LTE Physical Layer Fundamentals and Test Requirements

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octoScope

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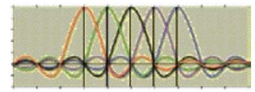
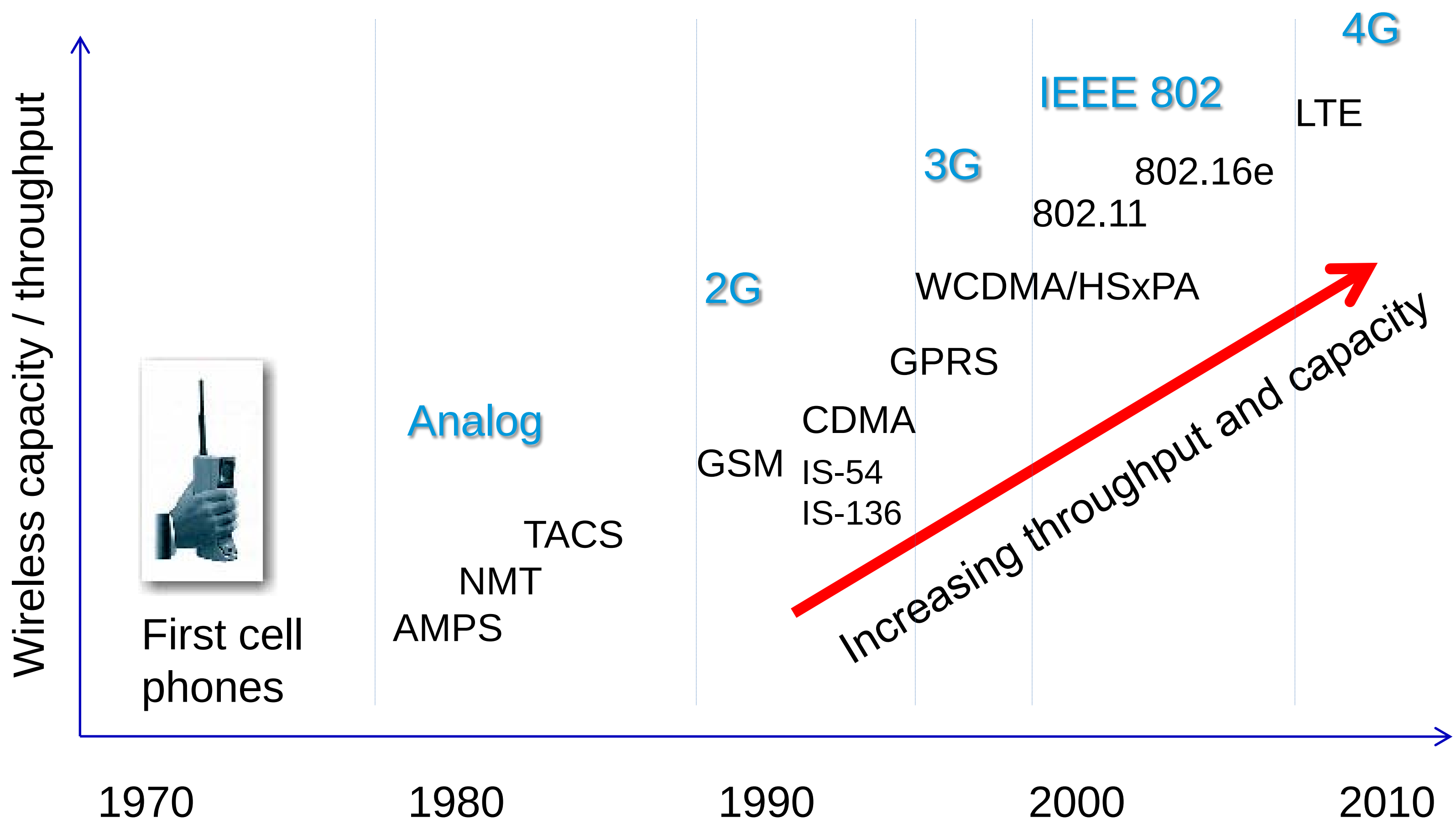
Agenda

- The 'G's – brief history of wireless
- Standards organizations
  - 3GPP, ITU, GCF, PTCRB
- Introduction to LTE
  - OFDMA, SC-OFDM
  - MIMO / Multiple antenna techniques
  - UE (user equipment) categories
  - FDD, TDD, channelization
- Fading and multipath in the wireless channel
  - Standard channel models
- Test methods
  - R&D, certification, production

3GPP	3rd Generation Partnership Project
ITU	International Telecommunication Union
GCF	Global Certification Forum
PTCRB	PCS Type Certification Review Board

Brief History





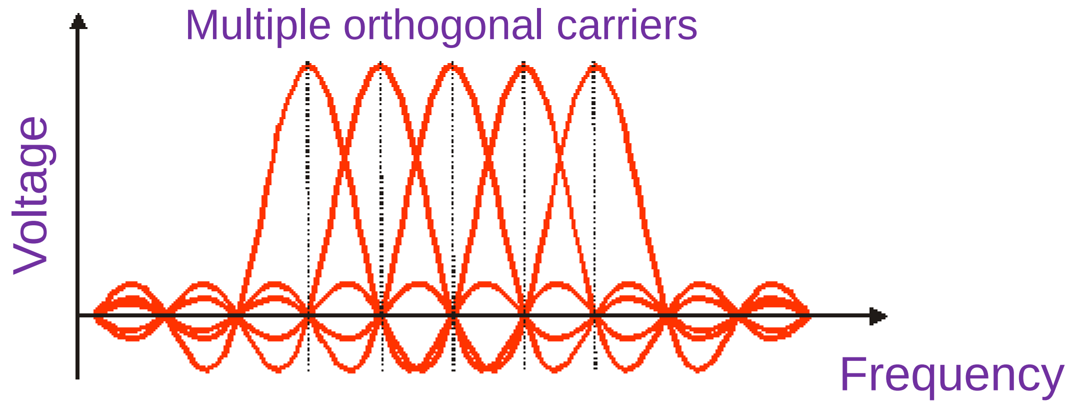
The G’s

G		Peak Data Rate (Mbps)	
		Downlink	Uplink
1	Analog	19.2Kbps	
2	Digital – TDMA, CDMA	14.4 Kbps	
3	Improved CDMA variants (WCDMA, CDMA2000)	144 Kbps (1xRTT); 384 Kbps (UMTS); 2.4 Mbps (EVDO)	
3.5	HSPA (today)	14 Mbps	5.76 Mbps
3.75	HSPA (Release 7) DL 64QAM or 2x2 MIMO; UL 16QAM	28 Mbps	11.5 Mbps
	HSPA (Release 8) DL 64QAM and 2x2 MIMO	42 Mbps	11.5 Mbps
4	WiMAX (Release 1.0, TDD 2:1 UL/DL ratio) 10 MHz channel	40 Mbps	10 Mbps
	LTE, FDD 5 MHz UL/DL, 2 Layers DL	43.2 Mbps	21.6 Mbps
	LTE CAT-3	100 Mbps	50 Mbps

OFDM

OFDM (Orthogonal Frequency Division Multiplexing)

DVB, DAB
MediaFLO
Wi-Fi
WiMAX
LTE

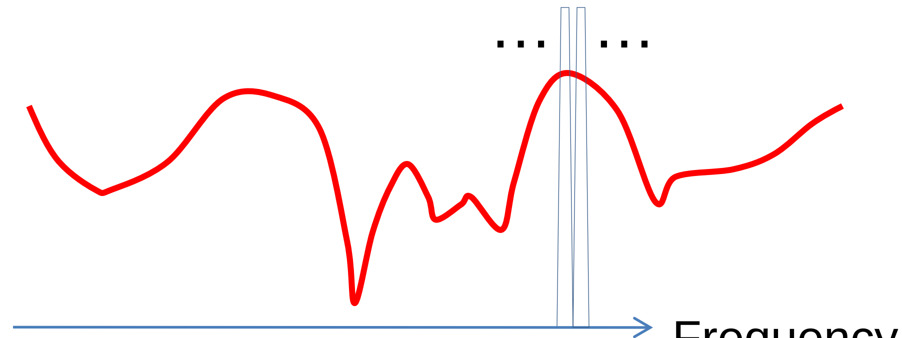


- OFDM is the most robust signaling scheme for a hostile wireless channel
  - Works well in the presence of multipath thanks to multi-tone signaling and cyclic prefix (aka guard interval)
- OFDM is used in all new wireless standards, including
  - 802.11a, g and draft 802.11ac, ad
  - 802.16d,e; 802.22
  - DVB-T, DVB-H, DAB
- LTE is the first 3GPP standard to adopt OFDM

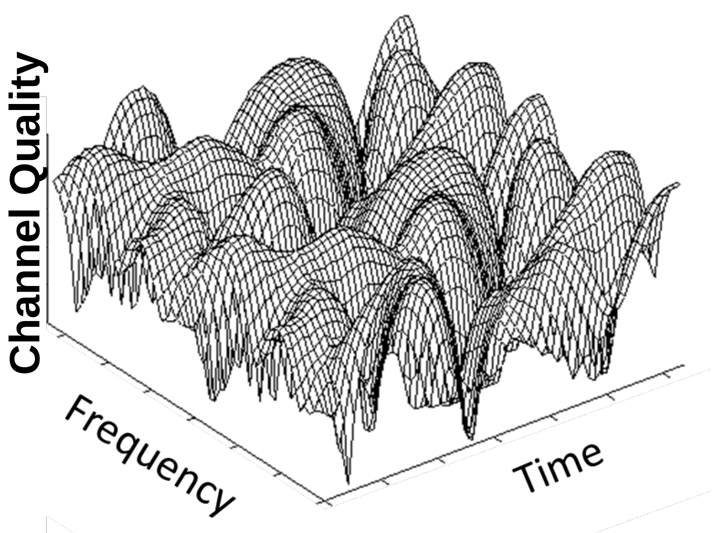
MediaFLO = Media Forward Link Only

OFDM for Frequency- and Time-Variable Channel

- OFDM transforms a frequency- and time-variable fading channel into parallel correlated flat-fading channels, eliminating the need for complex equalization



Frequency-variable channel appears flat over the narrow band of an OFDM subcarrier.

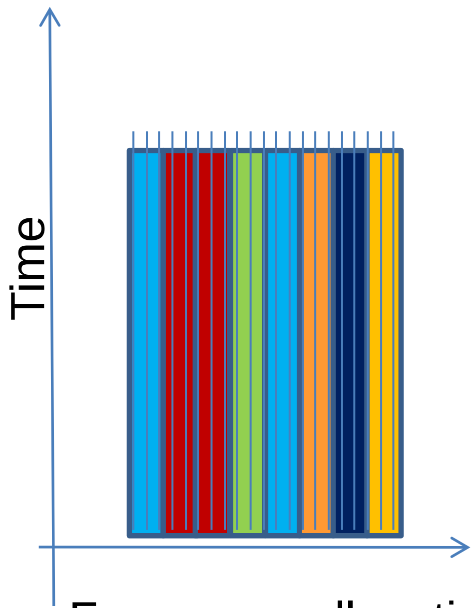


OFDM combined with multiple antenna techniques combats time- and frequency-variability of the wireless channel

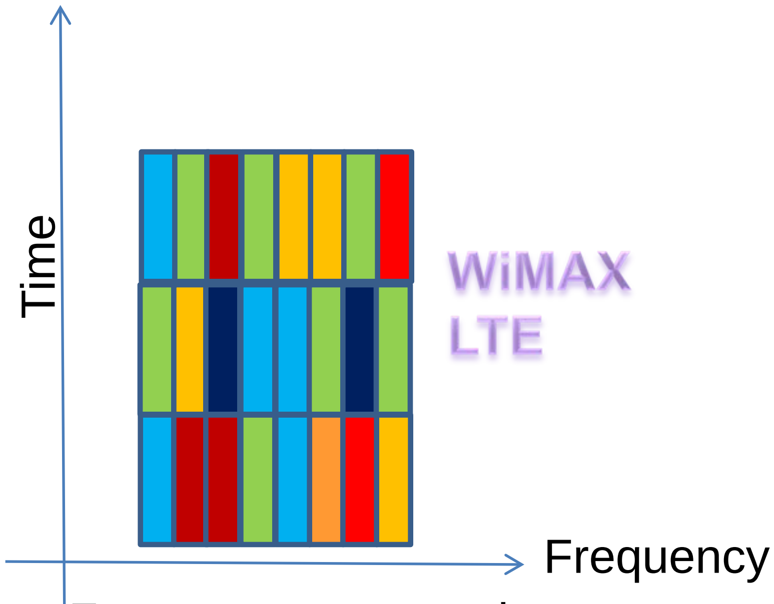
OFDMA (Orthogonal Frequency Division Multiple Access)

OFDM is a modulation scheme

OFDMA is a modulation and access scheme



Frequency allocation per user is continuous vs. time



Frequency per user is dynamically allocated vs. time slots

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3GPP (3rd Generation Partnership Project)

- Partnership of 6 regional standards groups that translate 3GPP specifications to regional standards
- Defines standards for mobile broadband, including UMTS and LTE

