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Agenda Item:

Source: Nokia[1]

Title: MIMO channel model for link-level simulations using correlated antennas

Document for: Discussion

1. Introduction

In a previous document [1], the simulation description of the ITU temporal channel model has been extended to take into account antenna correlation at Node B. We propose a further extension by considering multiple correlating antenna elements at both UE and Node B, which form a MIMO (multiple-input multiple-output) channel. Modelling of these correlations is important in MIMO channel simulations, but the required technique is not self-evident. In this document, antenna element correlation properties are combined in an innovative way to account for the correlation characteristics of the MIMO channel. Channel measurements support the proposed model.

2. Multi-element Tx/Rx channel model

Let us consider the set-up pictured in Figure 1 with M antennas at Node B and N antennas at UE. The signals at Node B are denoted $\mathbf{y}(t) = [y_1(t), y_2(t),..., y_M(t)]^T$, where $y_m(t)$ is the signal at the m^{th} antenna port and $(\cdot)^T$ denotes transposition. Similarly, the signals at UE are the components of the vector $\mathbf{s}(t) = [s_1(t), s_2(t),..., s_N(t)]^T$.

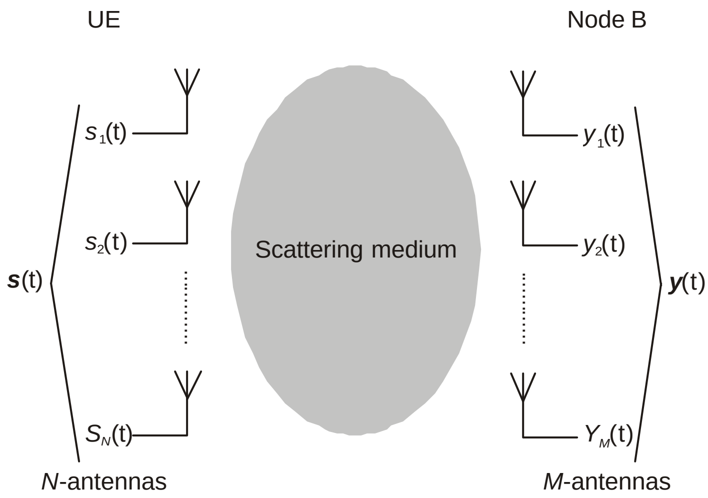

Figure 1: Arrays in a scattering environment

The wideband MIMO radio channel which describes the connection between UE and Node B can be expressed as

[1] In cooperation with the Cellular Systems (CSys) group of the Centre for PersonKommunikation (CPK) in Aalborg, Denmark, within the framework of the European IST (Information Society Technologies) METRA (Multiple Element Transmit/Receive Antennas) project [2].

$$\mathbf{H}(?)\ ?\ \sum_{l?1}^{L} \mathbf{A}_l ? ? ? ?_l ? \qquad (1)$$

where

?? $\mathbf{H}(?)\ ?\ \mathbf{C}^{\mathrm{MxN}}$

?? $\mathbf{A}_l\ ?\ ?\ ?_{mn}^{(l)} ?_{M?N}$ is a complex matrix which describes the linear transformation between the two considered antenna arrays at delay $?_l$

?? $?_{mn}^{(l)}$ is the complex transmission coefficient between antenna n at UE and antenna m at Node B.

This is a simple tapped delay line model, where the channel coefficients at the L delays are represented by matrices. The relation between the vectors $\mathbf{y}(t)$ and $\mathbf{s}(t)$ can thus be expressed as

$$\mathbf{y}(t)\ ?\ ?\mathbf{H}(?)\mathbf{s}(t ? ?)d? \qquad (2)$$

$$\mathbf{s}(t)\ ?\ ?\mathbf{H}^{T}(?)\mathbf{y}(t ? ?)d? \qquad (3)$$

depending on whether the transmission is from UE to Node B, or vice versa. The Power Delay Profile (PDP) of each of the *MN* channels can be set separately.

