LTE technology introduction
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UMTS / WCDMA today

UMTS = Universal Mobile Telecommunications System
WCDMA = Wideband Code Division Multiple Access

- 140 WCDMA networks launched commercially worldwide*
- 120 million WCDMA subscribers worldwide as of Mar 2006*
- Services: video telephony, video streaming, mobile TV, mobile e-mail,…
- Challenges:
  - Continuously improved end-user experience
  - Improved speed, service attractiveness, service interaction
  - Long-term 3G competitiveness

*Source: www.umts-forum.org
UMTS/HSPA voice and data traffic

How the data traffic will develop in the next years?

Source: Peter Rysavy, 3G Americas
Data traffic growth forecast

Hypothesis
Today's (air interface and) core network might not be able to handle the forecasted data traffic!?
Why LTE?

- Further demand for higher data rates (peak and average) and a significant decrease of latency,
- How this can be achieved?
  - Re-use of features like CQI, adaptive modulation and coding, HARQ,
  - Using higher bandwidths, but flexible and scalable, only possible by using another transmission scheme,
  - Further latency reduction with simpler and flatter network architecture,
  - Cost efficiency
    - Affordable roll-out costs (CAPEX$^1$), low maintenance cost (OPEX$^2$),
  - Worldwide network operator commitments for LTE,
Ambitious targets with LTE

- Significantly increased peak data rate, e.g. 100 Mbps (downlink) and 50 Mbps (uplink),
- Significantly improved spectrum efficiency, e.g. 2-4 times compared to 3GPP Release 6,
- Improved latency,
  - Radio access network latency (user plane Network Þ UE) below 30 ms,
  - Significantly reduced control plane latency, e.g. idle to active <100 ms,
- Scaleable bandwidth,
  - 5, 10, 15, 20 MHz,
  - Smaller bandwidths to allow flexibility in narrow spectral allocations,
- Support for inter-working with existing 3G systems and non-3GPP specified systems,
- Reduced CAPEX\(^1\) and OPEX\(^2\) including backhaul,
- Cost effective migration from release 6 UTRA radio interface and architecture,
- Efficient support of the various types of services, especially from the PS domain
- System should be optimized for low mobile speed but also support high mobile speed
- Operation in paired and unpaired spectrum should not be precluded (FDD and TDD modes)
- Enhanced Multimedia Broadcast Multicast Services (E-MBMS)

\(^1\) CApital Expenditures \(^2\) OPerational Expenditure
Don’t get confused…
**LTE = EUTRA(N) = Super3G = 3.9G**

1. **EUTRA(N) = Evolved UMTS Terrestrial Radio Access (Network)**
   - Used within 3GPP for LTE technology / network, like UTRA FDD and UTRA TDD is used within 3GPP for 3G/UMTS

2. **Super3G**
   - Is referring to LTE, like WCDMA is referring to UTRA FDD and TDD

3. **3.9G**
   - Used to indicate that LTE is *not* 4G, since the requirements for 4G are set by ITU / IMT-advanced, where 3GPP will approach these requirements with LTE-Advanced
## LTE Key Parameter

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>UMTS FDD bands and UMTS TDD bands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel bandwidth</td>
<td>1.4 MHz</td>
</tr>
<tr>
<td>1 Resource Block (RB)</td>
<td>6 RB</td>
</tr>
<tr>
<td><strong>Modulation Schemes</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Downlink</strong></td>
<td>QPSK, 16QAM, 64QAM</td>
</tr>
<tr>
<td><strong>Uplink</strong></td>
<td>QPSK, 16QAM, 64QAM (optional for handset)</td>
</tr>
<tr>
<td><strong>Multiple Access</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Downlink</strong></td>
<td>OFDMA (Orthogonal Frequency Division Multiple Access)</td>
</tr>
<tr>
<td><strong>Uplink</strong></td>
<td>SC-FDMA (Single Carrier Frequency Division Multiple Access)</td>
</tr>
<tr>
<td><strong>MIMO technology</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Downlink</strong></td>
<td>Wide choice of MIMO configuration options for transmit diversity, spatial multiplexing, and cyclic delay diversity (max. 4 antennas at base station and handset)</td>
</tr>
<tr>
<td><strong>Uplink</strong></td>
<td>Multi-user collaborative MIMO</td>
</tr>
<tr>
<td><strong>Peak Data Rate</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Downlink</strong></td>
<td>150 Mbps (UE category 4, 2x2 MIMO, 20 MHz)</td>
</tr>
<tr>
<td></td>
<td>300 Mbps (UE category 5, 4x4 MIMO, 20 MHz)</td>
</tr>
<tr>
<td><strong>Uplink</strong></td>
<td>75 Mbps (20 MHz)</td>
</tr>
</tbody>
</table>
## LTE UE categories (downlink and uplink)