ITU International Mobile Telecommunications

- **IMT-2000**
  - Global standard for third generation (3G) wireless communications
  - Provides a framework for worldwide wireless access by linking the diverse systems of terrestrial and satellite based networks.
  - Data rate limit is approximately 30 Mbps
  - Detailed specifications contributed by 3GPP, 3GPP2, ETSI and others
- **IMT-Advanced**
  - New generation framework for mobile communication systems beyond IMT-2000 with deployment around 2010 to 2015
  - Data rates to reach around 100 Mbps for high mobility and 1 Gbps for nomadic networks (i.e. WLANs)
  - IEEE 802.11ac and 802.11ad VHT (very high throughput) working to define the nomadic interface
  - 3GPP working to define LTE and LTE-Advanced high mobility interface and so is IEEE 802.16m

ITU = International Telecommunications Union

UMTS UE Certification Bodies

- **Global Certification Forum** (GCF) is responsible for LTE conformance testing with the focus on European operators

www.globalcertificationforum.org

- **PCS Type Certification Review Board** (PTCRB) provides UE certification for North American operators

www.ptcrb.com

- GCF and PTCRB have similar roles but each organization focuses on the frequency bands and regulatory limits relevant to their regions.
- Verizon plans to use GCF for its LTE certification program

PCS = Personal Communications System, a variation of GSM

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Benefits of LTE/SAE

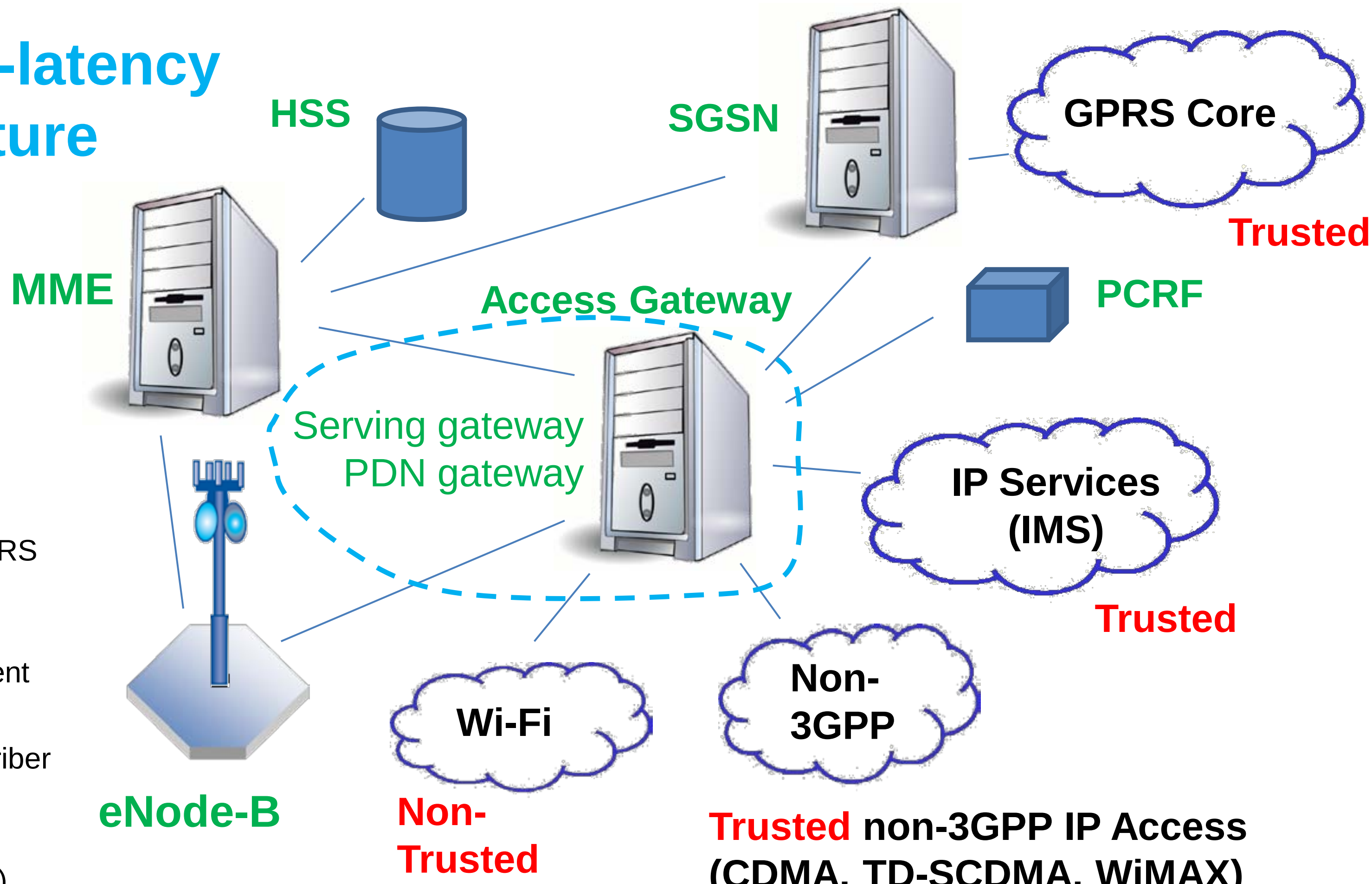
- **Increased data rates**
  - Up to 86 Mbps in the UL, 326 Mbps DL with 4 layers (streams)
- **High mobility**
  - Up to 162 km/h (300 Hz Doppler);
    standard evolving to support up 500 km/h

- **Scalable channel widths**
  - 1.4, 3, 5, 10, 15 and 20 MHz
- **Improved spectral efficiency**
  - 2x to 5x, depending on antenna configuration, vs. UMTS
- **MIMO, FDD and TDD improve throughput and access efficiency**
  - Part of 3G and LTE
- **Flat architecture, lower latency (< 5 ms)**
  - Key for real-time applications such as VoIP, video conferencing, gaming
- **Backwards compatibility to legacy networks**
- **Support for an all-IP network**

DL = downlink; UL = uplink
SAE = System Architecture Evolution

LTE EPS (Evolved Packet System)

Flat, low-latency architecture



SGSN (Serving GPRS Support Node)

PCRF (policy and charging enforcement function)

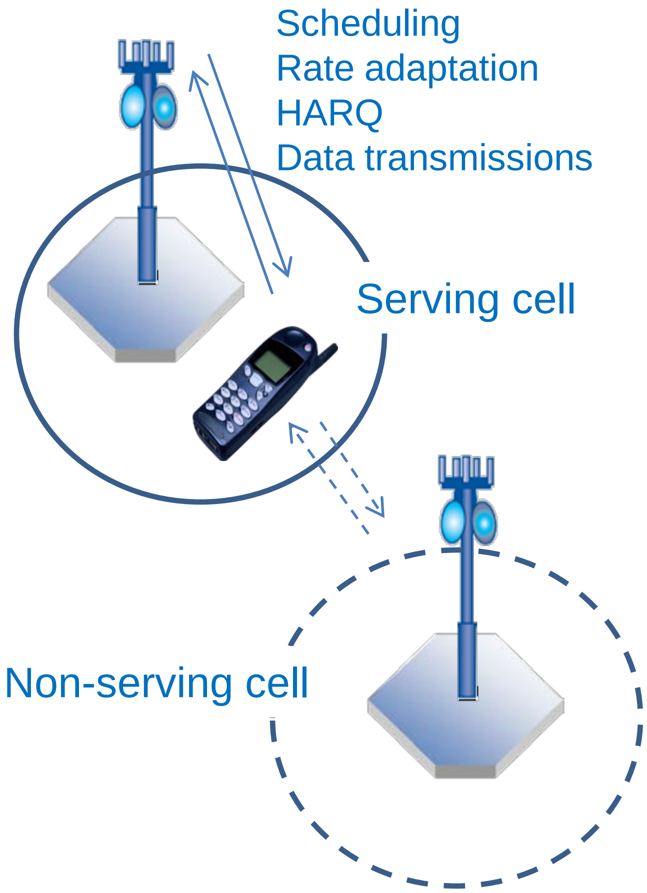
HSS (Home Subscriber Server)

MME (Mobility Management Entity)

PDN (Public Data Network)

Mobility Management

- **Mobility Management Entity (MME) is responsible for**
  - UE reachability
  - Tracking area
  - Inter-eNB mobility (resides in the serving gateway)
    - Intra-LTE handovers
  - Inter-3GPP mobility
    - Handovers between 3GPP 2G/3G access systems and LTE



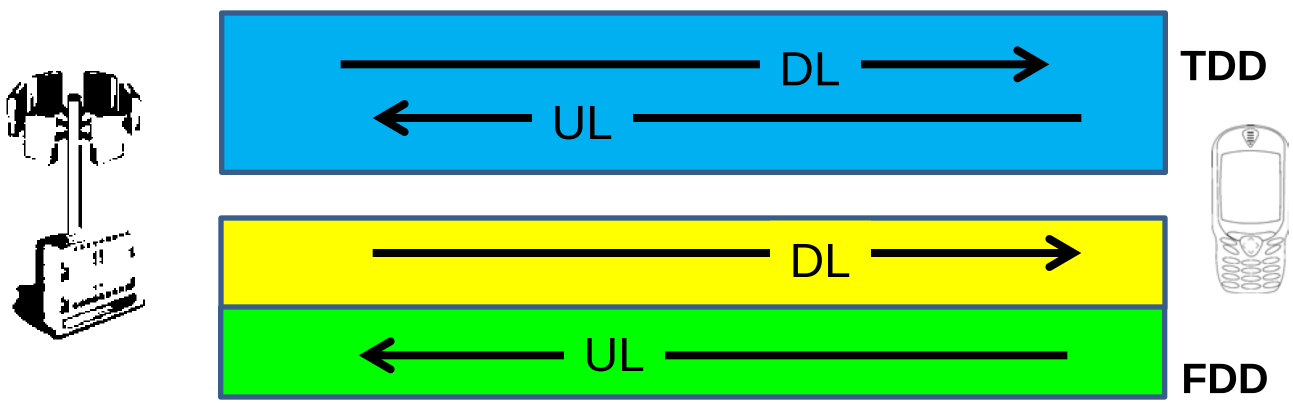
Quality of Service (QoS)

- **Radio Resource Management (RRM)**
  - Establishes, maintains and releases radio bearers
  - Dynamically allocates resources for sending data over the airlink
  - Manages RBs for minimum inter-cell interference
  - Load balancing: re-distributes traffic loads among multiple cells
  - Inter-RAT RRM manages inter-RAT handovers
- QoS is defined (3GPP document 22.278) for
  - Network access
  - Service access
  - Service retainability
  - Service integrity

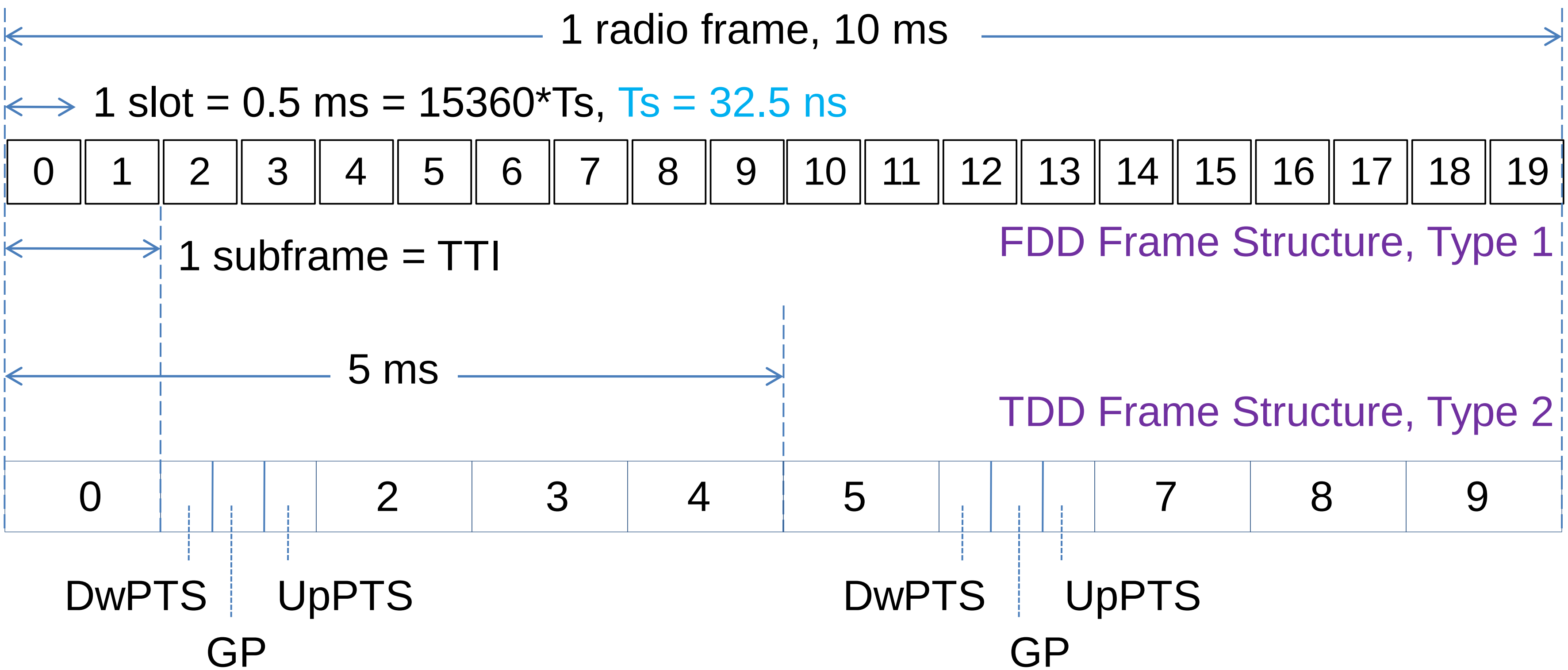
RAT = radio access technology

FDD and TDD Support

- FDD (frequency division duplex)
  - Paired channels
- TDD (time division duplex)
  - Single frequency channel for uplink an downlink
  - Is more flexible than FDD in its proportioning of uplink vs. downlink bandwidth utilization
  - Can ease spectrum allocation issues



