ETSF15 Communication Systems and Networks
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4G mobile communication system LTE
Plan of lecture

- Some history of mobile networks—Past and future
- Idea of network structure
- EPC packet networks
- LTE radio channel
- What comes next?
History of mobile systems

1\textsuperscript{st} generation

- Analog transmission with no security
- Small regions (countries)
  - First NTT (‘79), second NMT (‘81)
  - NMT (Nordic), AMPS (NA+Aus), TACS (UK), TZ80x (NTT), DDI (Jap), Radiocom 2000 (Fr), RTMI (It)
  - NMT shut down 2007
History of mobile systems

2nd generation

- Digital voice channel (10kb/s), Circuit switched
- News: SIM card, SMS
  - 3 December 1992: “Merry Christmas”
- Larger regions (continents)
  - GSM (Eur), IS-136 (N+S Am+Aus), IS-95 (NA+Asia), PDC (Jap)
  - GSM 1991

2.5 generation => Data channels

- HSCSD, GPRS, EDGE, IS-95B
History of mobile systems

3rd generation
- Packet switched for voice and data
- 144kb/s – 3Mb/s
- Global
  - UMTS (2001)
- News:
  - UTRAN

Universal Terrestrial Radio Access Network
History of mobile systems

4th generation

- Packet switched data traffic
  (Voice over IP or 3G)
- 100Mb/s-1Gb/s
- Global: LTE
  - Dec 2009 (Stockholm and Oslo by TeliaSonera)
- News: Smartphones and apps
  - iPhone 2007
History of mobile systems

5th generation

• Packet switched data traffic
• 1-100Gb/s
  • 1Gb/s/user
• ≈2020
• News: Small cells, home cell, IoT (M2M), Car2Car, Massive MIMO, etc
Mobile traffic (CISCO VNI)

- Global mobile data traffic grew 69% in 2014
  - 1.5 EB in Dec ’13 to 2.5 EB in Dec ’14
- Global mobile devices and connections in 2014 grew to 7.4 billion (11.5 B in 2019)
  - 26% smart devices generate 80% of traffic
  - 4G devices generate 10 times more traffic than non-4G
Total IP traffic

Figure 22. Global IP Traffic, Wired and Wireless

Source: Cisco VNI Global IP Traffic Forecast, 2014–2019
Total Mobile traffic

Figure 6. Effect of Smart Mobile Devices and Connections Growth on Traffic

Percentages refer to traffic share.
Source: Cisco VNI Mobile, 2015
Although there is an overall growth in the number of mobile devices and connections, there is also a visible shift in the device mix. This year we see a slight slowdown in the growth of tablets as a new device category, phablets (included in our smartphone category), were introduced. Tablet growth was also affected by the availability of lightweight laptops, which are quite similar to tablets in form factor but have more enhanced capabilities.

Throughout the forecast period, we see that the device mix is getting smarter with an increasing number of devices with higher computing resources, and network connection capabilities that create a growing demand for more capable and intelligent networks. We define smart devices and connections as those having advanced computing and multimedia capabilities with a minimum of 3G connectivity. As mentioned previously, 497 million mobile devices and connections were added in 2014, and smartphones accounted for 88 percent of that growth at 439 million net adds. The share of smart devices and connections as a percentage of the total will increase from 26 percent in 2014 to more than half, at 54 percent, by 2019, growing 3.3-fold during the forecast period (Figure 4).

Figure 4. Global Growth of Smart Mobile Devices and Connections

Percentages refer to device and connections share. Source: Cisco VNI Mobile, 2015
Trend 2: Defining Cellular Network Advances (2G, 3G, and 4G)

Mobile devices and connections are not only getting smarter in their computing capabilities but are also evolving from lower-generation network connectivity (2G) to higher-generation network connectivity (3G, 3.5G, and 4G or LTE). When device capabilities are combined with faster, higher bandwidth and more intelligent networks, it leads to wide adoption of advanced multimedia applications that contribute to increased mobile and Wi-Fi traffic.

