5G : An Overview

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Journées scientifiques d’URSI-France, Réseaux du futur : 5G et au-delà
March 2020
Overview and Requirements
RAN support for 5G use cases
eMBB, URLLC and mMTC

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Reliability</th>
<th>Energy and operations</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Massive MIMO</td>
<td>• Multi-connectivity</td>
<td>• Lean carrier</td>
<td>• Numerology support for shorter TTI</td>
</tr>
<tr>
<td>• Wider carrier and transmit bandwidths</td>
<td>• Cloud native</td>
<td>• Flexible numerology</td>
<td>• Mini-slot overwriting</td>
</tr>
<tr>
<td>• cmWave and mmWave bands</td>
<td></td>
<td>• Machine learning</td>
<td>• Grant free UL</td>
</tr>
<tr>
<td>• Shared uplink</td>
<td></td>
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<td>• RAN based QoS</td>
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<tr>
<td>• Multi-connectivity and NSA</td>
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<tr>
<th>Services</th>
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<tbody>
<tr>
<td>• Network slicing</td>
<td></td>
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<td>• 5GC QoS</td>
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<table>
<thead>
<tr>
<th>Connectivity</th>
<th></th>
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<tbody>
<tr>
<td>• NB-IoT and Cat M</td>
<td></td>
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<tr>
<td>• Signaling reduction (RRC Inactive)</td>
<td></td>
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<tr>
<td>• Contention access</td>
<td></td>
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</tbody>
</table>
Technology enablers for 5G New Radio (NR) interface and RAN

New spectrum options
Massive capacity and throughput

Cloud native
Flexible architecture

Flexible radio design
- For all use cases – Lean design, high capacity, flexibility

Massive MIMO
Massive capacity, improved end-user experience and coverage

Multi-connectivity and aggregation
End-user experience, extreme mobility, robustness and ultra reliability
From 5G to Industrial 5G
Long term roadmap for Industrial applications

5G standard releases roadmap

- **R15**: 5G NSA
  - Mobile BB / CSP deployments

- **R16**: 1st Critical Machine Communication support
  - NSA drop
  - SA drop

- **R17**: Full Critical Machine comm & new IoT profile

- **R18**: Full Massive IoT

5G ecosystem roadmap

- **2018**: 1st standard based 5G deployments possible

- **2019**: 1st 5G vertical features (uRLLC, Private 5G, etc.)

- **2020**: Massive IoT features & remaining vertical feature set (TSN, etc.)

- **2021**: 1st mass market commercial 5G end user devices

- **2022**: 1st 5G industrial features capable UE

- **2023**: Optimized 5G standard covering full 5G vision

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3GPP timeline
Release 15 to 17

Release 15: 5G First release focus on eMBB
- Split into three “drops”: “Early drop” 5G Non-Standalone (EN-DC NSA option 3) and 5G core (5GC); 5G Standalone (SA, option 2), eLTE (option 5); “Late Drop” for 5GC NSA solutions (NE-DC options 4 & NG-EN-DC option 7) and NR-DC

Release 16: Industrial IoT (IIoT), Wireline convergence, Non-public networks, NR-unlicensed
- Studies completed in 2018, rel. 16 completion due March 2020 with ASN.1 due June 2020

Release 17: NR-lite, IIoT enh, Beyond 52 GHz, Non-Terrestrial Networks
- Work started early 2020
Requirements driven by use cases
Evolution of throughput, reliability and latency

Traffic profiles
User density and service area
Latency (1ms to 100x ms)
Reliability & availability & survivability
TSN requirements

Flexible function placement
Flexible Radio design
Multi-connectivity
Disaggregated RAN
RAN Slicing
Transport FH & BH

Technological approaches

Wide range of requirements and use cases and need to efficiently use the radio resource
Spectrum and Migration
Spectrum: 5G bands from 300 MHz to 100 GHz

More spectrum × More beamforming × More cell sites = A lot more capacity

Bandwidth
- mm waves (30-100 GHz)
- Up to 2 GHz
- Up to 400 MHz
- Up to 100 MHz
- Up to 6 GHz
- Up to 20 MHz

Beam size
- Very small
- Narrow beams
- Small antenna
- Narrow beams
- Medium antenna
- Medium beams
- Large antenna
- Wide beams

Cell density
- Very dense small cell
- Dense small cell
- Urban Macro and small cell
- All Macro and urban small cell

Capacity
- Ultra high capacity booster
- Capacity booster
- Coverage and high capacity
- Coverage and new services

Frequency bands:
- 39 GHz
- 26/28 GHz
- 3.5 GHz
- 600-900 MHz

Wave types:
- cm waves (24-30 GHz)
- mm waves (30-100 GHz)
- <3 GHz
- 3-6 GHz
- 3.5 GHz
- 300 MHz
- 10 GHz
- 1 cm
- 3 mm
- 1 m
5G Spectrum and Coverage Footprint – combination of low and high bands