FDD and TDD Frame Structures



DwPTS = Downlink Pilot Time slot
UpPTS = Uplink Pilot Time Slot
GP = Guard Period
TTI = Transmission Time Interval

TDD Mode

Subframe

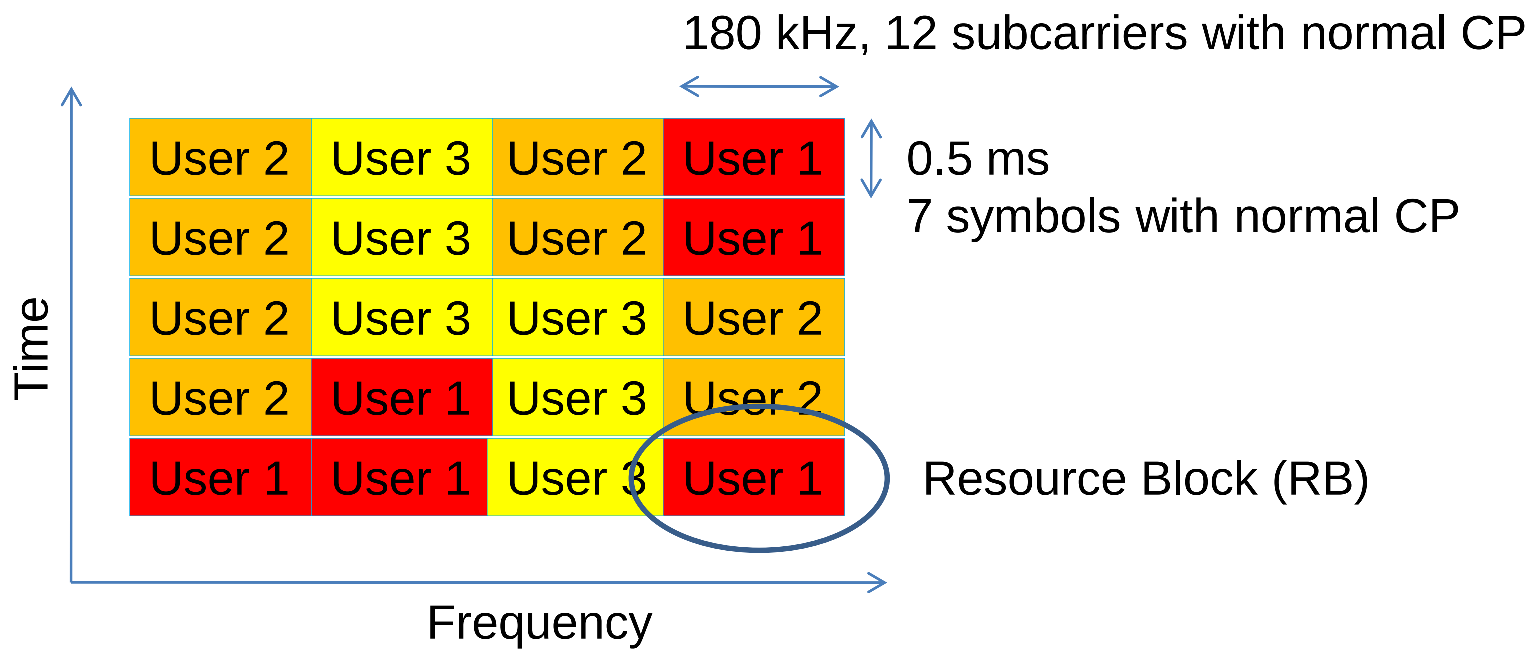
TDD Frame, Type 2

0 2 3 4 5 7 8 9

Config #	Subframe number									
	0	1	2	3	4	5	6	7	8	9
0	DL		UL	UL	UL	DL		UL	UL	UL
1	DL		UL	UL	DL	DL		UL	UL	DL
2	DL		UL	DL	DL	DL		UL	DL	DL
3	DL		UL	UL	UL	DL		DL	DL	DL
4	DL		UL	UL	DL	DL		DL	DL	DL
5	DL		UL	DL	DL	DL		DL	DL	DL
6	DL		UL	UL	UL	DL		UL	UL	DL

5 ms

Resource Allocation

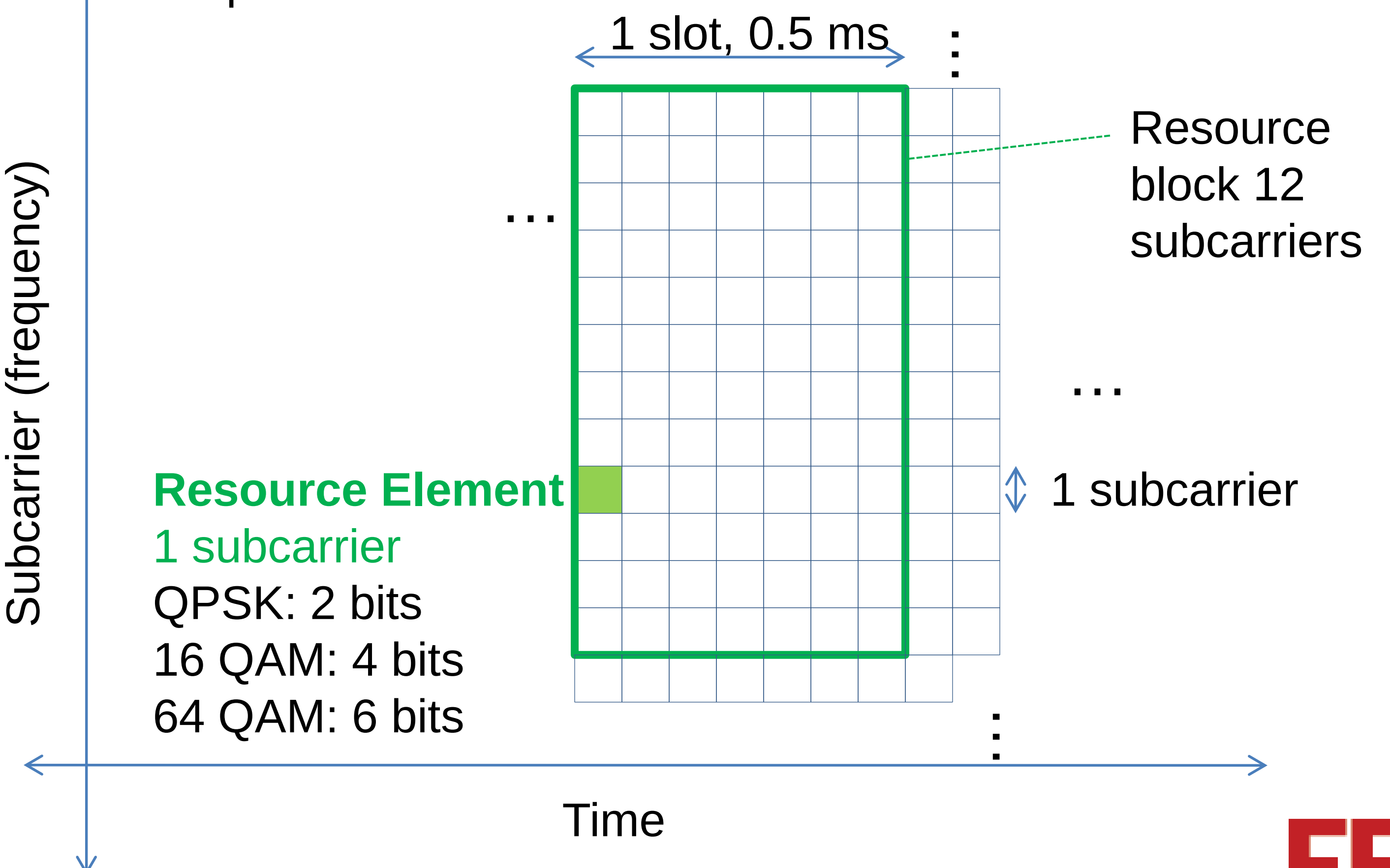


- Resources are allocated per user in time and frequency. RB is the basic unit of allocation.
- RB is 180 kHz by 0.5 ms; typically 12 subcarriers by 7 OFDM symbols, but the number of subcarriers and symbols can vary based on CP

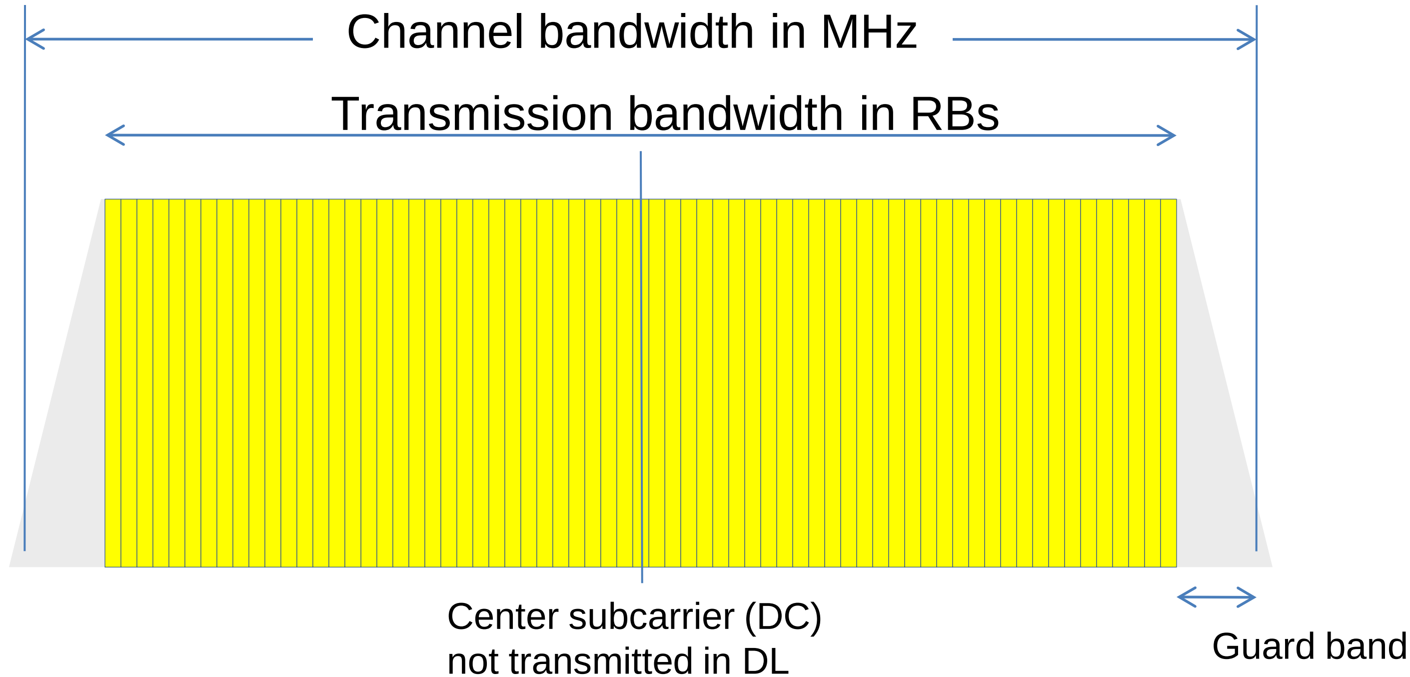
CP = cyclic prefix, explained ahead

Resource Block

A resource block (RB) is a basic unit of access allocation.
RB bandwidth per slot (0.5 ms) is12 subcarriers times 15 kHz/subcarrier equal to 180 kHz.



