LTE-Advanced: Status and 5G

Teck Hu

Distinguished Member of Technical Staff

Wireless Chief Technology Office (WCTO)

Alcatel-Lucent
Outline

- Overview of Wireless Broadband Evolutions
- From Textbook to Practice
- 4G LTE
- Preview of 5G
Introduction to 3G and 4G

Approximate timeline:

“Second Generation”
“Third Generation”
“Fourth Generation”

GSM GPRS EDGE
TD-SCDMA (China)
UMTS HSDPA HSUPA HSPA+

3GPP
Release 99 4 5 6 7 8 9 10 11...
Tight interworking

3GPP2
IS-95 CDMA 2000 CDMA EVDO CDMA EVDO Rev A CDMA EVDO Rev B

IEEE
802.16 2004 802.16 e 802.16 m
“fixed WiMAX” “mobile WiMAX”
Evolving Radio Interface Capabilities...
HSPA will more than double and LTE will grow 8-fold!

The shift away from 2G (GSM) is accelerating; decline of GSM
LTE Targets (Release 8)

- 100Mbps downlink / 50Mbps uplink
  - Uniform service provision & Improved cell-edge performance
- 2 to 4 times the spectral efficiency (bits/s per Hz) of UMTS Rel-6
- Reduced delays
- Flexible use of spectrum allocations
  - Up to 20MHz bandwidth and Scalable bandwidth (1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz, 20MHz)
  - New spectrum allocations will be required (e.g. in 2.5 - 3GHz region)
  - All terminals to support at least 20MHz bandwidth (receive and transmit)
  - Early deployments likely to be around 2.6GHz (Europe) and 700MHz (USA)
    - Also reuse of existing UMTS and GSM spectrum
- Strong pressure for common design for operation in paired and unpaired spectrum
  - Chinese pressure results in some minor differences for TDD operation
Peak data rate

- 1 Gbps data rate achieved by 4x4 MIMO and transmission bandwidth wider than approximately 70 MHz

Peak spectrum efficiency

- **DL:** Rel. 8 LTE satisfies IMT-Advanced requirement
- **UL:** Need to double from Release 8 to satisfy IMT-Advanced requirement

<table>
<thead>
<tr>
<th></th>
<th>Rel. 8 LTE</th>
<th>LTE-Advanced</th>
<th>IMT-Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak data rate</td>
<td>DL</td>
<td>300 Mbps</td>
<td>1 Gbps</td>
</tr>
<tr>
<td></td>
<td>UL</td>
<td>75 Mbps</td>
<td>500 Mbps</td>
</tr>
<tr>
<td>Peak spectrum efficiency [bps/Hz]</td>
<td>DL</td>
<td>15</td>
<td>30.6</td>
</tr>
<tr>
<td></td>
<td>UL</td>
<td>3.75</td>
<td>16.8</td>
</tr>
</tbody>
</table>
LTE-Advanced (Cont’d)

Capacity and cell-edge user throughput

- Targets for LTE-Advanced were set considering gain of 1.4 to 1.6 from Release 8 LTE performance

<table>
<thead>
<tr>
<th>Capacity [bps/Hz/cell]</th>
<th>Ant. Config.</th>
<th>Rel. 8 LTE</th>
<th>LTE-Advanced</th>
<th>IMT-Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL</td>
<td>2-by-2</td>
<td>1.69</td>
<td>2.4</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>4-by-2</td>
<td>1.87</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>4-by-4</td>
<td>2.67 ×1.4-1.6</td>
<td>3.7</td>
<td>–</td>
</tr>
<tr>
<td>UL</td>
<td>1-by-2</td>
<td>0.74</td>
<td>1.2</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>2-by-4</td>
<td>–</td>
<td>2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Cell-edge user throughput [bps/Hz/cell/user]</td>
<td>DL</td>
<td>2-by-2</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>4-by-2</td>
<td>0.06</td>
<td>0.09</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>4-by-4</td>
<td>0.08</td>
<td>0.12</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>UL</td>
<td>1-by-2</td>
<td>0.024</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-by-4</td>
<td>–</td>
<td>0.07</td>
</tr>
</tbody>
</table>
Theory to Practice
From Academics to Practical Systems

- Market and User Driven: Service Providers translate these into new LTE Requirements.
- Feasibilities Studies of Technologies to Satisfy the Requirements.
  - Evaluations, Studies, Comparisons etc
- Approved Technologies incorporated into New LTE Releases.

