(NR CSI-RS)
Channel State Information
Reference Signal

Optimization

Technology

Mohamed Eladawi

Agenda

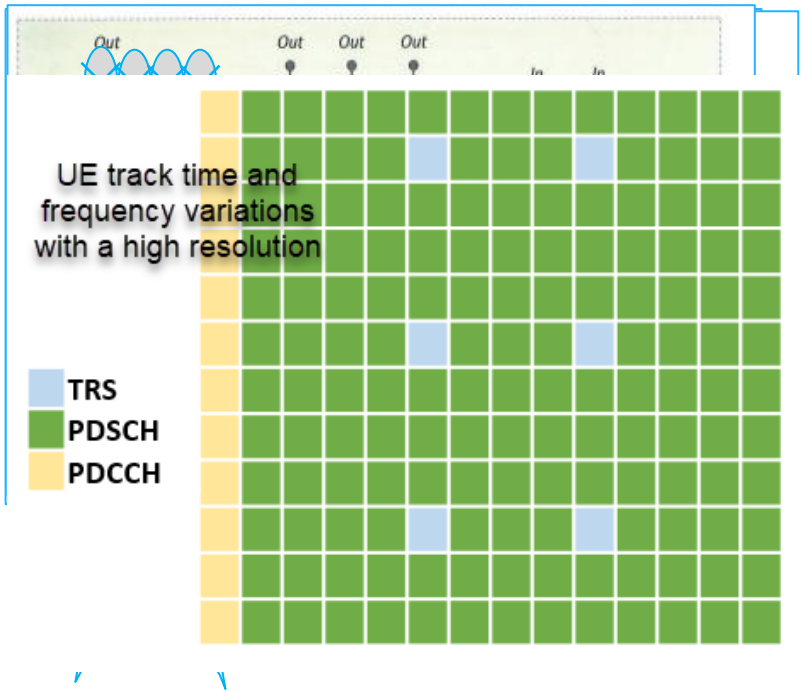
- CSI RS Main Function
- CSI-RS Key Characteristic
- CSI-RS Types & Categories(NZP, ZP & CSI IM RS)
- CSI-RS Main Parameters "Layer 3 messages"
- FREQUENCY & Time DOMAIN STRUCTURE OF CSI-RS CONFIGURATIONS
- CSI Reference Signal Planning

What CSI-RS Main Functions

- The Channel State information (CSI) Reference Signal is a multi-purpose DL Transmission. The Base Station can configure the UE to use the CSI-RS for one or more of the following:
- Some of the Procedures listed below can also be completed using SS/PBCH Blocks measurements. For Example, Connected Mode Mobility, RLF detection, and Beam Failure detection

CSI-RS Main Functions

- **CSI Reporting** — UE Provide CSI Reports, Which contains CQI, RI and PMI
- **Beam Management** — CSI is used to refine the Initial Beam selected based on SSB, A set of more direction Beams could be used to transmit the CSI Reference Signal.
- **Connected Mode Mobility** — Handovers can be triggered RSRP, RSRQ or SINR measured from the CSI-RS
- **RLF Detection** — The Physical Layers of the UE Can use the CSI-RS to generate in-Sync & Out-of-Sync Indications.
- **Beam Failure Detection and Recovery** — The UE uses CSI-RS to generate "Beam Failure Instance" indications. These indications are provided to the MAC Layer. Which uses them to monitor the beam and detect beam failure when the conditions are poor
- **Fine Tuning of Time and Frequency Synchronization** — 3GPP has adopted the CSI-RS as a solution for the TRS. The TRS is a DL Transmission that allows the UE to track time/Frequency variations with a high resolution.

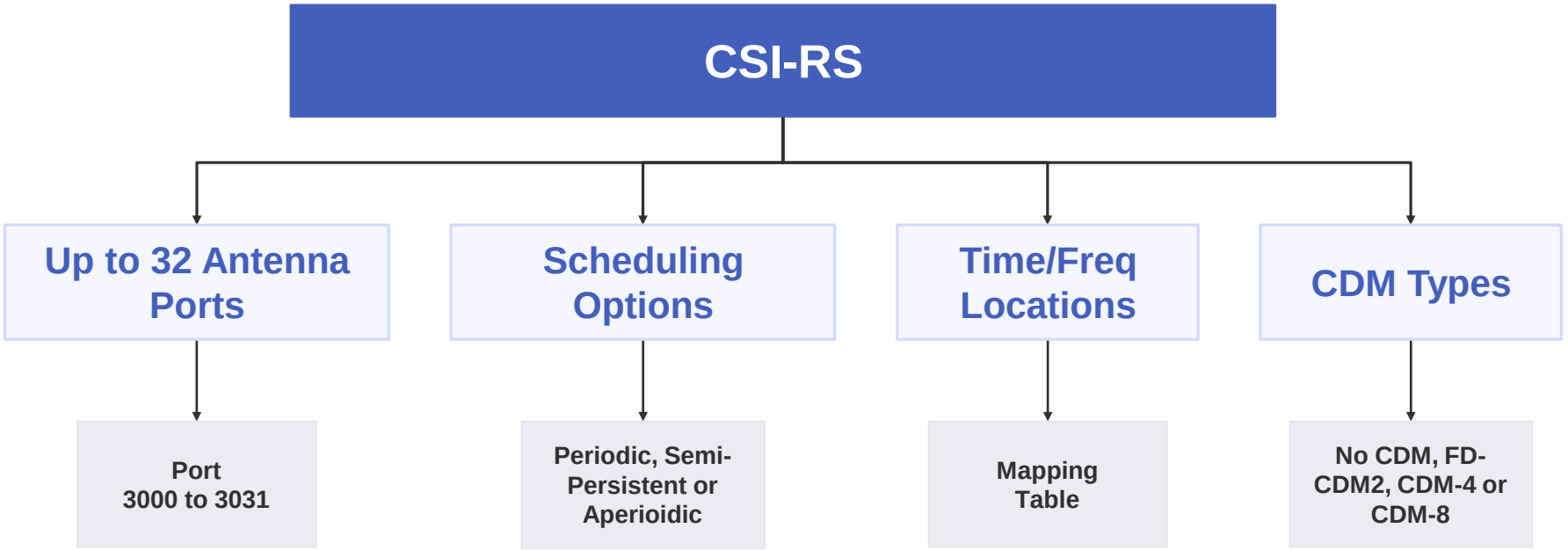


* The Procedures listed above use **"Non-Zero Power CSI Reference Signals"** configured for **"Channel Measurement."** Dedicated signaling is used to configure the UE to receive these Reference Signals

***Pictures Source: 5G NR in Bullets**

CSI-RS Key Characteristic

- Unlike LTE, **5G NR does not have cell-specific reference signals**. It must configure reference signals that a device can monitor and report on. These are called CSI-RS
- The Following Figure summarizes the key aspects of the CSI-RS. Various configuration options enable the CSI-RS to be sent on multiple ports with various scheduling options such as Periodic, Semi Persistent, and Aperiodic.



A configured CSI-RS may correspond to up to 32 different antenna ports, each corresponding to a channel to be sounded.