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

~300 Mbps peak DL data rate for 4x4 MIMO

~150 Mbps peak DL data rate for 2x2 MIMO

### UL-SCH transport block bits received a TTI

<table>
<thead>
<tr>
<th>UE category</th>
<th>Maximum number of UL-SCH transport block bits received within TTI</th>
<th>Support 64QAM in UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5160</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>25456</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>51024</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>51024</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>75376</td>
<td>Yes</td>
</tr>
</tbody>
</table>

~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
Spectrum flexibility

- LTE physical layer (FDD/TDD) supports any bandwidth from 1.4 to 20 MHz.
- Current LTE specification supports a subset of 6 different system bandwidths.
- All UE’s must support the maximum bandwidth of 20 MHz.

<table>
<thead>
<tr>
<th>Channel bandwidth BW_{\text{Channel}} [MHz]</th>
<th>1.4</th>
<th>3</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of resource blocks</td>
<td>6</td>
<td>15</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>

Channel Bandwidth [MHz]

Transmission Bandwidth Configuration [RB]

Active Resource Blocks

DC carrier (downlink only)
Deployment scenarios for LTE

LTE will use same frequency bands as 3G,
- Current 3G frequency blocks, licensed by operators in various countries provide not enough bandwidth, for example in Europe/USA, or a continuous frequency range, for example USA, to roll-out LTE and use the full capacity,

New frequency ranges will be used to use full capacity of LTE,
- Asia/Europe\(^1\) 2.5 to 2.7 GHz,
- USA\(^2\) 700 MHz Band,
- Inter-working between WCDMA/HSPA, CDMA2000 1xRTT/1xEV-DO and GSM/EDGE is considered and currently specified,

\(^1\) Auction in Norway, Sweden happened, Austria, Hong Kong, Netherlands Q1/2009, Germany, UK probably Q2/2009, Spain, Portugal probably Q4/2009, Italy, France probably Q1/2010
\(^2\) Auction happened, spectrum available in February 2009
What is OFDM basically?

Orthogonal Frequency Division Multiplex (OFDM) is a multi-carrier transmission technique, which divides the available spectrum into many subcarriers, each one being modulated by a low data rate stream,

Single Carrier Transmission (e.g. WCDMA)

(Orthogonal ) Frequency Division Multiplexing ((O)FDM)

Typically several 100 sub-carriers with spacing of x kHz

e.g. 5 MHz
OFDM Summary
Advantages and disadvantages

- High spectral efficiency due to efficient use of available bandwidth,
  - Scalable bandwidths and data rates,
- Robust against narrow-band co-channel interference, Intersymbol Interference (ISI) and fading caused by multipath propagation,
- Can easily adapt to severe channel conditions without complex equalization
  - 1-tap equalization in frequency domain,
- Low sensitivity to time synchronization errors,

