Lecture 13
UMTS
Long Term Evolution
Beyond 3G

- International Mobile Telecommunications (IMT)-2000 introduced global standard for 3G
- Systems beyond IMT-2000 (IMT-Advanced) are set to introduce evolutionary path beyond 3G
  - Mobile class targets 100 Mbps with high mobility and nomadic/local area class targets 1 Gbps with low mobility
- 3GPP and 3GPP2 are currently developing evolutionary/revolutionary systems beyond 3G
  - 3GPP Long Term Evolution (LTE)
  - 3GPP2 Ultra Mobile Broadband (UMB)
- IEEE 802.16-based WiMax is also evolving towards 4G through 802.16m
3GPP Evolution

- Release 99 (Mar 2000): UMTS/WCDMA
- Release-5 (Mar 2002): HSDPA
- Release-6 (Mar 2005): HSUPA
- Release-7 (2007): DL MIMO, IMS (IP Multimedia Subsystem), optimized real-time services (VoIP, gaming, push-to-talk)
- Long Term Evolution (LTE)
  - 3GPP work started in Nov 2004
  - Standardized in the form of Release 8
  - Spec finalized and approved in Jan 2008
  - Target deployment starting from 2010
  - LTE-Advanced study in progress

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IEEE 802.16 Evolution

➔ 802.16 (2002): Line-of-sight fixed operation in 10 to 66 GHz
➔ 802.16a (2003): Air interface support from 2 to 11 GHz
➔ 802.16d (2004): Minor improvements
➔ 802.16e (2006): Support for vehicular mobility and asymmetrical links
➔ 802.16m (2011): Higher data rate, reduced latency, efficient security mechanisms
Requirements of LTE

- **Peak data rate**
  - 100 Mbps DL/50 Mbps UP within 20 MHz bandwidth

- **Up to 200 active users in a cell (5 MHz)**

- **Less than 5 ms user-plane latency**

- **Mobility**
  - Optimized for 0-15 Km/h
  - 15-120 Km/h supported with high performance
  - Supported up to 350 Km/h or even up to 500 Km/h

- **Enhanced multimedia broadcast multicast service (E-MBMS)**

- **Spectrum flexibility: 1.25-20 MHz**

- **Enhanced support for end-to-end QoS**
LTE Enabling Technologies

- OFDM (Orthogonal Frequency Division Multiplexing)
- SC-FDMA (Single Carrier FDMA)
- MIMO (Multi-input Multi-output)
- Multicarrier channel-dependent resource scheduling
- Fractional frequency reuse
**LTE Enabling Technologies**

**Single Carrier FDMA (SC-FDMA)**

- A new multiple access technique which has similar structure and performance to OFDMA
  - Linearly pre-coded OFDMA
  - Utilizes single carrier modulation and orthogonal frequency multiplexing using DFT-spreading in the transmitter and frequency domain equalization in the receiver
- Low PAPR respect to OFDMA
Key Features of LTE

- **Multiple access scheme**
  - DL: OFDMA; UP: SC-FDMA

- **Adaptive modulation and coding**
  - DL/UP modulations: QPSK, 16QAM and 64QAM
  - Convolutional codes and Rel-6 turbo codes

- **Advanced MIMO spatial multiplexing techniques**
  - (2 or 4)x(2 or 4) downlink and uplink supported
  - Multi-user MIMO

- **TDD/FDD**

- **H-ARQ, mobility support, rate control, security, etc.**
**LTE Standard Specifications**

- Downloadable from 3GPP

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<th>Specification index</th>
<th>Description of contents</th>
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<td>Equipment requirements: Terminals, base stations, and repeaters.</td>
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<td>TS 36.2xx</td>
<td>Physical layer.</td>
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<td>TS 36.3xx</td>
<td>Layers 2 and 3: Medium access control, radio link control, and radio resource control.</td>
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<td>TS 36.4xx</td>
<td>Infrastructure communications (UTRAN = UTRA Network) including base stations and mobile management entities.</td>
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Protocol Architecture
LTE Network Architecture


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### LTE Network Architecture

- **eNB: enhanced Node B**
  - All radio interface-related functions
- **MME: Management Mobility Entity**
  - Manages Mobility, UE identity and security parameters
- **S-GW: Serving Gateway**
  - Node that terminates the interface towards E-UTRAN
- **P-GW: Packet Data Network Gateway**
  - Node that terminates the interface towards PDN
LTE Network Interfaces

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Nodes’ Functionalities

- eNB
  - Inter Cell RRM
  - RB Control
  - Connection Mobility Cont.
  - Radio Admission Control
  - eNB Measurement
    - Configuration & Provision
  - Dynamic Resource Allocation (Scheduler)
  - RRC
  - PDCP
  - RLC
  - MAC
  - PHY

- E-UTRAN

- MME
  - NAS Security
  - Radio State Mobility Handling
  - EPS Bearer Control

- S-GW
  - Mobility Anchoring

- P-GW
  - UE IP address allocation
  - Packet Filtering

- EPS: Evolved Packet System

- RRM: Radio Resource Management
- RB: Radio Bearer
- RRC: Radio Resource Control
- PDCP: Packet Data Convergence Protocol
- NAS: Non-Access Stratum
Protocol Stacks

*3GPP TS 36.300*
Radio Interface
Frame Structure

- Two radio frame structures
  - Type 1: FS1 FDD
  - Type 2: FS2 TDD

- A radio frame has a duration of 10 ms

- A resource block (RB) spans 12 subcarriers over a slot duration of 0.5 ms
  - One subcarrier has a 15 KHz bandwidth, thus 180 KHz per RB
Frame Structures

→ FDD

One radio frame = 10 ms
One slot = 0.5 ms

#0 #1 #2 #3

One subframe = TTI (Transmission Time Interval)

→ TDD

One radio frame = 10 ms
One half-frame = 5 ms
One subframe = 1 ms
One slot = 0.5 ms

DwPTS GP UpPTS DwPTS GP UpPTS

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Resource Grid

One radio frame

Slot #0

Resource block

$= N_{symb} \times N_{RB}^{RR}$ resource elements

Resource element

Subcarrier (frequency)

$N_{RB} \times N_{RB}^{RR}$

$N_{RB}^{RR} = 12$

OFDM/SC-FDMA symbol (time)

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## LTE Bandwidth/Resource Configuration

<table>
<thead>
<tr>
<th>Channel bandwidth [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>Number of resource blocks ($N_{RB}$)</td>
<td>6</td>
<td>15</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</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>IDFT(Tx)/DFT(Rx) size</td>
<td>128</td>
<td>256</td>
<td>512</td>
<td>1024</td>
<td>1536</td>
<td>2048</td>
</tr>
<tr>
<td>Sample 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>
<tr>
<td>Samples per slot</td>
<td>960</td>
<td>1920</td>
<td>3840</td>
<td>7680</td>
<td>11520</td>
<td>15360</td>
</tr>
</tbody>
</table>

*3GPP TS 36.104*
Bandwidth Configuration Example

- DL or UL symbol
- Resource block
- frequency
- 1 slot
- time

\[ N_{RB}^{sc} = 12 \quad (180 \text{ kHz}) \]
\[ N_{RB} \times N_{RB}^{sc} = 300 \quad (4.5 \text{ MHz}) \]
\[ M = 512 \quad (7.68 \text{ MHz}) \]

* 5 MHz system with frame structure type 1

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LTE Physical Channels

⇒ A set of subcarriers lasting some symbols
⇒ **DL:**
  ⇒ Physical Broadcast Channel (PBCH)
  ⇒ Physical Control Format Indicator Channel (PCFICH)
  ⇒ Physical Downlink Control Channel (PDCCH)
  ⇒ Physical Hybrid ARQ Indicator Channel (PHICH)
  ⇒ Physical Downlink Shared Channel (PDSCH)
  ⇒ Physical Multicast Channel (PMCH)
⇒ **UP:**
  ⇒ Physical Uplink Control Channel (PUCCH)
  ⇒ Physical Uplink Shared Channel (PUSCH)
  ⇒ Physical Random Access Channel (PRACH)
LTE Transport Channels