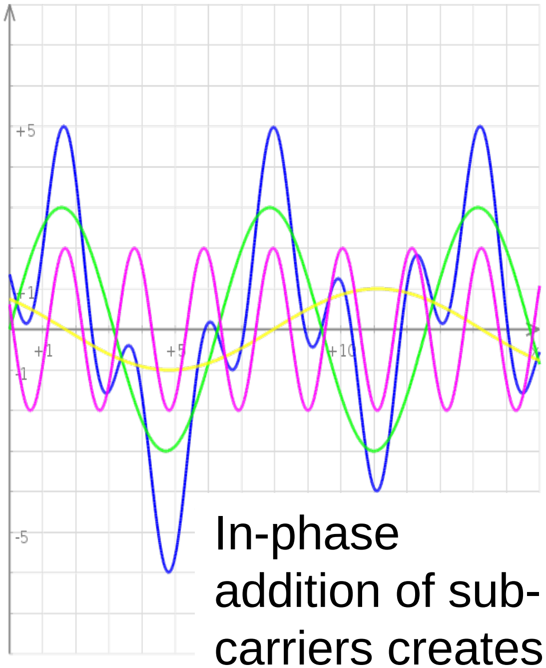
Scalable Channel Bandwidth



Channel bw	**1.4**	**3**	**5**	**10**	**15**	**20**	MHz
Transmission bw	1.08	2.7	4.5	9	13.5	18	
# RBs per slot	6	15	25	50	75	100	

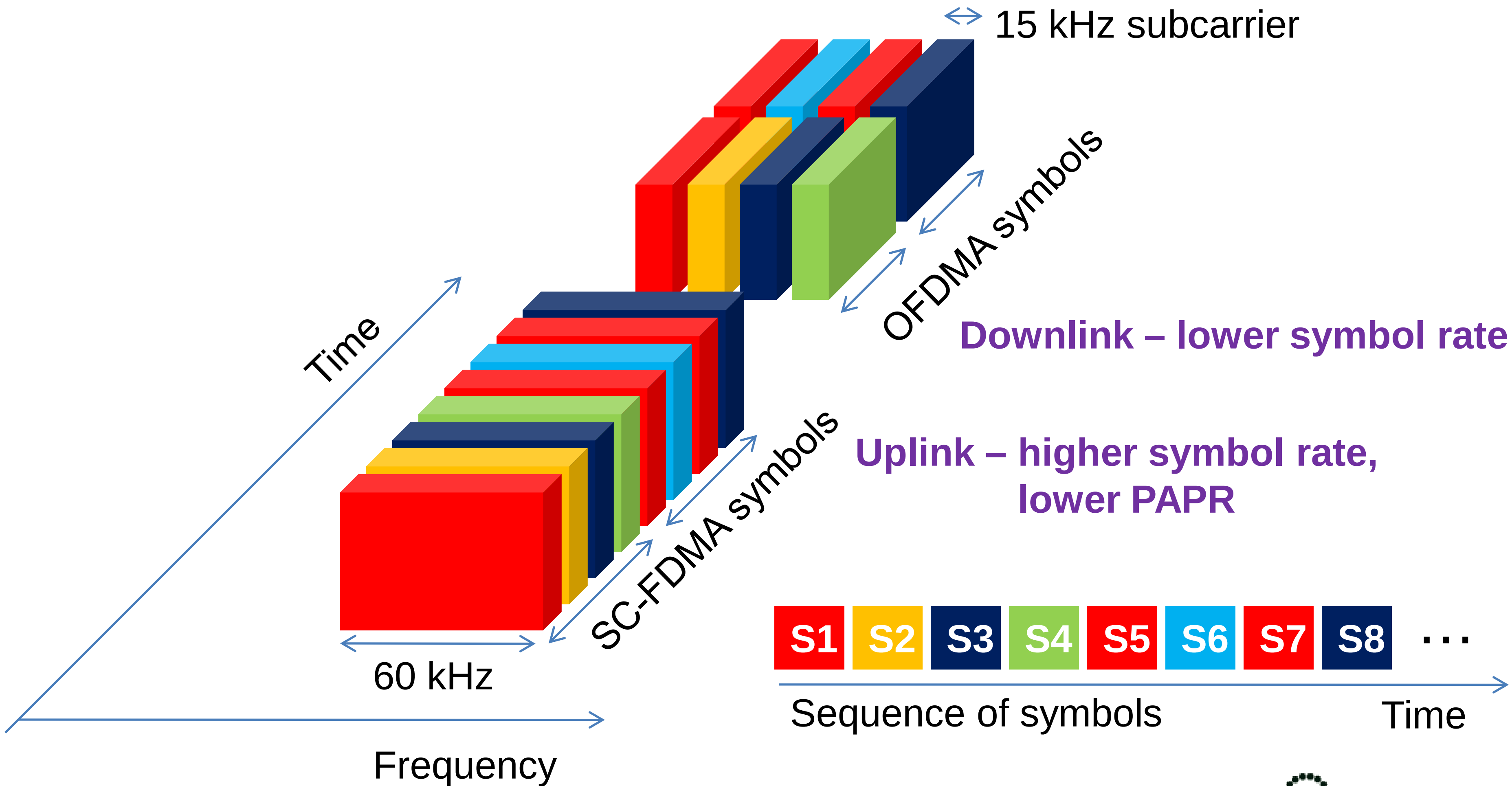
OFDMA vs. SC-FDMA

- Multi-carrier OFDM signal exhibits high PAPR (Peak to Average Power Ratio) due to in-phase addition of subcarriers.
- Power Amplifiers (PAs) must accommodate occasional peaks and this results low efficiency of PAs, typically only 15-20% efficient. Low PA efficiency significantly shortens battery life.
- To minimize PAPR, LTE has adapted SC-FDMA (single carrier frequency division multiple access) in the uplink. **SC-FDMA exhibits 3-6 dB less PAPR than OFDMA.**

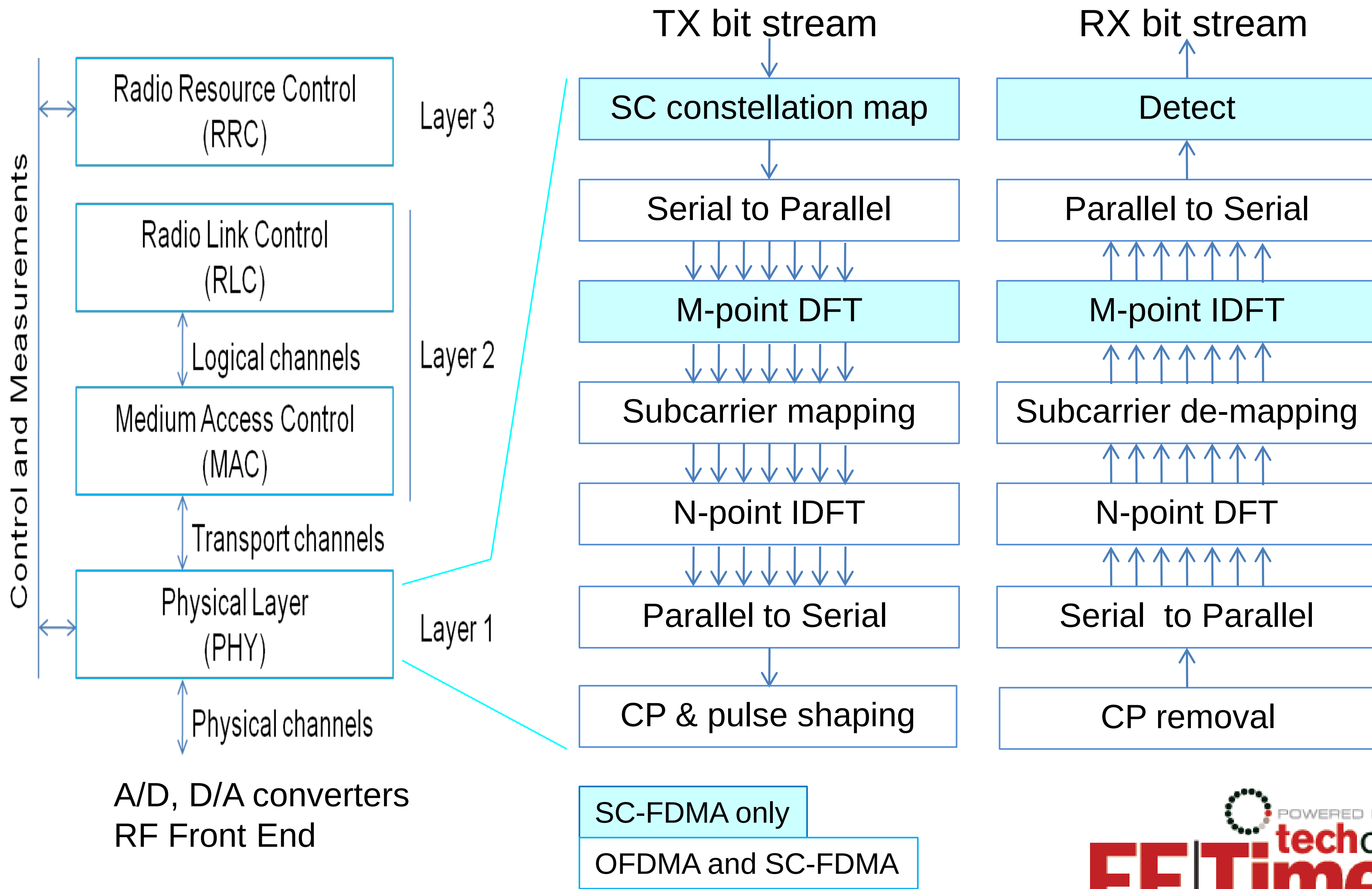


In-phase addition of sub-carriers creates peaks in the OFDM signal

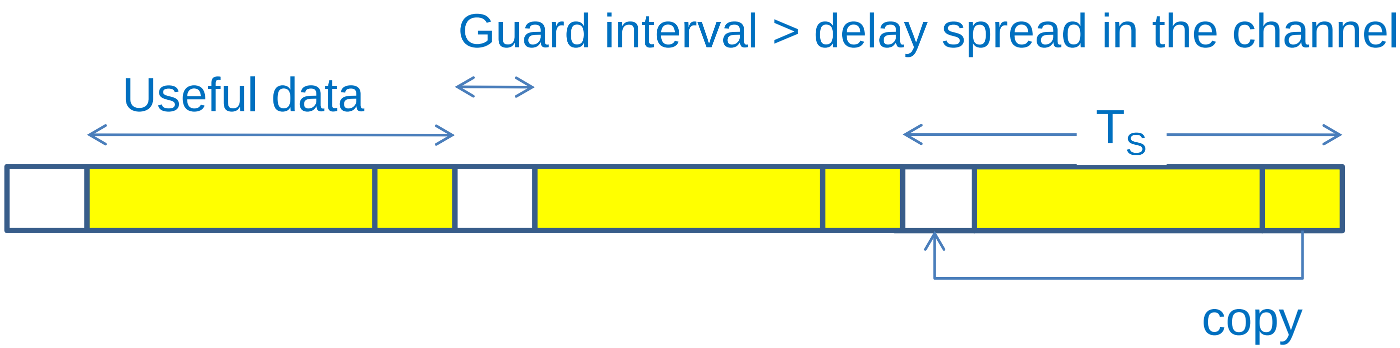
SC-FDMA vs. OFDMA



Radio Block Diagram



Cyclic Prefix

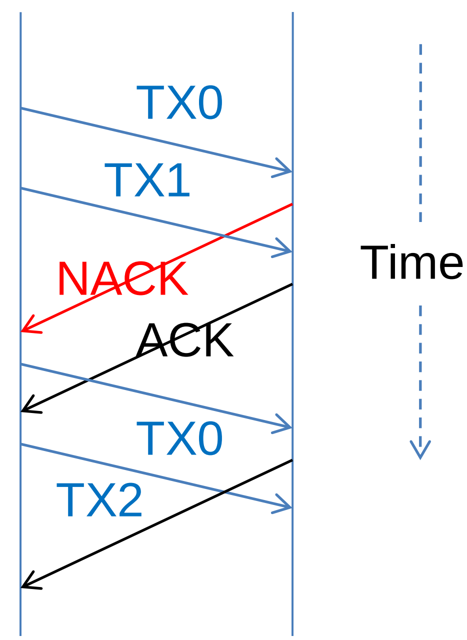


- After IDFT and parallel to serial conversion, the composite symbol is extended by repeating the end of the symbol in the beginning. This extension is called the Cyclic Prefix (CP).
- CP is a guard interval that allows multipath reflections from the previous symbol to settle prior to receiving the current symbol. CP has to be greater than the delay spread in the channel.
- CP eliminates Intersymbol Interference (ISI) and makes the symbol easier to recover.

