LTE - Signaling & Layer 1 Design incl. TDD

Course Duration:

- 3 days

Course Description:

- The course explains not only the concepts of LTE's Layer 1 but also demonstrates how the higher layer are built on top of the physical layer.
- We describe the behavior of higher layers (e.g. RLC/MAC, RRC and NAS and above) which are in one way or the other similar to EGPRS, HSPA and HSPA+. However, LTE's new Layer 1 concept allows to simply higher layers, particular RLC and RRC.
- The 1st chapter states the key concepts of LTE which are summarized as PS-Domain only, Hard Handover only (no RNC), OFDMA with Frequency Domain Scheduling, fast layer 1 resource allocation with HARQ, support of various MIMO modes (Transmit Diversity, Beamforming, Spatial Multiplexing and Multi-User MIMO), new evolved Core-network and above all an All IP network architecture with End-to-End QoS enforcement.
- At the end of chapter 1 we show how the UE attaches in LTE and gets it IP-address or IP-addresses immediately allocated <=> Default EPS Bearer activation as network initiated procedure.
- The 2nd chapter is all about MIMO and how the various Transmission Modes get configured and reconfigured using RRC. We explain the differences between downlink control information (DCI) and Transmission Mode (tm) and the fact that Transmit Diversity is an inherent fallback for all MIMO modes.
- We teach the relation ship between downlink SINR to CQI(s), Rank Indication and Precoding Matrix derivation.
- Special emphasis is put on the transmission 2, 3, 4, 5 and 7 which are related to SFBC (Transmit Diversity), Open Loop Spatial Multiplexing, Closed Loop Spatial Multiplexing, Multi-User MIMO and UE specific Reference Signal (Single Layer beamforming).
- All UE categories support all MIMO modes (tm 1 to tm 6) except Spatial Multiplexing (tm 3, tm 4) and Beamforming using Transmission Mode 7 and higher (enhanced Dual Layer Transmission).
- In chapter 2 we also lay the foundation of LTE's time-frequency grid and dive into the details of OFDMA design as well the uplink Single Carrier Concept with its advantage of lower PAPR (peak-to-average power ratio) compared to ordinary OFDM.
- The 3rd chapter explains UE's sensitivity requirements in LTE and dives then into the time-frequency grid of all physical control and data bearing channels.

- We explain the allocation of cell-specific and UE-specifc Reference Signals in a Resource Block for uplink and downlink and guide the student to the calculation of llevel-based RSRP and quality-based RSRQ measurements

- Further we show the peculiar design and use cases of Chadoff-Zhu sequences being used e.g. for Primary Synchronization Signals, uplink Sounding Reference Signals and Random Access Preambles.

- Special focus is put on the design of the uplink PUCCH which is used as a combined control channel by any other UE's as well for periodical reporting of CQI, PMI and RI but also Ack/Nack reporting and Scheduing Request.

- At the end of the chapter 3 we give the user an deep insight to LTE's layer procedures like Cell Search, Random Access, uplink Power Control, and Timing Advance.

- In chapter 4 we describe how RRC configures and reconfigures the lower layers in UE including the physical layer using RRC Connection Setup and RRC Connection Reconfiguration message.

- Quite some time is dedicated to Multi-RAT aspects of LTE and measurements of other RAT's using Measurement Gaps.

- We also highlight UE's Feature Group Indicator List which allows early UE implementation without waiting for proper Interoperability tests with E-UTRAN

- Radio Link Failure and RLC unrecoverable error are explained in order to provide a good understanding how the UE drops in LTE.

- For Operators OPEX saving LTE enforces that UE's in the field can be used for drive test minimization when doing Automatic Neighbor Reporting (LTE and Other RAT neighbors).

- At the end of the chapter we highlight LTE's fast Hard Handover performance.

- In the 5th chapter we look into the features of MAC, RLC and PDCP. We explain how the MAC-, RLC- and PDCP-header looks like with various Control fields and particular how Logical Channel multiplexing is realized by MAC.

- We explain particular MAC procedures like short/long DRX-cylce's, Semi-persistent Scheduling and Buffer Status Reporting.

- The RLC supports flexible PDU-size with Resegmentation in case of RLC-Acknowledged mode

- The PDCP-header compression for VoIP is explained in order to make the Voice over LTE efficient as particular RTP/UDP/IPv6 represent quite an overhead compared compared to AMR 12.2 kbit/s.

