

**Agenda item: 8.2.2**  
**Source: Nokia, Nokia Shanghai Bell**  
**Title: Beyond 52.6 GHz Study Objectives**  
**Document for: Discussion**

# PHY design above 52.6 GHz

## Introduction

- Fragmentation of 3GPP frequency ranges should be avoided to achieve the greatest economies of scale and the broadest applicability of commercial solutions
  - NR beyond 52.6 GHz is expected to focus on a common waveform from 52.6 GHz through 114.5 GHz (ongoing email discussion, to be decided by December 2019 RAN Plenary, RAN#86)
  - It is critical to ensure a common baseline to minimize hardware variants of NR-capable chipsets
- **Proposal: Study maximum commonality with the waveforms studied in 3GPP for the 52.6 GHz -- 114.5 GHz range**

# Key Use Cases

- The following use cases should be prioritized for 60 GHz and higher frequencies:
  - (1) “Integrated Access and backhaul (IAB)”
  - (2) “Broadband distribution network”
  - (3) “Factory automation/Industrial IoT (IIoT)” and
  - (4) “High data rate eMBB”/“Mobile data offloading”.
- The KPIs governing these use cases should drive our selection of technical solutions
  - Cell size and link range is one important KPI for both “IAB” and “Broadband network distribution” impacting the economics of deployments
  - Latency and reliability continue to be important KPIs critical to the IIoT
  - IIoT for factory automation may also require increased throughput for both UL and DL

**Proposal: KPIs for the study include cell size, link range, latency, and reliability.**

# High mm-Wave Bands for 5G and Beyond Systems

## Design requirements

**Larger carrier bandwidth** - component carriers  $> 400$  MHz

**Waveform design** – relevant considerations: power efficiency, demodulation complexity and numerology

**Enhanced beam management** – methods for managing narrower beams and greater number of beams should be studied

**Enhanced path diversity** – methods for improving path diversity and increasing the probability of LoS paths should be studied

**Specific enhancements to NR must be considered to operate effectively at higher band**

# Waveform enhancement

## When frequencies go beyond 52.6 GHz several notable differences are seen:

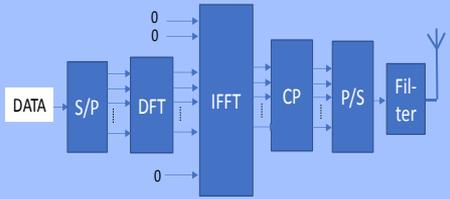
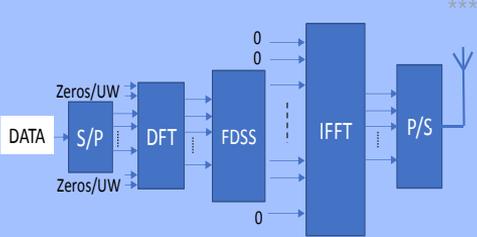
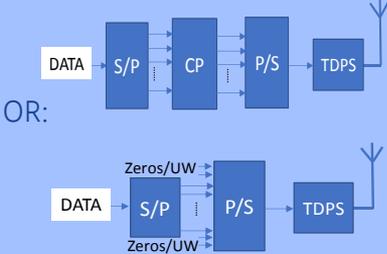
- Less efficient PA
- Performance can be noise-limited because more directional transmissions and larger BW  
→ increasing the transmit power will greatly improve the coverage
- The phase noise will be worse and Doppler frequencies higher
- Mostly LoS channels due to more challenging propagation (e.g. greater reflection loss)

## When considering all of the above, DL SC should be studied for the following reasons:

- The lower PAR that can be achieved is more critical to enable the less-efficient PAs to be driven harder, hence generating higher transmit power, resulting in improved DL coverage
- In LoS conditions SC provides similar link performance as CP-OFDM
- DL FDMA might not be necessary for beyond 52.6 GHz bands because the power consumption of ADC/DAC drives the use of analog RF beamforming resulting that only a single (or very few) RF beams can be steered at one time
- A single carrier waveform could employ an internal CP instead of a regular cyclic prefix, thus potentially providing additional benefits like the possibility to adjust CP overhead per UE, switch RF beam within a symbol without destroying cyclic property, and lower baseband emissions

**DL SC should be studied to maximize coverage and power amplifier efficiency**

# SC waveform candidates

SC-FDMA**	ZHT-SC-FDM*	SC-FDE**
		
<ul style="list-style-type: none"> <li>• LTE UL, NR Rel 15</li> <li>• Reference SC waveform</li> </ul>	<ul style="list-style-type: none"> <li>• Replace the CP with an internal guard intervals prior DFT composed of zero samples or predefined sequences</li> <li>• Frequency domain spectral shaping to reduce PAR</li> </ul>	<ul style="list-style-type: none"> <li>• SC modulation combined with cyclic prefix or UW/zeros to allow frequency-domain equalization at the receiver</li> </ul>
<ul style="list-style-type: none"> <li>• Moderate PAR ( can reduced by applying FDSS )</li> <li>• Fix CP overhead</li> <li>• Best frequency domain co-existency with Rel15 CP-OFDM</li> </ul>	<ul style="list-style-type: none"> <li>• Low PAR depending on the frequency domain shaping</li> <li>• Lower CP overhead because possibility to adapts guard parts according to delay spread and modulation order</li> <li>• Low overhead RF beam switching within symbol</li> <li>• The known sequences can be utilized for phase noise tracking or synchronization</li> <li>• Lower baseband emissions due to contiguous signal between symbols</li> </ul>	<ul style="list-style-type: none"> <li>• Low PAR depending on the time domain pulse shaping</li> <li>• Limited frequency domain flexibility</li> <li>• With UW/zeros similar flexibility share similar flexibility benefits ZHT-SC-FDM</li> </ul>

