# 5G NSA

RAN & New Radio in first commercial networks

**Course Duration:**

- 2.5 days

**Course Description:**

- This course addresses the needs of technical engineering staff who require a thorough understanding of 5G with clear focus on NSA-implementations. Still, also the majority of stand-alone related topics, especially in the PHY-layer are taken care of in detail.
- This course has been designed to meet the requirements of both: engineering experts to design and test 5G NSA related equipment, in particular on the UE-side and operations staff who require detailed knowledge about 5G NSA network configuration.
- The course starts out with a wrap-up of general 5G-topics like performance, time schedule and overview of technical enhancements.
- This chapter ends with a detailed analysis of NSA <=> EN-DC and the specifics of NSA-operation, especially in the protocol stack and the setup and combination of 4G-frequencies with 5G-frequencies, both FR1 and FR2.
- The whole next chapter is dedicated to RF and PHY-issues of 5G. Starting with a thorough analysis of the specifics of bands in FR1 < 1 GHz, up to 6 GHz and FR 2 > 6 GHz, we describe the particularities of the different subcarrier spacings and how and when they can be deployed.
- We continue with a detailed analysis of example bands like bands N78 / N258 for Europe or bands N5 / N260 for the US-market. Together, we calculate the maximum throughput for each example, considering the transmission bandwidth and the different subcarrier spacings.
- Next, we investigate IMD-related issues of NSA-operation and means to mitigate these issues.
- We also dedicated quite some focus on the analysis of the 5G TDD slot format and which implications and restrictions apply.
- This chapter leaves no questions unanswered w.r.t. channels and signals in 5G with clear focus on physical channels and physical signals, e.g. PSS and SSS and the SS-block.
- Finally, this chapter provides an introduction into LDPC and polar coding with a performance related comparison between LDPC on one hand and convolutional and turbo coding on the other hand.
- Focus of the next chapter is on the PHY operation in 5G, clearly highlighting the differences between stand-alone and non-stand-alone operation.
- We start with a detailed analysis of the cell search procedure in 5G but continue with the description of PDCCH-operation in 5G, introducing BWP and CORESETS. This part ends with a short presentation of all currently defined DCIs.

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- We continue with the random access procedure in 5G, pointing out differences between 4G and 5G.
- Next comes the analysis of Hybrid-ARQ in 5G, pointing out the operation itself and the differences between uplink and downlink HARQ and between HARQ in 4G and in 5G.
- Focus of the next chapter is on mMIMO. Initially, we clarify the terminology and differentiate mMIMO from 2D-MIMO, from beamforming and from spatial multiplexing.
- Then we use practical animations to clarify how beamforming operates physically and how antennas look like to enable beamforming.
- We take a look on practical antenna designs for mMIMO and which performance gain to expect through beamforming depending on different constraints.
- The final chapter is dedicated to the actual operation and signaling to manage NSA-operation. Clear focus is on the radio interface and RRC-signaling but we also investigate the signaling on the terrestrial interfaces, in particular on X2 and S1.
- The course ends with the analysis of signaling procedures like SgNB-addition, SgNB-modification and SgNB-release and present and investigate real-life logfiles and extracts.

**Prerequisites:**

- The students need to have basic understanding of 5G.
- Besides, the students need to be able to interpret ASN.1 PER-unaligned logfiles
- The students must possess detailed understanding of LTE, especially of the PHY-layer.

**Some of your questions that will be answered:**

- How precisely does option 3x operate and how does it differ from other options?
- How does cell search work with 5G? How is it different between stand-alone and non-stand-alone?
- Which bands 4G / 5G are combined with MR-DC in different parts of the world?
- To which degree can beamforming mitigate the additional attenuation from operation in the 3.X GHz bands or even in millimeter wave bands?
- How do active antennas look like and operate for 5G operation?
- Which number of antenna ports provides the optimum performance under which conditions?
- What is vertical beamforming and when does it make sense to deploy it?
- Under which conditions can Inter-Modulation-Distortion (IMD) jeopardize NSA-operation and which options exist to mitigate these RF-related problems?
- When will the UE display the 5G icon to the user?
- What are the implications of deploying different subcarrier spacings with NR?
- Which additional problems arise from TDD-operation in cellular vs FDD-operation?
- What is the meaning of the GSCN and the SS-block pattern?

