**3GPP TSG RAN WG1 #110 R1-2207725**

**Toulouse, France, August 22nd – 26th, 2022**

**Agenda Item: 9.1.4.2**

**Source: Moderator (InterDigital, Inc.)**

**Title:** **FL Summary on SRI/TPMI Enhancements; First Round**

**Document for:**  **Discussion and Decision**

# Background

In RAN plenary #94, the WID for Rel-18 MIMO enhancements was finalized [1]. According to the WID, some enhancements for SRI/TPMI are necessary to enable 8 TX UE transmission.

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| *Objective 5: Study, and if justified, specify UL DMRS, SRS, SRI, and TPMI (including codebook) enhancements to enable 8 Tx UL operation to support 4 and more layers per UE in UL targeting CPE/FWA/vehicle/Industrial devices**- Note: Potential restrictions on the scope of this objective (including coherence assumption, full/non-full power modes) will be identified as part of the study.* |

To accomplish the objective, the scope of this agenda item centers on codebook design for 8TX, CW to layer mapping, SRS enhancements to support 8 ports, impacts resulted from coherency characteristics of such UEs as well as UE operation with full power.

# High Priority Topics

In the last meeting, RAN1 agreed on EVM assumptions as well as some basic assumptions to further clarify the scope of the work under this agenda item in Rel-18 [2]. Based on the agreements made in the last meeting, and the provided discussion in companies’ contributions [3-26], following topics are recognized as high priority topics to be discussed for decision in WG1 #110.

# Codebook Design for UL Transmission for 8TX UE

In the last meeting, five alternatives were identified for down-selection. The main difference between the alternatives lies in whether/how NR Rel-15 UL 2TX/4TX codebooks or NR Rel-15 UL 2TX/4TX codebooks to be applied for a given UE coherence capability.

Based on the agreed alternatives, Table 1 captures companies’ preferences for the codebook design for UL 8TX UE. To aid the decision on this topic, 8 companies have provided their results and observations using LLS (1) and SLS (7) simulations.

* Based on the simulation results, 5 companies have argued in favour of **Alt1b** (**Qualcomm**, **OPPO**, **Intel**(2), **ZTE** and **MT**).
* **Huawei** shows simulation results in support of superiority of **Alt2a**. **Intel** reports a better performance can be achieved by Alt1b, however due to simplicity and less overhead, it flags **Alt2a** as their first choice.
* According to **Ericsson** evaluations, there is no clear performance gap among the agreed alternatives as the size of the codebook is quite large. **Ericsson** proposes to study solutions for reducing the codebook resolution.

Table 1

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| For 8TX UE codebook-based uplink transmission, down-select one of* Alt1-a:
	+ Study NR Rel-15 UL 2TX/4TX codebooks and/or 8x1 antenna selection vector(s) as the starting point for design of the codebook for non-coherent UEs
	+ Study NR Rel-15 DL Type I codebook as the starting point for design of the codebook for fully/partially-coherent UEs
* Alt1-b:
	+ Study NR Rel-15 UL 2TX/4TX codebooks and/or 8x1 antenna selection vector(s) as the starting point for design of the codebook for partially/non-coherent UEs
	+ Study NR Rel-15 DL Type I codebook as the starting point for design of the codebook for fully-coherent UEs
* Alt2-a:
	+ Study NR Rel-15 UL 2TX/4TX codebooks and/or 8x1 antenna selection vector(s) as the starting point for design of codebook for fully/partially/non-coherent UEs
* Alt2-b:
	+ Study NR Rel-15 UL 2TX/4TX codebooks and/or 8x1 antenna selection vector(s) in combination with those based on NR Rel-15 DL Type I codebooks as the starting point for design of codebook for fully/partially/non-coherent UEs
* Alt3:
	+ Study NR Rel-15 DL Type I codebook as the starting point for design of codebook for fully/partially/non-coherent UEs
* Transmission using one or multiple precoders corresponding to one or multiple SRS resources can be studied as part of the above alternatives.
 | * **Alt1-a:** Samsung, Sharp (2)
* **Alt1-b:** ZTE, Spreadtrum (1), vivo, Lenovo, OPPO, CATT, NEC, Intel (2), CMCC, MediaTek, Qualcomm, IDC(1), Apple NTT(1), Sharp (1)

 * **Alt2-a:** Huawei/HiSlicon, Spreadtrum (1), Google, IDC(2), Lenovo, Intel (1)
* **Alt2-b:** LG, NTT(2)
* **Alt3:** Nokia
 |

**FL Proposal 2.1a: RAN1 further studies Alt1b and Alt2a for down-selection in RAN1 meeting #110b-e.**

**FL Proposal 2.1b: For evaluation purpose of codebook alternatives when Rel-15 DL Type I is used, following oversampling ratios are assumed**

* **(O1, O2) = (1,1), (2.1)**
* **Note: Other values may be used and reported by companies**

In the last meeting, four main categories of antenna layouts were agreed for codebook design and evaluation. To have further alignment among companies, as suggested by **Xiaomi**, **Samsung**, **Apple**, **NTT**, **CMCC**, it would be helpful to clarify antenna layout for each category of UE coherency.

**FL Proposal 2.1c: For evaluation of codebook alternatives for full-coherent and partial-coherent 8TX UE, the followings are assumed**

* **Full coherent: Antenna layout 1a (Ng=1, M=2, N=2, P=2), 1b (Ng=1, M=1, N=4, P=2)**
* **Partial coherent:**
	+ **Antenna layout 2a, 2b (Ng=2, M=1, N=2, P=2)**
	+ **Antenna layout 3a, 3b (Ng=4, M=1, N=1, P=2)**

Table 2

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# Number of Layers for UL Transmission

In NR Rel-17, uplink transmission is restricted to a maximum of 4 layers for transmission. However, for 8TX UEs, some companies have proposed to increase the number of layers. Table 3 shows the overall state of views expressed by companies.

On this topic, 9 companies have provided SLS simulation results and some observation in support of their preferred proposals as captured below.

