NR Physical Layer Design: NR MIMO

Younsun Kim
3GPP TSG RAN WG1 Vice-Chairman (Samsung)

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Considerations for NR-MIMO Specification Design

NR-MIMO Specification Features

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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

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Higher Frequency Band

- Pathloss is proportional to the square of frequency

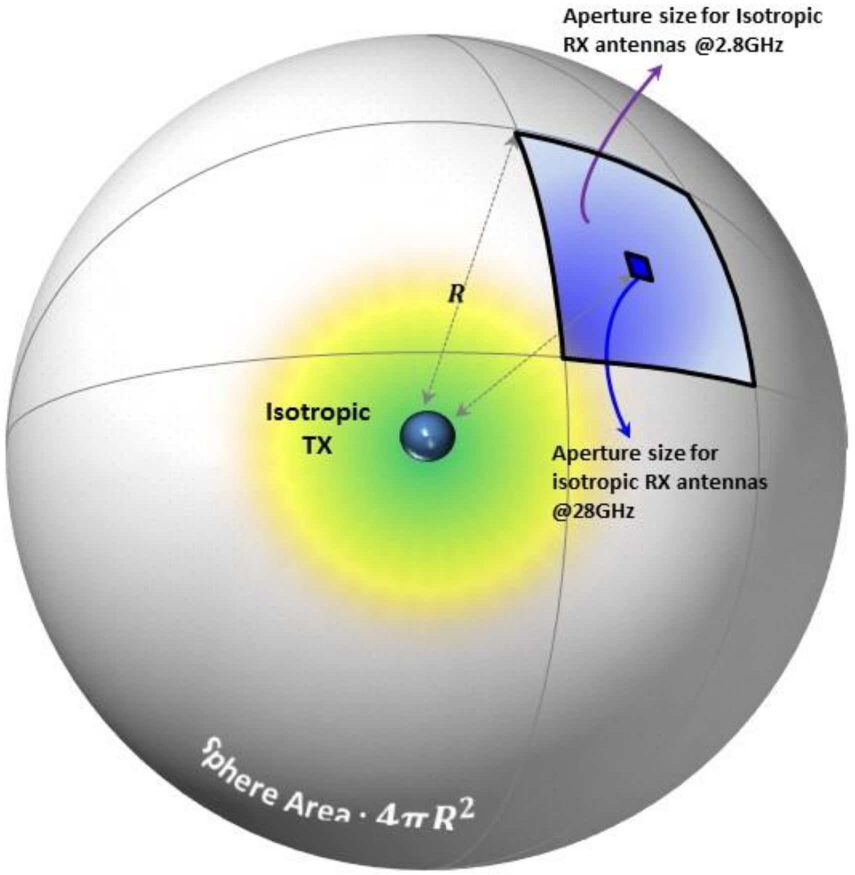
$$P_{RX} = P_{TX}\underbrace{G_{TX}G_{RX}}_{=1\text{ for Isotropic}}\underbrace{\left(\frac{\lambda}{4\pi R}\right)^2}_{\text{Path-loss}}$$

$$= P_{TX}\cdot 1\cdot 1\cdot \underbrace{\left(\frac{\lambda^2}{4\pi}\right)}_{\text{Aperture size}}\underbrace{\left(\frac{1}{4\pi R^2}\right)}_{\text{Spherical area}}$$

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

Carrier frequency

(c: speed of light)



- 2.8GHz vs 28GHz

	2.8 GHz	28 GHz
RX Aperture Size	9.135 cm^2	0.091 cm^2
Path-loss (R=1m)	-41.4 dB	-61.4 dB

-20dB

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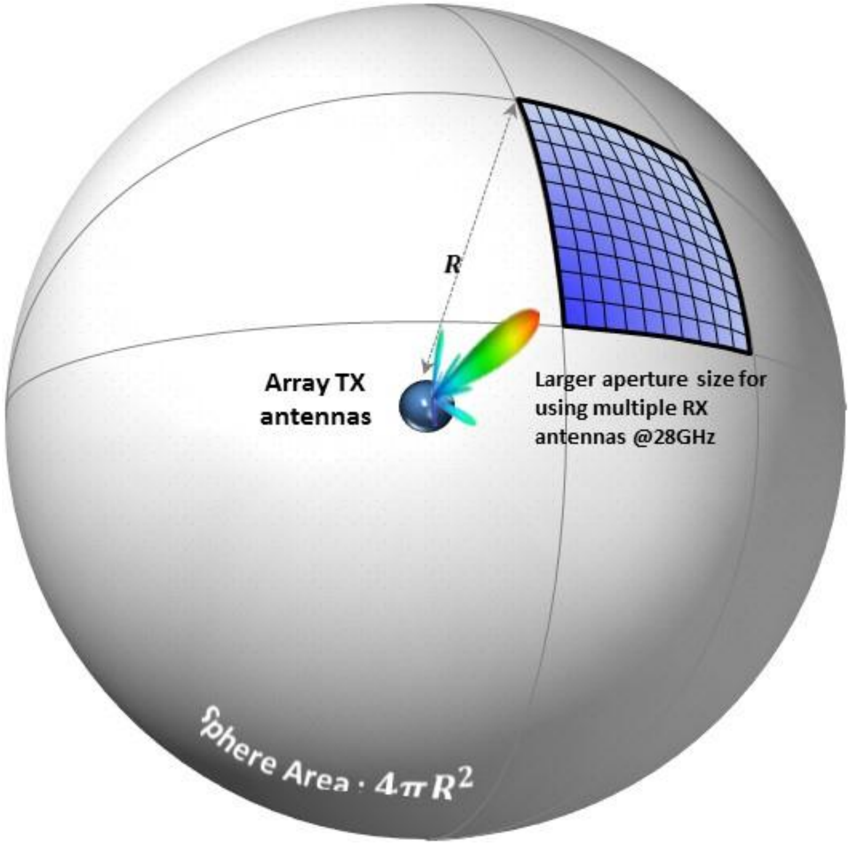
Higher Frequency Band

