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Source: Motorola

# Transmit Diversity schemes for Broadcast channels of the TDD mode

## 1 Introduction

STTD was proposed in WG#5 and WG#6 as an open loop transmit diversity technique for broadcast channels of the TDD mode [1,2]. STTD lead to small complexity increases when Interference Cancellation was used at the UE. However, the proposal implied a substantial complexity increase of the receiver when a Joint Detector was used. The block STTD scheme was presented in [3]. This scheme has the same complexity as the normal STTD when Interference Cancellation is used at the UE but it allows implementation of low complexity Joint Detectors. This document introduces in more detail the block STTD scheme, shows its complexity and compares its performance to Delay Diversity (DD).

## 2 Symbol STTD

Documents [1,2] proposed to perform STTD encoding symbol by symbol at the transmitter (Figure 1).

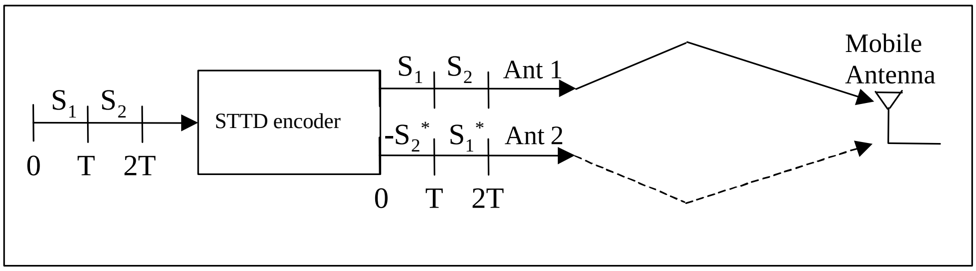


**Figure 1: STTD transmitter**

This system can be represented by the following equations [1]:

$$\begin{bmatrix} y \\ y^* \end{bmatrix} = \begin{bmatrix} A & B \\ B^* & A^* \end{bmatrix} \begin{bmatrix} x \\ x^* \end{bmatrix} + \begin{bmatrix} \bar{n} \\ \bar{n}^* \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where

x is the data symbol sequence to be transmitted
* represents the complex conjugate
n is the AWGN at the input of the receiver
y is the received sequence after channel filtering
A and B are the matrix used to represent a system using joint detection at the receiver [4]

From equation (1) it can be seen that this implementation of STTD required to use the received sequence e and its complex conjugate e* to estimate the transmitted symbols. This implies a multiplication by a factor 2 of the system size at the receiver. Note that a system not using STTD will have a matrix representation only involving x and y (see Annex 1). It can be demonstrated that the main complexity increase of the symbol STTD scheme for a Joint Detection receiver is in the forward substitution (complexity is multiplied by 2 ~ 20 MIPs increase).

## 3 Block STTD

The block STTD has the following structure [3]:

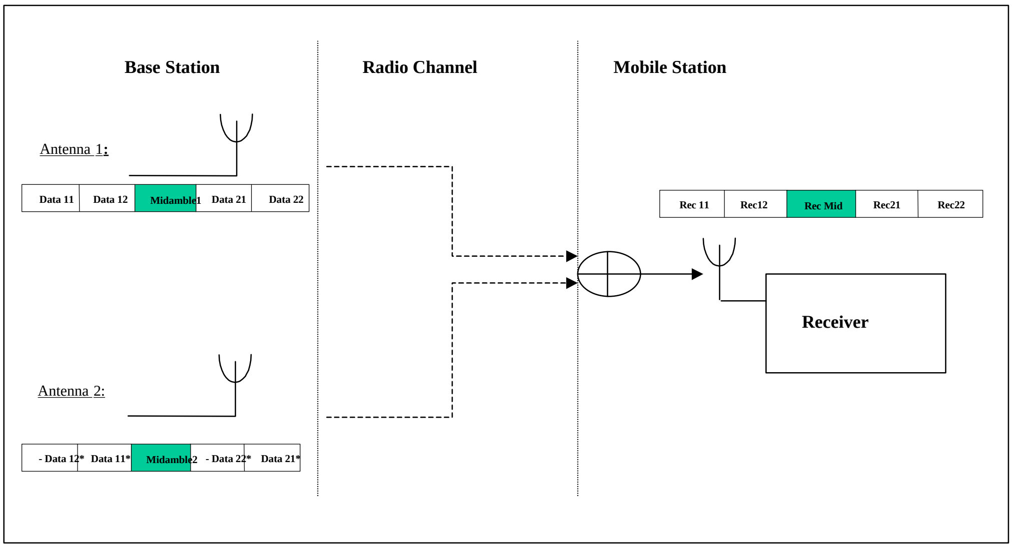


Figure 2: Modified STTD scheme

***This system can be modelled by the same equations then the symbol STTD using the received data ands their conjugates. That will lead exactly to the same complexity figures as described in [2].***

However, considering that the length of the blocks Dataii is much longer than the delay spread of the channel, the model can be simplified to the following :

$$\begin{bmatrix} Rec_{11} \\ Rec_{12}^{*} \end{bmatrix} = \underbrace{\begin{bmatrix} C & -D \\ F^{*} & G^{*} \end{bmatrix}}_{E} \begin{bmatrix} Data_{11} \\ Data_{12}^{*} \end{bmatrix} + \begin{bmatrix} n_{11} \\ n_{12}^{*} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

where Dataii and Recii are represented in Figure 2 and C and D are matrix having representing the symbol spreading and channel propagation [4]. It has to be noted that this simplified system cannot remove the interference between adjacent blocks transmitted by different antennas (i.e. Data11 with Data11* and Data12,-Data12* with Data 11* and Data12,…). However, the degradation introduced by this is very small compared with the complexity reduction achieved (the system has the same size as the single Tx antenna case).

