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Title: **Spatial correlation modeling with 8-Tx cross-polarized antennas**

Document for: **Discussion and Decision**

1 Introduction

In this contribution we further refine 8-Tx MIMO correlation modeling with cross-polarized antenna configurations [1], focusing on the following aspects:

- Derivation of the polarization correlation matrix Γ and associated element indexing.
- Derivation of the correlation matrix for 8x{2,4} cases and associated spatial correlation coefficient indexing.
- RAN1 compliant MIMO channel coefficient indexing and associated channel generation.
- Spatial correlation scenarios for E-DL MIMO verification and considerations on the mapping to CSI test cases.

2 8-Tx MIMO correlation with cross-polarized antennas

During RAN4#57AH meeting, common understanding was found on the fact that spatial correlation matrices for cross-polarized antenna arrays may be modeled as $R = R_{eNB} \otimes \Gamma \otimes R_{UE}$, where R_{eNB} and R_{UE} are correlation matrices for ULA sub-arrays at base station and terminal side, respectively, and Γ is the so-called polarization correlation matrix. However, opinions differed on which form the matrix Γ should take as well as on the overall channel coefficient indexing [1][2][3][4]. We address these questions in the following.

2.1 Deriving the polarization correlation matrix

We start by investigating the spatial correlation between two pairs of dual-polarized antennas at the transmitter and receiver (see Figure 1).

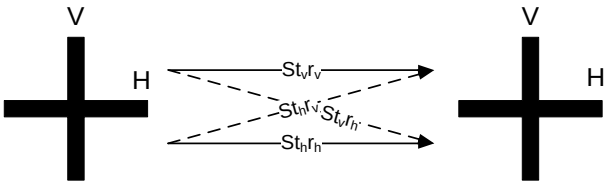

Figure 1: Cross-polarized antenna elements at eNB and UE with slant angles of {0, 90} deg.

Let us define the corresponding 2x2 channel matrix S between vertical (v) and horizontal (h) nominal polarizations as:

$$S = \begin{bmatrix} S_{t_v r_v} & S_{t_h r_v} \\ S_{t_v r_h} & S_{t_h r_h} \end{bmatrix},$$

where the pair of indices $t_i r_j$, $i, j \in \{v, h\}$, refers to channel branch between eNB (transmitter) antenna t_i and UE (receiver) antenna r_j, subscripts v, h corresponding to vertical and horizontal nominal polarization, respectively. Hence UE antenna index is tied to the row index and eNB antenna index is tied to the column index.

Now taking the relative orientation of eNB and UE antennas into account we reach the configuration in Figure 2, where eNB antenna elements are slanted by {+45, -45} degrees relatively to the nominal v/h orientations ({0, 90} deg.). Let us consider the transmission model $y = Qx$, where $x = [x_{t_i}, x_{t_j}]^T$ and $y = [y_{r_m}, y_{r_n}]^T$ are the 2x1 transmit and received signal vectors respectively, with the following definition of the 2x2 equivalent channel matrix:

$$Q = \begin{bmatrix} Q_{t_i r_m} & Q_{t_j r_m} \\ Q_{t_i r_n} & Q_{t_j r_n} \end{bmatrix}.$$

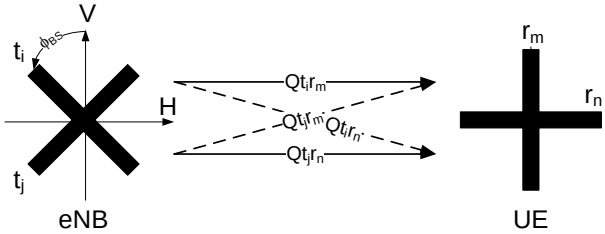

Figure 2: Cross-polarized antenna elements at eNB and UE with respective slant angles {+45, -45}, {0, 90} deg.

The matrix Q can be expressed as:

$$Q = R_{MS} \times S \times R_{BS}\ .$$

With $R_{MS} = \begin{bmatrix} \cos\phi_{MS} & \sin\phi_{MS} \\ -\sin\phi_{MS} & \cos\phi_{MS} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ since $\phi_{MS} = 0°$, and $R_{BS} = \begin{bmatrix} \cos\phi_{BS} & -\sin\phi_{BS} \\ \sin\phi_{BS} & \cos\phi_{BS} \end{bmatrix} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix}$ since $\phi_{BS} = 45°$, the matrix Q is found as:

$$Q = \frac{1}{\sqrt{2}}\begin{bmatrix} (S_{t_v r_v} + S_{t_h r_v}) & (-S_{t_v r_v} + S_{t_h r_v}) \\ (S_{t_v r_h} + S_{t_h r_h}) & (-S_{t_v r_h} + S_{t_h r_h}) \end{bmatrix}.$$