- 5G mm-waves
  - 1000x local capacity
  - 20 Gbps / 1000MHz.
- 5G 3500 mMIMO
- LTE1800
  - 10x capacity with Massive MIMO
  - Matches LTE 1800 coverage thanks to MMIMO
  - 2 Gbps / 100MHz @3.5GHz
- LTE800
  - Large cells & Deep indoor
  - IoT and critical communications 200 Mbps / 10MHz
- 5G 700

The combination of different frequency bands fulfills diverse usage needs and coverage
New options for sharing LTE and NR spectrum
Supplemental UL, UL sharing, Spectrum refarming and DSS

<table>
<thead>
<tr>
<th><strong>Supplemental UL (SUL)</strong></th>
<th><strong>UL sharing</strong></th>
<th><strong>Spectrum refarming</strong></th>
<th><strong>Dynamic spectrum sharing (DSS)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower-frequency carrier for NR UL transmission in addition to NR’s dedicated UL carrier.</td>
<td>NR UL resources overlap LTE UL band with UL schedulers managing split point</td>
<td>Longer term solution for legacy 2/3G and LTE bands</td>
<td>Transition solution mixing LTE and NR on same carrier</td>
</tr>
</tbody>
</table>
Architecture
### Stand-Alone (SA) and Non-Standalone (NSA)

#### 3GPP background – New Radio (NR) functionality

<table>
<thead>
<tr>
<th>Feature</th>
<th>Standalone (SA)</th>
<th>Non-standalone (NSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master carrier</td>
<td>NR</td>
<td>LTE</td>
</tr>
<tr>
<td>Secondary carrier</td>
<td>-</td>
<td>NR</td>
</tr>
<tr>
<td>Core choice</td>
<td>5G core (5GC)</td>
<td>4G EPC</td>
</tr>
<tr>
<td>Operator perspective</td>
<td>Simple, high performance overlay</td>
<td>Leveraging existing 4G deployments</td>
</tr>
<tr>
<td>Vendor perspective</td>
<td>Independent RAN product</td>
<td>Requires tight interworking with LTE</td>
</tr>
<tr>
<td>End user experience</td>
<td>Peak bitrate set by NR</td>
<td>Peak bitrate is sum of LTE and NR</td>
</tr>
<tr>
<td></td>
<td>Dedicated Low Latency transport</td>
<td>Latency impacted if routed via LTE master</td>
</tr>
</tbody>
</table>

NR (5G) 
LTE/eLTE (4G) 
NR (5G)
Functional RAN decomposition

Backhaul domain

Fronthaul domain

High Layer Split

Low Layer Split

- eNB-DU (LTE)
- gNB-DU (NR)
- RU
- Central Unit (CU)
  - RRC, SDAP and PDCP
  - User plane and control plane
- Distributed Unit (DU)
  - High-PHY layers, MAC and RLC
- Radio unit (RU)
  - Low-PHY layers

Central cloud

Edge cloud

Cell site

Central Unit (CU)

Distributed Unit (DU)

Radio unit (RU)

F1c

F1u

NGc

NGu

S1c

S1u

X2c/Xnc

X2u/Xnu
Flexible functions placement
Wide range of potential deployment use cases

Central cRAN (LLS)
- CU-UP
- CU-CP
- RU

Split cRAN (HLS)
- CU-UP
- CU-CP
- RU
- RU
- RU
- DU

Dual split cRAN (HLS+LLS)
- CU-UP
- CU-CP
- RU
- RU
- RU
- DU
- E1

Remote CU-UP (HLS)
- CU-UP
- CU-CP
- Local app
- RU
- RU
- RU
- DU
- E1

Central CU-UP (HLS)
- CU-UP
- CU-CP
- Local app
- RU
- RU
- RU
- DU
- E1

Cell site dRAN (monolithic)
- CU-UP
- CU-CP
- Local app
- RU
- RU
- RU
- DU
- E1

DU: Digital Unit, CU: Central Unit, RU: Radio Unit. UP user plane, CP control Plane
Flexible radio design
“New Radio” (NR) numerology building on LTE

