台灣資通產業標準協會
Taiwan Association of Information and Communication Standards

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Introduction to LTE-A Rel-13 FD-MIMO

顏嘉邦

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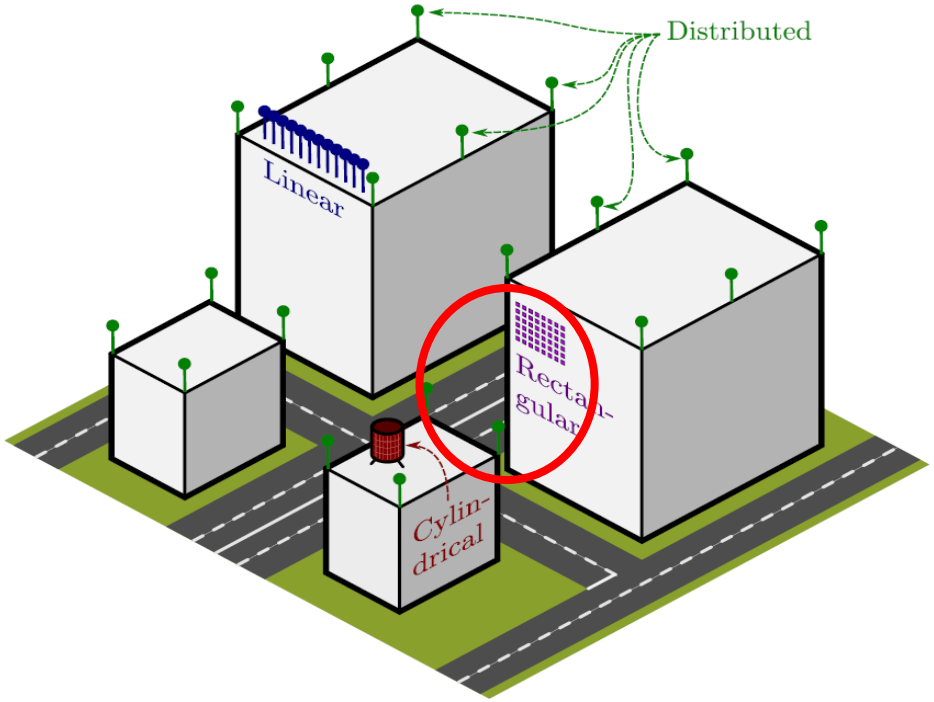
Outline

- Motivation of Full-Dimension (FD)-MIMO
- LTE MIMO Background
  - Multi-user MIMO (MU-MIMO)
  - Reference Signals (RS)
  - Channel State Information (CSI) Process
- FD-MIMO Beamforming Structure
- FD-MIMO Class A – Non-Precoded CSI-RS
- FD-MIMO Class B – Beamformed CSI-RS
  - K>1: New CSI Process Definition
  - K=1: Per-port Beamforming

Motivation of Full-Dimension (FD-)MIMO

- **Research in recent years have shown great potentials of MIMO systems equipping with a large number of antennas. This new paradigm dubbed as "Massive-MIMO" has been regarded as one of the key candidate technologies for 5G.**

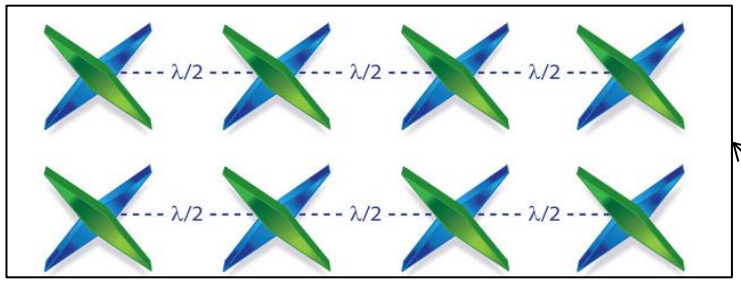
- Benefits of Massive-MIMO:
  - Energy efficiency
  - High spatial-multiplexing gain (for MU-MIMO)
  - Eliminating of fading effects and noise asymptotically
  - Channel hardening



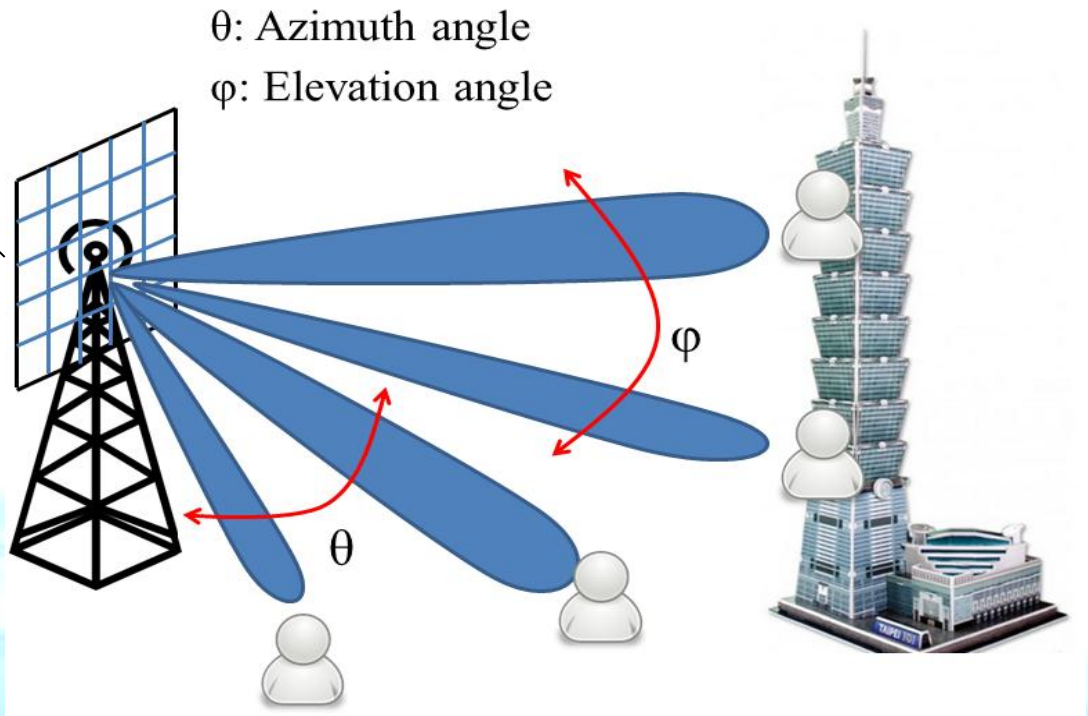
Source: E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta, Massive MIMO for Next Generation Wireless Systems, IEEE Commun. Mag., vol. 52, no. 2, pp. 186-195, Feb. 2014.

Introduction to FD-MIMO (1/2)

- FD-MIMO is a special case of Massive-MIMO for 3GPP LTE Rel-13 with:
  - Two-dimensional rectangular antenna array
  - The number of antenna ports for 2D arrays can be **8**, **12**, or **16**
- Beams can be steered in both azimuth and elevation dimensions, so more users can be co-scheduled in MU-MIMO operation.