The polarization matrix covariance matrix Γ_{cov} is calculated as:

$$\Gamma_{\text{cov}} = E_S[vec(Q) \times vec(Q)^H],$$

where $vec(Q) = [Q_{t_i r_m}, Q_{t_i r_n}, Q_{t_j r_m}, Q_{t_j r_n}]^T = [(S_{t_v r_v} + S_{t_h r_v}), (S_{t_v r_h} + S_{t_h r_h}), (-S_{t_v r_v} + S_{t_h r_v}), (-S_{t_v r_h} + S_{t_h r_h})]^T$. The matrix Γ_{cov} expands as:

$$\Gamma_{\text{cov}} = \frac{1}{2}\begin{bmatrix} E_S[(S_{t_v r_v} + S_{t_h r_v})(S_{t_v r_v} + S_{t_h r_v})^*] & E_S[(S_{t_v r_v} + S_{t_h r_v})(S_{t_v r_h} + S_{t_h r_h})^*] & E_S[(S_{t_v r_v} + S_{t_h r_v})(-S_{t_v r_v} + S_{t_h r_v})^*] & E_S[(S_{t_v r_v} + S_{t_h r_v})(-S_{t_v r_h} + S_{t_h r_h})^*] \\ E_S[(S_{t_v r_h} + S_{t_h r_h})(S_{t_v r_v} + S_{t_h r_v})^*] & E_S[(S_{t_v r_h} + S_{t_h r_h})(S_{t_v r_h} + S_{t_h r_h})^*] & E_S[(S_{t_v r_h} + S_{t_h r_h})(-S_{t_v r_v} + S_{t_h r_v})^*] & E_S[(S_{t_v r_h} + S_{t_h r_h})(-S_{t_v r_h} + S_{t_h r_h})^*] \\ E_S[(-S_{t_v r_v} + S_{t_h r_v})(S_{t_v r_v} + S_{t_h r_v})^*] & E_S[(-S_{t_v r_v} + S_{t_h r_v})(S_{t_v r_h} + S_{t_h r_h})^*] & E_S[(-S_{t_v r_v} + S_{t_h r_v})(-S_{t_v r_v} + S_{t_h r_v})^*] & E_S[(-S_{t_v r_v} + S_{t_h r_v})(-S_{t_v r_h} + S_{t_h r_h})^*] \\ E_S[(-S_{t_v r_h} + S_{t_h r_h})(S_{t_v r_v} + S_{t_h r_v})^*] & E_S[(-S_{t_v r_h} + S_{t_h r_h})(S_{t_v r_h} + S_{t_h r_h})^*] & E_S[(-S_{t_v r_h} + S_{t_h r_h})(-S_{t_v r_v} + S_{t_h r_v})^*] & E_S[(-S_{t_v r_h} + S_{t_h r_h})(-S_{t_v r_h} + S_{t_h r_h})^*] \end{bmatrix}.$$

Now, under the assumption that $E\left[S_{t_i r_j} S^*_{t_k r_l}\right] = 0, (t_i r_j) \neq (t_k r_l)$, i.e. different nominal polarization channel branches are mutually uncorrelated, the above expression simplifies to:

$$\Gamma_{\text{cov}} = \frac{1}{2}\begin{bmatrix} \left(E_S\left[|S_{t_v r_v}|^2\right] + E_S\left[|S_{t_h r_v}|^2\right]\right) & 0 & \left(-E_S\left[|S_{t_v r_v}|^2\right] + E_S\left[|S_{t_h r_v}|^2\right]\right) & 0 \\ 0 & \left(E_S\left[|S_{t_v r_h}|^2\right] + E_S\left[|S_{t_h r_h}|^2\right]\right) & 0 & \left(-E_S\left[|S_{t_v r_h}|^2\right] + E_S\left[|S_{t_h r_h}|^2\right]\right) \\ \left(-E_S\left[|S_{t_v r_v}|^2\right] + E_S\left[|S_{t_h r_v}|^2\right]\right) & 0 & \left(E_S\left[|S_{t_v r_v}|^2\right] + E_S\left[|S_{t_h r_v}|^2\right]\right) & 0 \\ 0 & \left(-E_S\left[|S_{t_v r_h}|^2\right] + E_S\left[|S_{t_h r_h}|^2\right]\right) & 0 & \left(E_S\left[|S_{t_v r_h}|^2\right] + E_S\left[|S_{t_h r_h}|^2\right]\right) \end{bmatrix}.$$