The equations and approximations to reduce the complexity of this scheme are completely described in Annex 2.

## 4 Performance Results

Simulations have been performed under the following conditions

- 4 Data channels + BCCH
- MMSE Joint Detector.
- 1 midamble shift per user
- 2 midambles used by BCCH when STTD encoding is applied
- 4 chip delay when DD is applied to BCCH

## 4.1 BCCH channel transmitted with the same power as DCH

*Indoor A channels*

Figure 3 shows that STTD brings 2.8 dB gain and DD 2.6 dB gain compared to the single Tx antenna at Pe=1e-2. However, DD introduces a degradation of 0.3 dB for the DCH transmitted in parallel with the BCCH. STTD does not show this degradation.

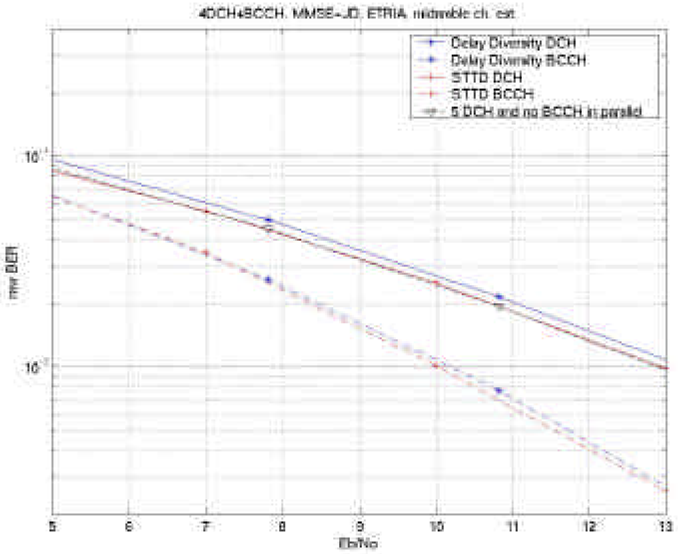


**Figure 3: Indoor A channel**

*Pedestrian B channels*

Figure 4 shows that STTD brings 0.8 dB gain and DD 0 dB gain compared to the single Tx antenna at Pe=1e-2. For the DCH transmitted in parallel with the BCCH, STTD introduces a degradation of 0.6 dB and DD a degradation of 0.8 dB.

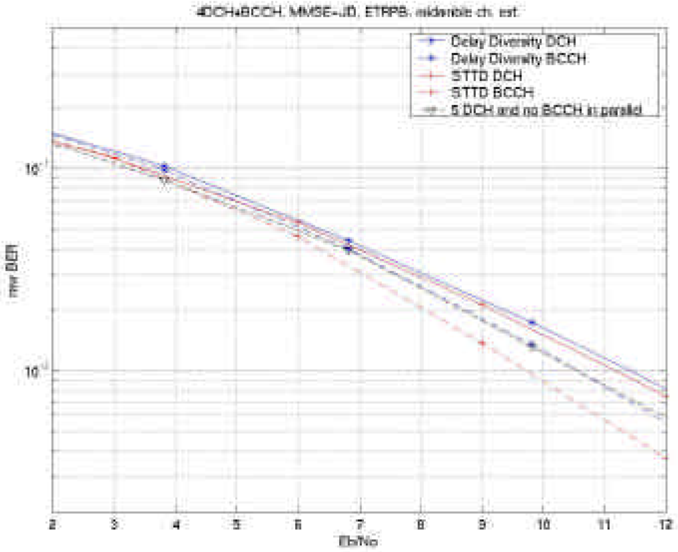


**Figure 4: Pedestrian B channel**

*Vehicular A channels*

Figure 5 shows that STTD brings 0.25 dB gain and DD 0 dB gain compared to the single Tx antenna at Pe=7e-2. For the DCH transmitted in parallel with the BCCH, STTD introduces a degradation of 0.2 dB and DD a degradation of 0.5 dB.

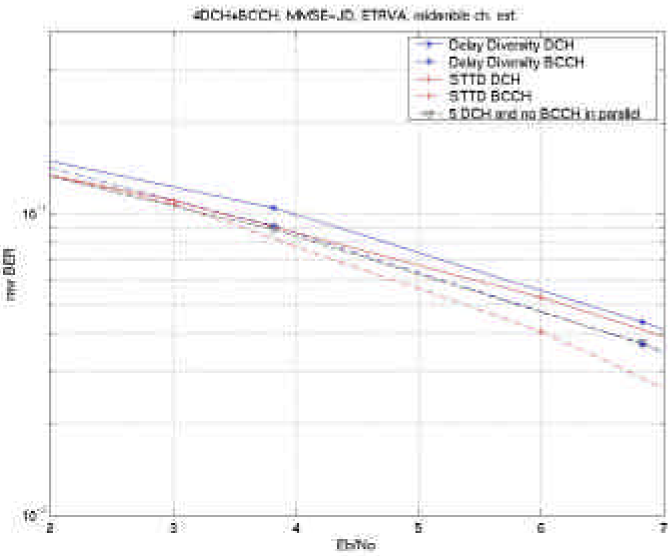


**Figure 5: Vehicular A channel**

*Vehicular B channels*

Figure 6 shows that for this particular scenario both techniques degrade system performance both for BCCH and DCH. This is due to the fact that this channel has a lot of frequency diversity and the channel paths ar far apart the ones to the others. Therefore, the non-orthogonal components introduced by DD and STTD degrade performance instead of improving it.