Forward Error Correction and Hybrid Automatic Repeat reQuest

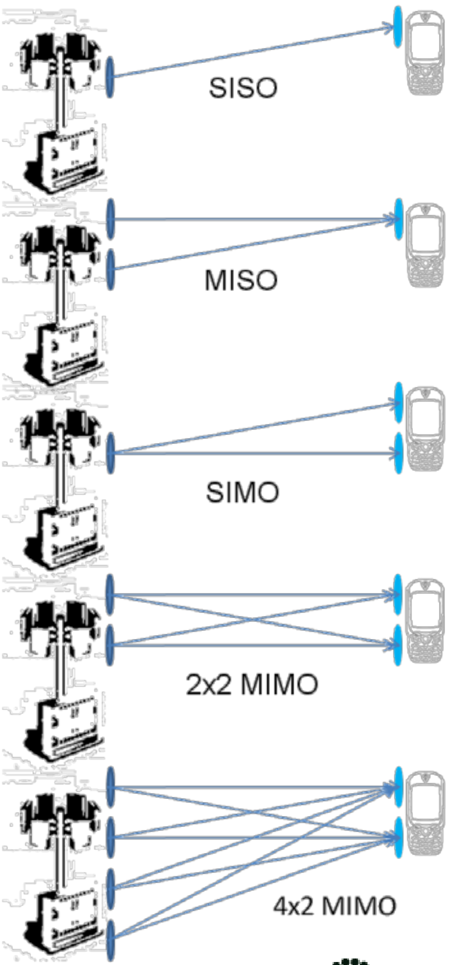
- LTE uses
  - Turbo Convolutional Coding
  - AMC (Adaptive Modulation Coding)
  - Type II Hybrid Automatic Repeat reQuest (HARQ)
- For time-varying channels, an adaptive scheme such as the Incremental HARQ is used
  - Codeword is subsequently punctured and transmitted over the channel until it is successfully delivered to the receiver.
  - Successive interference cancellation

HARQ process



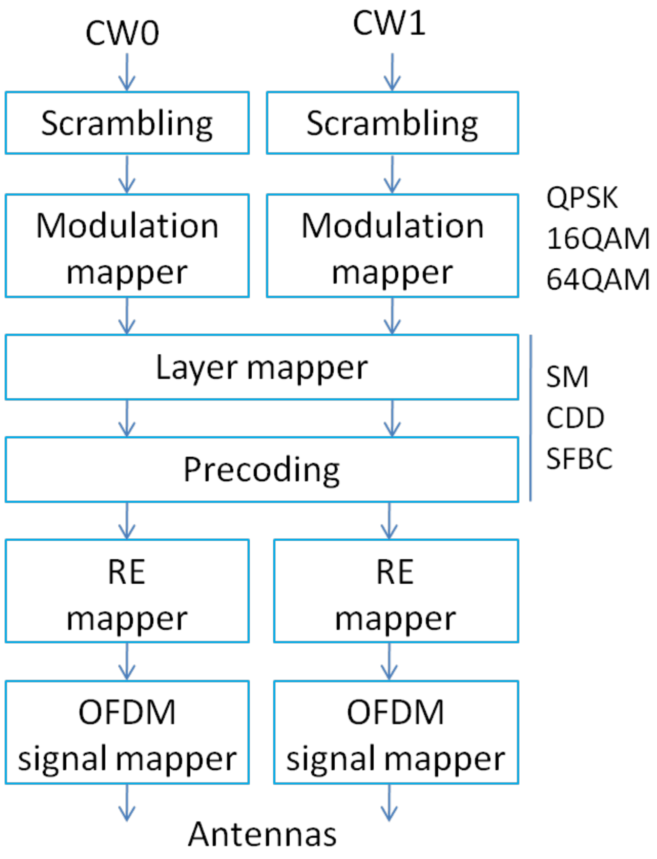
Multiple Antenna Techniques

- **SISO (Single Input Single Output)**
  - Traditional radio
- **MISO (Multiple Input Single Output)**
  - Transmit diversity
  - Space Frequency Block Coding (SFBC) or Cyclic Delay Diversity (CDD)
- **SIMO (Single Input Multiple Output)**
  - Receive diversity
  - Maximal Ratio Combining (MRC)
- **MIMO (Multiple Input Multiple Output)**
  - Spatial Multiplexing (SM) to transmit multiple layers (streams) simultaneously; can be used in conjunction with Cyclic Delay Diversity (CDD); works best in high SINR environments and channels de-correlated by multipath
  - TX and RX diversity, used independently or together; used to enhance throughput in the presence of adverse channel conditions



Multiple Antenna Precoding

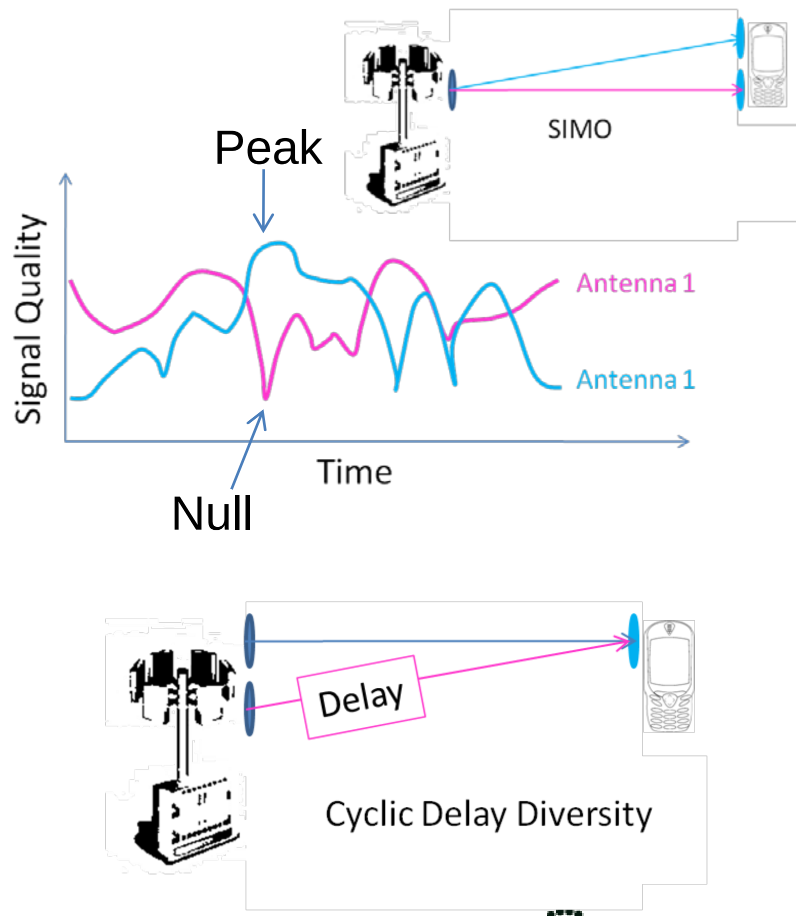
- Codeword (CW0, CW1) is a block of data
- For Spatial Multiplexing (SM) 2 to 4 layers (streams) can transmitted
- The process of precoding is used to format layers for TX diversity (CDD, SFBC), SM or beamsteering



SFBC = Space Frequency Block Coding
CDD = Cyclic Delay Diversity

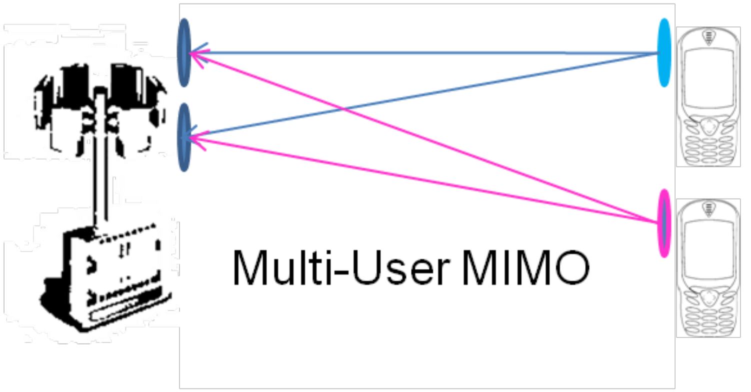
Receive and Transmit Diversity

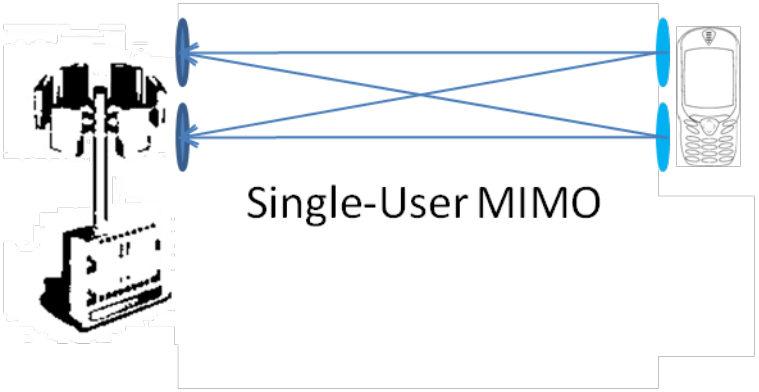
- Receive diversity, MRC, makes use of the highest signal quality, combining signals from both antennas
- Transmit diversity techniques, CDD or SFBC, spread the signal so as to create artificial multipath to decorrelate signals from different antennas with the goal of delivering a peak on one receive antenna while there may be a null on another.



Single-, Multi-User MIMO

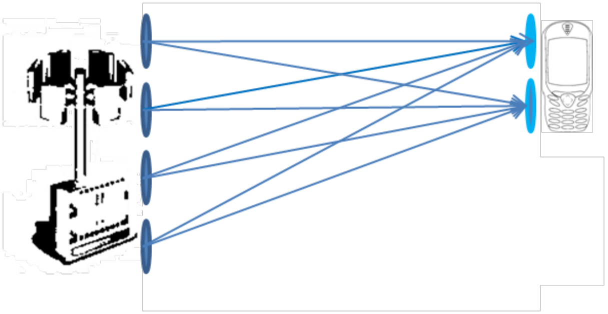
- MU-MIMO allows two UEs to share RBs provided their channels to the eNB are sufficiently decorrelated.
- MU-MIMO increases uplink capacity.
- SU-MIMO requires a UE to have two transmitters, which is currently considered detrimental to battery life and cost

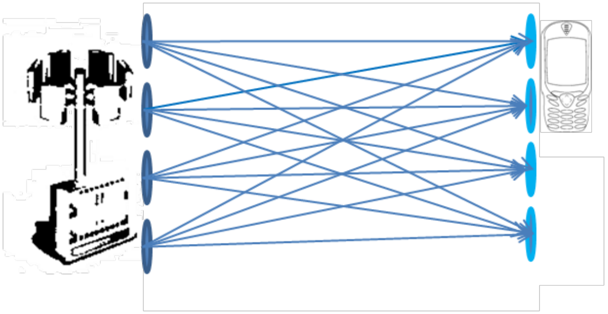




LTE Multi-Antenna Configurations

- eNB TX antennas: 1, 2 or 4
- UE RX antennas: 2 or 4 for MRC
- DL TX diversity: SFBC (space frequency block coding); TDD
- DL SM (spatial multiplexing): codebook-based precoding; up to 2 parallel codewords
- Closed loop MIMO is used for beamforming
  - Requires channel sounding and exchange of channel response between the UE and eNB





Maximum Raw Uplink Data Rate

	1 TX
Total bandwidth	20 MHz
Total Resource Blocks	100
Resource Elements per Resource Block	84
Resource Element overhead (uplink reference signals)	12
Available Resource Elements per Resource Block (after overhead)	72
Resource Elements per Resource Block pair (in 1 ms)	144
Total Resource Elements available per subframe	14400
Bits per Resource Element, 64 QAM	6
Total bits per subframe	86400
Raw Channel Bandwidth	**86.4 Mbps**

Source: http://www.lteuniversity.com/blogs/chrisreece/archive/2009/08/04/the-magic-86.aspx

Maximum Raw Downlink Data Rate

	2x2 MIMO	4x4 MIMO
Total bandwidth	20 MHz	20 MHz
Total Resource Blocks	100	100
Resource Elements per Resource Block	84	84
Resource Elements per Resource Block pair	168	168
Resource Element Overhead – PDCCH (Assuming only one OFDM symbol for PDCCH)	12	12
Resource Element Overhead - Reference Signals	12	20
Resource Elements per Resource Block pair (in 1 ms)	144	136
Total Resource Elements available per subframe	14400	13600
Bits per Resource Element (64 QAM)	6	6
Total bits per subframe	86400	81600
Throughput per layer	86.4 Mbps	81.6 Mbps
Throughput for 2x2 MIMO, 2 layers (streams)	**172.8 Mbps**	
Throughput for 4x4 MIMO, 4 layers (streams)		**326.4 Mbps**

Source: http://www.lteuniversity.com/blogs/chrisreece/archive/2009/08/04/the-magic-86.aspx

UE Categories 1-5

Category	DL/UL data rates (top uplink modulation)	Multiple Antenna eNB TX x UE RX
Cat 1	10/5 Mbps (16QAM)	1 x 2
Cat 2	51/25 Mbps (16QAM)	2 x 2
Cat 3	102/51 Mbps (16QAM)	2 x 2
Cat 4	150/51 Mbps (16QAM)	2 x 2
Cat 5	302/75 Mbps (64QAM)	4 x 4

- 64QAM only used by Category 5 UE
- Assumption: Ideal channel conditions with optimum coding rate (approximately .98)

