Addressing Design and Test Challenges for the new LTE-Advanced Standard

Sheri DeTomasi
Modular Program Manager
LTE-A Multi-Channel Apps
When Separated, Agilent’s EM Business will be named KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years
Our Key Purpose Has Not Changed

We believe in “Firsts”

• It’s in our DNA.

• Bill Hewlett and Dave Packard shaped our purpose of believing in firsts 75 years ago.

• It launched Silicon Valley.

• We are committed to bring you a new generation of firsts – unlocking insights for you so you can bring a new generation of technologies into the world.
Addressing Design and Test Challenges for the new LTE-Advanced Standard

Sheri DeTomasi
Modular Program Manager
LTE-A Multi-Channel Apps
The Data Challenge

- Internet
- Email
- Navigation
- Texting
- Music
- Safety alerts
- Youtube
- TV
- Social networking
- Video/Photo Sharing
- Games
- Cloud
- Imaging
- Banking
And in the Future?

Everything Connected
Everywhere
All the time

Need network capability to handle current and future data needs
What you can expect from today’s presentation

- Overview of the new features and benefits in LTE-Advanced
- Understanding the new design and test challenges with carrier aggregation and MIMO in LTE-Advanced
- Test methods to reduce complexity and cost of test
Agenda

• LTE-Advanced Market Overview and Test Challenges

• Carrier Aggregation
  • Technical Overview
  • Design and Test Challenges
  • Test Methodologies

• Multiple Antenna Techniques
  • MIMO and Beamforming Technical Overview
  • Design and Test Challenges
  • Test Methodologies

• Demo

• Summary and Looking Forward
A Demand for More Data

- Mobile data traffic is growing exponentially
- Mobile penetration continues to grow: >6.5 billion subscribers worldwide by end of 2012; >92% of world population
- Single video streaming = Around 500,000 text messages
- > 2 Billion App Downloads per Month
- In addition to subscriber growth, there is parallel growth in cellular peak data rates

Growth in cellular peak data rates (theoretical) showing more than 2500 times higher data rate over a period of 10 years
Wireless Evolution 1990 – 2013

Increasing efficiency, bandwidth and data rates

- 300 LTE networks in more than 107 countries
- 245.4 million LTE subscribers (More than half in North America)
- Over 1,563 LTE devices
- LTE is the fastest developing mobile technology ever
Key LTE Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access modes</td>
<td>FDD &amp; TDD</td>
</tr>
<tr>
<td>Channel BW</td>
<td></td>
</tr>
<tr>
<td>1 RB = 12 subcarriers = 180 kHz</td>
<td>1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz</td>
</tr>
<tr>
<td>6 RB</td>
<td>15 RB, 25 RB, 50 RB, 75 RB, 100 RB</td>
</tr>
<tr>
<td>Transmission Scheme</td>
<td></td>
</tr>
<tr>
<td>Downlink:</td>
<td>OFDMA (Orthogonal Frequency Division Multiple Access)</td>
</tr>
<tr>
<td>Uplink:</td>
<td>SC-FDMA (Single Carrier Frequency Division Multiple Access)</td>
</tr>
<tr>
<td>Modulation Schemes</td>
<td>QPSK, 16QAM, 64QAM</td>
</tr>
<tr>
<td>MIMO Technology</td>
<td></td>
</tr>
<tr>
<td>Downlink:</td>
<td>Tx diversity, Rx diversity, Single-User MIMO (up to 4x4), beamforming</td>
</tr>
<tr>
<td>Uplink:</td>
<td>Multi-User MIMO</td>
</tr>
<tr>
<td>Peak Data Rates</td>
<td></td>
</tr>
<tr>
<td>Downlink:</td>
<td>150 Mbps (2x2 MIMO, 20 MHz, 64QAM); 300 Mbps (4x4 MIMO, 20 MHz, 64QAM)</td>
</tr>
<tr>
<td>Uplink:</td>
<td>75 Mbps @ 20 MHz BW, 64QAM</td>
</tr>
<tr>
<td>Bearer services</td>
<td>Packet only – no circuit switched voice or data services are supported ➔ voice must use VoIP</td>
</tr>
<tr>
<td>Transmission Time Interval</td>
<td>1 ms</td>
</tr>
</tbody>
</table>
## LTE-Advanced Technical Goals

