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Technology Manager Wireless

5G New Radio
Fundamentals, procedures, testing aspects

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Disclaimer
This presentation contains forward looking statements and milestones on products and technology. Such statements are based on our current expectations and are subject to certain risks and uncertainties and are of course subject to be changed.
5G stretching the use case of LTE

- eMBB: Devices and applications with massive payload (eCA, LAA, shared spectrum, WLAN offload)
- LTE: Mbit/s
- URLLC: Devices requiring high reliability and low latency (LTE V2X, short symbol duration, dual connectivity)
- mMTC: Large number of devices with low payload and ubiquitous connections (eMTC, NB-IoT, UE Cat M2, UE Cat NB2)
- uRLLC: eMBB

User density 1,000,000/km²
Review of 5G Use Cases

eMBB remains priority 1 but …

**Massive IoT**
- A diverse ecosystem (operators, manufacturers, local authorities, certification only for some technologies)
- Mix of technologies (GSM, Lora, Zigbee, WLAN, Bluetooth, Cat M, NB-IoT,…)
- It’s all about cost efficiency and massive connectivity
- 3GPP: No NR based solution; will be addressed by evolving LTE-M (eMTC) and NB-IoT

**URLLC**
- A significantly enhanced and diverse ecosystem (operators (?), manufacturers, verticals, certification not existing (yet))
- Principal support with high SCS and self-contained slots
- It’s all about reliability and security (data and capacity)

**eMBB – the known playground**
- Established ecosystem (operators, manufacturers, certification of devices)
- Evolution from existing technologies and revolutionary additions (cm- / mm-wave)
- It’s all about data (speed and capacity)
- Realizing and facing the challenges of cm-wave spectrum and OTA testing; 3.5GHz is important!
… the URLLC potential is the future!

5G – A problem solver

- Ericsson conducted a survey of large companies (with a minimum of 1,000 employees) across 10 key industries during October and November 2017.
- Each of the 10 industries identified key areas that could be resolved through business process transformation with respect to 5G.
- The survey revealed that, across all sectors, 5G technology will improve issues that center around data security, connectivity issues, and automating processes.

Source: Ericsson report

Figure 6: 5G-enabled industry digitalization revenues for ICT players, 2020

We estimate that 5G-enabled industry digitalization revenues for ICT players will be USD 1.3 trillion in 2026.

Expected 5G commercial launch dates (mobile or FWA)

Source: GSA report: Evolution from LTE to 5G: Global Market Status, January 2019
## 3GPP RAN NR Standardization Overview

### Status after 3GPP RAN #83 (March 2019)

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Year</th>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rel-14 Release 15</strong></td>
<td>2017</td>
<td></td>
<td>LTE Adv Pro: Dec 2017 / RAN #78 L1/L2 specification for NSA option 3 / eMBB completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mar 2018 / RAN #79 L3 specs. (ASN.1) for option 3 / eMBB completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>June 2018 / RAN #80 L1/L2 specs. for SA option 2 &amp; 5 / URLLC completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sep 2018 / RAN #81 L3 specs (ASN.1) for option 2 &amp; 5 completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dec 2018 ASN.1 Update</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Rel-15 “Late Drop”</strong></td>
<td>Now</td>
</tr>
<tr>
<td></td>
<td>2018</td>
<td></td>
<td>Rel-15 NR Phase 1: Focus on early NSA / SA deployment scenarios for eMBB/URLLC use cases</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rel-15 LTE Advanced Pro evolution (V2X, IoT, …)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dec 2019 / RAN #82 RAN #82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>June 2018 / RAN #80 L3 specs. (ASN.1) for option 3 / eMBB completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>March 2019 / RAN #83 (“late drop”) L1/L2 specs for option 4 &amp; 7 incl. NR-NR-DC completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sep 2018 / RAN #81 L3 specs (ASN.1) for option 2 &amp; 5 completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>December 2018 ASN.1 Update</td>
</tr>
<tr>
<td></td>
<td>2019</td>
<td></td>
<td>Rel-16 NR Phase 2: Further NR use cases (V2X, NTN)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rel-16 LTE Advanced Pro evolution (IoT, broadcast, …)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>June 2019 / RAN #84 (“late drop”) L3 specs (ASN.1) for option 4 &amp; 7 completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>March 2020 / RAN #87 Rel-16 completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>June 2020 / RAN #88 L3 specs (Rel-16 ASN.1) completed</td>
</tr>
</tbody>
</table>

### Rel-16 Milestones

- **Study-Item Phase completed**
- **Work-Item Phase ongoing**

---

**NR:** New Radio  
**SA:** Standalone  
**NSA:** Non Standalone  
**eMBB:** Enhanced Mobile Broadband  
**URLLC:** Ultra-Reliable Low Latency Communication  
**mMTC:** Massive Machine Type Communication
3GPP RAN NR Standardization Overview
Status (June 2019)