Let us assume further that $E_S\left[|S_{t_v r_v}|^2\right] = E_S\left[|S_{t_h r_h}|^2\right]$=1 and that $E_S\left[|S_{t_h r_v}|^2\right] / E_S\left[|S_{t_v r_v}|^2\right] = E_S\left[|S_{t_v r_h}|^2\right] / E_S\left[|S_{t_h r_h}|^2\right] = \text{XPR}$, which leads to:

$$\Gamma_{\text{cov}} = \frac{1}{2}\begin{bmatrix} (1 + XPR) & 0 & (-1 + XPR) & 0 \\ 0 & (XPR + 1) & 0 & (-XPR + 1) \\ (-1 + XPR) & 0 & (1 + XPR) & 0 \\ 0 & (-XPR + 1) & 0 & (XPR + 1) \end{bmatrix}$$

The polarization correlation matrix Γ is finally found as by normalizing Γ_{cov} (divide by $(1 + \text{XPR})/2$):

$$\Gamma = \begin{bmatrix} 1 & 0 & \gamma & 0 \\ 0 & 1 & 0 & -\gamma \\ \gamma & 0 & 1 & 0 \\ 0 & -\gamma & 0 & 1 \end{bmatrix},$$

where:

- The first row (or equivalently columm) of Γ refers to channel branches indexed by **[$t_i r_m$, $t_i r_n$, $t_j r_m$, $t_j r_n$]** due to the chosen indexing convention for the matrix Q which assumes that row indexing goes along UE Rx antennas and column indexing goes along eNB Tx antennas, as pointed out in [5].

- The parameter γ depends on the cross-polarization ratio (XPR) as $\gamma = (\mathrm{XPR} - 1)/(\mathrm{XPR} + 1)$, with the following definition of $XPR = \frac{E\left[\left|s_{t_h r_v}\right|^2\right]}{E\left[\left|s_{t_v r_v}\right|^2\right]} = \frac{E\left[\left|s_{t_v r_h}\right|^2\right]}{E\left[\left|s_{t_h r_h}\right|^2\right]}$. The value $\gamma = 0$ corresponds to $\mathrm{XPR} = 1$ meaning polarization channel branches with equal power while $\gamma = 1$ corresponds to $\mathrm{XPR} = 0$ which in turn means perfect polarization discrimination by the channel (i.e. no power flowing in the channel from vertical to horizontal polarization and vice-versa).
- eNodeB/UE relative antenna orientation (i.e. slants) is now part of the above spatial correlation modeling. Other orientation than {+45,-45} degrees relative slants between eNB and UE antenna polarizations will lead to potentially different structure for the polarization correlation matrix Γ.
- The normalization of the correlation matrix Γ relative to the covariance matrix should be accounted for in the final channel model or by scaling the transmitted power. For the correlation matrices Γ above the power scaling factor is ½.

2.2 Deriving the 8-Tx spatial correlation matrix

In this section we derive the whole spatial correlation matrix as

$$R = R_{eNB} \otimes \Gamma \otimes R_{UE}. \qquad \text{(Eq. 1)}$$

We focus on the 8x2 case with cross-polarized antenna elements at both eNB and UE end. We also provide the corresponding expression for the 8x4 case. Antenna element indexing/labeling is of importance when it comes further to CSI testing with the agreed 8-Tx double codebook. We propose to adopt the same antenna indexing as in the one in RAN1 during 8-Tx codebook studies [6]:

- *If antennas are cross-polarized, label the N antennas such that antennas for one polarization are listed from 1 to N/2 and antennas from the other polarization are listed from N/2 + 1 to N. If antennas are single-polarized, they are simply listed from 1 to N. N refers to the number of transmit or receiver antennas*.

The above labelling rules are illustrated in Figure 4 and Figure 5 below.

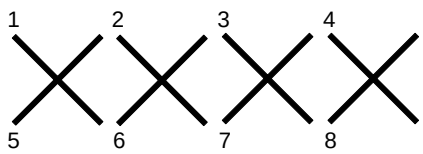

Figure 3: Antenna indexing for N_t=8 cross-polarized antennas at eNB.