Periodic: Transmitted at fixed Nth Slots, Semi-Persistent: Alike to Periodic, but CSI-RS Transmission can be switched on and off using MAC CE and Aperiodic: Event-based; Transmission is triggered by the DCI when required

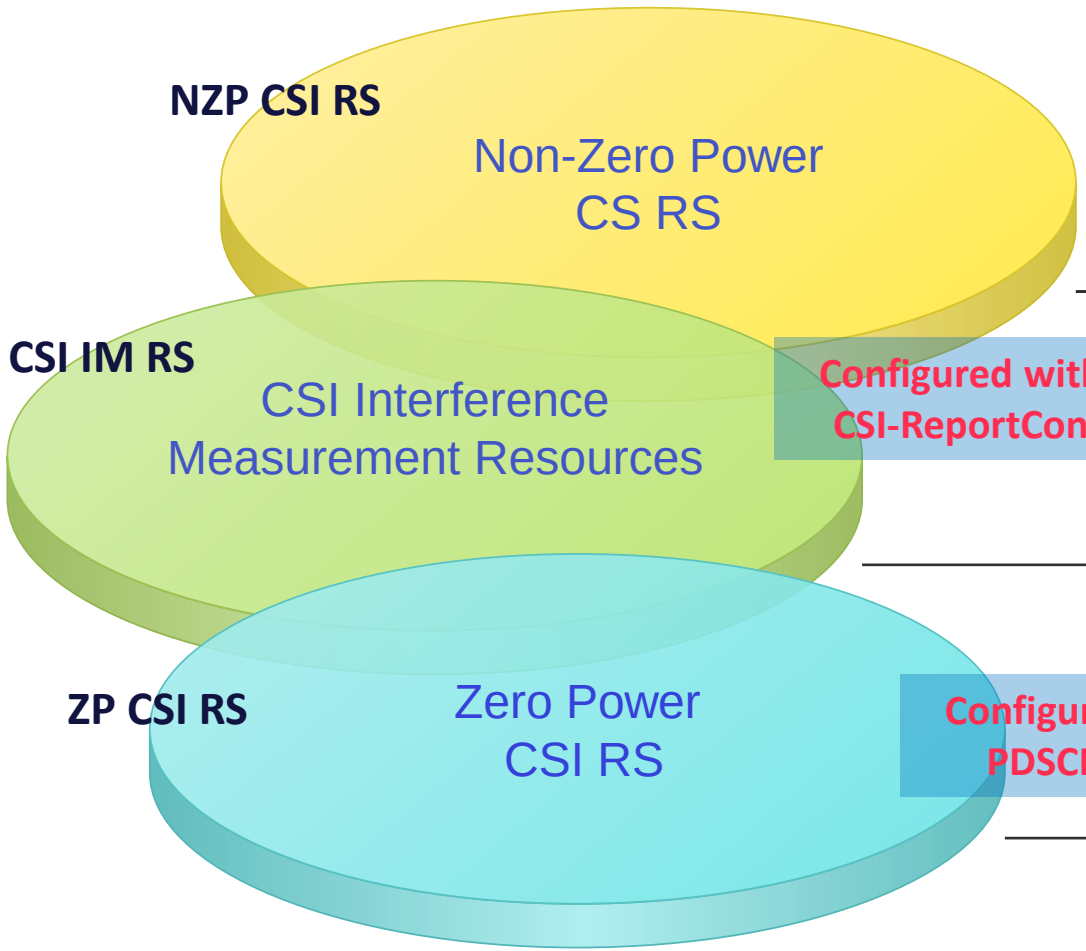
CSI RS Mapping to Resource elements table has 18 Combinations

CDM: Code Division Multiplexing
FDM: Freq Division Multiplexing

***CSI-RS: Channel State Information Reference Signals.**

CSI-RS Types & Categories(NZP, ZP & CSI IM)

Types



Configured within CSI-ReportConfig

Configured within PDSCH-Config

Categories

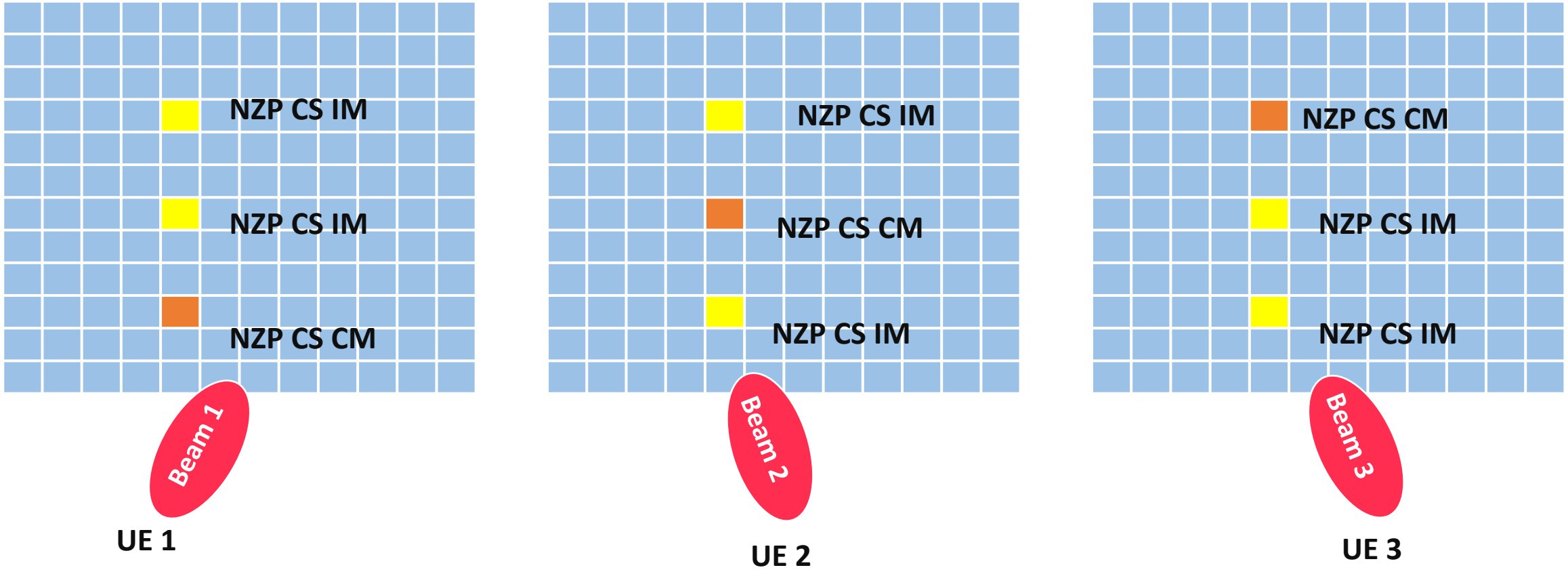
1. For Channel Measurement
   CSI, BM, RLF, Beam Recovery and Mobility
2. For Interference Measurement
   “Intra-Cell Interference”
3. For Interference Measurement
   “Inter-Cell Interference”
4. ● Define a Rate matching Pattern
   ● Serving Cell May transmit on configured REs

*CSI-RS: Channel State Information Reference Signals.