- Very sensitive to frequency synchronization,
  - Phase noise, frequency and clock offset,
- Sensitive to Doppler shift,
- Guard interval required to minimize effects of ISI and ICI,
- High peak-to-average power ratio (PAPR), due to the independent phases of the sub-carriers mean that they will often combine constructively,
  - High-resolution DAC and ADC required,
- Requiring linear transmitter circuitry, which suffers from poor power efficiency,
  - Any non-linearity will cause intermodulation distortion raising phase noise, causing Inter-Carrier Interference (ICI) and out-of-band spurious radiation.
LTE Physical Layer Concepts
OFDMA in the Downlink
Difference between OFDM and OFDMA

- OFDM allocates user just in time domain,
- OFDMA allocates user in time and frequency domain,
## Downlink physical channels and signals

### LTE Downlink Physical Signals

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary and Secondary Synchronization Signal</td>
<td>Provide acquisition of cell timing and identity during cell search</td>
</tr>
<tr>
<td>Downlink Reference Signal</td>
<td>Cell search, initial acquisition, coherent demod., channel estimation</td>
</tr>
</tbody>
</table>

### LTE Downlink Physical Channels

<table>
<thead>
<tr>
<th>Channel Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Broadcast Channel (PBCH)</td>
<td>Provides essential system information e.g. system bandwidth</td>
</tr>
<tr>
<td>Physical Control Format Indicator Channel (PCFICH)</td>
<td>Indicates format of PDCCH (CFI)</td>
</tr>
<tr>
<td>Physical Downlink Control Channel (PDCCH)</td>
<td>Carries control information (DCI = Downlink Control Information)</td>
</tr>
<tr>
<td>Physical Downlink Shared Channel (PDSCH)</td>
<td>Carries data (user data, system information, ...)</td>
</tr>
<tr>
<td>Physical Hybrid ARQ Indicator Channel (PHICH)</td>
<td>Carries ACK/NACK (HI = HARQ indicator) for uplink data packets</td>
</tr>
<tr>
<td>Physical Multicast Channel (PMCH)</td>
<td>Carries MBMS user data</td>
</tr>
</tbody>
</table>
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,
How to derive information in LTE?

Check the **PDCCH** for an unique **IDENTITY**\(^1\). As soon as you have found it, you will get all the information you need there.

---

Physical Downlink Control Channel (PDCCH)

I would like to read the **PDSCH** but I don't know which resources are allocated for the transport of system or paging information or data and how they look like?

---

\(^1\) 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 MAC Protocol Specification.
Indicating PDCCH format

Check **PCFICH**! It will tell you how many symbols (1, 2, 3 (or 4)) in the beginning of each subframe are allocated for **PDCCH**!

**Physical Control Format Indicator Channel (PCFICH)**

**Physical Downlink Control Channel (PDCCH)**

I would like to read the **PDCCH** but where is it?
Resource Allocation

- Smallest resource unit is Resource Element, which is 1 symbol on 1 subcarrier.
- But minimum allocation for transmission is a Resource Block (RB).
- 1 RB spans 12 sub-carriers (12*15 kHz = 180 kHz) in the frequency domain and 1 Time Slot (= 0.5 ms) in the time domain,
  - 10 MHz = 50 RB ⇒ 50 RB*180 kHz = 9.0 MHz + 1 unused DC subcarrier (= fCarrier) = 9.015 MHz
  - TTI is 1 subframe, which is 2 time slots,
  - With normal (extended) cyclic prefix (CP) we got 7 (6) OFDM symbols per time slot,

<table>
<thead>
<tr>
<th>Configuration</th>
<th>OFDM Symbols</th>
<th>Sub-carrier</th>
<th>Cyclic Prefix Length in Samples</th>
<th>Cyclic Prefix Length in μs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal CP</td>
<td>7</td>
<td>12</td>
<td>160 for 1st symbol 144 for other symbols</td>
<td>5.2 for 1st symbol 4.7 for other symbols</td>
</tr>
<tr>
<td>Extended CP</td>
<td>6</td>
<td>12</td>
<td>512</td>
<td>16.7</td>
</tr>
<tr>
<td>Extended CP</td>
<td>3</td>
<td>3</td>
<td>33.3</td>
<td></td>
</tr>
</tbody>
</table>

