TSG-RAN Working Group 1 Meeting No. 6 *TSGR1#6(99)918*
July 13-16, Espoo, Finland

Agenda Item: **Ad Hoc 1**

Source: **Bosch**

Title: **Tx Diversity with Joint Predistortion**

Document for: **Discussion**

Introduction

Joint predistortion (JP) is a technique for reducing UE detection complexity in the TDD mode. Tx diversity, and in particular smart antennas, is another promising technique for greatly improving system capacity. This paper shows that both techniques are compatible and benefit from each other. First the principle of combining joint predistortion and smart antennas will be described. The required complexity will be discussed. Corresponding simulation results will be presented.

Principles

The principle of JP is to modify the transmit signal such that it will be optimally detected by a one finger Rake receiver. Channel distortions are accounted for by the transmitter. So, the received signal does not depend on the mobile channel in use. This allows for using smart antennas simply by predistorting the transmit signals separately on each smart antenna element. Fig.1 illustrates this technique (scheme 1).

Another possibility is to simultaneously predistort the signals of all antenna elements. This technique results in higher BER performance and requires less computational power. Fig.2 illustrates the principle (scheme 2). A corresponding algorithm is given in the appendix.

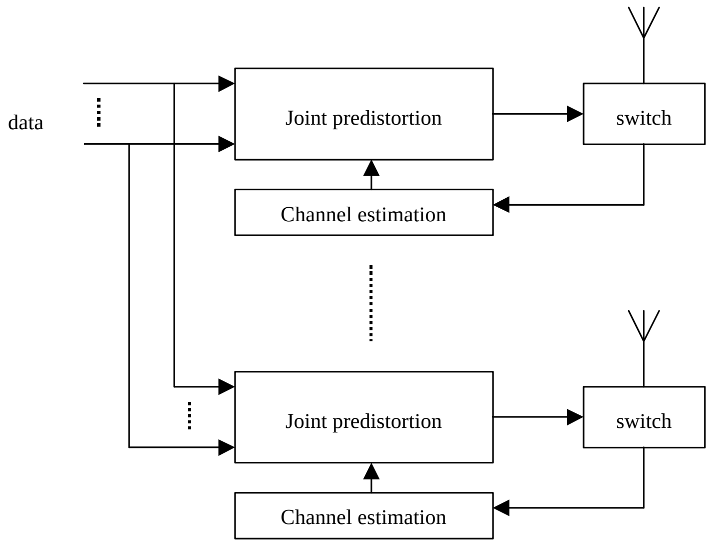

Fig.1: Scheme 1: transmitter with smart antennas by separate joint predistortion separately on all antenna elements.

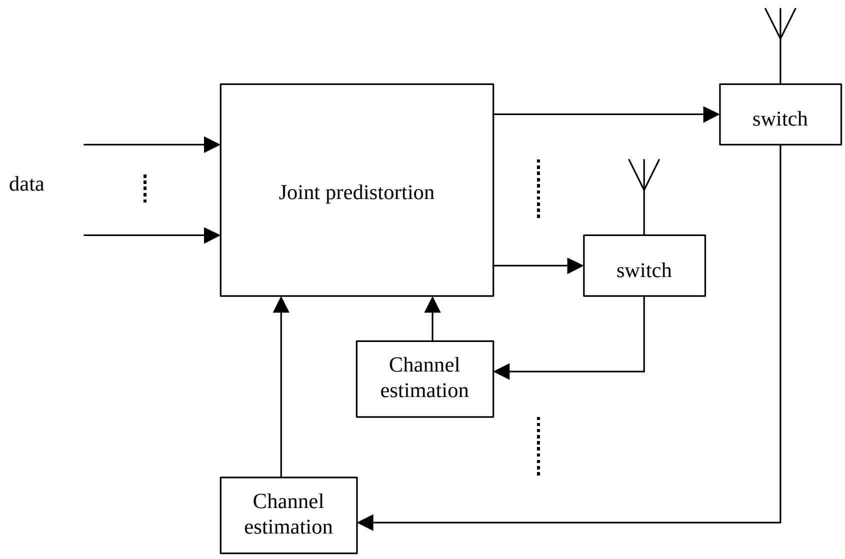

Fig.2: Scheme 2: transmitter with smart antennas by simultaneous joint predistortion on all antenna elements.