- Example: Rel-12 Enhanced DL MIMO

RP-121416.zip  R1-132840.zip  R1-132836.zip
Why a Standardized Technology

Benefits:
- Interoperability & Low barrier to entry promotes competition
- Facilitates control of access to spectrum
- Economies of scale
- Transcends national boundaries & Generates new markets

Disadvantages
- Consensus based: path towards acceptance of new technologies could be long
- IPR issues...lawsuits
4G Broadband
UMTS - LTE Technology Evolution

Two parallel activities ongoing in 3GPP:

- **UMTS Wideband CDMA (WCDMA) Evolution**
  - Retaining competitiveness in a 5MHz bandwidth
  - Release 99 = “3G”
  - Releases 5 to 8 = “3.5G”
  - Currently at HSPA+

- **Long-Term Evolution (LTE)**
  - Technology revolution: new air interface + network architecture
    - “3.99G”?
  - LTE-Advanced: 4G at last?
  - Currently LTE-Advanced Rel-12
LTE-Advanced Features (1)

- **Carrier Aggregation**
  - Satisfy requirements for peak data rate: Multiple Component Carriers (CCs) up to 100 MHz
  - Spectrum aggregation
    - Enables diverse spectrum assignments to be exploited jointly
    - Both contiguous and non-contiguous aggregation supported

- **Heterogeneous Networks**
  - LTE is designed to operate as a reuse 1 system for a homogeneous network
  - Source of interference in LTE is purely inter-cell for regular macro cell operation. No intra-cell interference (subcarrier transmissions are orthogonal)
    - Interference randomization: Frequency selective scheduling & Hopping
    - Interference control: Power Control & Interference over Thermal (IoT) control in UL
    - Interference suppression: IRC Receiver, Beamforming
    - Interference coordination/shaping/Avoidance (ICIC, PDSCH/PUSCH only)
LTE-Advanced Features (2)

- Enhanced MIMO Operation in DL and UL
  - The main tool to reach IMT-A requirements in difficult environments
    - New Transmission Mode 9 (TM9)
    - 8 Layer SU-MIMO
    - Commonality with TM8 (Rel-9)
      - Dynamic switching between SU-MIMO and MU-MIMO
      - Up to 4 users with 1 layer MU-MIMO
      - Up to 2 users with 2 layer MU-MIMO

- Relay
  - Supports deployment of cells in areas where wired backhaul is not available or very expensive - *LTE for wireless backhauling*
  - Coverage Extension: In Homogeneous deployments, it may have the following challenges: Severe propagation loss due to higher frequency bands, Poor cell edge coverage, Potential coverage hole
Heterogeneous Networks (Rel-10 LTE-A)

Heterogeneous networks combine multiple technologies and radio access options.

CoMP Techniques (Rel-11 LTE-A)

- **Coherent combining or dynamic cell selection**

- **Joint transmission/dynamic cell selection**

- **Coordinated scheduling/beamforming**

- **Joint Processing (JP):** Data is available at each point in CoMP cooperating set and data transmission occurs from one or multiple transmission points.

- **Dynamic point selection (DPS):** This includes dynamic point blanking, where data is available at each point in CoMP cooperating set but data transmission occurs only from the selected point.

- **Coordinated Scheduling/Beamforming (CS/CB):** Data is only available at the serving cell but user scheduling and beamforming decisions are made using coordination among cells in the CoMP cooperating set.
Rel-12 LTE-A Enhancements

2010 to 2012

Initial Deployments
- Mostly 5 MHz or 10 MHz Radio Channels
- 2x2 Multiple Input Multiple Output (MIMO) Antennas
- Initial Self-Optimization/Organization for Auto Configuration

2013 to 2016

Higher Capacity/Throughput and/or Efficiency
- Wider Radio Channels: 20 MHz
- Carrier Aggregation: up to 100 MHz
- Advanced Antenna Configurations
- More Advanced MIMO (Higher Order, Multi-User, Higher Mobility)
- Coordinated Multipoint Transmission
- Het-nets (Macrocells/Picocells/Femtocells)
- Het-net Self Optimization/Organization
- More Intelligent and Seamless Offload

Greater Capabilities
- Voice Widely Handled in the Packet Domain
- Policy-Based Quality of Service

Enables more users, more applications and a better experience
Beyond LTE-A: Roadmap and Timeline

- Ref: 5G: A Technology Vision, Huawei
Small Cells

- **Release 8**
  - Small cells have been supported by the LTE specifications since the beginning of LTE;
  - Frequency-domain inter-cell interference coordination (ICIC)

- **Release 9**
  - Additional time-domain ICIC can be used in het nets of macro and isolated small cells

- **Release 10**
  - New base station classes introduced for local area and home deployments

- **Release 11**
  - Further optimizations and enhancements for small cells, including dense small cell deployments

- **Release 12**

**Diagram:**
- Macro
- Pico

**Legend:**
- Macro
- Pico
Antenna Enhancements

- **At the Base Station**
  - **Downlink**
    - Useful gain with enhanced feedback was observed for more practical medium load and non-full traffic.
    - New 4Tx dual codebook design for precoding matrix feedback: Mainly for 4Tx closely-spaced or widely-spaced cross-polarized antenna arrays
    - 3D-MIMO and Active Antenna Arrays
  - **Uplink**
    - Performance improvement with 8 Rx antennas
    - MMSE-IRC Receiver

- **At the UE**
  - **MMSE-IRC**
  - **Network Assisted Advanced Receivers**
Active Antenna Arrays - 3D MIMO