* Support up to 8 layers
	+ According to their evaluation, **Lenovo** shows that 25% of channel conditions exhibits a higher rank than 4.
	+ Based on the evaluation results provided by **Huawei**, **ZTE**, **Ericsson**, **NTT** and **Nokia**, a rank 8 transmission results in a higher throughput, regardless of the max modulation order, i.e., 64QAM or 256QAM. **Huawei** has also demonstrated that their observation holds up for both P0 values of -50dBm and -80 dBm.
* Prioritize 4 layers
	+ **Vivo** and **MediaTek** argue that a 4-layer transmission with 256QAM gives a similar or only slightly better performance than an 8-layer with 64QAM.
	+ According to **Qualcomm**’s evaluations, in terms of mean and cell-center throughput, an 8-layer transmission with 64QAM has a marginal gain over a 4-layer transmission with 256QAM, but it has a marginal loss for the cell-edge throughput. Hence, the benefit of supporting more than 4 layers is insignificant.

Table 3

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| Number of layers for codebook and non-codebook UL transmission for 8TX UE,* **Alt1**: Support up to 8-layer UL transmission for 8TX UE
* **Alt2**: Prioritize up to 4-layer UL transmission for 8TX UE
 | * **Alt1**: Huawei/HiSilicon, ZTE, Sony, Lenovo, CATT, Xiaomi, CMCC, Ericsson, NTT, Nokia
* **Alt2:** Intel, vivo, Samsung, Qualcomm, MediaTek(?)
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**FL Proposal 2.2: Support up to 8 layers for codebook and non-codebook UL transmission for 8TX UE.**

Table 4

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# Number of Codewords for UL Transmission

In NR Rel-17, uplink transmission is restricted to single codeword. For 8TX UEs, some companies have proposed to enhance uplink transmission by increasing the number of codewords for 8TX UE.

Several companies (9) are in favor of adoption of dual codeword for uplink transmission, from the list of supporting companies, 3 companies state that the usage of more than one codeword should be conditioned/linked to other operational characteristics or system parameters. On the other hand, 3 companies have stated their preference for continued usage of single codewords due to significant increase in the specification process. Based on **vivo** evaluation results, the performance gain of dual codeword compared to single codeword is negligible.

Table 5

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| Number of codewords with >4 layers for codebook and non-codebook UL transmission for 8TX UE,* **Alt1**: Single codewords
* **Alt2**: Dual codewords
 | * **Alt1**: Intel, vivo, IDC(1)
* **Alt2**:
	+ Supported by: Xiaomi, CMCC, Qualcomm, NTT, Nokia
	+ Conditionally supported by: ZTE, IDC(2), Sony
		- Condition: To link its usage based on other operational parameters, e.g., panel, coherency, CSI, etc.
 |

**FL Proposal 2.3: Support dual codeword** **for codebook and non-codebook UL transmission for 8TX UE** **conditioned/linked to other operational characteristics or system parameters.**

* **FFS conditions to enable dual codeword, i.e., number layers, panels, antenna group, etc.**

Table 6

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# Numeration of Antenna groups

In the last meeting, the notion of antenna group for full-coherent or partial-coherent 8TX UE was discussed and agreed [1]. As such, for a fully/partially-coherent 8TX UE, Ng>=1 antenna groups can be considered where each group comprises coherent antennas, and across groups, antennas can be non-coherent/coherent depending on device types.

An important remaining aspect related to antenna group that may be also relevant to the design of the codebook is the range of Ng. On this issue, 9 companies have provided their recommendations as captured in Table 7.

Table 7

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| * For a full-coherent or partial-coherent 8TX UE, antenna ports can be divided into one or two or four antenna port groups, the antenna ports within an antenna port group are fully-coherent and the antenna ports in different antenna port groups are non-coherent.
 | * Xiaomi, Google, Lenovo, OPPO, ZTE(?), CATT, IDC, LG, Nokia
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**FL Proposal 2.4: For a full-coherent or partial-coherent 8TX UE, support Ng=1, 2, 4.**

Table 8

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# Medium Priority Topics

# SRI/TPMI Indication for Codebook UL Transmission

For SRI and TPMI indication, companies have provided their high-level views about their preferred indication mechanism. In codebook-based UL transmission, TPMI and SRI are used for indication of rank, precoder and antenna ports for PUSCH transmission.

To support codebook-based transmission, SRI/TPMI indication for an 8TX UE can require significant specification work, and also can become costly in terms of overhead. Table 9 shows companies views on this topic. Based on companies’ perspectives, two main solutions can be considered for SRI/TPMI indication,

* Use a single field to indicate rank and precoder: This may be more efficient from overhead perspective; however, it requires some specification work that involved some new additions, e.g., tables, fields, etc.
* Use separate fields to indicate rank/precoder per port group: This solution may require more overhead as the first solution; however the specification impact is less as existing indicator can be reused.

Table 9

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| TPMI/SRI indication for Codebook-based  | * **Alt1:** Single field to indicate rank and precoder
	+ Supported by: ZTE, Samsung, IDC (partial update), NTT,
* **Alt1:** Separate fields to indicate rank/precoder per port group
	+ Supported by: ZTE, OPPO, Samsung, Ericsson,
 |

**FL Proposal 3.1: Study low overhead solutions for SRI/TPMI indication for codebook and non-codebook transmission by an 8TX UE.**

* **FFS using single or separate fields**
* **FFS DCI-based, DCI+RRC, DCI+MAC CE, etc.**

Table 10

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# SRS Configuration for non-CodeBook UL Transmission

Table 11 captures main proposals for SRS configuration for non-codebook UL transmission for an 8TX UE. For codebook transmission, the enhancement for configuration seems more straightforward, hence most companies have discussed configuration for non-codebook transmission.

For SRS configuration in non-codebook transmission mode, two main alternatives have been proposed by companies,

* Configuring a single SRS resource set that is configured with up to 8 single-port SRS resources. Hence a single SRI indication can be used for indication of a preferred spatial filter. However, the SRI field needs to be enhanced to support the additional SRS port combination introduced by an 8TX UE.
* Configuring two SRS resource sets that each is configured with 4 single-port SRS resources. As such, two SRI indications should be used for indication of preferred spatial filter. Therefore, there should not be any need to redesign/enhance the existing SRI field, how two SRI indication may be needed.