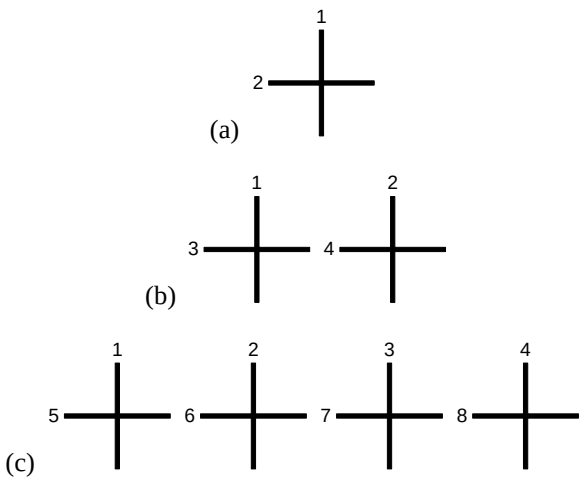

Figure 4: Antenna indexing for 2 (a), 4 (b) and 8 (c) cross-polarized antennas at UE.

<u>Spatial correlation coefficient indexing</u>

With the above antenna labelling, it is important to note that spatial correlation coefficients in matrix R stemming from Eq. (1) are such that the first row (or column) of R refers to channel branches indexed by $[\mathbf{t_1r_1,\ldots,t_1r_{Nr}, t_5r_1,\ldots,t_5r_{Nr}, t_2r_1,\ldots,t_2r_{Nr}, t_6r_1,\ldots,t_6r_{Nr}, t_3r_1,\ldots,t_3r_{Nr}, t_7r_1,\ldots,t_7r_{Nr}, t_4r_1,\ldots,t_4r_{Nr}, t_8r_1,\ldots,t_8r_{Nr}}]$.

8x2 configuration with cross-polarized antennas at both eNB and UE side (xxxx->+)

For an 8x2 antenna configuration, assuming slant angles of {+45, -45} degrees at eNB and {0, 90} degrees at UE side, the whole MIMO channel correlation matrix is obtained as:

$$R = R_{eNB} \otimes \Gamma \otimes R_{UE}, \text{ with } R_{eNB} = \begin{bmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{1/9^*} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{4/9^*} & \alpha^{1/9^*} & 1 & \alpha^{1/9} \\ \alpha^{*} & \alpha^{4/9^*} & \alpha^{1/9^*} & 1 \end{bmatrix}, \Gamma = \begin{bmatrix} 1 & 0 & \gamma & 0 \\ 0 & 1 & 0 & -\gamma \\ \gamma & 0 & 1 & 0 \\ 0 & -\gamma & 0 & 1 \end{bmatrix} \text{ and } R_{UE} = 1. \text{ (Eq. 2)}$$

The above expression of R may be simplified as follows:

$$R = \begin{bmatrix} R_{eNB}(1,1) \times \Gamma & R_{eNB}(1,2) \times \Gamma & R_{eNB}(1,3) \times \Gamma & R_{eNB}(1,4) \times \Gamma \\ R_{eNB}(2,1) \times \Gamma & R_{eNB}(2,2) \times \Gamma & R_{eNB}(2,3) \times \Gamma & R_{eNB}(2,4) \times \Gamma \\ R_{eNB}(3,1) \times \Gamma & R_{eNB}(3,2) \times \Gamma & R_{eNB}(3,3) \times \Gamma & R_{eNB}(3,4) \times \Gamma \\ R_{eNB}(4,1) \times \Gamma & R_{eNB}(4,2) \times \Gamma & R_{eNB}(4,3) \times \Gamma & R_{eNB}(4,4) \times \Gamma \end{bmatrix} = \begin{bmatrix} \Gamma & \alpha^{1/9}\Gamma & \alpha^{4/9}\Gamma & \alpha\Gamma \\ \alpha^{1/9^*}\Gamma & \Gamma & \alpha^{1/9}\Gamma & \alpha^{4/9}\Gamma \\ \alpha^{4/9^*}\Gamma & \alpha^{1/9^*}\Gamma & \Gamma & \alpha^{1/9}\Gamma \\ \alpha^{*}\Gamma & \alpha^{4/9^*}\Gamma & \alpha^{1/9^*}\Gamma & \Gamma \end{bmatrix},$$

where $R_{eNB}(i,j)$ denotes the element of the matrix R_{eNB} at i-th row and j-th column.

Following the labelling conventions in Figure 4 and 5, the first row (or equivalently columm) of R refers to channel branches indexed by **[t_1r_1, t_1r_2, t_5r_1, t_5r_2, t_2r_1, t_2r_2, t_6r_1, t_6r_2, t_3r_1, t_3r_2, t_7r_1, t_7r_2, t_4r_1, t_4r_2, t_8r_1, t_8r_2]**, where t_ir_j denotes the channel branch between eNB (transmitter) antenna t_i and UE (receiver) antenna r_j, i=1,...,8 and j=1,2.