<table>
<thead>
<tr>
<th>Year</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel-15</td>
<td>RAN #80 June 2018</td>
<td>Late-Drop for Option 4, 7</td>
<td>Rel-15 completed (RAN 1, 2, 3, 4 (core))</td>
<td>Rel-15 completed (RAN 4 (perf), RAN5)</td>
<td>Rel. 15 core spec is now finalized. T&amp;M spec still ongoing</td>
</tr>
<tr>
<td>Rel-16</td>
<td>Rel-16 Study-Item Phase</td>
<td>Rel-16 Work-Item Phase</td>
<td>June 2019</td>
<td>Dec 2019</td>
<td>Rel-16 completed</td>
</tr>
<tr>
<td>Tentative Rel-17 Schedule</td>
<td>Rel-17 Kick-Off Workshop</td>
<td>E-mail discussion of work areas</td>
<td>Approval of Rel-17 Study-Items / Work-Items</td>
<td>Study-Item Phase</td>
<td>Work-Item Phase</td>
</tr>
<tr>
<td>Rel-17</td>
<td>June 2019</td>
<td>Rel-17 not yet started. But at least a timeline 😊</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: RP-190563

Rel. 16 is in work item phase = features and technology will be specified with more details
5G Key Technology Components
NR builds on four main pillars

New Spectrum
- < 1GHz
- ~ 3.5 GHz
- ~ 26/28/39 GHz

Massive MIMO & Beamforming
- Hybrid beamforming
- > 6GHz also UE is expected to apply beam steering

Multi-Connectivity
- Initially based on Dual Connectivity with E-UTRA as master

Network flexibility - virtualization
- Flexible physical layer numerology
- Network Slicing
- NFV/SDN
5G Network Architecture Vocabulary

LTE Core = EPC
- MME
- SGW

5G Core = 5GC
- AMF
- UPF

MME = Mobility Management Entity
S-GW = Serving Gateway

AMF = Access and Mobility Management Function
UPF = User Plane Function

LTE BS = eNB
(connected to EPC)

5G BS = gNB
(connected to 5GC)

A base station in a DC (= Dual Connectivity) connection with the UE may have different roles:
MN = Master Node
or
SN = Secondary Node
5GC overall architecture
Architecture Options
Option 3 is priority 1 in 3GPP, followed by Option 2

Option 3: DC EN: E-UTRA-NR
- eNB
- gNB
- MME
- SGW
- EPC

eNB is the Master Node

Option 2: Standalone
- gNB
- AMF
- UPF
- 5GC
Architecture Options
Additional options are specified

Option 4
DC NE: NR-E-UTRA

Option 5

Option 7
DC NGEN: NG-RAN E-UTRA-NR

gNB is the Master Node

NG-gNB is the Master Node
CMWflexx with CMX500 – modular concept, highest flexibility

Why extend CMWflexx setups???

- Benefit from rock-solid LTE support
- NSA Mode (e.g. Option3) **always needs an LTE** anchor cell. NR Cell is just an extension to an existing LTE Network like CMX500 is an extension to existing LTE Setups
- Secure Investment
  - Re-use of existing CMW500 – investment is secured by just upgrading CMW500 to its latest HW revision (160MHz TRX)
- Full Legacy Support
  - Setups remain **functional for all LTE-only / legacy testing needs**
- CMW500 Multi Technology Platform
  - Flexible use of CMW500 as either sub6-NR or LTE-cell within the setup → covers complicated iterations between LTE CA and Sub6 CA scenarios within a single setup

CMWflexx

CMX500

Remote head

Antenna

OTA
5G NR: Quality of Service flow
TS 23.501 defines standardized 5QI for GBR, non-GBR and latency critical GBR
5G NR data rate calculation

Data rate (in Mbps) = \(10^{-6} \cdot \sum_{j=1}^{J} \left(\frac{N_{\text{PRB}}^{\text{DL}}(j,\mu) \cdot 12 \cdot (1 - OH(j))}{T_s^{\mu}}\right)\)

FR1 example for single layer 15kHz SCS in DL with 256QAM:

- Number of Carriers “J”
- Bits per Symbol from modulation scheme “Qm”
- Number of Layers “v”
- Max. coderate “Rmax”
- Sub carrier per RB
- Numerology “\(\mu\)”
- Adjustment to Mbps
- Scaling factor “f”
- Max. number of RBs “N”
- Average OFDM symbol duration “Ts”
- Overhead “OH”

Data rate = \(10^{-6} \cdot 1 \cdot 1 \cdot 8 \cdot 1 \cdot \frac{948/1024}{1} \cdot (270 \cdot 12) \cdot \frac{14 \cdot 2^0}{10^{-3}} \cdot (1 - 0.14) = 288.9 \text{ Mbps}\)

Source: 3GPP TS 38.306 V15.2.0 (2018-06)
## Maximum 5G NR data rate per layer

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>SCS</th>
<th>Bandwidth</th>
<th>DL</th>
<th>UL</th>
<th>Efficiency DL</th>
<th>Efficiency UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>15 kHz</td>
<td>50 MHz</td>
<td>288.9 Mbps</td>
<td>309.1 Mbps</td>
<td>5.78 bps/Hz</td>
<td>6.18 bps/Hz</td>
</tr>
<tr>
<td></td>
<td>30 kHz</td>
<td>100 MHz</td>
<td>584.3 Mbps</td>
<td>625 Mbps</td>
<td>5.84 bps/Hz</td>
<td>6.25 bps/Hz</td>
</tr>
<tr>
<td></td>
<td>60 kHz</td>
<td>100 MHz</td>
<td>577.8 Mbps</td>
<td>618.1 Mbps</td>
<td>5.78 bps/Hz</td>
<td>6.18 bps/Hz</td>
</tr>
<tr>
<td>FR2</td>
<td>60 kHz</td>
<td>200 MHz</td>
<td>1.08 Gbps</td>
<td>1.18 Gbps</td>
<td>5.40 bps/Hz</td>
<td>5.90 bps/Hz</td>
</tr>
<tr>
<td></td>
<td>120 kHz</td>
<td>400 MHz</td>
<td>2.15 Gbps</td>
<td>2.37 Gbps</td>
<td>5.38 bps/Hz</td>
<td>5.93 bps/Hz</td>
</tr>
<tr>
<td>Compare to LTE</td>
<td>15 kHz</td>
<td>20 MHz</td>
<td>100 Mbps</td>
<td>100 Mbps</td>
<td>5.00 bps/Hz</td>
<td>5.00 bps/Hz</td>
</tr>
</tbody>
</table>
5G NR applies independent security functions for UP and CP:

- Authentication
- Encryption
- Integrity protection
5G NR – physical layer aspects

- Downlink
- Uplink

**FDD**
- DL frequency
- UL frequency

**TDD**
- DL UL DL UL
- DL DL UL UL

Time

Frequency
Frequency trends for 5G

NR frequency range 1
reserved numbers 65-256

<table>
<thead>
<tr>
<th>Downlink</th>
<th>Uplink</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>n77</td>
<td>3.3 – 4.2 GHz 3.3 – 4.2 GHz</td>
</tr>
<tr>
<td>n78</td>
<td>3.3 – 3.8 GHz 3.3 – 3.8 GHz</td>
</tr>
<tr>
<td>n79</td>
<td>4.4 – 5.0 GHz 4.4 – 5.0 GHz</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

NR frequency range 2
Reserved numbers 257-512

<table>
<thead>
<tr>
<th>Downlink</th>
<th>Uplink</th>
</tr>
</thead>
<tbody>
<tr>
<td>n257</td>
<td>26.5 – 29.5 GHz 26.5 – 29.5 GHz</td>
</tr>
<tr>
<td>n258</td>
<td>24.25 – 27.5 GHz 24.25 – 27.5 GHz</td>
</tr>
<tr>
<td>n259</td>
<td>n/a n/a</td>
</tr>
<tr>
<td>n260</td>
<td>37 – 40 GHz 37 – 40 GHz</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Europe
700 MHz
3.4 - 3.8 GHz
24.25 - 27.5 GHz

China
2.5 – 2.6 GHz
3.3 - 3.6 GHz
4.8 - 5.0 GHz
24.75 - 27.5 GHz (study)
37 - 43.5 GHz (study)

US
600 MHz
2.4 GHz
[CBRS band (3.5GHz)]
27.5 - 28.35 GHz
37 - 40 GHz

Australia
3.6 GHz
26 GHz

Korea
3.42 - 3.7 GHz
26.5 - 28.9 GHz

Japan
4.4 - 4.9 GHz
28 GHz
Two basic frequency ranges (FR1 and FR2) are used in 3GPP specifications

- **FR1: 450 MHz to 7.125 GHz, FR 2: 24.25 to 52.6 GHz** for 3GPP Release 15

Note that requirements throughout the RF specifications are in many cases defined separately for these different frequency ranges.

RAN4 definition for reference frequencies (channel raster, synchronization raster):

\[ F_{\text{REF}} = F_{\text{REF-Offs}} + \Delta F_{\text{Global}} (N_{\text{REF}} - N_{\text{REF-Offs}}) \]

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>( \Delta F_{\text{Global}} )</th>
<th>( F_{\text{REF-Offs}} )</th>
<th>( N_{\text{REF-Offs}} )</th>
<th>Range of ( N_{\text{REF}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 3000 MHz</td>
<td>5 kHz</td>
<td>0 MHz</td>
<td>0</td>
<td>0 – 599999</td>
</tr>
<tr>
<td>3000 – 24250 MHz</td>
<td>15 kHz</td>
<td>3000 MHz</td>
<td>600000</td>
<td>600000 – 2016666</td>
</tr>
<tr>
<td>24250 – 100000 MHz</td>
<td>60 kHz</td>
<td>24250.08 MHz</td>
<td>2016667</td>
<td>2016667 - 3279165</td>
</tr>
</tbody>
</table>

Source: TS 38.104
### 5G NR spectrum: operating bands in FR1 (<24GHz)

<table>
<thead>
<tr>
<th>NR Operating Band</th>
<th>Uplink (UL) operating band</th>
<th>Downlink (DL) operating band</th>
<th>Duplex Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BS receive</td>
<td>BS transmit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UE transmit</td>
<td>UE receive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( F_{UL_low} - F_{UL_high} )</td>
<td>( F_{DL_low} - F_{DL_high} )</td>
<td></td>
</tr>
</tbody>
</table>