<table>
<thead>
<tr>
<th></th>
<th>LTE</th>
<th>New Radio (NR)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bands</strong></td>
<td>&lt;4 GHz</td>
<td>&lt; 3GHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-6 GHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 6 GHz</td>
</tr>
<tr>
<td><strong>Multiple access</strong></td>
<td>CP-OFDM / SC-OFDM</td>
<td>CP-OFDM / CP-OFDM (+ SC-OFDM)</td>
</tr>
<tr>
<td><strong>Duplex</strong></td>
<td>FDD, TDD</td>
<td>FDD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TDD</td>
</tr>
<tr>
<td><strong>Sub-carrier (kHz)</strong></td>
<td>15</td>
<td>15, 30, 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15, 30, 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60, 120</td>
</tr>
<tr>
<td><strong>Carrier BW (MHz)</strong></td>
<td>1.4 .. 20</td>
<td>5 .. 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 .. 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 .. 400</td>
</tr>
<tr>
<td><strong>Carrier loading</strong></td>
<td>90%</td>
<td>90 .. 97%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90 .. 98%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td><strong>Slot per 10ms frame</strong></td>
<td>10</td>
<td>10-20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
</tr>
<tr>
<td><strong>Channel codes</strong></td>
<td>Turbo</td>
<td>LDPC (plus Polar for PBCH and PxCCH channels)</td>
</tr>
</tbody>
</table>

NR radio interface: a more flexible OFDM than LTE
Flexible NR Framework

- NR provides flexible framework to support different services and QoS requirements
  - Scalable slot duration, mini-slot and slot aggregation
  - Self-contained slot structure
  - Traffic preemption for URLLC
  - Support for different numerologies for different services
  - Forward compatibility

- NR transmission is well-contained in time and frequency
  - Future features can be easily accommodated
5G Enhances Spectral Utilization
Example: loading within 100 MHz spectrum allocation

More efficient than multicarrier LTE
- LTE limited to 100 PRB per 20 MHz carrier (i.e. 90% of carrier bandwidth)
- NR supports wider carriers and larger transmit BW (up to 98% of carrier BW)
- No unnecessary guard bands between carriers
5G Spectrum Utilization up to 98%

5G spectrum utilization is up to 98% of carrier bandwidth with 40-100 MHz bandwidth
5G utilization is more than 95% with at least 20 MHz bandwidth with 15 kHz subcarrier spacing
LTE utilization is 90%
Flexible radio design
Lean carrier also offers base station power savings

LTE

- Cell specific reference signal transmission 4x every millisecond
- Synchronization every 5 ms
- Broadcast every 10 ms

NR

- No cell specific reference signals
- Synchronization every 20 ms
- Broadcast every 20 ms

5G enables advanced base station power savings

Very limited capability for base station power savings due to continuous transmission of cell reference signals
Flexible radio design
Mapping and coding of Channels and Physical layer Signals to Symbols

UL-SCH
UL shared TrCh

UL-SCH
UL shared TrCh

PUSCH
Shared channel

PUSCH
Shared channel

PUCCH
Control channel

PUCCH
Control channel

PRACH
Random access ch

PRACH
Random access ch

DM-RS
Demodulation RS

DM-RS
Demodulation RS

PT-RS
Phase tracking RS

PT-RS
Phase tracking RS

SRS
Sounding RS

SRS
Sounding RS

UL-SCH
UL shared TrCh

UL-SCH
UL shared TrCh

PUSCH
Shared channel

PUSCH
Shared channel

PUCCH
Control channel

PUCCH
Control channel

PRACH
Random access ch

PRACH
Random access ch

DM-RS
Demodulation RS

DM-RS
Demodulation RS

PT-RS
Phase tracking RS

PT-RS
Phase tracking RS

SRS
Sounding RS

SRS
Sounding RS

NR defines simplified set of Uplink and Downlink channels

• RS: Reference signal
• CH: Channel
• SCH: shared Channel

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Beamforming – How to provide coverage for the common channels

The common channels need to be heard by all UEs.
But narrow beams, by definition, do not provide wide-area coverage.

The solution is: **beam sweeping**.
The common channels are transmitted in sequence across all beams, like a lighthouse.

*Common channels: Synch, PBCH, (minimum) system info, paging*
Downlink MIMO Framework: Beam Management

- **Initial gNB Beam Acquisition**
- SSB

---

- **gNB Beam Refinement**
  - CSI-RS (RSRP)
  - CSI-RS (CRI)
  - SRS

---

- **UE Beam Refinement**

Forming beam ports for MIMO transmission (TX and RX)
### DL-MIMO Operation – Sub-6GHz

#### Single CSI-RS
- CSI-RS may or may not be beamformed
- Leverage codebook feedback
- Analogous to **LTE Class A**
- Process:
  - gNB transmits CSI-RS
  - UE computes RI/PMI/CQI
- Maximum of 32 ports in the CSI-RS (codebooks are defined for up to 32 ports)
- Typically intended for arrays having 32 TXRUs or less with no beam selection (no CRI)