• Zero Head Tail-Single Carrier-Frequency Domain Modulation (ZHT-SC-FDM)

\*\* Single Carrier-Frequency Domain Equalization (SC-FDE)

\*\*\*[R1-1609599, Way forward waveform for carrier frequencies beyond 40 GHz Nokia, Alcatel-Lucent Shanghai Bell, Mitsubishi Electric, InterDigital Communication]

# SC DL design

SC-FDMA waveform can be introduced for PDSCH with relatively modest changes by following LTE/NR UL design

Remaining problem is high PAR of DL control channels such as SS/PBCH and PDCCH because they have been designed for OFDM

Reuse of Rel-15 OFDM based control channel design with SC waveform for data is not seen as a feasible solution because coverage and power efficiency may be limited by control channel

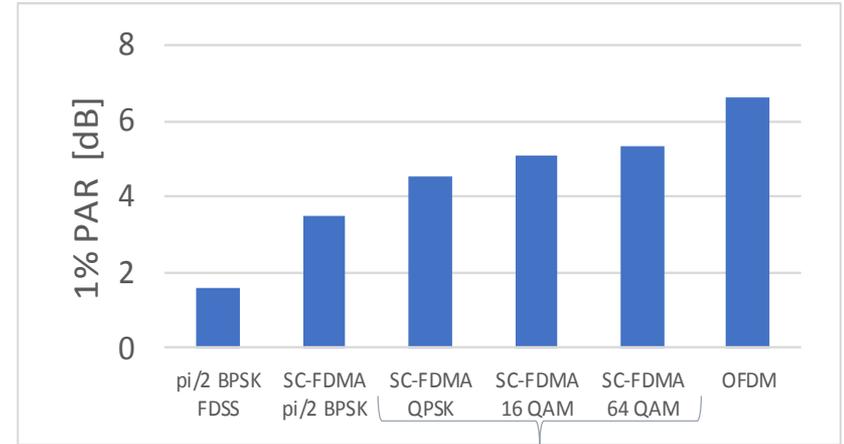
***Low PAR DL CTRL channel structure should be studied to maximize coverage and power amplifier efficiency***

# Modulation enhancements

To maximize coverage and power efficiency, the max EIRP is available only with the lowest modulation order (e.g.  $\pi/2$  BPSK with FDSS) while higher order modulations are transmitted by greater PA backoff at lower power

NR Rel15 UL SC-FDMA allows very low PAR for spectrally shaped  $\pi/2$  BPSK but provides only moderate PAR reduction for spectral efficiencies > 1 Bit /Hz

Methods for decreasing PAR at spectral efficiencies > 1 bit/Hz should be studied to improve coverage of higher bitrates



# Numerology enhancement

Larger bandwidths are available above 52.6 GHz, where bandwidths as large as 10 GHz are possible

Subcarrier spacings must increase to tackle phase noise and provide larger carrier BW's with reasonable FFT size

New  $u$  values for wider BW's by keeping NR Rel-15 framework

- $2^n$  scaling of subcarrier spacing
- IFFT/FFT block length  $2^n$
- Clock rate  $2^n$  related to LTE

NR Rel15 scalable slot length results in poor coverage at higher subcarrier spacings because the symbol & slot duration scales down

- NR Rel-15 scalable slot length should be revised for  $>52.6$  GHz

	$u$	Subcarrier spacing [kHz]	Max BW 4k FFT [Mhz]	Slot length [us]
FR1	0	15	50	1000
	1	30	100	500
	2	60	200	250
FR2	3	120	400	125
	4	240	800	62.5
$>52.6$ GHz	5	480	1600	31.25
	6	960	3200	15.625
	7	1920	6400	7.8125
	8	3840	12800	3.9063

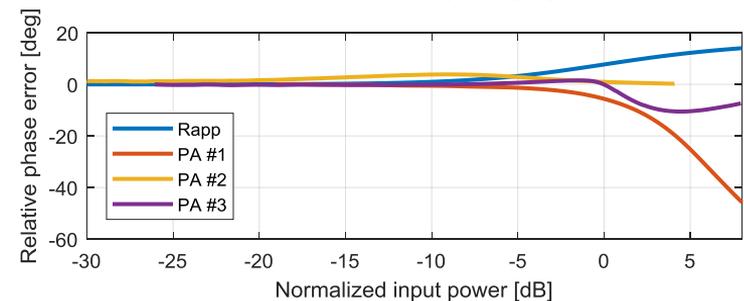
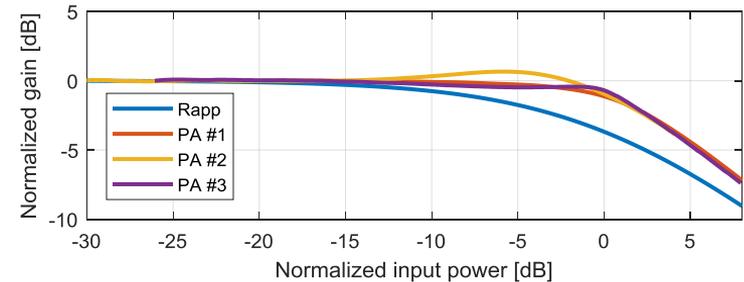
# Comparison of achievable transmit power (SC-FDMA/OFDMA)

