LTE – A Technical Overview

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Scope of Presentation

- Cellular wireless systems
- LTE system & architecture
- Key Technologies
Cellular Wireless Systems
Wireless Standard Evolution

1G | 2G | 2.5G | 3G | 4G

Analog AMP

IEEE802.16
IEEE802.20

TDMA
GPRS
EDGE
EDGE-E

GSM
PDC

UMTS
HSxPA
3G-LTE
LTE-A

CDMA
CDMA2000

EV-DO
EV-DO Rev-A
EV-DO Rev-B
EV-DO Rev-C

TD-SCDMA

1G 2G 2.5G 3G 4G
IEEE802

• IEEE802.16
  – IEEE standard that defines a wireless network on a metropolitan area (WMAN)
  – Original goal to support fixed and nomadic users (16a~d)
  – Evolved to mobility (vehicular speeds) and increased data rates (16e)
  – 16m under development

• IEEE802.20
  – Span off from 802.16 to support high mobility applications
  – For whatever reasons, it lost momentum
  – Its survival is in doubt
3GPP2 Evolution

- CDMA2000 1X (1999)
- CDMA2000 1xEV-DO (2000)
- Ultra Mobile Broadband (UMB) (a.k.a. EV-DO Rev. C)
  - Based on EV-DO, IEEE 802.20, and FLASH-OFDM
  - Commercially available in 2009
- UMB’s fate?
3GPP Evolution

- Release 99 (Mar. 2000): UTRA in FDD and TDD (3.84 Mcps) modes
- Rel-4 (Mar. 2001): TD-SCDMA
- Rel-6 (Mar. 2005): HSUPA with MBMS
- Rel-7 (2007): DL MIMO, optimized real-time services (VoIP, gaming, push-to-talk)
- Rel-8 (Dec. 2008) Long Term Evolution (LTE)
System & Architecture
LTE

• Standardization effort started in late 2004
  – With HSPA (downlink and uplink), UTRA will remain highly competitive for several years
  – IEEE is standardizing mobile WiMAX => Threat for loosing competitive edge

• LTE focus:
  – Enhancement of the UTRA
  – Optimisation of the UTRAN architecture
  – To ensure the continued competitiveness of the 3GPP technologies for the future

• LTE was the first and only technology recognized by the Next Generation Mobile Network alliance to meet its broad requirements

• Target deployment in 2010
Service Capabilities

• Reduced cost per bit
  – Improve spectrum efficiency (e.g. 2-4 x Rel6)
  – Reduce cost of backhaul (transmission in UTRAN)
• Increased service provisioning – more services at lower cost with better user experience
• Focus on delivery of services utilising "IP"
• Reduced latency, to 10 msec round-trip time between user equipment and the base station, and to less than 100 msec transition time from inactive to active
• Increase the support of QoS for the various types of services (e.g. VoIP)
• Increase “cell edge bit rate” whilst maintaining same site locations as deployed today
• Reasonable terminal power consumption
• Flexibility of use of existing and new frequency bands
System Capabilities

- Downlink peak data rates up to 326 Mbps with 20 MHz bandwidth
- Uplink peak data rates up to 86.4 Mbps with 20 MHz bandwidth
- Operation in both TDD and FDD modes.
- Variable duplex technology within bands as well as between bands
- Scalable bandwidth up to 20 MHz, covering 1.4, 2.5, 5, 10, 15, and 20 MHz
- Increased spectral efficiency over Release 6 HSPA by a factor of two to four
- Enhance the bit rate for MBMS (e.g. 1-3 Mbps)
Architecture & Mobility Capabilities

- UTRAN Evolution and UTRA Evolution with simplified architecture
- Open interfaces to support Multi-vendor deployments
- Robustness – no single point of failure
- Support of multi-RAT with resources controlled from the network
- Support of seamless mobility to legacy systems as well as to other emerging systems including
  - Inter-RAT Handovers
  - Service based RAT Selection
- Maintain appropriate level of security
Evolved Packet System (EPS)

- AGW (Access Gateway)
  - MME (Mobility Management Entity), which manages mobility, UE identity, and security parameters
  - S-GW (Serving Gateway) - Node that terminates the interface towards E-UTRAN
  - P-GW (PDN [Packet Data Network] Gateway) - Node that terminates the interface towards PDN
- eNB (E-UTRAN NodeB), which carries out all radio-related functions
- MME/ S-GW/ P-GW (Evolved Packet System (EPS))
- X2
- Other 3GPP Networking
Functional Split between eNB & AGW

- **eNB functions**
  - Selection of aGW
  - Routing towards activation;
  - Scheduling and transmission of paging messages;
  - Scheduling and transmission of BCCH information;
  - Dynamic allocation of resources to UEs in both uplink and downlink;
  - The configuration and provision of eNB measurements;
- **AGW functions**
  - Paging origination
  - Ciphering of the user plane
  - PDCP
  - SAE Bearer Control
  - Ciphering and integrity protection of NAS signaling
Protocol Stack