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- How can NR deploy beam-centric operation already in idle mode?
- Why is there no more DC-subcarrier?
- What are self-contained TTI and dynamic TTI?
- Which reference signals does NR use and how is this different from 4G?
- Which performance gain to expect from mMIMO with more than 8 antenna ports on the network side?
- How does uplink beamforming operate?
- What are the NR- and MR-DC - specific contents of a UE-Radio-Access-Capability Message?
- How is a 5G cell added to an existing RRC-connection?

**Course Target:**

- The students will gain a thorough understanding of 5G operation, with focus on NSA.
- This relates to all operational aspects from PHY to RRC.
- The students are enabled to interpret and investigate upcoming 5G-network and UE-problems and to resolve them, both in the lab and in the field.

**Table of Content:**

## Chapter 1: 5G in a Nutshell (1 – 2 h)

- **Timeline of 5G: NSA / SA / Phase 1 and Phase 2**
- **General Network Topology for 5G:** gNB-CU, gNB-DU, virtualization, network slicing, stand-alone vs. non-stand-alone, mMIMO
- **5G-services: eMBB, URLLC and mMTC**
- **EN-DC:** Dual-Connectivity, Multi-Connectivity, EN-DC, NGEN-DC and NE-DC
- **NSA:** Option 3x vs Option 3 and 3a, other Options
- **Network Architecture with NSA**
- **Main Changes in the Radio**
- **Voice in 5G:** VoNR, Vo5G

## Chapter 2: Digging Deeper into NR (4 - 5 h)

- **Frequency Ranges: FR1 < 1 GHz, 1 GHz – 6 GHz, FR2 > 24.25 GHz**
  Transmission bandwidth, FFT-size, subcarrier spacings, guard bands
- **Paving the way to the 5G NR: Reviewing OFDM-Properties with LTE / LTE-A:** Radio frame, subframe and slot, TTI, cyclic prefix, achievable performance in LTE
- **Details of the different Numerologies:**
  F-OFDM Configuration with $\Delta f = 15$ kHz
  From $\Delta f = 15$ kHz to $\Delta f = 30$ kHz, $\Delta f = 60$ kHz, $\Delta f = 120$ kHz and $\Delta f = 240$ kHz
  Summarizing the Numerologies
- **Frequency Bands and their Characteristics**
  Example 1 < 1 GHz: Bands N5, N28: Channel Raster, GSCN, No of RB's, max performance, etc.
  Example 2 < 6 GHz: Bands N78: Channel Raster, GSCN, No of RB's, max performance, etc.
  Example 3 > 24.25 GHz: Bands N258, N260: Channel Raster, GSCN, No of RB's, max performance
- **Frequency planning for 4G / 5G EN-DC operation in different parts of the world (APAC, EU, Americas)**
- **Sweeping beams: mitigating the high attenuation of 3.X GHz (only introduction with animation, details in chapter 4)**
- **5G TDD-operation in 3.4 – 3.7 GHz (e.g. time sharing UL/DL) / Constraints of TDD-operation (e.g. network layout, receive transmit transition time, ...)**
- **Operation in FR2: Propagation Models, typical deployment scenarios in UE and network**
- **Concept of BWP**
- **EN-DC Band Combinations:** Intra-band contiguous, Intra-band non-contiguous, Inter-band EN-DC FR1, Inter-band EN-DC FR2, Inter-band EN-DC FR1+FR2, Inter-band FR1+FR2, each with examples and use cases
- **Slot Format and dynamic TDD**: D / U / F-symbols, relationship between cell size, subcarrier spacing and number of F-slots

