The Centre Tecnològic de Telecomunicacions de Catalunya

A gateway to advanced communication technologies

SPACE-TIME CODING

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CODIGOS OSTBC

The coder matrix $\underline{\underline{B}}.\underline{\underline{B}}^{H} \quad \underline{\underline{I}}_{n_T}$

The Tx and Rs signals as well as the estimated symbol are:

$$\underline{\underline{X}}_{T,n} \quad \underline{\underline{B}}.s1(n)$$

$$\underline{\underline{X}}_{R,n} \quad \underline{\underline{H}}.\underline{\underline{X}}_{T,n} \quad \underline{\underline{W}}_{n}$$

$$\widehat{s1} \quad Traza \quad \underline{\underline{B}}^{H}\,\underline{\underline{H}}^{H}.\underline{\underline{X}}_{R,n}$$

For nt=2 there are several possibilities with entries entailing no operation

1	0	1	0	1	0	1	0	
0	1	0	1	0	1	0	1	
0	1	0	1	0	1	0	1	
1	0	1	0	1	0	1	0	...

For two PAM symbols (real) and 2 antennas

$$\underline{\underline{X}}_T \quad \underline{\underline{B}}_1.s1 \quad \underline{\underline{B}}_2.s2$$

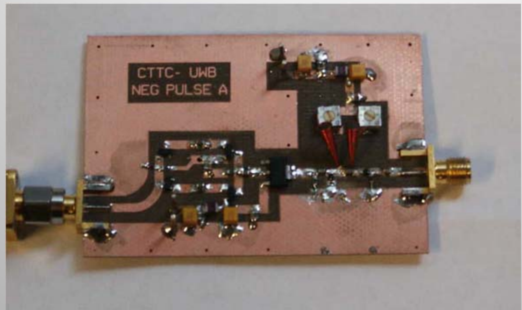
$$\hat{s}1 \quad Traza \quad \underline{\underline{B}}_1^H.\underline{\underline{R}}_H.\underline{\underline{B}}_1 \quad .s1 \quad Traza \quad \underline{\underline{B}}_1^H.\underline{\underline{R}}_H.\underline{\underline{B}}_2 \quad .s2$$

desired *ISI*

The no-ISI constrain is:

$$Traza \quad \underline{\underline{B}}_1^H.\underline{\underline{R}}_H.\underline{\underline{B}}_2 \qquad Traza \quad \underline{\underline{R}}_H.\underline{\underline{B}}_2.\underline{\underline{B}}_1^H \qquad 0 \qquad \underline{\underline{B}}_2.\underline{\underline{B}}_1^H \quad \underline{0}\,?$$

Not orthogonal just to be amicable



$$\underline{\underline{B}}_1.\underline{\underline{B}}_2^H \qquad \underline{\underline{B}}_2.\underline{\underline{B}}_1^H$$

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$$\underline{\underline{B}}_1 \quad \begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix} \qquad \underline{\underline{B}}_2 \quad \begin{matrix} 0 & 1 \\ 1 & 0 \end{matrix}$$

$$\underline{\underline{X}}_T \quad \underline{\underline{B}}_1.s1 \quad \underline{\underline{B}}_2.s2 \quad \begin{matrix} s1 & s2 \\ s2 & s1 \end{matrix}$$

To further achieve full-rate, we need two additional matrices, that being amicable in order to detect two imaginary parts, do not promote ISI with the real symbols.

$$\underline{\underline{B}}_1 \quad \begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix} \qquad \underline{\underline{B}}_2 \quad \begin{matrix} 0 & 1 \\ 1 & 0 \end{matrix} \qquad \underline{\underline{B}}_3 \quad \underline{\underline{B}}_4$$

$$\underline{\underline{X}}_T \quad \underline{\underline{B}}_1.s1 \quad \underline{\underline{B}}_2.s2 \quad j.\underline{\underline{B}}_3.s3 \quad j.\underline{\underline{B}}_4.s4$$

It is easy to check that this is the constraint---→

$$\underline{\underline{B}}_1.\underline{\underline{B}}_3^H \quad \underline{\underline{B}}_3.\underline{\underline{B}}_1^H$$

$$\underline{\underline{B}}_2.\underline{\underline{B}}_4^H \quad \underline{\underline{B}}_4.\underline{\underline{B}}_2^H$$

In summary:

$$\underline{\underline{B}}_1.\underline{\underline{B}}_1^H \quad \underline{\underline{B}}_2.\underline{\underline{B}}_2^H \quad \underline{\underline{B}}_3.\underline{\underline{B}}_3^H \quad \underline{\underline{B}}_4.\underline{\underline{B}}_4^H \quad \underline{\underline{I}}_2$$

$$\underline{\underline{B}}_1.\underline{\underline{B}}_2^H \quad \underline{\underline{B}}_2.\underline{\underline{B}}_1^H \quad \underline{\underline{B}}_4.\underline{\underline{B}}_3^H \quad \underline{\underline{B}}_3.\underline{\underline{B}}_4^H$$

$$\underline{\underline{B}}_1.\underline{\underline{B}}_3^H \quad \underline{\underline{B}}_3.\underline{\underline{B}}_1^H \quad \underline{\underline{B}}_2.\underline{\underline{B}}_4^H \quad \underline{\underline{B}}_4.\underline{\underline{B}}_2^H$$

The Alamouti's code:

$$\underline{\underline{B}}_1 \quad \begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix} \qquad \underline{\underline{B}}_2 \quad \begin{matrix} 0 & 1 \\ 1 & 0 \end{matrix} \qquad \underline{\underline{B}}_3 \quad \begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix} \qquad \underline{\underline{B}}_4 \quad \begin{matrix} 0 & 1 \\ 1 & 0 \end{matrix}$$

$$\underline{\underline{X}}_T \quad \underline{\underline{B}}_1.s1 \quad \underline{\underline{B}}_2.s2 \quad \underline{\underline{B}}_3.j.s3 \quad \underline{\underline{B}}_4.j.s4 \quad \begin{matrix} s1 & j.s3 & s2 & js4 \\ s2 & j.s4 & s1 & j.s3 \end{matrix} \quad \begin{matrix} z1 & z2^* \\ z2 & z1^* \end{matrix}$$