NZP CSI Reference Signal

- This figure illustrates an example MU MIMO Scenario which involves 3 UE being allocated a common set of Resource Blocks and symbols. Each UE is configured with 2 NZP CSI RS resources for IM and 1 NZP CSI RS resource for CM. The Resources are configured such that 2 UE complete IM while the 3rd UE receives its NZP CSI RS for CM, i.e. 2 UE measures the interference levels generated when transmissions are scheduled towards the 3rd UE.
- This allows each UE to generate CQI reports which reflect the MU MIMO radio conditions.

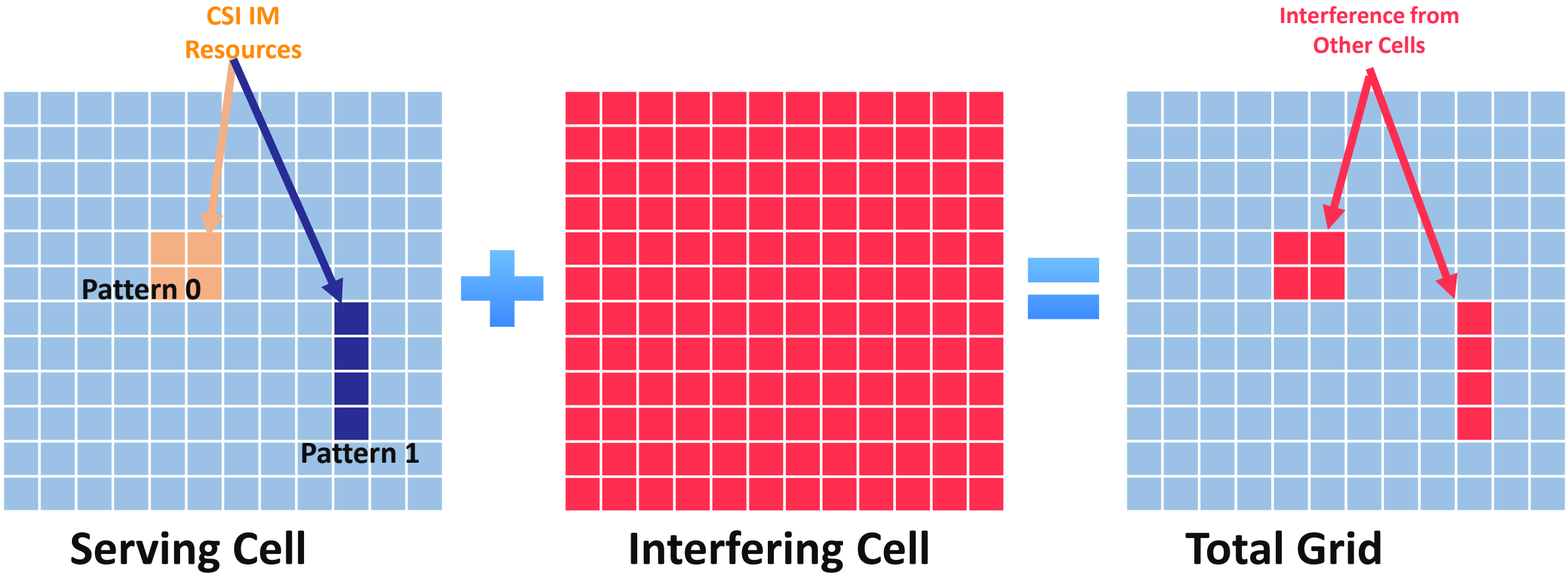
NZP CSI RS for CM & IM with Multi-User MIMO



*IM: Interference measurement, *CM: Channel measurement

CSI Interference Measurement Resources(CS IM Resources)

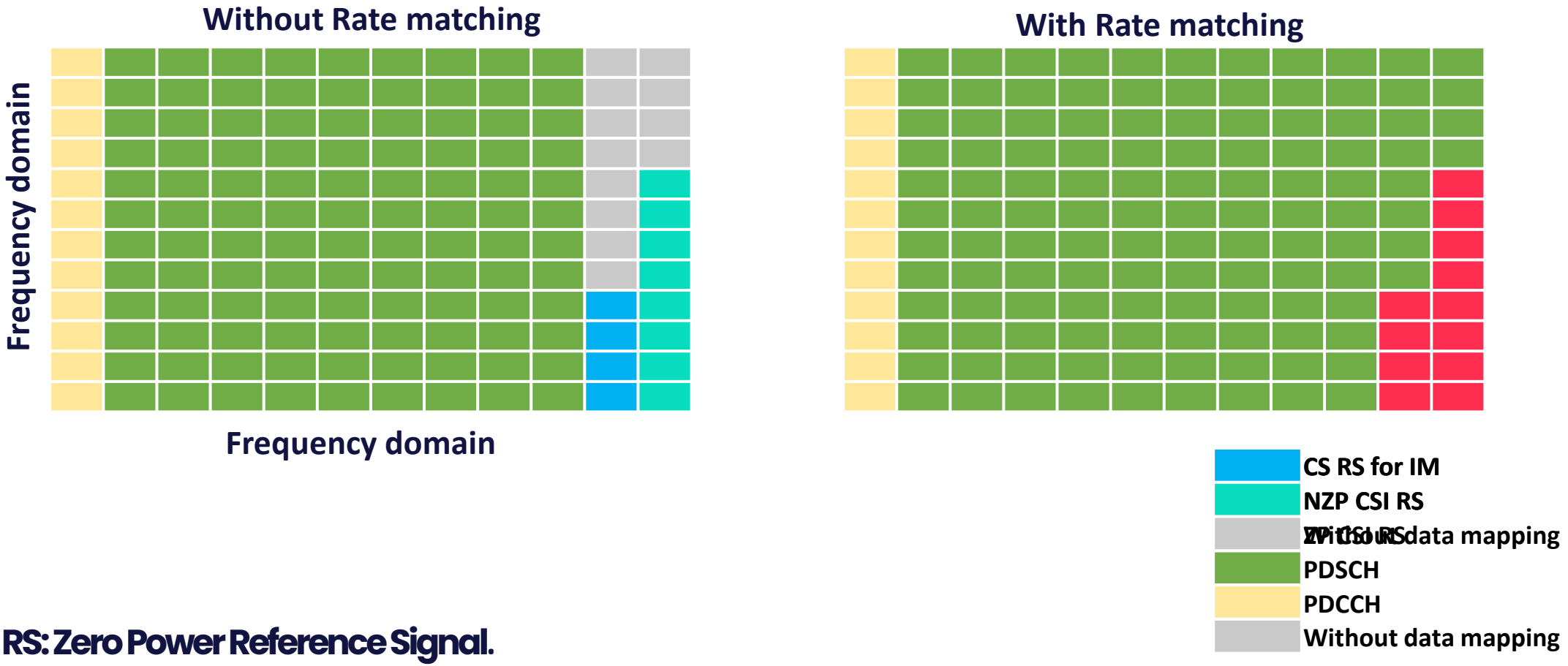
- 3GPP Specified a third category of CSI Reference Signal resources that can be used for detecting interference from the NBR Cells. The Resource element configured for this purpose may be used to measure background interference Levels.
- The serving cell does not transmit anything within these Resource elements so that the UE can measure background interference originating from the NBR Cells



***Pattern 0 corresponds to a 2X2 & *Pattern 1 corresponds 4X1 grid of REs.**

ZP RS"CSI-RS rate matching"