**Table 11**

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| SRS configuration for non-CB | * **Alt1:** A single SRS resource set configured with up to 8 single-port SRS resources (Single SRI indication)
	+ Supported by: ZTE, Lenovo, Apple, LG, Samsung, Xiaomi, Intel, OPPO
* **Alt2:** Two SRS resource sets, each configured with 4 single-port SRS resources (Two SRI indications)
	+ Supported by: vivo, Samsung, Xiaomi
 |

**FL Proposal 3.2: For SRS configuration for non-codebook UL transmission for an 8TX UE, down-select from**

* **Alt1: A single SRS resource set configured with up to 8 single-port SRS resources**
* **Alt2: Two SRS resource sets, each configured with 4 single-port SRS resources**

 Table 12

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# Full Power Operation

Many companies have expressed the importance of full power transmission for 8TX UE. In Rel-16, full power transmission for codebook transmission is supported by Mode 0, Mode 1 and Mode 2. Several companies have stated that to support full power transmission for 8 TX UE, Rel-16 full power transmission schemes can be re-used with necessary enhancements.

Table 13

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| Full power operation for 8TX UE | * Reusing Rel-16 full power transmission schemes with necessary enhancements
	+ Supported by: Qualcomm, Nokia, NTT, Ericsson, IDC
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**FL Proposal 3.3: Extend Rel-16 full power Mode 0, Mode 1 and Mode 2 to support to 8TX UE.**

Table 14

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# Low Priority Topics

Following topics have been brought up by companies as the next step issues for support of 8TX UE. Please provide your additional inputs for each topic.

# PTRS-related Enhancements

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| **Topic** | **Companies’ views** |
| Aspects for PTRS-DMRS association, * Definition and indication of mapping between PTRS and PUSCH ports
 | Supported by: vivo, Lenovo, Qualcomm |
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# Codebook Configuration

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| **Topic** | **Companies’ views** |
| Aspect related to codebook configuration and power mode,* For a full-coherent or partial coherent UE, UE further reports other information
	+ FFS other information, e.g., antenna layout, virtualization capability across antenna ports, etc.
 | Supported by: Apple, IDC  |
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# Feature-lead Proposals for Approval

# Round1

# List of Companies’ Proposals

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| --- | --- |
| **InterDigital** | ***Proposal 1:*** *For enabling 8 Tx UL for UEs with many antennas, it should be discussed how/when to use single or dual codeword based on considered scenarios, UE types, coherency types, and so forth.* ***Proposal 2:*** *Consider UE to report its capabilities on a supported type of antenna/panel structure or virtualization capability across UE antenna ports such as SRS antenna ports, enabling up to 8 Tx UL.* ***Proposal 3:*** *Support antenna grouping with further studies on how to associate parameters between the group, and consider enhancements on precoding design at least based on Rel-15 UL 2TX/4TX codebooks (Alt1-b, Alt2-a) to enable up to 8 Tx UL.* ***Proposal 4:*** *To reduce signaling overhead associated to SRI/TPMI indication for a 8TX UE, RAN1 studies partial update of TPMI/SRI information for 8TX UE.* ***Proposal 5:*** *Support to retain the full power transmission mode of operation with necessary enhancements to be also applicable for the new enhanced UL-MIMO transmission case supporting up to 8-Tx UL.* |
| **Huawei** | ***Proposal 1:*** *Support maximal 8 layers for 8TX UL transmission.****Proposal 2:*** *SRI enhancement with overhead reduction to enable 8TX NCB based UL transmission should be supported.****Proposal 3****：Block-wise codebook based on legacy 2TX and 4TX UL codebook should be supported for UL 8TX.****Proposal 4:*** *The beamformed CSI-RS should be considered to indicate UL precoders to UE.* |
| **ZTE** | ***Proposal 1:*** *Regarding 8 Tx-UL operation in Rel-18, support 8-Tx and up to 8 layers for UL transmission.* ***Proposal 2:*** *Regarding codebook design for 8-Tx, Alt 1-a is preferred.** *Full-coherent codebook can be based on NR Rel-15 DL type I;*
	+ *Some parameters can be optimized per rank, e.g., oversampling value can be lower for lower rank(s).*
* *Partial-coherent codebook can be based on NR Rel-15 UL 4-Tx/2-Tx UL codebooks*
	+ *FFS: only full coherent UL 4-Tx/2-Tx UL codebooks vs. Full+partial+non coherent UL 4-Tx/2-Tx UL codebooks*
* *For non-coherent codebook,*
	+ *FFS: full flexibility vs. partial flexibility*
	+ *FFS: whether to be supported by some of partial coherent codebooks*

***Proposal 3:*** *Regarding codebook indication for 8-Tx, consider one of the following options:* * *Option A: One table, each entry indicating one or more ranks + one or more TPMIs for one or more port groups.*
* *Option B: Indication for # of port groups, and separate fields each indicating rank+TPMI for a port group*
* *Option C: One field for rank combination indication, and zero or more fields for a shared TPMI or multiple TPMIs (each TPMI corresponding to one port group).*

***Proposal 4:*** *Regarding non codebook based transmission design for 8-Tx,* * *The number of SRS resources in an SRS set can be up to 8*
* *Potential optimization for SRI re-design considering DCI overhead, e.g., 8 bits or less*