8x4 configuration with cross-polarized antennas at both eNB and UE side (xxxx->++)

The model in Eq. (2) extends in a rather straightforward manner for more than 2 Rx at the UE side by using a non-scalar R_{UE} matrix for the UE side ULA sub-array. For an 8x4 antenna configuration with cross-polarized antennas at both eNB and UE side this translates to:

$$R = \begin{bmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{1/9^*} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{4/9^*} & \alpha^{1/9^*} & 1 & \alpha^{1/9} \\ \alpha^{*} & \alpha^{4/9^*} & \alpha^{1/9^*} & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & 0 & \gamma & 0 \\ 0 & 1 & 0 & -\gamma \\ \gamma & 0 & 1 & 0 \\ 0 & -\gamma & 0 & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & \beta \\ \beta^* & 1 \end{bmatrix}, \qquad \text{(Eq. 3)}$$

where the parameter β governs the correlation between co-polarized antenna elements at the receiver.

Following the labelling conventions in Figure 4 and 5, the first row (or equivalently columm) of R refers to channel branches indexed by **[t_1r_1, t_1r_2, t_1r_3, t_1r_4, t_5r_1, t_5r_2, t_5r_3, t_5r_4, t_2r_1, ..., t_2r_4, t_6r_1, ..., t_6r_4, t_3r_1, ..., t_3r_4, t_7r_1, ..., t_7r_4, ..., t_4r_1, ..., t_4r_4, t_8r_1, ..., t_8r_4]**, where t_ir_j denotes the channel branch between eNB (transmitter) antenna t_i and UE (receiver) antenna r_j, i=1,...,8 and j=1,4.

8x8 configuration

At this stage our preference is to leave 8x8 MIMO correlation modeling for further study for essentially two reasons:

- Following the discussion in [7], we see as preferable to introduce requirements for E-DL MIMO with respect to different Rx antenna configurations in a phased manner based on practical and commercial considerations.
- High rank transmission – above rank 2 – requires well-conditioned channel realizations (i.e. channel rank is sufficient) which needs to be ensured for related testing. The higher the rank, the fewer channel realizations allow sustaining the transmission of the corresponding rank even with uncorrelated coefficients. Reference [8] also echoes this issue already in the context of 4x4 transmission, which may also pertain to the 8x4 case for rank greater than 2.

2.3 Channel coefficient generation

The downlink MIMO input-output relationship typically reads:

$$y = Hx,$$

where x is an N_tx1 input (transmit) signal vector, y is an N_rx1 output (received) signal vector and H is an N_rxN_t MMO channel matrix. Assuming N_t=8 transmit antennas and N_r receive antennas, let us define the matrix H as:

$$H = \begin{bmatrix} H_{t_1r_1} & H_{t_2r_1} & H_{t_3r_1} & H_{t_4r_1} & H_{t_5r_1} & H_{t_6r_1} & H_{t_7r_1} & H_{t_8r_1} \\ H_{t_1r_2} & H_{t_2r_2} & H_{t_3r_2} & H_{t_4r_2} & H_{t_5r_2} & H_{t_6r_2} & H_{t_7r_2} & H_{t_8r_2} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ H_{t_1r_{N_r}} & H_{t_2r_{N_r}} & H_{t_3r_{N_r}} & H_{t_4r_{N_r}} & H_{t_5r_{N_r}} & H_{t_6r_{N_r}} & H_{t_7r_{N_r}} & H_{t_8r_{N_r}} \end{bmatrix},$$

where $vec(H)$ is indexed as **[t_1r_1,..., t_1r_{Nr}, t_2r_1,..., t_2r_{Nr}, t_3r_1,..., t_3r_{Nr}, ..., ..., t_7r_1,..., t_7r_{Nr}, t_8r_1,..., t_8r_{Nr}]**. For each channel tap, a spatially correlated MIMO channel matrix H of size $N_r \times N_t$ may be generated as follows:

$$H = \sqrt{P_{tap}} \cdot unvec\left(R^{1/2} \times vec(H_{iid})\right), \qquad \text{(Eq. 4)}$$

where P_{tap} is the tap power, H_{iid} is a MIMO channel matrix of size $N_r \times N_t$ with complex circular i.i.d. Gaussian random coefficients and operators $vec(\cdot)$ and $unvec(\cdot)$ perform respectively vectorization/de-vectorization.