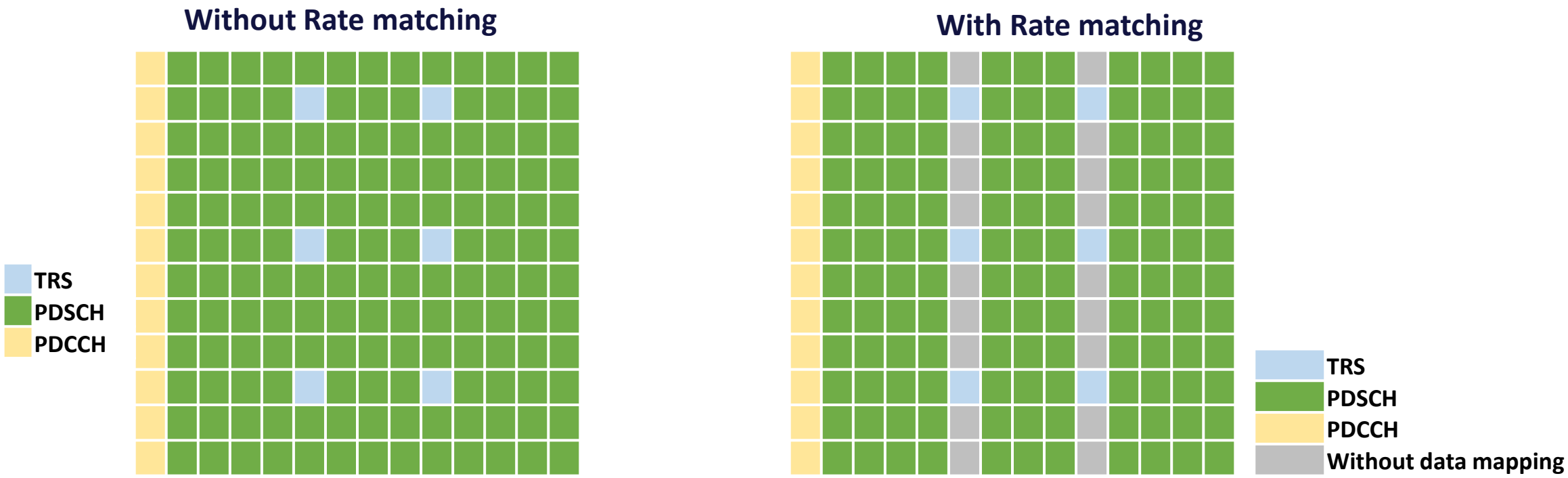
- On a time-domain OFDM symbol, **CSI-RS for IM or NZP CSI-RS occasionally does not fully occupy the corresponding frequency-domain resources**. In accordance with specifications, ZP CSI-RS is used to inform UEs of the REs that are not mapped onto any data, as shown in the below figure.
- The gNodeB uses ZP CSI-RS resources to inform UEs of the remaining frequency-domain resources for mapping data, thereby increasing the number of available REs of the UEs.



* ZP RS: Zero Power Reference Signal.

TRS & TRS rate matching

- 3GPP Adopted the CSI RS as a solution for the TRS, The Tracking Reference Signal is a DL transmission which allow the UE to track time and frequency variations with a high resolution
- TRS uses single port with a high density of 3 Resource Elements per RB. The relatively high density helps to improve the UE`s ability to track time and frequency offsets
- TRS rate matching ensures that the PDSCH of a neighboring cell and the TRS of the Serving cell do not interfere with each other. This can eliminate the interference and helps to increase the SINR



***TRS: Tracking Reference Signals.**

Layer 3 Parameters Structure & Frame of CSI Report

CSI Report Config

- Used to configure which CSI Resource Config ID “NZP & CSI IM”
- ReportConfigType” Periodic, etc.”
- Other information for CSI Reporting(Report quantity, ReportFreqConfig, etc.)

“CSI Meas Config”

CSI Resource Set

- Specifies on what type of reference signal(nzp-CSI-RS-SSB, csi-IM-Resource) is to be transmitted

CSI RS Resource set

CSI RS Resources

- Defines all related Physical resources for individual UEs

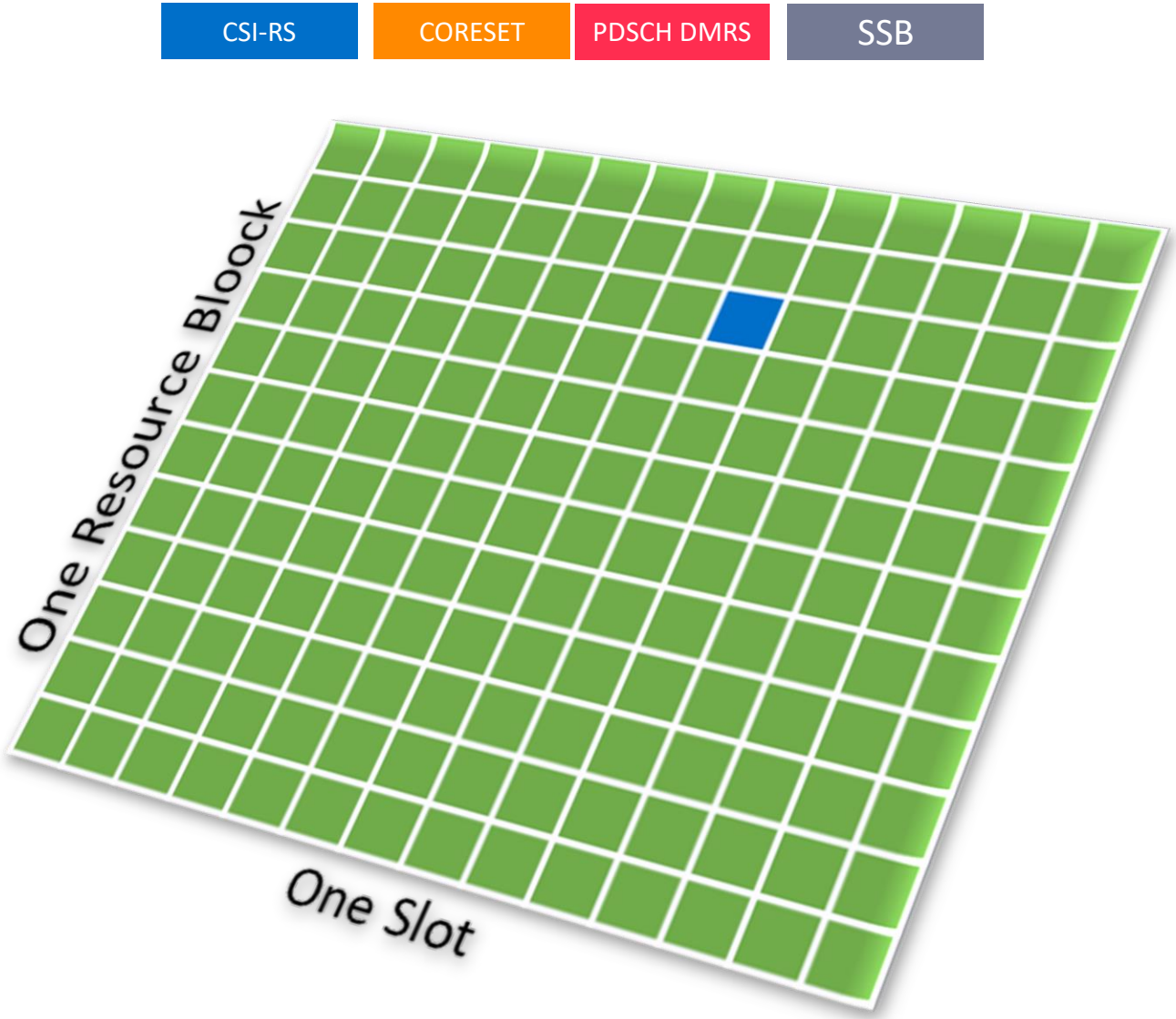
BASIC CSI-RS STRUCTURE

- A single-port CSI-RS occupies **a single resource element** within a block corresponding to **one resource block** in the frequency domain and **one slot** in the time domain.