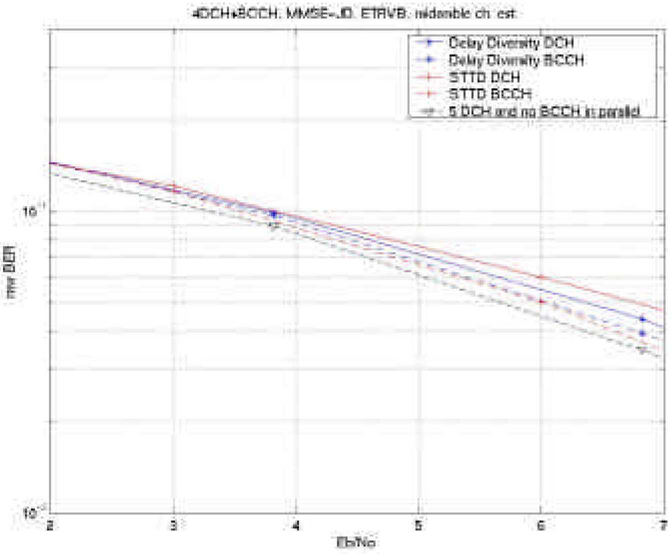


**Figure 6: Vehicular B channel**

### 4.2 BCCH transmitted 10dB higher than DCH

*Indoor A channels*

Figure 7 shows that STTD and DD bring the same gain at Pe=1e-2. For the DCH transmitted in parallel with the BCCH, STTD performs 0.5 dB worse than DD.

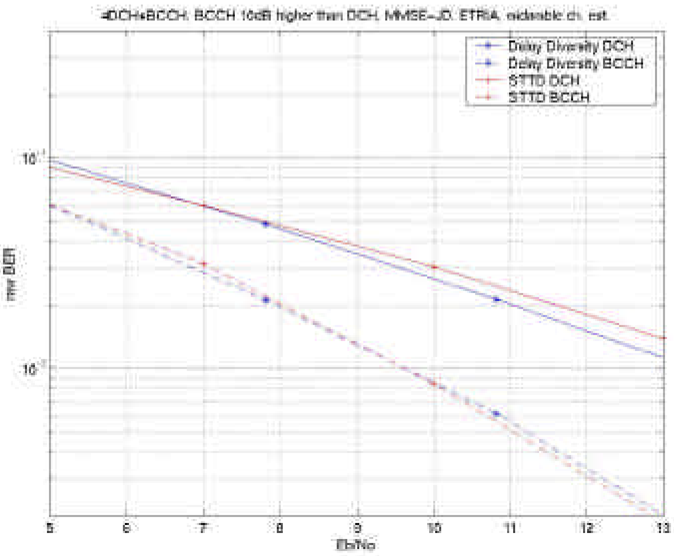


**Figure 7: Indoor A channel**

*Pedestrian B channels*

Figure 8 shows that STTD performs 0.5 dB better than DD bring the same gain at Pe=1e-2. For the DCH transmitted in parallel with the BCCH, DD performs 0.2 dB worse than DD.

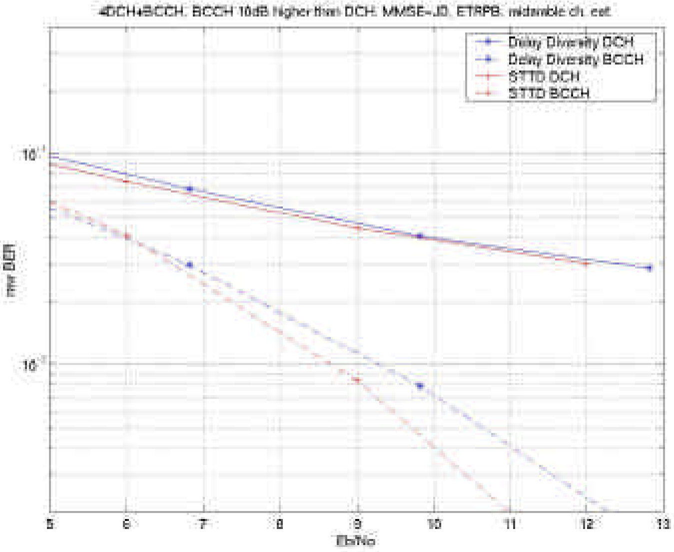


**Figure 8: Pedestrian B channel**

*Vehicular A channels*

Figure 9 shows that STTD performs 0.3 dB better than DD bring the same gain at Pe=7e-2. For the DCH transmitted in parallel with the BCCH, DD performs 0.6 dB worse than DD.

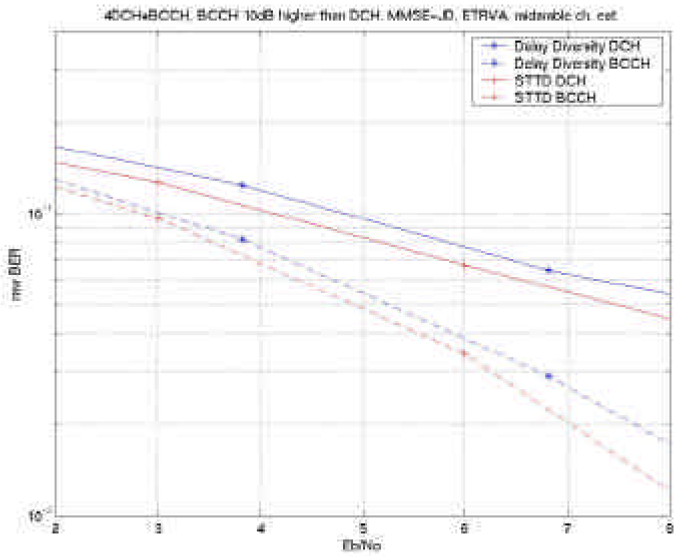


**Figure 9: Vehicular A channel**

*Vehicular B channels*

Figure 10 shows that STTD and DD have very similar performance at Pe=7e-2 for BCCH and DCH channels.