Let us take the 8x2 case as example. Given the expression of R in Eq. (2) and the associated mapping of spatial correlation coefficients to channel branches, the channel matrix H takes the form:

$$H = \begin{bmatrix} H_{t_1r_1} & H_{t_5r_1} & H_{t_2r_1} & H_{t_6r_1} & H_{t_3r_1} & H_{t_7r_1} & H_{t_4r_1} & H_{t_8r_1} \\ H_{t_1r_2} & H_{t_5r_2} & H_{t_2r_2} & H_{t_6r_2} & H_{t_3r_2} & H_{t_7r_2} & H_{t_4r_2} & H_{t_8r_2} \end{bmatrix},$$

where $vec(H)$ is indexed as **[t_1r_1, t_1r_2, t_5r_1, t_5r_2, t_2r_1, t_2r_2, t_6r_1, t_6r_2, t_3r_1, t_3r_2, t_7r_1, t_7r_2, t_4r_1, t_4r_2, t_8r_1, t_8r_2]**. However, the above expression for the channel matrix H does not comply with the RAN1 indexing rule stating that antennas for one polarization are listed from 1 to N/2 and antennas for the other polarization are listed from N/2+1 to N, where N refers to the number of transmit or receive antennas.

One simple solution is to apply a permutation matrix prior to de-vectorization in Eq. (4), as suggested in [2],

$$\widetilde{H} = \sqrt{P_{tap}} \cdot unvec\left(P \times R^{1/2} \times vec(H_{iid})\right), \qquad \text{(Eq. 5)}$$

where P is a permutation matrix of size $N_t x N_r$ x $N_t x N_r$ defined in [2] as:

$$P(a,b) = \begin{cases} 1 & for\ \ a = (j-1)\cdot N_r + i\ \ and\ \ b = 2\cdot(j-1)\cdot N_r + i, & i = 1,\dots,N_r,\ \ j = 1,\dots,N_t/2 \\ 1 & for\ \ a = (j-1)\cdot N_r + i\ \ and\ \ b = 2\cdot(j-N_t/2)\cdot N_r - N_r + i, & i = 1,\dots,N_r,\ \ j = N_t/2+1,\dots,N_t \\ 0 & otherwise \end{cases}$$

Coming back to the 8x2 case, P reads as follows:

```
P =

     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     1     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0
     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     1     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     1     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1
```

The resulting channel matrix $\widetilde{H}$ is now compliant with the labelling in [6]:

$$\widetilde{H} = \begin{bmatrix} H_{t_1r_1} & H_{t_2r_1} & H_{t_3r_1} & H_{t_4r_1} & H_{t_5r_1} & H_{t_6r_1} & H_{t_7r_1} & H_{t_8r_1} \\ H_{t_1r_2} & H_{t_2r_2} & H_{t_3r_2} & H_{t_4r_2} & H_{t_5r_2} & H_{t_6r_2} & H_{t_7r_2} & H_{t_8r_2} \end{bmatrix}.$$

2.4 Channel capacity considerations for 8-Tx MIMO correlation

2.4.1 Applicability of the capacity criterion to LTE Rel-10

In the following, we discuss the possible extension of the Rel-8 capacity-based methodology to Rel-10.

Low spatial correlation scenarios:

Low MIMO channel correlation is easily achieved e.g. by considering cross-polarized antennas at both eNB and UE side and setting $\alpha = 0, \gamma = 0$ in Eq. (2) for the 8x2 case and $\alpha = 0, \gamma = 0, \beta = 0$ in Eq. (3) for the 8x4 case.

Medium spatial correlation scenarios:

During Rel-8, medium correlation was primarily aimed at testing transmit diversity (TxD) demodulation performance. There is no such need anymore since Rel-10 operates with dedicated reference signals and at the same time there is no standardized TxD scheme besides the ones associated with Rel-8 Tx modes. In Rel-10 correlation matrices are primarily intended for CSI testing with the focus on high/low spatial correlation scenarios. Besides targeting completeness of MIMO correlation modeling in TS 36101, there is seems no other use for medium correlation in Rel-10.

High spatial correlation scenarios:

The situation in Rel-10 differs notably from Rel-8 because of the use of cross-polarized antennas. Let us focus for instance on an 8x2 configuration assuming cross-polarized antennas at eNB. Depending on the UE receiver antenna configuration, the channel capacity may differ significantly in the case of high spatial correlation at the transmitter:

- 2-Rx cross-polarized antennas at the UE: Polarization modeling brings two extra uncorrelated channel dimensions which leads to rather low overall MIMO channel correlation and high associated channel capacity (as observed in [1]). Such channel allows sustaining rank-2 transmission for sufficiently high SNR.

- 2-Rx uniform linear array at the UE: This case leads to high overall MIMO channel correlation and low associated channel capacity (see [1]). Such channel allows mostly rank-1 transmission.