The spatial correlation coefficient between antennas m_1 and m_2 at Node B,

$$?_{m_1 m_2}^{\mathrm{Node\,B}}\ ?\ \left\langle \left|?_{m_1 n}^{(l)}\right|^2, \left|?_{m_2 n}^{(l)}\right|^2 \right\rangle \qquad (4)$$

is easily obtained from the literature, e.g. [3]. Notice from (4) that it is assumed that the spatial correlation function at Node B is independent of n. This is a reasonable assumption provided that all antennas at the MS are closely co-located and have similar radiation patterns, so they effectively illuminate the same surrounding scatterers.

The spatial power correlation coefficient observed at UE is defined in a similar way as in (4) for the Node B. It writes

$$?_{n_1 n_2}^{\mathrm{UE}}\ ?\ \left\langle \left|?_{mn_1}^{(l)}\right|^2, \left|?_{mn_2}^{(l)}\right|^2 \right\rangle \qquad (5)$$

It has also been extensively studied in the literature, e.g. [3]. Assuming UE surrounded by local scatterers, antennas separated by more than $\frac{?}{2}$, where $?$ represents the wavelength, can be regarded as practically uncorrelated [4], so (5) nearly equals zero for $n_1\ ?\ n_2$. However, experimental results reported in [5] show that in some situations antennas separated with $\frac{?}{2}$ might be highly correlated, even in indoor environments. Under such conditions, an approximate expression of the spatial correlation function averaged over all possible azimuth orientations of UE is derived in [6].

Given (4) and (5), let us define the symmetrical correlation matrices $\mathbf{R}_{\mathrm{Node\,B}}\ ?\ ??_{pq}^{\mathrm{Node\,B}} ?_{MxM}$ and $\mathbf{R}_{\mathrm{UE}}\ ?\ ??_{pq}^{\mathrm{UE}} ?_{NxN}$ for later use. The spatial correlation function at Node B and at UE does not provide sufficient information to generate the matrices $\mathbf{A}_l$. The correlation of two transmission coefficients connecting two different sets of antennas also needs to be determined, i.e.

$$\rho^{n_1 m_1}_{n_2 m_2} = \left\langle \left|\alpha^{(l)}_{m_1 n_1}\right|^2, \left|\alpha^{(l)}_{m_2 n_2}\right|^2 \right\rangle \tag{6}$$

$$= \rho^{\mathrm{UE}}_{n_1 n_2}\,\rho^{\mathrm{Node\,B}}_{m_1 m_2} \tag{7}$$

Following the approach of [7], where it was found that the correlation between two spatially separated antennas with different polarisations is given by the product of their spatial and polarisation correlation coefficients, an approximation of (6) is proposed in (7). This assumption, first presented in [8], is validated in [3]. In this last reference, eigenanalysis results based on data collected from measurement campaigns on the one hand, and generated by the proposed MIMO channel simulator on the other hand, fairly match. Figure 3 shows such results, obtained with simulated date generated using the correlation matrices $\mathbf{R}_{\mathrm{Node\,B}}$ and $\mathbf{R}_{\mathrm{UE}}$ detailed in Figure 2 ($\otimes$ stands for the Kronecker product).

$$\underbrace{\begin{bmatrix} 1 & .5442 & .0968 & .1284 \\ .5442 & 1 & .2622 & .1631 \\ .0968 & .2622 & 1 & .2104 \\ .1284 & .1631 & .2104 & 1 \end{bmatrix}}_{\mathbf{R}_{\mathrm{Node\,B}}} \otimes \underbrace{\begin{bmatrix} 1 & .3409 & .2893 & .0772 \\ .3409 & 1 & .2354 & .1814 \\ .2893 & .2354 & 1 & .2403 \\ .0772 & .1814 & .2403 & 1 \end{bmatrix}}_{\mathbf{R}_{\mathrm{UE}}}$$

