

Agenda item: 4.4.1

Source: Renesas Electronics Europe

Title: Further considerations on 8-Tx spatial correlation modeling with cross-polarized antennas

Document for: Discussion and Decision

1 Introduction

During RAN4#57 meeting, progress was made in the field of 8-Tx MIMO correlation modeling and the text proposal in [1] was agreed. The agreements therein may be summarised as follows:

- As a simple extension to the existing framework it is seen useful to include 8 Tx MIMO correlation modeling for uniform linear array (ULA) to the UE TR 36.807 in order to complete the work and avoid any future work regarding channel modeling issues. As a consequence:
 - o Annex C.1 was added to TR 36.807 and describes correlation matrices for E-DL MIMO transmission using ULA.
 - o Values for parameters α and β are provided for low and high correlation cases while the need for medium correlation for 8-Tx E-DL-MIMO was left for further study.
- Correlation matrices for E-DL MIMO transmission with cross-polarized antennas will be introduced for Rel-10 and should be prioritized for E-DL MIMO transmission performance requirements, such as CSI testing.

In this contribution we further discuss 8-Tx MIMO correlation modeling with cross-polarized antenna configurations and provide views on possible parametrization, focusing on 8x2 and 8x4 cases.

2 8-Tx MIMO correlation with cross-polarized antennas

2.1 Existing framework in TS 36.101 for ULA

The current version of TS 36.101, Section B.2.3 in [9] defines MIMO correlation matrices for Tx/Rx configurations with one, two or four transmit antennas and two or four receive antennas assuming ULA:

- The eNodeB side correlation matrices R_{eNB} are defined for $N_t = 1, 2, 4$ transmit antennas. For $N_t = 2, 4$, the matrix R_{eNB} is parametrized by α , which governs the correlation between the ULA transmitter elements.

	One antenna	Two antennas	Four antennas
eNodeB correlation	$R_{eNB} = 1$	$R_{eNB} = \begin{bmatrix} 1 & \alpha \\ \alpha^* & 1 \end{bmatrix}$	$R_{eNB} = \begin{bmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{1/9*} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{4/9*} & \alpha^{1/9*} & 1 & \alpha^{1/9} \\ \alpha^* & \alpha^{4/9*} & \alpha^{1/9*} & 1 \end{bmatrix}$

- The UE side correlation matrices R_{UE} are defined for $N_r = 1, 2, 4$ receive antennas. For $N_r = 2, 4$, the matrix R_{UE} is parametrized by β , which governs the correlation between the ULA receiver elements.

	One antenna	Two antennas	Four antennas
UE correlation	$R_{UE} = 1$	$R_{UE} = \begin{bmatrix} 1 & \beta \\ \beta^* & 1 \end{bmatrix}$	$R_{eNB} = \begin{bmatrix} 1 & \beta^{1/9} & \beta^{4/9} & \beta \\ \beta^{1/9*} & 1 & \beta^{1/9} & \beta^{4/9} \\ \beta^{4/9*} & \beta^{1/9*} & 1 & \beta^{1/9} \\ \beta^* & \beta^{4/9*} & \beta^{1/9*} & 1 \end{bmatrix}$

- The channel spatial correlation matrix R_{spat} is expressed as the Kronecker product of R_{eNB} and R_{UE} as

$$R_{spat} = R_{eNB} \otimes R_{UE}.$$
- A single channel correlation matrix is defined, which simplifies simulations and offers at the same time equivalent modeling to per tap correlation under practical assumptions [2].
- For each channel tap, a MIMO channel matrix H of size $N_r \times N_t$ is generated as

$$H = \sqrt{P_{tap}} \cdot unvec \left(R_{spat}^{1/2} \times vec(H_{iid}) \right),$$

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.