Complexity

JP complexity at the transmitter is defined by channel estimation complexity and by the complexity of the actual JP algorithm in use. Channel estimation does not require any additional complexity, since it has to be done anyway in the uplink on all antenna elements in order to jointly detect uplink data.

The actual JP algorithm may be performed by the same operations as joint detection (JD). For example the algorithm described in the appendix uses the same operations as the ZFBLE joint detector does. Like in JD, approximate algorithms are also applicable here. Corresponding MIPS requirements may be found in [1].

Of course, using smart antennas increases the JP algorithm's complexity. Fig.3 shows the complexity of both separate and simultaneous smart antenna JP as a function of the number of antenna elements. Simultaneous smart antenna JP requires considerably lower complexity than separate smart antenna JP. 10 antenna elements require only about three times the complexity of one antenna element.

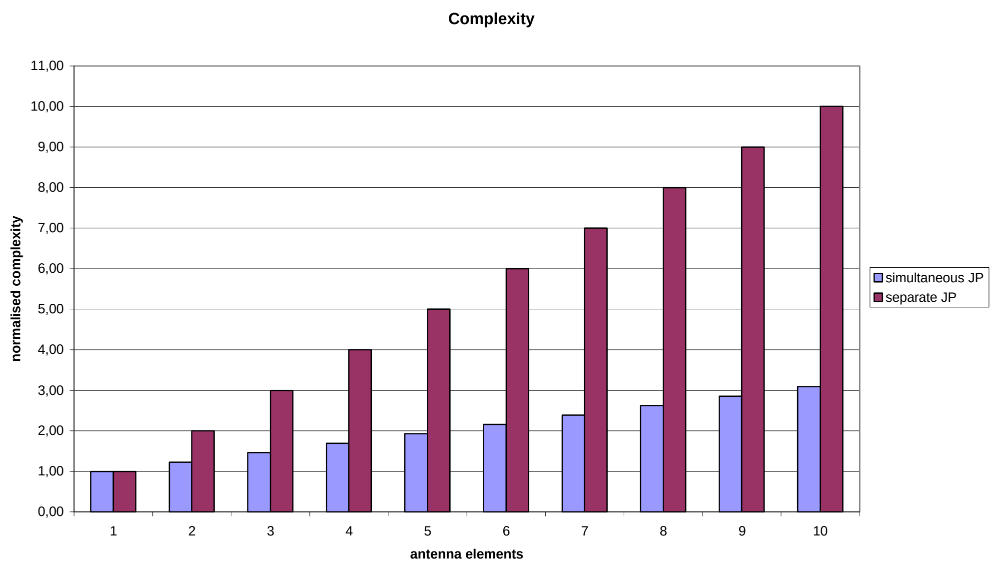

Fig.3: normalised complexity of smart antenna JP.

Simulations

Simulations have been carried out to evaluate the raw BER performance of JP when applied to two transmit antennas. These simulations extend the set of results presented for PATD, STD, TxAA and STTD in [3].
In order to allow a direct comparison of all Tx diversity results the same simulation parameters have been used:

- MMSE joint detector in the case of a single Tx antenna
- Matched filter detector in the case of JP
- 8 Users, 1 code per user, all users in one slot
- Burst type 1
- Vehicular A channel model
- User speed from 0 to 40 km/h

Two different frame structures were investigated:

FS1: Single switching points with symmetric DL/UL allocation (8/8)

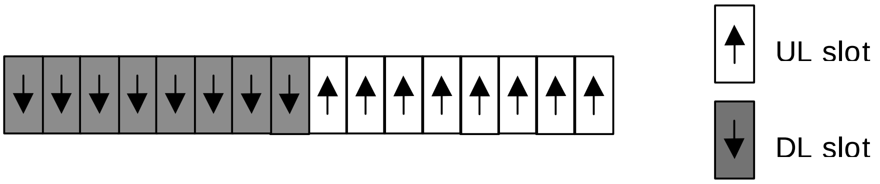

Fig.4: TDD FS1.