- A configured CSI-RS may correspond to **up to 32 different antenna ports.**

- In NR, a CSI-RS is always configured **on a per-device basis**.

- The CSI-RS can be configured to occur anywhere within the Resource block

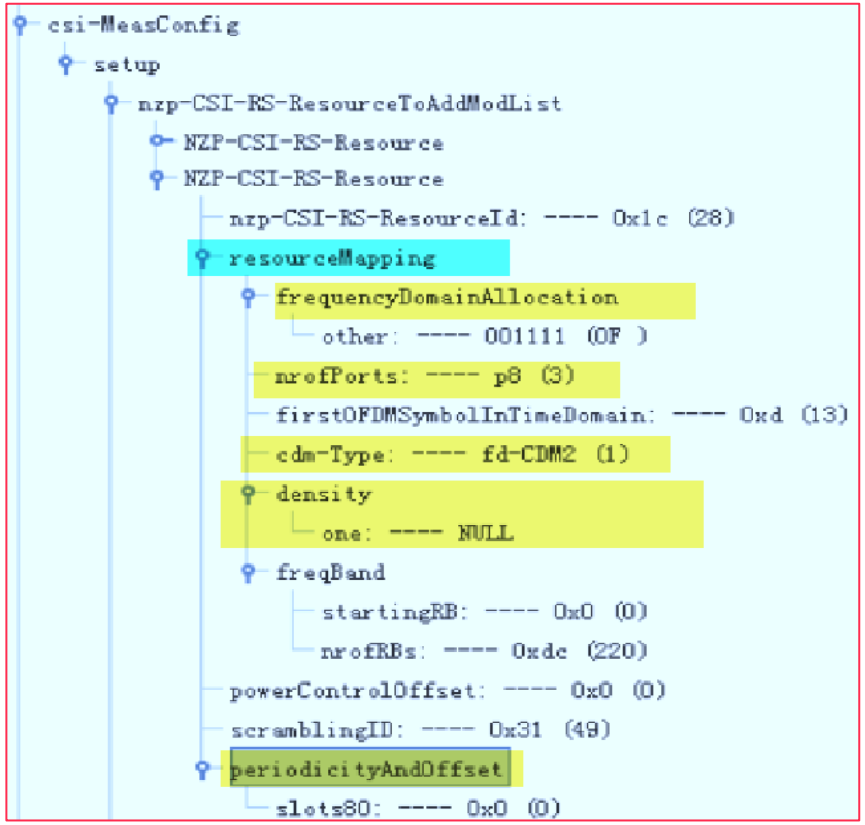


CSI-RS Main Parameters

- In SA networking, check the traced RRCReconfiguration message" *csi-MeasConfig" and "PDSCH-CONFIG"*
- In NSA networking, check the SgNB Addition Request Acknowledge

Resource Mapping

Parameter Name	Range	Description
Frequencydomainallocation row number	row1{4 bits} row2{12 bits} row4{2 bits} other{6 bits}	Specify the starting subcarrier allocation for the CSI Reference Signal, this present the parameter K in the 3GPP Table
nrofports	1, 2, 4, 8, 16, 24, 32	A configured CSI-RS may correspond to 1 to 32 different antenna ports, each corresponding to a channel to be sounded.
firstOFDMSymbokI nTimeDomain	0 to 13	Specify the starting Symbols in time domain and present the parameter I0 in the 3GPP Table
cdm-type	noCDM, fd-CDM2, cdm4-FD2-TD2, cdm8-FD2-TD4	Applicable when multiple ports share the same RE allocation. In this case, code division multiplexing is used to differentiate the transmissions from each port. Fd-CDM2 means that CDM is used to differentiate 2 REs occupying different subcarriers. Cdm4-FD2-TD2 means that CDM is used to differentiate 2 REs, which occupy a grid of 2 subcarriers X 2 Symbols
density	0.5, 1, 3	Quantifies the number of REs allocated to the CSI RS per RB per Port.
freqband	starting RB(0 to 274, step4) nrofRBs(24 to 276, step4)	Specifies the set of RBs allocated to the CSI Reference Signal, If the values of startingRB and nrofRBs lead to a resource allocation which extends outside the relevant Bandwidth part then the resource allocation is truncated
powercontroloffset	"-8 to 15	Specifies the tranmist power differences between the CSI RS and the PDSCH, Knowledge of this power difference is important when generating CSI. For example, a UE will report lower CQI Values if the PDSCH transmit power is reduced High Value < PDSCH Pwr < CQI
powercontroloffsetSS	"-3, 0, 3, 6 dB	Specifies the tranmist power differences between the CSI RS and the SSS. High Value < SS Pwr < Access
periodicityAndOffset	4~640 Slots	**Applicable to periodic and semi-persistent** CSI RS Resources. It is used to define the slot timing of the CSI RS Transmissions



UE Capability Check


```
.phy-Parameters
...phy-ParametersCommon
.....nzp-CSI-RS-IntefMgmt --- supported(0)
.....csi-RS-IM-ReceptionForFeedback
.......maxConfigNumberNZP-CSI-RS-PerCC --- 0x8(8)
.......maxConfigNumberPortsAcrossNZP-CSI-RS-PerCC ---
.......maxConfigNumberCSI-IM-PerCC --- n8(3)
.......maxNumberSimultaneousNZP-CSI-RS-PerCC --- 0x4(
.......totalNumberPortsSimultaneousNZP-CSI-RS-PerCC -
```

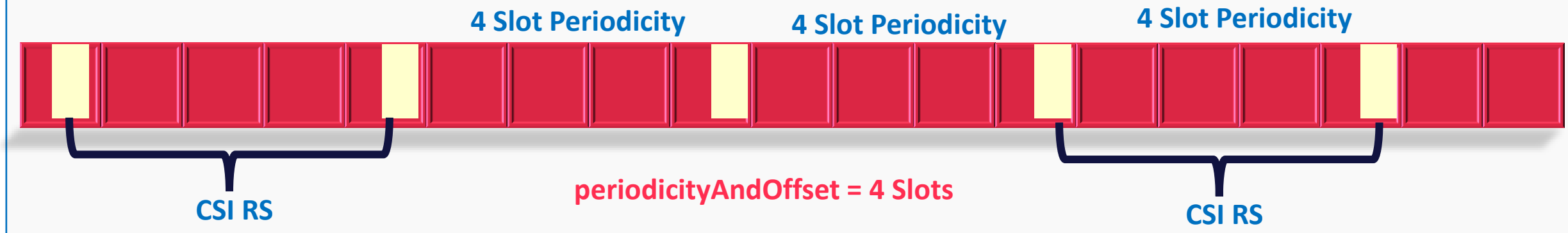
```
............codebookParameters
..............type1
................singlePanel
..................supportedCSI-RS-ResourceList
....................SupportedCSI-RS-Resource
......................maxNumberTxPortsPerResource:p16 (4)
```

"UE capability information elements" in 3GPP TS 38.331 V15.9.0”

FREQUENCY & Time DOMAIN STRUCTURE OF CSI-RS CONFIGURATIONS(0)

CSI-RS occurrences in the time domain can be scheduled in three different ways: periodic, semi-persistent, and aperiodic.