***Proposal 5:*** *On 8-Tx UL transmission enhancement, 2 CWs for UL transmission should be supported for more than 4 layers UL 8-Tx transmission, for multiple panel simultaneous transmission, and for 2~4 layers.* * *Condition of enabling >1 CWs for UL transmission can be further studied in RAN1, e.g., if the number of Tx(s) and the number of UL layers exceeds threshold(s).*
 |
| **Spreadtrum Communications** | ***Proposal 1***：*For 8TX UE codebook-based uplink transmission, Alt2-a is preferred and Alt1-b is second preferred.****Proposal 2:*** *Further study the potential methods to reduce DCI overhead for SRI indication.* |
| **vivo** | ***Proposal 1:*** *Support both codebook and non-codebook based schemes for 8Tx UL transmission.****Proposal 2:*** *Support fully-coherent, partially-coherent and non-coherent UEs for 8Tx UL transmission.****Proposal 3:*** *Two SRI fields corresponding to two SRS resource sets for non-codebook transmission can be considered to simplify the SRI indication.****Proposal 4:*** *Codebook constructed by two 4Tx precoders indicated by two TPMI fields can be considered for partial and none coherent antenna assumption.****Proposal 5:*** *DL type1 codebook can be considered for fully coherent antenna assumption.****Proposal 6:*** *First, focus on transmission rank<=4, further discussed number of supported codewords if transmission rank>4 is supported.****Proposal 7:*** *Following issues should be further discussed:** *PTRS-DMRS association indication when rank>4, if supported*
* *Impact on full power modes*
 |
| **Sony** | ***Proposal 1:*** *Up to 8 layers UL transmission can be supported for 8Tx UE.****Proposal 2:*** *Two CWs can be supported for in UL 8Tx transmission.****Proposal 3:*** *Panel-specific CW to layer mapping can be considered for multi-panel UE UL transmission.****Proposal 4:*** *Channel state-based CW to layer mapping can be considered for 8 Tx UE UL transmission.****Proposal 5:*** *Dynamic CW to layer mapping indication scheme can be considered 8 Tx UE UL transmission.****Proposal 6:*** *Enhanced TPMI indication with finer precoding information can be considered for UE UL transmission enhancements.* |
| **Google** | ***Proposal 1:*** *Support to prioritize the codebook design for antenna layout 3-a and 3-b.****Proposal 2:*** *The enhancement of 8Tx transmission supports both coherent and partial coherent transmission, where the partial coherent transmission assumes coherent transmission within a panel.****Proposal 3:*** *Support to define the 8Tx UL codebook based on Rel-15 DL Type1 multi-panel codebook, where additional precoders with panel selection can be introduced.* |
| **Lenovo** | ***Proposal 1:*** *Prioritize full coherence and partial coherent UE capability for 8Tx UL operation****Proposal 2:*** *Use antenna grouping to represent different UL Tx coherence assumptions, with the following conditions** *Antenna configurations of different antenna groups are identical*
* *Coherence assumptions of two antennas within an antenna group are the same*
* *Coherence assumptions of two antennas across two antenna groups are the same*

***Proposal 3:*** *Support Alt1-b and Alt2-a for further study of codebook design****Proposal 4:*** *Study the performance benefits, signaling overhead and specification impact of supporting frequency-selective precoding for 8Tx UE****Proposal 5:*** *TPMI signaling overhead is considered as a performance metric when studying different alternatives for 8Tx UL codebook design****Proposal 6:*** *More than 4 layers PUSCH transmission should be supported for 8TX PUSCH transmission with 2 codewords.****Proposal 7:*** *Study codeword-to-layer mapping for 8TX UL PUSCH transmission with more than 4 layers scheduling.****Proposal 8:*** *Study UCI multiplexing in PUSCH scheduled with 2 codewords.****Proposal 9:*** *Study mapping beteen PTRS ports and PUSCH antenna ports, as well as the indication of associated DMRS port for each PTRS for 8TX PUSCH transmission.****Proposal 10:*** *To support 8Tx UL transmission, on the SRS configuration,** *One or two SRS resources with 8 SRS ports can be configured in the SRS resource set for CB when codebook based UL transmission is configured, and*
* *Up to 8 SRS resources with single port can be configured in the SRS resource set for nCB when non-codebook based UL transmission is configured.*
 |
| **OPPO** | ***Proposal 1:*** *Strive for a unified codebook design applicable to all considered antenna layouts.****Proposal 2:*** *For full-coherent codebook with uniform linear antenna array of 8 ports,** *Prioritize linear array of cross-polarized antenna configuration*
* *NR DL 8Tx Type 1 CB (wideband beam and co-phasing) is used as baseline with less beams.*

***Proposal 3:*** *For partial-coherent 8 ports codebook,** *Prioritize linear array of cross-polarized antenna configuration*
* *Support codebook design based on Rel-15 UL 2TX/4TX codebooks*
* *Each group of cross-polarized antennae is assumed to be coherent, and two groups of cross-polarized antennae can be coherent or non-coherent.*

***Proposal 4:*** *For non-coherent 8 ports codebook,** *Prioritize linear array of single-polarized antenna configuration*
* *Support 8x1 antenna selection vector for each layer with restricted codebook size*

***Proposal 5:*** *Consider separate indication of TRI and TPMI if two-stage codebook is agreed for 8 Tx uplink.****Proposal 6:*** *Introduce SRI enhancement to indicate up to 8 SRS resources for non-codebook uplink transmission, considering signaling overhead and standardization complexity.* |
| **CATT** | ***Proposal 1:*** *UL 8Tx with up to 8 layers is supported in Rel-18.****Proposal 2:*** *For UL 8Tx with DFT-s-OFDM, precoding matrices in Table 1 are adopted for non-coherent codebook.****Proposal 3:*** *For UL 8Tx with CP-OFDM, whether all or a subset of port selection precoding matrices are supported for non-coherent codebook shall be considered.****Proposal 4:*** *For UL 8Tx operation, all or a subset of precoding matrices in non-coherent codebook included in partial-coherent codebook and full-coherent codebook is considered.****Proposal 5:*** *On codebook design for partial-coherent UE with UL 8Tx, two coherent groups with four coherent antennas per group, and four coherent groups with two coherent antennas per group are considered.****Proposal 6:*** *On codebook design for partial-coherent UE with UL 8Tx,** *If two coherent groups are supported, the two coherent ports groups are {0,2,4,6} and {1,3,5,7}, respectively;*
* *If four coherent groups are supported, the four coherent port groups are {0,4}, {1,5}, {2,6}, and {3,7}, respectively.*