- Three pairs of values (α, β) are defined for low, medium and high correlation. The choice of values stems from the capacity criterion $C_\lambda = (1 - \lambda)C_0 + \lambda C_1$ where C_0 and C_1 denote the MIMO channel capacity at 15 dB SNR for zero and full correlation, respectively, and $\lambda = 0.5$ and $\lambda = 0.9$ for medium and high correlation, respectively.
- Finally, for each of low, medium and high spatial correlation, matrices R_{spat} are provided for 1x2, 2x2, 4x2 and 4x4 antenna configurations. Note that values are adjusted where needed to ensure positive semi-definite matrices.

2.2 Extension to 8-Tx cross-polarized antennas

It is seen as highly desirable to reuse the above existing framework for defining 8-Tx correlation matrices while some adjustments are obviously needed to include polarization modeling. These are discussed in the following.

A known fact is that one may not model the MIMO correlation matrix between two pairs of dual-polarized antennas (see Figure 1 & 2 in [3]) in the form of a Kronecker multiplication as $R_{spat} = R_{eNB} \otimes R_{UE}$. This is essentially because:

- There may exist branch power imbalances which require weighting at each spatial correlation coefficient of R_{spat} as discussed in [5];
- Vertical/horizontal polarization branches are typically mutually uncorrelated.

Therefore, a model of the following kind is considered as more appropriate [3][4][5]:

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

where Γ is the so-called *polarization correlation matrix*.

In the following, we extend the framework and derivations in [3] to 8x2 and 8x4 antenna configurations considering either co- or cross-polarized antennas at the UE side.

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 correlation matrix is obtained as:

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

where during the derivation it was assumed that different polarization branches are mutually uncorrelated. The parameter γ depends on the cross-polarization ratio (XPR) as $\gamma = (1 - \text{XPR}) / (1 + \text{XPR})$ (see [3] for the relation of the XPR to the channel branch coefficients). The value $\gamma = 0$ corresponds to $\text{XPR} = 1$ meaning polarization channel branches with equal power while $\gamma = 1$ corresponds to $\text{XPR} = 0$ 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).

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

As discussed in [3][4], the modeling in Eq. (2) fails at achieving medium-to-high MIMO correlation regardless the value of α . This is because each of the two Rx antenna elements is associated to different and mutually uncorrelated polarization branches. One preferred way to circumvent this issue is to resort to 2-Rx ULA configuration at the UE side, which leads to the following MIMO correlation matrix in the 8x2 case:

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

where the parameter β governs the correlation between ULA antenna elements at the receiver and $\delta = 1$, which corresponds to the case that no power is received along one polarization at the UE.

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:

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

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

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

Similarly to the 8x2 case, one may need to resort to 4-Rx ULA configuration in the 8x4 case in order to reach medium-to-high correlation. The MIMO correlation matrix takes then the following form:

$$R = \begin{bmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{1/9*} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{4/9*} & \alpha^{1/9*} & 1 & \alpha^{1/9} \\ \alpha^* & \alpha^{4/9*} & \alpha^{1/9*} & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & \delta \\ \delta & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & \beta^{1/9} & \beta^{4/9} & \beta \\ \beta^{1/9*} & 1 & \beta^{1/9} & \beta^{4/9} \\ \beta^{4/9*} & \beta^{1/9*} & 1 & \beta^{1/9} \\ \beta^* & \beta^{4/9*} & \beta^{1/9*} & 1 \end{bmatrix}, \quad (\text{Eq. 5})$$

where the parameter β governs the correlation between ULA antenna elements at the receiver and $\delta = 1$, which corresponds to the case that no power is received along one polarization at the UE.

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 [6], 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 [7] also echoes this issue already in the context of 4x4 transmission, which may also pertain to the 8x4 case for rank greater than 2.

General remarks

A few remarks are now in order:

- eNodeB/UE relative antenna orientation (i.e. slants) is now part of previously described 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 $1/2$.
- Antenna element indexing/labeling is of importance when it comes further to CSI testing with the agreed 8-Tx double codebook. Hence it needs to be explicitly defined, i.e. which pairs of MIMO branches each correlation coefficient refers to. We propose to adopt the same antenna indexing as in the one in RAN1 during 8-Tx codebook studies [8], that is:

- o *If antenna 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

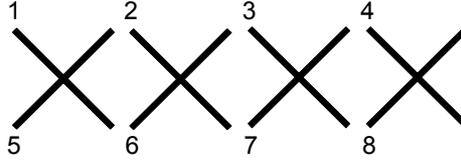


Figure 1: Antenna indexing for 8-Tx cross polarized array at eNB.