- Better spectral efficiency
- Higher data rates
- Interoperability with existing wireless standards

<table>
<thead>
<tr>
<th></th>
<th>DL/UL</th>
<th>LTE</th>
<th>LTE-Advanced</th>
<th>IMT-Advanced</th>
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<tbody>
<tr>
<td><strong>Peak Data Rate</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>DL</td>
<td>300 Mbps</td>
<td>1 Gbps</td>
<td></td>
<td>100 Mbps (HM)</td>
</tr>
<tr>
<td>UL</td>
<td>75 Mbps</td>
<td>500 Mbps</td>
<td></td>
<td>1 Gbps (LM)</td>
</tr>
<tr>
<td><strong>Peak Spectrum Efficiency [bps/Hz]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DL</td>
<td>15</td>
<td>30</td>
<td></td>
<td>15</td>
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<tr>
<td>UL</td>
<td>3.75</td>
<td>15</td>
<td></td>
<td>6.75</td>
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<tr>
<td><strong>Tx Bandwidth</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UL &amp; DL</td>
<td>Up to 20 MHz</td>
<td>Up to 100 MHz</td>
<td>Up to 40 MHz</td>
<td></td>
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<tr>
<td><strong>MIMO (spatial multiplexing)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL</td>
<td>Up to 4x4</td>
<td>Up to 8x8</td>
<td></td>
<td>Up to 4x4</td>
</tr>
<tr>
<td>UL</td>
<td>N/A</td>
<td>Up to 4x4</td>
<td></td>
<td>Up to 2x4</td>
</tr>
<tr>
<td><strong>Beamsteering</strong></td>
<td>Dual layer DL</td>
<td>Up to 8 layer DL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• Better spectral efficiency
• Higher data rates
• Interoperability with existing wireless standards
New LTE-A Features at a Glance

- **Carrier aggregation**
  - Higher data rates (bps)

- **Enhanced multi-antenna & beamforming**
  - Higher spectral efficiency (bps/Hz)
  - DL MIMO 8x8
  - UL MIMO 4x4

- **Het-Nets**
  - Higher spectral efficiency per coverage area (bps/Hz/Km²)
LTE-Advanced Test Challenges

Engineers need to

• Validate eNB, microcell, picocell and UE characteristics and performance

• Parametric test of components such as amplifiers, filters

• Performance characterization and verification of RF sub-systems

**Key Challenges:**

• Complexity of designing and testing multi-channel, multi-antenna transmitter and receiver components and subsystems

• Get new designs to market quickly

• Keep cost low
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• Summary and Looking Forward
Why LTE-Advanced Carrier Aggregation?

• Peak throughput performance of OFDM (LTE) systems is achieved at bandwidths >10 MHz

• To achieve 150 Mbps in the downlink, 20 MHz of bandwidth is required

• Most operators do not have 20 MHz of contiguous spectrum!

• However many operators around the world hold spectrum in more than one frequency band

Solution

**LTE Advanced Carrier Aggregation**

• Achieves wider bandwidth transmissions
• Higher peak data rates
• Facilitates efficient use of fragmented spectrum
• Enables 150 Mbps in typical deployments when 20 MHz contiguous spectrum is not an option
What is Carrier Aggregation?