- 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



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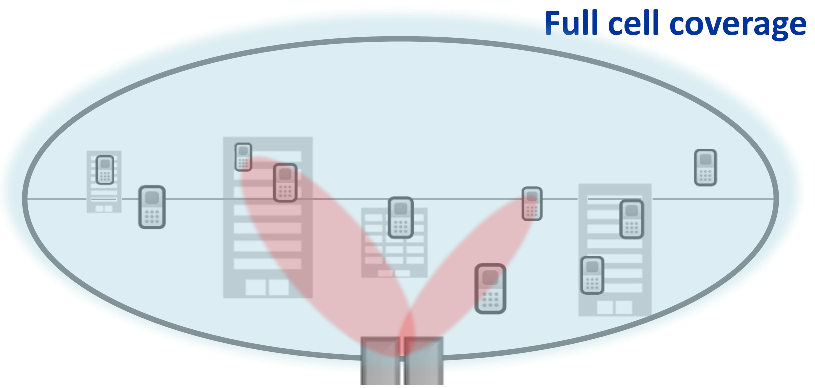
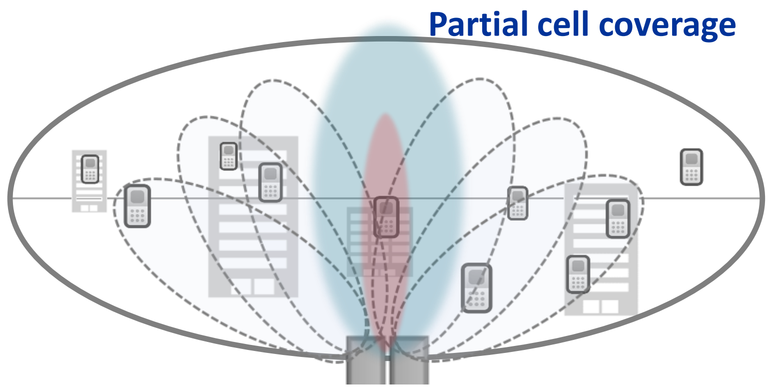
Analog and Digital Beamforming

- 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

Single fixed analog beam



Multiple steerable analog beams



Analog beam   Digital beam

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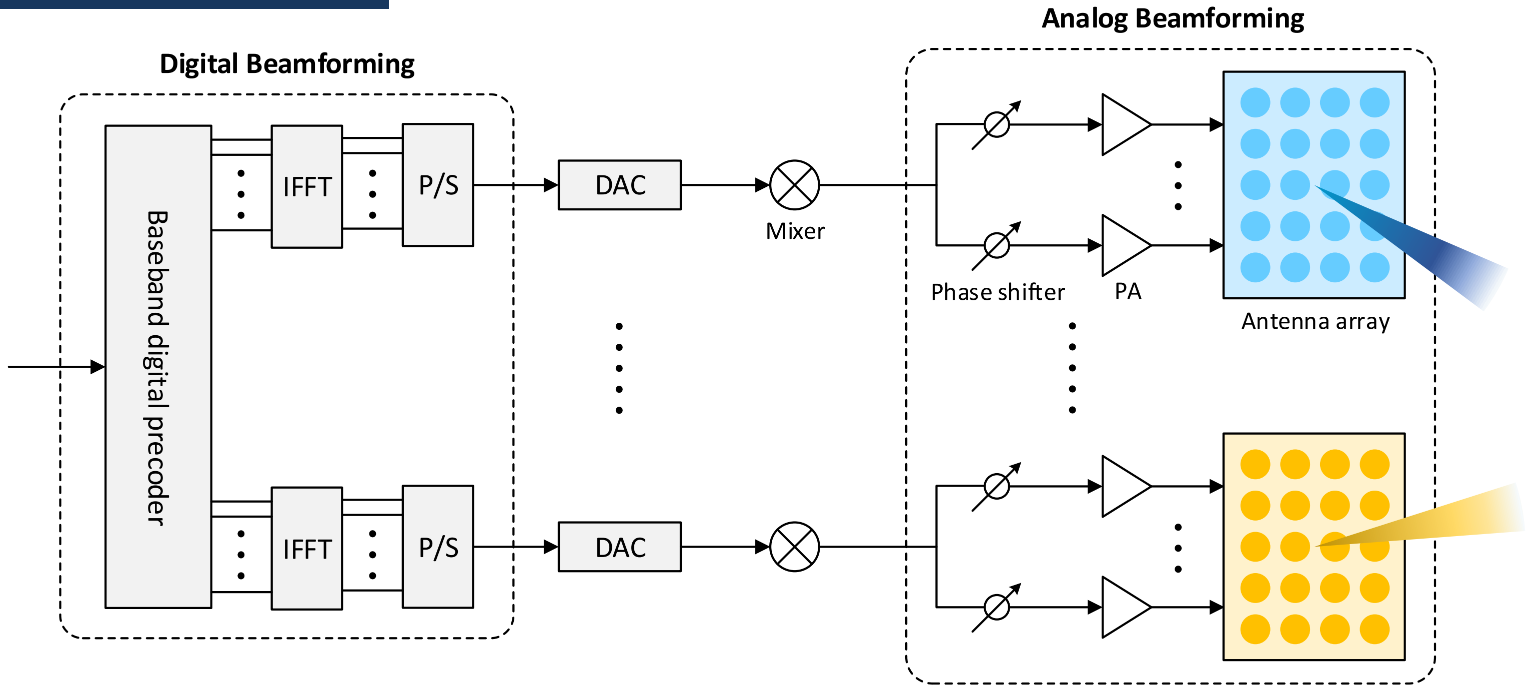
Hybrid Beamforming