Periodic: Transmitted at fixed Nth Slots



Semi-Persistent: Like the Periodic case but CSI-RS Transmission can be switched on and off

Aperiodic: Event-based; Transmission is triggered by the DCI when required

FREQUENCY & Time DOMAIN STRUCTURE OF CSI-RS CONFIGURATIONS(1)

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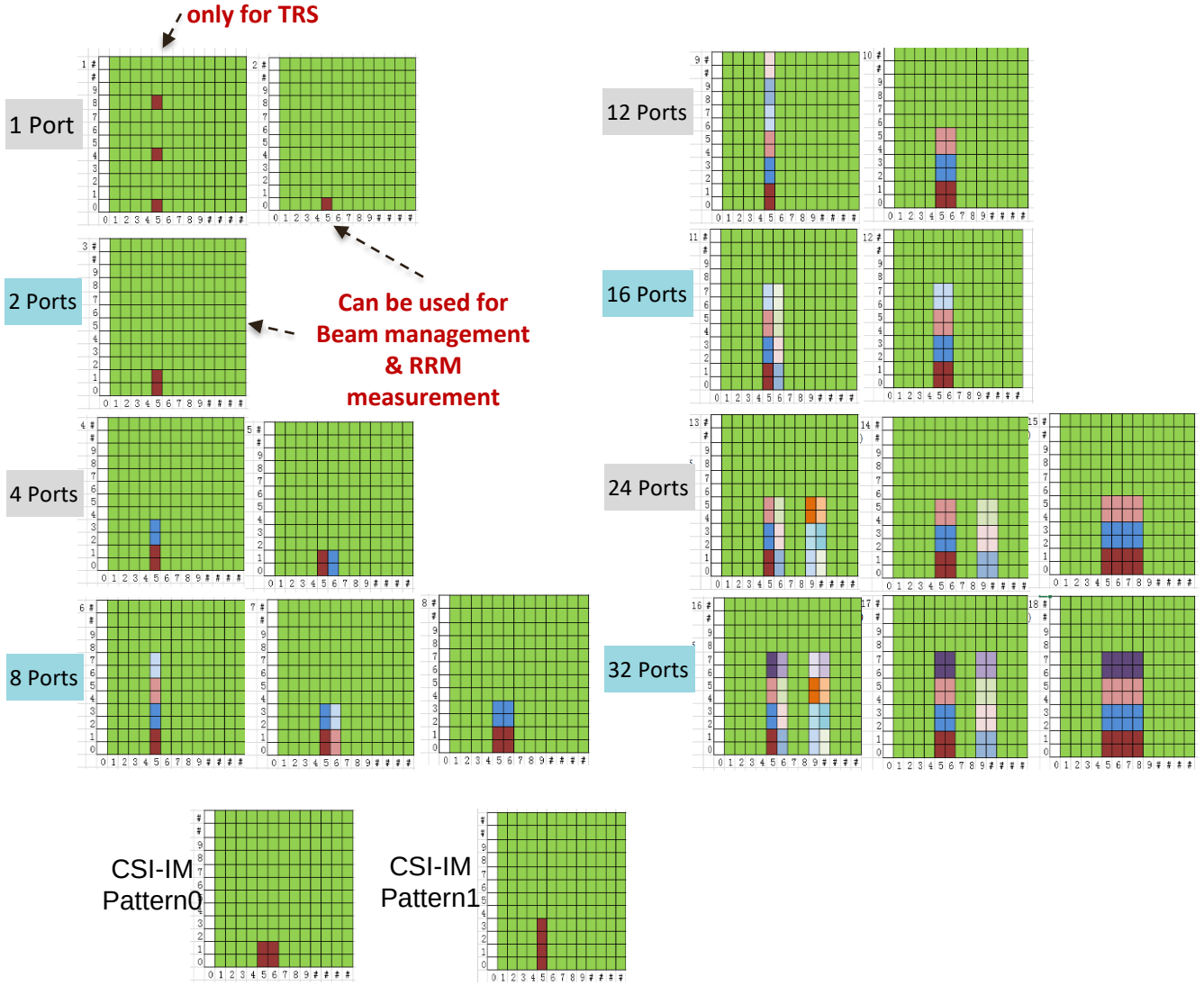
Table 7.4.1.5.3-1: CSI-RS locations within a slot.

Row	Ports X	Density ρ	*cdm-Type*	$(\bar{k},\bar{l})$	CDM group index j	k'	l'
1	1	3	noCDM	$(k_0,l_0),(k_0+4,l_0),(k_0+8,l_0)$	0,0,0	0	0
2	1	1, 0.5	noCDM	(k_0,l_0),	0	0	0
3	2	1, 0.5	fd-CDM2	(k_0,l_0),	0	0, 1	0
4	4	1	fd-CDM2	$(k_0,l_0),(k_0+2,l_0)$	0,1	0, 1	0
5	4	1	fd-CDM2	$(k_0,l_0),(k_0,l_0+1)$	0,1	0, 1	0
6	8	1	fd-CDM2	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_3,l_0)$	0,1,2,3	0, 1	0
7	8	1	fd-CDM2	$(k_0,l_0),(k_1,l_0),(k_0,l_0+1),(k_1,l_0+1)$	0,1,2,3	0, 1	0
8	8	1	cdm4-FD2-TD2	$(k_0,l_0),(k_1,l_0)$	0,1	0, 1	0, 1
9	12	1	fd-CDM2	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_3,l_0),(k_4,l_0),(k_5,l_0)$	0,1,2,3,4,5	0, 1	0
10	12	1	cdm4-FD2-TD2	$(k_0,l_0),(k_1,l_0),(k_2,l_0)$	0,1,2	0, 1	0, 1
11	16	1, 0.5	fd-CDM2	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_3,l_0),(k_0,l_0+1),(k_1,l_0+1),(k_2,l_0+1),(k_3,l_0+1)$	0,1,2,3, 4,5,6,7	0, 1	0
12	16	1, 0.5	cdm4-FD2-TD2	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_3,l_0)$	0,1,2,3	0, 1	0, 1
13	24	1, 0.5	fd-CDM2	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_0,l_0+1),(k_1,l_0+1),(k_2,l_0+1),(k_0,l_1),(k_1,l_1),(k_2,l_1),(k_0,l_1+1),(k_1,l_1+1),(k_2,l_1+1)$	0,1,2,3,4,5, 6,7,8,9,10,11	0, 1	0
14	24	1, 0.5	cdm4-FD2-TD2	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_0,l_1),(k_1,l_1),(k_2,l_1)$	0,1,2,3,4,5	0, 1	0, 1
15	24	1, 0.5	cdm8-FD2-TD4	$(k_0,l_0),(k_1,l_0),(k_2,l_0)$	0,1,2	0, 1	0, 1, 2, 3
16	32	1, 0.5	fd-CDM2	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_3,l_0),(k_0,l_0+1),(k_1,l_0+1),(k_2,l_0+1),(k_3,l_0+1),(k_0,l_1),(k_1,l_1),(k_2,l_1),(k_3,l_1),(k_0,l_1+1),(k_1,l_1+1),(k_2,l_1+1),(k_3,l_1+1)$	0,1,2,3, 4,5,6,7, 8,9,10,11, 12,13,14,15	0, 1	0
17	32	1, 0.5	cdm4-FD2-TD2	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_3,l_0),(k_0,l_1),(k_1,l_1),(k_2,l_1),(k_3,l_1)$	0,1,2,3,4,5,6,7	0, 1	0, 1
18	32	1, 0.5	cdm8-FD2-TD4	$(k_0,l_0),(k_1,l_0),(k_2,l_0),(k_3,l_0)$	0,1,2,3	0,1	0,1, 2, 3



