LTE and the Evolution to LTE-Advanced Fundamentals - Part 2

Based on the 2nd Edition book

*LTE and the Evolution to 4G Wireless – Design and Measurement Challenges*

Jan Whitacre and Frank Palmer
Agilent Technologies
Agenda

• MIMO Concepts
• LTE-Advanced Major Features and Design Challenges
  – Carrier Aggregation
  – Enhanced Uplink Multiple Access (clustered SCFDMA)
  – High Order MIMO (8x8)
  – Other Study Items
• RF Conformance and Acceptance Testing
• Question and Answer
Multi-Antenna Techniques

Objective of Multiple Antennas: To increase coverage and physical layer capacity.

Three kinds of multiple-antenna applications:

• Path diversity
• Beamsteering
• Spatial multiplexing

Beamforming: Feedback of channel conditions is used to pre-code the signal.
System & Antenna Configurations, Terms

“Input” and “Output” Refer to the Channel

SISO

SIMO

MISO

MIMO

Spatial Multiplexing
More on MIMO

SIMO + MISO ≠ MIMO
Or
Transmit Diversity + Receive Diversity ≠ Spatial Multiplexing

• The I and O in MIMO refers to the channel from transmission to reception,
• Just because there is more than one antenna, doesn’t mean it’s MIMO
• Diversity can be combined with MIMO Spatial Multiplexing to improve performance
• For MIMO to work, the paths must be decorrelated.
• Layer: With spatial multiplexing, it is synonymous with a stream
How does MIMO work?

1: Consider a moment in time, at a single frequency, and model the channel as a box with fixed components inside:

```
A

Input

Z1

Z2

Z3

Z4

B

Output
```

If we add two completely different signals at A and B, they’ll get mixed together, but in a precisely defined way, dependant on the values of Z1- Z4

2: Send a training signal first, that’s unique to A and to B. Measure what comes out and therefore how they got coupled. [If you know how they get coupled, you can work out how to uncouple them]

3: Everything going into the box will be coupled the same way, so you apply what you found to the real data you want to sent
Single-User MIMO
Precoding or MIMO Beamforming

Base Station transmits multi-channel signal

Mobile measures channel as part of demodulation process
Does a best fit with agreed set of channels. Codes this information and transmits to Base Station

Base Station uses this to transform the signal to match the channel before transmission
LTE has seven different Downlink transmission modes:

1. Receive diversity - Basic SIMO
2. Transmit diversity - MISO
3. Open-loop SU-MIMO - no precoding
4. Closed-loop SU-MIMO - with precoding
5. Multi-user MIMO Uses separate UEs
6. Closed-loop beamsteering
7. UE Specific RS beamforming
Transmission Modes 3, 4 and 5

**Single User MIMO**

3. **Open Loop**
   - *Used when conditions are changing too rapidly*

4. **Closed Loop**
   - *Uses Precoding*

5. **Multi-User MIMO**
   - *Doesn’t increase data rate but increases capacity of the cell*
MIMO Design Issues

TRANSMITTER

• Cross Coupling through power supplies, poor grounding etc – Requires analyzer to pick out the right signal and look at power characteristics
• It gets worse for picocells & femtocells
• Signal Coding Verification – Need the analyzer to figure out what all the signals are before making measurements.
• Distortion in Power Amplifiers – Needs out of band spectrum measurements.

RECEIVER

• Receiver needs to differentiate/recover simultaneous multiple signals – Requires a wide range of test conditions/scenarios
• Need to adequately stress amplifiers, I/Q modulators, filters, etc – Need to simulate real-world signals including fading
• Receivers must deal with complex interference – Need to provide the ability to add impairments to the test signals.
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## UMTS Long Term Evolution