MBMS Scenario
LTE frame structure type 1 (FDD), downlink

1 radio frame = 10 ms
1 slot = 0.5 ms
1 subframe = 1 ms

L1/2 downlink control channels
User data allocations
Downlink reference signal

Screenshot of R&S SMU200A signal generator

ROHDE & SCHWARZ
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LTE frame structure type 2 (TDD)

1 radio frame = 10 ms

- 1 slot = 0.5 ms
- 1 subframe = 1 ms

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):

<table>
<thead>
<tr>
<th>Uplink-downlink configuration</th>
<th>Downlink-to-Uplink Switch-point periodicity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>D</td>
</tr>
<tr>
<td>1</td>
<td>D</td>
</tr>
<tr>
<td>2</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
</tr>
</tbody>
</table>

Screenshot of R&S SMU200A signal generator
LTE Physical Layer Concepts
SC-FDMA in the Uplink
How to generate a 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 parameterization (FDD and TDD)

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

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Number SC-FDMA Symbols</th>
<th>Number of Subcarrier</th>
<th>Cyclic Prefix Length in Samples</th>
<th>Cyclic Prefix Length in μs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal CP $\Delta f = 15$ kHz</td>
<td>7</td>
<td>12</td>
<td>160 for 1st symbol 144 for other symbols</td>
<td>5.2 for 1st symbol 4.7 for other symbols</td>
</tr>
<tr>
<td>Extended CP $\Delta f = 15$ kHz</td>
<td>6</td>
<td></td>
<td>512</td>
<td>16.7</td>
</tr>
</tbody>
</table>

**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,
Uplink physical channels and signals

<table>
<thead>
<tr>
<th>LTE Uplink Physical Channels</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Uplink Shared Channel (PUSCH)</td>
<td>Carries user data</td>
</tr>
<tr>
<td>Physical Uplink Control Channel (PUCCH)</td>
<td>Carries control information (UCI = Uplink Control Information)</td>
</tr>
<tr>
<td>Physical Random Access Channel (PRACH)</td>
<td>Preamble transmission for initial access</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LTE Uplink Physical Signals</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Demodulation Reference Signal (DRS)</td>
<td>Enables channel estimation and data demodulation</td>
</tr>
<tr>
<td>Sounding Reference Signal (SRS)</td>
<td>Enables uplink channel quality evaluation</td>
</tr>
</tbody>
</table>
I would like to send data on PUSCH but I don’t know which resource blocks and transport formats I can use?

Physical Downlink Control Channel (PDCCH)

Check PDCCH for your UE ID. As soon as you are addressed, you will find your uplink scheduling grants there.

Physical Uplink Shared Channel (PUSCH)

(QPSK, 16QAM modulated, 64QAM is optional for the UE)
**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 4\textsuperscript{th} 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),

![Screenshot of R&S® SMU200A Vector Signal Generator](image-url)
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,
LTE MIMO
MIMO?

- **MIMO** = Multiple Input Multiple Output
- Refers to the use of multiple antennas at transmitter and/or receiver side
- Requirement of 100 Mbps peak downlink data rate
  => MIMO urgently needed in LTE
Topics related to MIMO in LTE

- Classical configuration with 2 Tx and 2Rx antennas
- Scenarios with 4 Tx antennas are also supported
- Modes of operation of multiple transmit antennas:
  - Spatial multiplexing (linear codebook-based precoding)
  - Beamforming
  - Single stream transmit diversity
- Single User - MIMO and Multiple User - MIMO systems are supported
- Multiple codeword (MCW) transmission is agreed for the SU-MIMO
MIMO in LTE

- Requirement of 100 Mbps peak downlink data rate
  => MIMO urgently needed in LTE
- Configuration with 2 Tx and 2 Rx antennas
- Scenarios with 4 Tx antennas also supported
- Modes of operation of multiple transmit antennas:
  - Open or closed loop spatial multiplexing
  - Single stream transmit diversity
  - Beamforming
- Single User - MIMO and Multiple User - MIMO systems are supported
MIMO modes