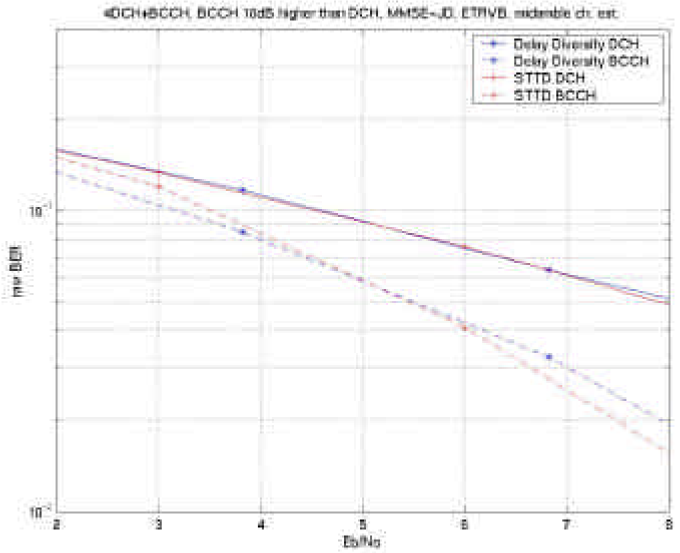


**Figure 10: Vehicular B channel**

## 5 Complexity Analysis

The complexity analysis has been performed under the following assumptions:

- 4 instructions per complex multiplication
- 2 instructions per coplex addition
- 6 instructions per complex division
- 10 instructions per square root
- Use of an MMSE-JD and the first order approximation described in Annex 2
- Complexity figures for an IC receiver can be found in [2]
- 7 DCHs + BCCH

| | **No Tx Diversity on BCCH** | **BCCH STTD encoded** |
|---|---|---|
| Matched Filter | 13.86 | 14.13 |
| AHA generation | 2.22 | 2.81 |
| Cholesky decomposition | 10.26 | 10.41 |
| Forward substitution | 21.66 | 22.22 |
| Backward substitution | 21.66 | 22.22 |
| **Total complexity in MIPS** | **69.68** | **71.78** |

**Table 1: Block STTD encoding complexity analysis for a JD receiver**

***The overall complexity increase for block STTD is 3%.***

## 6 Conclusion

The block STTD coding can bring significant BER performance improvement for common channels with UE complexity increases around 3% for all possible receiver implementations (JD or IC). Moreover, it has been shown as well that in general STTD gives better performance than Delay diversity with less degradation of BER of DCH transmitted in the same slot as the BCCH.

From an implementation point of view, broadcast channels will have fixed positions in the frame and users can directly assume STTD encoding for these channels. Block STTD will require a different midamble to be used in each of the Tx antennas. As a rule of the thumb, the first and the second midamble shifts can be reserved for STTD encoding of BCCH in slots containing these kind of channels.

## 7 References

[1] TI, ‘Open Loop Transmit…’ R1-99572, Cheju, WG1#5
[2] TI, ‘STTD for BCH of TDD’ R1-99971, Espoo, WG1#6
[3] Motorola, TI, ‘STTD applied to broadcast …’R1-99994, Espoo, WG1#6
[4] A. Klein et al., ‘Zero Forcing and MMSE equalisation for multiuser …’, IEEE Trans on Vehic Tech vol 45 No2 May 1996.

## ANNEX 1: *Normal Joint Detection description*

Assuming a sistem having K users, transmitting N symbols, using K different signatures of length Q, transmitted over K different channels of length L and using a single Tx antenna. The received signal y can be represented in the following notation:

$$y = A * x + n$$

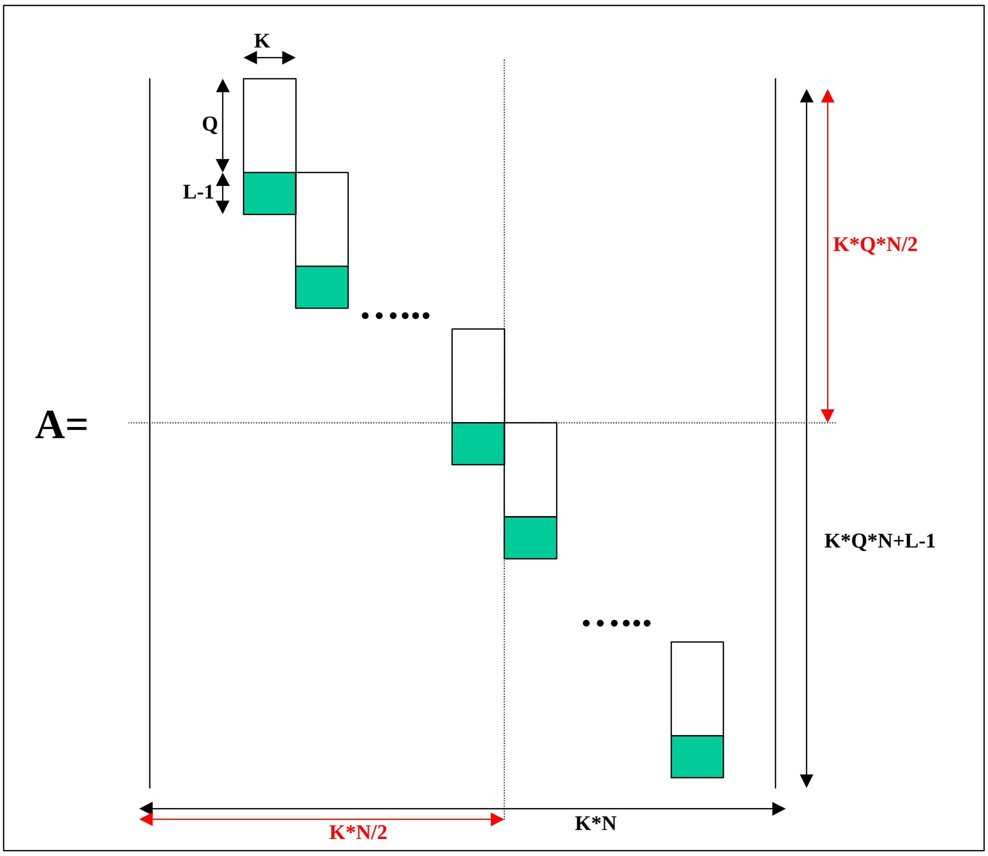
$$\textit{where,}$$

$$x = \left[x_1^1, x_1^2, \ldots, x_1^K, \cdots, x_N^1, x_N^2 \ldots, x_N^K\right]^T$$

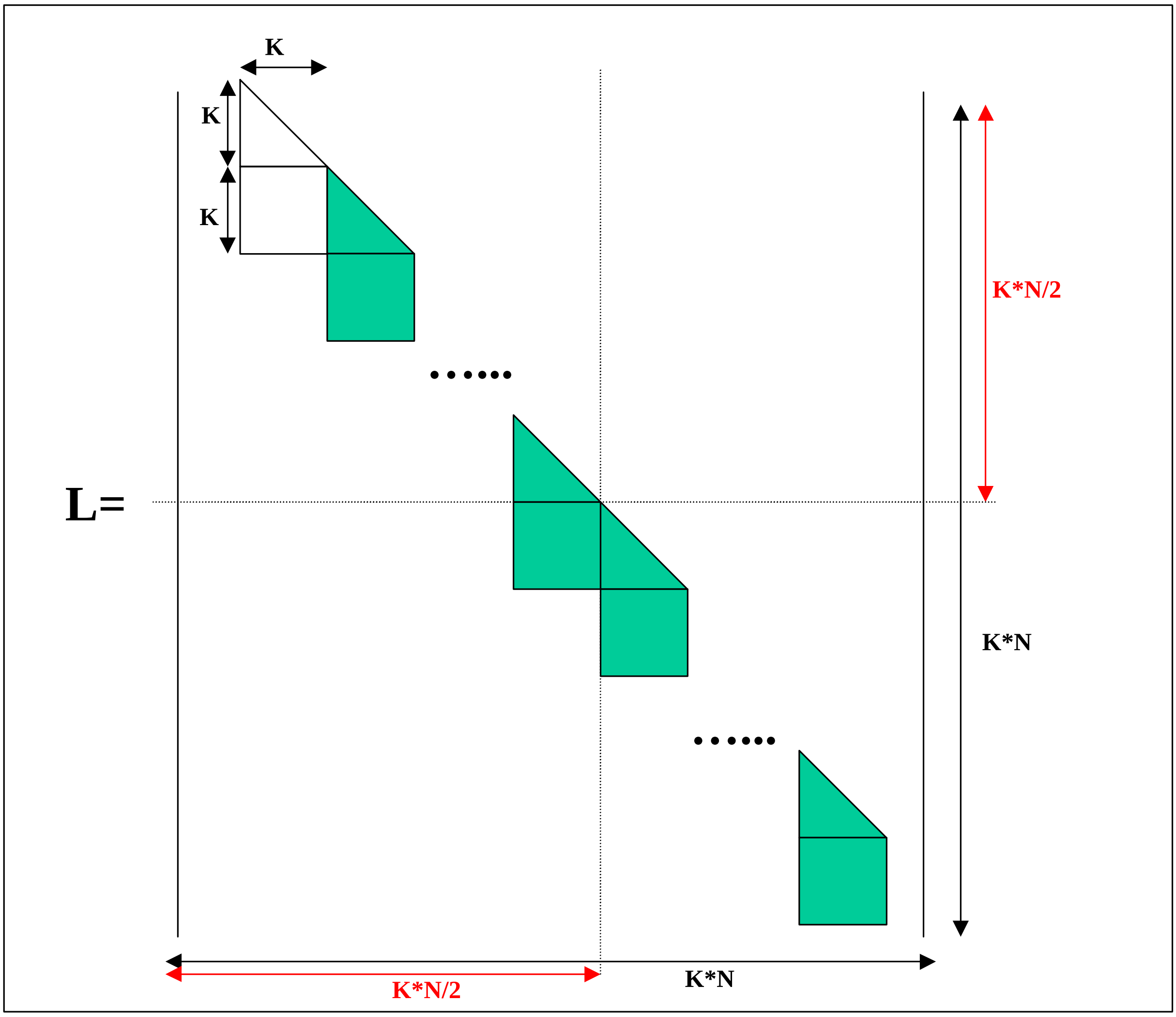
$$y = \left[y_1, \cdots, y_{K*N*Q}, \ldots, y_{K*N*Q+L-1}\right]^T$$

$$n = \left[n_1, \cdots, n_{K*N*Q}, \ldots, n_{K*N*Q+L-1}\right]^T$$

$$A = (K * N * Q + L - 1) \times (K * N) \qquad matrix$$



When using a Joint detection in the receiver a Cholesky decomposition of $A^H A$ ahs to be performed. This Cholesky decomposition can be easily implemented using the block diagonal properties of $A^H A$. That leads to solutions similar to the one depicted in the following figure (only some blocks of the L matrix need to be calculated).