Source: 36.306

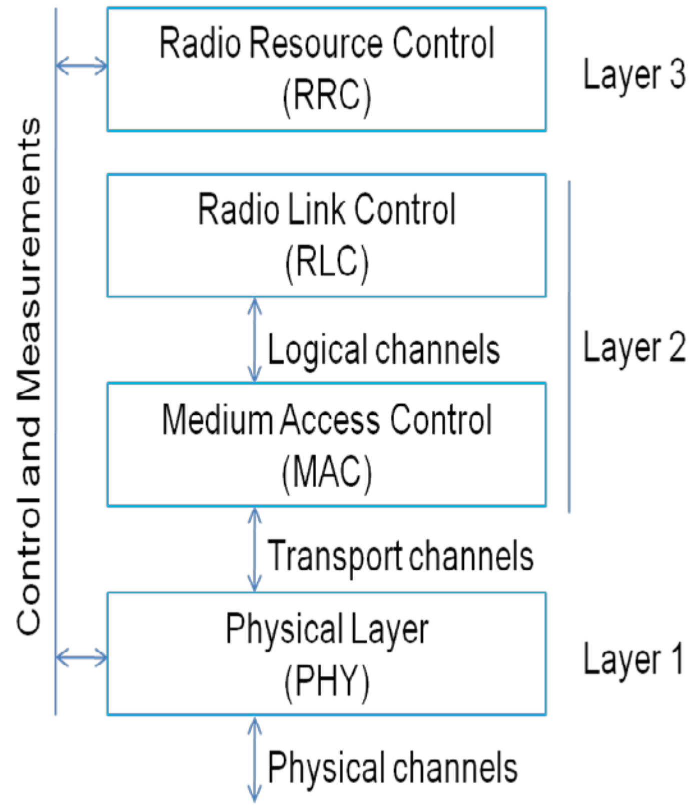
LTE Transmission Modes

Transmission mode	
1	Single-antenna; port 0
2	Transmit diversity
3	Open loop spatial multiplexing
4	Closed loop spatial multiplexing
5	MU-MIMO
6	Closed loop rank=1 precoding
7	Single-antenna; port 5

Source: 3GPP document 36.213

Dynamic Nature of the LTE Radio

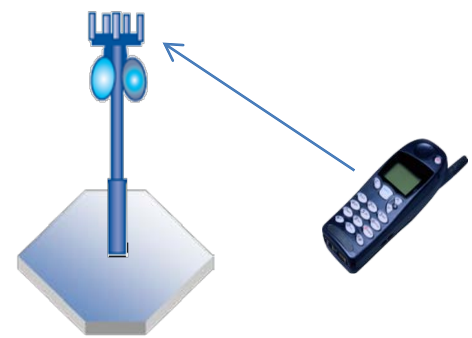
- Resources, coding and multiple antenna techniques are dynamically varied by the LTE radio in response to time-variable channel conditions
- MAC
  - Multiplexes data from logical channels to transport blocks on the transport channels
  - Performs error correction through HARQ
  - eNB MAC dynamically allocates RBs among UEs
  - Channel Quality Indicators (CQI) reported form the UE to the eNB are used for scheduling decisions



MAC = medium access control

Channel State Information (CSI) Uplink Control Signaling

- CQI (channel quality indicator)
  - Computed at the UE for each codeword based on SINR (signal to interference and noise ratio)
  - Wideband CQI is computed for the entire channel
  - CQI can also be computed for groups of RBs
- RI (rank indicator)
  - Represents the number of layers to be used in the next downlink transmission
- PMI (precoding matrix indicator)
  - Index to the preferred precoding matrix to optimize MIMO operation



CSI indicators are computed by the UE and reported to eNB for resource allocation decision making by the eNB MAC and higher layers

LTE Frequency Bands - FDD

Band	Uplink (UL)	Downlink (DL)	Regions
1	1920 -1980 MHz	2110 - 2170 MHz	Europe, Asia
2	1850 -1910 MHz	1930 - 1990 MHz	Americas, Asia
3	1710 -1785 MHz	1805 -1880 MHz	Europe, Asia, Americas
4	1710 -1755 MHz	2110 - 2155 MHz	Americas
5	824-849 MHz	869 - 894 MHz	Americas
6	830 - 840 MHz	875 - 885 MHz	Japan
7	2500 - 2570 MHz	2620 - 2690 MHz	Europe, Asia
8	880 - 915 MHz	925 - 960 MHz	Europe, Asia
9	1749.9 - 1784.9 MHz	1844.9 - 1879.9 MHz	Japan
10	1710 -1770 MHz	2110 - 2170 MHz	Americas
11	1427.9 - 1452.9 MHz	1475.9 - 1500.9 MHz	Japan
12	698 - 716 MHz	728 - 746 MHz	Americas
13	777 - 787 MHz	746 - 756 MHz	Americas
14	788 - 798 MHz	758 - 768 MHz	Americas
17	704 - 716 MHz	734 - 746 MHz	

Source: 3GPP TS 36.104 V8.4.0 (2008-12)

LTE Frequency Bands - TDD

Band	UL and DL	Regions
33	1900 - 1920 MHz	Europe, Asia (not Japan)
34	2010 - 2025 MHz	Europe, Asia
35	1850 - 1910 MHz	
36	1930 - 1990 MHz	
37	1910 - 1930 MHz	
38	2570 - 2620 MHz	Europe
39	1880 - 1920 MHz	China
40	2300 – 2400 MHz	Europe, Asia

Source: 3GPP TS 36.104 V8.4.0 (2008-12)

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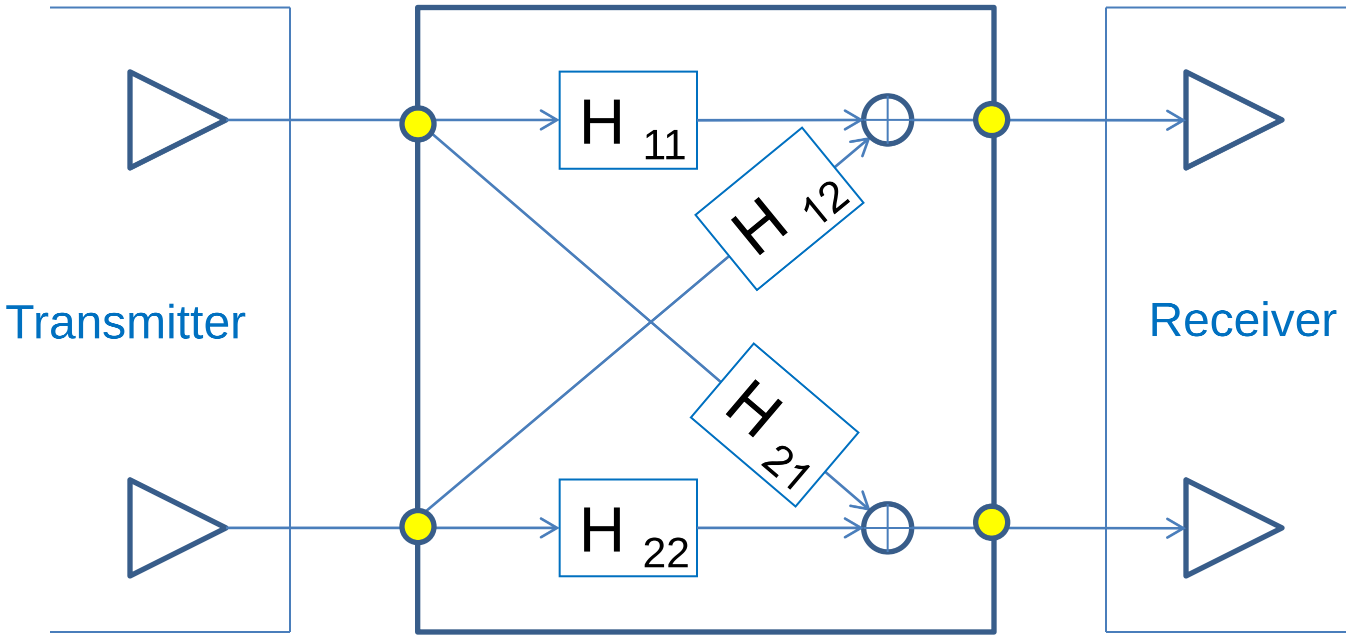
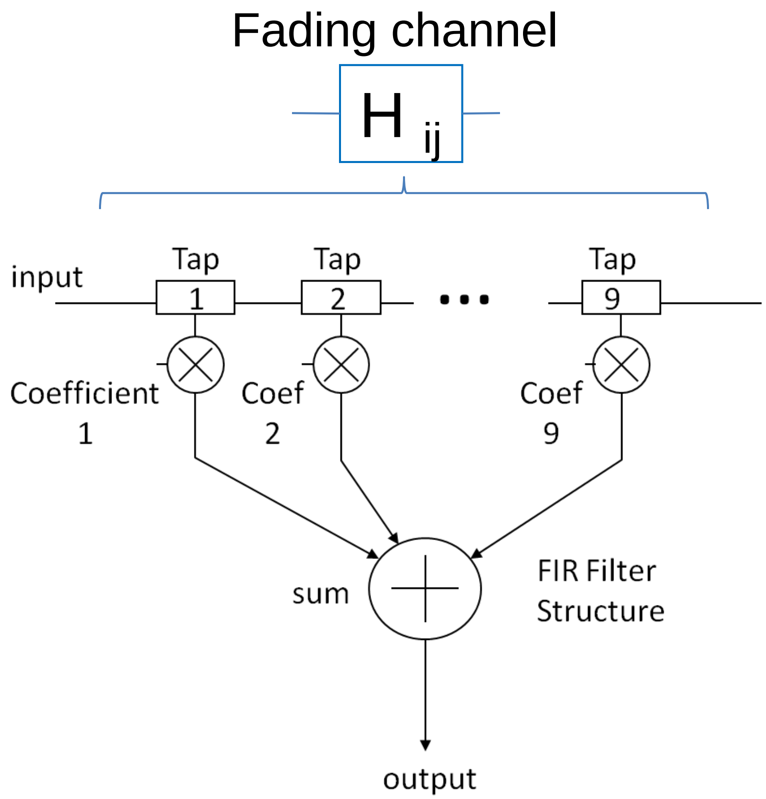
Multipath Fading MIMO Channel



- Time-varying FIR filter weights
  - Spatially correlated: H_{11} correlated with H_{12}, etc., according to antenna spacing
  - Doppler fading

LTE Channel Models

- 3GPP TR 25.996 v6.1.0 (2003-09) defines dynamic fading models with multipath and correlations
  - Spatial Channel Model (SCM)
  - 9 taps, max tap delay 5000 ns
  - Models derived from ITU M.1225
- Each tap represents a reflection (or a path); multiplier coefficients are dynamically changing to model Doppler shift, angle of arrival and angle of departure
- Number of fading channels is number of TX times number of RX



Industry Standard Channel Models

Model	Description	Document
ITU	Ped-B, Veh-A	Recommendation ITU-R M.1225, Guidelines for Evaluation of Radio Transmission, Technologies for IMT-2000, 1997
	Indoor Hotspot, Urban Macro, Urban Micro, Rural Macro, Sub-urban Macro	ITU-R Report M.2135, Guidelines for evaluation of radio transmission technologies for IMT-Advanced, 2008
WiMAX	AWGN, ITU Ped-B, Veh-A, Modified Veh-A for 10 usec impulse response and 120 km/hr	WiMAX Forum Mobile RCT XX xxx xxx v2.2.0, Appendix 4
LTE	Extended Pedestrian A model (EPA) Extended Vehicular A model (EVA) Extended Typical Urban model (ETU)	3GPP 36-521, UE Conformance Specification, Annex B
IEEE 802.11n	Models A-F	IEEE 11-03-0940-04-000n-tgn-channel-models
Bypass	Identity matrix or butler matrix	
Doppler Spectrum	Classical Jakes, Bell shaped, Bell + Spike (802.11n)	
Fading	Rayleigh, Ricean	

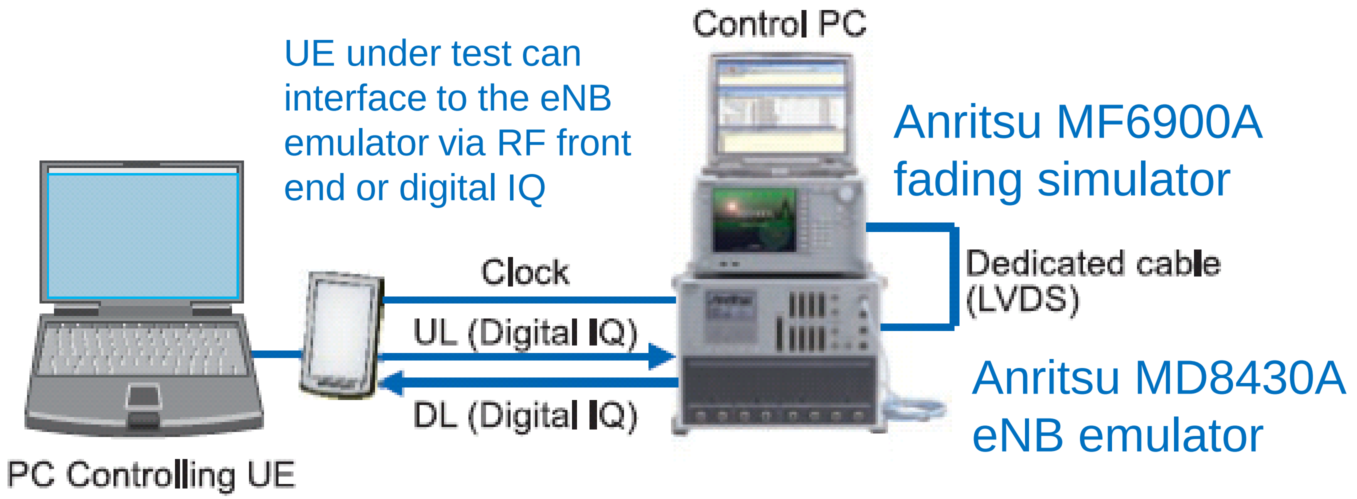
Agenda

- The ‘G’s – brief history of wireless
- Standards organizations
  - 3GPP, ITU, GCF, PTCRB
- Introduction to LTE
  - OFDMA, SC-OFDM
  - MIMO / Multiple antenna techniques
  - UE (user equipment) categories
  - FDD, TDD, channelization
- Fading and multipath in the wireless channel
  - Standard channel models
- Test methods
  - R&D, certification, production

