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Source : **Motorola France**

Title : **Extended STTD with Switching for Open Loop Transmit Diversity for more than 2 Antennas**

1. Introduction

Space Time Transmit Diversity (STTD) was chosen by ETSI as the preferred Open-Loop transmit diversity scheme for the 2 antenna case on the basis of superior performance and power balanced operation at the transmission antennas.

However, as mentioned in ETSI XX.18, the case of Open-Loop schemes with more than 2 transmission antennas needs to be investigated. Motorola believes that this case will be important for future system deployments. However, STTD approaches are not readily applicable to the case of more than 2 antennas [1] without changes in the coding rate and/or increased code resource usage.

Motorola has studied various approaches to Open-Loop transmit diversity for the case of more than 2 transmission antennas, which have high commonality with STTD, and which do not require a change in coding or interleaving schemes or require more code resource. Two promising approaches are presented here.

2. STTD with 2 Antennas

The context for the proposed scheme is the UMTS/ARIB (3GPP) downlink of the FDD mode, for which control bits (DPCCH) and data bits (DPDCH) are mapped to QPSK symbols, spread with a user-specific orthogonal variable spreading factor (OVSF) channelisation code c_{ch}, and scrambled by cell-specific scrambling code c_{scramb}.

The transmission scheme for STTD is:-

Figure 1 : STTD scheme for 2 antennas.

S_i is a complex sequence which represents the iíth QPSK modulation symbol of the slot, spread by the length N OVSF code c_{ch}. The α_i^j are the channel coefficients of the iíth path seen from the jíth antenna.

Si^* represents the complex conjugate of Si. Consider a static flat fading channel with channel powers $p_1=(\alpha_1^1)^2$ and $p_2=(\alpha_1^1)^2$. The receiver processing for STTD gives the soft de-interleaved received bits, before decoding, to be:

$(p_1+p_2)b_1$ $(p_1+p_2)b_2$ $(p_1+p_2)b_3$ $(p_1+p_2)b_4$ $(p_1+p_2)b_5$ÖÖ.

(assuming perfect channel estimation).

2.1 Limitations of STTD:

The transformation applied to the modulation symbols as shown in figure 1 can be represented as:

Antenna 1: $S1\ c_{ch}$ | $S2\ c_{ch}$
Antenna 2: $-S2^{*}c_{ch}$ | $S1^{*}\ c_{ch}$

where time in symbol intervals proceeds from left to right. Dropping the channelisation code for notational convenience, this becomes:

Antenna 1: $S1$ | $S2$
Antenna 2: $-S2^{*}$ | $S1^{*}$

For the case of 3 or 4 antennas, a similar scheme cannot be applied without changing the coding rate and decreasing the spreading factor of the transmission (4 modulation symbol times are required to transmit 3 symbols) [1]. This requires the use of more code resource in the downlink which is a disadvantage since code resources are generally limited in the downlink direction for UMTS FDD.

3. Proposed schemes: case of 4 Antennas

For the 4 antenna case, the STTD 2 antenna approach can be used such that the 4 antennas are grouped into 2 sets of 2 antennas, with STTD applied within the set. Note that no additional code resource is required. This can be done in two different manners is illustrated in figure 2, which shows the arrangement of bits over antennas for the 1,2 and 4 antenna case.

3.1 Scheme A

The 2 sets of STTD can be represented in a matrix form as follows.

Antenna 1:	S_1	S_1	S_2	S_2
Antenna 2:	$-S_2^*$	$-S_2^*$	S_1^*	S_1^*
Antenna 3:	S_3	$-S_3$	S_4	$-S_4$
Antenna 4:	$-S_4^*$	S_4^*	S_3^*	$-S_3^*$

where complex symbols S_i are formed from the suitably interleaved data. This scheme is power balanced.

3.2 Scheme B

The 2 sets of STTD can be represented in a matrix form as follows.

Antenna 1:	S_1	S_2			
Antenna 2:	$-S_2^*$	S_1^*			
Antenna 3:				S_3	S_4
Antenna 4:				$-S_4^*$	S_3^*

where complex symbols S_i are formed from the suitably interleaved data. Of course, this scheme is not power balanced.

Figure 2 : scheme comparison between 1 Tx antenna, STTD (2 antennas) and extended STTD schemes for 4 antennas.