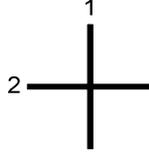


Figure 2: Antenna indexing for 2-Rx cross polarized antenna at UE.

- Given the above convention, the previously described correlation matrices are indexed as (first row):
 - 8x2, Eq. (2) and Eq. (3):
 $[t_{1r_1}, t_{1r_2}, t_{5r_1}, t_{5r_2}, t_{2r_1}, t_{2r_2}, t_{6r_1}, t_{6r_2}, t_{3r_1}, t_{3r_2}, t_{7r_1}, t_{7r_2}, t_{4r_1}, t_{4r_2}, t_{8r_1}, t_{8r_2}]$, where t_{i,r_j} denotes the MIMO channel branch from Tx antenna t_i to Rx antenna r_j , $i=1,\dots,8$ and $j=1,2$.
 - 8x4, Eq. (4) and Eq. (5):
 $[t_{1r_1}, t_{1r_2}, t_{1r_3}, t_{1r_4}, t_{5r_1}, t_{5r_2}, t_{5r_3}, t_{5r_4}, t_{2r_1}, \dots, t_{2r_2}, t_{6r_1}, \dots, t_{6r_4}, t_{3r_1}, \dots, t_{3r_4}, t_{7r_1}, \dots, t_{7r_4}, \dots, t_{4r_1}, \dots, t_{4r_4}, t_{8r_1}, \dots, t_{8r_4}]$, where t_{i,r_j} denotes the MIMO channel branch from Tx antenna t_i to Rx antenna r_j , $i=1,\dots,8$ and $j=1,\dots,4$.
 - Polarization correlation matrix in Eq. (2) and Eq. (4):

$$\Gamma = \begin{bmatrix} 1 & 0 & \gamma & 0 \\ 0 & 1 & 0 & -\gamma \\ \gamma & 0 & 1 & 0 \\ 0 & -\gamma & 0 & 1 \end{bmatrix}$$
, where the first row is indexed as $[t_{1r_1}, t_{1r_2}, t_{5r_1}, t_{5r_2}]$. Note that this assumes that $\Gamma = E[\text{vec}(Q) \cdot \text{vec}(Q)^H]$ with a signal model of the form $y = Q \cdot x$ where row indices of the matrix Q are for UE Rx antennas and column indexing goes along eNB Tx antennas (see [3] for derivation of Γ).

In the following section we discuss the considered approaches for MIMO correlation modeling and the choice of parameters from a channel capacity perspective.

2.3 Channel capacity considerations for 8-Tx MIMO correlation modeling

2.3.1 Capacity criterion in LTE Rel-8

During Rel-8 timeframe, RAN4 made use of a channel capacity based criterion in order to set the pairs of parameters (α, β) governing the MIMO correlation and derived correspondingly matrices for low, medium and high correlation. A particular choice of values stems from the following capacity criterion:

$$C_\lambda = (1 - \lambda)C_0 + \lambda C_1, \quad C_u = \log \left(\det \left(I + \frac{SNR}{N_t} H_c \times H_c^H \right) \right), \quad u = \{0, 1, \lambda\}, \quad (\text{Eq. 4})$$

where H_c is the $N_r \times N_t$ spatially correlated MIMO channel matrix of interest, C_0 and C_1 denote the corresponding MIMO channel capacity at 15 dB SNR for zero and full correlation respectively. It was agreed to use $\lambda = 0.5$ and $\lambda = 0.9$ for medium and high correlation.

In LTE Rel-8 modeling, there is a one-to-one mapping between channel correlation, spatial correlation at eNB/UE side and channel capacity, which is illustrated in Table 1.

Table 1: Methodology followed for MIMO correlation in Rel-8; assumes ULA at both eNB and UE side.