| n1     | 1920 MHz – 1980 MHz | 2110 MHz – 2170 MHz | FDD |
| n2     | 1850 MHz – 1910 MHz | 1930 MHz – 1990 MHz | FDD |
| n3     | 1710 MHz – 1785 MHz | 1805 MHz – 1880 MHz | FDD |
| n5     | 824 MHz – 849 MHz   | 869 MHz – 894 MHz    | FDD |
| n7     | 2500 MHz – 2570 MHz | 2620 MHz – 2690 MHz | FDD |
| n8     | 880 MHz – 915 MHz   | 925 MHz – 960 MHz    | FDD |
| n20    | 832 MHz – 862 MHz   | 791 MHz – 821 MHz    | FDD |
| n28    | 703 MHz – 748 MHz   | 758 MHz – 803 MHz    | FDD |
| n38    | 2570 MHz – 2620 MHz | 2570 MHz – 2620 MHz | TDD |
| n41    | 2496 MHz – 2690 MHz | 2496 MHz – 2690 MHz | TDD |
| n50    | 1432 MHz – 1517 MHz | 1432 MHz – 1517 MHz | TDD |
| n51    | 1427 MHz – 1432 MHz | 1427 MHz – 1432 MHz | TDD |
| n66    | 1710 MHz – 1780 MHz | 2110 MHz – 2200 MHz | FDD |
| n70    | 1695 MHz – 1710 MHz | 1995 MHz – 2020 MHz | FDD |
| n71    | 663 MHz – 698 MHz   | 617 MHz – 652 MHz    | FDD |
| n74    | 1427 MHz – 1470 MHz | 1475 MHz – 1518 MHz | FDD |
| n75    | N/A                 | 1432 MHz – 1517 MHz  | SDL |
| n76    | N/A                 | 1427 MHz – 1432 MHz  | SDL |
| n78    | 3300 MHz – 3800 MHz | 3300 MHz – 3800 MHz | TDD |
| n77    | 3300 MHz – 4200 MHz | 3300 MHz – 4200 MHz | TDD |
| n79    | 4400 MHz – 5000 MHz | 4400 MHz – 5000 MHz | TDD |
| n80    | 1710 MHz – 1785 MHz | N/A                  | SUL |
| n81    | 880 MHz – 915 MHz   | N/A                  | SUL |
| n82    | 832 MHz – 862 MHz   | N/A                  | SUL |
| n83    | 703 MHz – 748 MHz   | N/A                  | SUL |
| n84    | 1920 MHz – 1980 MHz | N/A                  | SUL |
### 5G NR spectrum: operating bands in FR2 (>24GHz)

<table>
<thead>
<tr>
<th>NR Operating Band</th>
<th>Uplink (UL) operating band BS receive &amp; UE transmit</th>
<th>Downlink (DL) operating band BS transmit &amp; UE receive</th>
<th>Duplex Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F&lt;sub&gt;UL_low&lt;/sub&gt; – F&lt;sub&gt;UL_high&lt;/sub&gt;</td>
<td>F&lt;sub&gt;DL_low&lt;/sub&gt; – F&lt;sub&gt;DL_high&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>n257</td>
<td>26500 MHz – 29500 MHz</td>
<td>26500 MHz – 29500 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>n258</td>
<td>24250 MHz – 27500 MHz</td>
<td>24250 MHz – 27500 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>n260</td>
<td>37000 MHz – 40000 MHz</td>
<td>37000 MHz – 40000 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>n261</td>
<td>27500 MHz – 28350 MHz</td>
<td>27500 MHz – 28350 MHz</td>
<td>TDD</td>
</tr>
</tbody>
</table>
5G NR – physical layer aspects, general idea behind F-OFDMA

Flexible subcarrier spacing for each subband

Flexible symbol and CP duration for each subband

Symbol duration

CP

Time

Frequency

5G NR physical layer simplified:
Use OFDMA, but make OFDMA more flexible!
- Subcarrier spacing not constant.
- Cyclic prefix length not constant.
- Symbol duration not constant.
### 5G NR F-OFDMA features flexible numerologies

<table>
<thead>
<tr>
<th>Subcarrier spacing (kHz)</th>
<th>15</th>
<th>30</th>
<th>60</th>
<th>120</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol duration (µs)</td>
<td>66.7</td>
<td>33.3</td>
<td>16.7</td>
<td>8.33</td>
<td>4.17</td>
</tr>
<tr>
<td>CP duration (µs)</td>
<td>4.7</td>
<td>2.3</td>
<td>1.2 (normal)</td>
<td>0.59</td>
<td>0.29</td>
</tr>
<tr>
<td>Max. nominal bandwidth (MHz)</td>
<td>50</td>
<td>100</td>
<td>100 for FR1 200 for FR2</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Max. FFT size</td>
<td>4096</td>
<td>4096</td>
<td>4096</td>
<td>4096</td>
<td>4096</td>
</tr>
<tr>
<td>Symbols per slot</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Slots per subframe</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Slots per frame</td>
<td>10</td>
<td>20</td>
<td>40</td>
<td>80</td>
<td>160</td>
</tr>
</tbody>
</table>
5G NR F-OFDMA flexibility in spectrum, bandwidth parts

5G NR idea:
Channel bandwidth
Using different BWP and numerologies to enable QoS on layer1

Carrier bandwidth is divided into different BWPs. Mixed numerology allows the provision of various QoS on the radio interface. One bandwidth part is one fixed numerology. BWPs are allocated to UEs.
**5G NR – resource grid details**

- **Channel bandwidth**
  - Resource grid #1, numerology #1
  - Resource grid #2, numerology #2

- **Offset to carrier**
  - BWP
  - BWP size in # physical RBs

- **Location and bandwidth**
  - (BWP start and length)

- **Resource block**
  - 12 subcarriers
  - CRB #0
  - CRB #1
  - CRB #2

- **BWP for different UEs can overlap**

- **Point A, signaled as absolute frequency point A, expressed as ARFCN**

- **Physical resource blocks**
  - (relative to common RBs) but linked to BWP

- **Common resource blocks for numerology #2**
  - (reference to point A, SCS specific)
Bandwidth part scenarios