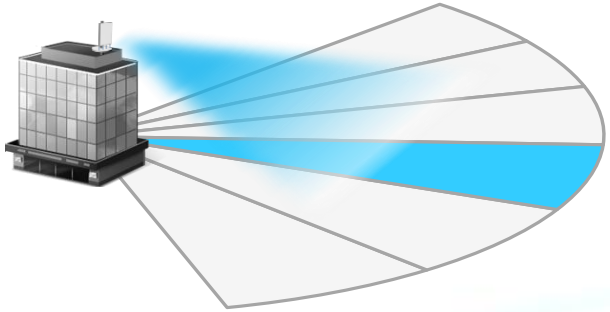
2D X-Pol Antenna Array



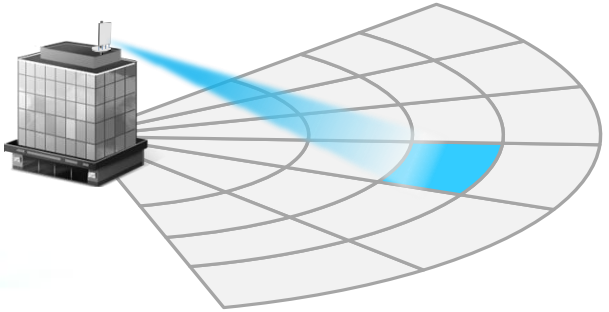
Introduction to FD-MIMO (2/2)

- An illustrative comparison between conventional MIMO and FD-MIMO:
  - More focused energy
  - Less interference

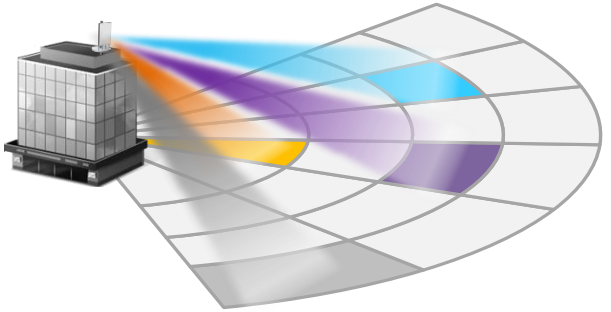
Conventional MIMO or BF in horizontal direction



FD-MIMO for single UE in horizontal/vertical direction



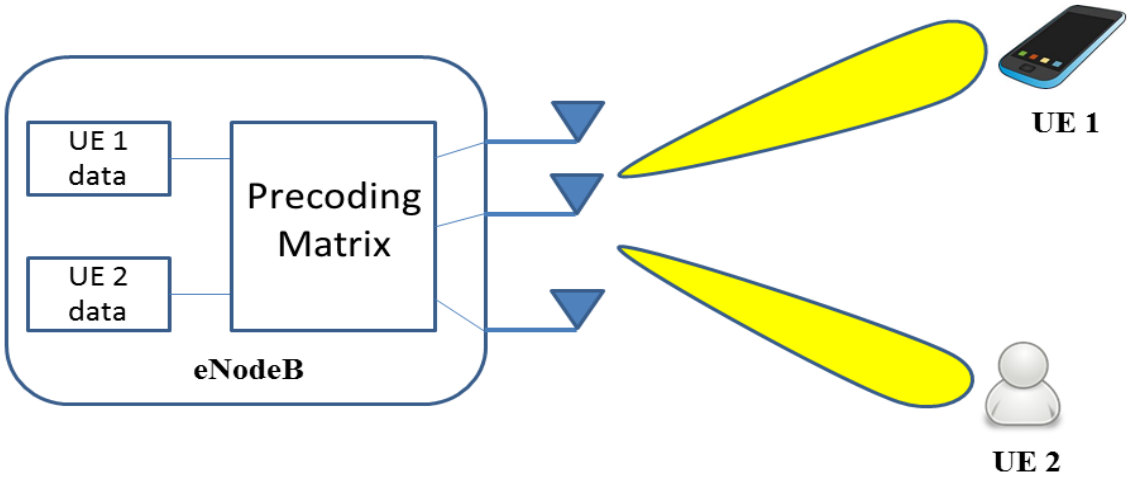
FD-MIMO for multiple UEs in horizontal/vertical direction



Source: R1-143883, “High-level views on FD-MIMO and elevation beamforming”, Samsung, 3GPP RAN1 #78bis

Multi-User (MU)-MIMO

- **Spatial Multiplexing can be extended to serve multiple users in the same radio resource block via spatial separation.**



- **Performance of MU-MIMO can be affected by many factors:**
  - User pairing and channel orthogonality
  - Multi-user diversity
  - Accuracy of Channel State Information (CSI) reports

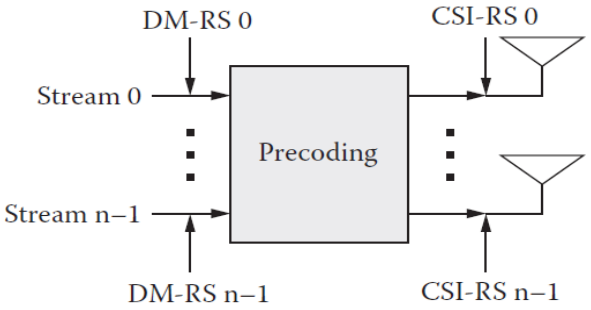
Downlink Reference Signals in LTE-A

- **Channel (CSI) can be estimated by Reference Signals (RS)**
  - **Cell-Specific Reference Signals (CRS)**
    - Available in Release-8 and Beyond
  - **DeModulation Reference Signals (DMRS)**
    - Available in Release-8 and Beyond
    - A.k.a UE-specific Reference Signal
  - **Channel State Information Reference Signals (CSI-RS)**
    - Available in Release-10 and Beyond

Downlink Reference Signals in LTE

- **Channel State Information Reference Signals (CSI-RS)**
  - Mainly used for CSI measurements – to support 8TX in Rel-12.
  - UE-specific configured resources – very low density

- **In general, CSI-RS are not precoded**



$$y_{DMRS} = HWs_{DMRS} + n$$

$$y_{CSI-RS} = Hs_{CSI-RS} + n$$

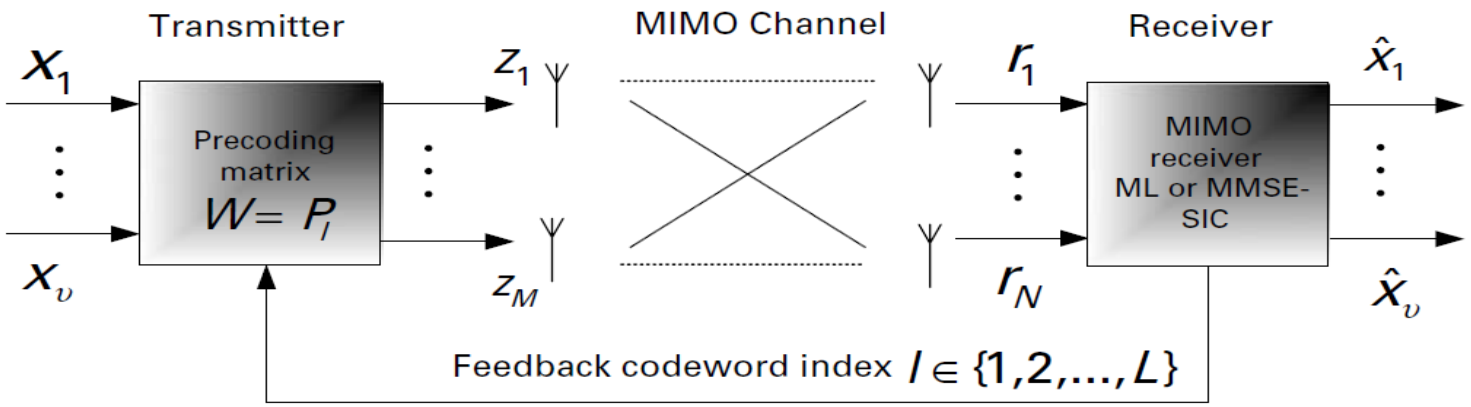
Based on the received DM-RS, the UE estimates the effective channel response *HW*.

Based on the received CSI-RS, the UE estimates the true channel response *H*.

Why CSI?