Correlation scenario	Spatial correlation at transmitter (eNB)	Spatial correlation at receiver (UE)	Channel capacity
Low	Low ($\alpha = 0$)	Low ($\beta = 0$)	High (maximum) ($\lambda = 0$ at 15 dB SNR)
Medium	Medium ($\alpha = 0.3$)	High ($\beta = 0.9$)	Medium ($\lambda = 0.5$ at 15 dB SNR)
High	High ($\alpha = 0.9$)	High ($\beta = 0.9$)	Low ($\lambda = 0.9$ at 15 dB SNR)

2.3.2 Applicability of the capacity criterion to LTE Rel-10

In the following, we discuss the possible extension of the Rel-8 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. (4) for the 8x4 case.

Medium spatial correlation scenarios:

During Rel-8 timeframe, 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 transmission modes. In Rel-10 correlation matrices are primarily intended for CSI testing with the focus on high/low spatial correlation scenarios. Hence, besides targeting completeness of MIMO correlation modeling in TS 36101, we don't see much 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 [3][4]). 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 (as seen further from provided results). Such channel allows mostly rank-1 transmission.

Earlier terminology becomes hence a bit misleading and Table 2 attempts at clarifying the situation by defining two distinct scenarios for high spatial correlation. The use of two distinct UE antenna configurations is further motivated by CSI testing considerations (discussed in a companion paper [10]).

Table 2: Potential methodology for 8x2 MIMO correlation in Rel-10; cross-polarized antennas at eNB and either co- or cross-polarized antennas at UE side.

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

2.3.3 Simulation results for 8x2 and 8x4 configurations

In Figure 3, 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 [8]. Table 3 summarizes the simulated cases and provides the values for the achieved λ at 15 dB SNR according to the capacity criterion in Eq. (4). 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).

Table 3: Simulated cases for 8x2 MIMO capacity; values of parameters (α, β); achieved value for λ

Legend		Description	Spatial correlation modeling	α	β	λ
[xxxx->+]	C_0	Capacity with zero spatial correlation	$R = \begin{bmatrix} 1 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & 1 \end{bmatrix}$	-	-	0
[xxxx->+]	C_1	Capacity with full spatial correlation	$R = \begin{bmatrix} 1 & \dots & 1 \\ \vdots & \ddots & \vdots \\ 1 & \dots & 1 \end{bmatrix}$	-	-	1
[xxxx->+]	$C(\alpha = 0, \gamma = 0, \beta = N/A)$	Capacity assuming the spatial correlation matrix in Eq. (2) with $\gamma = 0$	Eq. (2)	0	-	0.0003
[xxxx->+]	$C(\alpha = 0.9, \gamma = 1, \beta = N/A)$	Capacity assuming the spatial correlation matrix in Eq. (2) with $\gamma = 1$		0.9	-	0.2021
[xxxx->+]	$C_{SCM, \times \times \times (\lambda/2) \rightarrow +}$	Capacity of SCM channel model with 8 deg. azimuth spread; eNB: 8-Tx XP antennas with $\lambda/2$ spacing and $\{+45, -45\}$ deg. slant; UE: 2 Rx XP antenna with $\{0, 90\}$ deg. slant	SCM	-	-	0.1913
[xxxx->+]	$C_{SCM, \times \times \times (4\lambda) \rightarrow +}$	Capacity of SCM channel model with 8 deg. azimuth spread; eNB: 8-Tx XP antennas with 4λ spacing and $\{+45, -45\}$ deg. slant; UE: 2 Rx XP antenna with $\{0, 90\}$ deg. slant		-	-	0.0353
[xxxx->]	$C(\alpha = 0.2, \delta = 1, \beta = 0.7)$	Capacity assuming the spatial correlation matrix in Eq. (3) with $\delta = 1$	Eq. (3)	0.2	0.7	0.4826
[xxxx->]	$C(\alpha = 0.3, \delta = 1, \beta = 0.9)$			0.3	0.9	0.6995
[xxxx->]	$C(\alpha = 0.9, \delta = 1, \beta = 0.9)$			0.9	0.9	0.9065
[xxxx->]	$C_{SCM, \times \times \times (\lambda/2) \rightarrow }$	Capacity of SCM channel model with 8 deg. azimuth spread; eNB: 8-Tx XP antennas with $\lambda/2$ spacing and $\{+45, -45\}$ deg. slant; UE: 2 Rx ULA antenna with $\lambda/2$ spacing and 0 deg. slant	SCM	-	-	0.3987
[xxxx->]	$C_{SCM, \times \times \times (4\lambda) \rightarrow }$	Capacity of SCM channel model with 8 deg. azimuth spread; eNB: 8-Tx XP antennas with 4λ spacing and $\{+45, -45\}$ deg. slant; UE: 2 Rx ULA antenna with $\lambda/2$ spacing and 0 deg. slant		-	-	0.148