- Allows combining multiple LTE Channels in order to increase data throughput
- Extends the max transmission bandwidth to supports a maximum of five component carriers (CC) yielding a maximum bandwidth of 100 MHz
- Supports all 3GPP bandwidths (1.4, 3, 5, 10, 15 or 20 MHz)
- Is backward compatibility with LTE Rel - R8/R9 carriers
- Supports symmetric or asymmetric DL/UL CA configurations
- Used to achieve Max 1 Gbps in downlink & 500 Mbps in uplink, with MIMO configurations

Component Carrier (CC)—up to 20 MHz BW
Intra-Band Carrier Aggregation

**Intra-Band CA:**
- Multiple CCs are used inside of a single frequency band
- CCs can be contiguous or non-contiguous or both if more than 2 are used

**Intra-band contiguous**
- Five 20 MHz component carriers occupying 100 MHz BW

**Intra-band non-contiguous**
- Three 20 MHz component carriers
Inter-Band Carrier Aggregation

**Inter-band CA:**

- CCs are in different frequency bands
- Allows service providers to combine their spectrum assets to gain higher throughput
- More expensive to implement since UE must support 2 receivers
- Probably the most common network implementation since it optimizes the spectrum holdings of many carriers (In US, 700 MHz + 1900 MHz)

---

**LTE downlink inter-band carrier aggregation**

Channel 1

Channel 2

Inter-band

- Two 20 MHz component carriers in different frequency bands
Example North American Inter-Band LTE Operator

Operators want to offer the performance and efficiency of 20 MHz LTE

**Solution:** Combine spectrum at 700 MHz with 1900 MHz to offer the performance of a 20 MHz LTE network using inter-band CA

![Diagram showing LTE downlink inter-band carrier aggregation](image-url)
Operating Bands for Release 11 CA

Intra-band contiguous CA bands

<table>
<thead>
<tr>
<th>CA Band</th>
<th>E-UTRA operating band</th>
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</thead>
<tbody>
<tr>
<td>CA_1</td>
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<td>CA_7</td>
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<td>CA_38</td>
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<td>CA_40</td>
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<td>CA_41</td>
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Inter-band CA bands

<table>
<thead>
<tr>
<th>CA Band</th>
<th>E-UTRA operating band</th>
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</thead>
<tbody>
<tr>
<td>CA_1-5</td>
<td>1 and 5</td>
</tr>
<tr>
<td>CA_1-18</td>
<td>1 and 18</td>
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<tr>
<td>CA_1-19</td>
<td>1 and 19</td>
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<tr>
<td>CA_1-21</td>
<td>1 and 21</td>
</tr>
<tr>
<td>CA_2-17</td>
<td>2 and 17</td>
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<tr>
<td>CA_2-29</td>
<td>2 and 29</td>
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<tr>
<td>CA_3-5</td>
<td>3 and 5</td>
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<tr>
<td>CA_3-7</td>
<td>3 and 7</td>
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<tr>
<td>CA_3-8</td>
<td>3 and 8</td>
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<td>CA_3-20</td>
<td>3 and 20</td>
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<tr>
<td>CA_7-20</td>
<td>7 and 20</td>
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<tr>
<td>CA_8-20</td>
<td>8 and 20</td>
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<tr>
<td>CA_11-18</td>
<td>11 and 18</td>
</tr>
</tbody>
</table>

Intra-band non-contiguous CA bands – *new in Release 11*

<table>
<thead>
<tr>
<th>CA Band</th>
<th>E-UTRA operating band</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA_25-25</td>
<td>25</td>
</tr>
<tr>
<td>CA_41-41</td>
<td>41</td>
</tr>
</tbody>
</table>

- **Release 11** – 21 New combinations
- **Release 12** – 87 NEW CA combinations with 3 component carriers in inter-band
- **Release 13** – 21 NEW CA combinations
Carrier Aggregation Design Challenges

- Inter-band carrier aggregation requires multiple simultaneous receive and/or transmit chains
  - Front-end designs that help reduce harmonics, and other intermodulation
  - Complicates antenna design

- UE intra-band contiguous aggregated carriers
  - More stringent linearity requirements on the power amplifier to use less transmitter power for the amplifier to remain in the linear region
  - Similar properties for wider bandwidths

Example of CCDF plot using N7624B LTE/LTE-Advanced Signal Studio software
Key Test Challenges for Carrier Aggregation

Variable and wider bandwidths
- Up to 100 MHz BW
- New ACLR and SEM requirements for intra-band non-contiguous allocations