<table>
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<tr>
<th>Release</th>
<th>Stage 3: Core specs complete</th>
<th>Main feature of Release</th>
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<tr>
<td>Rel-99</td>
<td>March 2000</td>
<td>UMTS 3.84 Mcps (W-CDMA FDD &amp; TDD)</td>
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<td>Rel-4</td>
<td>March 2001</td>
<td>1.28 Mcps TDD (aka TD-SCDMA)</td>
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<td>Rel-5</td>
<td>June 2002</td>
<td>HSDPA</td>
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<td>Rel-6</td>
<td>March 2005</td>
<td>HSUPA (E-DCH)</td>
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<td>Rel-7</td>
<td>Dec 2007</td>
<td>HSPA+ (64QAM DL, MIMO, 16QAM UL). LTE &amp; SAE Feasibility Study, Edge Evolution</td>
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</table>
| Rel-8   | Dec 2008                    | LTE Work item – OFDMA air interface  
SAE Work item – New IP core network  
UMTS Femtocells, Dual Carrier HSDPA |
| Rel-9   | Dec 2009                    | Multi-standard Radio (MSR), Dual Carrier HSUPA, Dual Band HSDPA, SON, LTE Femtocells (HeNB)  
LTE-Advanced feasibility study, MBSFN |
| Rel-10  | March 2011                  | LTE-Advanced (4G) work item, CoMP Study  
Four carrier HSDPA, eICIC |
| Rel-11  | Sept 2012                   | CoMP, eDL MIMO, eCA, MIMO OTA, HSUPA TxD & 64QAM MIMO, HSDPA 8C & 4x4 MIMO, MB MSR |
| Rel-12  | March 2013 stage 1          | New carrier type, LTE-Direct, Active Antenna Systems |
Where to find more on LTE-Advanced

• LTE-Advanced is a subset of Release 10

• A comprehensive summary of the entire LTE-Advanced proposals including radio, network and system can be found in the 3GPP submissions to the first IMT-Advanced evaluation workshop.


• Historical documents:
  Study Item RP-080599
  Requirements TR 36.913 v9.0.0 (2009-12)
  Study Phase Technical Report TR 36.912 v9.3.0 (2010-06)

• The LTE-A specifications are drafted in the Release 10 specifications  ftp.3gpp.org/specs/latest/Rel-10/
## Comparing LTE, LTE-Advanced and IMT-Advanced Requirements

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<td>3GPP Release 10</td>
<td>International Telecommunications Union “True 4G”</td>
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<td><strong>Peak Data Rate</strong></td>
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<td>DL</td>
<td>300 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps (high mobility) 1 Gbps (low mobility)</td>
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<td>UL</td>
<td>75 Mbps</td>
<td>500 Mbps</td>
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<td><strong>Peak Spectrum Efficiency [bps/Hz]</strong></td>
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<td>30</td>
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<td>UL</td>
<td>3.75</td>
<td>15</td>
<td>6.75</td>
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<td><strong>Tx Bandwidth</strong></td>
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<td></td>
<td>20 MHz</td>
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LTE-Advanced and Beyond Features

1. Carrier aggregation
2. Enhanced uplink multiple access
   a) Clustered SC-FDMA
   b) Simultaneous Control and Data
3. Enhanced multiple antenna transmission
   a) Downlink 8 antennas, 8 streams
   b) Uplink 4 antennas, 4 streams
4. Heterogeneous network support
5. Coordinated Multipoint (CoMP)
6. Relaying
7. Home eNB mobility enhancements
8. Customer Premises Equipment
9. Self Optimizing networks (SON)

Rel-10 LTE-A

Other Rel-10 and beyond

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1. What is Carrier Aggregation?

- Extends the maximum transmission bandwidth, up to 100 MHz, by aggregating up to five LTE carriers – also known as component carriers (CCs).
- Lack of sufficient contiguous spectrum forces use of carrier aggregation to meet peak data rate targets:
  - 1 Gbps in the downlink and 500 Mbps in the uplink.
- Motivation:
  - Achieve wide bandwidth transmissions
  - Facilitate efficient use of fragmented spectrum
  - Efficient interference management for control channels in heterogeneous networks.
1. Carrier Aggregation Modes

Component Carrier (CC)—up to 20 MHz BW

- **Intra-band contiguous allocation**
- **Intra-band non-contiguous allocation**
- **Inter-band non-contiguous allocation**
1. Carrier Aggregation Band Combinations

• One of RAN WG4’s most intense activities is in the area of creating RF requirements for specific band combinations.

