5G New Radio (NR) : Physical Layer Overview and Performance
IEEE Communication Theory Workshop - 2018

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Nokia Bell Labs
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## 5G New Radio : Key Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Benefit</th>
<th>Feature</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage of sub 6GHz and mmWave spectrum</td>
<td>10x..100x more capacity</td>
<td>Advanced Channel Coding</td>
<td>Large data block support with low complexity</td>
</tr>
<tr>
<td>UE agnostic Massive MIMO and beamforming</td>
<td>Higher Capacity and Coverage</td>
<td>Aggregation of LTE + 5G carriers</td>
<td>Higher data rate with smooth migration</td>
</tr>
<tr>
<td>Lean carrier design</td>
<td>Low power consumption, less interference</td>
<td>Integrated Access and Backhaul</td>
<td>Greater coverage @ mmWave with lower cost</td>
</tr>
<tr>
<td>Flexible frame structure</td>
<td>Low latency, high efficiency</td>
<td>Flexible connectivity, mobility and sessions</td>
<td>Optimized end-to-end for any services</td>
</tr>
<tr>
<td>Scalable OFDM based air-interface</td>
<td>Address diverse spectrum and services</td>
<td>Beamformed Control and Access Channels</td>
<td>Greater Coverage</td>
</tr>
<tr>
<td>Scalable numerology</td>
<td>Support of multiple bandwidths and spectrum</td>
<td>Higher Spectral Usage</td>
<td>Enhanced Efficiency</td>
</tr>
</tbody>
</table>
### Potential 5G Bands in (Early) 5G Deployments

<table>
<thead>
<tr>
<th>Band</th>
<th>Region</th>
<th>Infrastructure Type</th>
<th>5G Options</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 MHz</td>
<td>North America</td>
<td>LTE/5G</td>
<td></td>
<td>Full coverage with &lt;1 GHz</td>
</tr>
<tr>
<td>700 MHz</td>
<td>APAC, EMEA, LatAm</td>
<td>LTE/5G</td>
<td></td>
<td>Dense urban high data rates at 3.5 – 4.5 GHz</td>
</tr>
<tr>
<td>3.3-3.4 GHz</td>
<td>APAC, Africa, LatAm</td>
<td>LTE/5G</td>
<td></td>
<td>Hotspot 10 Gbps at 28/39 GHz</td>
</tr>
<tr>
<td>3.4-3.6 GHz</td>
<td>Global</td>
<td>LTE/5G</td>
<td></td>
<td>Future mmwave options</td>
</tr>
<tr>
<td>3.55-4.2 GHz</td>
<td>US</td>
<td>LTE/5G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.6-3.8 GHz</td>
<td>Europe</td>
<td>5G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.5 GHz</td>
<td>Japan, China</td>
<td>5G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 GHz</td>
<td>US, Korea, Japan</td>
<td>5G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39 GHz</td>
<td>US</td>
<td>5G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24.25-27.5 GHz</td>
<td>WRC-19 band</td>
<td>5G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31.8-33.4 GHz</td>
<td>WRC-19 band (Fra, UK)</td>
<td>5G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>~40, ~50, ~70</td>
<td>WRC-19 bands</td>
<td>5G</td>
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</tr>
</tbody>
</table>

Most of the 3.5Ghz already awarded – Spectrum re arrangement to happen to support larger block.
5G Coverage Footprint – Combination of Low and High Bands

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Bandwidth</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5G mm-waves</td>
<td>1000x local capacity</td>
<td>20 Gbps / 1000 MHz</td>
</tr>
<tr>
<td>5G 3500 mMIMO</td>
<td>10x capacity with LTE grid with massive MIMO</td>
<td>2 Gbps / 100 MHz</td>
</tr>
<tr>
<td>LTE-AWS</td>
<td>IoT and critical communication with full coverage</td>
<td>200 Mbps / 10 MHz</td>
</tr>
<tr>
<td>LTE700</td>
<td></td>
<td></td>
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<tr>
<td>5G600</td>
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</tr>
</tbody>
</table>

Let’s make 3.7-4.2 GHz available

- High bands for capacity
- Low band for IoT and low latency critical communication
5G Enhances Spectral Utilization

- Wideband 5G carrier is more efficient than multicarrier LTE
- Faster load balancing
- Less common channel overhead
- No unnecessary guard bands between carriers. LTE uses 10% for guard bands.
5G Lean Carrier for Enhanced Efficiency

**LTE**

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

Very limited capability for base station power savings due to continuous transmission of cell reference signals

**5G**

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

5G enables advanced base station power savings
Physical Channels & Physical Signals

