The Year of LTE

Daniel Wong, Ph.D. (Stanford)
Daniel Wireless LLC
18 Sep 2012
dwong@danielwireless.com

Overview

- Introduction
  - What is LTE?
  - How is LTE doing?
- 7 myths
- What next?
Wireless System Evolution Threads

3gpp
GSM  UMTS(WCDMA)  UMTS (HSPA)  LTE

3gpp2
IS95 CDMA  cdma2000 1x  1xEV-DO

IEEE
802.11-1997  802.11-1999  802.11-2007  802.11-2012

IEEE
802.16-2001  802.16-2004  802.16-2009

Evolved Packet Core: all IP protocol stack

PSTN
CS
RAN

GSM
CS
RAN

GSM with GPRS
CS
RAN

3G with IMS
CS
PS
RAN

IMS
PS
RAN

EPS in LTE

Original
GSM

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**Exponential Growth of Mobile Data**

Exabytes Per Month

<table>
<thead>
<tr>
<th>Year</th>
<th>Data (Exabytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>0.6</td>
</tr>
<tr>
<td>2012</td>
<td>1.3</td>
</tr>
<tr>
<td>2013</td>
<td>2.4</td>
</tr>
<tr>
<td>2014</td>
<td>4.2</td>
</tr>
<tr>
<td>2015</td>
<td>6.9</td>
</tr>
<tr>
<td>2016</td>
<td>10.8</td>
</tr>
</tbody>
</table>

Source: Cisco VNI Mobile, 2012

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**LTE Deployment Status – Sep 2012**

- LTE is “the fastest developing mobile system technology ever” (GSA)
• 347 operators investing in LTE in 104 countries
  - 292 operator commitments in 93 countries
  - 55 pre-commitment trails in 11 more countries

Accelerating deployments and subscriptions

GSA forecasts 152 commercial LTE networks by end 2012.
Ecosystem: Devices

7 Myths About LTE

**MYTH: LTE is 4G**
Wireless System Evolution Threads

3gpp
- GSM
- UMTS (WCDMA)
- UMTS (HSPA)
- LTE

3gpp2
- IS95 CDMA
- cdma2000
- 1x
- 1xEV-DO

IEEE
- 802.11-1997
- 802.11-1999
- 802.11-2007
- 802.11-2012

IEEE
- 802.16-2001
- 802.16-2004
- 802.16-2009

IMT-Advanced Requirements for 4G

- A high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner
- Capability of interworking with other radio access systems
- Worldwide roaming capability
- Enhanced peak data rates to support advanced services and application
  - 100 Mbps for high mobility and 1 Gbps for low mobility
### Does LTE Satisfy the Requirements?

- 3GPP Release 8 (completed) - and subsequent evolution
- Significant gains intended in throughput & capacity, latency & experience, flexibility

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Minimum Requirements*</th>
<th>Criteria</th>
<th>Minimum Requirements*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility Support</td>
<td>Seamless mobility, service continuity 120 km/hr</td>
<td>Spectrum &amp; BW Flexibility</td>
<td>Support for FDD, TDD, &amp; both FDD/TDD</td>
</tr>
<tr>
<td>Uplink Data Rates</td>
<td>Peak: 30-50Mbits (For 20MHz carrier – no MIMO at terminal)</td>
<td>Cost Per MB</td>
<td>As close to x DSL as possible</td>
</tr>
<tr>
<td>DL Data Rates</td>
<td>Peak: &gt; 100Mbits (For 20MHz carrier – 2 receive antennas)</td>
<td>Terminal Support</td>
<td>Highly intelligent, multi-purpose, converged</td>
</tr>
<tr>
<td>Latency (Round-trip Time)</td>
<td>Core &lt; 10 ms, RAN &lt; 10 ms</td>
<td>Integration &amp; Convergence</td>
<td>One network – with RAN, Core, Transport</td>
</tr>
<tr>
<td>Spectral Efficiency</td>
<td>At least 3-5 X improvement</td>
<td>Roaming Support</td>
<td>Extra high speed BB radio with seamless interworking</td>
</tr>
<tr>
<td>QoS Support</td>
<td>E2E QoS throughout all segments</td>
<td></td>
<td>Universality – QoS-based global roaming &amp; inter-working</td>
</tr>
<tr>
<td>Simplified Network</td>
<td>Simplify architecture and reduce nodes (flatter network)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* These are intended to provide an indication of defined requirements and may not necessarily be representational of all scenarios or implementations.