- The 6th and final chapter shows the difference between Frame Structure Type 1 and 2 (TDD) and particiular highlights the changes in Layer 1, HARQ and MAC. Higher layers are not affected by TDD operation.

Prerequisites:

- The participant must have already good experience in Mobile Networks and a deep understanding of wireless communications like GSM or UMTS or other systems e.g. CDMA..

Course Target:

- The student is enabled to understand the concepts of the LTE's physical layer procedures.
- The student is able to develop and to test Layer 1 MIMO features like SFBC, large Cyclic Delay Diversity or Closed Spatial Multiplexing with Beamforming.
- The student will be enabled to effectively communicate Layer 1 Design Issues to his/her peers.

Some of your Questions that will be answered:

- What are the bandwidths needs of various UE categories to support the max throughput?
- How is the UE able and how is it commanded to read Cell-ID's (Cell Global Identities) in UMTS, GSM and LTE as part of the ANR feature set of LTE?
- What are the new bands and required bandwidths for each band the UE's need to support?
- What are the new Physical and Transport Channels in LTE and how are new physical (reference) signals being used?
- What are the new signaling nodes and interfaces the E-UTRAN and EPC consists of ?
- How are the EPS-Bearers mapped on Data Radio Bearers and how are these mapped onto Logical Channels?
- What Downlink Control Information are used for System Information Transfer, Paging and Random Access Response?
- What are the DCI's for supporting the various MIMO respectively downlink Transmission Modes
- With what Reporting Mode should the UE report 2 x CQI's and when should it report Rank Indication and Precoding Matrix Indication?
- What are the differences between periodical reporting using PUCCH and aperiodic reporting using PUSCH?
- How does the Sampling Clock of 30.72 MHz relate to 15 kHz subcarrier spacing with 20 MHz bandwidth how do lower bandwidths of 15 MHz, 10 MHz, 5 MHz, 3 MHz and 1.4 MHz go along with lower sampling frequencies?
- What is the gain of SC-FDMA in uplink compared to pure OFDM in downlink?
- Can the fundamental Resource Block in LTE support an voice call using AMR-codec?

Who should attend this Course:

- Test engineers who need to understand the details of the LTE Layer 1 implementation.
- Design staff of handsets and E-UTRAN who require a deep inside view of the LTE physical layer performance.

Table of Content:

⇒ X2 User Plane Protocol Stack

- **Overview Channels of E-UTRAN**

⇒ Channel Types
Logical Channels, Transport Channels, Physical Channels

⇒ Introducing Logical Channels of E-UTRAN
BCCH – Broadcast Control Channel, PCCH – Paging Control Channel, CCCH – Common Control Channel , MCCH – Multicast Control Channel (from Rel. 9 onwards), DCCH – Dedicated Control Channel, DTCH – Dedicated Traffic Channel, MTCH – Multicast Traffic Channel (from Rel. 9 onwards)

⇒ Introducing Transport Channels of E-UTRAN
RACH – Random Access Channel, UL-SCH – Uplink Shared Channel, BCH – Broadcast Channel , PCH – Paging Channel, MCH – Multicast Channel, DL-SCH – Downlink Shared Channel

⇒ Physical Channels of E-UTRAN
PBCH, PDCCH, PCFICH, PUCCH, PRACH, PHICH, PDSCH, PMCH, PUSCH, Downlink reference signal, Primary and secondary synchronization signal, Uplink reference signal or UL pilot symbol, Uplink sounding reference signal (SRS), Random Access Preamble

⇒ Mapping of Channels in E-UTRAN

- **Attachment through E-UTRAN / new MME**
EMM Combined Attach Request & Accept , Established User Bearers and Channel Types after Default EPS Bearer Activation

⇒ Network Layout and Important Identifiers
Organization of the E-UTRAN, Tracking Areas, NAS Identifiers of the UE (Mobility Management), M-TMSI and S-TMSI, UE-ID for Paging in legacy GSM, GPRS and UMTS as well in E-UTRAN, GUTI (Globally Unique Temporary UE Identity), Conversion of LAI/RAI and TMSI resp. P-TMSI to GUTI

2 Key Technologies of the LTE Physical Layer

- **Generic Assessment of Smart Antenna Techniques**

⇒ Physical Basics of the Multipath Dimension
Signal Fading and Alteration between Tx and Rx, Scattering, Refraction, Reflection, Diffraction, Consequences for the different Signal Paths, Macro-Diversity vs Micro-Diversity, Spatial Multiplexing Introduction