CDM type: The grid number of each color represent the port number

FREQUENCY & Time DOMAIN STRUCTURE OF CSI-RS CONFIGURATIONS(2)

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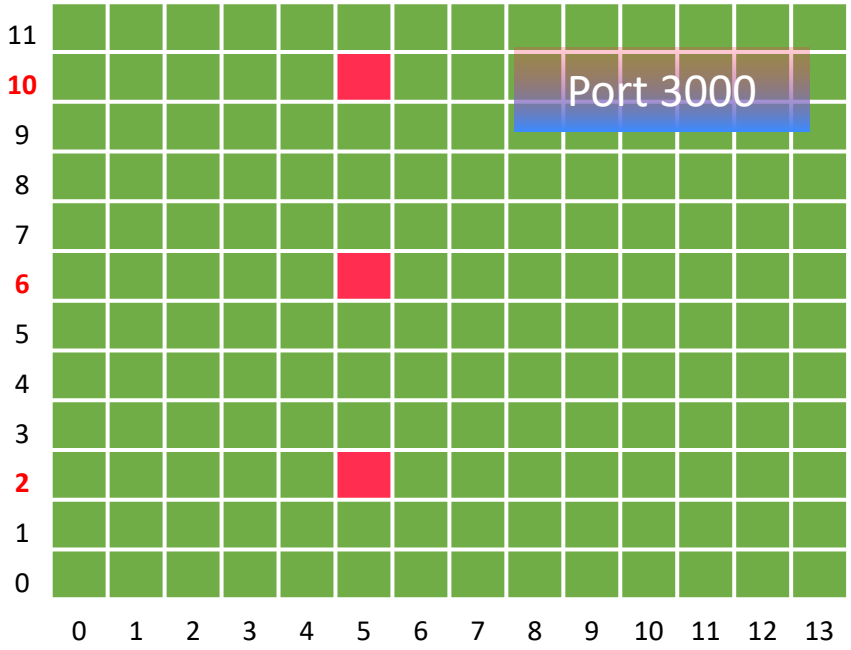
Table 7.4.1.5.3-1: CSI-RS locations within a slot.

Row	Ports X	Density ρ	*cdm-Type*	$(\bar{k},\bar{l})$	CDM group index j	k'	l'
1	1	3	noCDM	$(k_0, l_0), (k_0+4, l_0), (k_0+8, l_0)$	0,0,0	0	0
2	1	1, 0.5	noCDM	(k_0, l_0),	0	0	0

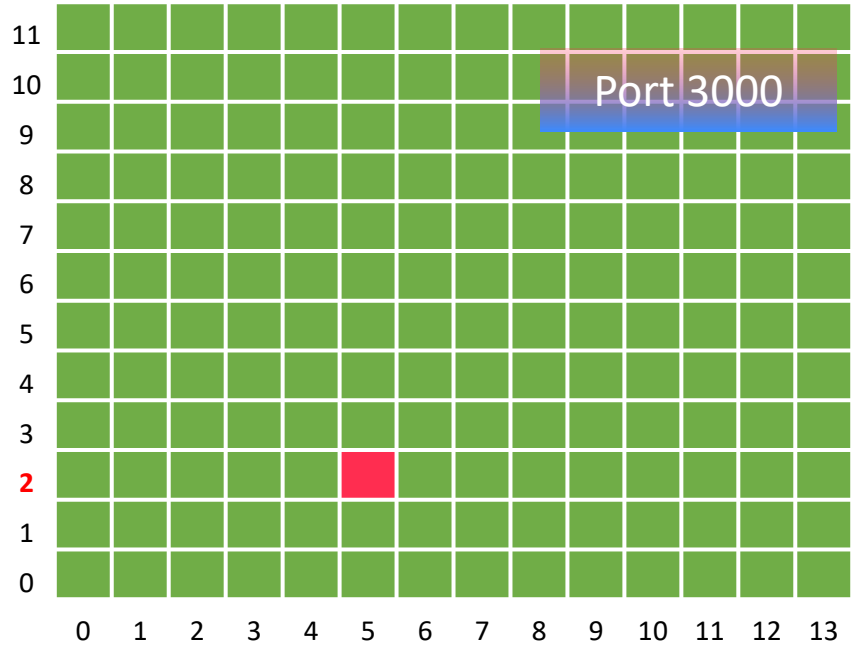
K0 is set equal to the bit position

Parameter Name	Range
Frequencydomainallocation row number	row1{4 bits}
	row2{12 bits}
	row4{2 bits}
	other{6 bits}

Row1
FrequencyDomainAllocation- Row1 = 0010 = SC 2,6,10
FirstOFDMASymbolInTimeDomain = 5
Density = 3 REs, Port = 1



Row2
FrequencyDomainAllocation- Row2 = 0010 0000 0000
FirstOFDMASymbolInTimeDomain = 5
Density = 1, 0.5 REs, Port = 1

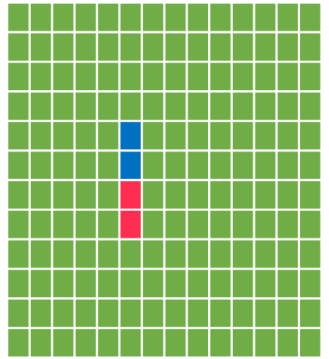


NZP CSI RS
PDSCH

FREQUENCY & Time DOMAIN STRUCTURE OF CSI-RS CONFIGURATIONS(3)

Table 7.4.1.5.3-1: CSI-RS locations within a slot.