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

Example of hybrid beamforming



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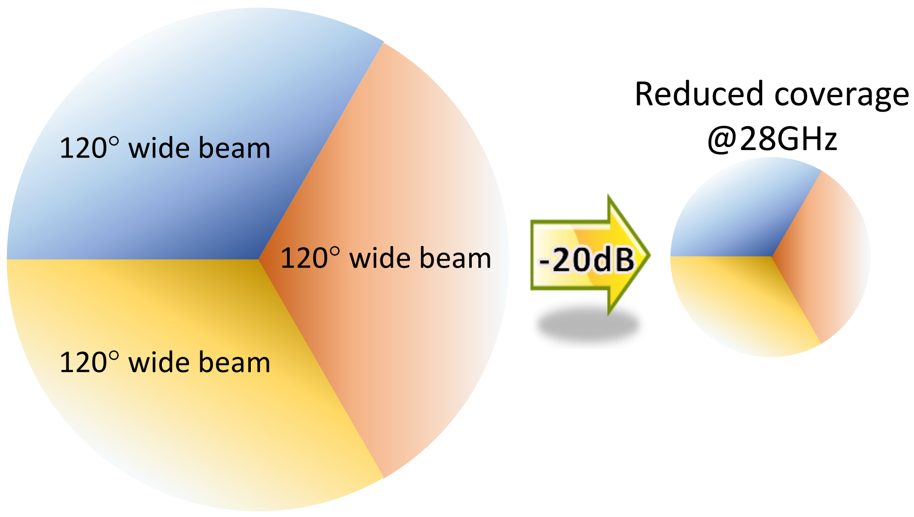
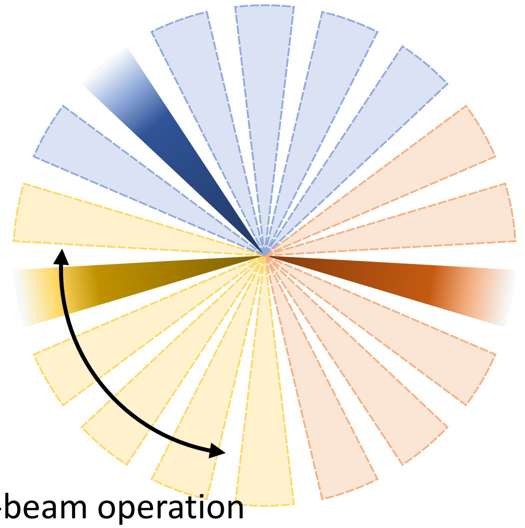
Single vs Multi-Beams

- 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



Multi-beam per sector @28GHz



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Considerations for NR-MIMO Specification Design

NR-MIMO Specification Features

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Comparison of NR-MIMO vs LTE MIMO