• In theory there could be as many as 5 carriers but so far all the activity is around dual carrier combinations

• The original CA work in Rel-10 was limited to three combinations

<table>
<thead>
<tr>
<th>Band</th>
<th>E-UTRA operating Band</th>
<th>Uplink (UL) band</th>
<th>Downlink (DL) band</th>
<th>Duplex mode</th>
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<tr>
<td></td>
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<td>UE transmit / BS receive</td>
<td>Channel BW MHz</td>
<td>UE receive / BS transmit</td>
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<tr>
<td></td>
<td></td>
<td>$F_{UL\text{low}}$ (MHz) – $F_{UL\text{high}}$ (MHz)</td>
<td></td>
<td>$F_{DL\text{low}}$ (MHz) – $F_{DL\text{high}}$ (MHz)</td>
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<td>5</td>
<td>824 – 849</td>
<td>[TBD]</td>
<td>869 – 894</td>
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<td>CA_3-7</td>
<td>3</td>
<td>1710 – 1788</td>
<td>20</td>
<td>1805 – 1880</td>
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<tr>
<td></td>
<td>7</td>
<td>2500 – 2570</td>
<td>20</td>
<td>2620 – 2690</td>
</tr>
</tbody>
</table>

• In Rel-11 there are now up to 18 CA combinations being specified
1. Rel-11 Carrier Aggregation Combinations

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<tr>
<th>Band</th>
<th>Lead company</th>
<th>Uplink</th>
<th>Downlink</th>
<th>Uplink</th>
<th>Downlink</th>
<th>Mode</th>
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<td>CA-B3_B7*</td>
<td>TeliaSonera</td>
<td>1710 - 1785</td>
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<td>2620 - 2690</td>
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<tr>
<td>CA-B4_B17</td>
<td>AT&amp;T</td>
<td>1710 – 1755</td>
<td>2110 - 2155</td>
<td>704 – 716</td>
<td>734 - 746</td>
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<td>CA-B4_B13</td>
<td>Ericsson (Verizon)</td>
<td>1710 – 1755</td>
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<td>CA-B4_B12</td>
<td>Cox Communications</td>
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<td>2110 - 2155</td>
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<td>CA-B20_B7</td>
<td>Huawei (Orange)</td>
<td>832 – 862</td>
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<td>CA-B5_B17</td>
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<td>CA-B7</td>
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<td>1920 - 1980</td>
<td>2110 - 2170</td>
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<td>CA-B4_B7</td>
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<td>CA-B38</td>
<td>Huawei (CMCC)</td>
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<td>CA-B41</td>
<td>Clearwire</td>
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<td>3600 - 3800</td>
<td>3600 - 3800</td>
<td>3600 - 3800</td>
<td>TDD</td>
</tr>
</tbody>
</table>

* Carried forwards from Rel-10
Design Challenges – Intra-Band Carrier Aggregation

• Not such an issue for the eNB because already dealing with multi-carriers
• Major challenge for the UE
• For Intra-band: Wider Carrier being transmitted
  – More stringent linearity requirements on the power amplifier
  – UE will need to use less transmitter power for the amplifier to remain in the linear region

Example of CCDF plot using N7624B LTE/LTE-Advanced Signal Studio software
Design Challenges – Inter-Band Carrier Aggregation

- For Inter-Band: Multiple simultaneous transmit and receive chains

  - Challenging radio environment in terms of intermodulation and cross-modulation within the UE device

  - Need to design front-end components that help reduce harmonics, and other intermodulation products, which meet 3GPP requirements
2. Enhanced Uplink Multiple Access
Clustered SC-FDMA and Simultaneous PUCCH/PUSCH

**Release 8: SC-FDMA with alternating PUSCH/PUCCH**

- Partially allocated PUSCH
- Partially allocated PUSCH
- Lower PUCCH
- Upper PUCCH
- Fully allocated PUSCH

**Release 10: Clustered SC-FDMA with simultaneous PUSCH/PUCCH**

- Partially allocated PUSCH + PUCCH
- Partially allocated PUSCH + PUCCH
- Partially allocated PUSCH + 2 PUCCH
- Partially allocated PUSCH only
- Fully allocated PUSCH + PUCCH
The use of clustered SC-FDMA increases the PAPR above non-clustered SC-FDMA, but not as much as full OFDM which can exceed the PAPR of Gaussian noise.
2. Enhanced Uplink Multiple Access
Design and Test Challenges

This is a typical spectrum of a single carrier signal

Wanted signal: Two RB at channel edge

Derived from R4-100427 ftp://ftp.3gpp.org/tsg_ran/WG4_Radio/TSGR4_54/Documents/R4-100427.zip
2. Enhanced Uplink Multiple Access Design and Test Challenges

The presence of two in-channel carriers creates 25 to 50 dB worse spurs.