Complexity in modulated signal
- OFDM + Clustered SC-FDM
- Greater number of complex transmitter configurations for performance testing

Carrier aggregation multi-channel needs
- Component carriers in two or more separate bands
- Time synchronization for simultaneous demodulation of the multiple component carriers
- Added complications when MIMO is included
Carrier Aggregation Test Requirements

- Up to 100 MHz BW to support up to 5 CC
- Set channel power, data modulation type and add fading and impairments
- Create multi-carrier waveforms to simulate multi-user and multi-cell signals
- Independent configuration for each component carrier with cross-carrier scheduling
- Analyze the multiple transmit and receive chains simultaneously

Key signal generation & measurements characteristics
- ACLR & SEM
- EVM
- Time Alignment Error (TAE)
- Other spectrum measurements such as channel power, amplitude flatness, center frequency and occupied BW
Carrier Aggregation: Power Amplifier Characterization

Test Challenge: Characterizing the LTE-Advanced UE or eNB power amplifier presents RF challenge. The different carrier aggregation configurations will stress the amplifier in different ways since each will have different peak-to-average ratios.

Agilent Solution:

- N7624B Signal Studio software generates LTE-Advanced FDD signals to test power and modulation characteristics of components and transmitters
- CCDF curve to get insight into the waveform power statistics as system parameters are varied
- Configure up to 5 component carriers within up to 160 MHz I/Q bandwidth with MXG vector signal generator or M9381A PXIe vector signal generator

Configure up to 5 component carriers
Carrier Aggregation: Inter-band Analysis

**Test Challenge:** Demodulating inter-band carrier aggregated signals require signal analyzer with bandwidth that spans multiple frequency bands (ex. 800 MHz and 2100 MHz)

![Diagram](image)

**Agilent solutions:**
- Two time synchronized PXAs, PXIe VSAs or N7109A, plus 89600 VSA software. VSA software acquires all the CCs simultaneously, demodulate the captured signals, and measure the time alignments.

![Equipment Images](image)

**89600 VSA software**

- Up to 4 ch VSA
- 160 MHz BW
- 2,4,8 ch signal analyzer
- 40 MHz BW
- Dual signal analyzer
- 40 MHz BW
- 10 MHz Freq ref.
- Time sync
- CC from “Band A”
- CC from “Band B”
- Two CCs at 800 MHz
- Three CCs at 2100 MHz
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What are Multi-Antenna Techniques and MIMO?

- **Multiple antennas on basestations and User Equipment**
- **Objective is to increase coverage and physical layer capacity through multiple antennas**

Three kinds of multiple-antenna applications:

- Path diversity
- Spatial multiplexing
- Beamsteering

DL 8x8 MIMO

UL 4x4 MIMO
Enhanced Multi-Antenna Techniques

Path diversity
- Improves robustness

Spatial multiplexing
- Improves spectral efficiency and throughput

Beamsteering
- Increases signal robustness with the added advantage of improved throughput through spatial multiplexing MIMO
Enhanced Multi-Antenna Techniques

Path diversity

Use transmit diversity to increase robustness to noise:

* Transmit orthogonally modified redundant copies across multiple antenna’s
  • Robustness to channel fading / noise
  • Primarily used in networks were the connection suffers from poor SNR
Enhanced Multi-Antenna Techniques

Spatial multiplexing

Use spatial multiplexing to improve data rate/throughput

- Transmit different data streams simultaneously across multiple antenna’s
- MIMO systems introduce a new dimension in test—the cross coupling of signals between hardware transmit and receive paths

<table>
<thead>
<tr>
<th></th>
<th>DL/UL</th>
<th>LTE</th>
<th>LTE-Advanced</th>
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<tbody>
<tr>
<td>MIMO (spatial multiplexing)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL</td>
<td>Up to 4x4</td>
<td></td>
<td>Up to 8x8</td>
</tr>
<tr>
<td>UL</td>
<td>N/A</td>
<td>Up to 4x4</td>
<td></td>
</tr>
</tbody>
</table>
Enhanced Multi-Antenna Techniques