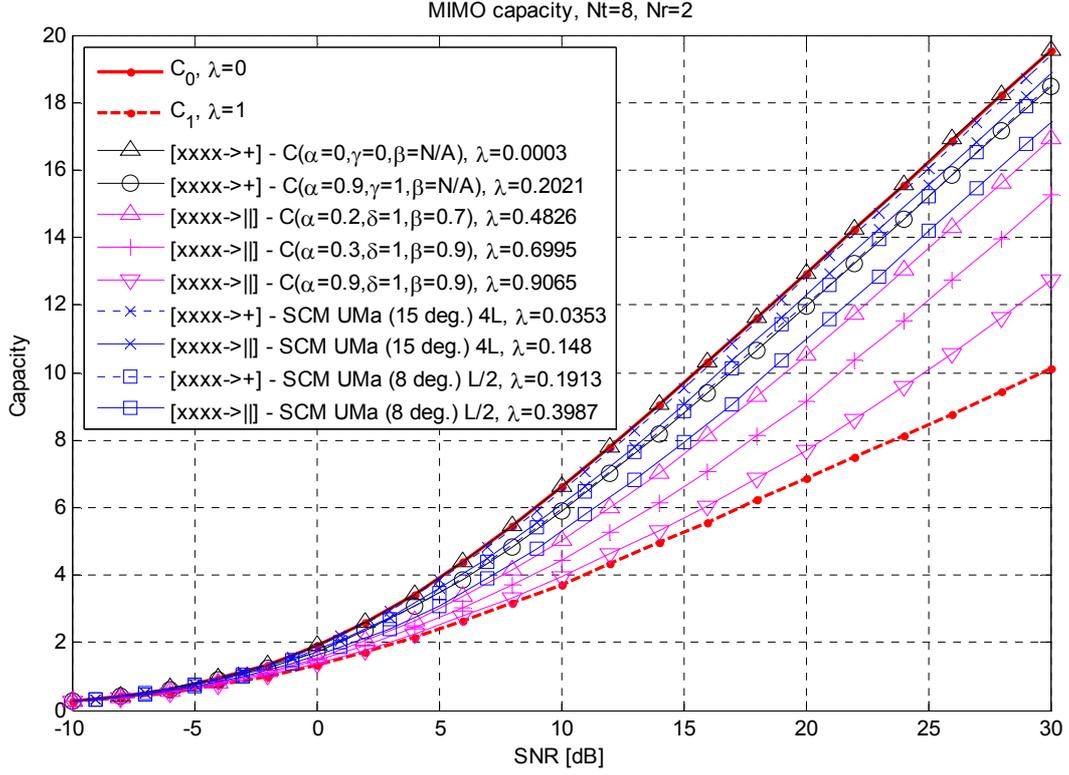


Figure 3: 8x2 MIMO channel capacity.

In Figure 4 and Table 4 we provide a similar analysis for the 8x4 case.

