Today's Topics

1. Introduction (History and UMTS overview)
2. Radio Access Network Architecture
3. Spreading, Scrambling, Multiplexing, Coding
4. Transmit Power Control (Inner- and Outer Loop)
5. Space-Time Transmit Diversity
6. Rake receiver and its performance, soft handover
7. High Speed Downlink Packet Access (Rate Adaptation and Hybrid ARQ)
8. Advanced Receivers for HSDPA
9. Multimedia Broadcast Multicast Service (MBMS)
10. System Architecture Evolution (eNobe B cooperation)
11. Long Term Evolution (MIMO OFDM)
12. MIMO Systems
UMTS Long Term Evolution: Evolved UMTS Radio Access Network

The Radio Access Network becomes even more meshy

Source: LTE Forum 2007 @ R&S, München
Evolved UMTS Radio Access Network

- **eNode B**: Evolved Node B (UMTS LTE Base Station)
- **RNC**: Radio Network Controller
- **MSC**: Mobile Switching Center
- **PSTN**: Public Services Telecommunications Network
- **SGSN**: Servicing GPRS Switching Node
- **GGSN**: Gateway GPRS Switching Node
- **UE**: User Equipment / Mobile Station
- **UTRAN**: UMTS Terrestrial Radio Access Network
- **CN**: Core Network

15 May 2009
Fractional Re-Use: Users near the base station re-use the same frequencies (OFDM sub-carriers), whereas users at the cell boarder are allocated to sub-carriers in a co-ordinated manner.
UMTS LTE Frequency Re-use

Figure 14.2 Example of inter-cell interference coordination, where parts of the spectrum is restricted in terms of transmission power.

Source:

A scheme for re-allocating the bandwidth from the partial re-use region to the full re-use region is shown in Fig. 3.

Fig. 3. Proposed model for frequency reuse pattern and bandwidth partitioning
The cell capacity is defined as the sum capacity of the full- and partial re-use regions

\[ C = C_{FR} + C_{PR} \]

The expressions for the individual capacities are calculated by integrating capacity density over the corresponding region

\[ C_{FR} = 2\pi \int_0^\rho B_{FR} \log_2 \left( 1 + \frac{\Gamma_e}{r^\alpha [1 + \Gamma_e S(r)]} \right) r\,dr \]

\[ C_{PR} = 2\pi \int_\rho^1 3B_{PR} \log_2 \left( 1 + \frac{\Gamma_e}{r^\alpha} \right) r\,dr \]

The optimization problem for maximizing the cell capacity is

\[
\text{maximize} \quad C \\
\text{subject to} \quad 0 \leq \rho \leq 1
\]
Fractional Re-Use: Users near the base station re-use the same frequencies (OFDM sub-carriers), whereas users at the cell boarder are allocated to sub-carriers in a co-ordinated manner.
UMTS LTE simplified PHY processing for Downlink Shared Channel

Figure 15.7  Simplified physical-layer processing for DL-SCH.

UMTS LTE Turbo Encoder

Figure 16.11  LTE Turbo encoder.

UMTS LTE simplified PHY processing for Downlink Shared Channel

1 or 2 transport blocks of dynamic size per TTI

Hybrid-ARQ

CRC

Coding, rate matching

Data modulation

Antenna mapping

Resource mapping

Hybrid-ARQ

CRC check

Decoding

Data demodulation

Antenna demapping

Resource demapping

MAC

PHY

ACK/NAK

Hybrid-ARQ info

Redundancy version

Modulation scheme

Antenna assignment

Resource assignment

eNodeB

mobile terminal

Figure 15.7  Simplified physical-layer processing for DL-SCH.

Data Modulation

- Switching between two modulation formats is possible: 4-QAM, 16-QAM, and 64-QAM.
UMTS LTE simplified PHY processing for Downlink Shared Channel

1 or 2 transport blocks of dynamic size per TTI

MAC scheduler

Hybrid-ARQ

ACK/NAK

Hybrid-ARQ info

Redundancy version

Modulation scheme

Antenna assignment

Resource assignment

CRC

Coding, rate matching

Data modulation

Antenna mapping

Resource mapping

eNodeB

Hybrid-ARQ

ACK/NAK

Hybrid-ARQ info

Redundancy version

Error indication

CRC check

Decoding

Data demodulation

Antenna demapping

Resource demapping

mobile terminal

Figure 15.7  Simplified physical-layer processing for DL-SCH.

15 May 2009
Antenna Mapping

Figure 16.19  LTE antenna mapping consisting of layer mapping followed by pre-coding. Each square corresponds to one modulation symbol.