**Beamsteering**

Use beamforming for directional transmission or interference avoidance

- Transmit per antenna weighted signal copies across multiple antenna’s
- Coherent beamforming gain (dB) at receiver
- Introduces phase and amplitude offsets to the whole of the signal feeding each transmitting antenna
- Focuses the signal power in a particular direction
- Only considered for 4 or more antenna options
Enhanced Multi-Antenna Techniques

**Multi-user MIMO**

- Increases system efficiency
  - Used in the downlink only
  - Up to 4 users
  - Up to 4 streams/user
  - Total 8 streams max
LTE DL Transmission Modes

3GPP Release 8

TM1: SISO single antenna transmissions
TM2: Tx Diversity using 2 or 4 antennas
TM3: Open-Loop SU-MIMO (spatial multiplexing) with CDD
TM4: Closed-Loop SU-MIMO
TM5: Closed-Loop MU-MIMO
TM6: Closed-Loop, Rank 1 spatial multiplexing
TM7: Rank 1 spatial multiplexing (single-layer beamforming)

3GPP Release 9

TM8: Rank 2 spatial multiplexing (dual-layer beamforming)

3GPP Release 10

TM9: Up to 8 layer transmissions using ports 7 to 14
Key Design and Test Challenges for MIMO

**Complicated test setup for higher order MIMO**
- Apply higher order MIMO up to 8 channels
- Support multi-antenna techniques such as TX diversity, spatial multiplexing (MIMO), and beamsteering

**Parametrics in the PHY layer**
- Challenging measurement configurations resulting from spectral, power and time variations due to traffic type and loading
- Cross correlation and intermodulation between multiple transmitter and/or receiver chains

**Expensive to test**
- More antennas - more to test, more equipment, longer test times
- Complexity of testing the cross coupling of signals between hardware transmit and receive paths
Additional Test Requirements for MIMO

- Select transmission modes for transmitter diversity, spatial multiplexing and beamforming up to 8x8 MIMO in DL
- Generate inter-band carrier aggregation w/ cross-carrier scheduling applied in conjunction with up to 8x8 MIMO in each frequency band
- Multiple, independently tuned channels
- Cross-channel amplitude and phase corrections for 8x8 beamforming
**MIMO Plus Inter-Band Carrier Aggregation: UE Rx Tests**

**Test Challenge:** Test UE’s ability to decode signals with component carriers in two separate RF bands with the additional challenges when each component carrier is configured for MIMO.

**Solution**
- Inter-band carrier aggregation in 2 RF bands requires 2 VSGs. 4x4 or 8x8 MIMO in each band requires up time synchronized 16 VSGs.
- Independent configuration for each component carrier:
  - Transport channel coding
  - Cross-carrier scheduling enables control information to be carried on another carrier
  - *Signal Studio* synchronizes and automatically controls up to 16 signal generators
Characterizing 8x8 DL MIMO, Cross Channel Amplitude and Phase Corrections for Multi-Antenna

**Test Challenge:** Characterizing the full set of LTE tests, including 8x8 downlink MIMO, cross channel timing measurements and multi-antenna beamforming, which typically includes 4 or 8 antenna elements

**Solution:**

8-ch TD-LTE measurements
- TD-LTE TM7, single layer beamforming using Port 5 (8x1)
- TD-LTE TM8, single & dual layer beamforming using Ports 7 & 8 (8x2)

**N7109A multi-channel analyzer and 89600 VSA software**
- Multi-channel measurements for general device testing, including: *phase coherence*, cross correlation, cross spectrum, frequency response, impulse response
- Version 15 or later - integrated Correction Wizard for accurate amplitude & phase measurements at the device-under-test
8x2 BF modulation analysis example

MIMO/BF – downlink

Antenna beam patterns

C-RS propagation matrix, etc

BF weights etc

89600 VSA software and N7109A multichannel signal analyzer

LTE - Agilent 89600 VSA Software (64-bit)
MIMO is also Implemented in 802.11ac

- Wider channel bandwidths
- Higher-order modulation
- Up to 8 antennas (8x8)
- Diversity, Spatial Multiplexing, Beamforming or Multi-user MIMO