Likely to be in LTE Rel-13 timeframe

UE-specific 3D precoding in elevation as well as azimuth
- Facilitates deep indoor penetration in urban environments
- Supports higher-order MU-MIMO
- Support no more than 8 CSI-RS ports
- Enables improved intra-cell and inter-cell interference coordination

Standards changes required to support 3D MIMO would focus on:
- Reference signals for elevation antenna elements
- CSI feedback for 3D precoding
- Dynamic switching between vertical and horizontal beamforming
CoMP for Non-Ideal Backhaul

Rel-11 CoMP evaluations assumed ideal backhaul

Rel-12 enhancement is focused on non-ideal backhaul for inter-vendor operation

- Consideration of typical backhaul delay in the evaluation
- Need to identify which CoMP technique(s) for inter-eNB operation can give useful gain, and their potential impact on inter-eNB signalling (RAN3).

Network architecture

- Possible approaches for inter-eNB scheduling coordination may be centralized or distributed

Relevant CoMP schemes are typically based on semi-static coordinated scheduling and/or beamforming

- Potential gains are very dependent on implementation

For inter-vendor operation, standardized inter-eNB signalling is needed
Towards 5G…
A Preliminary View
What are the Drivers

- Explosive Growth of Traffic Demand
  - Much higher BW with much reduced latency

- Service Ubiquity with Diverse Data Types
  - Increase in Connected devices: Machine-Machine

- Energy Efficient Approaches
  - Enhancements at the Network and the Users/Machine

![Exabytes per month graph]

Source: Cisco VNI Mobile Forecast, 2013
Radio Link Spectral Efficiency

Improvements in spectral efficiency per link are approaching theoretical limits.

The next generation of technology is about improving spectral efficiency per unit area.

Source:
http://netseminar.stanford.edu/seminars/01_29_09.pdf
Visions of 5G: Radio Access Networks

- More Sites
  - >10X
  - Cloud Radio Access
  - Context-aware Multi-connections
  - D2D, Multi-hop

- Higher Efficiency
  - ~10X
  - Massive MIMO
  - More efficient radio links
  - Advanced Interference management

- More Spectrum
  - ~10X
  - Spectrum expansion: from 300~500MHz to 1500MHz
  - High frequency spectrum
  - Enhanced carrier aggregation
  - Authorized Shared Access (ASA)
  - Licensed Shared Access (LSA)

Ref: 5G: Driving the Divergence of the Physical and Digital World, ZTE
Greater Link Efficiency - FFS

**Massive MIMO**

- Higher Spectral Efficiency; Very large numbers of antenna elements, e.g. 32, 64 resulting in Large number of Beams. Elevation BF with AAS

**New Air Interface**

- Existing OFDM; Parameterisation may be optimised for the higher carrier frequency and associated propagation characteristics
  - e.g. Shorter CP for lower delay spread, Narrower subcarriers for lower mobility, Modified reference signal patterns

- **Introducing Controlled Interference**
  - Non-orthogonal Multiple Access
  - Faster than Nyquist (FTN): Introduce controlled ISI
    - Ref: Faster than Nyquist Signaling, J.E. Mazo, BLTJ, 1975
    - Ref: LTE Enhancements & Future Radio Access, NTT Docomo
Cell Densification

Small Cells

- More cells, smaller cells with Miniaturised base stations
- Low power and Deployed wherever demand dictates

Device-2-Device

- Offload of bandwidth usage from Network

Machine-Type Communications

- The “internet of things” with billions of connected devices
Machine-Type Communications (MTC)

MTC involves communications without (or only limited) human intervention

- Electronic Commerce, Manufacturing, Smart Grid, Sensors, etc.
- “Never Send a Human to do a Machine’s Job” The Matrix!

Radio Challenges:
- Cost Reduction & Long Battery Life: Single receive chain and Reduced peak data rate
- Possible coverage enhancement: Up to 15dB (deep basement)
Device to Device (D2D)

Important for Public Safety Systems and Commercial D2D discovery based services.

Priority of current work in 3GPP is on the essential functionality to support Public Safety usage of LTE

- Direct Communications between terminals
- Supports off-network operation; Operation outside network coverage and Resilience against power outages or major disasters in which network infrastructure is destroyed
Spectrum Optimization and Expansion - FFS

LTE-Unlicensed

- Unlicensed spectrum as an effective complement to licensed cellular operators

Flexible Duplexing

- Exploiting spare time slots or frequency resources in UL for low power downlink transmissions, and vice versa

Higher Operating Frequencies (e.g. mm-Wave)

- Propagation characteristics substantially different from those for which the LTE air interface is optimised.
- Typically confined to i.e. single room with Low mobility, Low propagation delay, Low delay spread.
Further Reading

- http://www.alcatel-lucent.com/small-cells/
- http://lteworld.org/whitepaper
- http://www.smallcellforum.org/aboutsmallcells-small-cells
- 3GPP: www.3GPP.org
- 4G America: www.4Gamerica.org