The receiver------>

$$\hat{s}1 \quad \mathrm{Re} \quad Traza \quad \underline{\underline{B}}_1^H.\underline{\underline{R}}_H.\underline{\underline{X}}_R$$

$$\hat{s}2 \quad \mathrm{Re} \quad Traza \quad \underline{\underline{B}}_2^H.\underline{\underline{R}}_H.\underline{\underline{X}}_R$$

$$\hat{s}3 \quad \mathrm{Im} \quad Traza \quad \underline{\underline{B}}_1^H.\underline{\underline{R}}_H.\underline{\underline{X}}_R$$

$$\hat{s}4 \quad \mathrm{Im} \quad Traza \quad \underline{\underline{B}}_1^H.\underline{\underline{R}}_H.\underline{\underline{X}}_R$$

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Unfortunately no such full-rate codes exist for any number of antennas. There are solution for rates lower than one like the code shown below for 4 antennas and rate ¾.

$$\begin{matrix} s1 & 0 & s2 & s3 \\ 0 & s1 & s3^* & s2^* \\ s2^* & s3 & s1^* & 0 \\ s3^* & s2 & 0 & s1^* \end{matrix}$$

Convolutional S-T Codes: Trellis codes

output input state

$$\underline{x} \quad \underline{\underline{G}}_1 . \underline{a} \quad \underline{\underline{G}}_2 . \underline{b}$$

Measurement equation

$$\underline{b} \quad \underline{\underline{G}}_3 . \underline{a} \quad \underline{\underline{G}}_4 . \underline{b}$$

State equation

$\underline{a}=[a(1),a(2),....,a(R)]^T$ input bits

L bits per component output $\underline{x}$

L=2 bits Components 0(00),1(01),2(10),3(11) that correspond to the four signals in a QPSK constellation

Code rate=R/L over n_T antennas

K bits for M components of the state vector $\underline{b}$

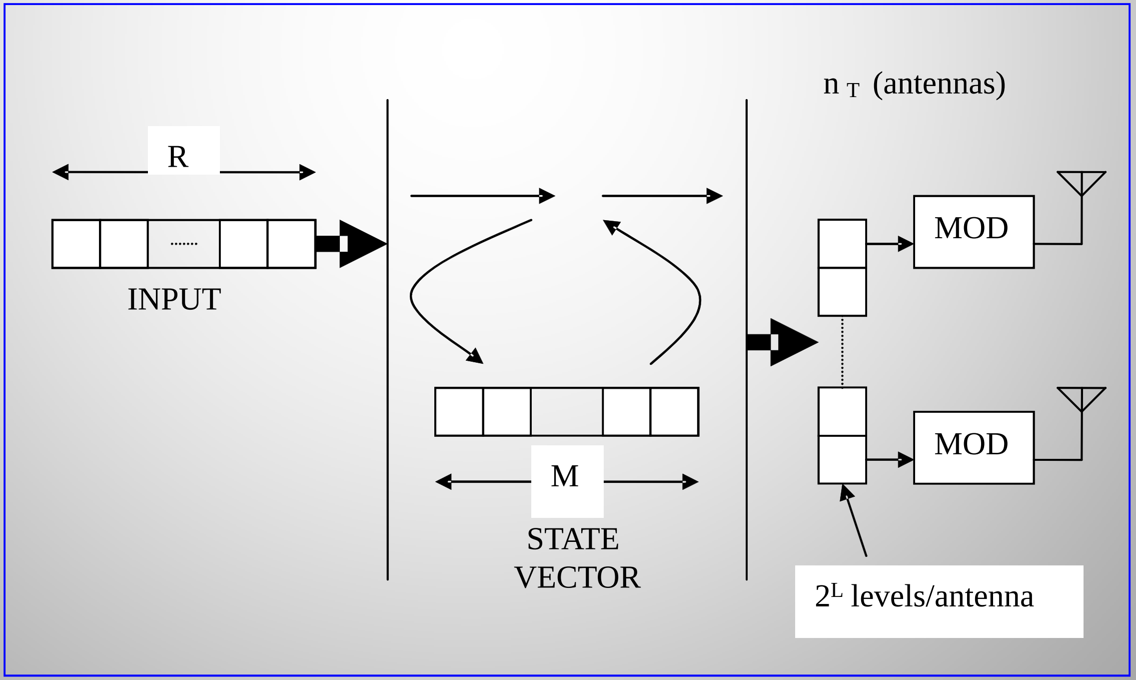
Code specification:

-Number of Tx antennas n_T

-Bits/Hz or size of the radiated constelation L

-Complexity at Tx or number of states $2^{K.M}$

-Code Rate equal to R/L



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A more compact formulation of the state model is:

Grouping input and state vectors in a single one

$$\underline{c} \quad a(1) \quad \ldots \quad a(R) \quad b(1) \quad \ldots \quad b(M)$$

$$\underline{x} \quad \underline{\underline{G}}.\underline{c}$$

And, the state vector is formed by the last M bits after a shift of a given number of components vector $\underline{c}$ from left to right