⇒ Spatial Multiplexing - “True” MIMO
MIMO and AAS combined = multiple rank beamforming, When MIMO fails, The Codebook – Rank & Precoding Vectors, Optimum beamforming weights, Signaling of sub-optimum beamforming weights, Signaling of used Smart Antenna Algorithms, Conditions for closed loop algorithms, Conditions for open loop algorithms, PDCCH scheduling indications, Single User- vs Multi User-MIMO, MIMO Channel Matrix -Spatial Multiplexing

⇒ STBC and SFBC

⇒ Transmit Beamforming – suboptimum Beamforming

⇒ Smart Antenna Techniques in LTE
Overview, Receive Diversity, SFBC (for 2 TX-Antenna Ports), SU-MIMO, MU-MIMO, Transmit Beamforming, Processing Chain and Terminology, Purpose of Scrambling in LTE, The Term: "Codeword" (CW), The Term: "Layer" – Spatial Layer, The Term: "Precoding", Cyclic Delay Diversity (CDD), Antenna Port vs Antenna

- **Transmission Modes and signaled DCI**

⇒ Overview on Rank Indicator & Transmission Mode (2 TX)
Single Antenna Port 0 – Transmission Mode 1, Closed Loop Rank 1 Beamforming – Transmission Mode 6, Closed Loop SM or Open Loop SM (Large Delay CDD) – TM3 and TM4, Transmit Diversity (SFBC) – Transmission Mode 2

⇒ Overview on Rank Indicator & Transmission Mode (4 TX)

⇒ Single Antenna Port:0 – "Transparent" Precoding (TM 1)

⇒ Transmit Diversity – SFBC (Space Frequency Block Coding) Details for 2 Antenna-ports (TM 2)

⇒ Closed Loop Rank 1 Beamforming (e.g. TM 6 or fallback of TM 4)
General beam-forming

⇒ Closed Loop Spatial Multiplexing (TM 4) - 2 TX Ports

⇒ Open Loop Spatial Multiplexing - large CDD
Cyclic-delay diversity

⇒ Taxonomy of Antenna Configurations in Rel. 8
Physical Antenna Categorization, Antennas for MIMO

- **OFDM (Orthogonal Frequency Division Multiplex)**

⇒ The Multipath Phenomenon
Single Carrier Modulation and Channel Equalization, Delay Spread, Multipath-induced Time Delays result in ISI

⇒ Technique behind OFDM – FFT (Fast Fourier Transform)
Basics on FFT / IFFT , IFFT/FFT processing , How does the FFT process keep the individual modulated carriers from interfering with one another? , How is OFDM implemented ? , What are the downsides to OFDM? , And what is OFMDA? , How is OFDMA accomplished?

⇒ Simple OFDM Processing Chain

⇒ Impact of Orthogonality in the Frequency Domain
Practical Exercise: Physical Basics of OFDM / OFDMA

⇒ OFDM / OFDMA and IFFT
Considering a Discrete Oscillator Array Option, Details of the IFFT Option, Why is it called F a s t Fourier Transformation?, Considering UMTS Clock of 3.84 MHz and 15 kHz Subcarrier Spacing

⇒ Modulation Scheme Overview

⇒ Tackling Inter-Symbol Interference (ISI)
Introduction, Delay Spread, Cyclic Prefix (CP), Variable Duration and other Assets of the Cyclic Prefix, Inter Carrier Interference (ICI)

⇒ From generic OFDM/OFDMA to the LTE-Implementation
LTE specific OFDM/FFT and subcarrier Parameters, Time / Frequency View on OFDM: The "Grid", Subcarrier Spacing in LTE, Transmission Bandwidth in LTE, Definition of Radio Frame, Sub-Frame and Slot in LTE, Cyclic Prefix Options in LTE, Definition of Slot, Subframe and Radio Frame, Resource Block Pair and TTI in LTE, Virtual vs Physical Resource Blocks, System Bandwidth and Resource Blocks, Uplink Carrier Leakage – SC-FDMA

- **SC-FDMA**

⇒ Why SC-FDMA? - Amplifier Backoff & Cubic Metric
PAPR of Single-Carrier vs. Multi-Carrier Systems