FS2: Multiple switching points with asymmetric DL/UL allocation (4/12)

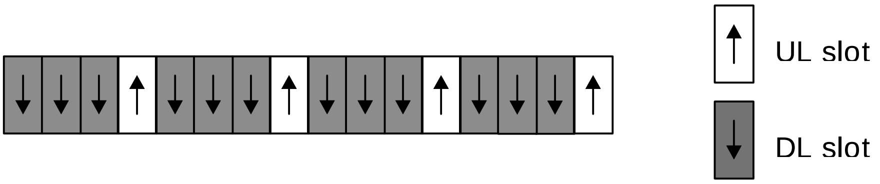

Fig.5: TDD FS2.

The worst case with respect to UL channel estimation was always used, which means that UL and DL slots have the maximum time separation.
Figure 5 presents the raw BER performance of scheme 1 (see figure 1) and scheme 2 (see figure 2) with ideal UL channel estimation compared to the single Tx antenna case with joint detection at the UE. The user velocity is 5 km/h.
Figure 6 shows the dependency on user velocity of JP scheme 2 for the two different frame structures FS1 and FS2. The UL E_b/N_0 is 6 dB the DL E_b/N_0 is 4 dB. Midamble UL channel estimation with hard threshold is applied.

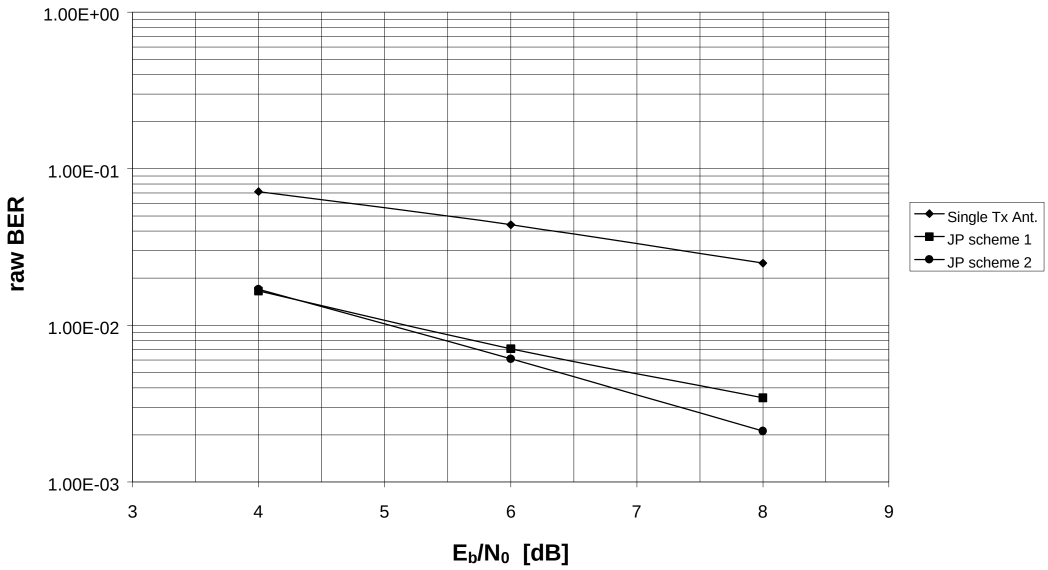

Fig.6: Ideal performance of JP scheme 1 and JP scheme 2 compared to single Tx antenna with joint detection.