- **Channels & Signals with 5G NR:**
  Logical Channels: BCCH, PCCH, CCCH, DCCH, DTCH
  Transport Channels: RACH, UL-SCH, BCH, PCH, DL-SCH
  Physical Channels: PBCH, PDCCH, PUSCH, PDSCH, PUCCH, PRACH
  Physical Signals: PSS & SSS, CSI-RS, DM-RS, PT-RS, SRS
  The Concept of Quasi-Collocation
- **The SS-Block (Synchronization Signal and PBCH-block)**
  Time and frequency dimension, content, zoom in
- **New FEC: LDPC and Polar Codes:** From Data Bits to Encoded Bits, Performance Comparison (BER vs SNR) for different FEC-technologies

## Chapter 3: Operation (3 – 4 h)

- **Cell Search Procedure in 5G Stand-Alone:**
  The Grid: Synchronization Signals and PBCH in LTE vs NR
  SS-Block: How to determine the time and frequency positions, repetitions, PointA, Constraints of the SS-Burst Set: No of SS-blocks, Case A-E, The Synchronization Raster or how to determine on which Frequencies to look for SS-Blocks
- **Differences in cell search between SA and NSA**
- **Beamforming of SS-Blocks:** Operation and Constraints, Dependency of number of beams with FR1 / FR2
- **Link budget in 5G**
- **Reading and interpreting the Contents of the MIB**
- **Resource Allocation in 5G**
  From BWP to search spaces and CORESETs.
  DCI 0-0 – DCI 2-3: Meaning and tasks
- **Random Access procedure in 5G**
  Msg1 – Msg 4
  Differences to 4G
- **Hybrid ARQ in 5G**
  Downlink HARQ
  Uplink HARQ

## Chapter 4: mMIMO (2 h)

- **Reviewing SISO, SIMO, MISO and MIMO**
- **What is mMIMO?**
- **Beamforming and Beam Sweeping and how they work**
- **One-Dimensional Beamforming (horizontal) vs. Two-Dimensional Beamforming (horizontal + vertical)**
- **Real-life antenna constructions for mMIMO**
  Example 1: Real-Life Antennas with 2, 4 and 8 Antenna Ports
  Example 2: Real-Life Antennas with 16 Antenna Ports
  Example 3: Real-Life Antennas with 32 Antenna Ports
  Example 4: Real-Life Antennas with 64 Antenna Ports
- **Use Cases and Usefulness:**
  **=> of different Antennas**
  **=> of two-dimensional beamforming**

## Chapter 5: Architecture & Protocol Stacks (1 h)

- **5G Network Architecture**
- **User Equipment**
- **NG-RAN**
- **NGC**
- **More Details on the 5G RAN**
  gNB-CU and Functional Split
  gNB-DU
  F1-Interface: F1-AP-protocol, SDAP-protocol
- **Functional Split inside gNB-DU through eCPRI**
  eCPRI-Split Options
  … and their pros and cons
  eCPRI protocol stack
- **Protocol Stacks**
  Control Plane
  User Plane
  Protocol Stacks in Uu-, Xn- and N2/N3-interfaces
- **Details of the NGC**
  Various network functions (e.g. AMF, UPF, SMF, NSSF, ...)
  Virtualization
  Network Slicing

## Chapter 6: Higher Layer Operation (2 – 3 h)

- **Overview: The UE's way in and out of 5G with NSA**
- **Options: When to display 5G icon on the UE-display?**
- **Detailed Analysis of Scenario SgNB-Addition**
  **=> Part 1: Attachment to the MeNB**
  **=> Part 2: UE Radio Access Capability Transfer (with 5G and MRDC-specifics)**
  **=> Logfile Analysis: Extract of Containers: UE-NR-Capability and RF-Parameters**
  **=> Logfile Analysis: Extract of Container: UE-MRDC-Capability**
  **=> Logfile Analysis: RRC_CONN_RECONF with NSA-assistance information**
  **=> Part 3: Measurement Report from the UE to indicate 5G cell**
  **=> Part 4: SgNB Addition through RRC_CONN_RECONF**
  **=> Logfile Analysis: RRC_CONN_RECONF**
  **=> Part 5: Cell Activation**
- **Detailed Analysis of Scenario SgNB-Modification**
- **Detailed Analysis of Scenario SgNB-Release**