***Proposal 7:*** *On codebook design for partial-coherent UE with UL 8Tx, Rel-15 UL 2TX/4TX codebook is selected as the starting point.****Proposal 8:*** *For UL 8Tx operation, all or a subset of precoding matrices of partial-coherent codebook included in full-coherent codebook is considered.****Proposal 9:*** *On codebook design for full-coherent UE with UL 8Tx in DFT-S-OFDM, searching precoding matrices by computer can be considered.****Proposal 10:*** *On codebook design for full-coherent UE with UL 8Tx in CP-OFDM, NR Rel-15 DL Type I codebook can be considered as the starting point.****Proposal 11:*** *For UL 8Tx for codebook based PUSCH, TPMI/SRI indication is designed after the codebook and SRS design are available.****Proposal 12:*** *For UL 8Tx for non-codebook based PUSCH, one SRI field is used to indicate SRS resource(s).* |
| **NEC** | ***Proposal 1:*** *From UE perspective, reporting capability of full, partial and non coherent is sufficient. And considering the partial coherent layouts, more than one type of partial coherent for different number of antennas within a group can be introduced.****Proposal 2****: For codebook based uplink transmission, support Alt 1-b for codebook design.****Proposal 3:*** *Overhead reduction for partial and non coherent codebook should be studied, for example, based on antenna groups.* |
| **Intel** | ***Proposal 1:*** *For 8Tx UL codebook design, if RAN1 strives for unified solution for different coherence, then Alt2-a is preferred, i.e., the full coherent/partial coherent/non-coherent precoders could be based on Rel-15 2Tx/4Tx codebook.** *Otherwise, the codebook design could be based on Alt1-b, i.e.,*
	+ *The non-coherent precoders are antenna selection vectors or based on Rel-15 2Tx/4Tx codebook*
	+ *The partial coherent precoders could be based on Rel-15 2Tx/4Tx codebook*
	+ *The full coherent precoders could be based on Rel-15 Type I codebook*

***Proposal 2:*** *For 8Tx UL codebook design, RAN1 to take the overhead into account.****Proposal 3:*** *For 8Tx UL transmission, the maximum of 4 layers could be prioritized.****Proposal 4:*** *For 8Tx UL transmission, single codeword is preferred.****Proposal 5:*** *For codebook based transmission with 8Tx, one SRS resource set could be configured. The number of SRS resources and number of ports for SRS resources could be discussed together with full power operation.****Proposal 6:*** *RAN1 to discuss the UE PA architectures to be considered for full power operation with 8Tx in Rel-18.****Proposal 7:*** *For non-codebook based transmission, one SRS resource set could be configured, and joint encoding of SRI and RI is preferred.* |
| **Xiaomi** | ***Proposal 1:*** *Support 8Tx with more than 4 transmission layers for the UL.****Proposal 2:*** *For the PUSCH, the number of antenna ports should be extended to 8 accordingly.****Proposal 3:*** *Support both codebook based UL transmission and non-codebook based UL transmission.****Proposal 4:*** *2 codewords should be supported for up to 8 layers of uplink transmission.****Proposal 5:*** *The supported 2 codeword transmission scheme can be enabled when more than X transmission layers is configured, X is up to UE capability.****Proposal 6:*** *Support the extension of the maximum number of SRS resources in a SRS resource set to 8.****Proposal 7:*** *Support the configuration of the SRS resources in one or two SRS resource sets;****Proposal 8:*** *For non-codebook based PUSCH transmission with 8Tx, SRI indicated by the bitmap of the SRS resources of the SRS resource configured in either one or two SRS resource set(s) is preferred for the simplicity without any effort on the design of new SRI tables.****Proposal 9:*** *The following cross-polarized antenna layout configurations can be considered as a starting point, i.e., (N1,N2,Ng)=(4,1,1), (N1,N2,Ng)=(2,2,1), (N1,N2,Ng)=(2,1,2), and (N1,N2,Ng)=(1,1,4) with d=0.5λ.****Proposal 10:*** *The subset of Rel-15 DL Type I 8Tx codebook with reduced oversampling factors (N1,N2,O1,O2) = (4,1,2,1) and (2,2,2,2) can be used for Rel-18 UL 8Tx fully-coherent codebook. The subset selection principle can be based on CSI estimation, distance from the optimal codeword obtained by SVD, BLER or throughput performance, and so on. A group of codewords with the same beam (i1) or co-phasing (i2) can be selected with high priority.****Proposal 11:*** *Concentrating two or four (same or different) Rel-15 UL 4Tx fully-coherent codewords with a co-phasing factor* $φ$ *(e.g., +1, -1,+j, -j) can be adopted for Rel-18 UL 8Tx fully-coherent codebook, e.g.,*$W\_{8Tx,L}=\left[\begin{matrix}W\_{4Tx,\left⌈{L}/{2}\right⌉}&W^{'}\_{4Tx,\left⌈{L}/{2}\right⌉}\\φW\_{4Tx,\left⌈{L}/{2}\right⌉}&-φW^{'}\_{4Tx,\left⌈{L}/{2}\right⌉}\end{matrix}\right]$*,*$W\_{8Tx,L}=\left[\begin{matrix}W\_{4Tx,\left⌈{L}/{2}\right⌉}&W\_{4Tx,\left⌊{L}/{2}\right⌋}\\φW\_{4Tx,\left⌈{L}/{2}\right⌉}&-φW\_{4Tx,\left⌊{L}/{2}\right⌋}\end{matrix}\right]$*,**or*$W\_{8Tx,L}=\left[\begin{matrix}W\_{4Tx,\left⌈{L}/{2}\right⌉}&W\_{4Tx,8-L}\\φW\_{4Tx,\left⌈{L}/{2}\right⌉}&-φW\_{4Tx,8-L}\end{matrix}\right]$*.****Proposal 12:*** *The antenna ports can be divided into two or four antenna port groups, the antenna ports within an antenna port group are fully-coherent and the antenna ports in different antenna port groups are non-coherent.****Proposal 13:*** *For partially-coherent codewords, the Rel-15 DL Type I 8Tx codebook based Rel-18 UL fully-coherent codewords can be Hadamard multiplied by a sparse matrix which should guarantee the orthogonality between layers. The elements can be exchanged in a column-wised manner so that the Xth group of layers can be transmitted on the Xth antenna port group.****Proposal 14:*** *For partially-coherent codewords, four or two Rel-18 UL 4Tx fully-coherent codewords are concentrated for two or four antenna port groups, respectively, i.e.,*$W\_{8Tx,L}=\left[\begin{matrix}W\_{4Tx,\left⌈{L}/{2}\right⌉}&0\\0&W^{'}\_{4Tx,\left⌈{L}/{2}\right⌉}\end{matrix}\right]$ ***or*** $W\_{8Tx,L}=\left[\begin{matrix}W\_{4Tx,\left⌈{L}/{2}\right⌉}&0\\0&W\_{4Tx,\left⌊{L}/{2}\right⌋}\end{matrix}\right]$*for two antenna port groups, and*$W\_{8Tx,L}=\left[\overset{L-4 W\_{2Tx,2}}{\overbrace{\begin{matrix}W\_{2Tx,2}&0\\0&...\\0&0\end{matrix}}}\overset{8-L W\_{2Tx,1}}{\overbrace{\begin{matrix}0\\0\\W\_{2Tx,1}\end{matrix}}}\right]$*for four antenna port groups. Each layer of 4Tx codewords should be set as the corresponding antenna ports, when different antenna ports partition schemes are used.****Proposal 15:*** *A unified codebook design principle is recommend for Rel-18 UL 8Tx fully/partially-coherent codebook.****Proposal 16:*** *Antenna selection vector(s) can be used to construct the non-coherent codewords. Considering the TPMI overhead, 8 non-coherent codewords when rank=1 and 1 non-coherent codeword when rank>1 can be adopted.****Proposal 17:*** *Considering the TPMI overhead, the bit width of TPMI for 8Tx codebook can be set as 6, 7, or at most 8 bits.****Proposal 18:*** *The scaling factor can be set as sqrt(1⁄K) where K denotes the number of non-zero elements in the codeword.* |
| **Samsung** | ***Proposal 1:*** *Regarding the transmission scheme for 8Tx UL operations,** *Support both CB and NCB based UL transmission*
* *For RAN1 work, adopt a serialized approach and prioritize CB-based discussions next 1-2 meetings*