#### 7 Myths About LTE

**Myth: LTE Provides More-than-Enough Capacity**
Exponential Growth of Mobile Data

Exabytes per Month

Source: Cisco Visual Networking Index, 2012

Exponential Growth of Mobile Data

Exabytes per Month

Source: Cisco Visual Networking Index, 2012

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**Traffic Offload and Indoor Coverage**

- Use alternative IP access points (versus eNodeB)
  - GAN (before called UMA)
    - Dual Wi-Fi/LTE phone required
    - If AP is near, traffic will be sent via AP to core LTE
  - Femto
    - Regular LTE phone
    - Smaller base stations connected via IP to core LTE
- Traffic offload at the eNodeB
  - To another cell sites (load balancing)
  - Directly to the internet if possible

**GAN diagram**

- Dual Wi-Fi/LTE UE (outside Wi-Fi Area)
- Wi-Fi AP
- LTE OFDM
- Radio access network (RAN)
- eNode B
- EPC
- GAN
- IP network
- Edge router
- Core routers
- Handoff

GAN: Generic Access Network
UMA: Unlicensed Mobile Access

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Femtocell diagram

7 Myths About LTE

1. LTE is 4G
2. LTE provides more-than-enough capacity
3. LTE is more spectrally efficient than HSPA
4. …
Comparison with HSPA

- Often quoted
  - LTE designed for 3-4 times spectral efficiency of predecessor HSPA
- What do the requirements actually say?

For the downlink

- Actual requirement (3GPP 25.913)
  - “In a loaded network, target for spectrum efficiency (bits/sec/Hz/site), 3 to 4 times Release 6 HSDPA. This should be achieved assuming Release 6 reference performance is based on a single Tx antenna at the Node B with enhanced performance type 1 receiver in UE whilst the E-UTRA may use a maximum of 2 Tx antennas at the Node B and 2 Rx antennas at the UE.”
For the uplink

- Actual requirement (3GPP 25.913)
  - “In a loaded network, target for spectrum efficiency (bits/sec/Hz/site), 2 to 3 times Release 6 Enhanced Uplink (deployed with a single Tx antenna at the UE and 2 Rx antennas at the Node B). This should be achievable by the E-UTRA using a maximum of a single Tx antenna at the UE and 2Rx antennas at the Node B.”

### Spectrum Flexibility: Bandwidth

<table>
<thead>
<tr>
<th>Channel BW [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>Resource Blocks</td>
<td>6</td>
<td>15</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Recessed Subcarriers</td>
<td></td>
<td>72</td>
<td>180</td>
<td>300</td>
<td>600</td>
<td>900</td>
</tr>
</tbody>
</table>

| IDFT / DFT Size | 128 | 256 | 512 | 1024 | 1536 | 2048 |

(D)FST – (Inverse) Discrete Fourier Transform
Spectrum Flexibility: Deployment Band

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1920 MHz – 1980 MHz</td>
<td></td>
<td>2110 MHz – 2170 MHz</td>
<td>2110 MHz – 100 MHz</td>
<td>2 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>2</td>
<td>1880 MHz – 1940 MHz</td>
<td></td>
<td>1880 MHz – 1940 MHz</td>
<td>2 MHz</td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td>3</td>
<td>1710 MHz – 1770 MHz</td>
<td>1895 MHz – 1955 MHz</td>
<td>1895 MHz – 1955 MHz</td>
<td>20 MHz</td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td>4</td>
<td>1710 MHz – 1770 MHz</td>
<td>1895 MHz – 1955 MHz</td>
<td>1895 MHz – 1955 MHz</td>
<td>20 MHz</td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td>5</td>
<td>1630 MHz – 1690 MHz</td>
<td>1755 MHz – 1815 MHz</td>
<td>1755 MHz – 1815 MHz</td>
<td>25 MHz</td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td>6</td>
<td>1550 MHz – 1610 MHz</td>
<td>1675 MHz – 1735 MHz</td>
<td>1675 MHz – 1735 MHz</td>
<td>35 MHz</td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td>7</td>
<td>1450 MHz – 1510 MHz</td>
<td>1575 MHz – 1635 MHz</td>
<td>1575 MHz – 1635 MHz</td>
<td>55 MHz</td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td>8</td>
<td>1350 MHz – 1410 MHz</td>
<td>1475 MHz – 1535 MHz</td>
<td>1475 MHz – 1535 MHz</td>
<td>55 MHz</td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td>9</td>
<td>1250 MHz – 1310 MHz</td>
<td>1375 MHz – 1435 MHz</td>
<td>1375 MHz – 1435 MHz</td>
<td>70 MHz</td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td>10</td>
<td>1150 MHz – 1210 MHz</td>
<td>1275 MHz – 1335 MHz</td>
<td>1275 MHz – 1335 MHz</td>
<td>70 MHz</td>
<td></td>
<td>TDD</td>
</tr>
</tbody>
</table>