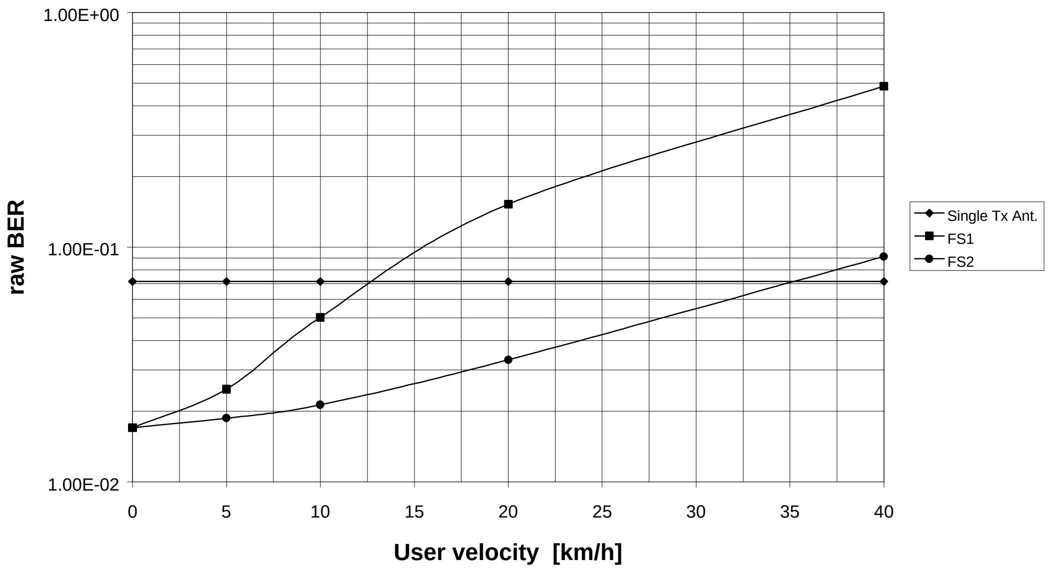

Fig.6: Dependency on user velocity of JP scheme 2 using FS1 and FS2.

Conclusions

The presented simulation results together with the results provided in [3] show that Tx diversity with Joint Predistortion leads to better performance compared to all other Tx diversity schemes up to 10 km/h user velocity if FS1 is applied. The maximum performance gain compared to the single Tx antenna case is about 5 dB in the vehicular A channel model compared to only 2 dB in the case of TxAA.
If FS2 is applied Tx diversity with JP leads to a gain compared to the single Tx case up to user velocities of 35 km/h.
JP significantly reduces the complexity of the UE. No channel estimation at the UE is required.

Appendix: a Smart Antennas Joint Predistortion Algorithm

In the following a JP algorithm operating jointly on all elements of a smart antennas array will be described in mathematical terms. The description is a modification of the JP algorithm given in [2].

Signals will be represented in time discrete form. Vectors are indicated by underscored lower case letters and matrices by upper case letters.

Let $\underline{d}^{(k)} = (d^{(k)}{}_1,\ldots,d^{(k)}{}_M)$, $k = 1,\ldots,K$ be the k-th user's data symbol vector of one data block to be transmitted. $\underline{d} = (\underline{d}^{(1)},\ldots,\underline{d}^{(K)})$ is the concatenation of all users' data blocks. CDMA-codes $\underline{c}^{(k)} = (c^{(k)}{}_1,\ldots,c^{(k)}{}_Q)$, $k = 1,\ldots,K$ of length Q are associated to each of the K users. With the k-th user's code matrix

$$C^{(k)} = \underbrace{\begin{pmatrix} \underline{c}^{(k)T} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \underline{c}^{(k)T} \end{pmatrix}}_{M} \Bigg\}_{M \cdot Q}, \; k = 1,\ldots,K$$

$$\underline{c}^{(k)T} = \text{ transposed vector } \underline{c}^{(k)}$$

the k-th user's data spreading can be written as

$$C^{(k)} \cdot \underline{d}^{(k)T}$$

The concatenated spreading signals of all users are

$$C \cdot \underline{d}^{T}$$

with

$$C = \begin{pmatrix} C^{(1)} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & C^{(K)} \end{pmatrix}$$

These signals will be linearly predistorted by the matrix P. The resulting user signals of a given antenna element l, ($l = 1,\ldots,L =$ number of antenna elements) are then summed up to yield the transmit signal $\underline{t}^{(l)}$ of that antenna element:
EMBED

$$\underline{t}^{T} = D \cdot P \cdot C \cdot \underline{d}^{T}$$

where $\underline{t} = (\underline{t}^{(1)},\ldots,\underline{t}^{(L)})$ denotes the concatenation of all antenna elements' signals $\underline{t}^{(l)}$. The summation matrix D is defined by

$$D = \underbrace{\begin{pmatrix} D_0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & D_0 \end{pmatrix}}_{L \cdot M \cdot Q \cdot K} \Bigg\} L \cdot M \cdot Q$$

$$D_0 = \underbrace{\begin{pmatrix} 1 & 0 & 0 & 1 & 0 & 0 & \cdots \\ 0 & \ddots & 0 & 0 & \ddots & 0 & \cdots \\ 0 & 0 & 1 & 0 & 0 & 1 & \cdots \end{pmatrix}}_{M \cdot Q \cdot K} \Bigg\} M \cdot Q$$