3.3 Performance of 4 antenna scheme

Again, consider a static flat fading channel with channel powers $p_1=(\alpha_1^1)^2$ and $p_2=(\alpha_1^1)^2$. Then the soft de-interleaved received bit sequence, before decoding, can be represented as:

$$(p_1+p_2)b_1 \ (p_3+p_4)b_2 \ (p_1+p_2)b_3 \ (p_3+p_4)b_4 \ (p_1+p_2)b_5 \ (p_3+p_4)b_6\text{Ö}.$$

which exhibits a higher order of diversity than either STTD or TSTD alone in the case of 2 antennas. The STTD element also provides superior performance than that of 4 element TSTD. This is shown by the simulation results presented in figures 3 and 4 below.

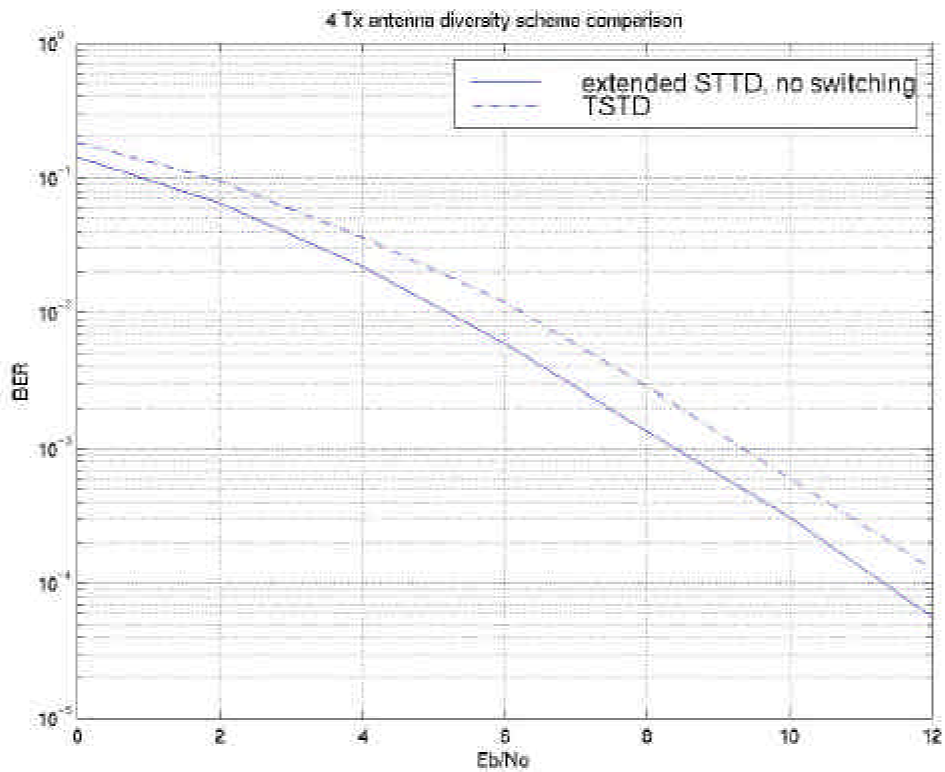

Figure 3 : Comparison between extended STTD and TSTD schemes, convolutional codes (rate 1/4 K=5), ideal channel estimation.