However, it is not clear yet whether two distinct UE antenna configurations (XP/ULA) are ultimately needed with cross-polarized antennas at the eNB based on CSI testing considerations. ULA/ULA setup may offer an alternative wherever high correlation and low channel capacity would be needed. Table 2 attempts at clarifying the situation by defining two corresponding scenarios for high spatial correlation. At this stage, our preferences are as follows:

- Introduce 8-Tx spatial correlation matrices involving cross-polarized antennas at both link ends for:
  - One scenario with ***low/low*** spatial correlation at transmitter/receiver side ("Low" in Table 2).
  - One scenario with as ***high/low*** spatial correlation at transmitter/receiver side ("High 1" in Table 2).
- FFS:
  - Scenario involving ULA at UE side ("High 2") only if required from CSI (PMI) testing perspective.
  - Scenario with medium spatial correlation.

Table 1: Potential methodology for 8x2 MIMO correlation in Rel-10.

Spatial correlation scenario	**Spatial correlation at transmitter (eNB) / Tx configuration**		**Spatial correlation at receiver (UE) / Rx configuration**		**Channel capacity**
Low	Low ($\alpha = 0$)	xxxx	Low ($\beta = 0$)	x	High (maximum)
[Medium]	[Medium]		[FFS]	[FFS]	[TBD]
High 1	High		Low	x	High
High 2			[High]	||	Low

2.4.2 Simulation results for 8x2 and 8x4 configurations

In Figure 5, we plot MIMO capacity curves as a function of the SNR assuming an 8x2 channel. A total of 10000 iterations per SNR point are considered. For reference we also include capacity curves assuming the SCM channel model as this has been used as baseline in RAN1 for 8-Tx codebook evaluation [6]. The figure legend summarizes the

simulated cases and provides the values for the achieved λ at 15 dB SNR according to the capacity criterion. Values shown here are tentative and proper tuning of parameters still needs to be done to reach the desired MIMO channel correlation for the various spatial correlation scenarios (to be agreed first by RAN4). In Figure 6 we provide a similar analysis for the 8x4 case. Related to the choice of the value for the parameter γ, it is stated in [2] that it would be prefererable to *introduce larger cross-talk (i.e. a small γ) so that the codebook design can be better tested*. Small values of γ correspond indeed to large cross-talk between nominal polarization branches as discussed in Section 2.1, which effectly randomizes the relative phase difference between two ULA sub-arrays at the transmitter side. This is turn requires frequency selective co-phasing by the second precoder W_2 of the 8-Tx codebook, which is precisely one feature to be tested as part of E-DL MIMO verification.

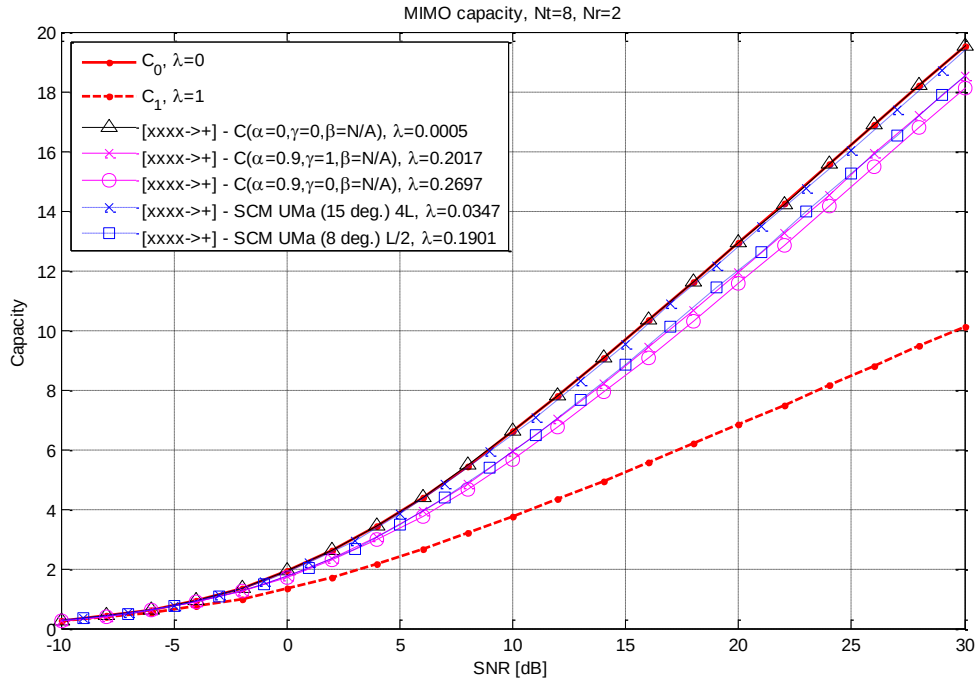

Figure 5: 8x2 MIMO channel capacity.