5G NR UE “smartphone” like with varying bandwidth and services, i.e. idle mode vs. connected mode changes

UE#1: cell acquisition

UE#1 idle (energy save mode)

UE#2 (Low complexity device)

UE#1 connected (numerology change possible)

5G NR UE with reduced bandwidth capability

Bandwidth part (BWP)

BWP

BWP

Channel bandwidth

Frequency

Time
Bandwidth part switching

1. UE acquires cell on initial BWP
2. Connection setup, RRC configures up to 4 BWPs, e.g. BWP_1 activated
3. During connection BWP can be changed via DCI scheduling
4. BWP change due to timer expiry
5G New Radio (NR) offers a flexible air interface

Summary of key parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FR1 (450 MHz – 6 GHz)</th>
<th>FR2 (24.25 – 52.6 GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier aggregation</td>
<td></td>
<td>Up to 16 carriers</td>
</tr>
<tr>
<td>Bandwidth per carrier</td>
<td>5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100 MHz</td>
<td>50, 100, 200, 400 MHz</td>
</tr>
<tr>
<td>Subcarrier spacing</td>
<td>15, 30, 60 kHz</td>
<td>60, 120, 240 (not for data) kHz</td>
</tr>
<tr>
<td>Max. number of subcarriers</td>
<td>3300 (FFT4096 mandatory)</td>
<td></td>
</tr>
<tr>
<td>Modulation scheme</td>
<td>QPSK, 16QAM, 64QAM, 256QAM; uplink also supports ( \pi/2 )-BPSK (only DFT-s-OFDM)</td>
<td></td>
</tr>
<tr>
<td>Radio frame length</td>
<td>10 ms</td>
<td></td>
</tr>
<tr>
<td>Subframe duration</td>
<td>1 ms (alignment at symbol boundaries every 1 ms)</td>
<td></td>
</tr>
<tr>
<td>MIMO scheme</td>
<td>Max. 2 codewords mapped to max 8 layers in downlink and to max 4 layers in uplink</td>
<td></td>
</tr>
<tr>
<td>Duplex mode</td>
<td>TDD, FDD</td>
<td>TDD</td>
</tr>
<tr>
<td>Access scheme</td>
<td>DL: CP-OFDM; UL: CP-OFDM, DFT-s-OFDM</td>
<td></td>
</tr>
</tbody>
</table>

Changed to 7.125 GHz
5G NR – physical layer resources

5G NR uses similar terms as LTE: Subcarrier, resource element, resource block, subframe etc.

1 resource block is defined only in the frequency domain!
12 subcarriers = 1 resource block
5G NR – frame structure

Radio frame 10 ms

Half frame 5 ms

Subframe 1 ms

2 half frames per frame

10 subframes per frame

Flexible allocation

Fixed allocation

\{1, 2, 4, 8, 16\} slots per subframe

\{12, 14\} symbols per slot

Slot

Symbol
5G NR – frame structure, interworking with multiple numerologies

Subcarrier spacing of $15 \text{ kHz} \cdot 2^\mu$ guarantees time alignment in subframe and frame of different numerologies!
5G air interface aspects: beam sweeping for initial access

Traditional approach: omnidirection TX of BCCH for cell detection

**Friis equation**

\[
\frac{P_{Rx}}{P_{Tx}} = G_{antenna} \left( \frac{c}{4\pi f d} \right)^\gamma
\]

At higher frequencies: Free space path loss is high -> beamforming with high gain

Beam sweeping procedure for power efficiency and cell detection
5G air interface: beam reporting, general aspects

UE reports the beam status via CSI reports

„the received power level on the specific beam is …. (define RSRP based on beams)“

Various beams have to be distinguished. Idea of beam specific reference Signals (CSI-RS)
5G NR air interface aspects: beam switching procedure

Beam switch to strongest beam RSRP indicated by UE in previous report

CSI report. Strongest beam will be new beam index
5G-NR mobility scenarios
SS/PBCH Blocks

- In the time domain, an SS/PBCH block consists of 4 OFDM symbols, numbered in increasing order from 0 to 3 within the SS/PBCH block, where PSS, SSS, and PBCH with associated DM-RS occupy different symbols.
- In the frequency domain, an SS/PBCH block consists of 240 contiguous subcarriers with the subcarriers numbered in increasing order from 0 to 239 within the SS/PBCH block.
- Two SS/PBCH block types:
  - Type A (15kHz and 30kHz)
  - Type B (120 and 240 kHz)

Like in LTE the Cell ID can be determined from the used PSS/SSS sequences.
SS/PBCH Blocks

Occurrence in the frame depends on SCS

Start symbol of SSB depends on SC spacing

<table>
<thead>
<tr>
<th>SC spacing</th>
<th>$f_c &lt; 3\text{GHz}$ ($L_{\text{max}} = 4$)</th>
<th>$3\text{GHz} &lt; f_c &lt; 6\text{GHz}$ ($L_{\text{max}} = 8$)</th>
<th>$f_c &gt; 6\text{GHz}$ ($L_{\text{max}} = 64$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A: 15 kHz</td>
<td>2,8,16,22</td>
<td>2,8,16,22,30,38,44,50</td>
<td>N/A</td>
</tr>
<tr>
<td>Case B: 30 kHz</td>
<td>4,8,16,20</td>
<td>4,8,16,20,32,36,44,48</td>
<td>N/A</td>
</tr>
<tr>
<td>Case C: 30 kHz</td>
<td>2,8,16,22</td>
<td>2,8,16,22,30,38,44,50</td>
<td>N/A</td>
</tr>
<tr>
<td>Case D: 120 kHz</td>
<td>N/A</td>
<td>N/A</td>
<td>4,8,16,20, ..., 508,512,520,524</td>
</tr>
<tr>
<td>Case E: 240 kHz</td>
<td>N/A</td>
<td>N/A</td>
<td>8,12,16,20, ..., 480,484,488,492</td>
</tr>
</tbody>
</table>
SS/PBCH Blocks details