Table 4: Simulated cases for 8x4 MIMO capacity; values of parameters (α, β); achieved value for λ

Legend	Description	Spatial correlation modeling	α	β	λ
[xxxx->++] C_0	Capacity with zero spatial correlation	$R = \begin{bmatrix} 1 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & 1 \end{bmatrix}$	-	-	0
[xxxx->++] C_1	Capacity with full spatial correlation	$R = \begin{bmatrix} 1 & \dots & 1 \\ \vdots & \ddots & \vdots \\ 1 & \dots & 1 \end{bmatrix}$	-	-	1
[xxxx->++] $C(\alpha = 0, \gamma = 0, \beta = 0)$	Capacity assuming the spatial correlation matrix in Eq. (4) with $\gamma = 0$	Eq. (4)	0	0	0.0005
[xxxx->++] $C(\alpha = 0.6, \gamma = 0, \beta = 0.9)$			0.6	0.9	0.5036
[xxxx->++] $C(\alpha = 0.3, \gamma = 0, \beta = 0.9)$			0.3	0.9	0.4398
[xxxx->++] $C(\alpha = 0.9, \gamma = 1, \beta = 0.9)$			0.9	0.9	0.5794
[xxxx->++] $C_{SCM, \times \times \times (\lambda/2) \rightarrow ++}$	Capacity of SCM channel model with 8 deg. azimuth spread; eNB: 8-Tx XP antennas with $\lambda/2$ spacing and $\{+45, -45\}$ deg. slant; UE: 4 Rx XP antenna with $\{0, 90\}$ deg. slant and $\lambda/2$ spacing between pairs of co-polarized elements	SCM	-	-	0.4017
[xxxx->++] $C_{SCM, \times \times \times (4\lambda) \rightarrow ++}$	Capacity of SCM channel model with 8 deg. azimuth spread; eNB: 8-Tx XP		-	-	0.0923

		antennas with 4λ spacing and $\{+45,-45\}$ deg. slant; UE: 4 Rx XP antenna with $\{0,90\}$ deg. slant and $\lambda/2$ spacing between pairs of co-polarized elements				
[xxxx->]	$C(\alpha = 0.5, \delta = 1, \beta = 0.9)$	Capacity assuming the spatial correlation matrix in Eq. (5) with $\delta = 1$	Eq. (5)	0.5	0.9	0.9016
[xxxx->]	$C(\alpha = 0.9, \delta = 1, \beta = 0.9)$			0.5	0.9	0.9608
[xxxx->]	$C_{SCM, \times \times \times (\lambda/2) \rightarrow }$	Capacity of SCM channel model with 8 deg. azimuth spread; eNB: 8-Tx XP antennas with $\lambda/2$ spacing and $\{+45,-45\}$ deg. slant; UE: 4 Rx ULA antenna with $\lambda/2$ spacing and 0 deg. slant	SCM	-	-	0.5053
[xxxx->]	$C_{SCM, \times \times \times (4\lambda) \rightarrow }$	Capacity of SCM channel model with 8 deg. azimuth spread; eNB: 8-Tx XP antennas with 4λ spacing and $\{+45,-45\}$ deg. slant; UE: 4 Rx ULA antenna with $\lambda/2$ spacing and 0 deg. slant		-	-	0.1943