PDSCH
DL shared channel

PBCH
Broadcast channel

PDCCH
DL control channel

DL Physical Signals
Demodulation Ref (DMRS)
Phase-tracking Ref (PT-RS)
Ch State Inf Ref (CSI-RS)
Primary Sync (PSS)
Secondary Sync (SSS)

UL Physical Signals
Demodulation Ref (DMRS)
Phase-tracking Ref (PT-RS)
Sounding Ref (SRS)

User Equipment

GNodeB

PUSCH
UL shared channel

PUCCH
UL control channel

PRACH
Random access channel
NR supports scalable numerology to address different spectrum, bandwidth, deployment and services

- Sub-carrier spacing (SCS) of 15, 30, 60, 120 kHz is supported for data channels
- $2^n$ scaling of SCS allows for efficient FFT processing
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
- NR transmission is well-contained in time and frequency
  - Future feature can be easily accommodated
Scalable NR Slot Duration

- One slot is comprised of 14 symbols
  - Slot length depends on SCS – 1ms for 15 kHz SCS to 0.125ms for 120 kHz SCS
- Mini-slot (2, 4, or 7 symbols) can be allocated for shorter transmissions
- Slots can also be aggregated for longer transmissions
NR frame/subframe structure

- **DL only subframe**
- **UL only subframe**
- **Self-contained subframe**

- **0.125ms frame with cascaded UL/DL control signals (120 KHz SC)**
- **1.0 ms user plane latency**
- **GP = 0**

- **Same physical layer in UL and DL**
- **Scalable Slot Duration**
- **Flexible UL/DL**

- **Control channel just before data**
- **Energy-effective processing**

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Initial Access

gNB periodically transmits synchronization signals and broadcast channels

SS Block #1

SS Block #N

PSS/SSS
PBCH
RMSI + OSI
RACH preamble (Msg1)
RAR (Msg2)
Msg3
Msg4
SS Block / CSI-RS
DCI
PUSCH/PUCCH
UE finds a good beam during synchronization, decodes MIB/SIB on that beam
UE attempts random access on the configured RACH resource
UE transmits Msg3 (e.g. RRC connection request)
UE responds with beam/CSI report
UE switches beam

gNB responds with RAR message

gNB requests beam/CSI reporting

gNB switches beam
SS Burst Example
# Overview of NR eMBB coding schemes

## LDPC
- **Data channel**
  - BG1 and BG2
  - Quasi-cyclic (QC)
  - Covers a wide range of coding rates and block sizes
  - Full IR-HARQ support
- **Benefits**
  - High throughput (parallel decoding in hardware)
  - Good performance

## Polar codes
- **Control channel**
  - DL: CRC-distributed polar codes
  - UL: CRC-aided and PC polar codes
- **Benefits**
  - Best performed short codes
  - Low algorithmic complexity
  - No error floor
What is “Massive MIMO”

**Massive MIMO** is the extension of traditional MIMO technology to antenna arrays having a large number (>>8) of controllable antennas.

Transmission signals from the antennas are adaptable by the physical layer via gain or phase control.

Not limited to a particular implementation or TX/RX strategy.

**Enhance Coverage:**
High Gain Adaptive Beamforming ➔ Path Loss Limited (>6GHz)

**Enhance Capacity:**
High Order Spatial Multiplexing ➔ Interference-limited (<6GHz)
# MIMO in 3GPP

<table>
<thead>
<tr>
<th>Release 8</th>
<th>Release 9</th>
<th>Release 10</th>
<th>Release 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 4x4MIMO</td>
<td>• 8TX TM8</td>
<td>• 8TX TM9</td>
<td>• Downlink CoMP (TM10)</td>
</tr>
<tr>
<td>• 4x2MIMO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 8RX uplink</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Uplink CRAN</td>
<td></td>
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<table>
<thead>
<tr>
<th>Release 12</th>
<th>Release 13</th>
<th>Release 14</th>
<th>Release 15+</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Downlink eCoMP</td>
<td>• Massive MIMO 16TX</td>
<td>• Massive MIMO 32TX</td>
<td>• 5G / NR Massive MIMO 32TX+</td>
</tr>
<tr>
<td>• New 4TX codebook</td>
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Massive MIMO: Why Now?