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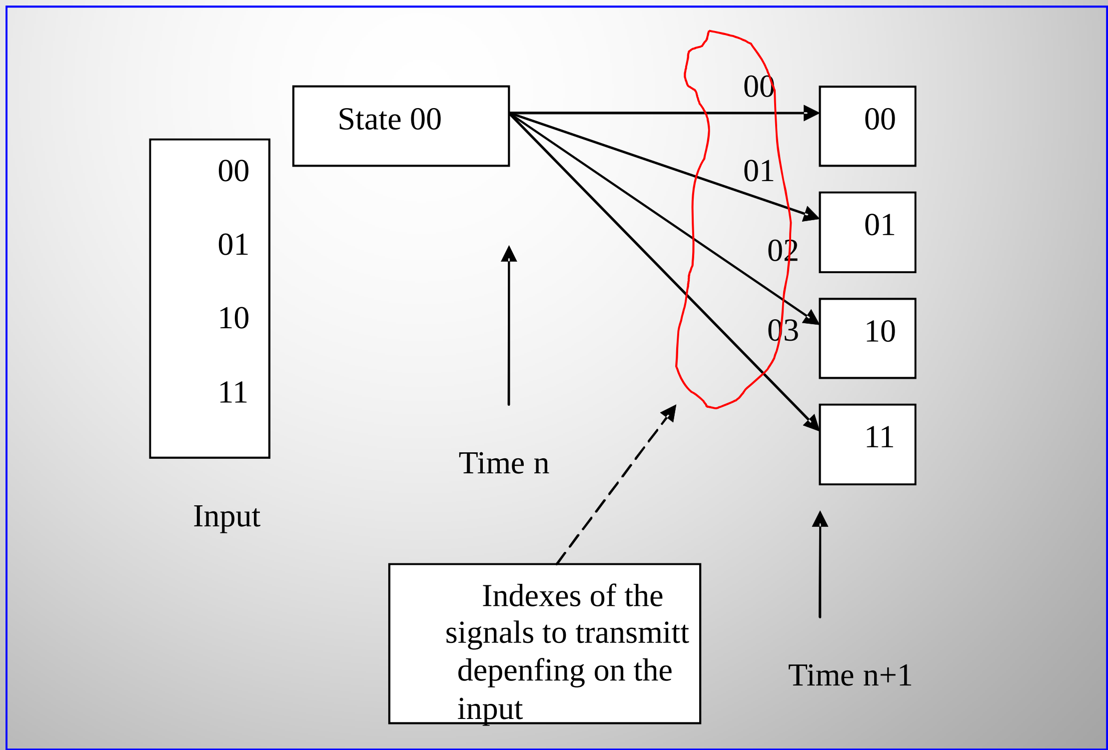
Code st2bh2est4rate1:

$$a(1) \quad a(2) \quad b(1) \quad b(2) \;.\; \begin{matrix} 0 & 2 \\ 0 & 1 \\ 2 & 0 \\ 1 & 0 \end{matrix} \qquad x1 \quad x2$$

Modul 2 operation for x1 and x2



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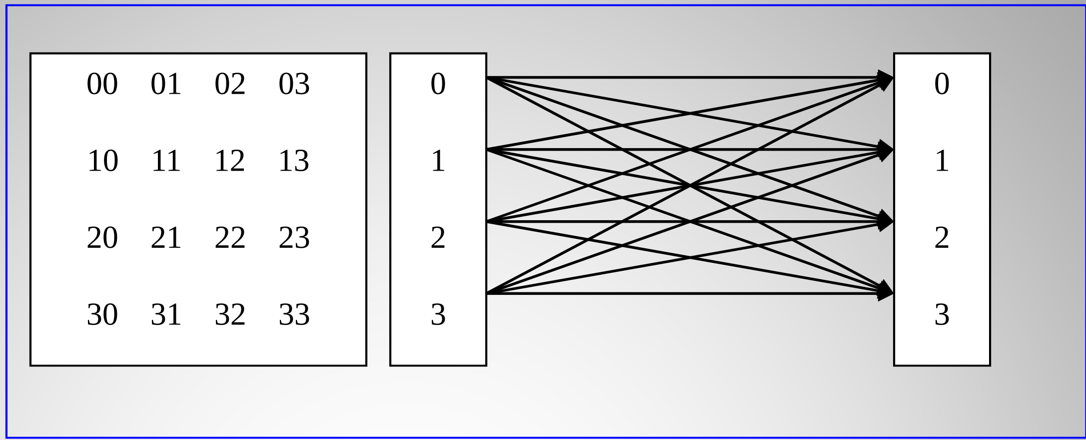
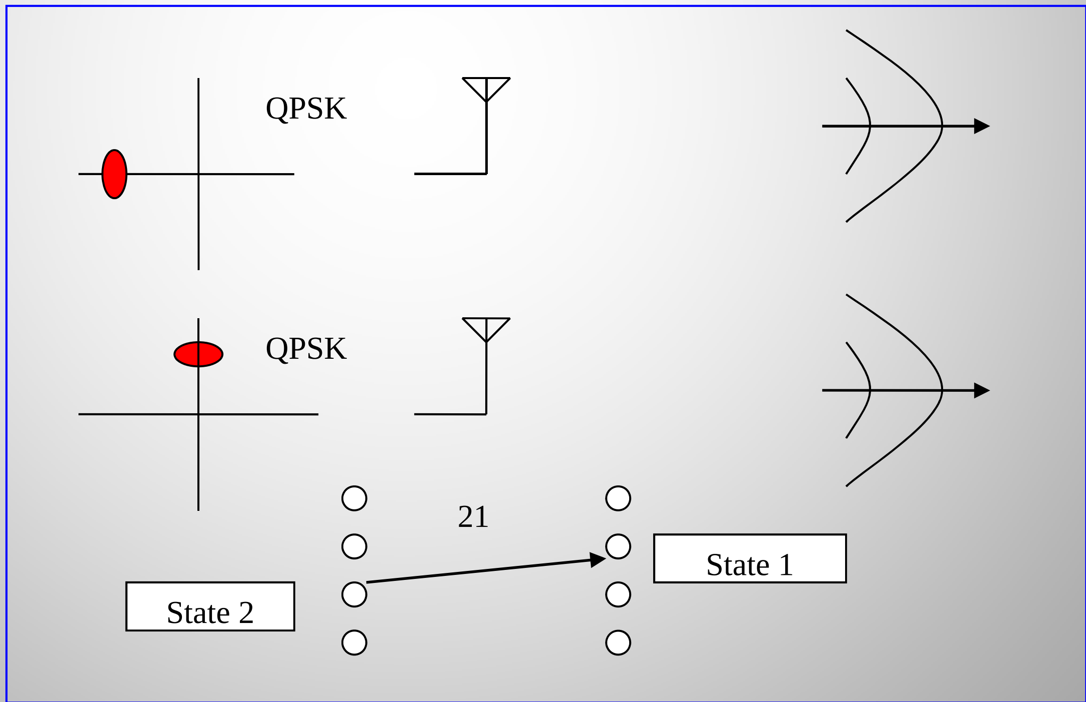
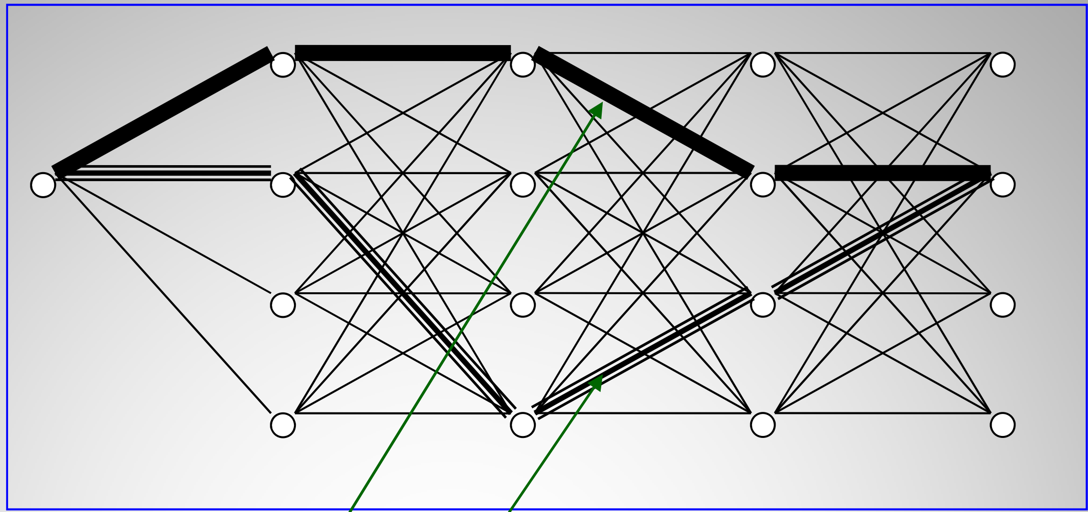