A GLOBAL INITIATIVE

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

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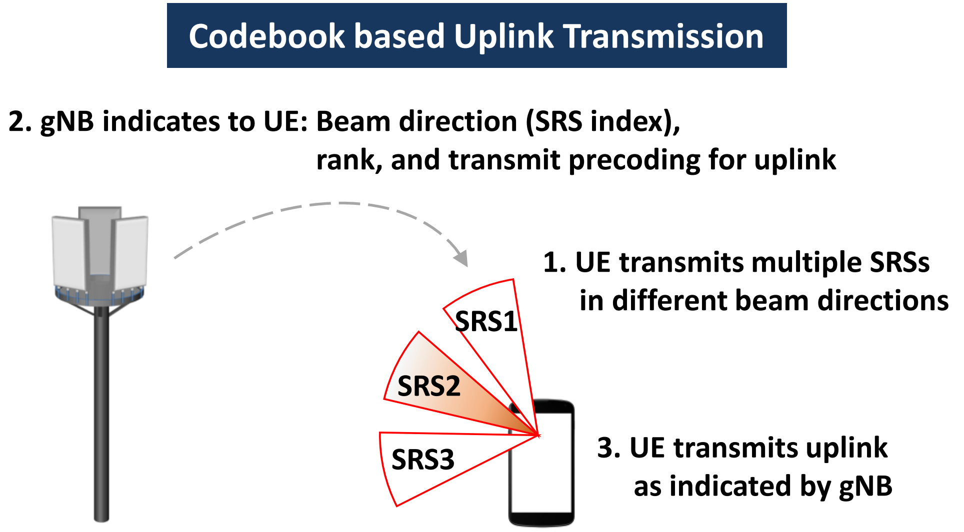
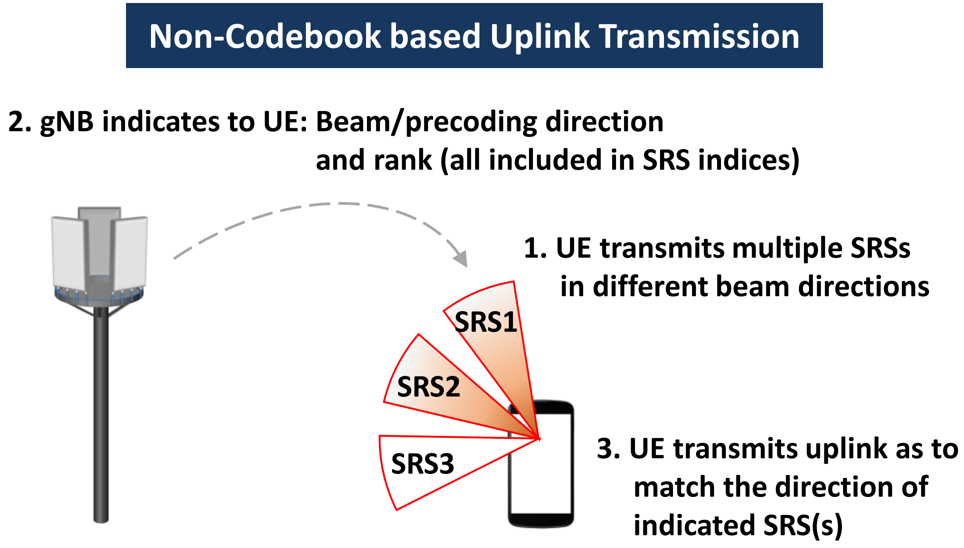
Uplink Transmission

- 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





- Uplink MIMO capability
  - Up to rank 4 per UE, up to 12 co-scheduled UEs with orthogonal DM-RS ports

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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

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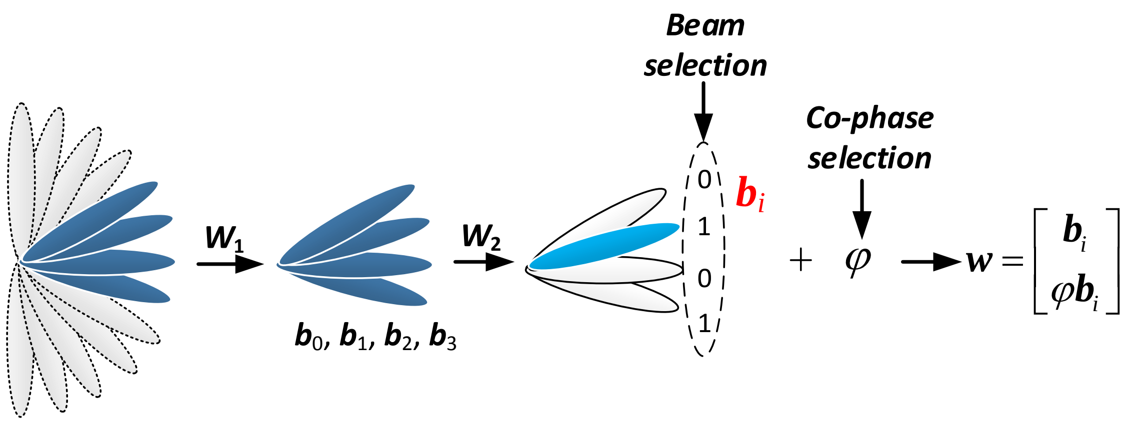
Channel Status Info: Type-I & Type-II