Derived from R4-100427 ftp://ftp.3gpp.org/tsg_ran/WG4_Radio/TSGR4_54/Documents/R4-100427.zip
3. Enhanced Multiple Antenna Transmission

Up to 8x8 Downlink (from 4x2 for Rel-8)
- Baseline being 4x4 with 4 UE Receive Antennae
- Peak data rate reached with 8x8 SU-MIMO

Up to 4x4 Uplink (from 1x2 for Rel-8)
- Baseline being 2x2 with 2 UE Transmit Antennae
- Peak data rate reached with 4x4 SU-MIMO

- Use of beamforming with spatial multiplexing to increase data rate, coverage and capacity
- Adds Downlink Transmission Modes 8 and 9
Future phone
3. Enhanced Multiple Antenna Transmission
Design and Test Challenges

• Higher order MIMO requires simultaneous transceivers
• Antennas also have to multiply in number x CA
• MIMO antennas need to be de-correlated
• Designing a multi-band, MIMO antenna in a small space for good de-correlation
• Conducted testing of higher order MIMO terminals is not effective - Work still continuing on MIMO Over the Air (OTA) testing.
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5. **Coordinated Multipoint (CoMP)**
6. **Relaying**
7. **Home eNB mobility enhancements**
8. **Customer Premises Equipment**
9. **Self Optimizing networks (SON)**

Rel-10 LTE-A

Other Rel-10 and beyond
4. Heterogeneous Networks

- Core Network
- Internet
- Relay
- Wireless
- Fiber Optic
- Macro
- RRH/DAS
- Pico/Micro
- Femto

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4. Heterogeneous Network Testing Challenges

- Interference
- Minimizing the cost of adding and maintaining cells
  - Self-configuration, Self-healing, and Self-optimization
- Handovers between different types of cells
  - Handover among large number and various types of Macrocell and small cells
5. Coordinated Multi-Point – (CoMP)

- Improves performance for higher data rates and cell-edge throughput
- Linked by some type of high speed data connection
6. In-Channel Relay and Backhaul

- Basic in-channel relaying uses a relay node (RN) that receives, amplifies and then retransmits DL and UL signals to improve coverage.

- Main use cases:
  - Urban/indoor for throughput or dead zone
  - Rural for coverage
7. Home eNB Mobility Enhancements

• The concept of Home eNB (femtocells) is not new to LTE-A

• In Release 8 femtocells were introduced for UMTS

• In Release 9 they were introduced for LTE (HeNB)

• In Release 10 there will be further enhancements to enable HeNB to HeNB mobility

• This is very important for enterprise deployments
8. Customer Premises Equipment (CPE)

• The CPE is a “mobile” intended for fixed (indoor) operation
• The antenna may be internal (omni) or external (directional)
• The max output power is increased to 27 dBm
• Lack of concern for power consumption and a better radio link budget mean the CPE can deliver much higher performance e.g. For rural broadband applications
9. Self Optimizing Networks (SON)

• Today’s cellular systems are very much centrally planned, and the addition of new nodes to the network involves expensive and time-consuming work, site visits for optimization, and other deployment challenges.

• The intent is to substantially reduce the effort required to introduce new nodes to the network.

• Examples of use cases:
  • Adding a new eNB
  • Self configuration
  • Self Healing
  • Continuous optimization
  • Interference control
  • Capacity and coverage optimization
LTE-A Deployment

• The first question to ask about LTE-A deployment timing is “which feature”

• LTE-A, Release 10 etc. Is a large grouping of backwards-compatible features, none of which are mandatory

• First to be deployed:
  • Some limited form of carrier aggregation to increase instantaneous bandwidth is particular local operator areas
    – Example: US operator combining 10 MHz at 700 with 10 MHz at 1700
  • Uplink MIMO
    – Requires two UE transmitters – expensive, battery issues
  • Enhanced downlink MIMO for example. 8x2
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- Question and Answer
Phases of LTE test

Goal of conformance test is to ensure a minimum level of performance as defined in the 3GPP specifications.

