NR Physical Layer Design: NR MIMO

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Considerations for NR-MIMO Specification Design

NR-MIMO Specification Features
Key Features of NR-MIMO

- Make cellular communications over millimeter wave (mmWave) spectrum a reality
  - ITU’s 5G requirement to support a peak rate of 20Gbps would not be possible without mmWave

- Improve system performance well beyond LTE
  - ITU’s 5G requirement is to achieve spectral efficiency of 3 times that of LTE

- Provide sufficient flexibility for wide range of 5G realizations
  - Considering deployment scenarios, network implementations, supportable spectrum bands, etc

Higher Frequency Bands
(Coverage for mmWave)

- Multi-beam operation

Performance
(Enhanced spectral efficiency)

- Enhanced channel status information (CSI)

Flexibility
(Deployment, implementation, spectrum, ...)

- Enhanced reference signals, transmission schemes, etc
Higher Frequency Band

Pathloss is proportional to the square of frequency

\[ P_{RX} = P_{TX} G_{TX} G_{RX} \left( \frac{\lambda}{4\pi R} \right)^2 \]

\[ = P_{TX} \cdot 1 \cdot 1 \cdot \left( \frac{\lambda^2}{4\pi} \right) \left( \frac{1}{4\pi R^2} \right) \]

\[ = P_{TX} \cdot 1 \cdot 1 \cdot \left( \frac{c^2}{4\pi} \cdot \frac{1}{f^2} \right) \left( \frac{1}{4\pi R^2} \right) \]

\[ (c: \text{speed of light}) \]

2.8GHz vs 28GHz

<table>
<thead>
<tr>
<th></th>
<th>2.8 GHz</th>
<th>28 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RX Aperture Size</td>
<td>9.135 cm²</td>
<td>0.091 cm²</td>
</tr>
<tr>
<td>Path-loss (R=1m)</td>
<td>-41.4 dB</td>
<td>-61.4 dB</td>
</tr>
</tbody>
</table>
Higher Frequency Band

- Pathloss of higher frequencies can be overcome by utilizing multi-antennas
  - Multiple Rx antennas to effectively increase aperture size
  - Multiple Tx antennas to direct energy

- NR facilitates the use of multi-antennas in at every stage of the radio operation:
  - Initial/random access
  - Paging
  - Data/control information
  - Mobility handling
Analog and Digital Beamforming

- LTE was designed on the assumption of a fixed analog beam per cell
  - The analog beam provides full coverage throughout the cell at any given time instance
- NR was designed on the concept of multiple steerable analog beams per cell
  - Each analog beam concentrates on a part of a cell at a given time so as to overcome large pathloss
- Digital beamforming is applied on top of analog beamforming in both LTE and NR
Hybrid Beamforming

A combination of digital and analog beamforming, or ‘hybrid beamforming’ can be used to realize large BF gains without excessively increasing implementation complexity.
Single vs Multi-Beams

- In lower frequencies, a single beam can be used to provide wide coverage.
- In higher frequencies, multiple beams can be used to extend coverage.

Single beam per sector @2.8GHz

- Reduced coverage @28GHz

Multi-beam per sector @28GHz

- Subset of beams transmitted in a time instance
- Multi-beam operation with multiple narrow beams
Considerations for NR-MIMO Specification Design

NR-MIMO Specification Features
Comparison of NR-MIMO vs LTE MIMO

<table>
<thead>
<tr>
<th>Purpose</th>
<th>LTE Rel-8</th>
<th>LTE-A Pro Rel-15</th>
<th>NR Rel-15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Spectral efficiency enhancement</td>
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<td>• Coverage enhancement (especially for above 6GHz)</td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
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<tr>
<td></td>
<td>• Coverage enhancement</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Multi-beam operation</td>
<td>• No specification support</td>
<td>• No specification support</td>
<td>• Beam measurement, reporting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Beam indication</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Beam failure recovery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uplink transmission</td>
<td>• Up to 4 layers per UE</td>
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</tr>
<tr>
<td></td>
<td>• Up to 8 layers for MU-MIMO</td>
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<td>• Up to 12 layers for MU-MIMO (orthogonal ports)</td>
</tr>
<tr>
<td></td>
<td>(cyclic shifts for ZC-sequence)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downlink transmission</td>
<td>• Up to 4 layers per UE</td>
<td>• Up to 8 layers per UE</td>
<td>• Up to 8 layers per UE</td>
</tr>
<tr>
<td></td>
<td>• Up to 4 layers for MU-MIMO</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference signal</td>
<td>• Fixed pattern, overhead</td>
<td>• Fixed pattern, overhead</td>
<td>• Configurable pattern, overhead</td>
</tr>
<tr>
<td></td>
<td>• Up to 4 TX antenna ports (CRS)</td>
<td>• Up to 32 TX antenna ports (CSI-RS)</td>
<td>• Up to 32 TX antenna ports (CSI-RS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Support for above 6GHz</td>
</tr>
</tbody>
</table>
Uplink Transmission