## Example simulation parameters for waveform evaluation

- Typical MPR simulation (for uplink) in RAN4 shows the achievable output power using the transmit configuration
- Use the same method for both DL and UL transmit power evaluations

Parameter	Value
Baseband EVM	1% RMS
IQ balance	30 dB
Phase noise	Based on TS38.803, example 2 for BS
PA models	Modified Rapp, 3 models based on measurements; normalized gain and saturation output power
Channel bandwidth	2 GHz
Subcarrier spacing	1920 kHz
FFT size	1024
Spectrum utilization	80 PRB (92.2%)

PA models: AM-AM and AM-PM curves



# Metrics for waveform comparison should include more than PAPR

## RAN1 and RAN4

- RAN1 selects the waveform from potential candidates
- RAN1 designs the waveform
- RAN4 defines output power requirements
  - Using realistic RF impairments
  - Against unwanted emissions limits (ACLR, out-of-band, in-band)
  - Against signal quality limits (EVM)
- RAN4 defines demod performance
  - Realistic receiver impairments and channel models

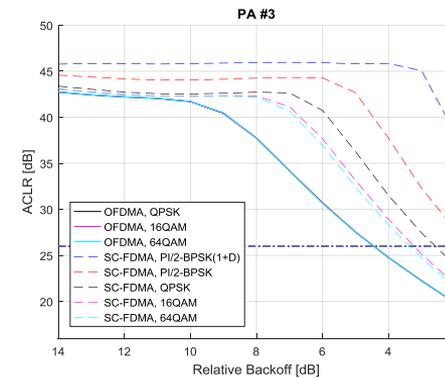
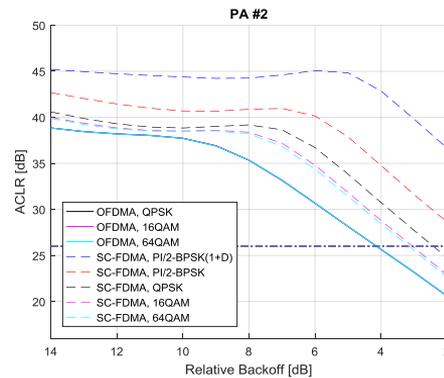
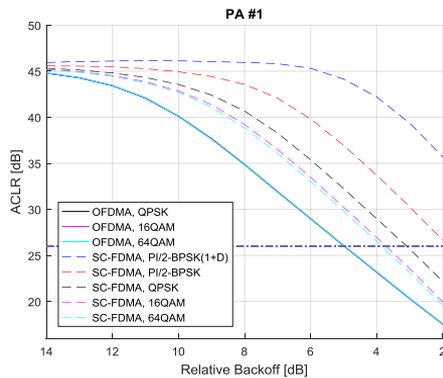
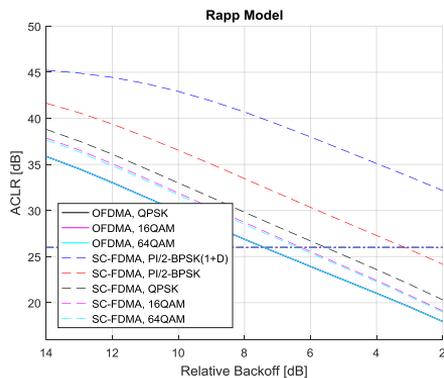
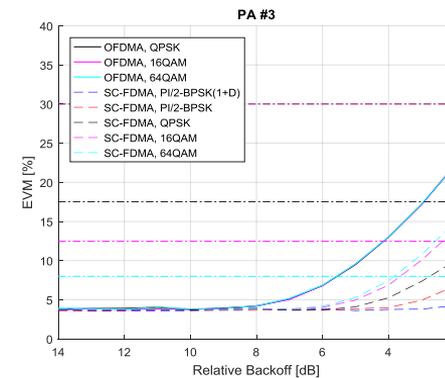
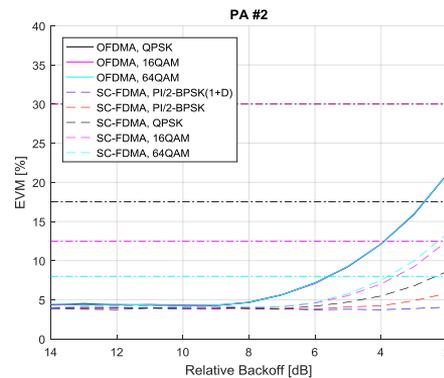
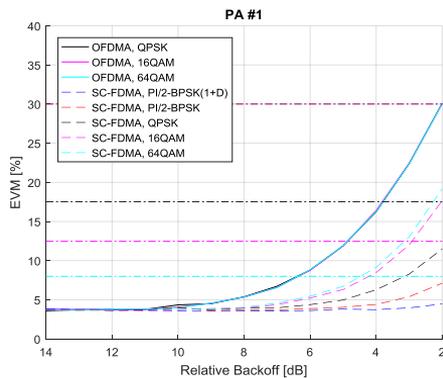
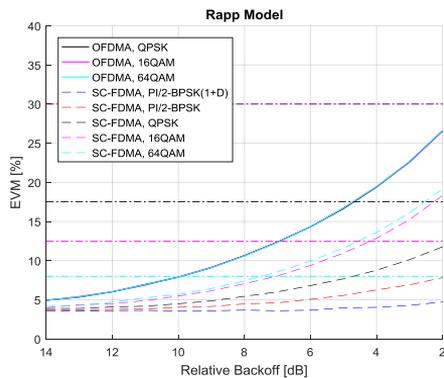
## Evaluation metrics

- Signal Cubic Metric and Peak-to-Average Power Ratio are too simplistic as a metric
- For output power, use RAN4-type MPR analysis with realistic RF impairment and PA models
- For demodulation performance, use RAN4-type demod analysis with realistic impairments and channel models
- Link budget = Achievable output power – demod performance
- Spectrum usage efficiency
- The complexity for both modulation and demodulation

**RAN4 evaluation criteria should be taken into use already in RAN1 waveform comparison phase!**

# Comparison of achievable transmit power (SC-FDMA/OFDMA)

## Simulation results – Evaluation against EVM and ACLR



Achievable output power depends on target EVM and unwanted emissions level

# Phase noise performance evaluation

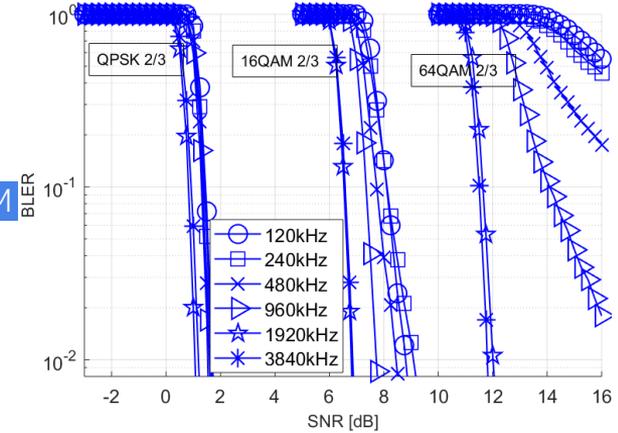
## Simulation parameters:

Parameter	Value
Carrier Frequency (GHz)	60
Subcarrier spacing (kHz)	120/240/480/960/1920/3840
Bandwidth (GHz)	2 (CA assumed when SUBC <960kHz)
Channel Model	CDL-E 10ns, 3km/h, k=15dB
PTRS overhead	~2% Rel. 15 configuration
CP	According to table in slide 7
BS antenna config	256 elements (8x16x2), x-pol, lambda/2 spacing
UE antenna config	32 elements (4x4x2), x-pol, lambda/2 spacing
Number of layers	1
Channel estimation	Real
Waveform	CP-OFDM, SC-FDMA
MCS	QPSK 2/3, 16QAM 2/3, 64QAM 2/3
Phase noise model	3GPP TR38.803 Example 2 for 60GHz (BS and UE models)
PA model	No

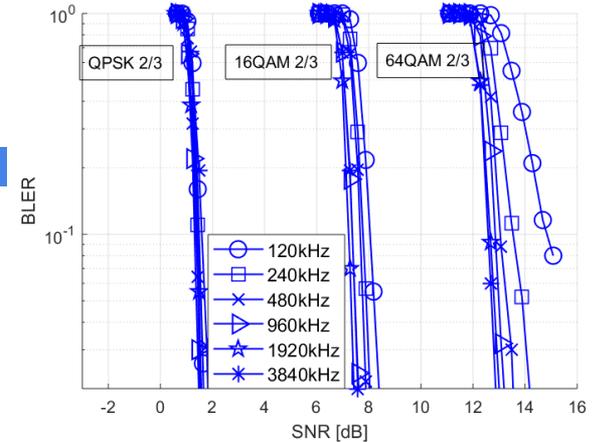
## With simple PN compensation:

- For low modulation order, Rel. 15 spacings ok
- For high modulation order, 960kHz required for CP-OFDM

CP-OFDM



SC-FDMA

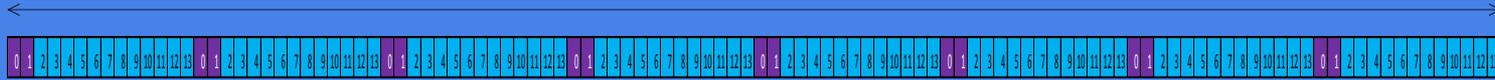


SC-FDMA slightly better with Rel. 15 PTRS structure, because it enables sub-symbol PN compensation directly in time

# Slot structure and PDCCH enhancements

## Scalable slot length according to Rel15:

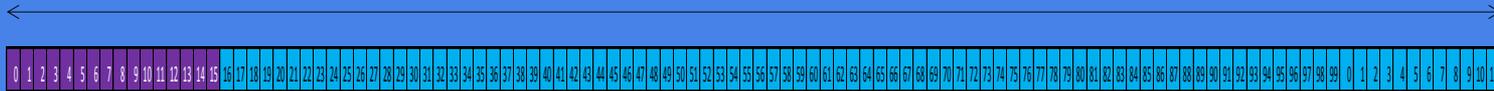
0.125 ms @ 960 kHz SCS



- 14 OFDM symbols reserved for PDCCH
- Slot length =  $\sim 1\text{ms}/64 = 15\mu\text{s}$  → unnecessary short scheduling unit
- 9 dB coverage loss compared to 120 kHz subcarrier spacing

Increased :

Minimum scheduling unit e.g 0.125 ms



- Scheduling unit (slot) size should increase in order to achieve comparable coverage with lower subcarrier spacing
- One approach is to define slot as  $8 \times 14$  OFDM symbols with 960 kHz SCS (i.e. approximately 0.125 ms)

# Beam management above 52.6GHz

## Beam Management

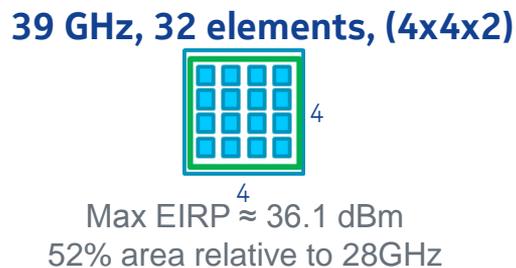
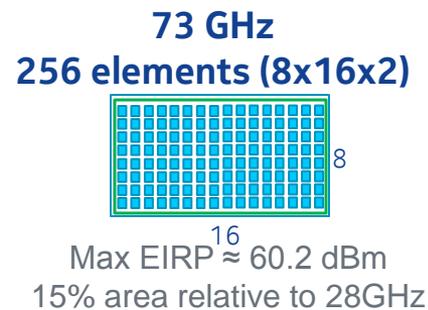
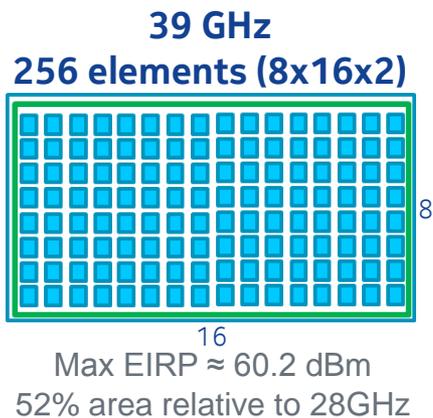
- Beam Indication:
  - Assists UE to set RX and TX beams properly
- Beam Measurement and Reporting:
  - Determining feasible DL and UL beams for the gNB and UE
- Beam Recovery:
  - Rapid link reconfiguration against blockages & fast re-alignment of gNB and UE beams
- Beam Tracking and Refinement:
  - Procedures to refine beams at gNB and UE

## Challenges above 52.6GHz

- Larger arrays (#elements) can be leveraged to overcome increased path losses above 52.6GHz
- Larger arrays (#elements) results in narrower beams that are more susceptible to “pointing errors”
- Narrower beams will necessitate more beams to cover the same angular space
- May need significantly more beams than are needed < 52.6 GHz
- Reducing the number of beams by increasing the beamwidth (e.g., via tapering, etc.) will reduce gain and reduce the benefits of using the larger number of elements

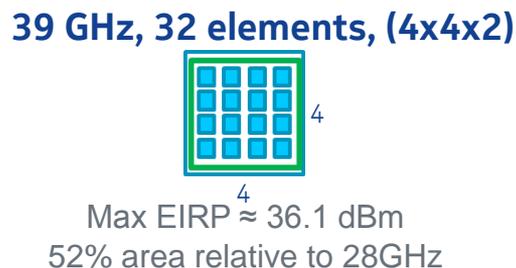
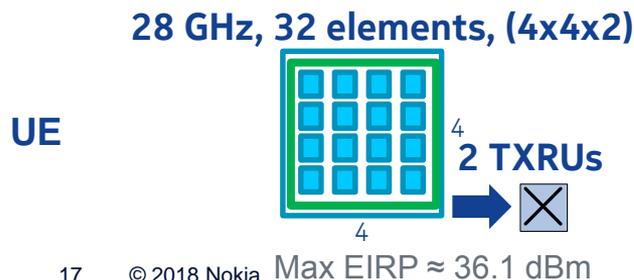
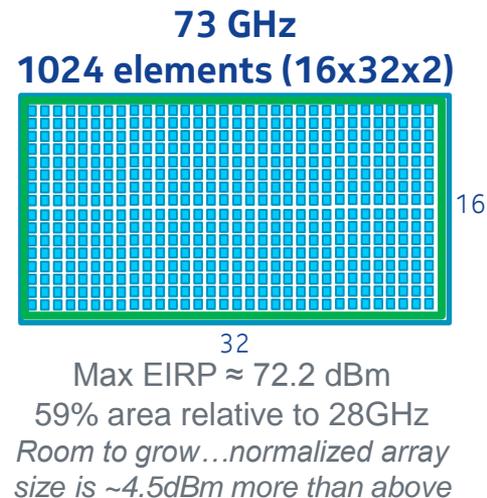
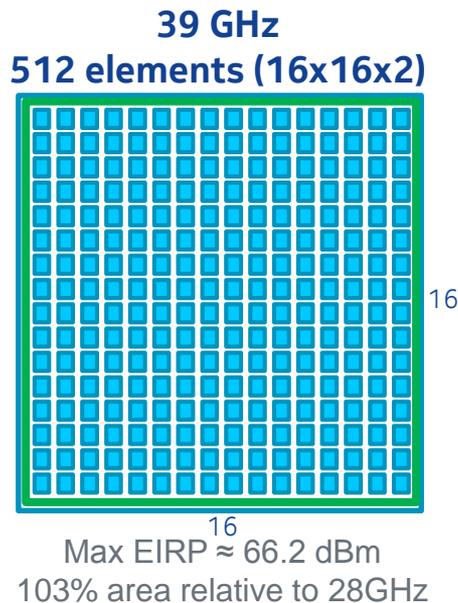
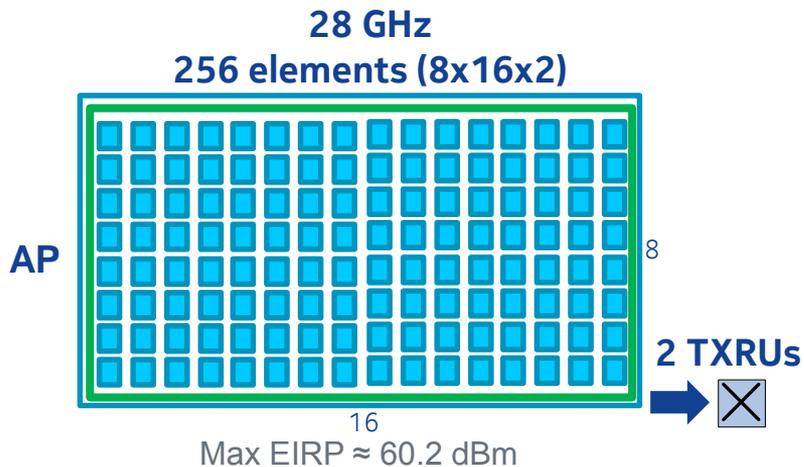
# Antenna Array Comparisons - Number of Elements Constant vs. Frequency