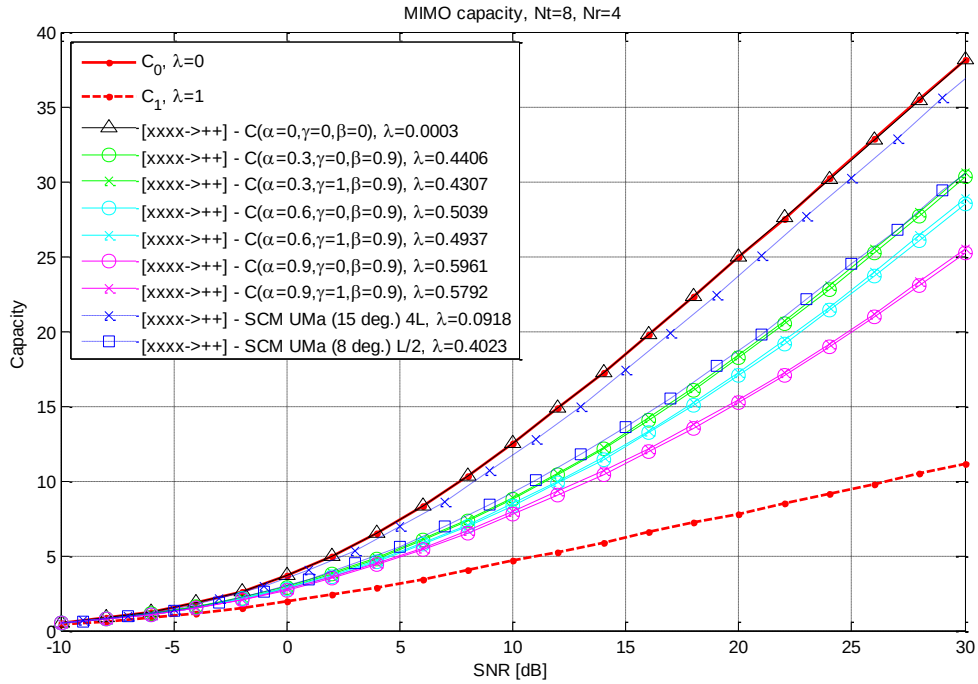

Figure 6: 8x4 MIMO channel capacity.

3 Conclusions

In this contribution we have further discussed MIMO correlation modeling for 8-Tx. Based on the analysis herein as well as on provided simulation results, we make the following proposals:

- In the case of an 8x{2,4} configuration with cross-polarized antennas, derive the spatial correlation matrix as:
$$R = R_{eNB} \otimes \Gamma \otimes R_{UE}.$$

- Introduce two spatial correlation scenarios involving cross-polarized antennas at both link ends:

  - One scenario characterized by **low** transmitter side correlation and **low** receiver side correlation:

$$R_{eNB} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \Gamma = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, R_{UE} = 1.$$

  - One scenario characterized by **high** transmitter side correlation and **low** receiver side correlation:

$$R_{eNB} = \begin{bmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{1/9^*} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{4/9^*} & \alpha^{1/9^*} & 1 & \alpha^{1/9} \\ \alpha^{*} & \alpha^{4/9^*} & \alpha^{1/9^*} & 1 \end{bmatrix}, \Gamma = \begin{bmatrix} 1 & 0 & \gamma & 0 \\ 0 & 1 & 0 & -\gamma \\ \gamma & 0 & 1 & 0 \\ 0 & -\gamma & 0 & 1 \end{bmatrix}, R_{UE} = 1.$$

    - The specific values for parameters α, β and γ need further study.

- The introduction of additional spatial correlation scenarios is left for further study and conditioned upon the need from CSI testing perspective.
- <u>The labeling of antenna elements and indexing/mapping spatial correlation coefficients to channel branches needs to be explicitly specified</u>, preferably following the same assumptions as RAN1 in [6].
  - One way to proceed is shown in Section 2.3.
  - To avoid further confusion, one could consider providing one candidate method for channel coefficient generation. One such example is given in Eq. (5).
- The following items require further study and discussion in RAN4:
  - 8x4 and 8x8 configurations with special attention on eigenvalue distributions when it comes to testing transmission ranks higher than 2.
  - Channel normalization and related power scaling needs to be agreed upon and defined (also relates to SNR definition).

References

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