Codebook based and non-codebook based uplink transmissions are supported

- Codebook based: gNB indicates the uplink beam direction and precoding to the UE
- Non-codebook based: gNB only indicates the beam direction only

**Codebook based Uplink Transmission**

1. UE transmits multiple SRSs in different beam directions
2. gNB indicates to UE: Beam direction (SRS index), rank, and transmit precoding for uplink
3. UE transmits uplink as indicated by gNB

**Non-Codebook based Uplink Transmission**

1. UE transmits multiple SRSs in different beam directions
2. gNB indicates to UE: Beam/precoding direction and rank (all included in SRS indices)
3. UE transmits uplink as to match the direction of indicated SRS(s)

Uplink MIMO capability

- Up to rank 4 per UE, up to 12 co-scheduled UEs with orthogonal DM-RS ports
Downlink Transmission

- gNB has full control of downlink precoding which can be determined either from channel status report or SRS transmission from UE
  - UE has no knowledge of actual precoding applied at the gNB (UE transparent)
  - UE only requires the combined effect of precoding and channel for demodulation purpose

- Downlink MIMO capability
  - Up to rank 8 per UE
  - Up to 12 co-scheduled UEs with orthogonal DM-RS ports
Two different Channel Status Information (CSI) types are supported in NR:

- **Type-I** which is optimized for Single User MIMO transmission with smaller uplink overhead
- **Type-II** which is optimized for Multi-User MIMO transmission with finer channel information and as a consequence, larger uplink overhead

Terminal selects beam and co-phase (relative phase difference between X-pol antennas) coefficient

Terminal selects multiple beams, amplitude scaling, and phase coefficients for linear combination between the beams
Multi-Beam Operation in NR

**Beam Measurement/Reporting**
Terminal measures different combinations of TX-RX beams for initial selection and further refinement.

**Beam Indication**
NW indicates beam direction for reference signals, and control/data transmission on downlink/uplink.

**Beam Failure Report**
A low latency procedure for recovering from beam failure.
Multi-Beam Operation in NR

**Multi-Beam Operation for Initial Access and Data-Control Channel**

- **TRP level beam sweeping for coverage**
  - Synchronization Signals
  - System Information
  - TX beam sweeping at TRP
  - RX beam sweeping at TRP
  - Random Access Channel

- **TRP and UE TX/RX beam acquisition**
  - Random Access Response
  - TX/RX beam acquired at TRP/UE
  - Other System Information
  - TX/RX beam acquired at TRP/UE

- **UE specific beam selection and beamforming**
  - Data/Control Channel
  - UE specific beamforming over acquired TX/RX beams
  - Data/Control Channel
Beam Failure Recovery

Due to the narrow beam width when multi-beam operation is in place, the link between the network and terminal is prone to beam failures.

Unlike out-of-coverage situations, beam failure tends to have dynamic time profile.

Beam failure recovery allows for prompt beam recovery using L1 procedures.

1. Terminal requests new beam assignment using contention free PRACH resources
2. NW reassigns beam based on the beam failure recovery request from terminal
3. New beam pair link established

Obstacle blocks beam connection between terminal and NW
NR Reference Signals

- LTE has a ‘one size fits all’ downlink reference signal design: CRS
  - Limits flexible network deployments, not network energy efficient, not applicable for higher spectrum (>6GHz), not MIMO friendly for large number of antennas
- NR downlink reference signals are tailored for specific roles and can be flexibly adapted for different deployment scenarios and spectrum
NR Reference Signals: DM-RS

- Designed for downlink/uplink channel estimation → coherent demodulation
- NR supports two different types of DMRS

<table>
<thead>
<tr>
<th></th>
<th>NR Type 1 DM-RS</th>
<th>NR Type 2 DM-RS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orthogonal Ports</strong></td>
<td>Up to 8</td>
<td>Up to 12</td>
</tr>
<tr>
<td><strong>Flexibility</strong></td>
<td>Can be adapted for frequency/time selectivity, robustness, number of co-scheduled UEs for MU-MIMO, etc.</td>
<td></td>
</tr>
<tr>
<td><strong>Waveform</strong></td>
<td>CP-OFDM (UL/DL) or DFT-S-OFDM (UL)</td>
<td>CP-OFDM only (UL/DL)</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>IFDMA based</td>
<td>Frequency domain orthogonal cover code based</td>
</tr>
<tr>
<td><strong>(figure for single symbol DM-RS)</strong></td>
<td><img src="image1" alt="IFDMA design" /></td>
<td><img src="image2" alt="Frequency domain orthogonal cover code design" /></td>
</tr>
<tr>
<td><strong>Overhead/Port</strong></td>
<td>Higher</td>
<td>Lower</td>
</tr>
</tbody>
</table>
NR Reference Signals: CSI-RS / TRS