Resources PSS, SSS, PBCH, and DM-RS for PBCH

- The sequence used for DM-RS in PBCH depends on the cell ID, the number of the half frame the PBCH is transmitted in the frame and the SS/PBCH index (details in TS38.213, section 4.1)
- This essentially allows to transmit $L_{\text{max}}$ different “common” beams

<table>
<thead>
<tr>
<th>Channel or signal</th>
<th>OFDM symbol number $l$ relative to the start of an SS/PBCH block</th>
<th>Subcarrier number $k$ relative to the start of an SS/PBCH block</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSS</td>
<td>0</td>
<td>56, 57, ..., 182</td>
</tr>
<tr>
<td>SSS</td>
<td>2</td>
<td>56, 57, ..., 182</td>
</tr>
<tr>
<td>Set to 0</td>
<td>0</td>
<td>0, 1, ..., 55, 183, 184, ..., 236</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>48, 49, ..., 55, 183, 184, ..., 191</td>
</tr>
<tr>
<td>PBCH</td>
<td>1, 3</td>
<td>0, 1, ..., 239</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0, 1, ..., 47, 192, 193, ..., 239</td>
</tr>
<tr>
<td>DM-RS for PBCH</td>
<td>1, 3</td>
<td>0$+$v, 4$+$v, 8$+$v, ..., 236$v$</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0$+$v, 4$+$v, 8$+$v, ..., 44$v$, 192$v$, 4$+$v, 196$v$, ..., 236$v$</td>
</tr>
</tbody>
</table>

$\nu$ depends on the cell ID according to:

$\nu = N_{\text{cell}} \mod 4$
SS/PBCH demodulation reference signals

Each SS/PBCH block has its own DMRS sequence, depending on cell ID

\[ r(m) = \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m + 1)) \]

Different DMRS sequences

With initials

\[ c_{\text{init}} = 2^{11} (\ell_{\text{SSB}} + 1) \left( \lfloor N_{\text{cell}}^\text{ID} / 4 \rfloor + 1 \right) + 2^6 (\ell_{\text{SSB}} + 1) + (N_{\text{cell}}^\text{ID} \mod 4) \]

\[ \ell_{\text{SSB}} = 4 \ell_{\text{SSB}} + n_{hf} \]

SSB index within half frame will init sequence generation

\[ r(0), \ldots, r(143) \]

SSB blocks can be mapped onto antenna ports individually

Mapping of SSB onto antenna: beam sweeping

Mapping of SSB onto antenna: static beam

5G NR Fundamentals, procedures and T&M aspects - France 41
Field measurements:
Exp.: SSB / beam ranking

- SSB / beam index visualized over time (history) and on the map
- Surprisingly good match with horizontal “micro sectors” (SSB beam indices)
Architecture Options, LTE and 5G NR

Difference between sectorized eNB and SSB-beamformed sectorized gNB cells
5G NR – physical channels

Physical downlink control channel PDCCH: Downlink and uplink scheduling decisions

Physical downlink shared channel PDSCH: Downlink data

Physical broadcast channel PBCH: Providing master information block

Physical uplink shared channel PUSCH: Uplink data + UCI optionally

Physical uplink control channel PUCCH: ACK/NACK for downlink packets, scheduling requests, channel status info

Physical random access channel PRACH: Initial access

Remark, no PHICH any longer, ACK/NACK sent asynchronously

Remark, no PCFICH any longer, PDCCH size by higher layer signaling
Reference signals in 5G NR – motivational aspects

Old style: one reference signal always on air and used for everything:
Channel estimation
Power detection
CQI evaluation etc.

New style: repurposing of reference channels:
Specialist for various purpose:
Channel status estimation
Demodulation assistance
Position estimation etc.
5G NR – physical signals

UL physical signals:
- Demodulation reference signals (DMRS) for PUSCH and PUCCH
- Phase-tracking reference signals (PTRS) for PUSCH
- Sounding reference signal (SRS)

DL physical signals:
- Demodulation reference signals (DMRS) for PDSCH, PDCCH and PBCH
- Phase-tracking reference signals (PTRS) for PDSCH
- Channel-state information reference signal (CSI-RS)
- Tracking reference signals (TRS)
- Primary synchronization signal (PSS)
- Secondary synchronization signal (SSS)
5G NR – physical signals. Demodulation reference signals (DMRS)

Length of front loaded DMRS is either single symbol or double symbols indicated by parameter `maxLength`

DL DMRS with possibility for additional DMRS symbols indicated by parameter `dmrs-AdditionalPosition`

- **dmrs-TypeA-Position = [2, 3]**
- **Symbol containing DMRS on certain subcarriers**
- **Resource block**
- **Position and # of subcarriers used for DMRS given by `DMRS_configuration_type1/2`**