EMBEDEMBEDEMBEDEMBED

The transmit signal of antenna element l will propagate to the k-th receiver through the k,l-th radio channel. Convolution with the radio channel's impulse response $\underline{h}^{(k,l)} = (h_1^{(k,l)}, \ldots, h_W^{(k,l)})$ can be formulated as multiplication with the Toeplitz-structured matrix

$$H^{(k,l)} = \underbrace{\begin{pmatrix} h^{(k,l)}_1 & 0 & 0 \\ \vdots & \ddots & 0 \\ h^{(k,l)}_W & \vdots & h^{(k,l)}_1 \\ 0 & \ddots & \vdots \\ 0 & 0 & h^{(k,l)}_W \end{pmatrix}}_{M \cdot Q} \Bigg\} M \cdot Q + W - 1$$

With the k,l-th channel's additive noise $\underline{n}^{(k,l)} = (n^{(k,l)}_1, \ldots, n^{(k,l)}_{M \cdot Q + W - 1})$ the k-th receiver gets the signal

$$\underline{s}^{(k)T} = (H^{(k,1)}, \ldots, H^{(k,L)}) \cdot D \cdot P \cdot C \cdot \underline{d}^T + \sum_{l=1}^{L} \underline{n}^{(k,l)T}$$

This signal will be despread by the one finger Rake matrix

$$R^{(k)} = \underbrace{\begin{pmatrix} 0 & 0 & 0 \\ \vdots & \vdots & \vdots \\ 0 & & \\ \underline{c}^{(k)T} & 0 & \\ 0 & \ddots & 0 \\ 0 & 0 & \underline{c}^{(k)T} \end{pmatrix}}_{M} \Bigg\} M \cdot Q + W - 1$$

to get the k-th estimated data vector

$$\underline{\hat{d}}^{(k)^T} = R^{(k)^H} \cdot \underline{s}^{(k)^T}$$

$$R^{(k)H} = \text{ conjugate transposed matrix } R^{(k)}$$

With the combining matrices

$$R = \begin{pmatrix} R^{(1)} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & R^{(K)} \end{pmatrix}$$

$$H = \begin{pmatrix} H^{(1,1)} & 0 & 0 & \cdots & H^{(1,L)} & 0 & 0 \\ 0 & \ddots & 0 & & 0 & \ddots & 0 \\ 0 & 0 & H^{(K,1)} & \cdots & 0 & 0 & H^{(K,L)} \end{pmatrix}$$

$$\underline{n} = (\sum_{l=1}^{L} \underline{n}^{(1,l)}, \ldots, \sum_{l=1}^{L} \underline{n}^{(K,l)})$$

the concatenation vector of all estimated user data becomes

$$\underline{\hat{d}} = R^H \cdot H \cdot D^T \cdot D \cdot P \cdot C \cdot \underline{d}^T + R^H \cdot \underline{n}^T$$

We choose

$$P = (R^H \cdot H \cdot D^T \cdot D)^H \cdot \left[(R^H \cdot H \cdot D^T \cdot D) \cdot (R^H \cdot H \cdot D^T \cdot D)^H\right]^{-1} \cdot \underline{d}^T \times \\ \times \frac{1}{\left\|C \cdot \underline{d}^T\right\|^2} \cdot (C \cdot \underline{d}^T)^H$$

P is well defined, since the $M \cdot K \times M \cdot Q \cdot K$-matrix $R^H \cdot H \cdot D^T \cdot D$ has rank $M \cdot K$. Thus $(R^H \cdot H \cdot D^T \cdot D) \cdot (R^H \cdot H \cdot D^T \cdot D)^H$ can be inverted.

The given choice results in

$$\underline{\hat{d}}^T = \underline{d}^T + R^H \cdot \underline{n}^T$$

So the one finger Rake receiver results in data estimates without any MAI or ISI.

References

[1] Tdoc SMG2 UMTS-L1 301/98, "Receiver complexity with variable spreading option (TDD part)", source: Alcatel, Sept. 1998.

[2] Tdoc SMG2 UMTS-L1 82/98, "Joint Predistortion: a Proposal to allow for Low Cost UMTS TDD Mode Terminals", source: Bosch, Apr. 1998.

[3] Tdoc 3GPP TSGR1#6(99)879, "More results on transmit diversity for the TDD mode", source: Motorola, July. 1999.