Closed-Loop Spatial Multiplexing

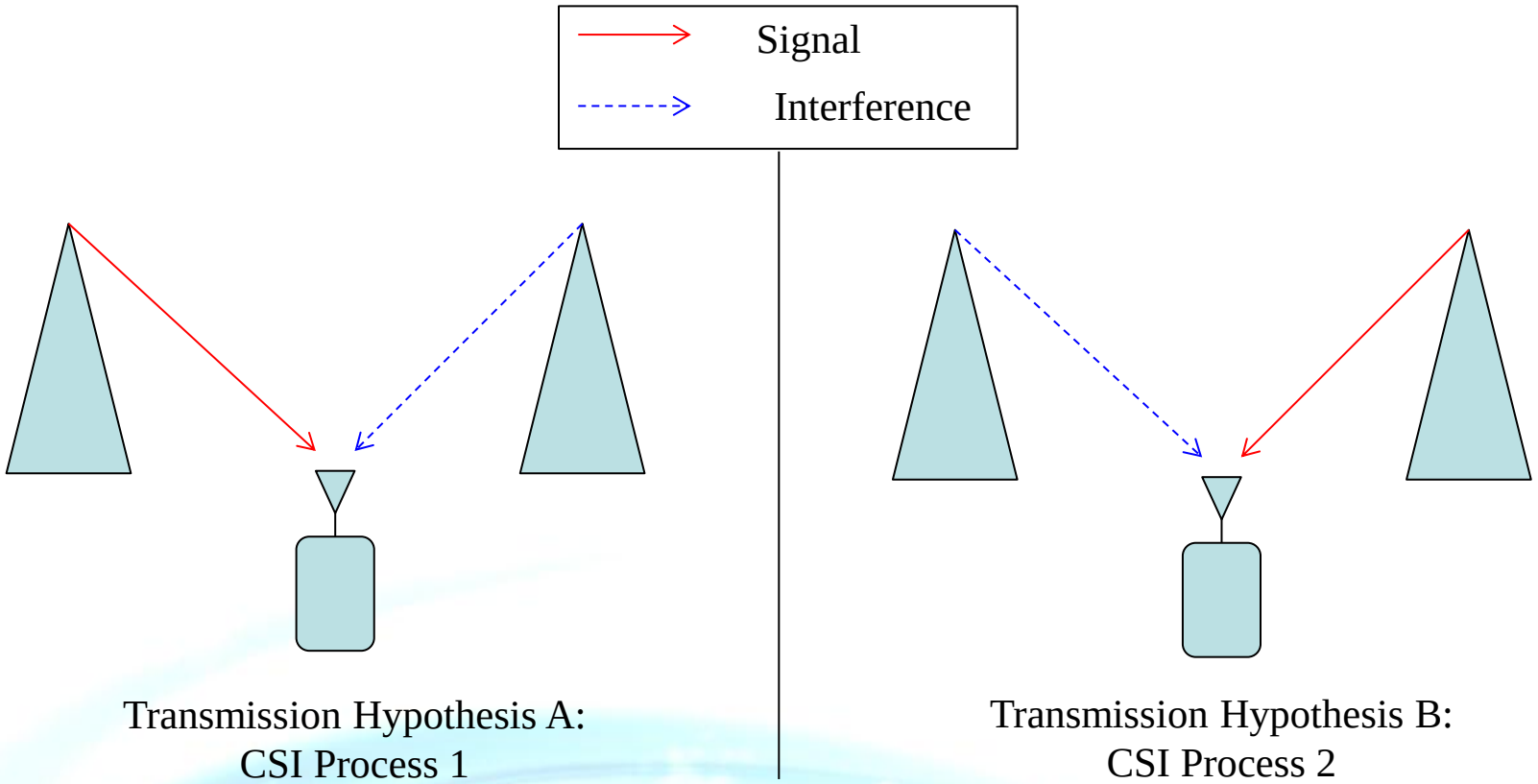
- **Spatial multiplexing allows joint transmission of multiple data layers in the same time-frequency resource, in order to increase the system peak rate**



- **With closed-loop operation, the UE should measure the Channel and reports the following Channel State Information (CSI) to the eNodeB:**
  - **RI** (Rank Indicator): The number spatial layers that can be jointly transmitted
  - **PMI** (Precoder Matrix Index): A selection (from a pre-defined codebook) of precoding matrix
  - **CQI** (Channel Qualify Indicator): A recommendation on modulation and coding scheme that reflects channel quality

Explanation of CSI Process (1/2)

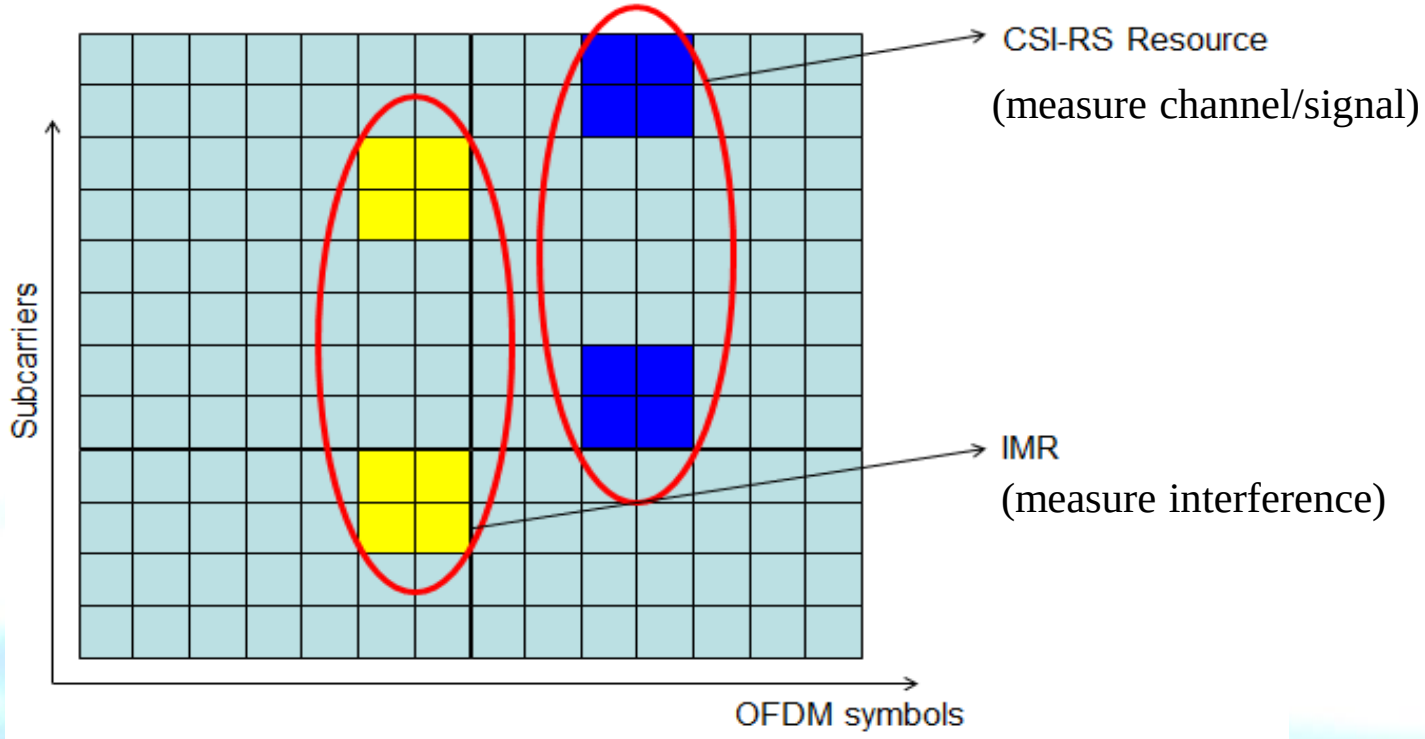
- **A CSI Process corresponds to a specific transmission hypothesis (CoMP)**
  - For example, consider DPS (Dynamic Point Selection) scheme for CoMP:



- **In TM10, the eNB can configure at most 3 CSI processes to a UE**

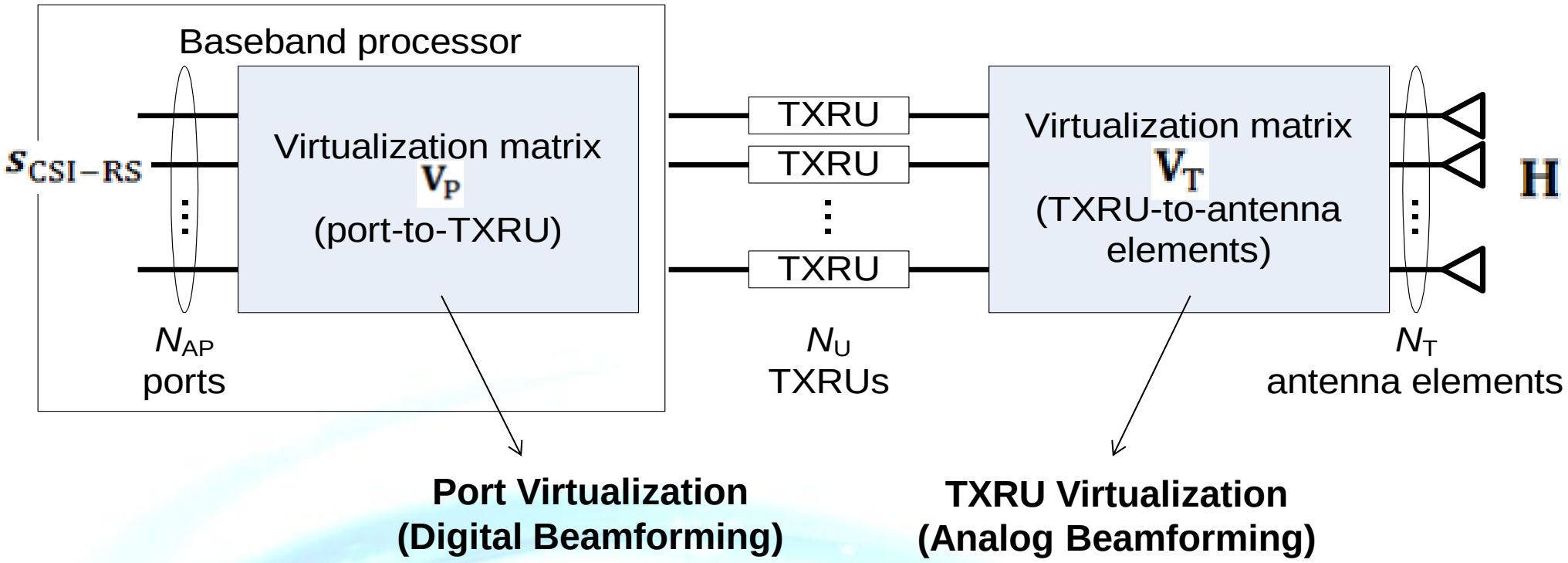
Explanation of CSI Process (2/2)

- **A configured CSI process is associated to one CSI-RS resource and one Interference Measurement Resource (IMR).**



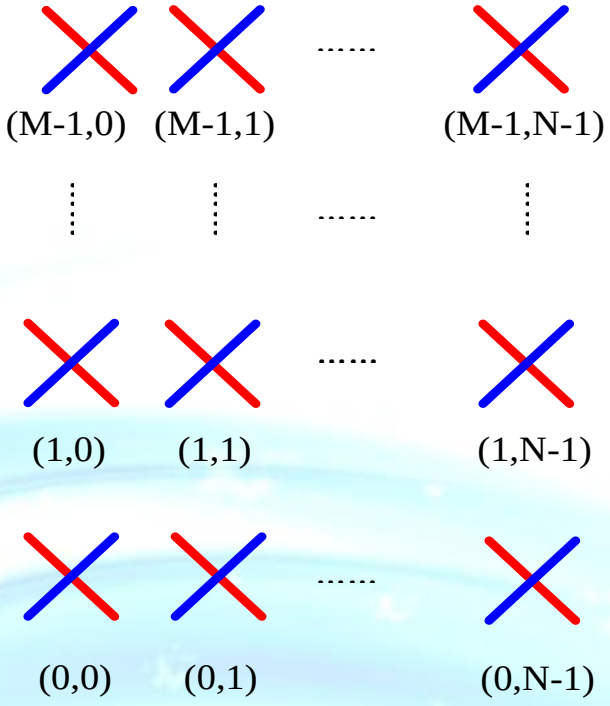
FD-MIMO Beamforming Structure

- **How signals on logical links (antenna ports) are mapped to physical antenna elements:**

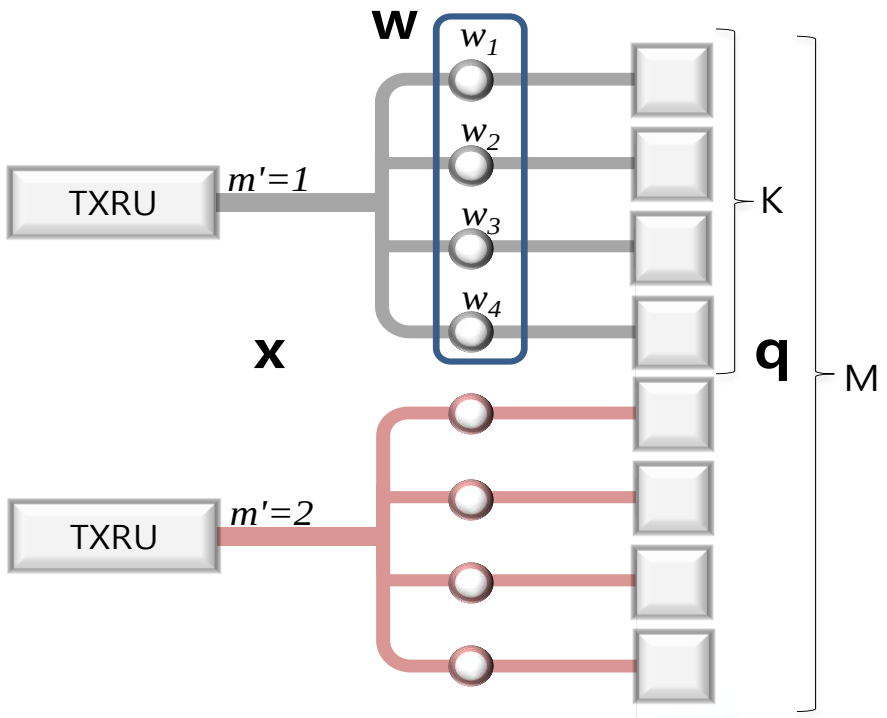


2D Antenna Array Model

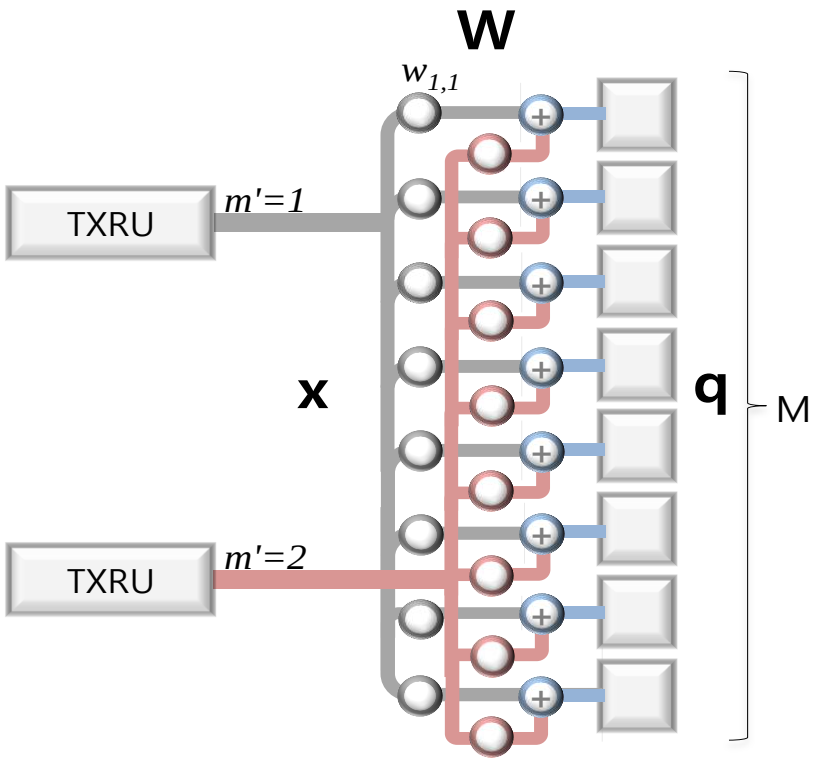
- **The configuration of a 2D planar uniformly spaced antenna array model is represented by (M, N, P):**
  - **M** is the number of antenna elements with the same polarization in each column.
  - **N** is the number of columns and
  - **P** is the number of polarization dimensions, e.g. P=2



TXRU Virtualization Models



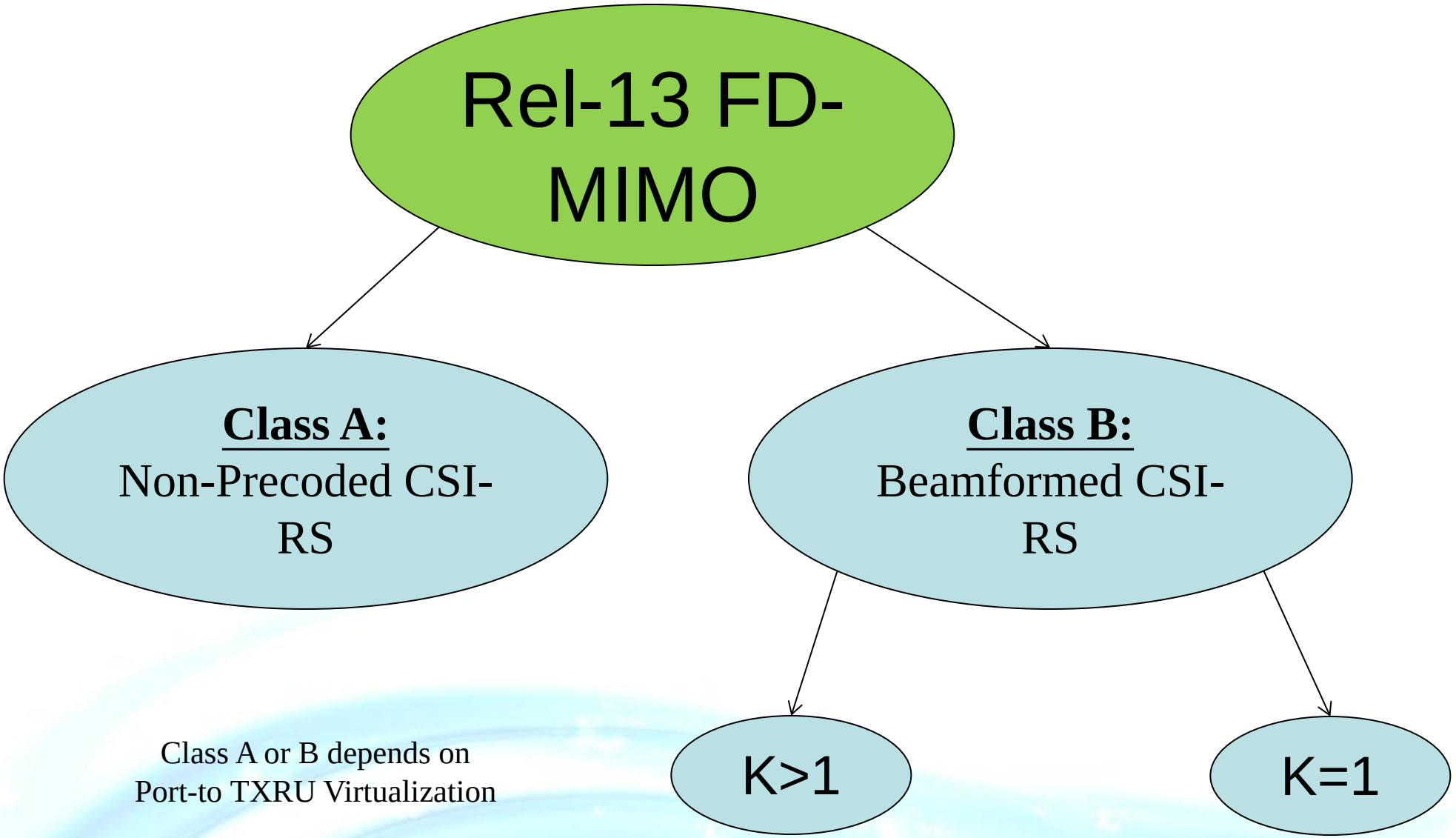
Sub-Array Model



Full-Connection Model

Source: 3GPP TR 36.987 – Study on EB/FD-MIMO for LTE

FD-MIMO Operations Classification

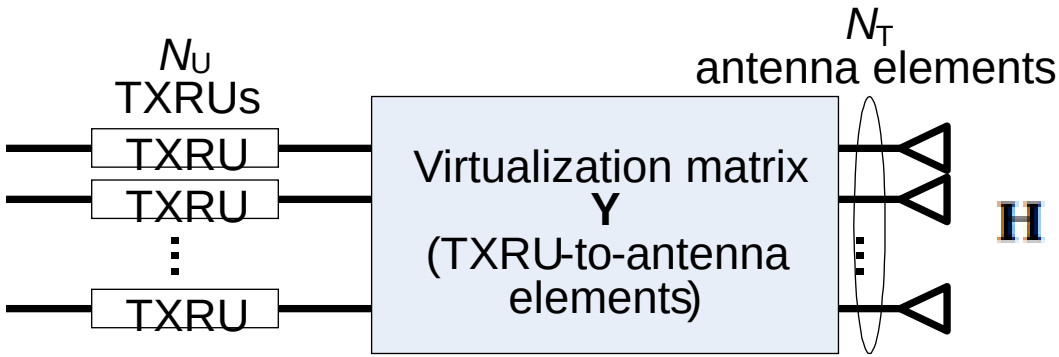


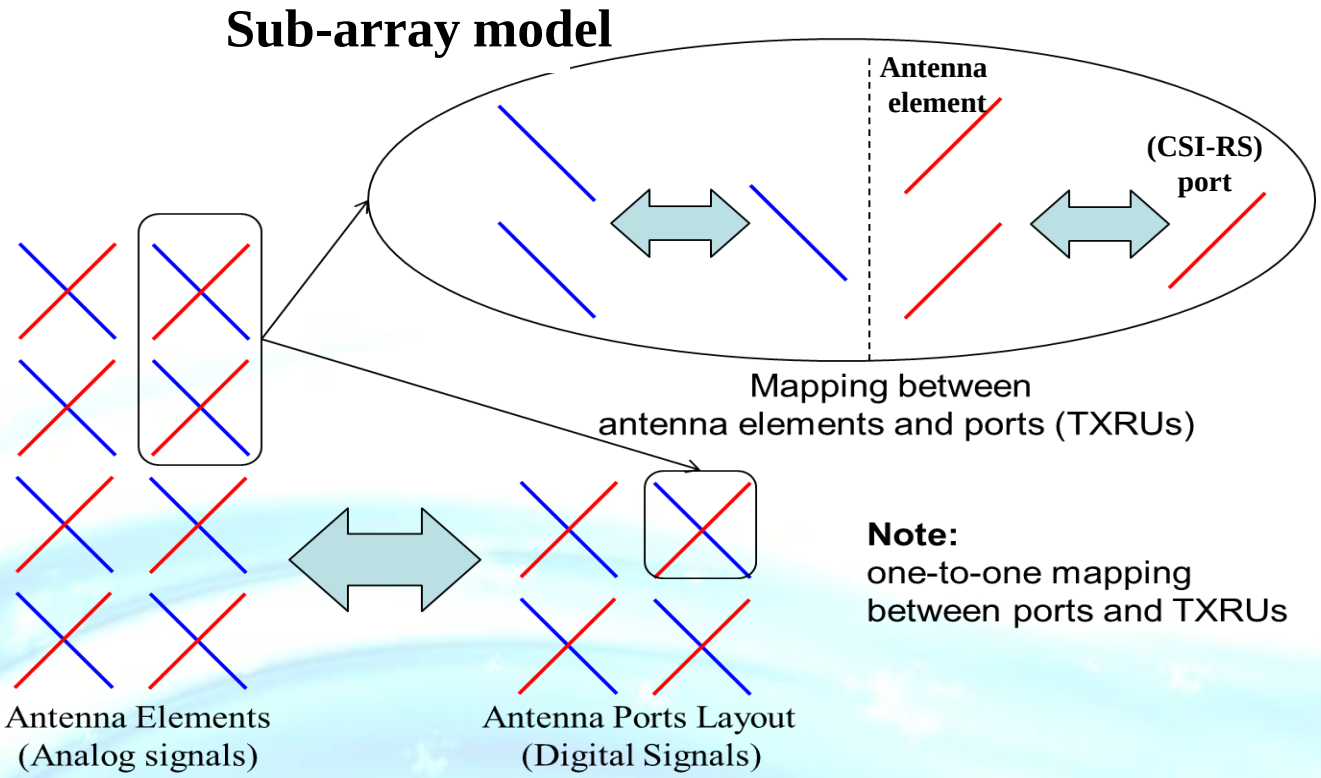
Class A or B depends on Port-to TXRU Virtualization

K: # of CSI-RS configuration

Class A: 2D Antenna Port Layout (1/2)

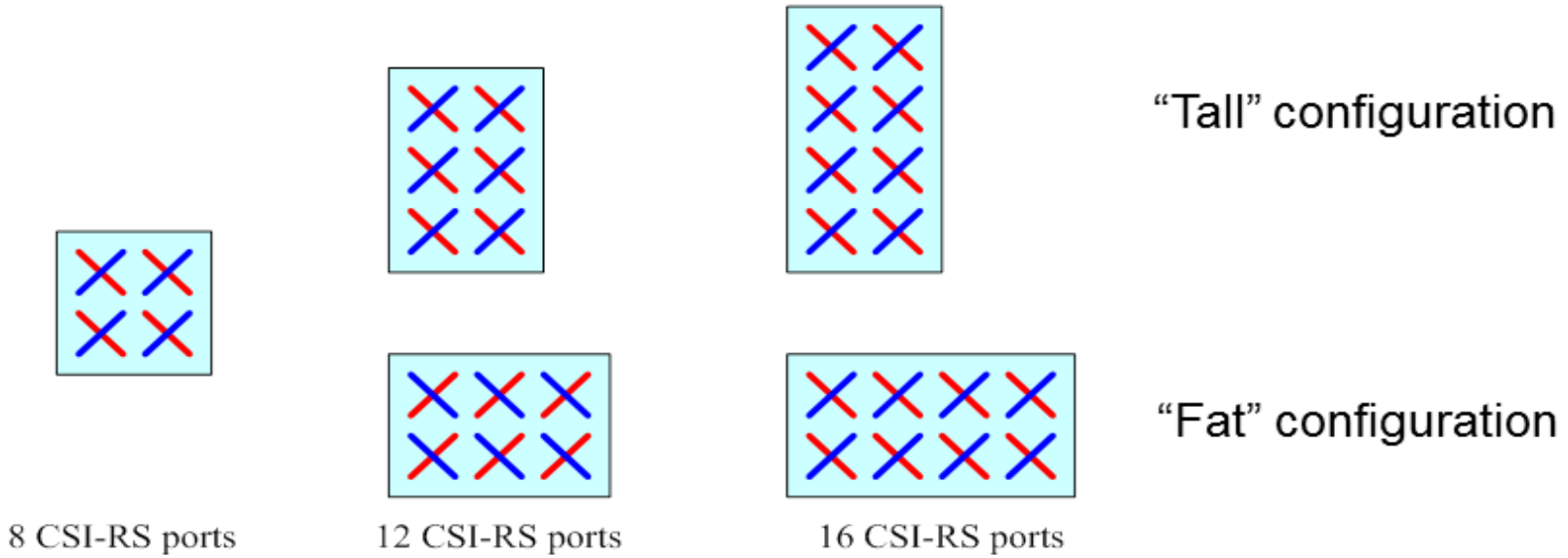
- **Antenna Port: the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed. [TS36.211]**





Class A: 2D Antenna Port Layout (2/2)

- **We may have different 2D antenna ports layouts with different antenna configurations:**

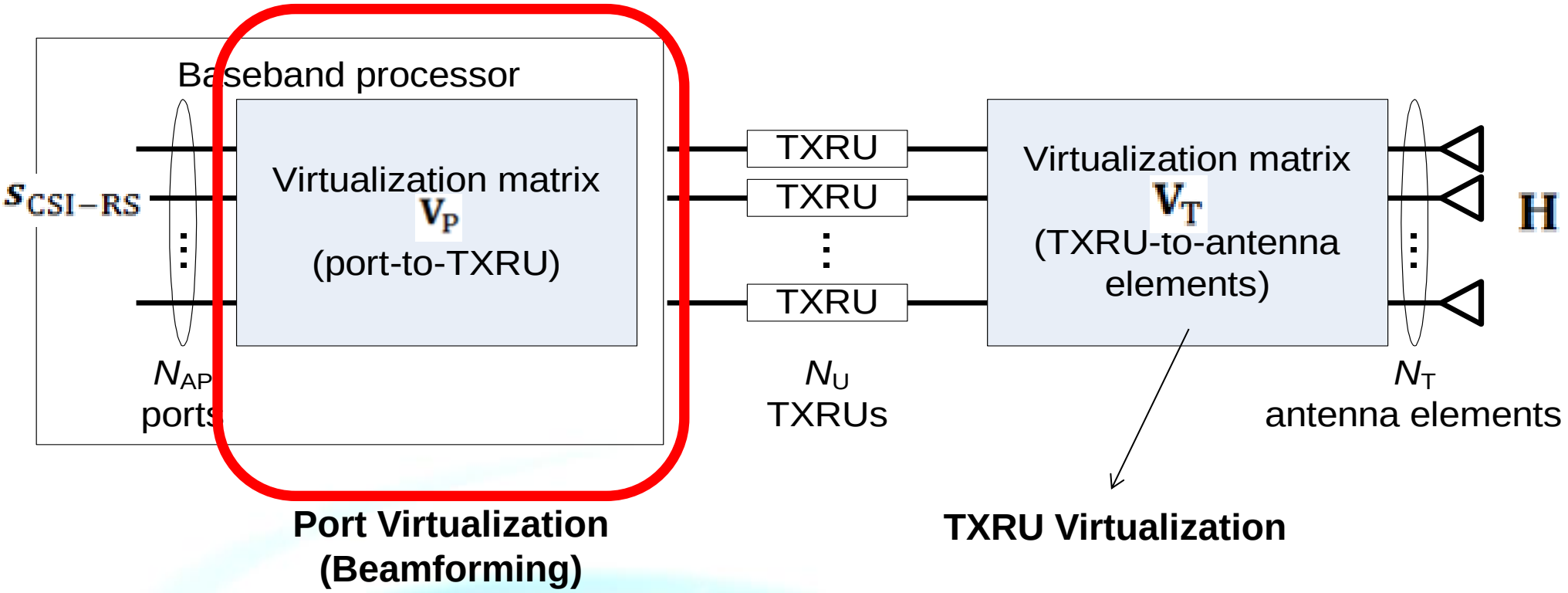


- **Rel-13 Codebook: A parameterized scalable codebook could be a "one-for-all" solution wherein the configurations of N_i (i = 1, 2) are signaled by the network.**

Source: R1-153168, "2D Codebook with KP structure and associated feedback", Ericsson, 3GPP RAN1 #81

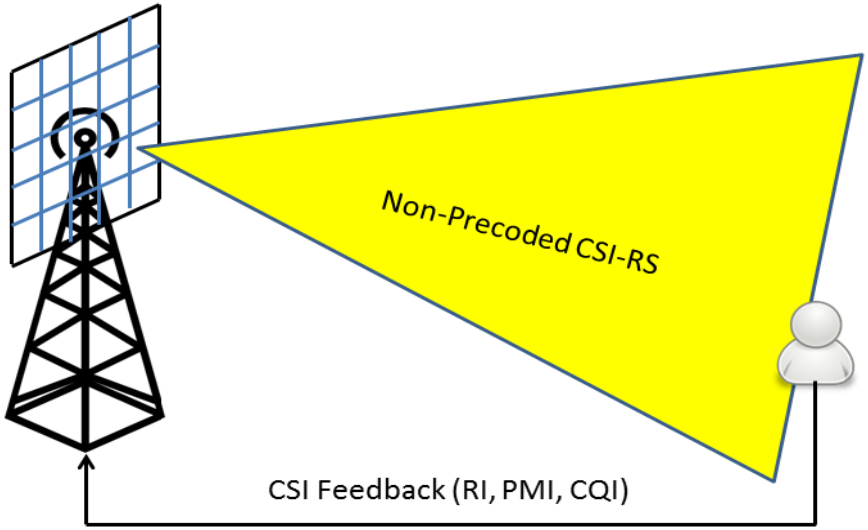
Class B: Beamformed CSI-RS

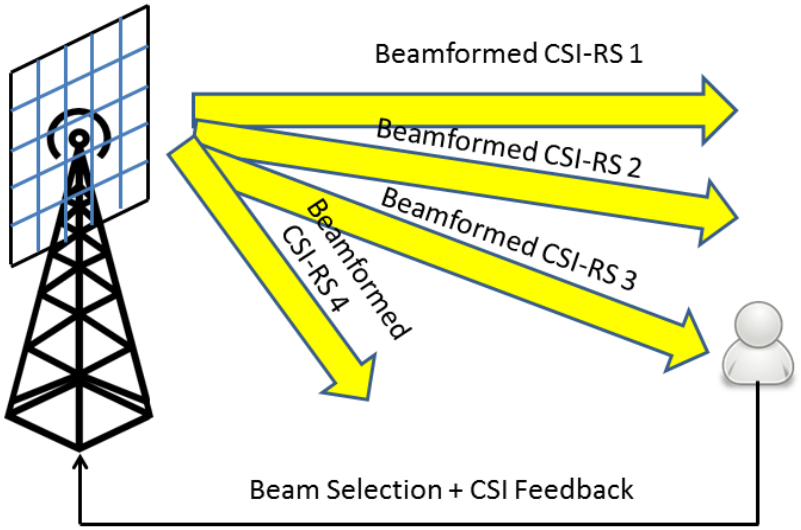
- **CSI-RS beamfomred via port-to-TXRU virtualization (Vp)**



- **At the receiver:** $y_{CSI-RS} = H V_T V_P s_{CSI-RS} + n$

Class A and Class B





Class A: Non-Precoded CSI-RS

- Wide cellular coverage Reference signals
- The number of antenna ports can be larger than 8 (upto 16, Rel-13)

Class B: Beamformed CSI-RS

- Narrow Beam Reference signals
- The number of antenna ports is smaller or equal to 8 (Rel-13)

Class A: Non-Precoded CSI-RS

- For non-precoded CSI-RS, antenna ports are one-to-one mapped to the TXRUs, which means port virtualization $\mathbf{V}_P$ is simply an identity matrix:

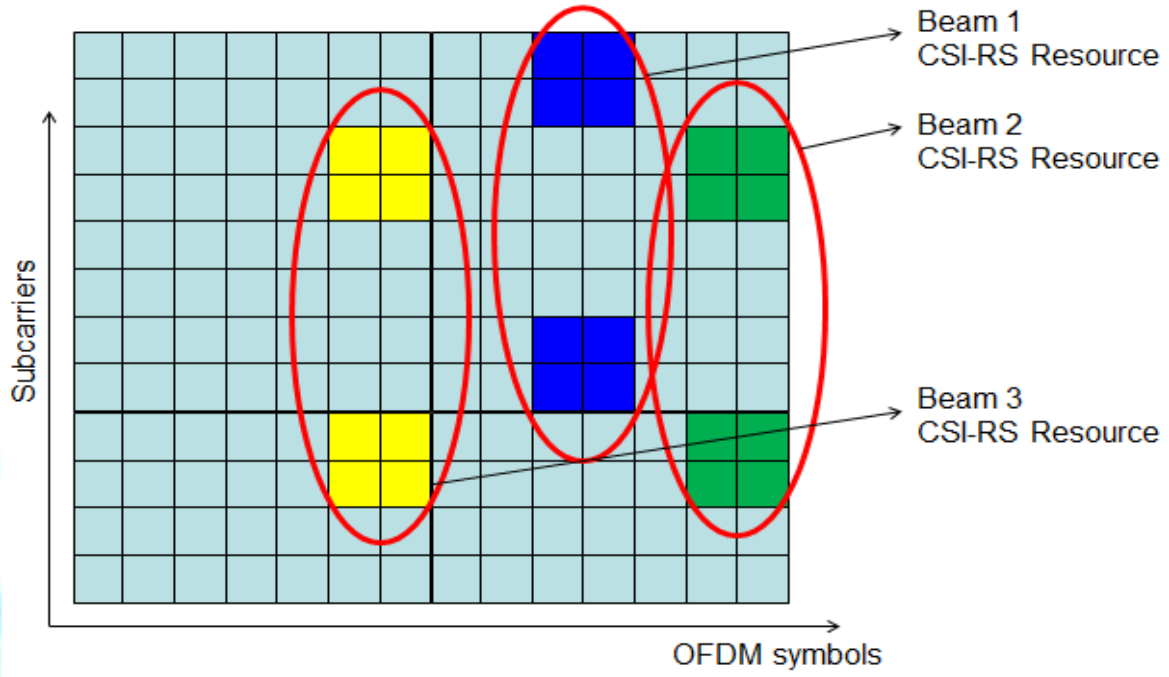
$$\boldsymbol{y}_{\mathrm{CSI-RS}} = \mathbf{H}\,\mathbf{V}_T\,\mathbf{V}_P\,\boldsymbol{s}_{\mathrm{CSI-RS}} + \boldsymbol{n}$$

$$\boldsymbol{y}_{\mathrm{CSI-RS}} = \mathbf{H}\,\mathbf{V}_T\,\boldsymbol{s}_{\mathrm{CSI-RS}} + \boldsymbol{n}$$

- In Rel-13 FD-MIMO, the number of antenna ports for Class A increase to 12/16.
  - *New precoder codebooks for 2D array*
  - *New CSI-RS configurations (see next page)*
  - *New CSI reporting mechanisms*

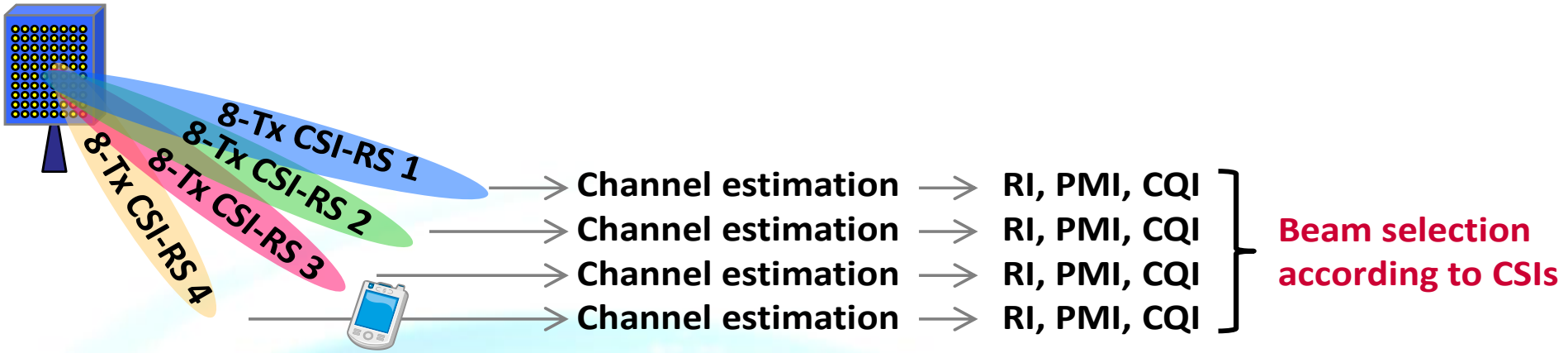
Class B with K>1: New CSI Process Definition

- **The definition of a CSI process has been changed for Class B FD-MIMO:**
  - A CSI process can be configured with up to K=8 CSI-RS resources. Each of the CSI-RS resource is beamformed differently (i.e. different port virtualization)



Class B with K>1: CSI-RS Resource Index (CRI)

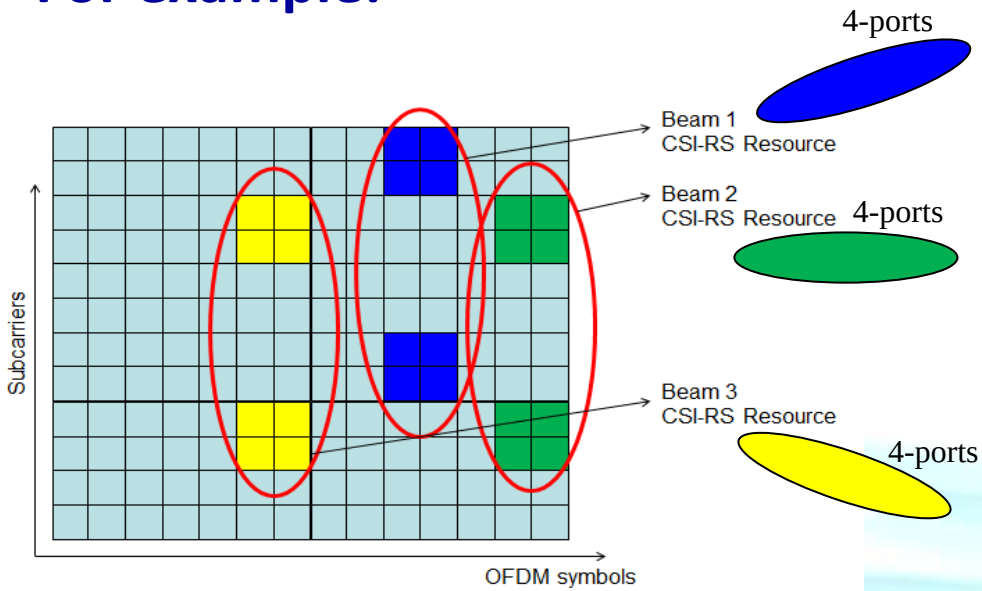
- With Beamformed CSI-RS, the UE should measure channel state information (CSI) on CSI-RS resources that are beamformed toward different directions, and select the most appropriate beam direction for potential PDSCH transmission.
- Thus, in addition to RI, PMI and CQI, the contents of a CSI process further include CSI-RS Resource Index (CRI).



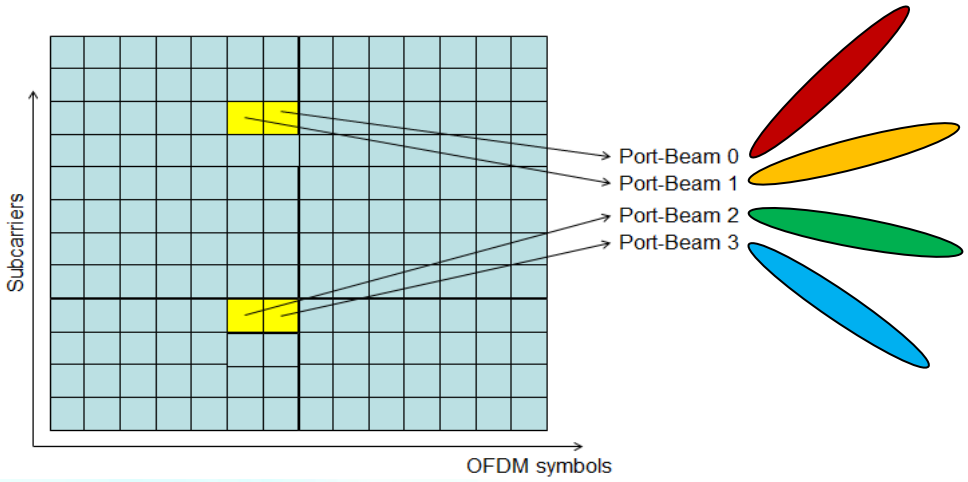
Source: R1-151983, "Enhanced precoding schemes for elevation beamforming and FD-MIMO",NTT Docomo, 3GPP RAN1 #80bis

Class B with K=1: Per-Port Beamforming

- **For Class B, if K=1 CSI-RS is configured for one CSI Process, then per-port beamforming is applied.**
  - Each port of a CSI-RS resource represents a beam.
  - UE should choose per-port beams for CSI reporting based on CSI-RS measurement (using W_2 PMI defined in Rel-10)
- **For example:**



Class B (K>1)



Class B (K=1, per port BF)

What's More?

- Rel-13 FD-MIMO Features
  - **Introduction of beamformed CSI-RS**
    - and relevant CSI mechanism
  - **Enhancement of non-precoded CSI-RS to support up to 16 ports**
    - and relevant CSI mechanism
  - Enhancement of DMRS
    - to support up to 4 orthogonal ports
  - Enhancement of SRS
    - to improve SRS capacity

Thank You!