For uniform code any two pair is good. Use the (0,0,0,0,0…) as reference.

Search fot the lowest distance covered to recover the zero path (This will be the worst matrix A to be used in the BER upper bound

$$\Pr \; \underline{s}_n \quad \underline{b}_n ; n \quad 1, N \qquad Q \; \sqrt{\frac{E_s}{2.N_0} \, .Traza \; \underline{\underline{R}}_H . \underline{\underline{A}}}$$

For length of N channels access

$$\underline{\underline{A}} \quad \sum_{n=1}^{N} \quad \underline{s}_n \quad \underline{b}_n \; . \; \underline{s}_n \quad \underline{b}_n \quad ^{H}$$

And the average BER

$$\Pr \; \underline{I}_0 \quad \underline{I}_e \quad k_1 . \prod_{p=1}^{n_R} \frac{1}{\det \; \underline{\underline{I}}_{n_T} \quad \frac{2E_S}{N_0} . \underline{\underline{A}}_{p}}$$

$$k_1 . \; \frac{2E_S}{N_0} ^{\,n_R . n_T} . \prod_{p=1}^{n_R} \frac{1}{\det \; . \underline{\underline{A}}_{p}}$$

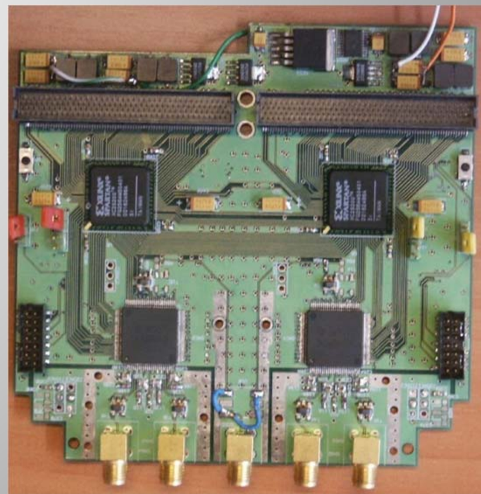
For moderate and high SNRs

or

$$\Pr \; \underline{I}_0 \quad \underline{I}_e \quad k_1 . \frac{2E_S}{N_0} {}^{n_R . n_T} \; . \prod_{p\;1}^{n_R} \frac{1}{\det \; . \underline{\underline{A}} ._p} \quad k_2 . \frac{2E_S}{N_0} {}^{n_R . n_T} \; . \; \det \; \underline{\underline{A}} {}^{n_R}$$