Row	Ports X	Density ρ	*cdm-Type*	$(\bar{k},\bar{l})$	CDM group index j	k'	l'
4	4	1	fd-CDM2	$(k_0, l_0), (k_0 + 2, l_0)$	0,1	0, 1	0
5	4	1	fd-CDM2	$(k_0, l_0), (k_0, l_0 + 1)$	0,1	0, 1	0



Row4

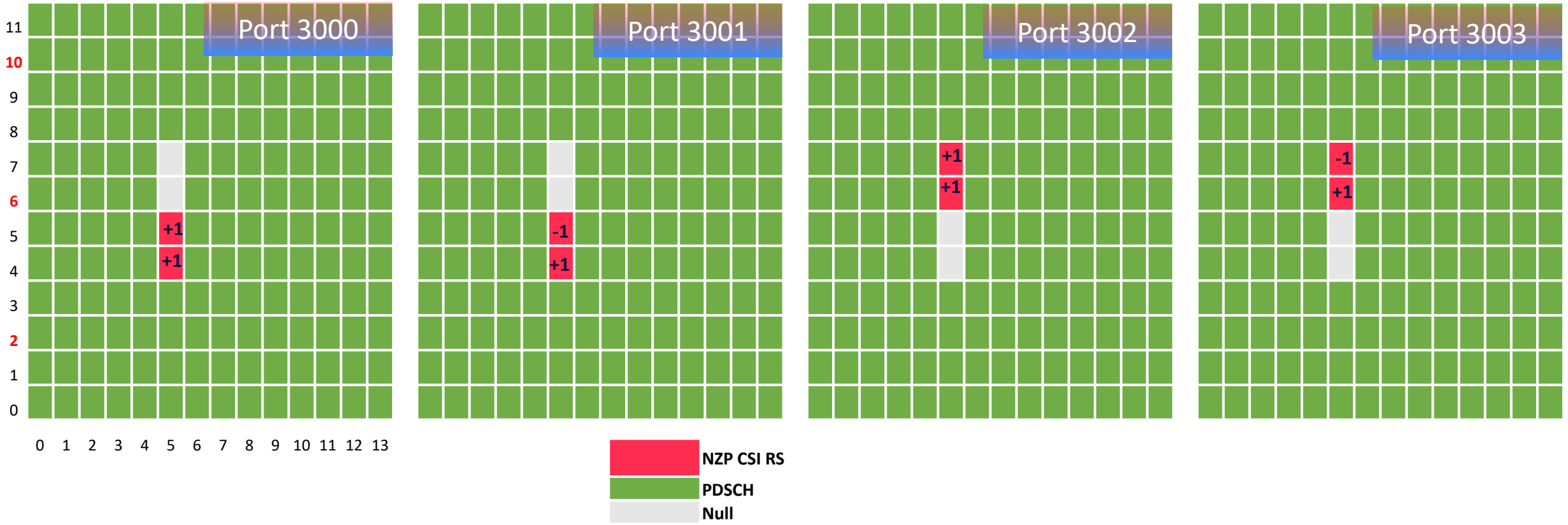
FrequencyDomainAllocation- Row4 = 010 = **Bit Position X 4 = 4 (4, 5, 6, 7)**

FirstOFDMASymbolInTimeDomain = 5

Density = 1 REs, Port = 4

K0 is set equal to the bit position

K= k0 + k`



FREQUENCY & Time DOMAIN STRUCTURE OF CSI-RS CONFIGURATIONS(4)

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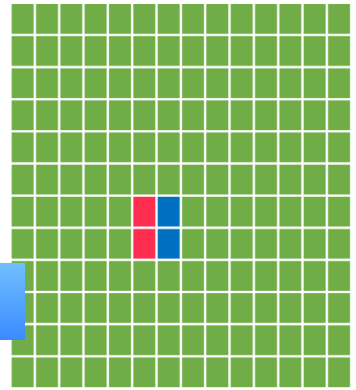
Table 7.4.1.5.3-1: CSI-RS locations within a slot.

Row	Ports X	Density ρ	*cdm-Type*	$(\bar{k},\bar{l})$	CDM group index j	k'	l'
4	4	1	fd-CDM2	$(k_0, l_0), (k_0 + 2, l_0)$	0,1	0, 1	0
5	4	1	fd-CDM2	$(k_0, l_0), (k_0, l_0 + 1)$	0,1	0, 1	0



Row5

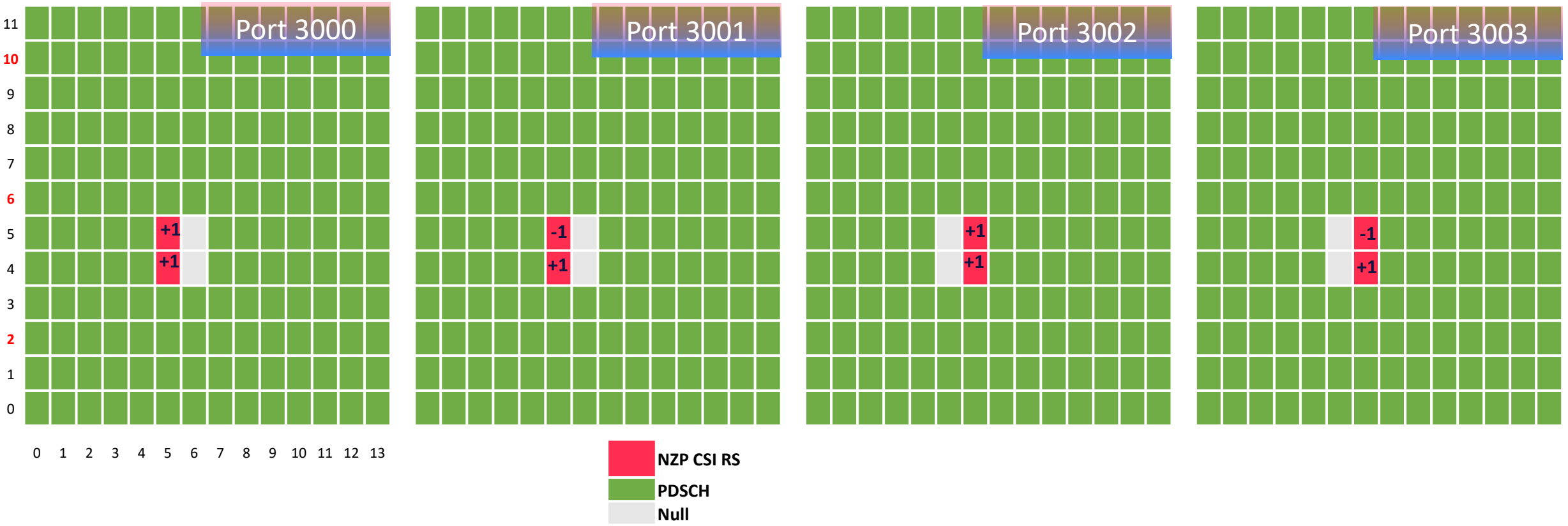
FrequencyDomainAllocation- OTHER = 010000 = K1= **Bit Position X 2 = 4**

FirstOFDMASymbolInTimeDomain = 5

Density = 1 REs, Port = 4

K0 is set equal to the bit position

K= k0 + k`



CSI Reference Signal Planning

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- The requirement for planning will depend upon the use case and the network implementation.
- The Vendor may provide a choice of CSI RS Densities, Densities 0.5, 1, and 3 RE per RB are supported
- Higher density allows the UE to complete its measurements with increased accuracy but Higher Overhead
- Configuring Lower density increases the scope for Frequency Multiplexing