***Proposal 2:*** *consider the following aspects of 8Tx antenna layout,** *Polarization: cross-polarized*
* *Antenna groups: 𝑁𝑔≥1 groups*
* *Antenna panels and coherence types:*
	+ *Single panel: one antenna group (𝑁𝑔=1) and full-coherence*
	+ *Multi-panel: multiple antenna groups (𝑁𝑔>1) and partial-/non-coherence*

***Proposal 3:*** *support a single unified 8Tx codebook structure for different coherence types (i.e. FC, PC, and NC) based on antenna groups** *Antennae within a group are coherent*
* *Antennae across multiple groups are non-coherent*

***Proposal 4:*** *regarding the 8Tx UL codebook,** *support Alt1-a*
* *reuse DL Type I codebook parameters (𝑁𝑔,𝑁1,𝑁2,𝑂1,𝑂2,𝐿)*
	+ *FC: (𝑁𝑔,𝑁1,𝑁2,𝑃)=(1,4,1,2),(1,2,2,2)*
	+ *PC: (𝑁𝑔,𝑁1,𝑁2,𝑃)=(2,2,1,2),(4,1,1,2)*
	+ *NC: (𝑁𝑔,𝑁1,𝑁2,𝑃)=(8,−,−,−)*
	+ *Study mechanisms to reduce TPMI payload, e.g. 𝐿=1, lower oversampling factors*

***Proposal 5:*** *study the following examples for the indication of (A) antenna group(s), and (B) UL precoding matrix,** *Ex1: two separate indicators, e.g. SRI for (A) and TPMI for (B)*
* *Ex2: a joint indicator, e.g. TPMI*

***Proposal 6:*** *Discussion on full power modes can be start after the 8Tx codebook is designed****Proposal 7:*** *regarding 8Tx NCB based UL transmission,** *Support number of SRS resources (𝑁𝑆𝑅𝑆) up to 8*
* *Support both one SRS resource set and two SRS resource sets*
* *When 𝑁𝑆𝑅𝑆≤4, the SRI indication follows legacy (Rel.15) scheme, and*
* *When 𝑁𝑆𝑅𝑆>4,*
	+ *Study the need for 𝐿𝑚𝑎𝑥>4*
	+ *study the following SRI indication schemes*
		- *Alt1: combinatorial index scheme*
		- *Alt2: bitmap based scheme*

***Proposal 8:*** *for STx2P, support both** *Case 1 (1 PUSCH): one SRI indicating a pair of SRS resources (e.g. STx2P to sTRP)*
* *Case 2 (2 PUSCHs): two SRIs, each indicating a SRS resource for a TRP (e.g. STx2P to mTRP)*

***Proposal 9:*** *regarding max number of layers** *prioritize the RAN1 work for max 4 layers*
* *>4 layers can be discussed, if its need and use cases can be identified*
 |
| **LG** | ***Proposal 1:*** *Support both codebook and non-codebook based 8Tx UL transmission in Rel-18 MIMO.****Proposal 2:*** *Support Alt2-b for 8Tx codebook design.****Proposal 3:*** *Support fully-coherent, partial-coherent and non-coherent UEs for 8Tx uplink transmission.****Proposal 4:*** *Support two-level partial coherency for codebook based 8Tx UL transmission.** *Level-1: 4-group 2Tx coherency*
* *Level-2: 2-group 4Tx coherency*

***Proposal 5:*** *For 8Tx UL codebook cons t ruction, consider the following two options** *Option 1. Common UL codebook for all potential antenna layouts*
* *Option 2. Multiple UL codebooks*