⇒ The Processing Chain of SC-FDMA

⇒ Example: Processing Data through SC-FDMA
Step 1 : Converting Binary Information into Sub-Symbols, Duration of a single Sub-Symbol, Step 2: Preparation of DFT / Number Conversion

⇒ Step 3: Introducing the Formula of DFT
Transform Precoding for SC-FDMA, SC-FDMA baseband signal generation

⇒ Step 4: Execution of M-Point DFT

⇒ Step 4: Final Result of the DFT: The 4 Subcarriers
Step 5: Shifting the Subcarriers to the Correct Frequency, Power Amplifier Backoff and Cubic Metric

⇒ Step 6: Execution of IFFT on Subcarrier x[0..3]

- **Introducing CAZAC-Sequences (Constant Amplitude Zero Aut-correlation)**

⇒ Reviewing Autocorrelation Properties
Zadoff-Chu Sequence Generation in LTE

3 Physical Layer Details

- **UE Transmitter and Receiver Characteristics**

⇒ UE Maximum Output Power

⇒ UE Receiver Sensitivity for QPSK

⇒ E-UTRA UE's Reference Sensitivity (Chart)

⇒ Fixed Reference Channel for Receiver Requirements (FDD)

- **Deep Dive intoe LTE's Physical Layer**

⇒ Practical Exercise: PHY Throughput Calculation for OFDM

⇒ Mapping Physical Channels to the OFDMA-Grid
Problem Description, Mapping of Downlink Channels and Signals, Primary & Secondary Synchronization Signals and PBCH, Content and Meaning of PSC and SSC, Content and Meaning of the PBCH, PCFICH – Physical Control Format Indicator Channel, PHICH – Physical Hybrid ARQ Indicator Channel , PDCCH – Master Control for uplink & downlink Resource Allocation, Relationship between PDCCH and PDSCH, Range of DCI formats and possible RNTI's, RRC Transmission Mode (tm) and DCI on PDCCH, Example for Downlink Resource Allocation:
DCI-Format 1 / Resource Allocation Type 0, Relationship between PDCCH and PUSCH, Example for Uplink Resource Allocation: DCI-Format 0 / Resource Allocation Type 2

⇒ FDD Time Structure / Frequency Grid in downlink
Reference Signals - Pilot RE's, Synchronization Signals , Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS), Physical Broadcast (PBCH), Physical Control Format Indicator Channel (PCFICH), Physical Downlink Control Channel (PDCCH), PDSCH and PMCH

⇒ Uplink Time-Frequency Grid (FDD)
Uplink Demodulation Reference Signals, Basic Principles behind uplink DRS transmission, Uplink Sounding Reference Signals (SRS), Uplink Layer 1/Layer 2 Control Signaling on PUCCH, Physical Uplink Shared Channel (PUSCH)

- **HARQ & IR for DL-SCH and UL-SCH**

⇒ Principle of Incremental Redundancy (IR)

⇒ Stop & Wait Processes – HARQ RTT in E-UTRAN

⇒ Rate Matching for PDSCH/PUSCH

- **PDSCH and PUSCH Resource Allocation Types**

⇒ Localized versus Distributed RB Allocation
Virtual Resource Block

⇒ Downlink Control Information (DCI) Formats & 'TM'
Transmission Mode for PDSCH, DCI Format Details, Transport Block Size Table (dimension 27 index's ×110 RB's), Modulation and TBS index table for PDSCH

⇒ Resource Block Allocation Type 0, 1 and 2
Resource Allocation Type 0, Resource Allocation Type 1, Resource Allocation Type 2

⇒ Practical Exercise: Derive the allocated RB's of a Resource Allocation Type 1

- **Physical Channel Details**

⇒ Primary and Secondary Sync Signals – FDD vs. TDD
Details on Primary Synchronization Signal (PSS) Sequences, Details on Secondary Synchronization Signal (SSS) Sequences, Cell Search Performance

⇒ Downlink Reference Signals (Pilot)
Common Reference Signals, UE-specific Reference Signal (RS), Practical Exercise: Calculate RSRP and RSRQ, Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ) , LTE Measurements: RSRQ and RSRP

⇒ PBCH Details for FDD
MIB Parameter Details, PBCH Transmission over 40 ms

⇒ Physical Downlink Control Channel PDCCH
PDCCH Formats (CCE's), Blind Decoding of PDCCH , PDCCH Candidates monitored by a UE, PDCCH CRC Attachment and Construction, Scheduling Process