<table>
<thead>
<tr>
<th>Capacity Requirements</th>
<th>Coverage Requirements</th>
<th>Technology Capability</th>
<th>3GPP Spec Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Macro Networks will become congested</td>
<td>Below 6GHz: desire to deploy LTE/NR on site grids sized for lower carrier frequencies</td>
<td>Active Antennas are becoming technically and commercially feasible</td>
<td>3GPP supports Massive MIMO in Rel-13/14 for LTE and Rel-15 for NR/5G</td>
</tr>
<tr>
<td>Spectrum &lt; 3GHz and base sites will run out of capacity by 2020</td>
<td>Above 6GHz: Large Bandwidths but poor path loss conditions</td>
<td>Massive MIMO requires Active Antenna technology</td>
<td>3GPPP-New-Radio will be a “beam-based” air interface</td>
</tr>
</tbody>
</table>
# Massive MIMO at Higher Carrier Frequencies (>>6 GHz)

<table>
<thead>
<tr>
<th>Poor path loss conditions</th>
<th>Cost &amp; power consumption</th>
<th>Antenna array implementation</th>
<th>Beam based air interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large number of antennas needed to overcome poor path loss</td>
<td>Full digital solutions require transceiver units behind all elements</td>
<td>Smaller form factors</td>
<td>Single sector-wide beam may not provide adequate coverage</td>
</tr>
<tr>
<td>Obtaining channel knowledge per element is difficult</td>
<td>Wide bandwidths: A/D and D/A converters are very power hungry</td>
<td>Distributed PA solutions</td>
<td>→ Beamform all channels!</td>
</tr>
<tr>
<td></td>
<td></td>
<td>→ Hybrid arrays Beamforming at RF with baseband digital Precoding</td>
<td>→ Support analog and hybrid arrays</td>
</tr>
</tbody>
</table>

Massive MIMO at Higher Carrier Frequencies (>>6 GHz)
NR-MIMO in the 3GPP New Radio

### Main Drivers of NR-MIMO Development

<table>
<thead>
<tr>
<th>Deployment</th>
<th>Scalable, Flexible Implementation</th>
<th>Purpose</th>
</tr>
</thead>
</table>
| • Support frequencies both below and above 6GHz  
• Support both FDD and TDD | gNB:  
  • support full digital array architectures (<6GHz)  
  • hybrid/analog architectures (>6GHz),  
  • arbitrary TXRU configurations  
  • arbitrary array sizes  
UE:  
  • support traditional UE antenna configurations  
  • higher numbers of antennas  
  • UEs operating above 6GHz (hybrid/analog architectures) | • Enhance capacity (interference-limited deployments)  
• Enhance coverage (coverage-challenged deployments) |
Massive MIMO in 3GPP New Radio – Beam-based air-interface

**Beamformed Control Channels**
- Lower carrier frequencies (digital arch) - Single-beam
- Higher carrier frequencies (hybrid/analog beamforming architecture) - Multi-beam

**Beam Scanning**

**Beam Management**

**Key features for beam-based AI**
- Scalable and Flexible CSI Acquisition Framework
- High performing CSI Acquisition Codebooks
- Improved UL framework
Downlink MIMO Framework: Beam Management

- Initial gNB Beam Acquisition
- SSB or CSI-RS

- gNB Beam Refinement
- E.g., CSI-RS

- 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 transmit 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 (multiple beamformed CSI-RS with **CRI** 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**
- Intended for exploiting TDD reciprocity
- Similar to SRS-based operation in LTE
- Supports arrays having an arbitrary number of TXRUs.
- Process:
  - UE transmits SRS
  - Base computes TX weights

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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)

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

**SU-MIMO**
- 8 TXRUs at gNB
- 1 UE at a time
- 8 Ports/UE in this example
- 1 ≤ Rank ≤ 8 (UE limit)

**MU-MIMO**
- 8 TXRUs at gNB
- Up to 4 UE(s) at a time
- 1 ≤ Rank ≤ 2 per UE
### Report Settings

- **Quantities to report:** CSI-related or L1-RSRP-related
- **Time-domain behavior:** Aperiodic, semi-persistent, periodic
- **Frequency-domain granularity:** Reporting band, wideband, sub-band
- **Time-domain restrictions** for channel and interference measurements
- **Codebook configuration** parameters
  - Type I
  - Type II

### Resource Settings

- A Resource Setting configures $S>1$ **CSI Resource Sets**
- Each CSI Resource Set consists of:
  - **CSI-RS Resources** (Either NZP CSI-RS or CSI-IM)
  - **SS/PBCH Block Resources** (used for L1-RSRP computation)
- **Time-domain behavior:** aperiodic, periodic, semi-persistent
- **Note:** # of CSI-RS Resource Sets is limited to $S=1$ if CSI Resource Setting is periodic or semi-persistent.