***Proposal 6:*** *Consider Table 4 for rank 1 8Tx codebook for CP-OFDM.****Proposal 7:*** *Consider Table 5 for rank 1 8Tx codebook for DFT-s-OFDM.****Proposal 8:*** *Consider following alternatives for enabling 8Tx non-codebook based UL transmission.** *Alt1. Increase # of SRS resource from 4 to 8.*
* *Alt2. Allow max 2 SRS ports per SRS resource*
* *Alt3. Reuse Rel-17 S-DCI based M-TRP PUSCH mechanism*
 |
| **CMCC** | ***Proposal 1:*** *Support maximal 8 layers UL transmission for 8 TX UE.****Proposal 2:*** *SRI field in Rel-15 can be reused for codebook based 8 TX UL transmission, when only one SRS resource is configured, the SRI field in DCI is absent, when two SRS resources are configured, 1 bit of SRI field in DCI is reused to indicate the selected SRS resource.****Proposal 3:*** *How to indicate up to 8 transmission rank and corresponding PUSCH precoder without increasing the SRI overhead for non-codebook UL transmission can be further studied.****Proposal 4****: Support Alt1-b: NR Rel-15 DL Type I codebook as the starting point for design of the codebook for 8TX fully-coherent UE.****Proposal 5:*** *The supported configurations of (N1, N2) for 8 TX UE can be N1=N2=2 or N1=4, N2=1 with the consideration of dual polarization, and the supported configurations of over sampling factor (O1, O2) can be further discussed for the codebook design of 8 TX fully-coherent UE.****Proposal 6:*** *Support Alt1-b: NR Rel-15 UL 2TX/4TX codebooks as the starting point for design of the codebook for partially-coherent UE.****Proposal 7:*** *If same spatial vector can be assumed among different antenna groups, the common spatial vector and phase offset design should support to indicate both partial-coherent and non-coherent codebooks for partially-coherent UE, and indicate {1, 2, 3, 4, 6, 8} layers codebook.****Proposal 8:*** *If different spatial vectors are assumed for different antenna groups, multiple TPMIs should be indicated to UE for each antenna groups for partially-coherent UE.****Proposal 9:*** *Support Alt1-b: 8x1 antenna selection vector(s) as the starting point for design of the codebook for non-coherent UE.****Proposal 10:*** *Enable 2 CWs with individual MCS, RV and NDI for 8 TX UL transmission can be studied.****Proposal 11:*** *Full power transmission for 8 TX UE with full rated PAs on each Tx chain can be discussed firstly, which is independent of codebook design.* |
| **MediaTek** | ***Proposal 1:*** *Support up to 4-layer transmission with 8TX UL operation.****Proposal 2:*** *Down select Alt 1-b for the CB design** *Alt1-b:*
	+ *Study NR Rel-15 UL 2TX/4TX codebooks and/or 8x1 antenna selection vector(s) as the starting point for design of the codebook for partially/non-coherent UEs*
	+ *Study NR Rel-15 DL Type I codebook as the starting point for design of the codebook for fully coherent UEs*

***Proposal 3:*** *Type I CB can be reduced for UL 8TX through the following techniques:** *Reduced DFT oversampling factors.*
* *Further quantize the beam co-phasing possibilities.*
* *FFS: Other techniques*

***Proposal 4:*** *Prioritize dual polarization over single polarization for full-coherent/partially coherent UEs.****Proposal 5:*** *Prioritize the CB design for partially coherent UE with two group and four group coherent antennas.****Proposal 6:*** *Study and support if justified, the additional co-phasing and amplitude compensation factors as a part of CB design across the panels of full coherent UEs.****Proposal 7:*** *SRS and SRI enhancement to support non-codebook based PUSCH with 8 Tx.** *FFS details on SRS and SRI enhancement for 8 TX via multiple SRS resource sets up to 8 ports.*
 |
| **Ericsson** | ***Proposal 1:*** *Support up to 8 layers for both codebook- and non-codebook-based transmission.****Proposal 2:*** *Support non-coherent precoders in 8 Tx codebook-based operation.****Proposal 3:*** *Consider restricting codebooks for 8 TX UEs such that elements of the precoding matrices are limited to the set {+1, +j, -1, -j}.****Proposal 4:*** *Study techniques to reduce/restrict the number of precoder candidates for 8 Tx codebook designs.****Proposal 5:*** *Focus the study of Rel-15 NCB-based operation with up to 8 layers on using Rel-15 principles, allowing any combination of SRS resources for a given maximum number of layers and SRS resources.****Proposal 6:*** *Study indicating multiple Rel-15/16 TPMIs, each corresponding to an SRS resource, where precoders do not combine coherently across SRS resources.* |
| ***Qualcomm*** | ***Proposal 1:*** *Rel-18 prioritize the specification for 8 Tx PUSCH with up to 4 layers, while deprioritize the specification for 8 Tx PUSCH with more than 4 layers.****Proposal 2:*** *NR Rel-18 reuse and concatenate existing Rel-15 2 Tx and/or 4 Tx PUSCH precoders to support 8 Tx PUSCH precoders with partial coherent or noncoherent 8 Tx (i.e., Alt 1-b).** *Prioritize the specification of the following two cases.*
	+ *Concatenate two 4 Tx precoders to build an 8 Tx precoder.*
	+ *Concatenate four 2 Tx precoders to build an 8 Tx precoder.*
* *FFS details on signalling to reuse and concatenate existing Rel-15 precoders.*
* *FFS how to reduce the size of the codebook.*

***Proposal 3:*** *As a starting point, Rel-18 study the new precoder codebook for PUSCH with fully coherent 8 Tx based on DFT matrix (i.e., Alt 1-b).****Proposal 4:*** *8 Tx UL codebooks reuse entries from QPSK constellation, without introducing constellation higher than QPSK.****Proposal 5:*** *For codebook based 8 Tx PUSCH in Rel-18, prioritize the specification for non-coherent and partial coherent 8 Tx precoders.****Proposal 6:*** *Rel-18 specify SRS and SRI enhancement to support non-codebook based PUSCH with 8 Tx.** *FFS details on SRI enhancement for 8 SRS ports sounding via a single SRS resource set.*
* *FFS details on SRI enhancement for 8 SRS ports sounding via multiple SRS resource set, each sounding less than 8 ports.*

***Proposal 7:*** *Increase # UL PTRS ports from up to 2 (in Rel-15/16/17) to up to 4, for both noncodebook based PUSCH and codebook based PUSCH.** *FFS: enhancements to support up to 4 PTRS ports.*

***Proposal 8:*** *Specify a new UE capability to indicate the number of PTRS ports, X, required by the UE, where X≤4.** *FFS: PTRS to DMRS association enhancements.*