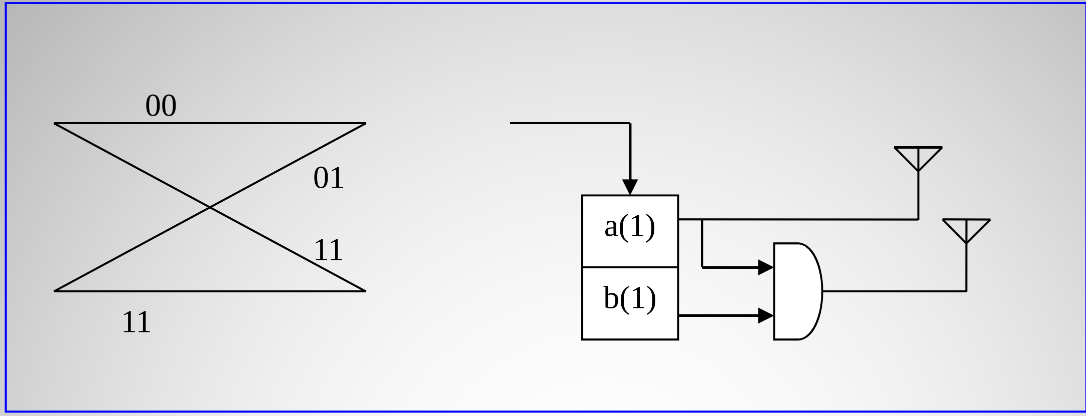
$$Ganancia \quad \det \; \underline{\underline{A}} \; {}^{r}$$

With $r=1/n_T$

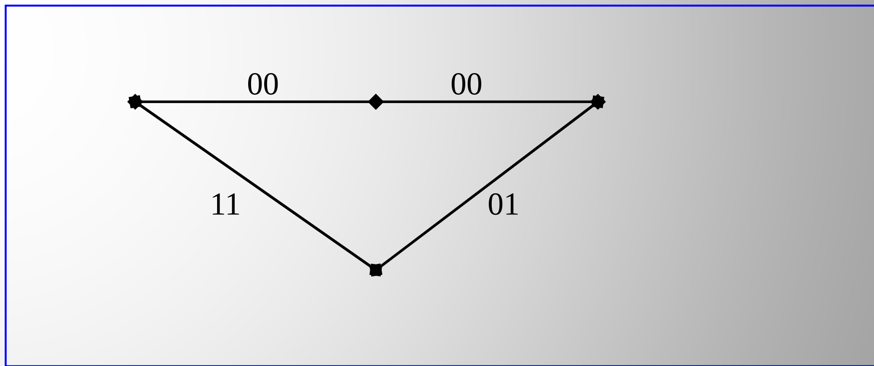


For st2bh1est2rate0.5

$$\underline{\underline{G}} \quad \begin{matrix} 1 & 1 \\ 0 & 1 \end{matrix}$$



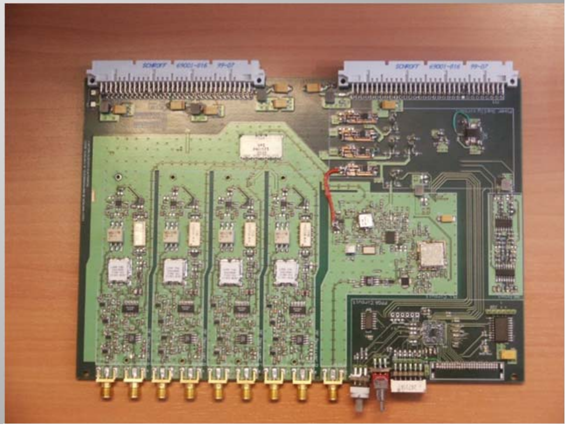
$$\underline{s}_1 \quad \underline{b}_1 \quad \begin{matrix} 2 \\ 2 \end{matrix} \quad y \quad \underline{s}_2 \quad \underline{b}_2 \quad \begin{matrix} 0 \\ 2 \end{matrix}$$



$$\underline{\underline{A}} \quad \begin{matrix} 2 \\ 2 \end{matrix} . \begin{matrix} 2 & 2 \end{matrix} \quad \begin{matrix} 0 \\ 2 \end{matrix} . \begin{matrix} 0 & 2 \end{matrix} \quad \begin{matrix} 4 & 4 \\ 4 & 4 \end{matrix} \quad \begin{matrix} 0 & 0 \\ 0 & 4 \end{matrix} \quad \begin{matrix} 4 & 4 \\ 4 & 8 \end{matrix}$$

$$\det \underline{\underline{A}} \quad 16 \qquad Ganancia \quad \sqrt{16} \quad 4$$

St2bh2est8	Gain $\sqrt{22}$	$\underline{\underline{G}}^T$	$\begin{matrix} 0 & 2 & 1 & 0 & 2 \\ 2 & 1 & 0 & 2 & 2 \end{matrix}$
St2bh2est16	Gain $\sqrt{32}$	$\underline{\underline{G}}^T$	$\begin{matrix} 0 & 2 & 1 & 1 & 2 & 0 \\ 2 & 2 & 1 & 2 & 0 & 2 \end{matrix}$
St2bh1est2	Gain 4	$\underline{\underline{G}}^T$	$\begin{matrix} 0 & 1 \\ 1 & 1 \end{matrix}$
St2bh1est4	Gain $\sqrt{48}$	$\underline{\underline{G}}^T$	$\begin{matrix} 0 & 2 & 1 & 0 & 2 \\ 2 & 1 & 0 & 2 & 2 \end{matrix}$
St2bh1est8	Gain $\sqrt{80}$	$\underline{\underline{G}}^T$	$\begin{matrix} 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \end{matrix}$
St2bh1est16	Gain $\sqrt{128}$	$\underline{\underline{G}}^T$	$\begin{matrix} 0 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 \end{matrix}$
St3bh1est8	Gain $\sqrt[3]{256}$	$\underline{\underline{G}}^T$	$\begin{matrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{matrix}$



Codes for No-CSI at Rx

Assume that $\log_2 M$ bits have to be transmitted using N access to the channel with n_T antennas. We will use M matrixes of n_T by N

$$\underline{\underline{C}}_m \quad m \quad 1, M$$

UPA at Tx

$$\underline{\underline{C}}_m . \underline{\underline{C}}_m^H \quad \underline{\underline{I}}_{n_T} \qquad m \quad 1, M$$