Mapping type A = Relative to slot start

Mapping type B = Relative to PDSCH start
5G NR – physical signals. Phase tracking reference signals (PTRS)
CSI-RS for beamforming support

- Multiple CSI-RS-Resources corresponding to different beam direction
- UE measures different CSI-RS resources and selects the best beam
- **CSI-RS Resources Indicator (CRI) is reported corresponding to best beam + RI/PMI/CQI reports are conditioned on reported CRI**

UE specific scrambling ID

$$c_{\text{init}} = (2^{10}(N_{\text{slot}}N_{sf}^\mu + l + 1)(2n_{ID} + 1) + n_{ID}) \mod 2^{31}$$

Orthogonal sequences for CDM

$$a^{(p,\mu)}_{k,l} = \beta_{\text{CSIRS}}w_{l'}(k')w_l(l')n_{sf}(m')$$

$$m' = \left[ n\alpha \right] + k' + \left[ \frac{\overline{k} + l'}{N_{\text{RB}}^\text{sc}} \right]$$

$$k = nN_{\text{sc}}^{\text{RB}} + \overline{k} + k'$$

$$l = \overline{l} + l'$$

$$\alpha = \begin{cases} 
\rho & \text{for } X = 1 \\
2\rho & \text{for } X > 1 
\end{cases}$$

$$n = 0,1,...$$

CSI can be non-zero power NZP or zero power ZP

- CSI can be non-zero power NZP or zero power ZP

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m+1))$$
5G NR – precoding, general model

- **CSI-RS beamforming config (e.g. matrix $W$)**
- **Antenna port mapping**
- **DL beamforming**
- **UL beamforming**
- **PUSCH data**
- **DMRS**
- **Precoding (optional + flexible) + beamforming**
- **Codebook type about antenna configuration**
- **Rank indicator feedback**
- **RI + TPMI command via DCI scheduling**

- **Different quasi co-location possible**
  - Codebook based precoding matrix $W$
  - (non-codebook optional)
gNB uses SSBs to be mapped on „static“ beams. PDSCH & PUSCH will also follow SSB beam concept.

Same PCI, different SSB indices
CSI-RS for beamforming support

- Multiple CSI-RS-Resources corresponding to different beam direction
- UE measures different CSI-RS resources and selects the best beam
- **CSI-RS Resources Indicator (CRI)** is reported corresponding to best beam + RI/PMI/CQI reports are conditioned on reported CRI

Orthogonal sequences for CDM

$\alpha_{k,j}^{(p,\mu)} = \beta_{\text{CSI-RS}} w_t(k') w_t(l') n_{\text{sc},f}(m')$

$m' = [n \alpha + k' + \frac{l \rho}{N_{\text{RB}}}]$

$k = n N_{\text{sc}} + \overline{k} + k'$

$l = \overline{l} + l'$

$\alpha = \begin{cases} 
\rho & \text{for } X = 1 \\
2\rho & \text{for } X > 1 
\end{cases}$

$n = 0,1,...$

$\rho_{\text{init}} = 2^{10} (N_{\text{symb}}^\mu + l + 1) (2n_{\text{ID}} + 1) + n_{\text{ID}} \mod 2^{31}$

$R(m) = \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m + 1))$

CSI can be non-zero power NZP or zero power ZP

UE specific scrambling ID
5G NR beamforming aspects

Same PCI, different SSB indices
+ UE specific CSI-RS for beamforming support

gNB uses SSBs to be mapped on „static“ beams.

CRI feedback

PDSCH & PUSCH will be on UE specific beams. CSI-RS and reporting needed to support beam adjustment
Example: Reporting Configuration (2 TRPs and 3 Beams)

CSI-Report Config 0

Resource setting 0

Channel status

Interference on ZP CSI-RS

Resource setting 1

Interference on NZP CSI-RS

Resource setting 2

Set0_1: 3 NZP CSI-RS
Set1_1: 2 ZP CSI-RS for IM
Set2_1: 3 NZP CSI-RS for IM

Set0_2: 3 NZP CSI-RS
Set1_2: 1 ZP CSI-RS for IM
Set2_2: 3 NZP CSI-RS for IM

TRP1

TRP2
5G NR beamforming aspects

Same PCI, different SSB indices + UE specific CSI-RS & precoding for beamforming support

gNB uses SSBs to be mapped on "static" beams.

PDSCH & PUSCH will be on UE specific beams. Beam refinement due to precoding and PMI feedback

PMI & CRI feedback
# 3GPP RAN Rel-16 Study-Item / Work-Item Status (March 2019)

<table>
<thead>
<tr>
<th>NR Study-Item / Work-Item Description</th>
<th>Study-Item</th>
<th>Work-Item</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR Core and Performance part</td>
<td></td>
<td>Rel-15 WI</td>
<td></td>
</tr>
<tr>
<td>NR MIMO enhancements</td>
<td>No Rel-16 SI</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>NR V2X</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>NR in unlicensed band</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>NR NOMA</td>
<td>completed</td>
<td></td>
<td>No Rel-16 work-item planned</td>
</tr>
<tr>
<td>2-step RACH for NR</td>
<td></td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>NR over non-terrestrial networks</td>
<td>ongoing</td>
<td></td>
<td>No Rel-16 work-item planned</td>
</tr>
<tr>
<td>NR UE power savings</td>
<td>ongoing</td>
<td>planned</td>
<td>SI to be completed in June 2019</td>
</tr>
<tr>
<td>NR positioning</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>NR eURLLC PHY enhancements</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>NR mobility enhancements</td>
<td>No Rel-16 SI</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>Multi-RAT Dual Connectivity/Carrier Aggregation enh.</td>
<td>No Rel-16 SI</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>NR Remote interference management</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** RP-190750  
Table lists important RAN1 and RAN2 led SI/WIs, does not include RAN4 band related SI/WIs, ITU related SI/WIs
## 3GPP RAN Rel-16 Study-Item / Work-Item Status (March 2019)