Note: This list is not exhaustive - there are other operational or planned bands

7 Myths About LTE

1. LTE is 4G
2. LTE provides more-than-enough capacity
3. LTE is more spectrally efficient than HSPA
4. LTE FDD mode will dominate TDD
5. …
**FDD vs TDD**

- **Advantages of FDD**
  - Frequency separation of uplink and downlink
  - Don’t need guard interval when switching
  - Simpler for voice-centric systems

- **Advantages of TDD**
  - Can have different number of timeslots for uplink and for downlink
  - Easier to adapt to changing uplink/downlink ratio
  - More flexibility for data traffic uplink/downlink allocation

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**LTE TDD**

- **Advantages**
  - Data traffic optimization
  - Uplink/downlink allocation flexibility
  - Easier upgrade path from WiMaX
  - Easier upgrade path from TD-SCDMA

- **The China Factor**
  - China Mobile, largest mobile operator in world
  - Economies of scale
  - LTE-TDD ecosystem?
LTE TDD Deployment Status

Source of data: GSA Evolution to LTE report. September 11, 2012

Myth: LTE is the latest cellular phone system

**LTE is the Latest Cellular Phone System**
Future converged network

Why the all-IP network?

- 2 parallel networks?
  - Packet switching good for data
  - Circuit switching good for voice
  - IP-based data network together with PSTN?
- Convergence, compromise
  - Treat voice as just another kind of data
  - Voice over packets, e.g., VoIP
  - Same for video
  - Converged network carrying voice/video and data
Evolved Packet Core: all IP protocol stack

Original GSM

GSM with GPRS

3G with IMS

EPS in LTE

LTE Architecture

MME and serving GW could be implemented as one entity

Packet data network

IMS

PCRF

PDN GW

Serving GW

MME

HSS

eNode B

eNode B

eNode B

eNode B

UE

e-UTRAN

Other access network, e.g. WLAN

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7 Myths About LTE

LTE Doesn’t Support Voice

Other aspects of VoIP

- Other potential benefits
  - Cost savings
  - New services, CTI, etc.
- But wait …
  - Sacrificing quality?
    - No more dedicated resources
    - “best effort” nature of IP networks
      - Delay
      - Delay variations – “jitter”
  - Need to re-engineer IP-based networks for suitable quality?
**LTE voice services options**

- All IP network for all services including voice
  - Voice standardized as VOLTE
  - Based on IMS
  - First commercial launch on 7 August 2012
- Interim/transition with limited LTE/IMS
  - SR-VCC for handoff between IMS/CS(legacy)
- Interim/transition when IMS not deployed
  - Circuit switched fallback (CSFB)
  - SVLTE
- VOLGA as alternative to VOLTE
  - Fallen out of favor

VOLTE: voice over LTE  
CSFB: circuit switched fallback  
SVLTE: simultaneous voice & LTE

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**IP multimedia subsystem (IMS)**

- Provides session interaction among multiple services reusing common resources
- Based on existing standards (SIP, diameter, etc.)
- Main functionalities
  - Call session control
  - Subscriber management
  - Open interface to multiple application servers
  - Interconnection with IP, Public Switched Telephony Network (PSTN) and Public Land Mobile Network (PLMN) networks
  - Charging and policy interfaces
- VoIP is one example of IMS-based services
VoLTE Deployment Status – Sep 2012