- **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**
Increasing data rate with spatial multiplexing

original
TX
RX

\[ h_{ij} = \text{channel coefficients in time domain from Tx antenna } j \text{ to Rx antenna } i \]

\[ H = \begin{bmatrix}
  h_{11} & h_{12} & \ldots & h_{1Nr} \\
  h_{21} & h_{22} & \ldots & h_{2Nr} \\
  \vdots & \ddots & \ddots & \vdots \\
  h_{Nr1} & h_{Nr2} & \ldots & h_{NrNt}
\end{bmatrix} \]

\( N_t \) antennas at node B
\( N_r \) antennas at UE

010110
010110
010110
010110

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Downlink spatial multiplexing - precoding

- The signal is “pre-coded” at Node B side before transmission

- Optimum precoding matrix is selected from predefined “codebook” known at Node B and UE side

- UE estimates the channel, selects the best precoding matrix at the moment and sends back its index
SU-MIMO versus MU-MIMO

**SU (Single User)-MIMO**
- Goal: to increase user data rate
- Simultaneous transmission of different data streams to 1 user
- Efficient when the user experiences good channel conditions

**MU (Multiple User)-MIMO**
- Goal: to increase sector capacity
- Selection of the users experiencing good channel conditions
- Efficient when a large number of users have an active data transmission simultaneously
Beamforming

1. Smart antennas are divided into two groups:
   - Phased array systems (switched beamforming) with a finite number of fixed predefined patterns
   - Adaptive array systems (AAS) (adaptive beamforming) with an infinite number of patterns adjusted to the scenario in realtime

*Figure 10: Switched beamformer and adaptive beamformer*
# MIMO in Radio Communications Systems

## MIMO implementation in standards

<table>
<thead>
<tr>
<th>MIMO Parameters in</th>
<th>Mobile WiMAX™</th>
<th>HSPA+</th>
<th>LTE</th>
<th>IEEE 802.11n</th>
<th>1xEV-DO Rev C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx Diversity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>DL Spatial Multiplexing</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>DL Beamforming</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>DL Precoding</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>DL Space Time Coding (STC) / DL Space Frequency Coding (SFC)</td>
<td>STC</td>
<td>SFC</td>
<td>STC</td>
<td>STC</td>
<td></td>
</tr>
<tr>
<td>UL Multi User MIMO / Collaborative MIMO</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>max Number of BS Antennas</td>
<td>2 (8 partly for Beamforming)</td>
<td>2 (4)</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>max Number of MS Antennas</td>
<td>2 (8 partly for Beamforming)</td>
<td>2</td>
<td>2 (4)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Implementation</td>
<td>mandatory</td>
<td>optional</td>
<td>mandatory</td>
<td>mandatory</td>
<td></td>
</tr>
</tbody>
</table>
MIMO and Fading

1. MIMO precoding

When testing MIMO receivers two major aspects need to be taken into account, the MIMO precoding and the channel simulation.
**Fading sources**

- **A**: free space
- **B**: reflection
  - (object is large compared to wavelength)
- **C**: diffraction
- **D**: scattering
  - (object is small or its surface irregular)
- **E**: shadowing
  - (birth death)
- **F**: doppler

![Diagram of fading sources]
MIMO receiver verification with R&S SMU200A

Code word and precoding selection for MIMO

MIMO Fading (R&S SMU-K74)
Signal Generation & MIMO Precoding
Supported Features in SMU/SMJ/SMATE/SMBV/AMU/AFQ

<table>
<thead>
<tr>
<th>Feature</th>
<th>mobile WiMAX IEEE 802.16e-2005 Option -K49/-K249</th>
<th>LTE (3GPP Release 8) Option -K55/-K255</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal generation (Pilots + Data)</td>
<td>Antenna 1 or 2</td>
<td>Antenna 1, 2, 3 or 4</td>
</tr>
<tr>
<td>TX Diversity coding (DL)</td>
<td>2 Tx, STC, Matrix A</td>
<td>2 or 4 Tx SFC</td>
</tr>
<tr>
<td>Spatial Multiplexing (DL)</td>
<td>2 Tx, Matrix B</td>
<td>2 or 4 Tx, Code Book (219 alternatives)</td>
</tr>
<tr>
<td>Collaborative / Virtual / Multi User MIMO (UL)</td>
<td>Yes, supported</td>
<td>Yes, supported</td>
</tr>
</tbody>
</table>