<table>
<thead>
<tr>
<th>Feature</th>
<th>Mandatory</th>
<th>Optional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel bandwidth</td>
<td>20 MHz, <strong>40 MHz, 80 MHz</strong></td>
<td>160 MHz, 80+80 MHz</td>
</tr>
<tr>
<td>Data subcarriers / pilots</td>
<td>52 / 4, <strong>108 / 6, 234 / 8</strong></td>
<td>468 / 16</td>
</tr>
<tr>
<td>Modulation types</td>
<td>BPSK, QPSK, 16QAM, 64QAM</td>
<td><strong>256QAM</strong></td>
</tr>
<tr>
<td>Spatial streams and MIMO</td>
<td>1</td>
<td>2 to 8 Multi-user MIMO (MU-MIMO)</td>
</tr>
</tbody>
</table>

```
2 x 2
80 MHz, 160 MHz

3 x 3
80 MHz, 160 MHz

Non contiguous 80+80 80 MHz
```
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LTE/LTE-A Multi-Channel Demonstration

Software

- N7624B/25B Signal Studio for LTE/LTE-A TDD and FDD
  Spectrally correct waveform creation

- Test solution software toolkit
  Trigger routing, LTE-A Carrier Aggregation and MIMO waveform and analysis setup files

- 89600 VSA software
  89620B WLA software
  Decode and analyze multiple channels simultaneously

Hardware

- 2 to 4 M9381A PXI vector signal generators
- 2 to 4 M9391A PXI vector signal analyzers
- M9018A PXIe chassis
- M9037A embedded controller

From signal generators

DUT

To signal analyzers

Agilent Technologies
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LTE / LTE-Advanced Design and Test Solutions

3D EM simulation SystemVue (BB) ADS/GG (RF/A)
Baseband generator and channel emulator
RF module development
RF proto → RF chip/module
RF and BB design integration L1/PHY
BTS or mobile
System design validation system level RF testing
Pre-conformance

Protocol development L2/L3
BTS and mobile BB chipset development L1/PHY
FPGA and ASIC
Conformance
Manufacturing
Network deployment

8960 comm test set
UXM wireless test set
LTE UE signalling, RF, protocol and functional test
RF handheld analyzers
Power measurement
EXM manufacturing test
Systems for RF and protocol conformance

89600 VSA/WLA software for signal analyzers, scopes, LA SystemVue and ADS
Scopes and logic analyzers
Battery drain characterization

Anticipate Accelerate Achieve
Agilent Technologies

LTE and LTE Advanced Presentation
Jan 21 2014
Looking Forward

5G A set of new requirements for wireless communications systems that mature beyond 2020

Agilent Technologies engaged in 5G definition

• New spectrum with mmwave
• Wider bandwidths
• New modulation techniques
• Enhanced small cell
• Massive MIMO w/ 100+ channels

One Example: Agilent 8x8 or 16x16 VSA system with 625MHz BW on each channel

Modular Instruments are ideal for addressing new multi-channel needs in the future
In Closing

The world is changing
More devices
More antennas
More mobile data traffic

Agilent’s Response

✓ Continued work with wireless standards bodies, industry forums, leading edge customers

✓ Integrated design simulation with test

✓ Multi-channel solutions that simplify test, are scalable and reduce cost

- Internet
- Email
- Navigation
- Texting
- Music
- Safety alerts
- Youtube
- TV
- Social networking
- Video/Photo Sharing
- Cloud
- Games
- Imaging
- Banking
Questions
Resources

Chapters in this 600 plus page book include:
• LTE Introduction
• Air Interface Concepts
• Physical Layer
• Upper Layer Signaling
• System Architecture Evolution
• Design and Verification Challenges
• Conformance Test and Acceptance Testing
• Looking Towards 4G: LTE-Advanced

Agilent LTE-Advanced solution information:
www.agilent.com/find/lteadvanced
www.agilent.com/find/solution-lte

3GPP specification for Base Station RF conformance test: