Uplink Coverage Enhancements

Taipei, 15th – 16th June, 2023

Agenda Item 5

Source: Nokia, Nokia Shanghai Bell

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Uplink Coverage Enhancements

Background

General observations

- Coverage is typically uplink-limited, especially in TDD deployments.
- Improving uplink coverage means not just increasing basic coverage but increasing the coverage of any data rate supported in the cell, including higher data rates.
- The UE transmission power is the most valuable resource in the uplink, and enhancements to unlock additional power are highly valuable for coverage.

What has been done so far

- **Release 15** introduces Dynamic UL LTE/NR power sharing and frequency domain spectrum sharing (FDSS) for pi/2 BPSK.
- **Releases 17-18** further enhances coverage capabilities for data and control channels
  - Basic feature design. Feature competitiveness needs improving to motivate early adoption.
- **Release 18** extends both RACH and PUSCH coverage
  - Limited available time and parallel WG activities hinder the completeness of both study and work item phase.

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Uplink Coverage Enhancements

Overview

Potential objectives addressing practical use cases can be categorized into two domains:

Improve coverage for higher data rates

- Rel-18 was the 1st release with power domain enhancements
- Several additional improvements can be envisioned:
  - Smaller A-MPR for certain (single carrier) scenarios
  - Smaller MPR for certain UL CA scenarios
- Complete any outstanding optimization to the Rel-18 MPR/PAR reduction schemes, e.g., Frequency-Domain Spectrum Shaping with Spectrum Extension
- Rel-19 could increase the maximum UE Tx power in these scenarios → Improved user experience

Resolve limitations of existing coverage features

- Multiple PRACH transmissions with different Tx beams
- PUSCH repetitions scheduled by DCI format 0_0 with CRC scrambled by RNTIs other than TC-RNTI
- Waveform switching for PUSCH scheduled by DCI format 0_0
- Further DMRS bundling enhancements

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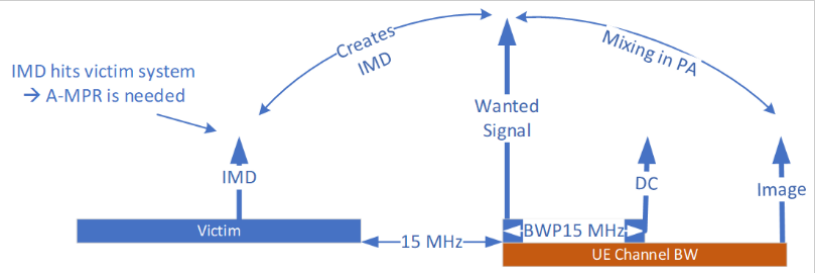
A-MPR reduction (1/2)

Background:

- When deriving A-MPR, current assumption is that d.c. is at the centre of the UE's channel bandwidth (CBW)
  - This can result in a worst-case estimate of required A-MPR due to the location of IMD



A-MPR evaluation: d.c. is at centre of CBW

Opportunities:

Compared to LTE,

- NR allows wider CBW (100 MHz vs. 20 MHz)
- Higher UE power classes are more popular

→ **Opportunities for great UL performance exist**

But, due to worst-case A-MPR estimation, the desired UL performance does not always materialize in the field:

- Example: PC2, n39
  - A-MPR for 20 MHz CBW is up to 5.5 dB,
  - A-MPR for 40 MHz CBW is up to 12.5 dB in some conditions

    → **7.0 dB difference in A-MPR**

    → **Up to 7.0 dB loss of link budget**

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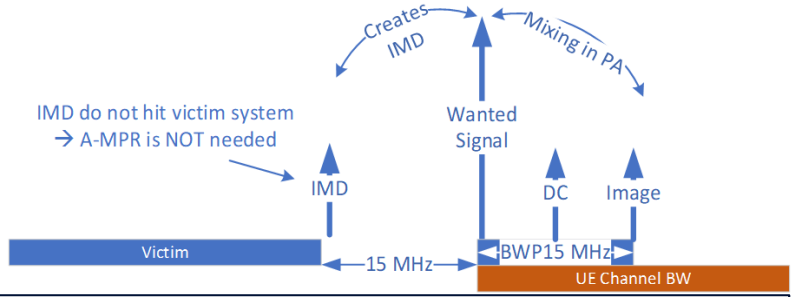
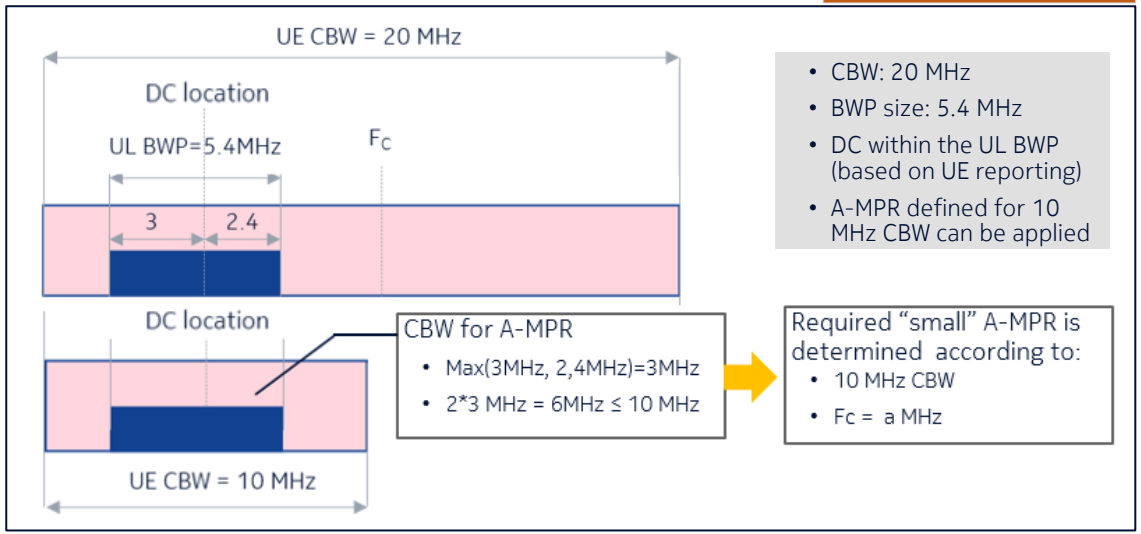
A-MPR reduction (2/2)

Examples:



Expected outcome and benefits:

- UE can indicate its capability for smaller output back-off in certain configurations (e.g., by positioning d.c. at centre of UL BWP), enabling the gNB to take this into account in the scheduling so larger UE Tx power can be used.
- Existing A-MPR values can be leveraged in the UE capability signalling: e.g. UE can indicate that it can fulfil A-MPR requirements of a smaller CBW than the current CBW, with certain UL BWP configurations.



Proposal

- **Identify condition(s) or configurations where UE can follow stricter A-MPR for given CBW**
- **Introduce UE capability signaling to indicate such configurations and associated A-MPR values to network**

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MPR reduction (1/2)

NR CA bandwidth class	Aggregated channel bandwidth	Number of contiguous CC
A	$BW_{Channel} \leq BW_{Channel,max}$	1
B	20 MHz $\leq BW_{Channel_CA} \leq$ 100 MHz	2
C	100 MHz $< BW_{Channel_CA} \leq 2 \times BW_{Channel,max}$	2

Background:

- TDD with (typical) DL-heavy configuration → UL performance is a challenge
- 5G-Advanced services require higher data rates in UL
  - UL CA provides higher data rates, but coverage is a bottleneck
  - Scenario: Intra-band CA with contiguous CCs [BW class B and C]

Motivation:

UL CA suffers from high MPR in general (compared to single-CC case)

- Very high MPR in case of outer RB allocations:
  - Applies especially to class C
  - When RB allocation is larger than 50% of the total number of RBs, MPR is determined according to "outer RB requirement"

→ intra-band CA configuration may not be configured, due to limited expected benefits

→ UL coverage for high data rates will be a bottleneck

Contiguous RB allocation for Power Class 3, Inner

Modulation		Single CC	MPR for bandwidth class B(dB)	MPR for bandwidth class C(dB)
		inner	inner	inner
DFT-s-OFDM	Pi/2 BPSK	0 (-2.8*)	1.0	2.5
	QPSK	0	1.0	2.5
	16QAM	≤ 1	1.5	2.5
	64QAM	≤ 2.5	3.0	5
	256QAM	≤ 4.5	5.5	7
CP-OFDM	QPSK	≤ 1.5	2.0	3.5
	16QAM	≤ 2	2.5	3.5
	64QAM	≤ 3.5	3.5	5
	256QAM	≤ 6.5	6.5	7

*) with power boost

Contiguous RB allocation for Power Class 3, Outer

Modulation		Single CC	MPR for bandwidth class B(dB)	MPR for bandwidth class C(dB)
		outer	outer	outer
DFT-s-OFDM	Pi/2 BPSK	0 (-1.8*)	3.5	**7**
	QPSK	≤ 1	3.5	**7**
	16QAM	≤ 2	3.5	**7**
	64QAM	≤ 2.5	4.0	**7**
	256QAM	≤ 4.5	6.0	**7.5**
CP-OFDM	QPSK	≤ 3	4.0	**8**
	16QAM	≤ 3	4.0	**8**
	64QAM	≤ 3.5	4.0	**8**
	256QAM	≤ 6.5	6.5	**8**

*) with power boost

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MPR reduction (2/2)

- A large margin exists between current MPR requirement values for UL CA and what can be measured via RF simulations
  → Rel-19 offers an opportunity to revisit them.

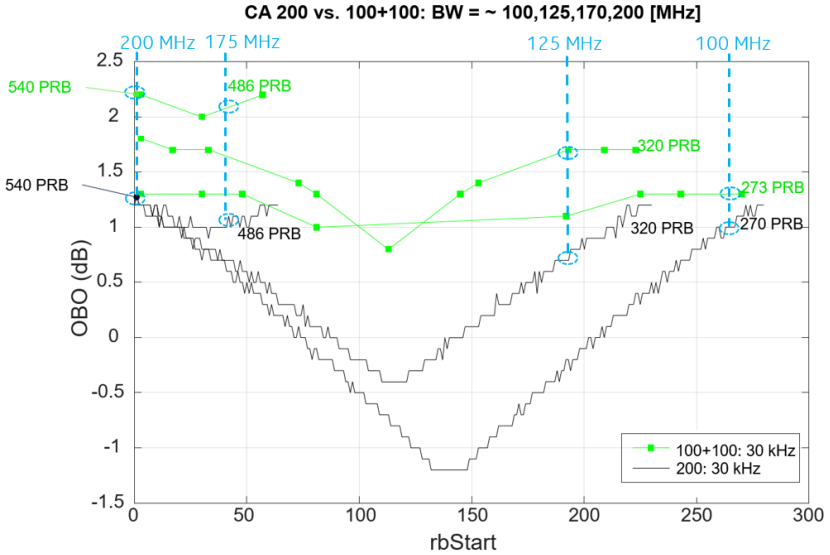
Expected outcome and benefits:

- UE can indicate its capability for smaller MPR with intra-band CA and contiguous RB allocation
- Friendlier intra-band CA configuration for gNB, thanks to more accurate view on UE's transmission power capabilities
- More efficient and frequent use of intra-band CA facilitates high UL data rates

Scenario: DFT-s-OFDM, 200 MHz - Contiguous RB allocation (Outer), QPSK

- MPR, CA class c: >7 dB
- MPR, single CC: >1dB (for 100 MHz CBW)

→ This corresponds to an "expected" 6dB difference in OBO, by spec



Allocation (MHz)	Max OBO difference (dB)
100	2.2
125	1.2
175	1.0
200	1.0

Proposal

- **Determine reasonable MPR values for UEs supporting lower MPR with contiguous RB allocations in intra-band CA**
- **Introduce corresponding UE capability signaling**

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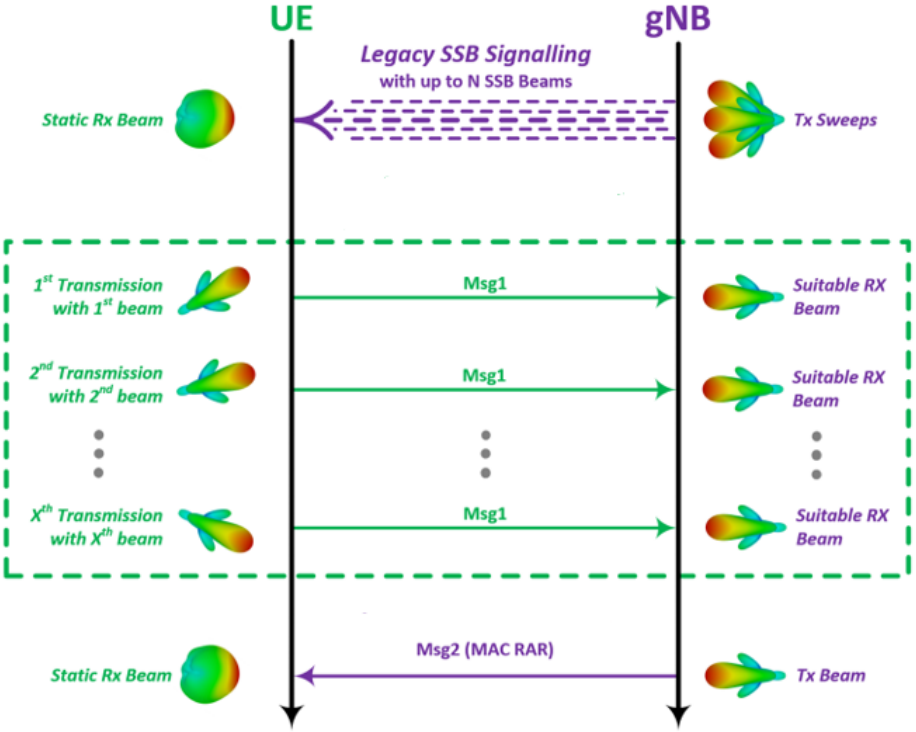
Multiple PRACH transmissions with different Tx beams (1/2)

Proposal:

Support differentiation between same and different Tx beams across multiple PRACH transmissions



Motivation and Objectives:

- **UE performs multiple preamble transmissions using a different beam for each preamble.**
  - Multiple higher gain PRACH preambles are sent in multiple directions before the beginning of the RAR window
  - This increases link budget and can reduce latency
- If each PRACH transmission/RO combination is unique then gNB can distinguish between them
- UE should use the received information to configure optimal beam for Msg3

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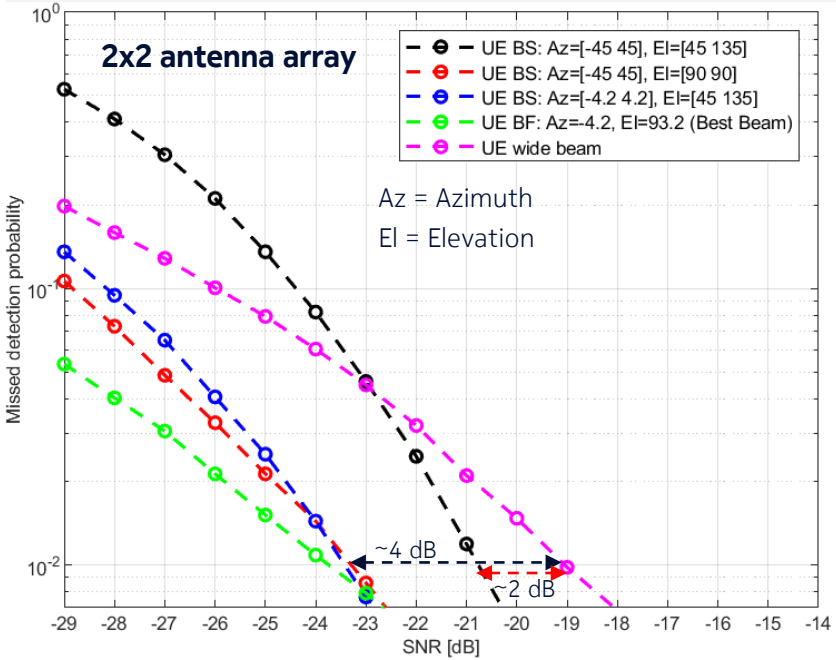
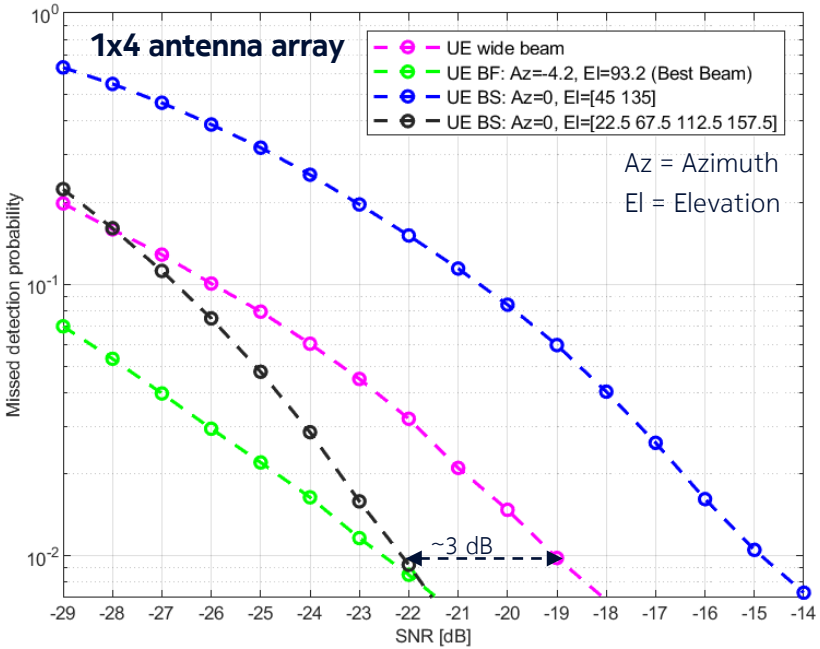
Multiple PRACH transmissions with different Tx beams (2/2)

Link performance examples: Here we assume the UE has 2 panels and is able to first select the best of the two panels for the gNB (e.g., from RSRP measurements). These evaluations then show a 2~4 dB gain in PRACH from using 4 different beams rather than a single wide beam. For reference, the performance of a genie-aided optimal beam is also shown (green curve).





<u>Proposal</u>: Specify at least PRACH resources differentiation between multiple PRACH transmissions with different Tx beams and multiple PRACH transmissions with same Tx beam

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PUSCH repetitions scheduled by DCI format 0_0 with CRC scrambled by RNTIs other than Temporary C-RNTI (TC-RNTI)

Background:

- PUSCH with repetitions is supported in Rel-15 and enhanced in Rel-16, but not when scheduled by DCI format 0_0
- Rel-17 further enhances PUSCH repetitions and also supports repetitions for retransmission of Msg3 PUSCH (scheduled by DCI format 0_0 scrambled by TC-RNTI)
- The applicability of the Rel-17 feature to PUSCH scheduled by DCI format 0_0 with CRC scrambled by other RNTIs has not been considered

Motivation and Objectives:

- Fallback DCI format 0_0 is relevant for coverage enhancements given its robustness thanks to small payload size
- Repetition for PUSCH scheduled by DCI format 0_0 with CRC scrambled by RNTIs other than TC-RNTI is beneficial before the first RRC configuration, during which only DCI format 0_0 is used. This is applicable for PUSCH carrying RRC setup complete message (also known as Msg5) or UE capability information reporting message
- Given the relevance of DCI format 0_0 for coverage enhancements, repetitions for PUSCH scheduled by DCI format 0_0 with CRC scrambled by RNTIs other than TC-RNTI should be supported in general and should not be limited to Msg5 PUSCH

Proposal: Specify repetitions for PUSCH scheduled by DCI format 0_0 with CRC scrambled by RNTIs other than TC-RNTI

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Waveform switching for PUSCH scheduled by DCI format 0_0

Background:

- Rel-18 specifies dynamic waveform switching (DWS) between CP-OFDM and DFT-s-OFDM for PUSCHs scheduled by DCI formats 0_1 and 0_2 by adding a new 1-bit field to the DCI
- Since the solution requires the change of DCI size, it's not straightforwardly applicable for the fallback DCI format 0_0, whose size is not expected to be changed
- Other solutions could be considered for supporting DCI format 0_0 without changing its size (e.g., implicit indication), however RAN1 did not have enough time in Rel-18 to specify it.
- Enhancement of power headroom report (PHR) for UEs to provide PH information of both waveforms, which could assist gNB on waveform selection, is supported by majority but may not be specified in Rel-18 due to some non-technical concerns: lack of time, RAN2 is not involved in the WID.

Motivation and Objectives:

- Fallback DCI format 0_0 is applicable not only for Msg3 PUSCH but also for other PUSCHs in general
- It's too restrictive to assume that network always configures DFT-s-OFDM for PUSCH scheduled by DCI format 0_0 (in *msg3-transformPecoder*)
- If DWS is not supported for initial transmission of Msg3 PUSCH in Rel-18, then supporting DWS for at least retransmission of Msg3 PUSCH (scheduled by DCI format 0_0 scrambled by TC-RNTI) has an even larger relevance.
- In addition, assisting information provided by UE is essential for an efficient use of DWS feature.

Proposal:

Specify:

- **Dynamic waveform switching (DWS) between CP-OFDM and DFT-s-OFDM for PUSCHs scheduled by DCI format 0_0**
- **DWS for initial and retransmission of Msg3 PUSCH (if not supported in Rel-18)**
- **Power headroom report (PHR) enhancement for assisting gNB in waveform selection for DWS.**

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Further DM-RS bundling enhancements

Background:

- Rel-17 supports DM-RS bundling feature which allows joint channel estimation across PUSCH transmissions within a bundle of PUSCH repetitions (i.e., with a same transport block)
  - DM-RS bundling feature in Rel-17 is also limited to modulation orders not higher than 4

Motivation and Objectives:

- During study item phase of Rel-17, benefits of joint channel estimation across PUSCH transmissions have been assessed thoroughly. However, this Rel-17 feature competitiveness is reduced due to the presence of too many configuration constraints
- Most of the existing constraints are unavoidable for UE to ensure power consistency and phase continuity across PUSCH. However, some constraints can be relaxed/further improved, e.g., the limitation on applicability to a same transport block, while relaxation of others would first need a preliminary study, e.g., low modulation order

Proposal:

- **Specify DM-RS bundling for PUSCH transmissions with different transport blocks**
- **Study, and if necessary, specify DM-RS bundling for modulation order higher than 4**

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Uplink Coverage Enhancements

Summary

Improve coverage for higher data rates

- Smaller A-MPR for certain scenarios, with conditions defined to enable gNB to know when the UE can use smaller A-MPR
- Smaller MPR for certain UL CA scenarios
- Complete any outstanding optimizations to the Rel-18 MPR/PAR reduction schemes, e.g., Frequency-Domain Spectrum Shaping with Spectrum Extension

Resolve limitations of existing coverage features

- Multiple PRACH transmissions with different Tx beams, enabling optimal beam selection for Msg 3 and subsequently.
- PUSCH repetitions scheduled by DCI format 0_0 with CRC scrambled by RNTIs other than TC-RNTI, to improve coverage before the first RRC configuration.
- Waveform switching for PUSCH scheduled by DCI format 0_0
- Further DMRS bundling enhancements to broaden its usefulness, e.g. across different transport blocks

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