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

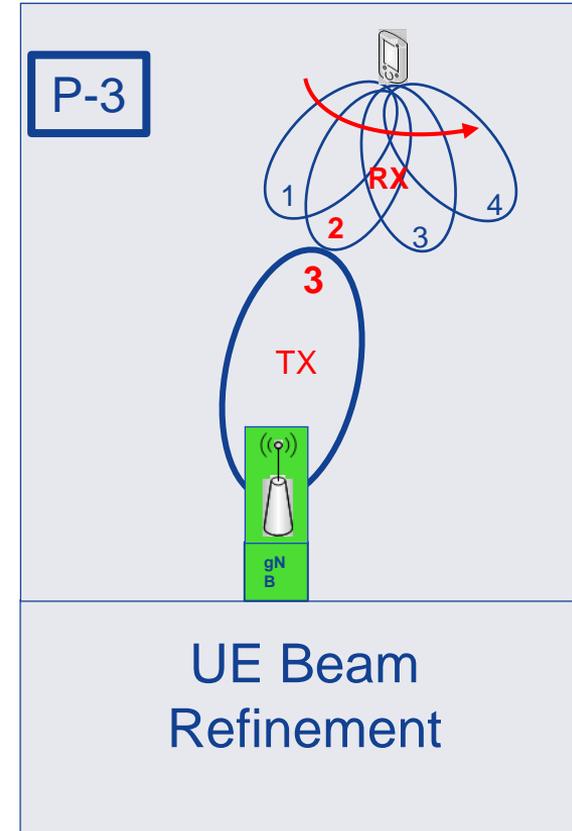
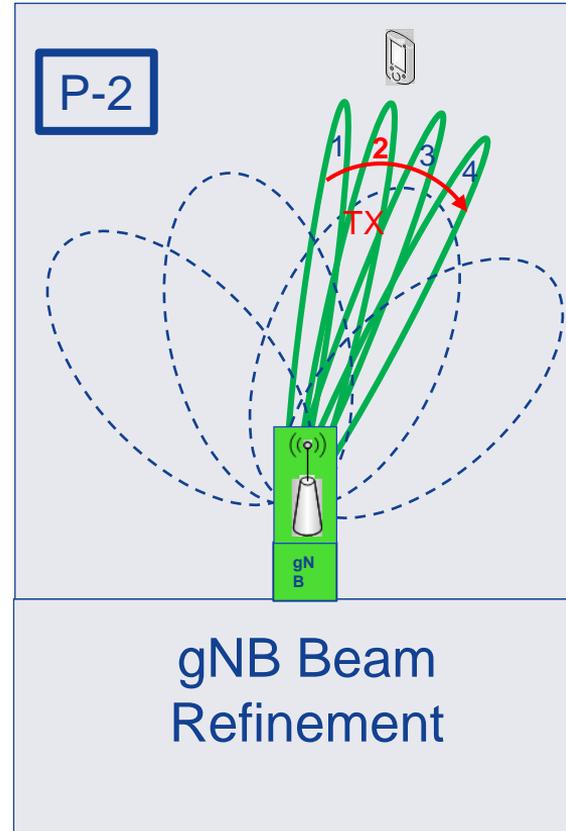
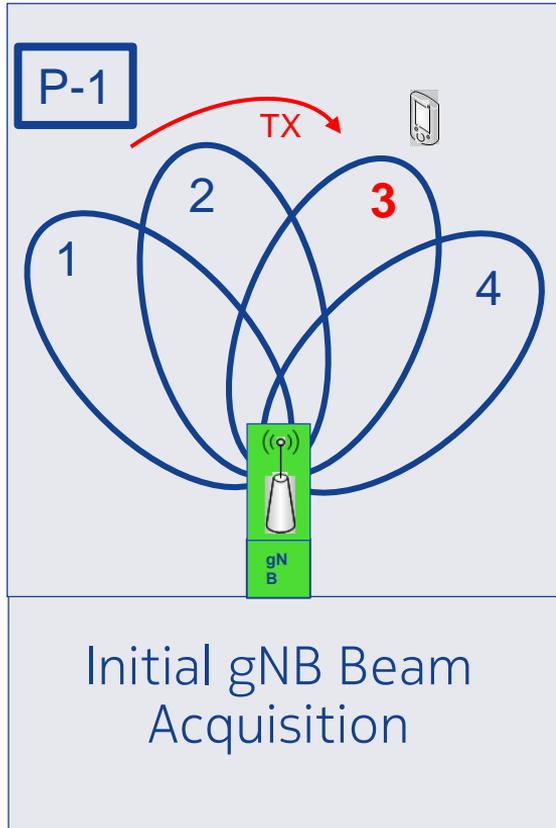


