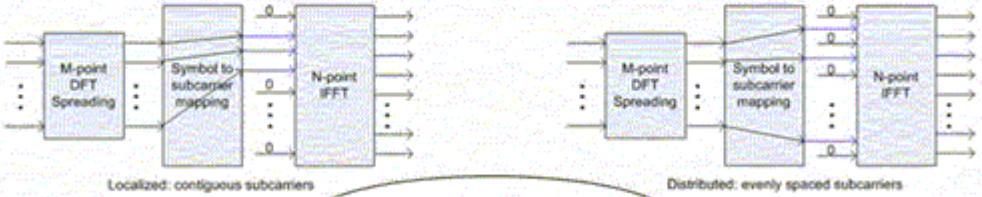
(a) OFDM subcarriers (b) DFT-s-OFDM subcarriers

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?



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)

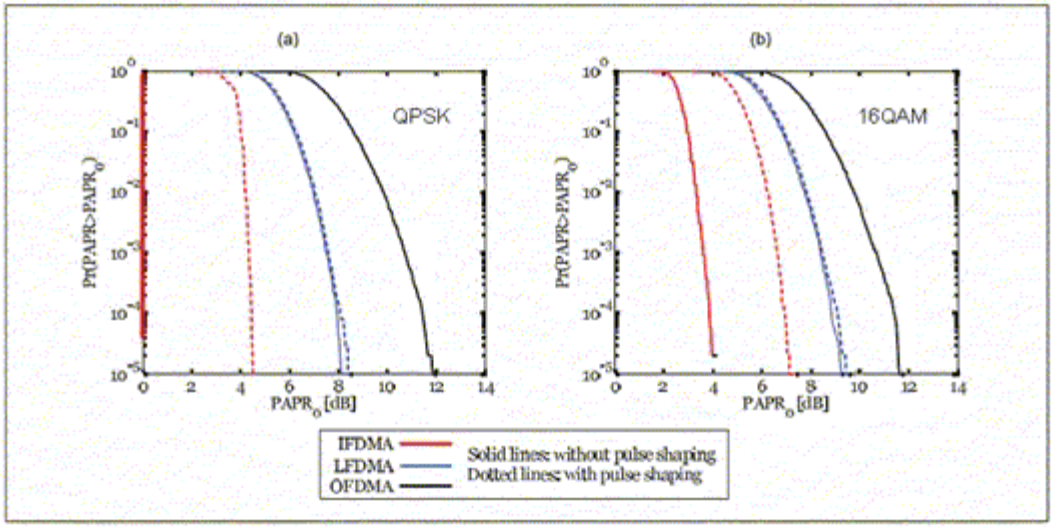


FIGURE 5 Comparison of CCDF of PAPR for IFDMA, LFDMA, and OFDMA with $M = 256$ system subcarriers, $N = 64$ subcarriers per user, and a = 0.5 rolloff factor; (a) QPSK; (b) 16-QAM.

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)

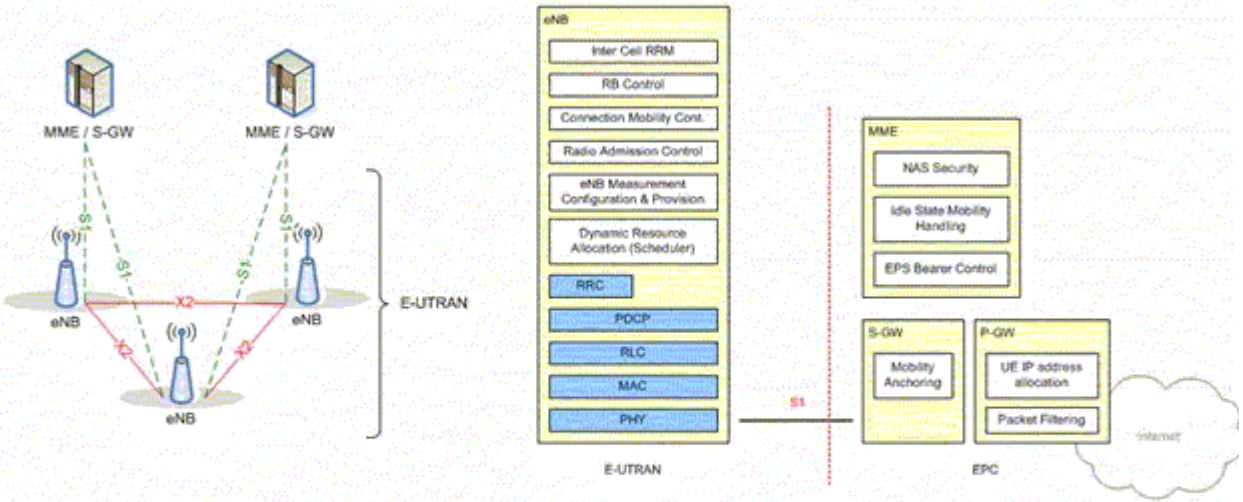
- **LTE FDD**
  - Same as in downlink,

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**
  - UL using 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