$$= \begin{bmatrix}
1 & .3409 & .2893 & .0772 & .5442 & .1855 & .1574 & .042 & .0968 & 0.33 & .028 & .0075 & .1284 & .0438 & .0371 & .0099 \\
.3409 & 1 & .2354 & .1814 & .1855 & .5442 & .1281 & .0987 & 0.33 & .0968 & .0228 & .0176 & .0438 & .1284 & .0302 & .0233 \\
.2893 & .2354 & 1 & .2403 & .1574 & .1281 & .5442 & .1308 & .028 & .0228 & .0968 & .0233 & .0371 & .0302 & .1284 & .0309 \\
.0772 & .1814 & .2403 & 1 & .042 & .0987 & .1308 & .5442 & .0075 & .0176 & .0233 & .0968 & .0099 & .0233 & .0309 & .1284 \\
.5442 & .1855 & .1574 & .042 & 1 & .3409 & .2893 & .0772 & .2622 & .0894 & .0759 & .0202 & .1631 & .0556 & .0472 & .0126 \\
.1855 & .5442 & .1281 & .0987 & .3409 & 1 & .2354 & .1814 & .0894 & .2622 & .0617 & .0476 & .0556 & .1631 & .0384 & .0296 \\
.1574 & .1281 & .5442 & .1308 & .2893 & .2354 & 1 & .2403 & .0759 & .0617 & .2622 & .063 & .0472 & .0384 & .1631 & .0392 \\
.042 & .0987 & .1308 & .5442 & .0772 & .1814 & .2403 & 1 & .0202 & .0476 & .063 & .2622 & .0126 & .0296 & .0392 & .1631 \\
.0968 & .033 & .028 & .0075 & .2622 & .0894 & .0759 & .0202 & 1 & .3409 & .2893 & .0772 & .2104 & .0717 & .0609 & .0162 \\
.033 & .0968 & .0228 & .0176 & .0894 & .2622 & .0617 & .0476 & .3409 & 1 & .2354 & .1814 & .0717 & .2104 & .0495 & .0382 \\
.028 & .0228 & .0968 & .0233 & .0759 & .0617 & .2622 & .063 & .2893 & .2354 & 1 & .2403 & .0609 & .0495 & .2104 & .0506 \\
.0075 & .0176 & .0233 & .0968 & .0202 & .0476 & .063 & .2622 & .0772 & .1814 & .2403 & 1 & .0162 & .0382 & .0506 & .2104 \\
.1284 & .0438 & .0371 & .0099 & .1631 & .0556 & .0472 & .0126 & .2104 & .0717 & .0609 & .0162 & 1 & .3409 & .2893 & .0772 \\
.0438 & .1284 & .0302 & .0233 & .0556 & .1631 & .0384 & .0296 & .0717 & .2104 & .0495 & .0382 & .3409 & 1 & .2354 & .1814 \\
.0371 & .0302 & .1284 & .0309 & .0472 & .0384 & .1631 & .0392 & .0609 & .0495 & .2104 & .0506 & .2893 & .2354 & 1 & .2403 \\
.0099 & .0233 & .0309 & .1284 & .0126 & .0296 & .0392 & .1631 & .0162 & .0382 & .0506 & .2104 & .0772 & .1814 & .2403 & 1
\end{bmatrix}$$

Figure 2: Typical measured correlation matrices for a 4x4 set-up, and their Kronecker product, which serves to generate the taps of the MIMO channel model

The correlated transmission coefficients can be obtained according to

$$\tilde{\mathbf{A}}_l = \sqrt{P_l}\,\mathbf{C}_l\,\mathbf{a}_l \tag{8}$$

where

- $\tilde{\mathbf{A}}_l = \left[\alpha^{(l)}_{11}\ \alpha^{(l)}_{21} \cdots \alpha^{(l)}_{M1}\ \alpha^{(l)}_{12}\ \alpha^{(l)}_{22} \cdots \alpha^{(l)}_{MN}\right]^T_{MNx1}$
- P_l represents the power of the l^{th} tap as defined by the Power Delay Profile,
- $\mathbf{C}_l \in \mathbf{R}^{\mathrm{MNxMN}}$ is a symmetrical mapping matrix defining the spatial correlation for l^{th} tap, derived from the outcome of the Kronecker product shown in Figure 2 [8],