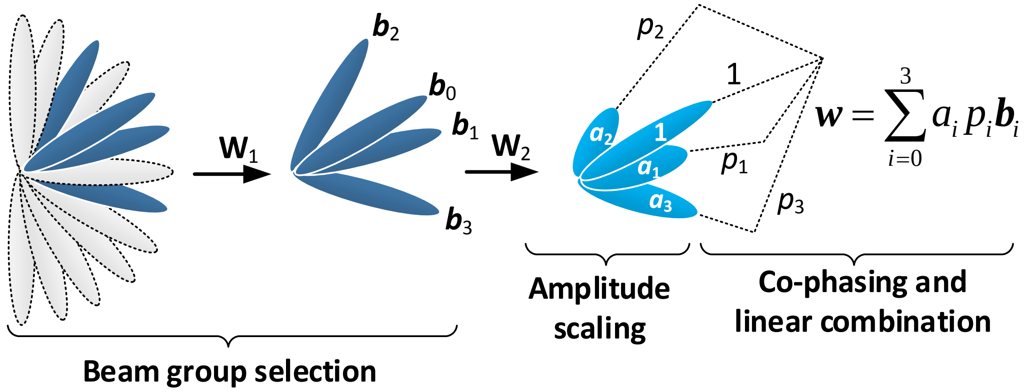
- Two different Channel Status Information (CSI) types are supported in NR
  - Type-I which is optimized for Single User MIMO transmission with smaller uplink overhead
  - Type-II which is optimized for Multi-User MIMO transmission with finer channel information and as a consequence, larger uplink overhead

Type-I Channel Status Information



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

Type-II Channel Status Information



Terminal selects multiple beams, amplitude scaling, and phase coefficients for linear combination between the beams

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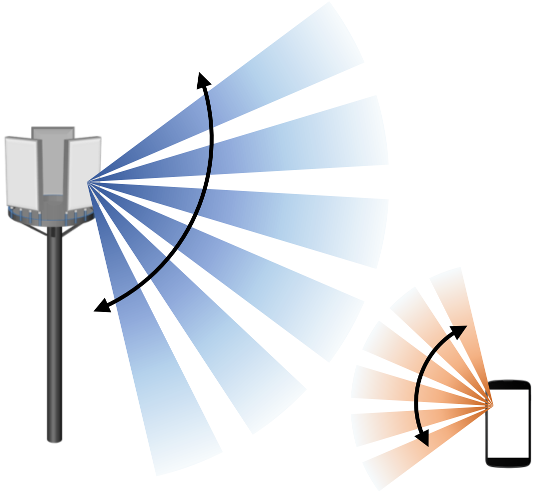
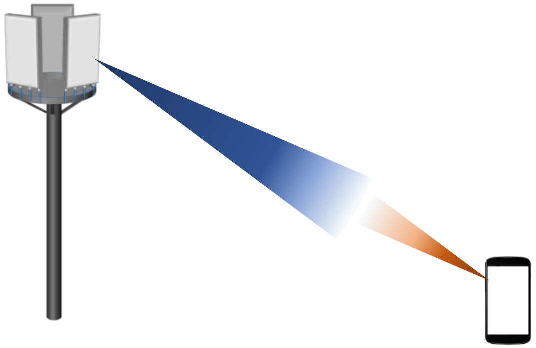
Multi-Beam Operation in NR

Beam Measurement/Reporting



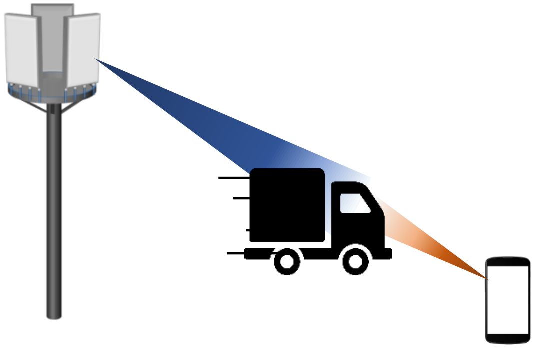
Terminal measures different combinations of TX-RX beams for initial selection and further refinement