### Trigger States

- Associates
- What CSI to report and when to report it with
- What signals to use to compute the CSI

- Links Report Settings with Resource Settings
- Contains list of associated CSI-ReportConfig

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Summary: UL MIMO

- **Two transmit schemes are supported for NR uplink MIMO**
  - Codebook based transmission
    - Up to 4Tx codebooks are defined for both DFT-S-OFDM and CP-OFDM
  - Non-codebook based transmission
    - UE Tx/Rx reciprocity based scheme to enable UE assisted precoder selection

- **Diversity schemes are not explicitly supported in NR specification**
  - No diversity based transmission schemes are specified in Rel-15 NR
  - UE can still use “transparent” diversity transmission scheme.
    - UE may use 1Tx port procedure for specification-transparent diversity Tx schemes
Downlink Massive MIMO: NR vs LTE: 16 and 32 TXRUs, Full Buffer Traffic

**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
  - 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></th>
<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>
<td></td>
</tr>
<tr>
<td>168</td>
<td>64</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

### Logical Configurations

- **Scenarios at 2GHz**
  - 3D-UMa (750m & 1500m ISD) 3D-UMi (200m ISD)
  - 16 = (1,8,2)
  - 32 = (2,8,2)
  - 32 = (4,4,2)
  - (2,4,2)
  - 16 = (4,2,2)
  - 16 = (8,2,2)

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Gain of NR over LTE: 16 Ports – Full Buffer, 2GHz, DL

- Gain of NR over LTE is roughly 19-35% in Mean SE, 14%-30% in cell edge (Full Buffer)
- Gains in bursty traffic will be higher
5G vs. 4G Capacity per Cell at 2GHz – 16x4 MIMO

LTE
2GHz
750m ISD
16x4
eNB= (1,8,2)

NR
2GHz
750m ISD
16x4
gNB= (1,8,2)

• In Full Buffer, NR Codebooks show significant gains over LTE Codebooks
  - Mean UE throughput: 26%
  - Cell edge: 25%

* Includes 20% improvement due to lean carrier in NR
**Uplink Performance: 32 Rx – Full Buffer, 2GHz**

<table>
<thead>
<tr>
<th>ISD200m, 500m, 750m</th>
<th>ISD 200m</th>
<th>ISD 500m</th>
<th>ISD 750m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean UE SE (b/s/Hz)</td>
<td>0.35</td>
<td>0.31</td>
<td>0.26</td>
</tr>
<tr>
<td>Cell Edge UE SE (b/s/Hz)</td>
<td>0.12</td>
<td>0.06</td>
<td>0.03</td>
</tr>
</tbody>
</table>

- **Cell Edge Performance of UL degrades significantly as ISD is increased from 200m to 750m.**
- **No major differences in UL performance with NR vs LTE**
Detailed Simulation Parameters: 28GHz

Access Point Parameters:

- AP512: cross-pol array with 512 physical antenna elements (16,16,2), 256 elements per polarization
- Physical antenna elements: 5dBi max gain per physical element, Half wavelength spacing between rows and columns, elements have 3dB beamwidth of 90 degrees.
- Max EIRP = 54dBm and 60dBm (assuming polarizations are not coherently combined), Noise figure of 5dB
- Single TXRU per polarization → 2TXRUs: SU-MIMO with open-loop rank 2 per UE on DL and UL

UE:

- UE32: Dual panel cross-pol array, 2 panels oriented back-to-back with best-panel selection at UE. Each panel is (4,4,2) with 32 physical elements per panel, 16 physical elements per polarization per panel, TX power fed to active panel element = 23dBm
- Physical elements in antenna array panel: 5dBi max gain per physical element, half wavelength spacing between rows and columns, elements have 3dB beamwidth of 90 degrees.
- Max EIRP = 40dBm in all cases (assuming all antenna elements can be coherently combined), Noise figure of 9dB
- Single TXRU per polarization → 2 TXRUs: SU-MIMO with open-loop rank 2 per UE on DL and UL
Downlink (800MHz): Mean & Cell Edge Throughput (Non Ideal RX)

**EIRP = 54dBm**

**Mean UE Throughput**

![Graph of Mean UE Throughput for EIRP = 54dBm](image1)

**Cell Edge Throughput**

![Graph of Cell Edge Throughput for EIRP = 54dBm](image2)

**EIRP = 60dBm**

**Mean UE Throughput**

![Graph of Mean UE Throughput for EIRP = 60dBm](image3)

**Cell Edge Throughput**

![Graph of Cell Edge Throughput for EIRP = 60dBm](image4)
Antenna Array Comparisons - AP Antenna Aperture Constant vs. Frequency

5dBi ant element gain, 7dBm AP Pout per element, 1dBm UE Pout per element, shown to scale

- **28 GHz**
  - 256 elements (8x16x2)
  - Max EIRP ≈ 60.2 dBm
  - 103% area relative to 28GHz