The explosion of mobile applications and phenomenal adoption of mobile connectivity by end users on the one hand and the need for optimized bandwidth management and network monetization on the other hand is fueling the growth of global 4G deployments and adoption. Service providers around the world are busy rolling out 4G networks to help them meet the growing end-user demand for more bandwidth, higher security, and faster connectivity on the move (Appendix B).

Globally, the relative share of 3G- and 3.5G-capable devices and connections will surpass 2G-capable devices and connections by 2017 (45 percent and 38 percent relative share). The other significant crossover will occur in 2019, when 4G will also surpass 2G connection share. By 2019, 26 percent of all global devices and connections will be 4G-capable (Figure 7). The global mobile 4G connections will grow from 459 million in 2014 to 3 billion by 2019 at a CAGR of 46 percent.

Figure 7. Global Mobile Devices and Connections by 2G, 3G, and 4G

Percentages refer to device and connections share.
Source: Cisco VNI Mobile, 2015
4G – LTE
Long Term Evolution

Standardized by 3GPP
(3rd Generation Partnership Project)

- Radio Access Networks (RAN)
- Service & Systems Aspects (SA)
- Core Network & Terminals (CT)
- GSM EDGE Radio Access Networks (GERAN).
EPS (Evolved Packet System)
EPS challenges

• High speed radio link
  • Bandwidth is extremely expensive. Squeeze out all bits you can

• Access to Internet
  • How to send IP packets

• Authentication and security
  • And accounting

• User mobility
  • When to change eNB and how to transfer data in the network

• Cost efficient use of infrastructure
EPS interfaces

EPC <-> eNB
- S1 interface
- Split in S1-MME and S1-U
- No centralised node

eNB <-> eNB
- X2 interface
- Coordination and positioning

eNB <-> UE
- LTE-Uu or EUTRAN-Uu
E-UTRAN
Evolved Universal Terrestrial Radio Access Network

RAN responsible for

- Resource management
  - Scheduling and dynamic resource allocation
- Compression
  - IP head compression reduces overhead
- Security
  - Encryption of data
- Positioning
  - UE physical position
- Connection to EPC
  - User and control plane
Protocol stack

• S1 often tunneled over the fix network architecture
• A tunnel is a way to send packets over other types of network. E.g.
  • IPv4 over IPv6 and vice versa
  • IP over IPsec
• GTP: GPRS Tunneling Protocol
Example of tunneling

IPv4 over IPv6 using GRE (Generic Routing Encapsulation)
IP packets in EPC (User plane)

PGW
- IP edge for user
- IP address allocation to UE
- QoS filtering
- Mobility anchor
  - Does not change during session. Preserves the IP addr

SGW
- Collecting charging info
- Local anchor towards eNB
  - Can change due to mobility
IP packets in EPC (User mobility)
Protocol stacks (User plane)

GTP: GPRS Tunneling Protocol
PDCP: Packet Data Convergence Protocol
  (IP<->Radio, Header compression, security)
RLC: Radio Link Control
  (Segmentation, reordering)
Control plane in EPC

MME
(Mobility Management Entity)
- Communicates with eNB and SGW
- Manage tunnels and encryption

HSS
(Home Subscriber Server)
- Subscriber data base
- SIM card key exchange
- AAA
  - Authentication, Authorization and Accounting
USIM card
UMTS Subscriber Identity Module

The USIM card is an application on a smart card and contains:

- IMSI (International mobile subscriber identity) 15 digits
- Authentication key K and sequence number SQN

Authentication process:

$K_{ASME}$ is used for encryption of messages
The radio channel

- Licensed frequency bands (slots of 20 MHz)
  - In 0.5-4 GHz
- Cost in order of Billions $
- Alternative: FDD and TDD
  - Most common FDD
- Efficient transmission
  - UE low power => longer battery life
  => very low power at receiver
Frequency allocation (3kHz-300GHz)

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

LTE

2.4/5.8 GHz Free (WiFi)
eNodeB structure (physical layer)
OFDM
Orthogonal Frequency Division Multiplexing

\[ a_i \in \mathbb{Z}_{16} \]

16-QAM mapping:

Can be used with \( M = 4, 16, 64 \) or 256
Time-frequency multiple access

**TDMA:**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>User 1</td>
<td></td>
</tr>
<tr>
<td>User 2</td>
<td></td>
</tr>
<tr>
<td>User 3</td>
<td></td>
</tr>
<tr>
<td>User 4</td>
<td></td>
</tr>
</tbody>
</table>

**FDMA:**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>User 1</td>
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<td></td>
</tr>
<tr>
<td>User 3</td>
<td></td>
</tr>
<tr>
<td>User 4</td>
<td></td>
</tr>
</tbody>
</table>
Time-frequency multiple access

In LTE

- A Resource Element (RE) is one carrier over one OFDM symbol

  This is the least time-frequency resolution

- 15 kHz X 71.4 us
Resource block (RB)

A pair of RB (subframe) is the least assigned resource.
Frame structure in time
Resource allocation in frequency

<table>
<thead>
<tr>
<th>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>N</td>
<td>128</td>
<td>256</td>
<td>512</td>
<td>1024</td>
<td>1536</td>
<td>2048</td>
</tr>
<tr>
<td>#alloc RB (in Freq)</td>
<td>6</td>
<td>12</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>#used carrier</td>
<td>72</td>
<td>144</td>
<td>300</td>
<td>600</td>
<td>900</td>
<td>1200</td>
</tr>
<tr>
<td>Oversampling</td>
<td>1.78</td>
<td>1.78</td>
<td>1.71</td>
<td>1.71</td>
<td>1.71</td>
<td>1.71</td>
</tr>
<tr>
<td>Max Rate [Mb/s]</td>
<td>6</td>
<td>12</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>

Max Rate is for 64-QAM, i.e. 6 bit/carrier
Then \( R = \#carrier \cdot 6 \cdot 7 \cdot 2 \cdot 10 \cdot 100 \) [b/s]
Impact of control signals and error control is not included
Example
One OFDM symbol for BW=10 MHz and 64-QAM
Example
One OFDM symbol for BW=10 MHz and 64-QAM

Plot of (all) frequency domain samples as I-Q
4G mobile networks

- Packet Network: EPC
  - Data plane: PGW & SGW
  - Control plane: MME & HSS
  - In core network

- Access Network: LTE (E-UTRAN)
  - Up to 20 MHz bandwidth (=> 100 Mbps)
  - OFDM signaling
What comes next 1
BBU hoteling

Radio unit (RU)
• BB samples to RF signal
  • Digital/analog conversion
  • Mixing to RF
  • AFE

Baseband unit (BBU)
• Binary data to BB samples
  • QAM mapping
  • IFFT
  • Coding
What comes next 1

BBU hoteling

To utilize recourses better split BBU and RRU in network

- Use CPRI to transmit BB samples between BBU and RRU

Problem: Data rate expansion in transmission of radio samples of approximately a factor 10
What comes next 2
Small cells

- Small cells work in
  - Short distance (low power)
  - High data rate (few users)
  - In public places, offices, shopping malls, etc
  - Even plans for small cells in homes
    - Instead or together with WiFi?

Problems
- How to backhaul/fronhaul
- Can they be part of coordination?
  - Pico cell: with coordination
  - Femto cell: no coordination
What comes next 3
Converged network

- Users becomes more mobile
  - When price and rate differences diminish most user will not care about choice of connection
- Convergence:
  - One network, many accesses
  - Flexible network
  - One AAA (and pricing)
  - Handover between e.g. LTE-WiFi
  - Dual connections and traffic off-loading
  - All units everywhere
- Problem:
  - Partly new network structure (e.g. common IP edge)
What comes next 3
Converged network

Fixed or mobile network (separated, SoA)

Fixed and mobile network (converged network)
What comes next 4

5G

- Roughly a factor of 10 in performance
  - 10 times faster, bandwidth, Data rate, etc
  - 10 battery life (for low power devices)
  - 1000 times traffic volume
  - 10 times harder (at least)
- Small cells everywhere
- M2M; Everything is connected
  - Car2Car, IoT, Skynet, ...
- Expected to launch latest 2020
- Problems:
  - Backhaul/fronthaul, RAN sync, Energy efficiency, etc