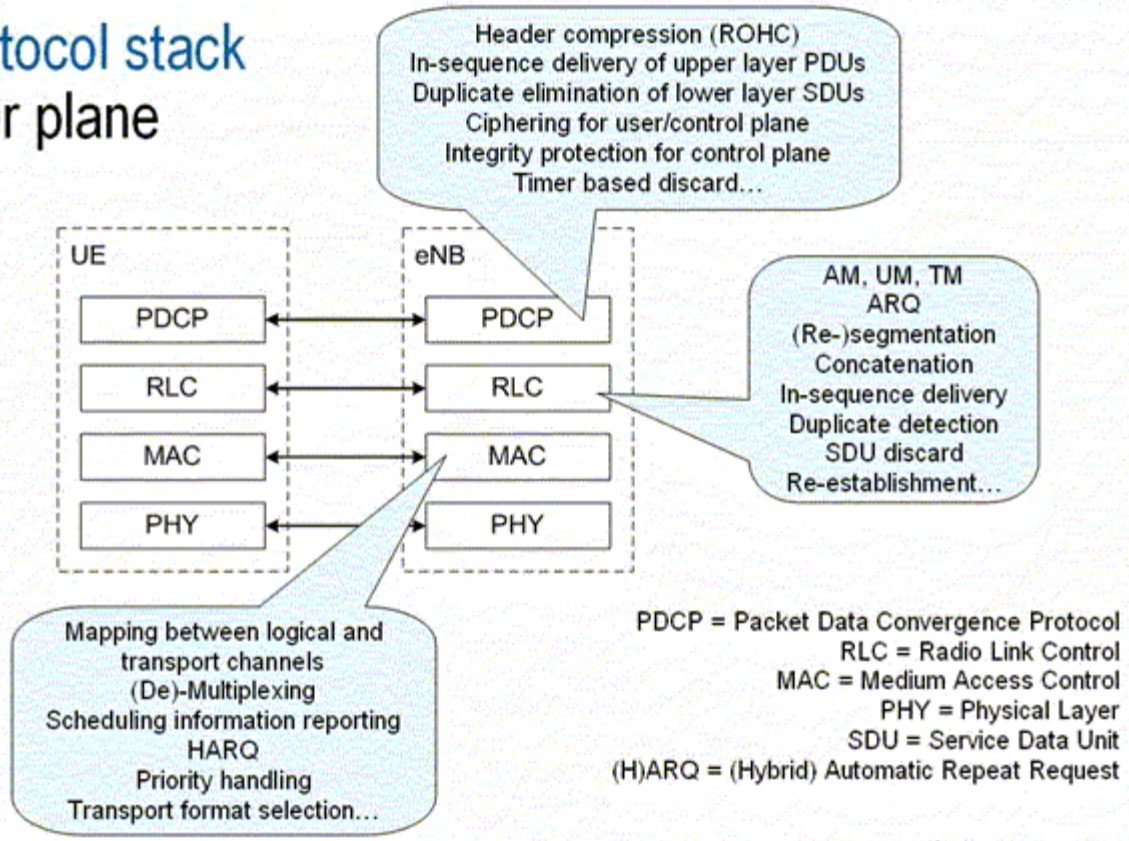
LTE/SAE network architecture



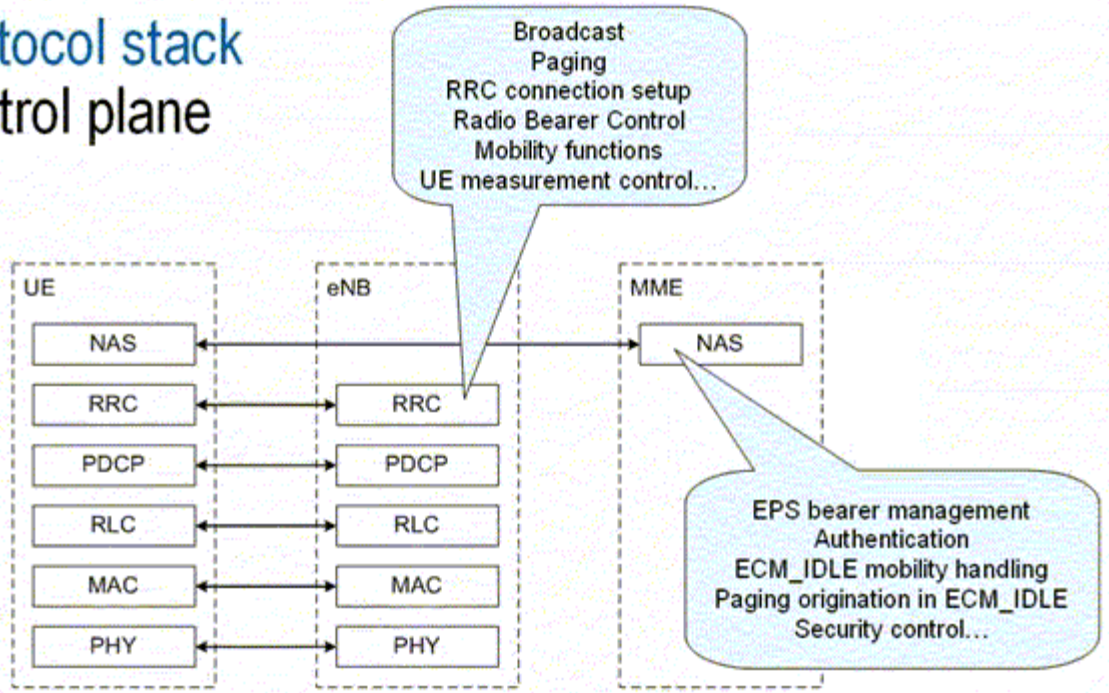
SAE = System Architecture Evolution
eNB = evolved Node B
MME = Mobility Management Entity
E-UTRAN = Evolved UMTS Terrestrial Radio Access Network
S-GW = Serving Gateway

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



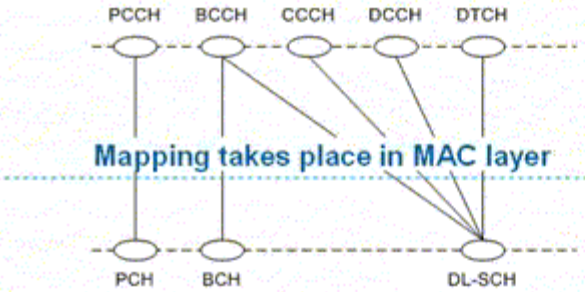
Protocol stack
control plane