## ANNEX 2: *Joint Detection with block STTD encoding*

Making the same assumptions as previously, but supposing that a broadcast channel is also transmitted in parallel using a quarter frame block STTD encoding. Then, the system can be modelled as follows taking x and y as defined in the previous case:

$$u = E * v + m$$

$$where,$$

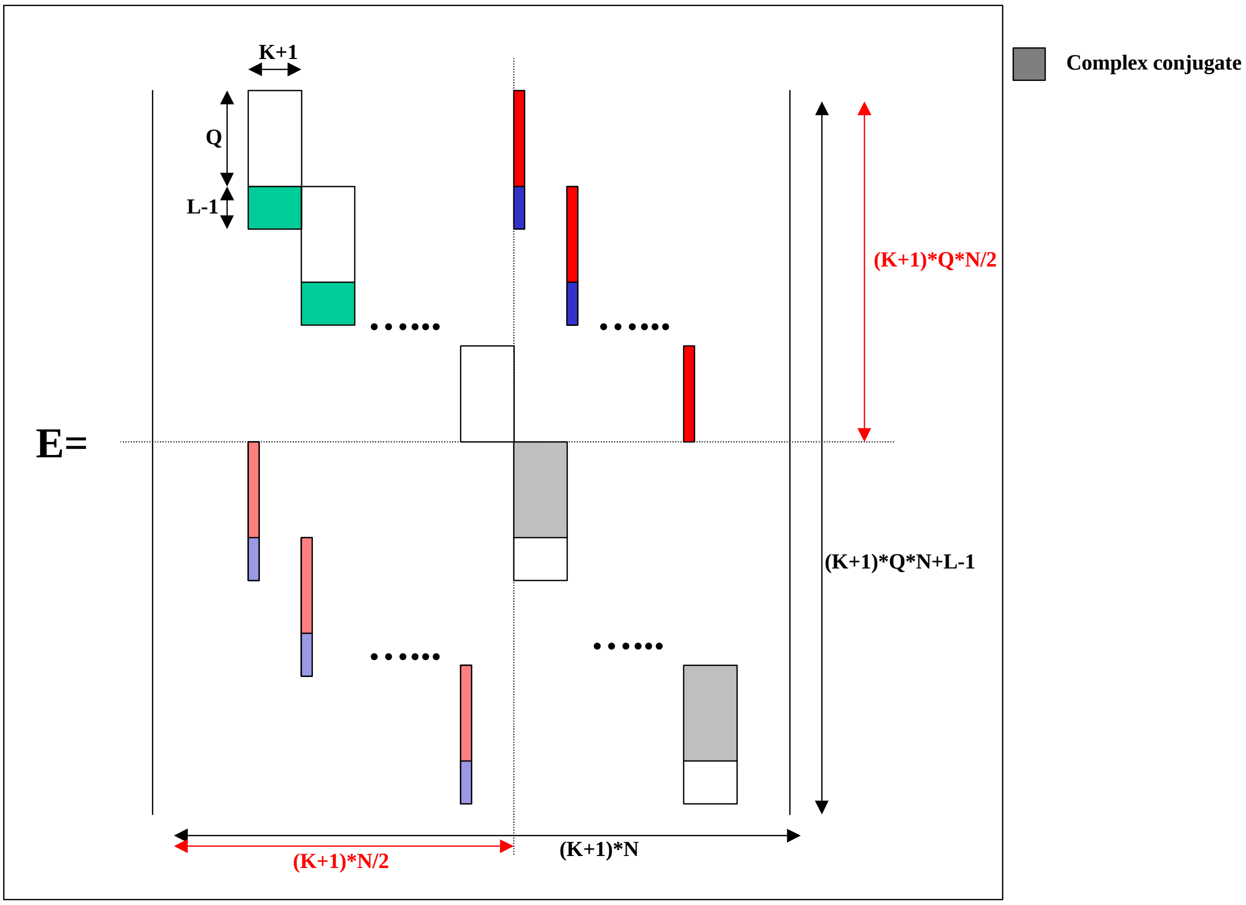
$$^{*}\ means\ the\ complex\ conjugate$$

$$v = \left[x^{1}_{1}, x^{2}_{1}, \ldots, x^{K+1}_{1}, \cdots, x^{1}_{N/2}, x^{2}_{N/2}, \ldots, x^{K+1}_{N/2}, x^{1*}_{N/2+1}, x^{2*}_{N/2+1}, \ldots, x^{(K+1)*}_{N/2+1}, \cdots, x^{1*}_{N}, x^{2*}_{N} \ldots, x^{(K+1)*}_{N}\right]^{T}$$

$$u = \left[y_{1}, \cdots, y_{(K+1)*N/2}, y^{*}_{(K+1)*N/2+1}, \cdots, y^{*}_{(K+1)*N*Q}, \ldots, y^{*}_{(K+1)*N*Q+L-1}\right]^{T}$$

$$m = \left[n_{1}, \cdots, n_{(K+1)*N/2}, n^{*}_{(K+1)*N/2+1}, \cdots, n^{*}_{(K+1)*N*Q}, \ldots, n^{*}_{(K+1)*N*Q+L-1}\right]^{T}$$