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

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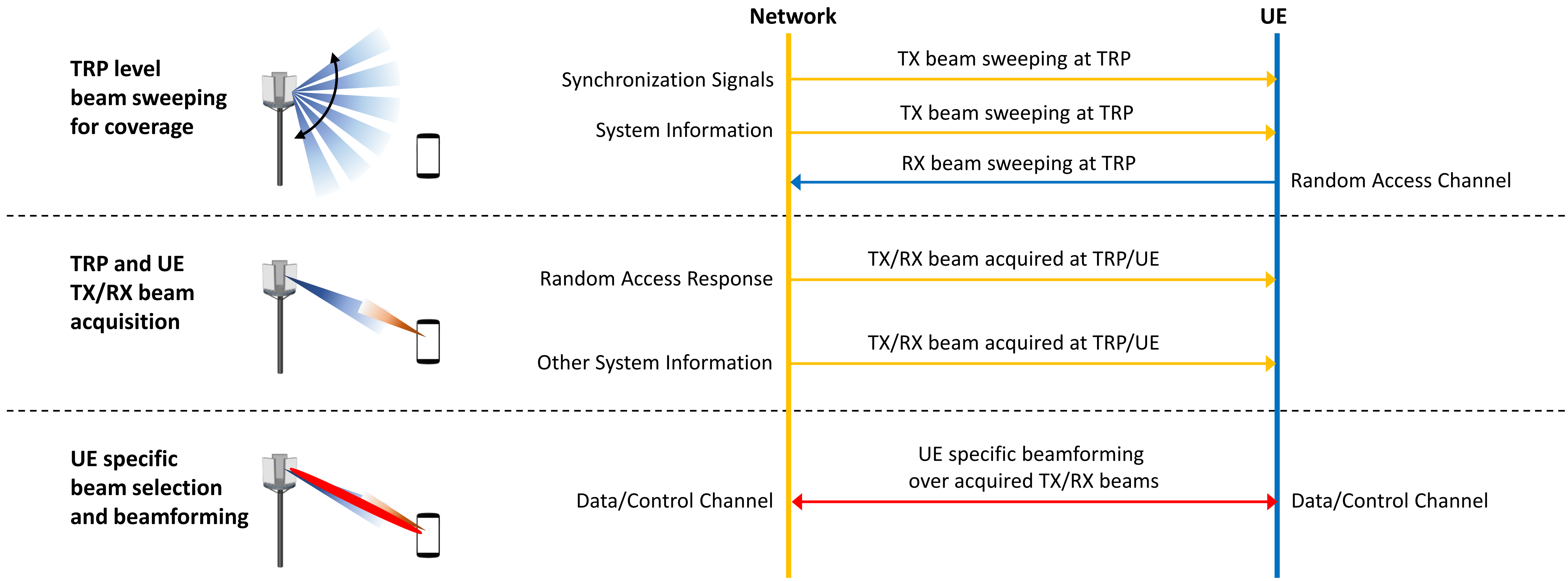
Multi-Beam Operation in NR

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



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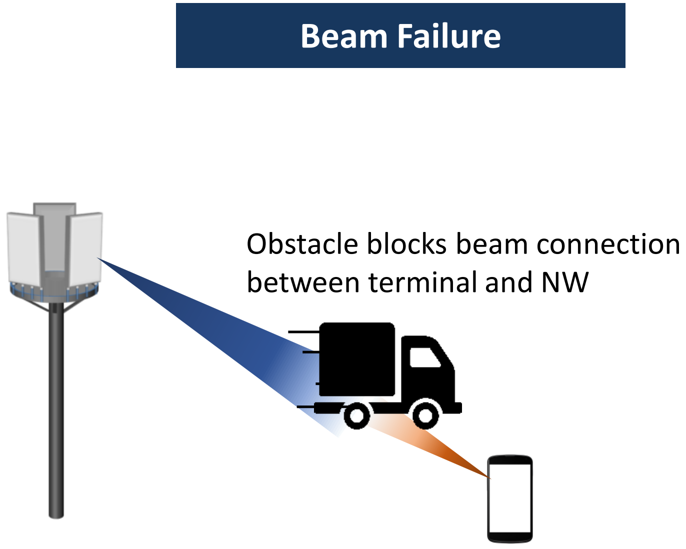
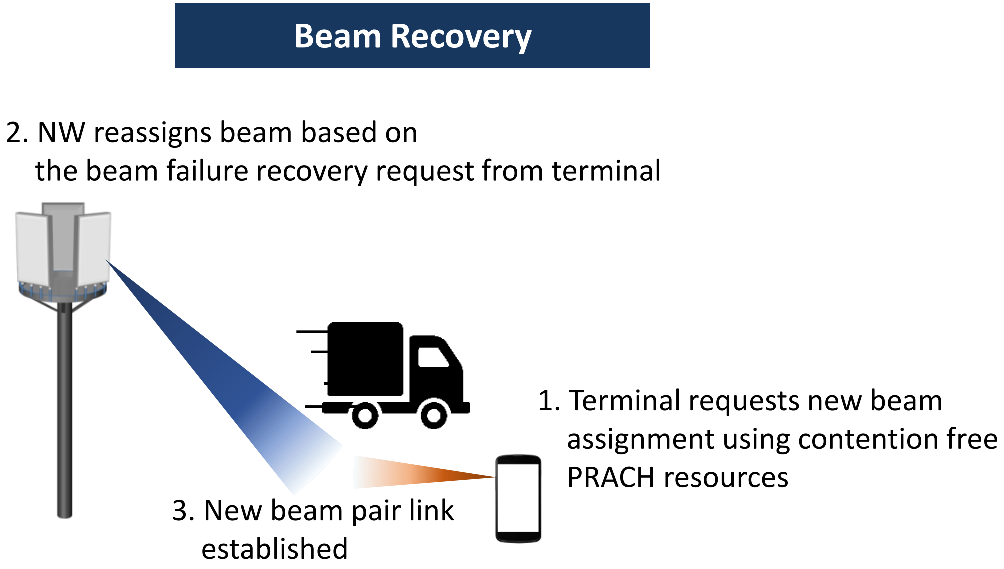
Beam Failure Recovery