⇒ Physical Downlink Shared Channel (PDSCH)
Downlink Transport Block Processing, Downlink HARQ and Timing

⇒ Physical uplink Shared Channel (PUSCH)
Uplink HARQ Timing

- **Uplink Control Signaling**

⇒ PUCCH and UCI (Uplink Control Indicator)
PUCCH Format 1, 1a and 1b, PUCCH Format 2, 2a and 2b, PUSCH taking over Control Signaling

- **Important Physical Layer Procedures**

⇒ E-UTRAN Cell Search – Blind CP Detection
Synchronization Sequences and Cell Search in LTE, Secondary Synchronization Signal (SSS) Sequences, Cell Search Performance in LTE, Cell Search with Basic NAS and AS Procedure's

⇒ Random Access
PRACH Structure Format 0, Random Access Procedure in E-UTRAN, Contention based and non-contention based random access procedure

⇒ Timing Advance Control
Principle, Procedure, TA while the UE is not synchronized to the eNB, TA while the UE is synchronized to the eNB

⇒ Uplink Power Control Principle (PUCCH and PUCCH)
Uplink Power Control Formulas , Power Control for PUCCH, Power Control for PUSCH

- **Channel Estimation DL**

⇒ Channel Estimation Principle of LTE
The description of the mobile radio channel, Coping with a frequency selective mobile radio channel, Coping with the time variance of the mobile radio channel

⇒ Channel Estimation Downlink
Normal configuration with 4 TX antennas, Normal configuration with less than 4 TX antennas, Extended configuration with 15 kHz subcarrier spacing, Extended configuration with 15 kHz subcarrier spacing for MBSFN, Extended configuration with 7.5 kHz subcarrier spacing for MBSFN

- **UE Throughput Classes**

⇒ Overview – Throughput in downlink and uplink
Classes 1-4, UE class 5

⇒ Calculation of the DL Peak Throughput for LTE UE Class 5

4 RRC Signaling in LTE

- **Differences between UMTS RRC and LTE**

⇒ Reduced User Plane Latency in E-UTRAN

⇒ Reduced Control Plane Latency (State Changes) in LTE

⇒ State Characteristics of RRC (E-UTRAN)
Characteristics of RRC_IDLE, Characteristics of RRC_CONNECTED

⇒ E-UTRAN Signaling Radio Bearers (SRB's)
Overview

⇒ E-UTRA States and Inter RAT Mobility Procedures
RRC_IDLE, RRC_CONNECTED:, Mobility Control in RRC_IDLE and RRC_CONNECTED, Mobility in RRC_IDLE mode, Mobility in RRC_Connected mode , Connection Re-Establishment Procedure, Handover to LTE, Mobility from LTE

- **RRC Messaging**

⇒ End to End Protocol Stack Overview (AS + NAS)

⇒ System Information Broadcasting & Acquisition

⇒ Paging Procedure in E-UTRAN for PS and CS Domain

⇒ Example Message Flows (AS + NAS)
RRC Establishment Procedure including Attach and PDN Connectivity Request , Default EPS Bearer Activation on RRC

⇒ Inter RAT RRC Procedures
Handover to E-UTRA (incoming HO from other RAT), Mobility from E-UTRA (Outgoing - towards other RAT's), Reception of the MobilityFromEUTRACommand by the UE, Inter-RAT cell change order from GERAN to E-UTRAN

- **Handover in LTE**

⇒ UTRAN and E-UTRAN differences in mobility UTRAN

⇒ Measurements

⇒ Report Configuration of Inter-RAT Neighbors (GERAN/UTRAN)

⇒ Example of E-UTRAN Measurement Control
Example for Intra-Frequency Hard HO

⇒ Measurement Events in E-UTRAN

⇒ Event Triggered (Periodical) Reporting
Intra Frequency ANR (Automatic Neighbor Reporting), Intra Frequency ANR Definition

- **NAS Message Transfer (EMM, ESM) and SMS**
- **RRC Procedure Delay**

⇒ Introduction

⇒ Fixed Procedure Delay Values for eNB originated RRC
Conditionally mandatory Release 9 features

- **Measurement Gaps and Compressed Mode**

⇒ Measurement Gaps in LTE

⇒ Compressed Mode in UMTS for E-UTRAN Measurements

- **Rel. 8 Access Stratum Feature Handling & Group Indicator -Early UE Handling**