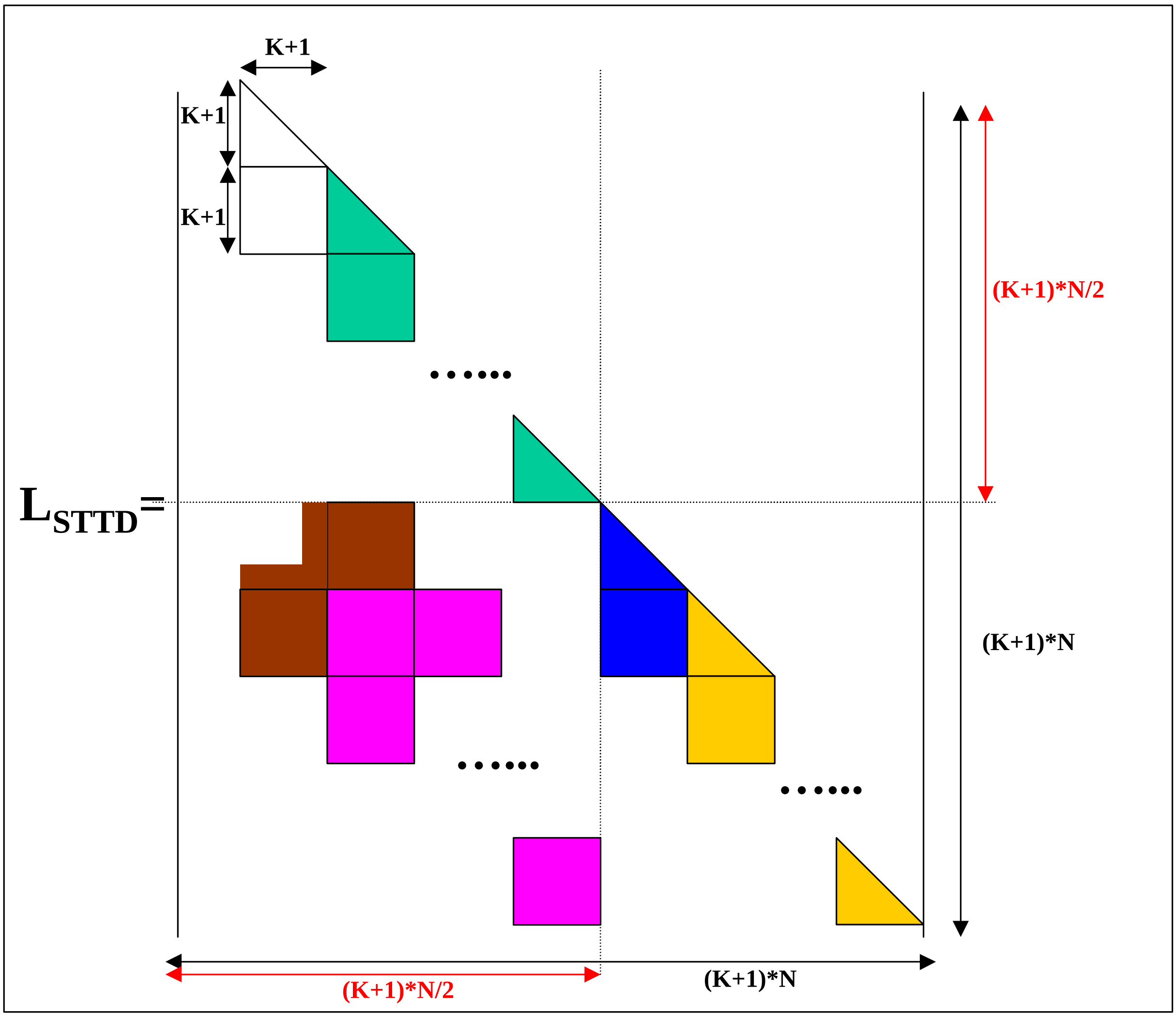
$$E = \left((K+1)*N*Q+L-1\right)\times\left((K+1)*N\right) \quad matrix$$



The matrix E does not take into account the ISI introduced between the first quarter of the frame and the second quarter of the frame.

The E matrix has some additional terms compared to the A matrix. These terms represent the STTD symbols transmitted in parallel by the second antenna.

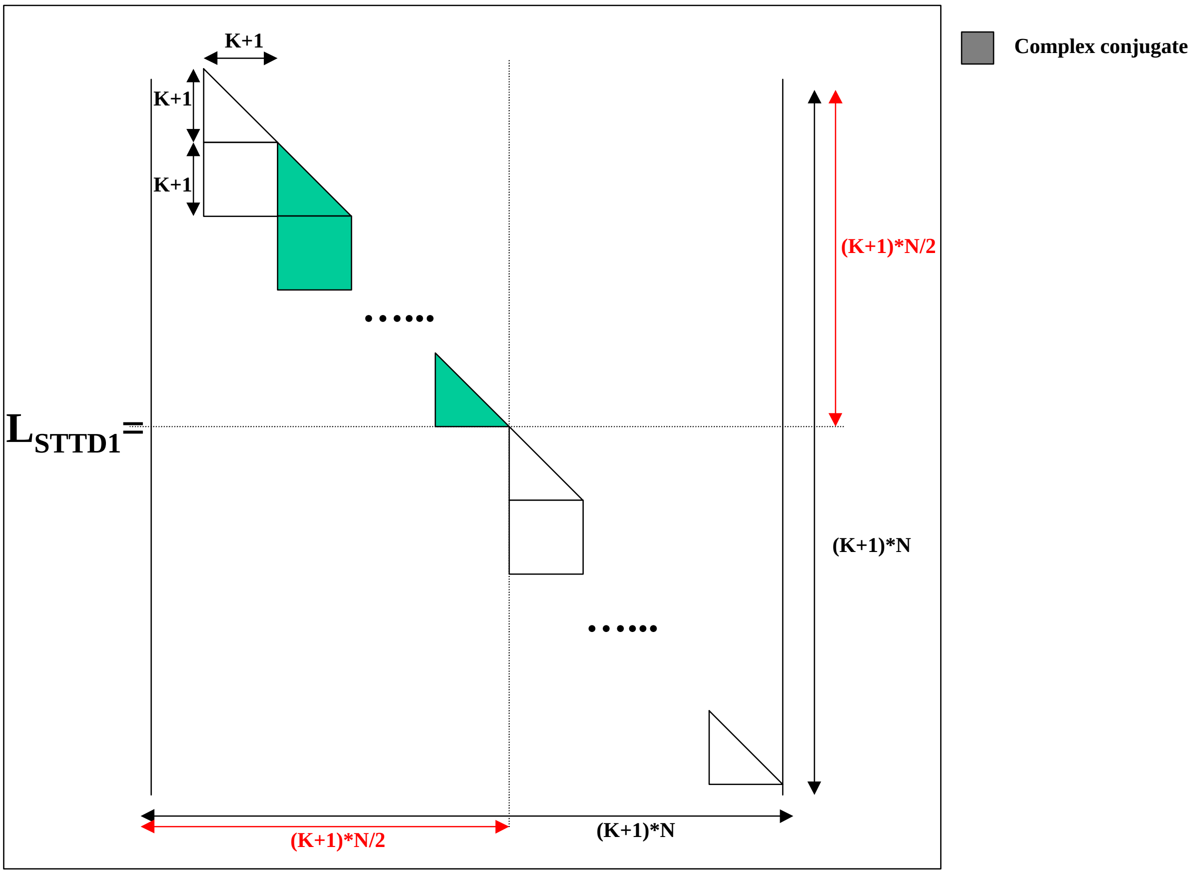
***The exact Cholesky decomposition*** of $E^H E$. will have the following form:



This Cholesky decomposition would require to calculate many more blocks than in the case where STTD was not used. This will lead to a complexity increase of the receiver.

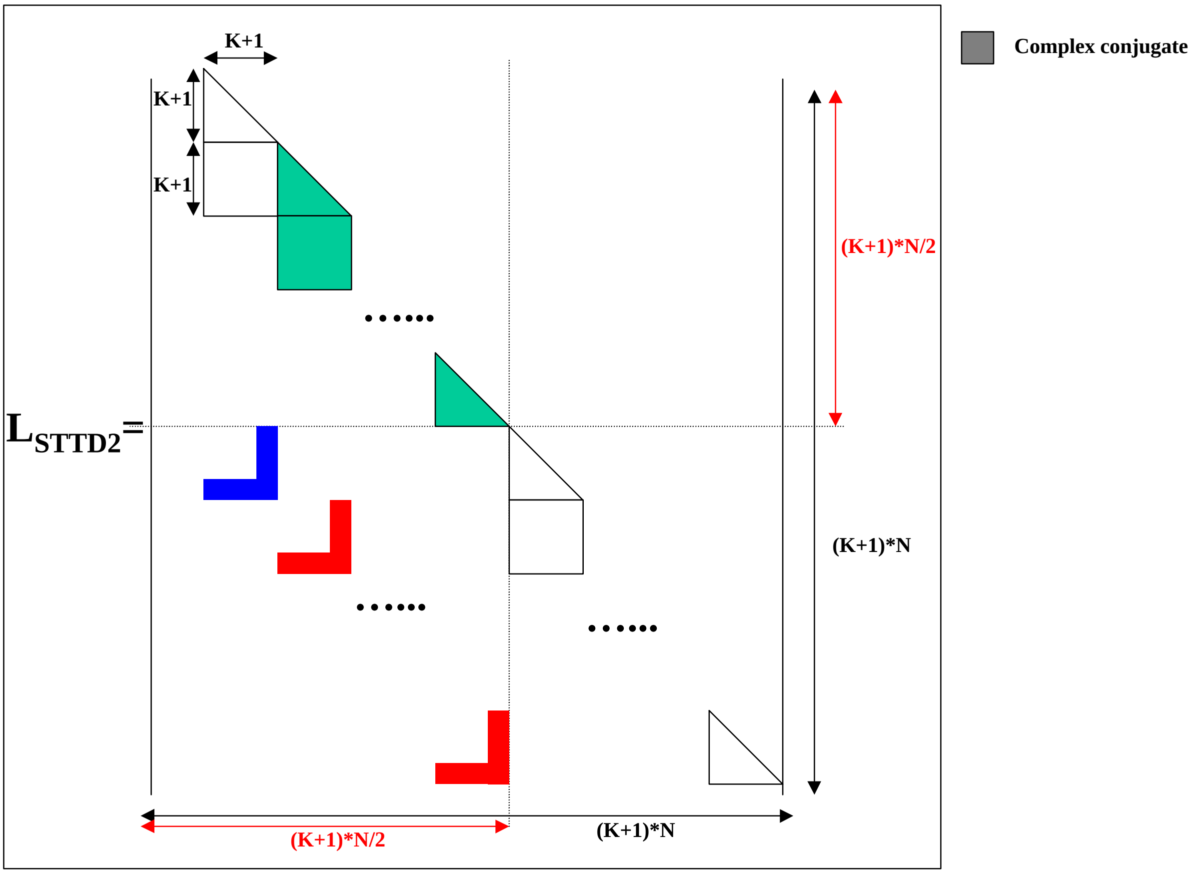
## *Simplification of the Cholesky Decomposition*

Taking the approach of TI described in document [2], the matrix would have the following form:



This approach does not take into account the interference terms of the second diagonal. This leads to some performance degradations.

Finally, taking a ***first order approximation*** of the Cholesky decomposition, the following matrix can be derived:



As for the case with no STTD we have a block repeating along the diagonal. The red terms represent the interference between the STTD encoded blocks transmitted by one antenna with the symbols transmitted by the other antenna. However, only interference between STTD symbols ransmitted by the second antenna with symbols transmitted in parallel at the same time is taken into account (only one block of the second diagonal is kept and repeated).

The complexity increase of this approach is very small and it has performance results very similar to the exact Cholesky decomposition.