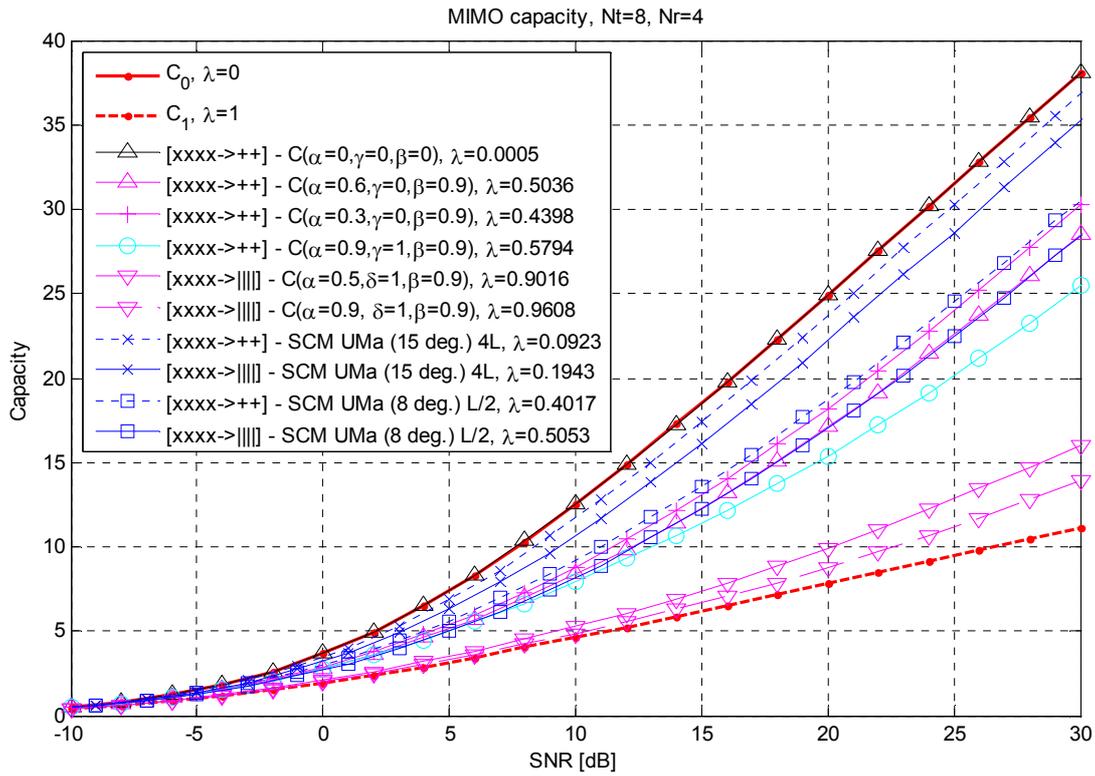


Figure 4: 8x4 MIMO channel capacity.

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 8x2 configuration with cross-polarized antennas, derive the MIMO correlation matrix as

$$R = R_{eNB} \otimes \Gamma \otimes R_{UE},$$

where we define:

- o One scenario for low spatial correlation:

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

- o Two scenarios for high spatial correlation:

- High 1 (cross-polarized antennas at both eNB and UE) characterized by high transmitter side correlation and low receiver side correlation

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

- High 2 (cross-polarized antennas at eNB and ULA at UE) characterized by high transmitter side correlation and high receiver side correlation

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

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

- The mapping/indexing of antenna elements and further of spatial correlation coefficients needs to be explicitly specified, preferably following the same assumptions as RAN1 in [8].
- The following items require further study and discussion in RAN4:
 - o Potential use cases & need for medium correlation besides achieving completeness of the description.
 - o 8x4 and 8x8 configurations with special attention on eigenvalue distributions when it comes to testing transmission ranks higher than 2.
 - o Channel normalization and related power scaling needs to be defined (also relates to SNR definition).

References

- [1] R4-104913, TP for TR 36.807: E-DL MIMO Correlation Matrices for 8 Tx Antennas, Ericsson, ST-Ericsson, Huawei, Nokia, Nokia Siemens Networks
- [2] R4-071317, Discussion on per channel versus per path correlation, Agilent Technologies
- [3] R4-104296, On correlation matrices for eDL-MIMO with eight transmit antennas, Nokia, Nokia Siemens Networks
- [4] R4-103570, DL-MIMO channel model, Huawei, HiSilicon
- [5] R4-104419, Correlation Matrices for E-DL MIMO Transmission using Cross-Polarized Antennas, Ericsson, ST-Ericsson
- [6] R4-104271, Verification of enhanced downlink MIMO, Nokia
- [7] R4-103700, On medium correlation values for 4x4 MIMO transmission, Ericsson, ST-Ericsson
- [8] R1-102508, Simulation Assumption for 8 Tx Codebook Design, Rapporteur (NTT DOCOMO)
- [9] TS 36.101, User Equipment (UE) radio transmission and reception (Release 9), V9.5.0 (2010-10)
- [10] R4-110327, Channel state feedback requirements for eDL-MIMO, Renesas Electronics Europe