⇒ First Part of Feature Group Table

⇒ Second Part of Feature Group Table
Rel. 9 Features supposed to be tested

⇒ UMTS Rel. 8 – LTE FGI for Mobility to E-UTRAN
UMTS - UE Multi-mode/Multi-RAT Capability

⇒ Mobility from LTE towards other RAT's & Inter-frequency HO

- **Layer 1 and Layer 2 Drops in LTE**

⇒ Layer 1 Drop – Radio Link Failure
Intra LTE Handover Event A3 – Drop in case of Slow HO, Radio Link Failure – N310 consecutive out of Sync's, Radio Link Monitoring Testing – SNR levels for Qin & Qout

⇒ Cell Selection after Drop – Call Re-Establishment

⇒ RRC Re-establishment Success or Reject
Re-Establishment Failure Cases

- **Intra LTE HHO**

⇒ X2-based Handover Scenario
Initial Conditions, Detailed Description, Seamless Handover

5 RLC/MAC Layer

- **Features of MAC**
  - ⇒ Overview
    Data transfer logical channels ←→ transport channels, Radio resource allocation, Special procedures
  - ⇒ Radio Network Temporary Identifiers (RNTI's) in E-UTRAN
    Usage of RNTI's, RNTI Values
  - ⇒ MAC Random Access Procedure
    Contention Based Random Access Procedure, Non-contention based random access procedure
  - ⇒ Structure of MAC-PDU
    MAC control element, Normal (non-transparent) MAC SDU, Transparent MAC SDU
  - ⇒ MAC Control Elements
    Contention resolution ID, Timing Advance, DRX, Padding, Power headroom report, C-RNTI, Short, long and truncated buffer status reports
  - ⇒ Practical Exercise: MAC Operation
  - ⇒ Practical Exercise: DL MAC PDU Construction
  - ⇒ MAC Configuration
    MAC Configuration in the Standard
- **Features of RLC**
  - ⇒ Overview
    Data transfer, Error detection and recovery, Reset
  - ⇒ Structure of RLC PDU
  - ⇒ Structure of RLC AM with PDCP PDU Segments
  - ⇒ RLC Configuration
    RLC Configuration in the Standard
- **How a TCP/IP MTU is reaching the UE / the Internet**
  TCP/IP layer, PDCP layer, RLC layer, MAC layer, PHY layer

6 Differences between LTE-FDD and LTE-TDD

- **Basic Layer 1 Details of TDD**
  - ⇒ Frame Structure Type 2
    UL and DL time slots, Downlink Pilot Timeslot (DwPTS) – downlink part of special subframe, Uplink Pilot Timeslot (UpPTS) – uplink part of special subframe, Guard Period (GP)
  - ⇒ The Special Subframe in LTE-TDD (DwPTS, GP, UpPTS)
    Configuration of special subframe (lengths of DwPTS/GP/UpPTS, Details on Special Subframe S, Frame structure Type 2 – UpPTS structure (SRS), Frame structure Type 2 – UpPTS structure (P-RACH)
  - ⇒ DL/UL Configurations of LTE-TDD
  - ⇒ LTE TDD Downlink Physical Channels
  - ⇒ UE Specific Reference Signals

⇒ LTE-TDD Synchronization Signals

⇒ LTE-TDD Random Access Channels

⇒ Coexistence between TD-SCDMA and LTE

⇒ TDD Portions in major 3GPP LTE Specifications

- **Radio Resource Management – Beam Forming**

⇒ GOB (GridOfBeam) and EBB (Eigenvalue Based Beamforming)

⇒ Dual-polarized 4+4 Antenna
Calculation of Antenna Weights for Beam Forming, Long Term Beamforming – Beamforming Antennas , Antenna Ports – Virtual Antennas

⇒ Beamforming Transmission Schemes for various Channels

⇒ LTE Beamforming and MIMO Evolution In 3GPP

- **Other Differences between FDD and TDD**

⇒ Max Number of DL HARQ Processes for TDD
HARQ Feedback for Downlink PDSCH Transmissions, ACK/NACK Multiplexing, ACK/NACK Bundling

⇒ Number of Synchronous UL HARQ Processes for TDD
eNodeB's HARQ Indicator for Uplink Transmission , PHICH Assignment Procedure, PHICH/PDCCH Detection - UE needs to do New/Retransmissions

Solutions for practical Exercises