# Antenna Array Comparisons - AP Antenna Aperture Constant vs. Frequency

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



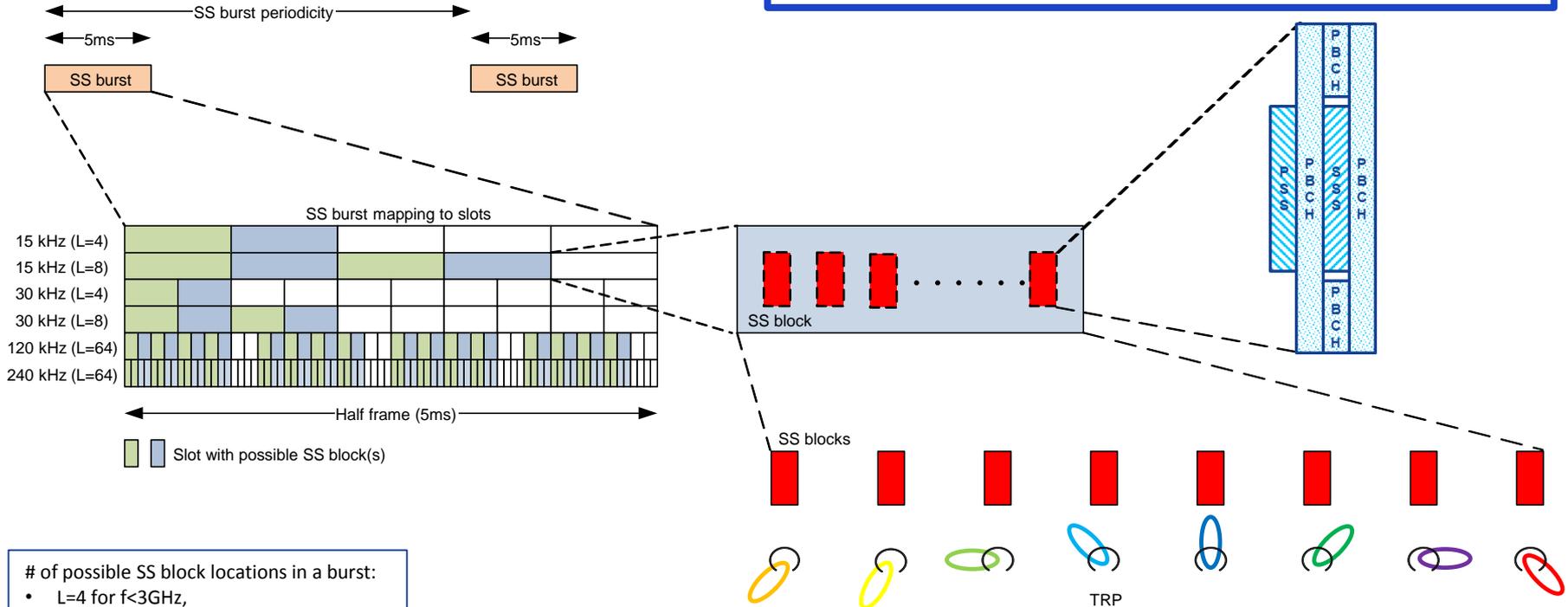
# Beam Management Procedures



# New Radio Rel-15: Synchronization Signal Burst Examples

- A Synchronization Signal (SS) burst is transmitted periodically by the network
- Periodicity is configurable by the network - {5, 10, **20**, 40, 80, 160} ms.
- Each SS Burst is confined to a half-frame (5ms) and contains up to L SS Blocks

- Maximum of 64 SSB beams in Rel-15 FR2
- Is this enough for >52.6GHz?



# of possible SS block locations in a burst:

- L=4 for  $f < 3\text{GHz}$ ,
- L=8 for  $3\text{GHz} \rightarrow 6\text{GHz}$
- **L=64 from 6 → 52.6 GHz**

- For different SS blocks within a burst, UE may **not** assume that the same physical beam is used
- For the same SS block index in different SS bursts, UE may assume the same physical beam is used

# Enhanced Path Diversity for 5G and Beyond Systems

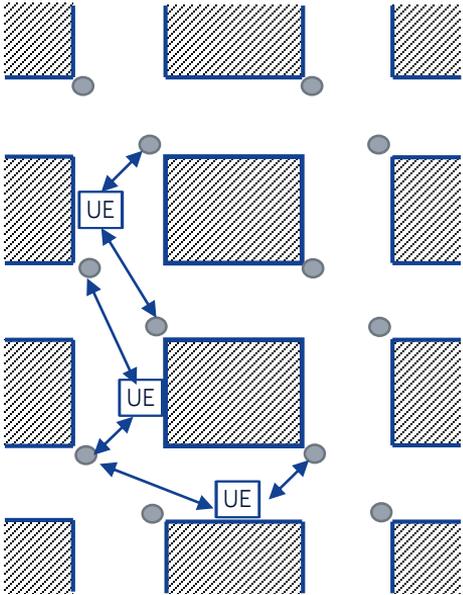
## Motivation

- At higher mmW frequency bands, narrow beams are used to compensate for pathloss
- LOS blockages can be frequent, disrupting the serving link
- Reflected NLOS paths, if present, are significantly degraded (by ~20-40dB [1])
  - UEs may experience excessive rate of ping-pong handovers between LOS and NLOS or between a strong LOS and a weak LOS links
- Many use cases are intolerant to link disruptions/degradation due to blockages
  - E.g. Augmented Reality (AR), Virtual Reality (VR)
- In the event of blockages, UE needs to switch to alternate transmission points with LOS links to maintain desired link quality
- Methods for improving path diversity and increasing the probability of LOS links should be studied