- 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





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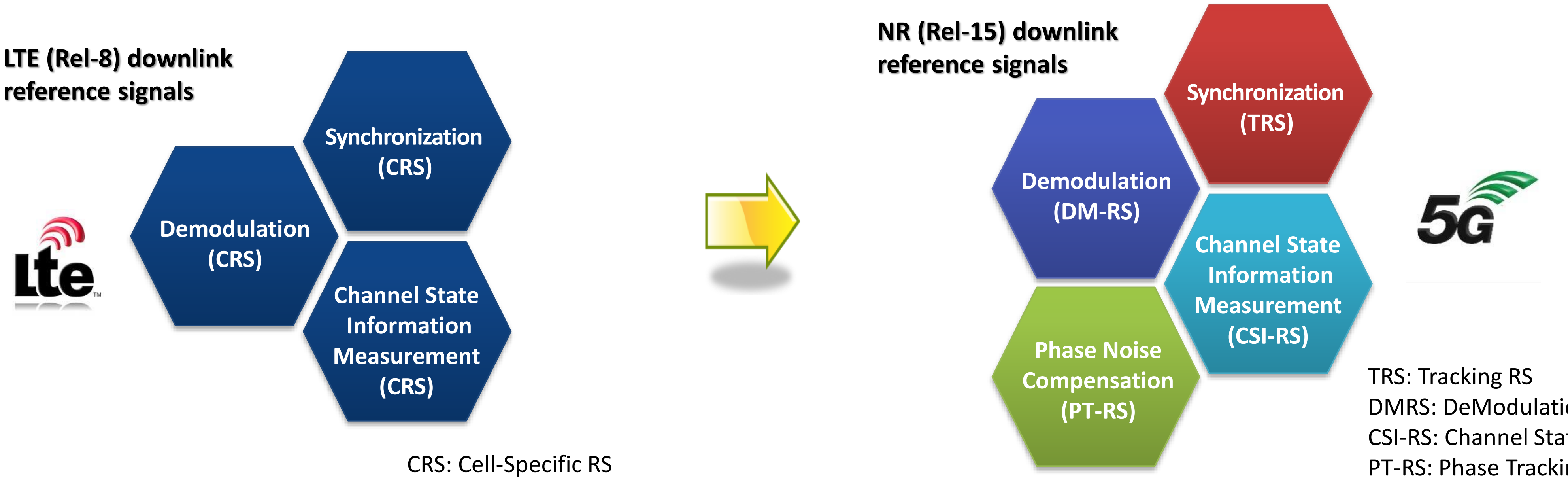
NR Reference Signals

- 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



CRS: Cell-Specific RS

TRS: Tracking RS
DMRS: DeModulation RS
CSI-RS: Channel Status Info RS
PT-RS: Phase Tracking RS

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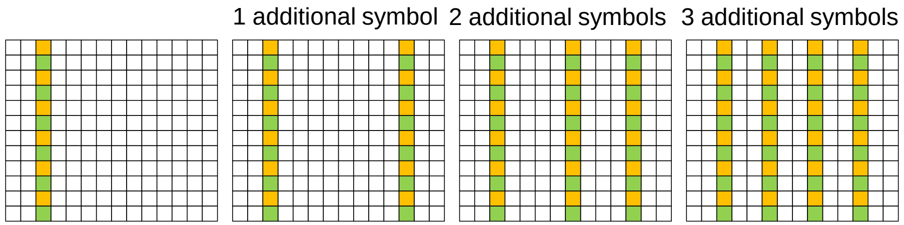
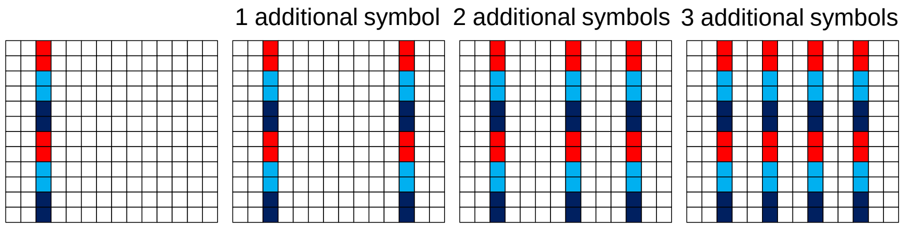
NR Reference Signals: DM-RS

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

	NR Type 1 DM-RS	NR Type 2 DM-RS
Orthogonal Ports	Up to 8	Up to 12
Flexibility	Can be adapted for frequency/time selectivity, robustness, number of co-scheduled UEs for MU-MIMO, etc	
Waveform	CP-OFDM (UL/DL) or DFT-S-OFDM (UL)	CP-OFDM only (UL/DL)
Design (figure for single symbol DM-RS)	IFDMA based 	Frequency domain orthogonal cover code based 
Overhead/Port	Higher	Lower

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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

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

- 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)