What

- Performance verification & regression test of components and integrated devices
- Check confidence of “pass” before spending time and expense on conformance
- Schedule time for independent (3rd party) testing of UE to defined test-cases
- More expansive testing of UEs for interoperability and performance against expected use models
- Calibrate and verify devices
- Customers form opinion, share experience, provide feedback

Where

- Development engineer’s bench
- Dedicated lab at developer site
- Authorized test laboratory
- Operator’s test laboratory
- Production Facility
- Out in the real world
LTE Conformance Testing

There are now more degrees of freedom – More to test

UE Conformance test is divided into 3 parts:
1. Radio Frequency (RF) in Specification 36.521-1 and 2
2. Radio Resource Management (RRM) in 36.521-3
3. Signaling in 36.523-1, 2 and 3

eNB/Base station Conformance tests:
Radio Frequency (RF) in Specification 36.141

Conformance tests are divided into Transmitter, Receiver and Performance Tests
<table>
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<th>UE RF transmitter test cases</th>
<th>UE RF receiver test cases</th>
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<td>Reference sensitivity level</td>
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<td>Maximum input level</td>
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<td>Maximum power reduction (MPR)</td>
<td>Adjacent channel selectivity</td>
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<td>Additional maximum power reduction (A-MPR)</td>
<td>In-band blocking</td>
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<td>Additional maximum power reduction (A-MPR) for intra-band contiguous CA</td>
<td>A In-band blocking for CA</td>
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<td>Configured UE transmitted output power</td>
<td>Out-of-band blocking</td>
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<td>Minimum output power</td>
<td>Out-of-band blocking for CA</td>
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<td>General ON/OFF time mask</td>
<td>Narrowband blocking</td>
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<td>PRACH time mask</td>
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<td>SRS time mask</td>
<td>Spurious response</td>
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<td>Power control absolute power tolerance</td>
<td>Spurious response for CA</td>
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<td>Power control relative power tolerance</td>
<td>Wideband intermodulation</td>
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<td>Aggregate power control tolerance</td>
<td>Spurious emission</td>
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<td>Transmit modulation—error vector magnitude (EVM)</td>
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<td>Transmit modulation—PUSCH-EVM with exclusion period</td>
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<td>Transmit modulation—carrier leakage</td>
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<td>Transmit modulation—in-band emissions for non-allocated RB</td>
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<td>Transmit modulation—EVM equalizer spectrum flatness</td>
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<td>Occupied bandwidth 2</td>
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<td>Out-of-band emission—spectrum emission mask</td>
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<td>Out-of-band emission—additional spectrum emission mask</td>
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<td>Out-of-band emission—adjacent channel leakage power ratio (ACLR)</td>
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<td>Transmitter spurious emissions</td>
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<td>Spurious emission band UE coexistence</td>
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<tr>
<td>Spurious emission band UE coexistence (Release 9 and forward)</td>
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<td>Additional spurious emissions</td>
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<tr>
<td>Transmit intermodulation</td>
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Structure of UE and eNB RF conformance tests

- Test purpose
- Test applicability
- Minimum conformance requirements
- Test description, including initial conditions, test procedure, and message contents (UE only)
- Test requirements

Test Channels

- Reference Measurement Channel (RMC) for UE Testing
- Fixed Reference Channel (FRC) for eNB Receiver (Uplink) testing
- E-UTRA Test Model (E-TM) for eNB Transmitter (Downlink) testing
Typical RF Conformance Test System Configuration

T4010S LTE RF Test System
Certification
Regulatory Conformance & Industry Conformance

Certified Product
LTE Industry Certification Groups

- Set the Certification rules
- Select Test Cases and their priority based on Operator requirements.
- Validate Test Platforms.
- Accredit Test Labs
Process for Defining Mobile Handset Certification

Standards body: 3GPP RAN5
- Conformance test spec 36.521-1/3 RF/RRM
- 36.523-1 Protocol

Test system vendors
- LTE test platforms with test cases

LTE UE manufacturers
- Prototype LTE UE

Certification body: GCF/PTCRB
- LTE work item descriptions

Validation test laboratory
- Perform test case validation

Test spec

Validation request

WID

Report validation
Operator Acceptance test

Passing all Conformance tests does not assure performance that is acceptable to users.