**DL:**
- Broadcast Channel (BCH)
- Downlink Shared Channel (DL-SCH)
- Paging Channel (PCH)
- Multicast Channel (MCH)

**UP:**
- Uplink Shared Channel (UL-SCH)
- Random Access Channel (RACH)
LTE Logical Channels

→ **Control channels for control-plane info**

- Broadcast Control Channel (BCCH)
- Paging Control Channel (PCCH)
- Common Control Channel (CCCH)
- Multicast Control Channel (MCCH)
- Dedicated Control Channel (DCCH)

→ **Traffic channels for user-plane info**

- Dedicated Traffic Channel (DTCH)
- Multicast Traffic Channel (MTCH)
Channel Mappings

Downlink

Uplink

Logical channels

Transport channels

Physical channels

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LTE Layer 2

ROHC: Robust Header Compression

* 3GPP TS 36.300

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RRC Layer

- Terminated in eNB on the network side
  - Broadcast, Paging
  - RRC connection management
  - Radio Bearer management
  - Mobility Functions
  - UE measurement reporting and control

- RRC states:
  - RRC_IDLE, RRC_CONNECTED
Resource Scheduling of Shared Channels

- Dynamic resource scheduler resides in eNB on MAC layer
- Radio resource assignment based on radio condition, traffic volume and QoS requirements
- Radio resource assignment consists of:
  - Physical Resource Block (PRB)
  - Modulation and Coding Scheme (MCS)
Radio Resource Management

- Radio Bearer Control (RBC)
- Radio Admission Control (RAC)
- Connection mobility Control (CMC)
- Dynamic resource allocation (DRA) or packet scheduling
- Inter-cell interference coordination (ICIC)
- Load Balancing (LB)
- Other: ARQ, H-ARQ, Rate Control, DRX, QoS, Security
DL Physical Channel Processing

1. Scrambling
2. Modulation mapping
3. Layer mapping
4. Precoding
5. Resource element mapping
6. OFDM signal generation

MIMO-related processing:
- Mapping onto one or more transmission layers
- Generation of signals for each antenna port
- IDFT operation
DL Reference Signal

Cell-specific Random Sequence is generated as the symbol-by-symbol product of an orthogonal sequence (OS) and a pseudo-random sequence (PRS)

- 3 different OS and about 170 different PRS
- Each cell (sector) ID corresponds to a unique combination of one OS and one PRS – 510 unique cell IDs

CDM of RS for cells of the same eNB, FDM of RS for each antenna in case of MIMO
DL MIMO

- Supported up to 4x4 configurations
- Support for both spatial multiplexing (SM) and TX diversity
  - SM
    - Unitary precoding based scheme based on feedback from user
  - TxD: maximum combining, switched TxD
- MU-MIMO supported
UL Resource Block

- Resource block (RB)
- Reference symbols (RS)
- 1 slot (0.5 ms)
- One SC-FDMA symbol

*PUSCH with normal CP
UL Physical Channel Processing

1. Scrambling
2. Modulation mapping
3. Transform precoding
4. Resource element mapping
5. SC-FDMA signal generation
6. DFT-precoding
7. IDFT operation

SC-FDMA modulation
SC-FDMA Modulation in LTE UP

One SC-FDMA symbol

Localized mapping with an option of adaptive scheduling or random hopping.

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UL Random Sequence Multiplexing

- For SIMO: FDM between different users
- For SU-MIMO: CDM between RS from each antenna
- For MU-MIMO: CDM between RS from each antenna
Cell Search

- **UE** acquires time and frequency synchronization with a cell and detects the cell ID of that cell
  - Based on BCH and hierarchical Synchronization signals
- **Primary-SCH and Secondary-SCH** are transmitted twice per radio frame for FDD
- **Cell search:**
  - 5 ms timing identified using P-SCH
  - Radio timing and group ID from S-SCH
  - Full cell ID from DL RS
  - Decode BCH
Random Access

- Open loop power controlled with power ramping
- RACH signal bandwidth: 1.08 MHz (6RBs)

* $T_{CP} = 0.1$ ms, $T_{GP} = 0.1$ ms

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