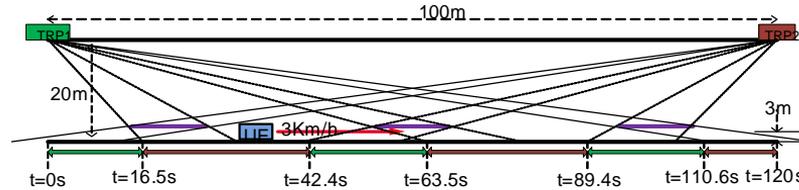
[1] Akdeniz, M. R., et al, "Millimeter Wave Channel Modeling and Cellular Capacity Evaluation", IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 32, NO. 6, JUNE 2014

# Enhanced Path Diversity for 5G and Beyond Systems

## Access point deployments for path diversity

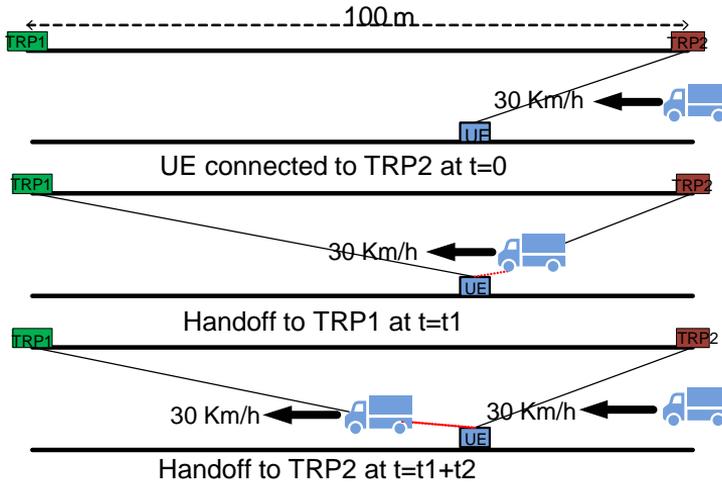


Example deployment for high LOS path diversity



- ↔ Served by TRP1
- ↔ Served by TRP2
- ↔ Fixed obstacle

Pedestrian UE walking through fixed obstacles



Pedestrian UE blocked by moving obstacles (e.g. trucks)

# Enhanced Path Diversity for 5G and Beyond Systems

## Minimizing service disruption in the event of blockage

### Fast blockage detection is essential

- **Need to study fast blockage detection techniques**
  - Blockage detection latency in NR Release 15/16 may run from tens to hundreds of msec
  - Blockage detection done by the UE using L2 and L3 procedures: Blockage results in RLF at the UE
    - L2 procedure: Beam Failure Detection (BFD) based on BFD-RS measurement and unsuccessful Beam Failure Recovery (after maximum number of RA attempts);
    - L3 procedure: Radio Link Monitoring based on RLM-RS measurement; T310 expiry
- **Need to study the tradeoff between blockage detection latency and false detection**

### Faster switching may be required

- **Fast handover to alternate TRP with LOS link**
  - Study effectiveness of Rel 15/16 enhancements of the HO procedures to overcome blockage
  - Conditional HO is activated by UE measurement reports indicating signal degradation; may not be suitable for blockage related path switching
- **Dual/Multi-connectivity solutions:**
  - Layer 2/3 solutions: MR-DC, NR-NR DC in Release 15/16
  - Path switching is based on detection of RLF for MCG or SCG; RLF detection has high latency
- **Physical layer multi-connectivity:**
  - Multi-TRP transmission in NR Release 16
  - Currently limited to reliability and robustness for URLLC using multi-TRP techniques for both control and data
  - Need further study on multi-TRP techniques for AR/VR applications which require both very low latency and high data rate

# Observations

## Specific enhancements to NR must be considered to operate effectively at higher band

### Waveform design:

- DL SC should be studied to maximize coverage and power amplifier efficiency
- Methods for decreasing PAR at spectral efficiencies  $>1$  bit/Hz should be studied to improve coverage of higher bitrates
- Low PAR DL CTRL channel channels structure should be studied

### Numerology:

- Subcarrier spacings needs to increase to tackle phase noise and provide larger carrier BW's with reasonable FFT size
- Scheduling unit (slot) size needs to increase in order to achieve comparable coverage with lower subcarrier spacings

### Beam Management:

- Mitigating path loss with larger arrays will result in narrower and more numerous beams
- Enhancements needed for efficiency, latency reduction, compatibility with waveforms

### Path Diversity:

- Minimizing service disruption in the event of blockages requires fast switching of data path to alternate LOS link

# Beyond 52.6 GHz Study Objectives

## Summary

- Fragmentation of 3GPP frequency ranges should be avoided to achieve the greatest economies of scale and the broadest applicability of our commercial solutions.
- The following use cases should be prioritized for higher frequencies:
  - (1) “Integrated Access and backhaul (IAB)”, (2) “Broadband distribution network”, (3) “Factory automation/Industrial IoT (IIoT)” and (4) “High data rate eMBB”/“Mobile data offloading”.
- The KPIs governing these use cases should drive our selection of technical solutions
- New waveforms, such as DL SC, should be studied to assess the benefit they provide over the existing waveform in NR for the proposed used cases
- Many challenges exist for frequencies near 114 GHz are already significant even at 52.6 GHz
  - High phase noise degrades the performance at higher order modulations and must be addressed for a viable solution
  - PA efficiency in both the downlink and uplink are critical for balanced links used in IAB and broadband distribution
  - Beam management resulting from the increased number of elements required to maintain the link budget and cell size

**NOKIA**