- **RLC Functions**
  - Transferring upper layer PDUs
  - Error correction through ARQ
  - Concatenation, segmentation and reassembly of RLC SDUs
  - Re-segmentation of RLC data PDUs

- **MAC Functions**
  - Mapping between logical channels and transport channels
  - Scheduling information reporting
  - Managing HARQ
  - Logical channel prioritization
  - Transport format selection
  - Supporting signaling and traffic between these two elements

- **Protocol Stack** between Core Network CN and User Equipment UE

- **NAS**
- **RRC**
- **PDCP**
- **RLC**
- **MAC**
- **PHY**

- **Control-plane only**
Key Technologies

- OFDMA for DL
- SC-FDMA (Single Carrier FDMA) for UL
- Bandwidth Flexibility
- Advanced antenna technology
- Link adaptation
- Inter-cell-interference coordination (ICIC)
- Two-layered retransmission (ARQ/HARQ)
- Multicarrier channel-dependent resource scheduling
- Discontinuous Rx and Tx
- MBMS
• Modulation - OFDM
  – An OFDM symbol consists of multiple subcarriers of a certain time duration
  – Transmitting data over a number of orthogonal subcarriers
  – Each subcarrier transports an information symbol (e.g., QPSK)

• Multiple-access scheme
  – Transmission organized into intervals
  – Time and frequency resource organized into resource blocks (RBs)
  – Multiple RBs assigned to individual users for transmission
Time and Frequency Resource

- **Resource element**: subcarrier in an OFDM symbol
  - uniquely identified by the index pair \((k, l)\) in a slot

- **Resource block** consisting of multiple RE Physical RB
  - Normal CP: 12x7
  - Extended CP: 12x6 (for 15KHz) and 24x3 (for 7.5KHz)
Frame Structure

- **Type 1**
  - Twenty time slots in a frame, each 0.5 ms long
  - A subframe consisting of two slots
  - Ten subframes for DL and 10 for UL

- **Type 2**
  - Two half-frames in a frame, each 5 ms long
  - A half-frame consisting of 5 subframes
  - A subframe consisting of 2 slots
Subframe

One subframe = two slots
\( T_{\text{subframe}} = 1 \text{ ms} \)

\( T_{\text{slot}} = 0.5 \text{ ms} \)

<table>
<thead>
<tr>
<th></th>
<th>( T_{\text{cp}} (\mu s) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>5.2 for 1\textsuperscript{st} symbol</td>
</tr>
<tr>
<td></td>
<td>4.7 for others</td>
</tr>
<tr>
<td>Extended</td>
<td>16.7 for all</td>
</tr>
</tbody>
</table>

Normal CP

\( T_{\text{CP}} \)
\( T_u \approx 66.7 \mu s \)

Extended CP

\( T_{\text{CP-e}} \)
\( T_u \approx 66.7 \mu s \)
DL Physical Channel Processing

- Scrambling of coded bits in each of the code words to be transmitted on a physical channel
- Modulation of scrambled bits to generate complex-valued modulation symbols
- Mapping of the complex-valued modulation symbols onto one or several transmission layers
- Precoding of the complex-valued modulation symbols on each layer for transmission on the antenna ports
- Mapping of complex-valued modulation symbols for each antenna port to resource elements
- Generation of complex-valued time-domain OFDM signal for each antenna port
UL Physical Channel Processing

- Scrambling
  - Scrambling of coded bits in each of the code words to be transmitted on a physical channel
- Modulation mapper
  - Modulation of scrambled bits to generate complex-valued modulation symbols
- Transform precoder
  - Transform precoding of the complex-valued modulation symbols to complex symbols
- Resource element mapper
  - Mapping of complex-valued symbols to resource elements
- SC-FDMA signal generation
  - Generation of complex-valued time-domain SC-FDMA signal for each antenna port

- SC-FDMA

- Utilizes single carrier modulation and frequency domain equalization
- SC-FDMA can be regarded as DFT-precoded or DFT-spread OFDMA
SC-FDMA

• Two types of SC transmission
  – Localized transmission
    • Multi-user scheduling gain in frequency domain
    • Need to feedback channel state information
    • Mainly for low-to-medium mobility users
  – Distributed transmission
    • Robust transmission for control channels and high mobility UE
    • Mainly for high mobility users
Bandwidth Flexibility

- Supported bandwidths: 1.4, 3.0, 5, 10, 15, 20 MHz
- All UE support bandwidth of 110 RBs (110x180 kHz ≈ 20 MHz)
- Fixed subcarrier spacing
- Modular sampling rates for different BWs
- Adjusting the numbers of RB for different BWs
- Fixed symbol length for all BWs