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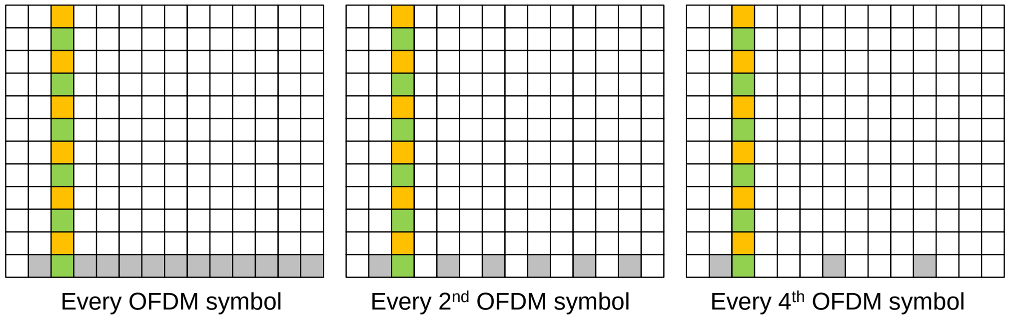
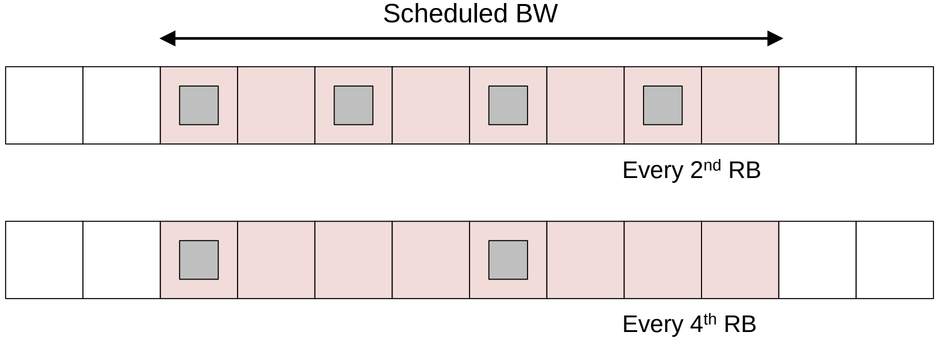
NR Reference Signals: PTRS

- 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

Scheduled MCS	Time domain density
$0 <= MCS < MCS_1$	No PTRS
$MCS_1 <= MCS < MCS_2$	Every OFDM symbol
$MCS_2 <= MCS < MCS_3$	Every 2nd OFDM symbol
$MCS_3 <= MCS < MCS_4$	Every 4th OFDM symbol



Scheduled bandwidth	Frequency domain density
$0 <= N_{RB} < N_{RB1}$	No PTRS
$N_{RB1} <= N_{RB} < N_{RB2}$	Every 2nd RB
$N_{RB2} <= N_{RB}$	Every 4th RB



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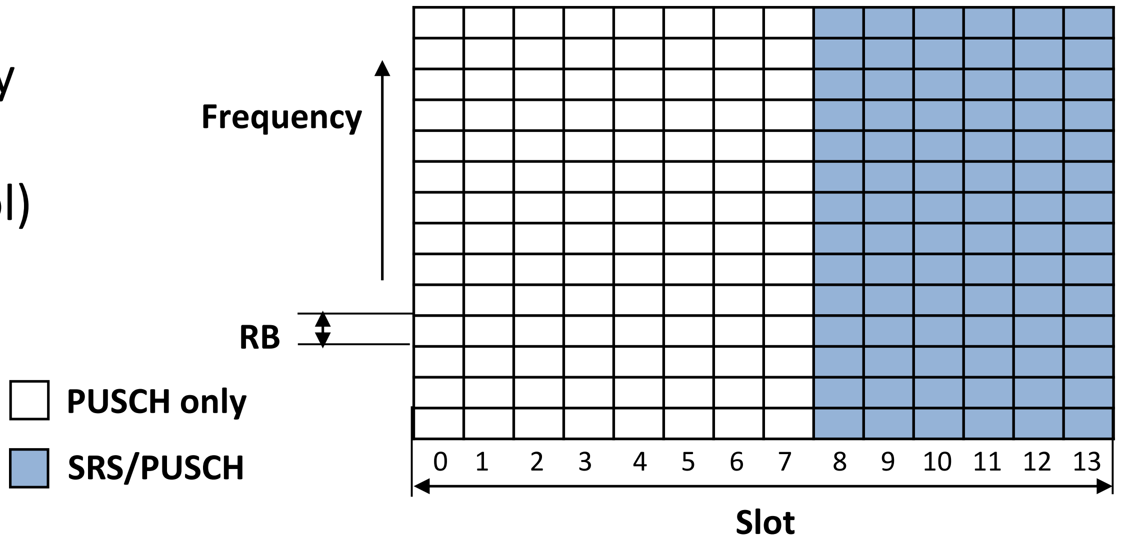
NR Reference Signals: SRS

- 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)



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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)

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Thank you!

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