<table>
<thead>
<tr>
<th>Country</th>
<th>Operator</th>
<th>VoLTE status</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Korea</td>
<td>SK Telecom</td>
<td>Launched</td>
</tr>
<tr>
<td>South Korea</td>
<td>LG U+</td>
<td>Launched</td>
</tr>
<tr>
<td>Canada</td>
<td>SaskTel</td>
<td>In deployment</td>
</tr>
<tr>
<td>Singapore</td>
<td>Starhub</td>
<td>Trial planned</td>
</tr>
<tr>
<td>South Korea</td>
<td>KT</td>
<td>In deployment</td>
</tr>
<tr>
<td>UAE</td>
<td>Etisalat</td>
<td>In deployment</td>
</tr>
<tr>
<td>USA</td>
<td>AT&amp;T</td>
<td>In deployment</td>
</tr>
<tr>
<td>USA</td>
<td>Clearwire</td>
<td>In deployment</td>
</tr>
<tr>
<td>USA</td>
<td>MetroPCS</td>
<td>In deployment</td>
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<tr>
<td>USA</td>
<td>Sprint</td>
<td>In deployment</td>
</tr>
<tr>
<td>USA</td>
<td>Verizon Wireless</td>
<td>In deployment</td>
</tr>
</tbody>
</table>

Service Delivery Platform options

- Wireless operators SDP: i.e., OSA, and more recently, One API initiative
- OTT (Over The Top) native SDPs
  - iPhone
  - Android
  - RIM
  - etc
**Operator Approaches to Skype: case of 3**

- No blocking, no surcharging, active promotion of VoIP to customers since 2006
  - “You can use whatever applications you want”
- Branded Skypephones launched in 2007
  - Deep integration of application and contact list
  - Access over the 3G circuit, to ensure quality
- No data charges for Skype from Q2 2009
- “Most Skype calls go abroad, to a PC”
- “Skype users use 14% more conventional voice minutes, 10% more SMS than average, show lower churn rates”

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**What next?**

*Is LTE the Final Destination?*
Is LTE the destination?

- On the bright side
  - Acceleration in LTE deployment
  - Acceleration in wireless data volume
  - Wireless all IP network has been the goal for years
    - We have arrived at a wireless all IP network
  - IMS development in progress
    - VOLTE
    - RCS
    - creating a controlled environment to deploy IP services that adds value

- On the other side
  - Rise of over-the-top (OTT) services
    - Skype, etc., for VoIP
    - Mobile operator becomes bit pipe provider
  - Continuing evolution of the Internet
  - Difficulties with IMS deployment
    - Interoperability
    - Evolving existing networks to add IMS
    - Filling in details – service creation/orchestration, device clients, BSS, OSS, etc.
  - Less ownership, less control, with operator
**LTE-advanced**

- Antenna technology evolution
  - 8x8 MIMO DL, 4x4 MIMO UL
- Higher channel bandwidth
- Carrier (bandwidth) aggregation
  - Contiguous
  - Non Contiguous
- Enhanced uplink
- Enhancements and innovations in Release 10 and beyond
  - Coordinated Multipoint (CoMP)
  - HeNB enhancements, e.g., HeNB to HeNB handoff
  - Relaying
  - Self-Organizing Networks (SON)
    - Introduced in Rel 8 and further defined in Rel 9
    - Great deal of focus in Rel 10
  - Others

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**Conclusions**

- LTE, the latest mobile system
  - OFDMA/SC-FDMA air interface
  - Amazing evolution from circuit-switched to all-IP packet-switched network
- Tremendous growth in LTE deployment
  - Growth of wireless data
  - Lots of momentum
- 7 myths dispelled
- New services
  - Opportunities and challenges
Additional Resources

- Daniel Wireless LLC
  - Consulting and Training

- Our courses
  - WCET cert exam prep course – 5 days
    - Offered in-house; contact us for more info
  - LTE, various formats
  - Wireless access, wireless networks, etc.

- Consulting in wireless technology
  - Wireless technology, R&D, etc.

- Books
  - “Fundamentals of wireless communication engineering technologies”, Wiley, Jan 2012
  - “Wireless Internet Telecommunications”, 2005