Antenna Mapping

![Diagram showing Antenna Mapping]

**Figure 16.20** Two-antenna Space-Frequency Block Coding (SFBC) within the LTE multi-antenna framework.

Antenna Mapping

Figure 16.21  *Beam-forming within the LTE multi-antenna framework.*

Figure 16.22  *Spatial multiplexing within the LTE multi-antenna framework (N_L = 3, N_A = 4).*
UMTS LTE simplified PHY processing for Downlink Shared Channel

Figure 15.7  Simplified physical-layer processing for DL-SCH.

Downlink carriers are grouped into resource blocks which occupy rectangular areas in the time-frequency domain:

1 resource block = 12 carriers x 0.5ms

DC subcarrier is not used (similar like WLAN)
UMTS LTE downlink time-frequency structure

\[ \Delta f = 15 \text{kHz} \]

One resource block (12 \cdot 7 = 84 resource elements)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{umltd_time_frequency.png}
\caption{Downlink resource block assuming normal cyclic prefix, i.e. seven OFDM symbols per slot. With extended cyclic prefix there are six OFDM symbols per slot and, consequently, a total of 72 resource elements in a resource block.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{umltd参考.png}
\caption{LTE downlink reference-signal structure assuming normal cyclic prefix, i.e. seven OFDM symbols per slot.}
\end{figure}

UMTS LTE is based on Orthogonal Frequency Division Modulation.

Sub-carrier spacing $\Delta f = 15$ kHz

Source: 3GPP
UMTS LTE is based on Orthogonal Frequency Division Modulation

- The sub-carrier spacing $\Delta f = 15$ kHz was chosen to make the design of dual-mode UMTS/LTE handsets easier.
- The corresponding required sampling rate is:

$$f_s = 15000N_{\text{FFT}} \text{ Samples / s}$$

Therefore, the sampling rate is an easy rational multiple of the UMTS chiprate 3.84 Mchip/s

$$\frac{3.84 \text{MHz}}{15 \text{kHz}} = 256$$
UMTS LTE is based on Orthogonal Frequency Division Modulation

Multiple-Input Multiple-Output Systems
MIMO
Channel Capacity for SISO System

Electro–magnetic waves via empty space:

\[ R < B \cdot \log_2 \left( 1 + \frac{E_b}{N_0} \cdot \frac{R}{B} \right) \]

bit rate \( \approx \) bandwidth \( \cdot \) logarithm of energy

Bit rate is linear in bandwidth, but logarithmic in energy.

Channel Capacity for SIMO System

Electro–magnetic waves via empty space:

\[ R < B \cdot \log_2 \left( 1 + \frac{2E_b}{N_0} \cdot \frac{R}{B} \right) \]

bit rate \( \approx \) bandwidth \cdot \text{logarithm of energy}

bit/s \hspace{1cm} \text{Hz} \hspace{1cm} \text{bit}

Channel Capacity for MISO System

Electro–magnetic waves via empty space:

\[ R < B \cdot \log_2 \left( 1 + \frac{2E_b}{N_0} \cdot \frac{R}{B} \right) \]

bit rate ≈ bandwidth \cdot \text{logarithm of energy} bit/s Hz

Channel Capacity for MIMO System

Electro-magnetic waves via empty space:

\[ R < B \cdot \log_2 \det \left( \mathbf{I} + \mathbf{H}^H \mathbf{H} \frac{E_b}{N_0} \cdot \frac{R}{B} \right) \]

\[ = 2B \cdot \log_2 \left( 1 + \frac{E_b}{N_0} \cdot \frac{R}{B} \right) \quad \text{for} \quad \mathbf{H} = \mathbf{I} \]

Electro-magnetic waves via empty space:

\[ R < B \cdot \log_2 \det \left( \mathbf{I} + \mathbf{H}^\dagger \mathbf{H} \cdot \frac{E_b}{N_0} \cdot \frac{R}{B} \right) \]

\[ \approx 2B \cdot \log_2 \left( 1 + \frac{E_b}{N_0} \cdot \frac{R}{B} \right) \quad \text{for} \quad \mathbf{H} \neq \mathbf{I} \]
From 3.9G to 4G

- 4G
  - OFDM
  - Cooperative communications
    - Ad hoc MIMO relaying
    - Cognitive radio in the spatial domain
  - Multiuser MIMO techniques are integrated
  - Interference management
    - Interference alignment
    - Network coordinates the radio resource access, coding, and modulation among interfering links.
- and more new stuff
3GPP Releases

- **Release 99**
  - 3GPP Release 99 contains a couple of serious bugs
  - A debugged 3GPP R’99 is in operation in Japan („FOMA“)

- **Release 4**
  - Rake receivers, 2x1 Alamouti, selective repeat ARQ

- **Release 5**
  - HSDPA (commercially marketed in Austria, March 2006)
  - All-IP networking as an option

- **Release 6**
  - All-IP networking

- **Release 7**
  - MIMO extensions, 4 Tx antennas

- **Release 8**
  - 64-QAM