<table>
<thead>
<tr>
<th>Channel bandwidth (MHz)</th>
<th>1.4</th>
<th>3</th>
<th>6</th>
<th>10</th>
<th>16</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcarrier spacing (KHz)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Number of occupied subcarriers</td>
<td>72</td>
<td>180</td>
<td>300</td>
<td>600</td>
<td>900</td>
<td>1200</td>
</tr>
<tr>
<td>Number of RB per slot</td>
<td>6</td>
<td>15</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>IDFT/DFT size</td>
<td>128</td>
<td>256</td>
<td>512</td>
<td>1024</td>
<td>1536</td>
<td>2048</td>
</tr>
<tr>
<td>Sampling rate (MHz)</td>
<td>1.92</td>
<td>3.84</td>
<td>7.68</td>
<td>15.36</td>
<td>23.04</td>
<td>30.72</td>
</tr>
</tbody>
</table>
DL Synchronization Signals

- Transmitted on the 72 centre sub-carriers (around DC sub-carrier)
- Primary sync signal
  - carrying 3 unique identities of a cell group
  - Tx at 1st and 5th subframes (Type 1) or at 2nd and 6th subframes (Type 2)
- Secondary sync signal
  - carrying 168 cell identity groups
  - Tx at 1st and 5th subframes
- Generated from Zadoff-Chu sequences
DL MIMO Modes

• Dynamic switching between spatial multiplexing and SFBC

• CL
  – PMI feedback from UE
  – Codebook-based linear precoding
  – PSRC
    • Uses diversity to transmit multiple data streams over multiple transmit antennas
  – MU-MIMO/SDMA
    • To improve capacity

• OL single stream
  – SFBC

• OL multiple streams
  – PARC
    • Uses diversity to transmit multiple data streams over multiple transmit antennas at different times
  – Beamforming
    • To improve coverage
• MIMO operation in the frequency domain

\[ y = Hs + n \]
**Link adaptation**

- Transmission power control
  - Support fractional path-loss compensation: UEs close to the cell border use less tx power

- Adaptive modulation and channel coding rate
  - Modulation and coding for the shared data channel adapted according to Channel Quality Indications reported by UE

- Adaptive transmission bandwidth
  - RB allocation
Inter-Cell-Interference Coordination

• Allowing frequency reuse >1 at cell edge
• UL ICIC
  – Supported through High-Interference and Overload Indicators, sent to neighboring cells
  – Avoiding scheduling UL use at the cell edge in some parts of the bandwidth
• DL ICIC
  – Restriction of tx power in some parts of the bandwidth
  – Coordination supported through RNTP indicator, sent to neighboring cells
ARQ/HARQ

- eNB or UE can request retransmissions of incorrectly received data packets.
- Use a two-layered mechanism to achieve low latency and low overhead without sacrificing reliability.
- Most errors captured by HARQ protocol.
HARQ Protocol

Hello -> Jello

Hello + Hello -> Hello
Scheduling

• eNB scheduler
  – Taking into account of different types of information
    • QoS parameters and measurements from the UE
    • UE capabilities and buffer status
  – Each subframe (1ms), determining
    • which users are allowed to transmit
    • on what frequency resource,
    • at what data rate
  – Example – channel dependent scheduling – taking advantage of channel quality variation for more efficient use of BW

• Types of scheduling
  – Dynamic scheduling
  – Semi-persistent scheduling
  – With HARQ
Power Saving: DRX and DTX

- LTE power save protocols
  - Discontinuous Reception (DRX)
  - Discontinuous Transmission (DTX)
  - Both reducing transceiver duty cycle while in active operation
  - DRX also applies to the RRC_Idle state with a longer cycle time than active mode
Long and Short DRX

- DRX may have long or short “off” durations, configured by the RRC
- Transition between long DRX and short DRX
  - Determined by the eNB (MAC commands) or by the UE based on an activity timer
- A lower duty cycle could be used during a pause in speaking during a voice over IP call
- When speaking resumes, this results in lower latency
- For packets arriving at a lower rate, the UE can be off for a longer period of time
- For packets arriving more often, the DRX interval is reduced during this period
MBMS

• MBMS is an essential requirement for LTE - an integral part of LTE.
• Cells may be configured to be part of an SFN for transmission of an MBMS service
  – the cells and content are synchronized to enable for the UE to soft-combine the energy from multiple transmissions
• The MBMS traffic can share the same carrier with the unicast traffic or be sent on a separate carrier
• Supported by MBSFN reference signals
**LTE -Advanced**

- Advanced version of LTE (3GPP Rel. 10) designed to meet IMT-Advanced requirements

- Evolution of current OFDMA approaches
- High-order MIMO (e.g., 4X4)
- Wider radio channels (e.g., 50 to 100 MHz).
- Optimization in narrower bands (e.g., less than 20 MHz) due to spectrum constraints in some deployments
- Multi-channel operation in either same or different frequency bands
- Ability to share bands with other services.
About Neocific

• A wireless technology company
  – Consulting
  – Prototyping and product development
  – Reference designs on HW/SW platforms

• Technical strength
  – OFDM/OFDMA broadband wireless system
  – IP networking software development
  – Embedded software development

• Current focus
  – Broadband wireless technologies: WiMAX, LTE, and others
  – Sensor networks
Thank you!