H matrix is random-> Average BER

At Rx→ $\underline{\underline{Y}}_R \quad \frac{2E_S}{N_0}^{1/2} . \underline{\underline{H}} . \underline{\underline{C}}_0 \quad \underline{\underline{W}} \qquad {}^{1/2} . \underline{\underline{H}} . \underline{\underline{C}}_0 \quad \underline{\underline{W}}$

$$= \quad E \quad \underline{\underline{Y}}_R^H . \underline{\underline{Y}}_R \quad \underline{\underline{I}} \quad \underline{\underline{C}}_0^H . E \quad \underline{\underline{H}}^H . \underline{\underline{H}} \quad . \underline{\underline{C}}_0 \quad \underline{\underline{I}} \quad . \underline{\underline{C}}_0^H . \underline{\underline{R}}_{HA} . \underline{\underline{C}}_0 \quad \underline{\underline{I}} \quad \left| H_0 \right|^2 . \underline{\underline{C}}_0^H . \underline{\underline{C}}_0$$

The ML receiver is:

$$\Pr \quad \underline{\underline{Y}}_R \Big/ \underline{\underline{C}}_0 \quad k_0 . \exp \quad Traza \quad \underline{\underline{Y}} . \underline{\underline{\ }}^{\ 1} . \underline{\underline{Y}}^H$$

$$k_0 . \exp \quad Traza \quad \underline{\underline{Y}} . \quad \underline{\underline{I}} \ - \quad ' . \underline{\underline{C}}_0^H . \underline{\underline{C}}_0 \quad . \underline{\underline{Y}}^H$$

$$\hat{m} \quad \underset{\underline{\underline{C}}_m , m \quad 1, M}{\arg\max} \quad Traza \quad \underline{\underline{Y}}_R . \underline{\underline{C}}_m^H . \underline{\underline{C}}_m . \underline{\underline{Y}}_R^H$$

Perfect detection occurs when:

$$Traza \quad \underline{\underline{Y}}_R . \underline{\underline{C}}_0^H . \underline{\underline{C}}_0 . \underline{\underline{Y}}_R^H \qquad Traza \quad \underline{\underline{Y}}_R . \underline{\underline{C}}_1^H . \underline{\underline{C}}_1 . \underline{\underline{Y}}_R^H$$

$$.Traza\ \underline{\underline{H}}.\ \underline{\underline{I}}\ \ \underline{\underline{C}}_0.\underline{\underline{C}}_1^H.\underline{\underline{C}}_1.\underline{\underline{C}}_0^H\ \ .\underline{\underline{H}}^H \qquad 2^{\ 1/2}.\mathrm{Re}\ Traza\ \underline{\underline{W}}.\ \underline{\underline{C}}_0^H.\underline{\underline{C}}_0\ \ \underline{\underline{C}}_1^H.\underline{\underline{C}}_1\ \ .\underline{\underline{C}}_0^H.\underline{\underline{H}}^H$$

$$\Pr\ \underline{\underline{C}}_0 \quad \underline{\underline{C}}_1 \quad Q\sqrt{\frac{2E_s}{N_0}.Traza\ \underline{\underline{H}}.\underline{\underline{A}}_{NOCSI}.\underline{\underline{H}}^H}$$

$$k_1.\exp \quad \frac{2E_s}{N_0}.Traza\ \underline{\underline{H}}.\underline{\underline{A}}_{NOCSI}.\underline{\underline{H}}^H$$

$$\Pr^{AVE} \quad k_2.\prod_{p\ 1}^{n_R} \frac{1}{\det\ \underline{\underline{I}} \quad \frac{E_s}{2.N_0}\ \underline{\underline{A}}_{NOCSI}.\underline{\underline{\ }}_p}$$

It is important to remark the loss due to the absence of CSI at Rx

$$E_S \quad \frac{N}{n_T}.E_T$$

$$\underline{\underline{A}}_{CSI} \quad \underline{\underline{C}}_0 \quad \underline{\underline{C}}_1 \quad \underline{\underline{C}}_0 \quad \underline{\underline{C}}_1 \quad ^H$$

$$\underline{\underline{A}}_{NOCSI} \quad \underline{\underline{I}} \quad \underline{\underline{C}}_0.\underline{\underline{C}}_1^H.\underline{\underline{C}}_1.\underline{\underline{C}}_0^H$$

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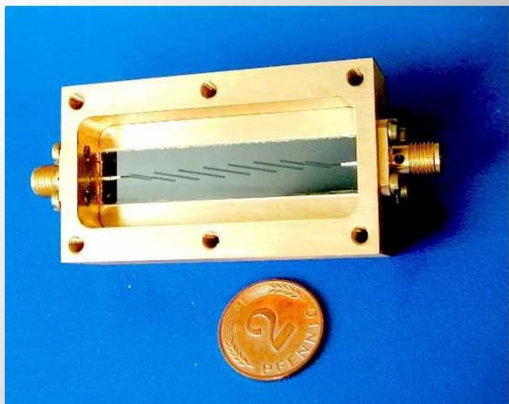
In order to compare both cases, note that:

$$\left| \underline{\underline{I}} \quad \underline{\underline{C}}_0 . \underline{\underline{C}}_1^H \right|^2 \quad \underline{\underline{I}} \quad \underline{\underline{C}}_0 . \underline{\underline{C}}_1^H \underline{\underline{C}}_1 . \underline{\underline{C}}_0^H \quad \underline{\underline{C}}_0 . \underline{\underline{C}}_1^H \quad \underline{\underline{C}}_1 . \underline{\underline{C}}_0^H$$

$$2.\underline{\underline{I}} \quad \underline{\underline{C}}_0 . \underline{\underline{C}}_1^H \quad \underline{\underline{C}}_1 . \underline{\underline{C}}_0^H \quad \underline{\underline{A}}_{NOCSI} \quad \underline{\underline{A}}_{CSI} \quad \underline{\underline{A}}_{NOCSI}$$