<table>
<thead>
<tr>
<th>NR Study-Item / Work-Item Description</th>
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<th>Work-Item</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR Integrated Access and Backhaul</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>Indoor channel model for Industrial IoT</td>
<td>ongoing</td>
<td></td>
<td>No follow-up work-item planned</td>
</tr>
<tr>
<td>NR Industrial IoT / Non-Public Networks (NPN)</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>Optimisations on UE radio capability signaling</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>SRVCC from 5G to 3G</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>NR test methods</td>
<td>completed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NR MIMO OTA test methods</td>
<td>ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 RX antenna exception for vehicles</td>
<td>completed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 dBm UE power class for B41/n41</td>
<td>completed</td>
<td>ongoing</td>
<td>to be completed in June 2019</td>
</tr>
<tr>
<td>NR in 7 – 24 GHz frequency range</td>
<td>ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NR design beyond 52.6 GHz</td>
<td>ongoing</td>
<td></td>
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</tr>
<tr>
<td>NR UE capability signaling</td>
<td>completed</td>
<td>ongoing</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** RP-190750  
Table lists important RAN1/2/4 led SI/WIs, does not include RAN4 band related SI/WIs, ITU related SI/WIs
5G broadcast: FeMBMS – further enhanced MBMS, Rel. 14 feature

- High power high tower (HPHT) concept
- True broadcast, independent on PLMN
- Resolution + formats in line with conventional broadcast
- Ability to stream video over IP
- Implementation scenario using supplementary downlink (SDL) concept of cellular networks
- Reception possible without SIM & authentication

No SIM card necessary => new device types possible + true broadcast
5G NR the right choice for broadcast: multi-link concept

Non-standalone (NSA): EN-DC

Standalone (SA): 5G-DC

5G NR is multi-link. Extension with HPHT broadcast possible

5G + broadcast as supplementary downlink (SDL)
Single Radio Voice Call Continuity: handover to 3G

- **gNodeB = 5G NR**
- **NodeB = UTRAN**

**Handover to UTRAN**

- **Radio Bearer reconfiguration: PS to CS mode**

- **VoIP in PS mode**

- **Voice call in CS mode**

- **5G NR Fundamentals, procedures and T&M aspects - Fra66e**

June 19
5G NR in Unlicensed Spectrum (NR-U)

- **Licensed Band**: LTE or 5G NR
- **Unlicensed Band**: Target 5 and 6 GHz ISM bands

**3 deployment scenarios.**
- LTE licensed + NR-U
- 5G NR licensed + NR-U
- Standalone NR-U

Discussion about common preamble for both: WLAN and 5G NR

LAA is 20MHz bandwidth => NR-U can use wider bandwidth, less complexity
5G NR positioning services

CID

E-CID (RSRP/TOA/TADV)

E-CID (RSRP/TOA/TADV) [Trilateration]

E-CID (AOA) [Triangulation]

Downlink / Uplink (O/U-TDOA) [Multilateration]

GNSS based
5G NR location based services – hybrid modes

Direction Finding (DF)–BLE Rel. 5.1–Estimation of angle

Angle of Arrival (AoA)

- Transmitter moving
- RF Switch
- Receiver
- calculation of the transmitter position
- fixed position

Angle of Departure (AoD)

- Receiver
- calculation of the transmitter position
- moving
- Transmitter
- fixed position

5G NR link using OTDO/UTDOA for trilateration

Bluetooth AoA for additional accuracy
5G NR over non-terrestrial networks

Déjà vu???

IMT2000 already defined the possibility of earth-to-satellite communication. Never took off commercially

Rel. 16 work item for 5G NR over Non-terrestrial networks. E.g. UE to airborne or satellite based gNBs.
5G NR industrial IoT

Support of time sensitive networks (TSN), i.e. common clock reference

Coordinated SIB / RRC broadcast

Ethernet RoHC or header removal

Intra-UE packet prioritization, L2/L3
5G NR mobility enhancements

Rel. 15 mobility

1. Handover command
2. RACH procedure
3. Connection established

Rel. 16 mobility

2. RACH procedure

Rel. 16 make before break approach + RACH less handover procedure

Rel. 15 handover based on LTE approach

5G NR Fundamentals, procedures and T&M aspects - France 66
5G NR C-V2X connection modes

Enhancements of LTE Uu and NR Uu to control NR sidelink from the cellular network
Enhancements of NR Uu to control LTE sidelink from the cellular network
NR Sidelink shall cover Ultra Reliable and high Data communication

Rel. 16 WI: Standalone first priority
Credits

Many graphics from this presentation were taken from:

Please use this link to get access to the online version of this technology book:

www.rohde-schwarz.com/5G-ebook/
“If you want to go fast, go alone.
If you want to go far, go together!”

African proverb