Introduction of LTE-Advanced DL/UL MIMO

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Outline

I. LTE MIMO

II. CoMP in LTE-A

III. DL MIMO in LTE-A

IV. UL MIMO in LTE-A

LTE MIMO – Downlink (1/4)

Introduction of multi-antenna technologies

Transmit diversity

Single user MIMO (SU-MIMO)

- Open-loop
- Closed-loop

Multi-user MIMO (MU-MIMO)

Closed-loop rank-1 precoding

Dedicated beamforming

LTE MIMO – Downlink (2/4)

design principles

Anti-fading	• Transmit diversity • Open-loop spatial multiplexing
Spectral efficiency ↑	• Spatial multiplexing
SNR ↑	• Dedicated beamforming • Codebook-based precoding
Channel adaptive	• Closed-loop precoding • Rank adaptation
CRS*-based	• Codebook-based precoding • Except for dedicated beamforming

*CRS: Cell-specific (or Common) Reference Signal

LTE MIMO – Downlink (3/4)

- **Features of transmit diversity**
  - Cell-specific transmit diversity scheme
  - One scheme for all the control channels but synchronization signals
  - Support for fallback operation
  - SFBC (2TxAnt), SFBC+FSTD (4TxAnt)

- **Features of open-loop spatial multiplexing**
  - Large delay CDD (Cyclic Delay Diversity)
  - Support for rank adaptation
    - Rank-1 OL-SM = Transmit diversity
    - Up to 2 codewords transmissions
  - No precoding (2TxAnt), Precoder cycling (4TxAnt)

LTE MIMO – Downlink (4/4)

- **Features of closed-loop spatial multiplexing**
  - Codebook-based precoding due to CRS-based transmissions
  - Codebook subset restriction
  - Support for rank adaptation
    - Up to 2 codeword transmissions
- **Features of MU-MIMO**
  - Codebook-based precoding
  - Developed under the assumption of highly correlated Tx antennas
- **Features of dedicated beamforming**
  - Non-codebook based precoding relying on DRS (Dedicated Reference Signal)
- **Design principles of precoder codebook**
  - Constant modulus for equal power utilization
  - Nested property for rank adaptation/override
  - Constraint alphabet (8PSK) for computation complexity reduction

LTE MIMO - Uplink

No support for spatial multiplexing

Support for antenna-selection transmit diversity

- Open-loop: implementation issue
- Closed-loop: indication of transmit antenna in the UL grant

Support for MU-MIMO

- Introduction of orthogonal DM-RS* in UL

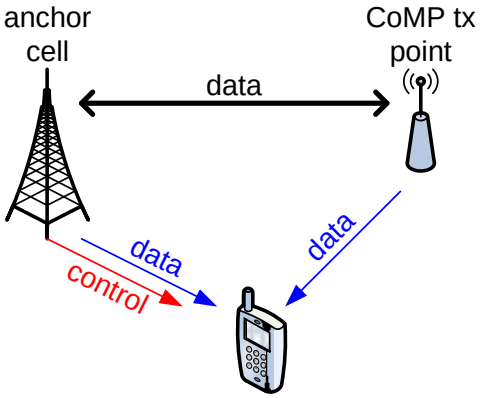
*DM-RS: DeModulation Reference Signal

MIMO enhancements in LTE-A

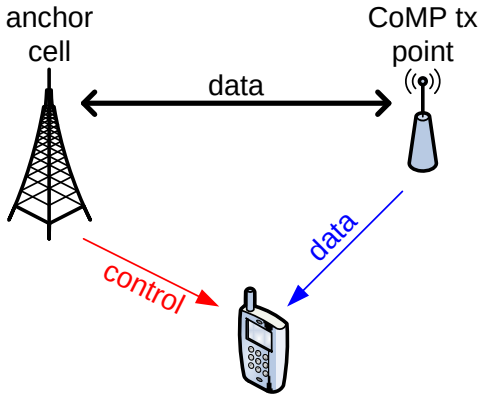
- **Goals of MIMO enhancements in LTE-A**
  - Increase the peak rates
  - Improve the system level performance
  - Support various transmission schemes with a universal structure
- **Scopes of LTE-A MIMO**
  - DL higher order MIMO
  - Enhanced DL MU-MIMO
  - Uplink spatial multiplexing
  - Uplink transmit diversity with multiple Tx antennas
  - Coordinated Multi-Point transmission/reception (CoMP)