#### Multiple CSI-RS
- Combines beam selection with codebook feedback
- Analogous to **LTE Class B**
- Process:
  - gNB transmits one or more CSI-RS, each in different “directions”
  - UE computes CRI/PMI/CQI
- Supports arrays having arbitrary number of TXRUs
- Max 32 ports per CSI-RS

#### SRS-Based
- Exploits TDD reciprocity
- Similar to SRS operation in LTE
- Supports arrays having an arbitrary number of TXRUs.
- Process:
  - UE transmits SRS
  - Base computes TX weights

---

Disclaimer: NR-MIMO is flexible enough to support many variations on what is described on this slide
DL-MIMO Operation – Above 6GHz

**Single Panel Array**
- Combination of RF Beamforming and digital precoding at baseband
- RF Beamforming is typically 1RF BF weight vector per polarization: a single “Cross-Pol Beam”
- 2 TXRUs, Single User MIMO only
- Baseband Precoding Options:
  - None (rank 2 all the time)
  - CSI-RS based (RI/PMI/CQI)
  - SRS-based (RI/CQI)

**Multi-Panel Array**
- Combination of RF beamforming and digital precoding at baseband
- RF Beamforming is typically 1RF BF weight vector per polarization per panel:
  - One “Cross-Pol Beam” per sub-panel
- Number of TXRUs = 2 x # of panels
- Baseband Precoding Options:
  - CSI-RS based (RI/PMI/CQI)
  - SRS-based (RI/CQI)
  - SU- and MU-MIMO (typically one UE per Cross-Pol Beam)

**SU-MIMO**
- 2 TXRUs at gNBI
- 1 UE at a time
- 1 ≤ Rank ≤ 2

**MU-MIMO**
- 8 TXRUs at gNBI
- 1 UE at a time
- Up to 4 UEs at a time
- 1 ≤ Rank ≤ 2 per UE
Some radio performance trends
Downlink Massive MIMO: NR vs LTE: 16 and 32 TXRUs – Case Study

**LTE:**
- **Rel-13 Codebook**
  - 16 Ports and 32 Ports, Maximum Rank = 8
  - (32 ports=Rel-13 extension CB approved in Rel-14)
- **Rel-14 codebook (Advanced CSI CB)**
  - 16 Ports and 32 Ports, Maximum Rank = 2

**NR:**
- **NR Codebook Type I**
  - 16 Ports and 32 Ports, Maximum Rank = 8
- **NR Codebook Type II**
  - 16 Ports and 32 Ports, Maximum Rank = 2

---

**Physical Array Structures**

<table>
<thead>
<tr>
<th>8 columns</th>
<th>4 columns</th>
<th>2 columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>(8,8,2)</td>
<td>(8,4,2)</td>
<td>(8,2,2)</td>
</tr>
<tr>
<td>128</td>
<td>64</td>
<td>32</td>
</tr>
</tbody>
</table>

**Logical Configurations**

- 16 = (1,8,2)
- 16 = (2,4,2)
- 32 = (2,8,2)
- 32 = (4,4,2)
- 16 = (4,2,2)
- 32 = (8,2,2)
LTE vs NR: DL Codebook Performance at 2GHz (full buffer traffic)

**SU-MIMO:**
- Slight gain from Rel-13 to Rel-14: 10%
- Bigger gain from NR Type I to NR Type II: 10-20%
- NR Type I CB performs similarly to LTE Rel-13 CB
- NR Type II CB outperforms LTE Rel-13, LTE Rel-14, NR Type I

**MU-MIMO:**
- Large gain over SU-MIMO for all codebooks
- LTE Rel-13 CB and Rel-14 CB and NR Type I CB all perform similarly
- NR Type II CB provides significant gain over other CBs

**Array Configuration:**
- The wide array significantly outperforms the other array configurations in mean and cell edge.

**NR vs LTE:**
- NR Type II CB significantly outperforms LTE Rel-13, LTE Rel-14, NR Type I CBs with MU-MIMO
- Large gains with the NR Type II CB and MU-MIMO
- Mean and Cell Edge show similar trends
Summary

- NR-MIMO enables a beam-based air-interface for supporting both sub-6GHz and mmWave deployments with arbitrary array configurations.
- NR-MIMO provides improvements in performance, efficiency, scalability, and flexibility over LTE-FD-MIMO:
  - Beam Management – new feature over LTE
  - Type II CSI codebook – significant improvements over LTE codebooks
  - CSI acquisition framework for enhanced scalability and flexibility
  - Support for UE beamforming on UL
- Lots of evolutions planned in 3GPP R17 and R18, including:
  - Support of higher users mobility
  - UL overhead reduction
  - Improved support of multiple TRP & CoMP
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Gain of NR over LTE is roughly 19-35% in Mean SE, 14%-30% in cell edge (Full Buffer)