Operators institute test methodologies to verify devices have adequate performance and security to meet their end-user expectations.

- In addition to type approval
- Performance and functional tests
- Typically private vs. public conformance tests
### Example Customer Profiles

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
<th>Teenager</th>
<th>Soccer mom</th>
<th>Business user</th>
<th>Grandparent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data consumption</td>
<td>Online gaming, video streaming, music and movie downloads</td>
<td>Very high</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Email and web surfing</td>
<td>Social networking, web browsing, email applications</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Talk time</td>
<td>Voice calls</td>
<td>High</td>
<td>Very high</td>
<td>Very high or high (depends on job)</td>
<td>High</td>
</tr>
<tr>
<td>SMS/MMS</td>
<td>Texting, sending photos to friends</td>
<td>Very high</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Back light</td>
<td>Using phone other than voice or at night</td>
<td>Very high</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Camera</td>
<td>Taking photos or video</td>
<td>Very high</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Location-based services</td>
<td>Navigation, geo-tagging</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Mobility</td>
<td>Using different modes of transport</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
<td>Low</td>
</tr>
</tbody>
</table>
# UMTS Long Term Evolution

<table>
<thead>
<tr>
<th>Release</th>
<th>Stage 3: Core specs complete</th>
<th>Main feature of Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel-99</td>
<td>March 2000</td>
<td>UMTS 3.84 Mcps (W-CDMA FDD &amp; TDD)</td>
</tr>
<tr>
<td>Rel-4</td>
<td>March 2001</td>
<td>1.28 Mcps TDD (aka TD-SCDMA)</td>
</tr>
<tr>
<td>Rel-5</td>
<td>June 2002</td>
<td>HSDPA</td>
</tr>
<tr>
<td>Rel-6</td>
<td>March 2005</td>
<td>HSUPA (E-DCH)</td>
</tr>
<tr>
<td>Rel-7</td>
<td>Dec 2007</td>
<td>HSPA+ (64QAM DL, MIMO, 16QAM UL). LTE &amp; SAE Feasibility Study, Edge Evolution</td>
</tr>
<tr>
<td>Rel-8</td>
<td>Dec 2008</td>
<td>LTE Work item – OFDMA air interface SAE Work item – New IP core network UMTS Femtocells, Dual Carrier HSDPA</td>
</tr>
<tr>
<td>Rel-9</td>
<td>Dec 2009</td>
<td>Multi-standard Radio (MSR), Dual Carrier HSUPA, Dual Band HSDPA, SON, LTE Femtocells (HeNB) LTE-Advanced feasibility study, MBSFN</td>
</tr>
<tr>
<td>Rel-10</td>
<td>March 2011</td>
<td>LTE-Advanced (4G) work item, CoMP Study Four carrier HSDPA, eICIC</td>
</tr>
<tr>
<td>Rel-11</td>
<td>Sept 2012</td>
<td>CoMP, eDL MIMO, eCA, MIMO OTA, HSUPA TxD &amp; 64QAM MIMO, CA Combinations, Interference avoidance</td>
</tr>
<tr>
<td>Rel-12</td>
<td>March 2013 stage 1</td>
<td>New carrier type, LTE-Direct, Active Antenna Systems</td>
</tr>
</tbody>
</table>
Agilent Solutions Across the Ecosystem for LTE

Electronic system design software

Vector signal analysis software

Signal Analyzers with a variety of wireless Measurement Apps

Signal Generators with Signal Studio software

LTE Signalling, RF, protocol and pre-conformance test platforms

Scopes and Logic Analyzers

Design Simulation

Module and Chipset Development

RF and BB Design Integration

System Design Validation

Protocol Development

Pre-conformance

Conformance

Manufacturing

Deployment

Battery Drain Test

Baseband generator and channel emulator

Interactive functional test SW

Widest bandwidth analysis for chipset design & verification

RF and Protocol Conformance test systems

Multi-channel signal analysis

Manufacturing test platforms

PXI solutions

RF Handheld Analyzers

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