CoMP – Downlink

- **Joint processing**

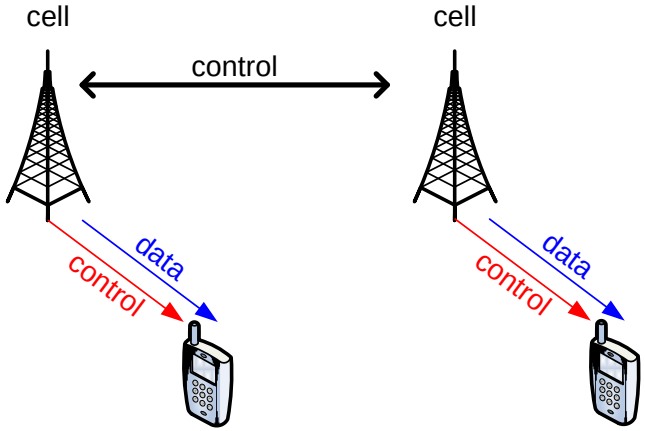


Joint transmissions



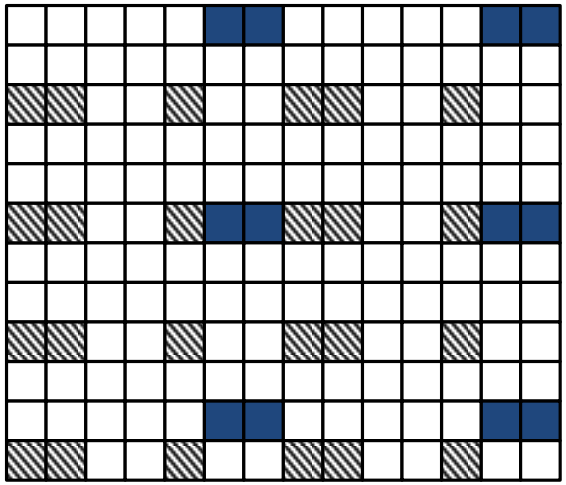
Fast cell selection

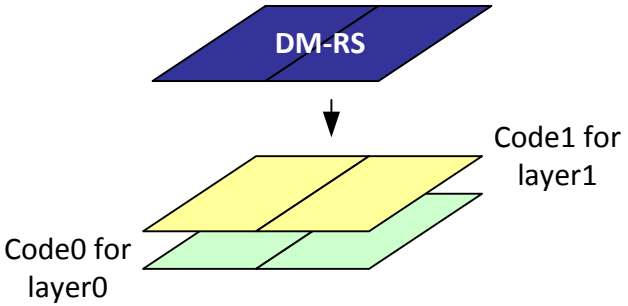
- **Coordinated scheduling / coordinated beamforming**



LTE Rel-9

- **Following work items are under discussions in 3GPP RAN1**
  - Positioning support
  - Dual stream beamforming
- **Dual stream beamforming**
  - Extension of DRS-based beamforming to support spatial multiplexing
  - *Forward compatible* to LTE-A (Rel-10)
  - Introduction of CDM (Code Domain Multiplexing) DM-RS



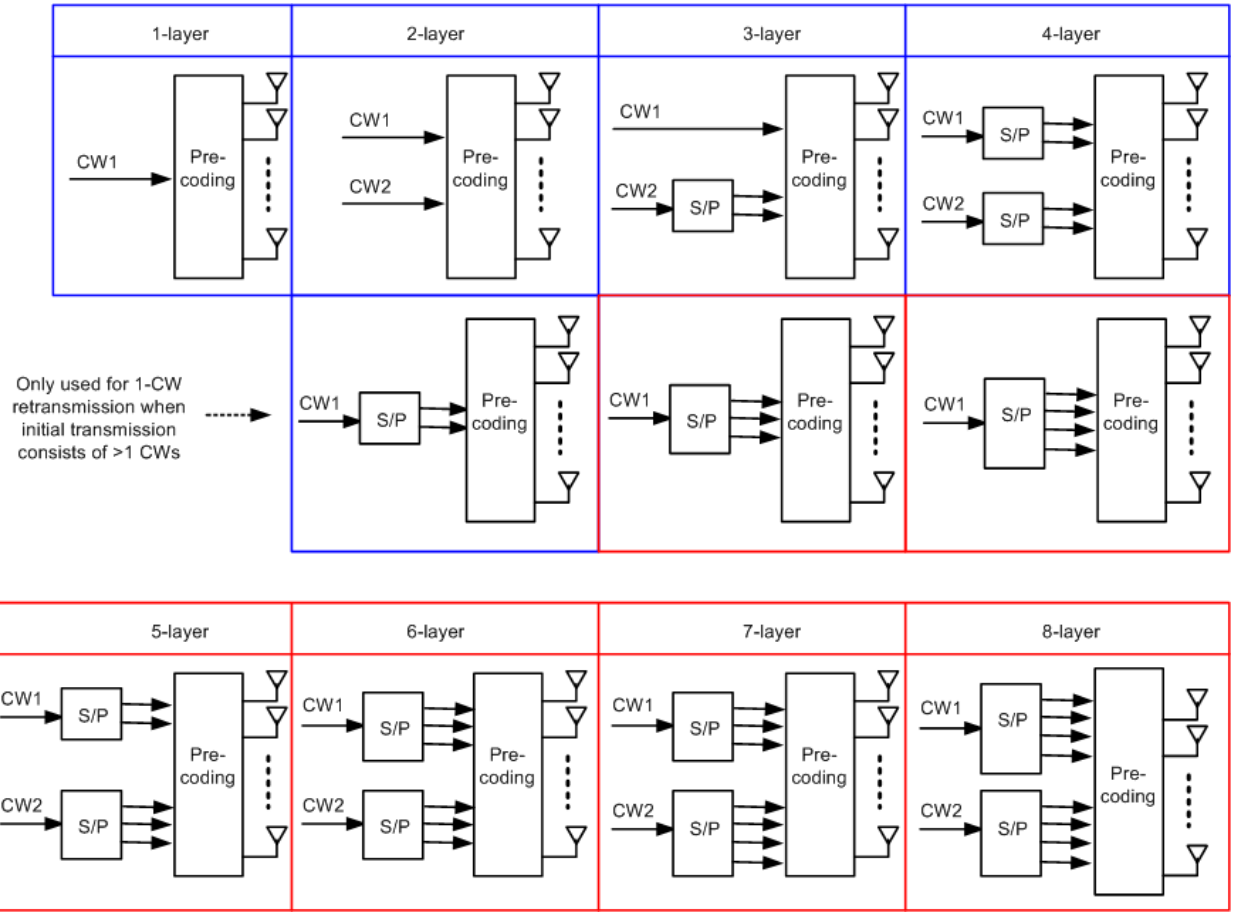


LTE-A MIMO – Downlink (1/3)

- **Major features of LTE-A DL MIMO**
  - Up to 8 transmit antennas
    - Up to rank-8 transmissions
    - Up to 2 codewords transmissions
  - Extension of ***non-codebook based*** precoding
    - Introduction of new reference signals (CSI-RS and DM-RS)
    - Commonality with MU-MIMO, CoMP
  - Reuse of LTE Rel-8 transmit diversity schemes
  - Enhanced MU-MIMO
    - Enabling improved precoding by virtue of DM-RS
      - Examples of precoding schemes
        - » Zero Forcing based
        - » SLR (Signal to Leakage Ratio) based
- **Feedback**
  - Explicit vs Implicit vs SRS-based vs Hybrid

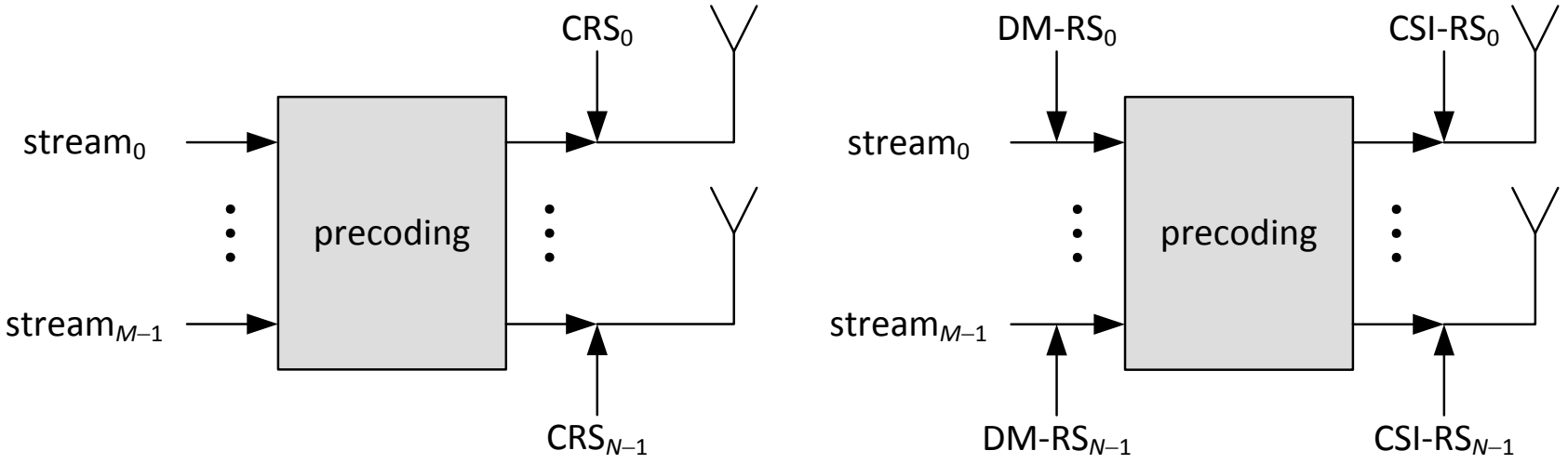
LTE-A MIMO – Downlink (2/3)

Codeword to layer mapping



LTE-A MIMO – Downlink (3/3)

CRS-based vs DM-RS-based



CRS-based **DM-RS-based**

LTE-A MIMO – Uplink (1/4)

- **Major features of LTE-A UL MIMO**
  - Introduction of spatial multiplexing
    - Layer shifting: FFS
      - HAR-ACK spatial bundling with layer shifting
      - No HARQ-ACK spatial bundling and no layer shifting
  - Codebook-based precoding
    - Rank-dependent codebook
    - Cubic Metric (CM) Preserving/Friendly
    - No nested property
    - Constraint alphabet
  - Precoded DM-RS based transmissions
  - Introduction of transmit diversity
    - PUCCH transmit diversity: Spatial Orthogonal-Resource Transmit Diversity (SORTD)
  - Default operation mode: UL Single Antenna Port Mode

Codebook for 2 Tx antennas

- **Rank-1 (Size=6)**

From 2TxAnt codebook of LTE Rel-8 | Antenna selection precoders

$$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix},\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix},\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix},\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix},\quad \frac{1}{\sqrt{2}}\begin{bmatrix}1\\0\end{bmatrix},\frac{1}{\sqrt{2}}\begin{bmatrix}0\\1\end{bmatrix}$$

- **Rank-2 (Size=1)**

$$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$$

LTE-A MIMO – Uplink (3/4)

Codebook for 4 Tx antennas

- **Rank-1 (Size=24)**

$$\overbrace{\begin{matrix}\frac{1}{2}\begin{bmatrix}1\\1\\1\\-1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\1\\j\\j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\1\\-1\\1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\1\\-j\\-j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\j\\1\\j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\j\\j\\1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\j\\-1\\-j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\j\\-j\\-1\end{bmatrix},\\ \frac{1}{2}\begin{bmatrix}1\\-1\\1\\1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\-1\\j\\-j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\-1\\-1\\-1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\-1\\-j\\j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\-j\\1\\-j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\-j\\j\\-1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\-j\\-1\\j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\-j\\-j\\1\end{bmatrix},\\ \underbrace{\frac{1}{2}\begin{bmatrix}1\\0\\1\\0\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\0\\-1\\0\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\0\\j\\0\end{bmatrix},\frac{1}{2}\begin{bmatrix}1\\0\\-j\\0\end{bmatrix},\frac{1}{2}\begin{bmatrix}0\\1\\0\\1\end{bmatrix},\frac{1}{2}\begin{bmatrix}0\\1\\0\\-1\end{bmatrix},\frac{1}{2}\begin{bmatrix}0\\1\\0\\j\end{bmatrix},\frac{1}{2}\begin{bmatrix}0\\1\\0\\-j\end{bmatrix}}_{\text{Antenna-pair tun-off}}\end{matrix}}^{\text{Constant Modulus}}$$

LTE-A MIMO – Uplink (4/4)

- **Rank-2 (Size=16)**
  - CM-preserving

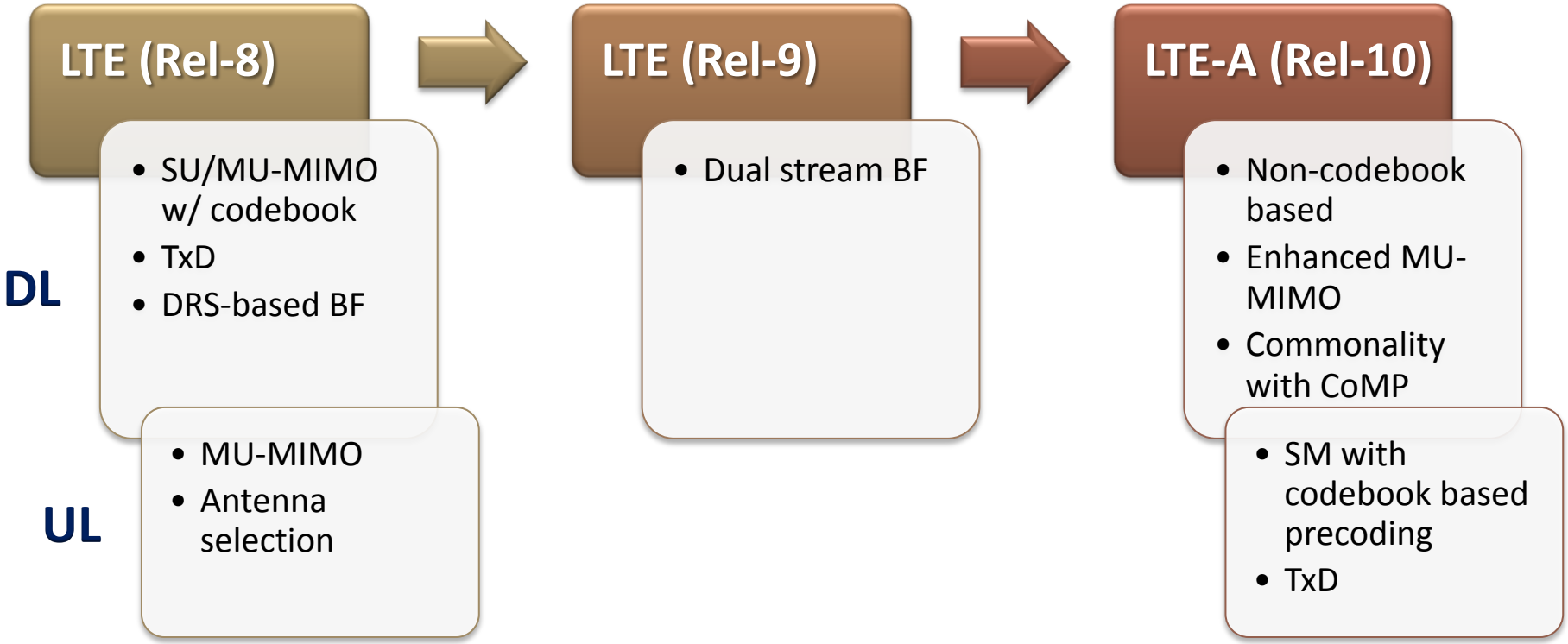
$$\frac{1}{2}\begin{bmatrix}1&0\\1&0\\0&1\\0&-j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\1&0\\0&1\\0&j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\-j&0\\0&1\\0&1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\-j&0\\0&1\\0&-1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\-1&0\\0&1\\0&-j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\-1&0\\0&1\\0&j\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\j&0\\0&1\\0&1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\j&0\\0&1\\0&-1\end{bmatrix},$$

$$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\1&0\\0&1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\0&1\\1&0\\0&-1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\0&1\\-1&0\\0&1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\0&1\\-1&0\\0&-1\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&1\\1&0\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&-1\\1&0\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&1\\-1&0\end{bmatrix},\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&-1\\-1&0\end{bmatrix}$$

- **Rank-3**
  - FFS: CM-preserving vs CM-friendly
- **Rank-4**

$$\frac{1}{2}\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$$

Summary


LTE (Rel-8)
LTE (Rel-9)
LTE-A (Rel-10)
DL
• SU/MU-MIMO w/ codebook
• TxD
• DRS-based BF
• Dual stream BF
• Non-codebook based
• Enhanced MU-MIMO
• Commonality with CoMP
UL
• MU-MIMO
• Antenna selection
• SM with codebook based precoding
• TxD