?? $\mathbf{a}_l$? $\left[a_1^{(l)} a_2^{(l)} \cdots a_{MN}^{(l)}\right]^T_{MNx1}$ with the $a_x^{(l)}$ are defined as random processes and embed fading information.

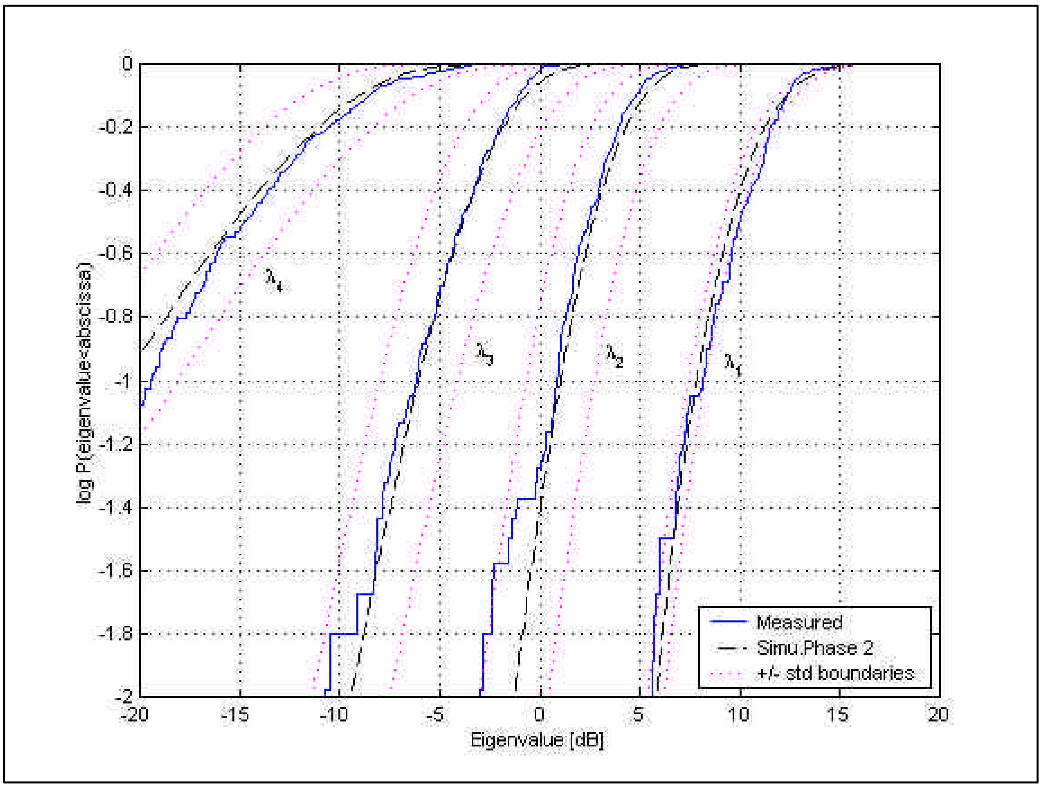

Figure 3: Comparison of eigenanalysis results of measured and simulated data. The measured eigenvalues match with the simulated ones within a one-standard-deviation boundary.

3. Choice of channel parameters

Guidelines for choosing the values of the channel parameters are given in [3]. Note that this spatial model can be applied to any path model, including 1-path Rayleigh, modified ITU Ped A and modified ITU Veh A.

4. Conclusion

We propose to extend the model of [1] by taking into consideration multiple element antennas at both ends of the communication link.

5. References

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