***Proposal 9:*** *For 2 CWs PUSCH with 8 layers in Rel-18, reuse Rel-15 2 CWs PDSCH CW to layer mapping procedure.****Proposal 10:*** *Study, and if necessary, specify HARQ enhancement to support two codewords PUSCH with 8 Tx including at least the following aspects** *NDI, RV, MCS signaling for the second CW*
* *CBG based PUSCH with 2 CWs*
* *Dynamic switch between 2 CW and single CW PUSCH*

***Proposal 11:*** *Study, if necessary, specify the UCI-multiplexing enhancement to support UCI multiplexing on two codewords PUSCH with 8 Tx including at least the following aspects** *Multiplex UCI only on one of the CWs or both CWs*
* *Whether allowing different beta offset values for the two CWs*

***Proposal 12:*** *Study, if necessary, specify the signaling on DMRS port indication in DCI to support PUSCH with more than 4 layers.****Proposal 13:*** *Support reusing Rel-16 full power transmission schemes with necessary enhancements for PUSCH with 8 Tx.* |
| **Apple** | ***Proposal 1:*** *For the support of 8 Tx UL with codebook based transmission scheme, UE reports:** *Whether it supports full coherency, partial coherency, or non-coherency in antenna configuration.*
* *For a full-coherent or partial coherent UE, it further reports the antenna layout.*
	+ *For a full-coherent UE, it reports whether it supports (2, 2, 2) or (4, 1, 2) layout.*
		- *Note that whether the layout is considered as (4, 1, 2) or (1, 4, 2) is not critical for the UE, because the UE may rotate the direction.*
	+ *For a partial-coherent UE, it reports whether it supports 2 or 4 antenna groups.*

***Proposal 2****: For codebook based transmission scheme with 8Tx UL, support 1 SRS resource with up to 8 ports.****Proposal 3****: For codebook based transmission scheme with 8Tx full coherent antenna configuration, reuse the Rel-15 DL Type I codebook design for 8 Tx with small oversampling factor (e.g. O=2).****Proposal 4:*** *For codebook based transmission scheme with 8Tx partial coherent antenna configuration, use the Rel-15 UL 2Tx/4Tx codebooks for the per-antenna-group precoding.** *FFS how the layers are split among the groups*

***Proposal 5:*** *For codebook based transmission scheme with 8Tx non-coherent antenna configuration, a mechanism that provides full flexibility for the antenna port selection is considered as the starting point for the design.** *FFS overhead reduction*

***Proposal 6:*** *For full power transmission, advanced UEs similar to a UE that supports ul-FullPwrMode-r16 in Rel-16 (with all full-rated PAs) should be assumed to simplify the design.****Proposal 7:*** *For non-codebook based transmission scheme with 8Tx UL, support 1 SRS resource set with up to 8 SRS resources, each with a single port.****Proposal 8:*** *For non-codebook based transmission scheme with 8Tx UL, a mechanism that provides full flexibility for the SRI indication is considered as the starting point for the design.** *FFS overhead reduction*
 |
| **NTT DOCOMO** | ***Proposal 1:*** *Support 8TX UL transmission with up to 8 layers per UE.****Proposal 2:**** *Support a unified TPMI/RI indication method for fully-/partially/non-coherent UEs.*
	+ *Support single precoder indication for new 8TX precoder for fully/partially/non-coherent UEs.*
	+ *Joint indication of layer and TPMI index is the starting point.*
* *The number of supported precoders for 8TX should be carefully considered to reduce the DCI indication overhead.*
* *For 8TX UL codebook design, support Alt1-b or Alt2-b.*
	+ *For partially/non-coherent precoders, NR Rel-15 UL 2TX/4TX codebook is the starting point. New 8TX precoder (each with a new TPMI index) is designed based on existing 2TX/4TX precoders.*
	+ *For fully-coherent precoders, NR Rel-15 DL Type I codebook is the starting point. New 8TX precoder (each with a new TPMI index) is designed based on existing DL Type I precoders.*
		- *Study the candidate value of N1, N2, O1, O2 to be supported.*

***Proposal 3:**** *Support two codewords for PUSCH transmission for more than 4 layers. Following enhancements can be further discussed.*
	+ *codeword-to-layer mapping for more than 4 layers for spatial multiplexing (reuse DL codeword-to-layer mapping)*
	+ *DCI enhancement with codeword-specific indications of MCS, NDI, and RV*
	+ *UCI multiplexing on two codewords PUSCH*
* *Support two codewords for simultaneous multi-panel UL transmission for less than 4 layers. The design on support of two codewords PUSCH should be common and can be discussed jointly for 8TX UL transmission and multi-panel UE transmission.*
 |
| **Sharp** | ***Proposal 1:*** *We should first study rectangular arrangement but no other layout is precluded. Also, the three layouts summarized in the table should be discussed with the same priority****Proposal 2:*** *Support different codebooks for each coherent capability that is Alt1-a or Alt1-b.****Proposal 3:*** *We should use different codebooks for each coherent type as a starting point for design and believe Alt1-b reduce the standardization efforts.****Proposal 4:*** *We should discuss how to reduce overhead with TPMI indication.****Proposal 5:*** *RRC configuration should be separated according to the number of antenna ports for 8Tx transmission.* |
| **Nokia** | ***Proposal 1:*** *Study NR DL (Type-I) 8Tx codebooks for uplink transmission, with consideration of uplink antenna implementations for CPE/FWA/vehicle/Industrial devices.****Proposal 2:*** *RAN1 shall discuss on whether DL 8Tx multi-panel codebook (Type-I codebook) should be studied in Rel-18.****Proposal 3:*** *Support 8TX for UL transmission and support up to 8 transmission layers on UL transmission.****Proposal 4:*** *Consider reusing Rel-15 uplink codebook design principle for 8Tx partial coherent codebooks with 𝑵𝒈=𝟐 and 𝑵𝒈=𝟒.****Proposal 5:*** *Extend Rel-16 full power mode 1 and mode 2 support to 8Tx.****Proposal 6:*** *If two codewords are supported for uplink Tx, consider to support rank combinations of 2+3, 3+3, 3+4, and 4+4.* |

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