CSI-RS is designed for downlink measurement → reporting channel status info
Three different types of CSI-RS is supported: Periodic, aperiodic, and semi-persistent CSI-RS

<table>
<thead>
<tr>
<th></th>
<th>Periodic CSI-RS</th>
<th>Aperiodic CSI-RS</th>
<th>Semi-Persistent CSI-RS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orthogonal Ports</strong></td>
<td>Up to 32</td>
<td>Up to 32</td>
<td>Up to 32</td>
</tr>
<tr>
<td><strong>Time domain behavior</strong></td>
<td>Periodic transmission once configured</td>
<td>Single transmission when triggered</td>
<td>Periodic transmission once activated until deactivated</td>
</tr>
<tr>
<td><strong>Activation/Deactivation</strong></td>
<td>RRC signaling</td>
<td>L1 signaling</td>
<td>MAC CE</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>No L1 overhead</td>
<td>Low latency</td>
<td>Hybrid of periodic and aperiodic CSI-RS</td>
</tr>
</tbody>
</table>

TRS is designed for time/frequency tracking and estimation of delay/Doppler spread
Configured as a CSI-RS with specific parameter restriction (time/freq location, RE pattern, etc)
NR Reference Signals: PTRS

 PTRS is designed for compensation of downlink/uplink phase noise compensation
‘Associated’ with DM-RS so that receiver can compensate for phase noise during demodulation
PTRS density in time, frequency is associated with scheduled MCS, bandwidth, respectively

<table>
<thead>
<tr>
<th>Scheduled MCS</th>
<th>Time domain density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt;= MCS &lt; MCS₁</td>
<td>No PTRS</td>
</tr>
<tr>
<td>MCS₁ &lt;= MCS &lt; MCS₂</td>
<td>Every OFDM symbol</td>
</tr>
<tr>
<td>MCS₂ &lt;= MCS &lt; MCS₃</td>
<td>Every 2ⁿᵈ OFDM symbol</td>
</tr>
<tr>
<td>MCS₃ &lt;= MCS &lt; MCS₄</td>
<td>Every 4ᵗʰ OFDM symbol</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scheduled bandwidth</th>
<th>Frequency domain density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt;= N_RB &lt; N_RB₁</td>
<td>No PTRS</td>
</tr>
<tr>
<td>N_RB₁ &lt;= N_RB &lt; N_RB₂</td>
<td>Every 2ⁿᵈ RB</td>
</tr>
<tr>
<td>N_RB₂ &lt;= N_RB</td>
<td>Every 4ᵗʰ RB</td>
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<table>
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<th>Scheduled BW</th>
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<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Every 2ⁿᵈ RB</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Every 4ᵗʰ RB</td>
</tr>
</tbody>
</table>

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NR Reference Signals: SRS

- SRS is designed for evaluation of uplink channel quality and timing
  - Can also be used for downlink channel information when channel reciprocity is applicable
  - Three different types of SRS is supported: Periodic, aperiodic, and semi-persistent SRS (same time domain behavior as that of CSI-RS)
  - SRS carrier switching is supported for transmitting SRS over more than one carrier using a single uplink transmitter
  - Up to 6 OFDM symbols can be used for SRS transmission to increase SRS capacity compared to LTE (Rel-8 LTE supports up to 1 OFDM symbol)
Enhancements on NR-MIMO for Rel-16

- Enhancements on **MU-MIMO** support:
  - Specify overhead reduction, based on Type II CSI feedback, taking into account the tradeoff between performance and overhead
  - Perform study and, if needed, specify extension of Type II CSI feedback to rank >2

- Enhancements on **multi-TRP/panel transmission** including improved reliability and robustness with both ideal and non-ideal backhaul:
  - Specify downlink control signalling enhancement(s) for efficient support of non-coherent joint transmission
  - Perform study and, if needed, specify enhancements on uplink control signalling and/or reference signal(s) for non-coherent joint TX
  - Multi-TRP techniques for URLLC requirements are included in this WI

- Enhancements on **multi-beam operation**, primarily targeting FR2 operation:
  - Perform study and, if needed, specify enhancement(s) on UL and/or DL TX beam selection specified in Rel-15 to reduce latency/overhead
  - Specify UL transmit beam selection for multi-panel operation that facilitates panel-specific beam selection
  - Specify a beam failure recovery for SCell based on the beam failure recovery specified in Rel-15
  - Specify measurement and reporting of either L1-RSRQ or L1-SINR

- Perform study and make conclusion in the first RAN1 meeting after start of the WI, and if needed, specify CSI-RS and DMRS (both DL and UL) enhancement for **PAPR reduction** for one or multiple layers (no change on RE mapping specified in Rel-15)

- Specify enhancement to allow **full power transmission** in case of uplink transmission with multiple power amplifiers (assume no change on UE power class)
Thank you!