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:

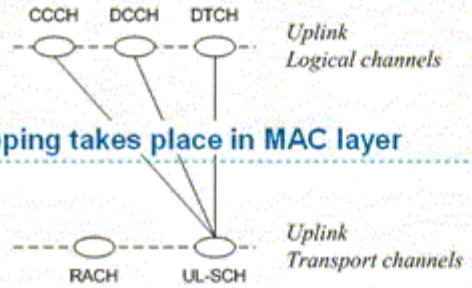


Downlink Logical channels

Downlink Transport channe

- 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

Uplink:

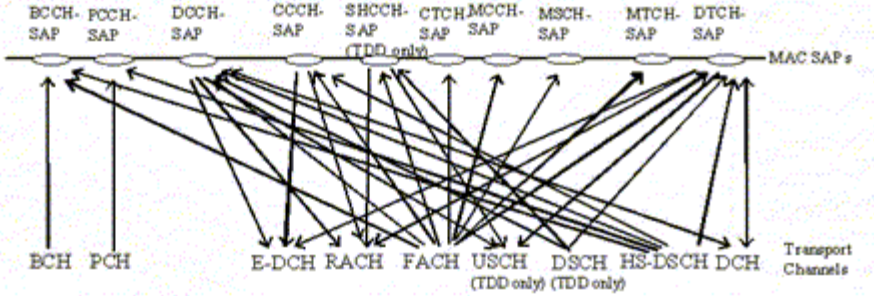


Uplink Logical channels

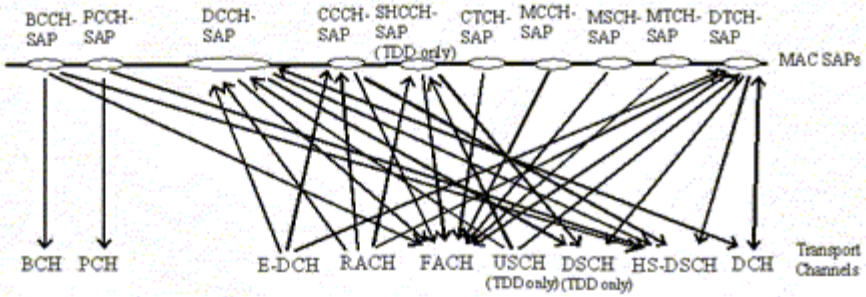
Uplink Transport channels

...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