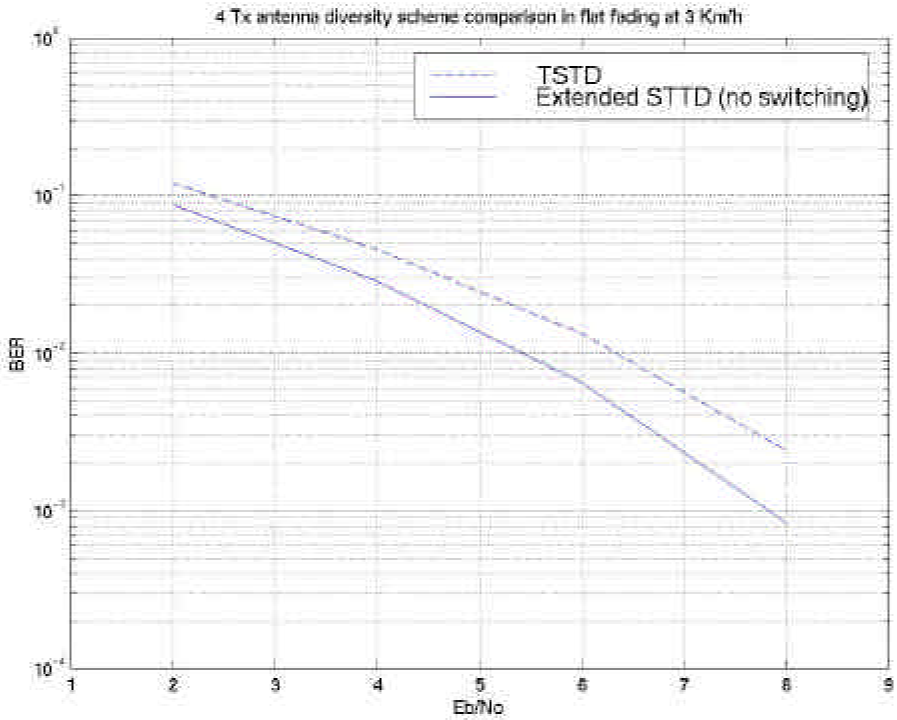

Figure 4 : Comparison between extended STTD and TSTD schemes, convolutional codes (rate 1/3 K=9), ideal channel estimation.

3.4 Optional Switching

As shown in figure 2, an optional switching element is provided. This may further increase the diversity of the input soft bits to the decoder is to implement antenna switching. This is applied every second slot, and is simply a rearrangement of the signals applied to the different antennas. For example, for scheme A:

```
For slots 1, 2, 5, 6,9,10Ö:

     Antenna 1:   S1  | S1   | S2   | S2   |
     Antenna 2:  -S2* |-S2*  | S1*  | S1*  |
     Antenna 3:   S3  |-S3   | S4   |-S4   |
     Antenna 4:  -S4* | S4*  | S3*  |-S3*  |

For slots 3,4,7,8,11,12Ö:

     Antenna 1:   S1  | S1   | S2   | S2   |
     Antenna 3:  -S2* |-S2*  | S1*  | S1*  |
     Antenna 2:   S3  |-S3   | S4   |-S4   |
     Antenna 4:  -S4* | S4*  | S3*  |-S3*  |

(note the change in antenna indices)
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Assuming a stationary channel, with appropriate interleaving, the soft de-interleaved received bits, before decoding, will be:

$$(p_1+p_2)b_1 \quad (p_3+p_4)b_2 \quad (p_1+p_3)b_3 \quad (p_2+p_4)b_4 \quad Ö.$$

Further simulations are needed to quantify the performance benefits.

4. Proposed schemes: case of 3 Antennas

Scheme A

In this case, the 4 antenna case is applied, except that the waveform previously corresponding to the 4th antenna (for example) is added to one of the three antennas, ensuring the signals remain orthogonal. For example:

```
Antenna 1:   S1  | S1   | S2   | S2   |

Antenna 2:  -S2* |-S2*  | S1*  | S1*  |
                    +
             S3  |-S3   | S4   |-S4   |

Antenna 3:  -S4* | S4*  | S3*  |-S3*  |
```

Power balancing will not be an issue for such a scheme. This is because, unlike TSTD, the transmissions remain continuous and the power is divided between the transmission waveforms.

Scheme B

For scheme B the 2 STTD outputs are switched between 3 antennas.

5. Conclusions

STTD is was selected at ETSI for the 2 antenna case based on its performance and power balanced transmission structure. However, STTD is not readily extendable to the case of more than 2 antennas. For the case of 3 or 4 transmit antennas, two schemes are proposed, both of which combine 2-antenna STTD with a switching element (inherent to TSTD). One scheme does not exhibit perfect power balance (implying potential added cost at the BS transmitter), but exhibits a high degree of compatibility for the MS receiver. The other solution results in power balanced operation, and might be somewhat less compatible in terms of MS implementation. Both schemes outperform TSTD applied to 3 or 4 antennas.

References

[1] V. Tarokh, H. Jafarkhani, A.R. Calderbank,îSpace-Time Block Coding for Wireless Communications : Theory of Generalized Orthogonal Designsî, AT&T Labs Research.