Asi pues,

$$\underline{\underline{A}}_{CSI} \quad \underline{\underline{A}}_{NOCSI} \quad \left| \underline{\underline{I}} \quad \underline{\underline{C}}_0 . \underline{\underline{C}}_1^H \right|^2$$



Codigos ST Diferenciales

Assuming that there is CSi at Rx

$$\left| \underline{\underline{X}}_R \quad E_s^{1/2}.\underline{\underline{H}}.\underline{\underline{C}}_m \right|_F \qquad \hat{\underline{\underline{C}}} \quad \underset{\underline{\underline{C}}_m;m\ 1,M}{Max} \ \mathrm{Re}\ Traza\ \underline{\underline{H}}.\underline{\underline{C}}_m.\underline{\underline{X}}_R$$

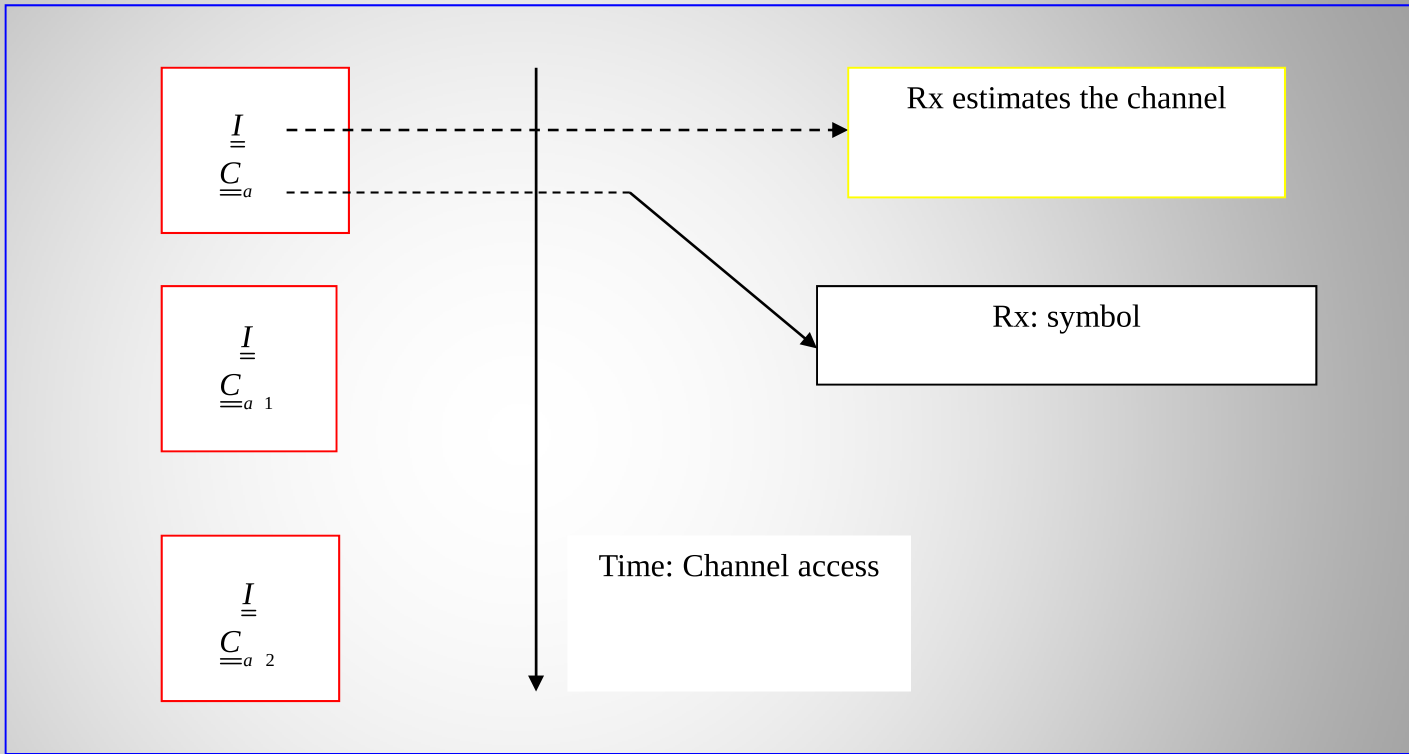
The probability of error is:

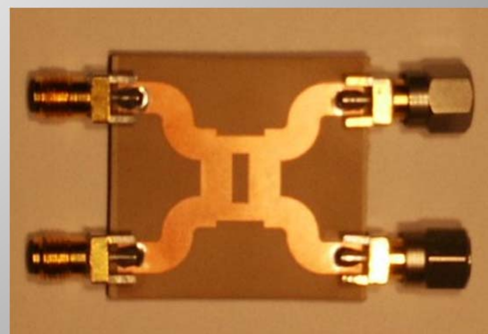
$$Pe \quad \Pr\ \underline{\underline{C}}_m \quad \underline{\underline{C}}_n; \underline{\underline{\tilde{C}}} \quad \underline{\underline{C}}_m \quad \underline{\underline{C}}_n \quad k_0.Q\sqrt{\frac{E_s}{2.N_0}.Traza\ \underline{\underline{R}}_H.\underline{\underline{\tilde{C}}}.\underline{\underline{\tilde{C}}}^H}$$

$$Pe \quad k_1.\exp \quad \frac{E_s}{4.N_0}.Traza\ \underline{\underline{R}}_H.\underline{\underline{\tilde{C}}}.\underline{\underline{\tilde{C}}}^H \qquad k_1.\exp \quad \frac{E_s}{4.N_0}.\sum_{p\ 1}^{n_R} \underline{h}_p^H.\underline{\underline{\tilde{C}}}.\underline{\underline{\tilde{C}}}^H.\underline{h}_p$$

$$Pe^{aver} \quad k_2.\prod_{p\ 1}^{n_R} \frac{1}{\det\ \underline{\underline{I}} \quad \frac{E_s}{4.N_0}.\underline{\underline{\tilde{C}}}.\underline{\underline{\tilde{C}}}^H.\underline{\underline{\lambda}}_j}$$

Using two symbols first estimate the channel second to decode.