3GPP	3rd Generation Partnership Project
ITU	International Telecommunication Union
GCF	Global Certification Forum
PTCRB	PCS Type Certification Review Board

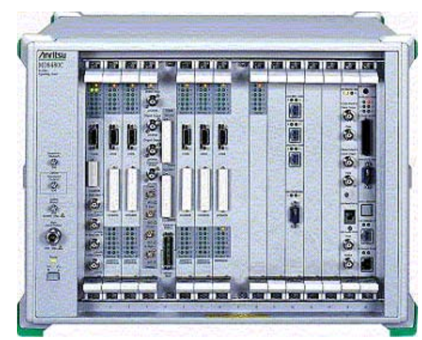
Typical UE Test Configuration

- Typical UE test configuration for a variety of tests, including:
  - R&D
  - IOT (interoperability)
  - PCT (protocol conformance test)
- … incorporates a base station emulator and a fading channel simulator



Base Station Emulator Requirements

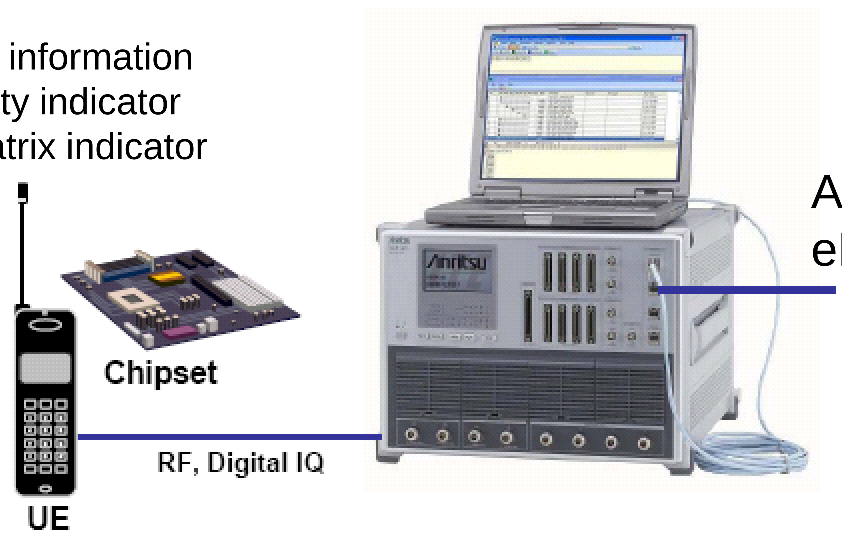
- Support 2G, 3G and 4G to test multi-mode UEs
  - GSM/GPRS/E-GPRS; W-CDMA/HSxPA; LTE
  - HSDPA up to 28 Mbps; HSUPA up to 11.5 Mbps for Release 7; provide upgrade path to Release 8
  - LTE Category 3 support for 100/50 Mbps (DL/UL) is important today; Category 4 support is desirable
  - FDD and TDD support
  - Frequency range should accommodate all common channels
- Support 2x2 MIMO handover between 3G and 4G



Dynamic Multi Base Station Tests

- Some eNB emulators can emulate multiple logical eNBs
  - E.g. Anritsu MD8430A can emulate 6 Cells
- Emulated eNB should be able to react to CSI from the UE (CQI, PMI and RI) to adjust MAC scheduling, including RBs, modulation and multiple antenna configurations.

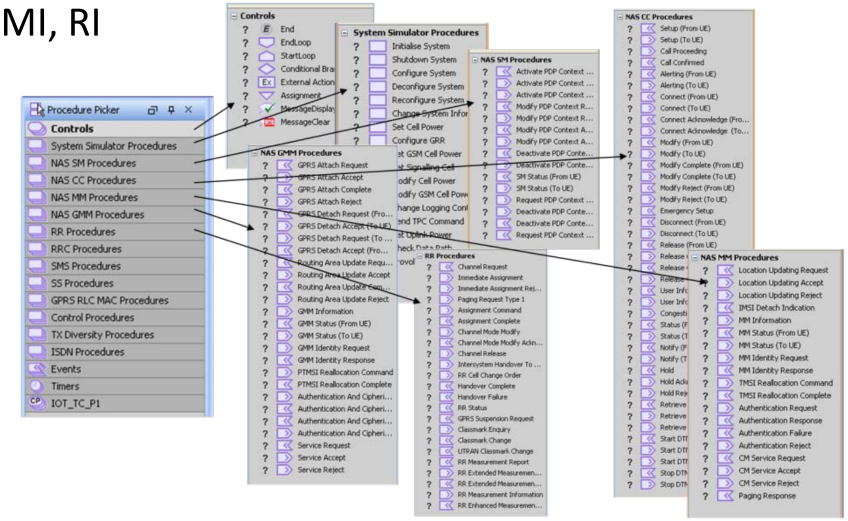
CSI = channel state information
CQI = channel quality indicator
PMI = precoding matrix indicator
RI = rank indicator



Anritsu MD8430A
eNB emulator

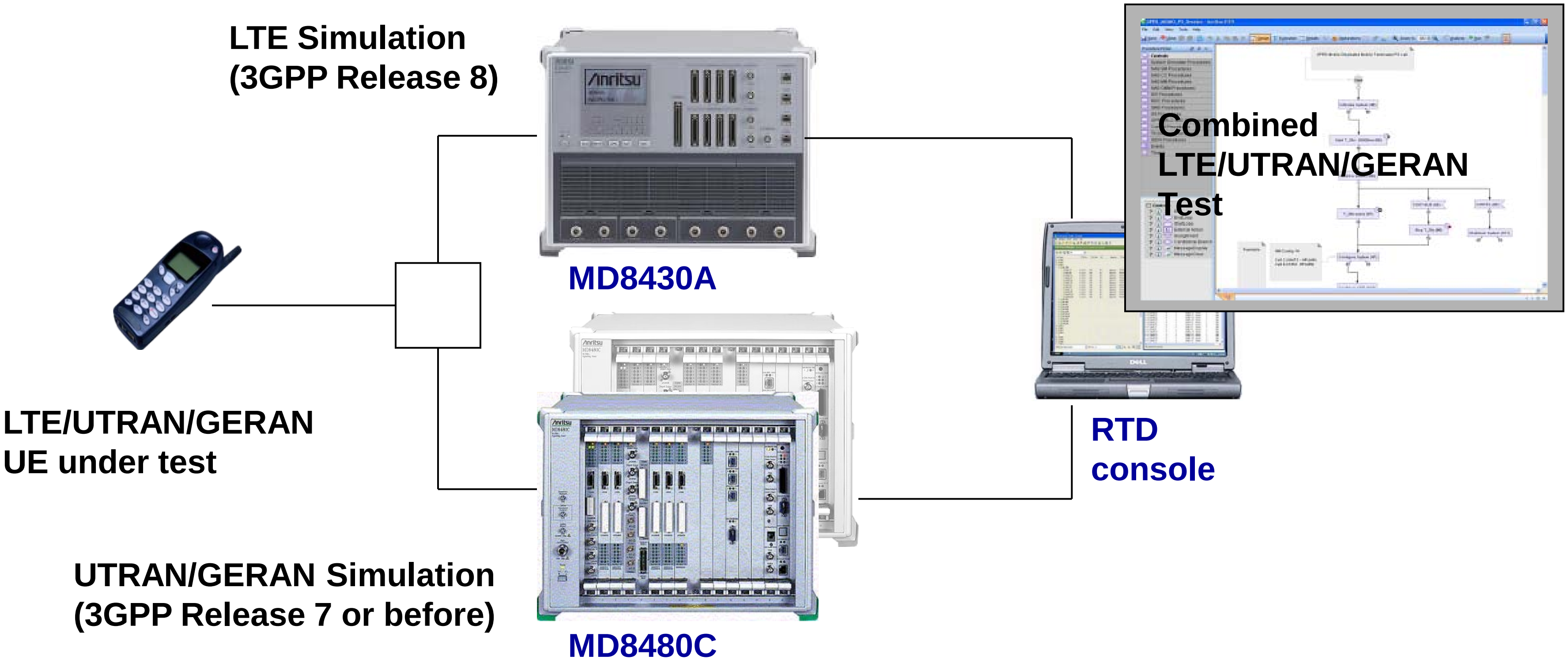
LTE UE Tests

- LTE UE testing includes a large number of test configurations. Configurations should include support for:
  - 5, 10, 15 and 20 MHz bands
  - UE categories 1-4
  - Up to 2x2 MIMO
  - Periodic, aperiodic and closed loop CQI, PMI, RI
  - Variety of handover scenarios
  - UL sequence and frequency hopping
  - All the required DCI formats
  - DL distributed VRB (virtual RB)
  - MU-MIMO
  - Scheduling
  - TTI bundling
  - HARQ



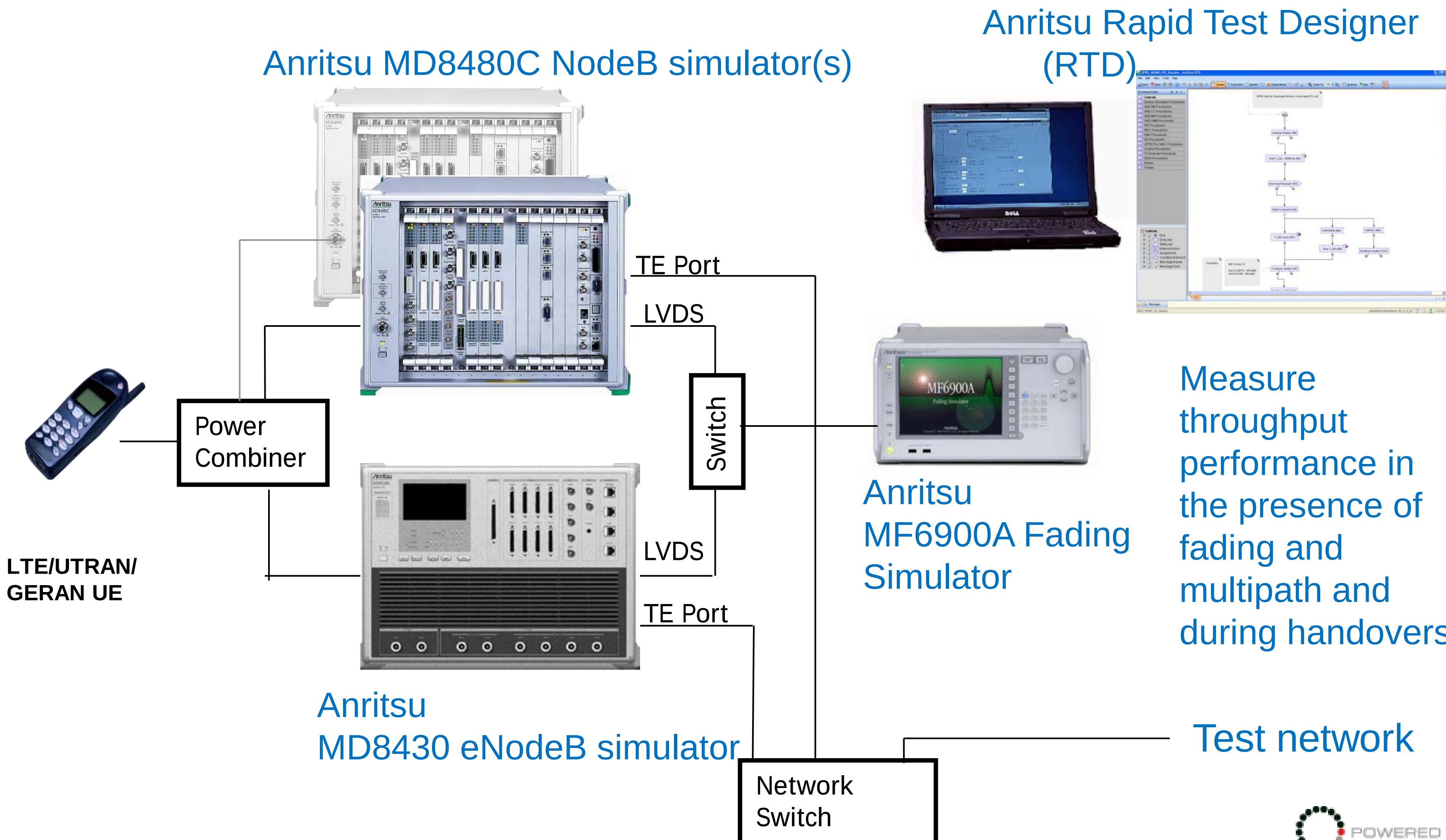
- The above are just examples. Total number of features and configurations is extremely large due to the considerable complexity of the LTE standards.