LTE with MIMO precoding available
Downlink MIMO receiver verification
Configuring MIMO mode and precoding

1. MIMO data precoding per allocation

![Screenshot of R&S SMU200A](attachment:image.png)
LTE MIMO channel model supported

- Particularly relevant for receiver performance tests
- Extension to traditional ITU fading models (tapped delay line) required to cover higher bandwidths of LTE and MIMO operation
- Propagation conditions agreed in 3GPP for:
  - Extended pedestrian A (EPA)
  - Extended vehicular A model (EVA)
  - Extended Typical Urban model (ETU)
- Definition of delay profile, Doppler spectrum and set of correlation matrices describing correlation between UE and BS antennas
Unique LTE/MIMO signal generation solution

**R&S® SMU200A**
- Vector signal generator
- LTE signal generation
- Dual channel baseband + RF
- Fading + AWGN simulator option
- 2x2 MIMO option K74

**R&S® AMU200A**
- Baseband signal generator
- LTE signal generation
- Stand-alone baseband fading + AWGN simulator
- Dual channel baseband in/out
- 2x2 MIMO option K74
Measurement Real-time MIMO fading up to 4 x 2 and 2 x 4

1. 4 x 2 MIMO up to 3 GHz using two SMU200A. Each of the four basebands represents one transmit antenna. The two receive antennas are represented by combining the first RF outputs of both SMU200A and the second RF outputs of both SMU200A by RF combiners respectively. By doing so, all eight possible fading channels of a 4 x 2 MIMO setup can be simulated.

2. Minimum instrument configuration:
   - Both SMU200A need the same options as described above for the 2 x 2 MIMO case.
LTE MIMO analysis (Software Option FSQ-K102)

- Supports 2x2 and 4x4 MIMO
- Supports Transmitt Diversity
- Supports Spacial multiplexing
- Supports Cyclic delay diversity
- Measurements are possible on single antennas or combined
LTE MIMO analysis
MIMO transmitter tests on multiple antennas

Precoded MIMO Signal

DUT
LTE RF Testing Aspects
UE/BS requirements according to 3GPP

**Transmitter Characteristics:**
- Transmit power
- Frequency error
- Output power dynamics
- Output RF spectrum emissions
- Transmit intermodulation
- Modulation quality, Error Vector Magnitude
- ...

**Receiver characteristics:**
- Reference sensitivity level
- UE maximum input level
- Adjacent channel selectivity
- Blocking characteristics
- Intermodulation characteristics
- Spurious emissions
- ...

**Performance requirements**

Currently captured in
TR 36.803: User Equipment (UE) radio transmission and reception
TR 36.804: Base Station (BS) radio transmission and reception
R&S LTE Portfolio for base station and network testing

**Development of Tx/Rx Modules, Amplifiers, RF Components**
- **NodeB Layer 1 / RF Testing**
  - Signal Generator / Fading Simulator
    - SMU200A, AMU200A
    - SMBV100A, ...
  - Signal Analyzer
    - FSQ, FSG, FSV

**NodeB Test Lab**
- Signal Generator / Fading Simulator / Signal Analyzer
- FSH handheld spectrum analyzer
- Radio coverage measurements

**Network Installation and Maintenance / Network Engineering**
- FSH handheld spectrum analyzer
- Radio network analyzers incl. ROMES Drive Test Tools

**Production Testing**
- Signal Generator
- SMJ100A or SMBV100A
- Signal Analyzer
- FSV
Further information on Technologies:
http://www2.rohde-schwarz.com/en/technologies