- **39 GHz**
  - 512 elements (16x16x2)
  - Max EIRP ≈ 66.2 dBm
  - 15% area relative to 28GHz

- **73 GHz**
  - 1024 elements (16x32x2)
  - Max EIRP ≈ 72.2 dBm
  - 59% area relative to 28GHz

Room to grow…normalized array size is ~4.5dBm more than above

- **28 GHz, 32 elements, (4x4x2)**
  - Max EIRP ≈ 36.1 dBm

- **39 GHz, 32 elements, (4x4x2)**
  - Max EIRP ≈ 36.1 dBm

- **73 GHz, 32 elements, (4x4x2)**
  - Max EIRP ≈ 36.1 dBm
System Simulation Results for the Suburban Micro Environment (Heavy Foliage)
Constant Antenna Aperture for 28 GHz, 39 GHz and 73 GHz

Mean UE Throughput

Cell Edge Throughput

Downlink

Uplink

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5G – LTE Dual Connectivity and Application Performance

- 5G (=NR) gives lowest latency for the packets = best application performance
- 5G + LTE aggregation increases latency and degrades performance
- Conclusions: use 5G for user plane without LTE aggregation as long as 5G is available

Radio assumptions on average
- 5G: 400 Mbps and 3 ms
- LTE: 100 Mbps and 30 ms
### 3GPP Release 16 outlook – RAN1 led items

<table>
<thead>
<tr>
<th>On-going</th>
<th>High Priority</th>
<th>Medium Priority</th>
<th>Need unclear</th>
</tr>
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<tbody>
<tr>
<td>Non-orthogonal multiple access</td>
<td>MIMO enhancements</td>
<td>NR-based V2X below 6.4 GHz</td>
<td>Air-to-ground</td>
</tr>
<tr>
<td>Non-terrestrial networks</td>
<td>URLLC enhancements</td>
<td>MBMS for 5G / EN-DC</td>
<td>Flexible duplex</td>
</tr>
<tr>
<td>eV2X evaluation methodology</td>
<td>Dual Connectivity optimization</td>
<td>High speed UE</td>
<td>Full Duplex</td>
</tr>
<tr>
<td>Unlicensed spectrum</td>
<td>Location enhancements*</td>
<td>Spectrum Efficiency Enhancements</td>
<td></td>
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<tr>
<td></td>
<td>Dynamic TDD</td>
<td>5G Above 52.6 GHz</td>
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<tr>
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<td>NR based IoT UE categories</td>
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<td>Initial access enhancements</td>
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<td>UE power saving &amp; Wake-up</td>
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*High priority applies for items with relevance for E911 accuracy requirements.*
5G mmWave Integrated Access and Backhaul (IAB)

Problem Statement

New radio would likely require **dense deployments right from the initial phases** to get sufficient coverage @ mmWave frequencies.

Economically not feasible to provide fiber connectivity to each site until the new radio deployments become mature.

Self-backhauling is enabling multi-hop networks with shared access-backhaul resources.

Key disruption

Self-backhaul using same antenna arrays to dynamically switch between access and backhaul with optimized scheduling and dynamic TDD enabling deployment cost reduction and improving system performance.

Topics

- Topology management for single-hop/multi-hop and redundant connectivity
- Route selection and optimization
- Dynamic resource allocation between the backhaul and access links
- Physical layer solutions to support wireless backhaul links with high spectral efficiency

3GPP Study Item

In Progress complete by Dec 2018

Reduce deployment cost by 10x
Improve Coverage by 2x
### 3GPP Standardization on 5G vs available spectrum?

#### 5G standards roadmap
- **3GPP 5G Phase 1 - Rel 15**
  - Mobile Broadband, Low latency & high reliability
- **3GPP 5G Phase 2 - Rel 16**
  - Massive IoT FMC
- **3GPP 5G Rel 17**
  - Optimized standard completing full 5G vision

#### 5G industry roadmap
- **2016**: Pre-standards 5G start
- **2017**: First standard based 5G deployments
- **2018**: Standards-based 5G mass rollout
- **2019**: NSA (*)
- **2020**: SA (*)
- **2021**: Realistic Timing for introduction of commercial 5G 3.5Ghz, 28Ghz, 600Mhz
- **2022**: Realistic Timing for introduction of commercial massive machine communication use case

#### 5G spectrum usage
- **US 28, 39 GHz**
- **Korea 28 GHz**
- **Japan 3.5 GHz**
- **EU/CN 4.5 GHz**
- **Korea 3.5 GHz**
- **EU 700Mhz 24GHz**
- **US 600MHz 2.5GHz**
- **Global availability > 24 GHz**