Handover Testing

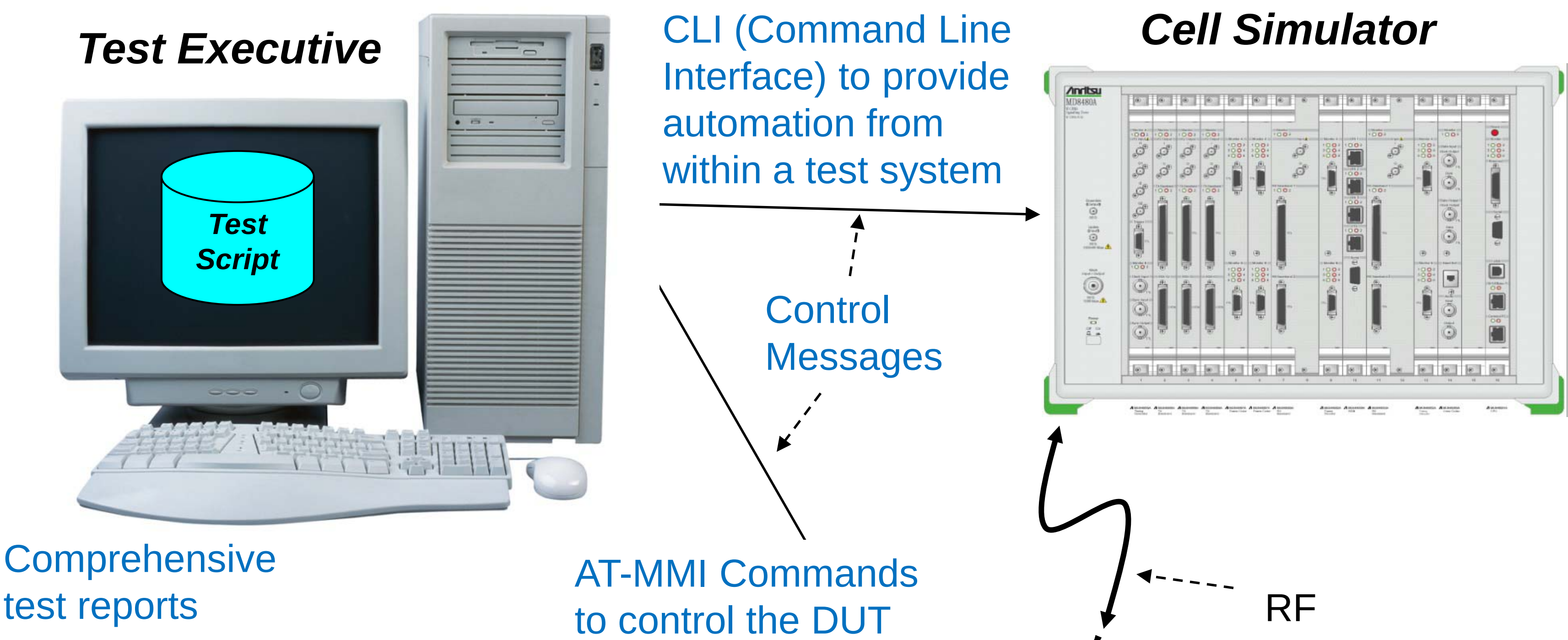


- Base station emulators, such as Anritsu MD8430A (LTE) or MD8480C (3G) are used with automated software, such as RTD to set up the conditions for inter-RAT or intra-RAT handover and verify UE behavior in a variety of handover scenarios and channel conditions

Complete System Test



Test Automation



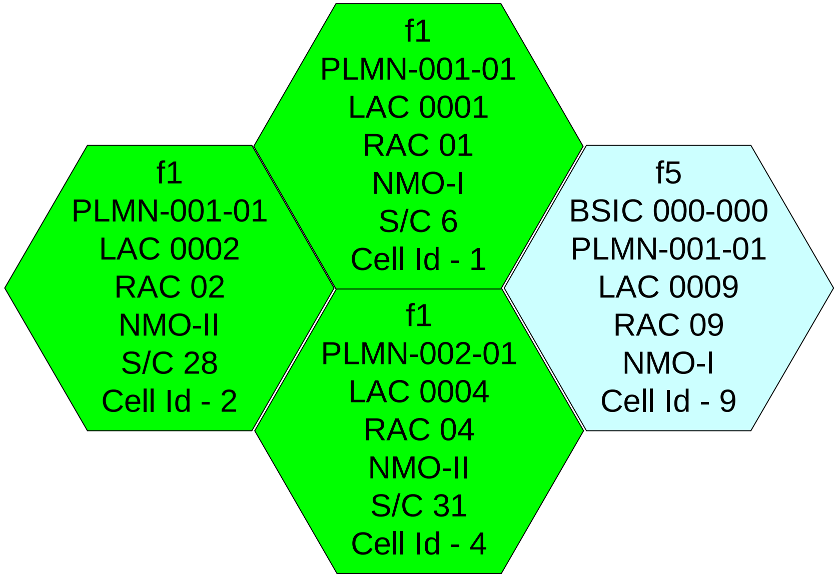
- Powerful test automation is critical due to complexity of test and the number of test cases.
- Meet 3GPP TS 27.007

AT = ATtention
MMI = Man-Machine Interface

Network Model

- Base station emulation equipment should be configurable to a variety of network models, including:
  - Individual cell definitions with cell-specific parameters
  - Definition for groups of cells with inter-dependent parameters

Network model example

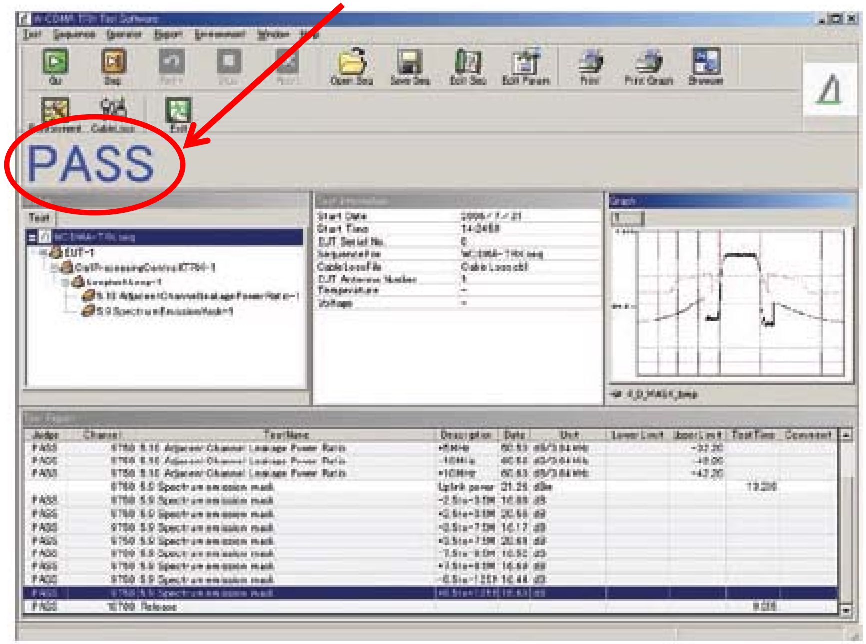


3 Cell UMTS (Intra-Frequency) + 1 Cell GSM

Conformance Testing

- Conformance test system should
  - Support the GCF and PTCRB requirements for conformance testing and offer pre-programmed GCF/PTCRB approved test cases
  - Come preconfigured with various instruments and dedicated software implementing the test suites
  - Support automated sequencing of tests, allowing long measurements to run unattended

Pass/Fail indicators

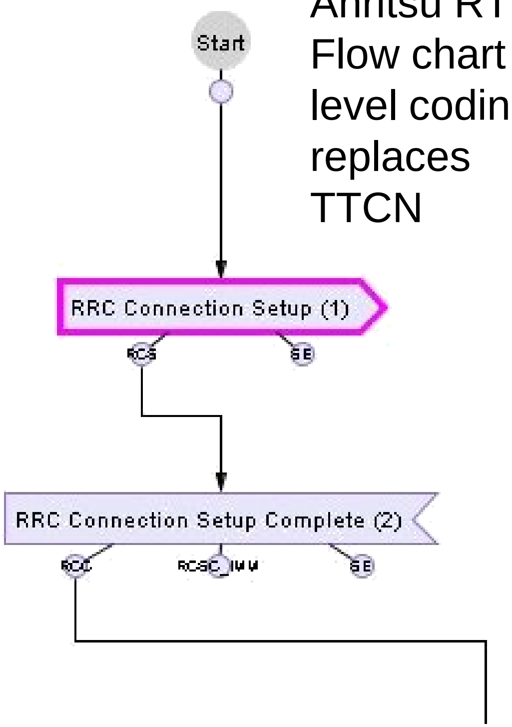


PTCRB (PCS Type Certification Review Board) is a similar test system certification organization to GCF composed mainly of North American members and performing conformance certification for frequency bands used in North America

GCF (Global Certification Forum) is responsible for certifying conformance to standards for UE and test systems. GCF is composed mainly of European members and performs certification for frequency bands used in Europe.

Test Complexity and Need for Test Automation

- Enormous complexity of 3GPP protocol testing calls for test automation.
- The best automation tools are expert systems, incorporating high level calls to detailed test cases and guiding the user through the complexity of the LTE protocol
  - Should not require knowledge of TTCN
  - Should provide expedient programming of emulation (base station and fading channel emulators) and measurement instruments (signal generators and signal analyzers)

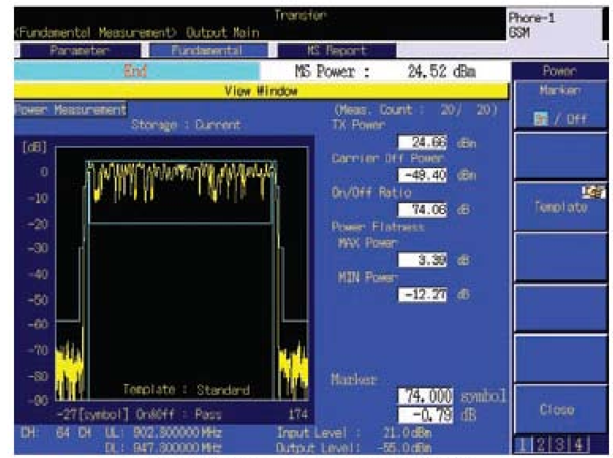


Anritsu RTD Flow chart level coding replaces TTCN

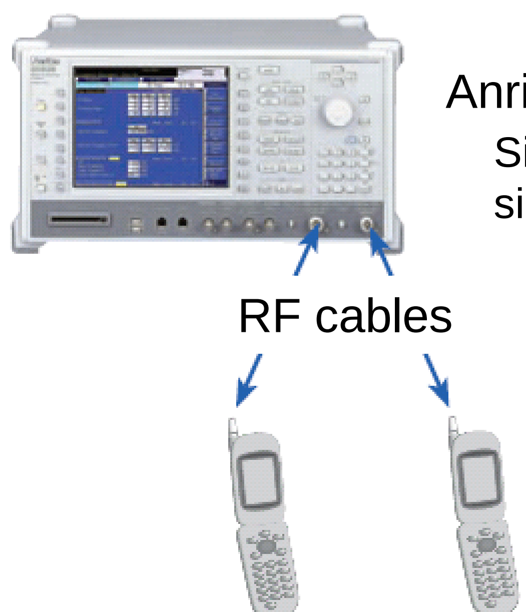
RTD = Rapid Test Designer
TTCN = Testing and Test Control Notation version

Production Testing of UE

- Speed and accuracy are key for production test
- Focus is on transmitter and receiver tests
  - RF adjustments and parametric tests using the test mode of the DUT
- Ability to test two UEs in parallel improves manufacturing efficiency and reduces production costs



Burst Waveform Display (8PSK)



Anritsu MT8820B

Signal generator and signal analyzer

Concluding Thoughts

- LTE standards and technology incorporate the latest innovations in wireless communications, including
  - OFDMA
  - MIMO
  - Dynamic resource allocation, antenna configurations and other settings
  - Channel width flexibility
  - Mobility management
  - Low latency IP networking
  - Backwards compatibility
- As a result, the LTE standards are extremely complex.
- **Complex technology does not work well unless it is well-tested.**

Thorough testing is key to making LTE successful in the market.

Learn More

- For more valuable LTE information, download Anritsu's newly released [LTE Resource Guide and White Paper]
  - http://www.anritsuco.com/LTE/offers.htm?utm_source=TechOnline&utm_medium=eCourse&utm_campaign=TechOnline%2BFundamentals%20Nov%202009

- Visit us on the web at www.anritsu.com

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