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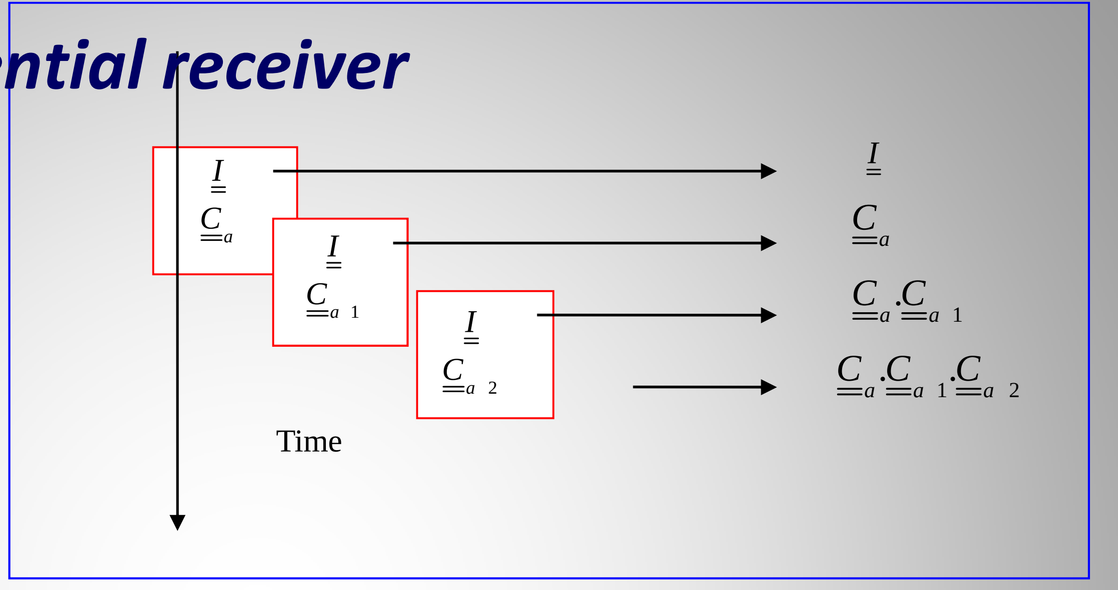
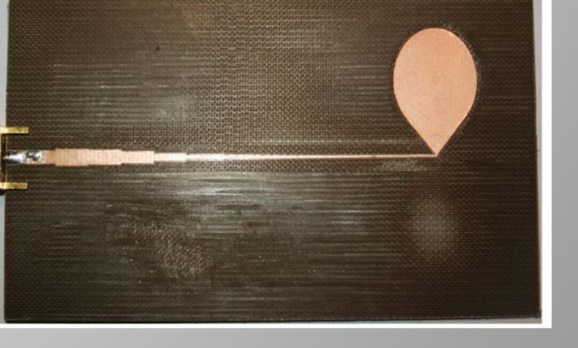
The differential receiver



The desired word received is $\underline{\underline{Z}}_{n\ 1} \quad {}_{a\ 1} \underline{\underline{C}}_{n\ a}$

And the received snapshot $\underline{\underline{X}}_{R,n\ 1} \quad \underline{\underline{H}}.\underline{\underline{Z}}_{n\ 1} \quad \underline{\underline{W}}_{n\ 1}$



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Hereafter it is shown that the ST code produces, in fact, a new channel together with 3 dB. increase of noise.

$$\underline{\underline{X}}_{R,n} \quad \underline{\underline{H}}.\underline{\underline{Z}}_{n\ \ 1}.\underline{\underline{C}}_{n} \quad \underline{\underline{W}}_{n} \qquad \underline{\underline{X}}_{R,n\ \ 1} \quad \underline{\underline{W}}_{n\ \ 1}\ .\underline{\underline{C}}_{n} \quad \underline{\underline{W}}_{n}$$

$$\underline{\underline{X}}_{R,n} \quad \underline{\underline{X}}_{R,n\ \ 1}.\underline{\underline{C}}_{n} \quad \underline{\underline{W}}_{n} \quad \underline{\underline{W}}_{n\ \ 1}.\underline{\underline{C}}_{n} \qquad \underline{\underline{H}}_{nuevo}.\underline{\underline{C}}_{n} \quad \underline{\underline{W}}_{nuevo}$$

Regardless the system is full-rate the decoder requires of two received codewords

$$\left| \underline{\underline{X}}_{R,n} \quad \underline{\underline{X}}_{R,n\ \ 1}.\underline{\underline{C}}_{n} \right|_{F} \qquad \hat{\underline{\underline{C}}} \quad \underset{\underline{\underline{C}}_{n};n\ \ 1,M}{Max} \ \mathrm{Re}\ \ Traza\ \ \underline{\underline{X}}_{R,n\ \ 1}.\underline{\underline{C}}_{n}.\underline{\underline{X}}_{R,n}^{H}$$

Also, the matrix <u>A</u> for the average BER is as follows:

$$2\,\underline{\underline{I}} \quad \underline{\underline{Z}}_{k\ 1}.\underline{\underline{C}}_0.\underline{\underline{C}}_1^H.\underline{\underline{Z}}_{k\ 1}^H \quad \underline{\underline{Z}}_{k\ 1}.\underline{\underline{C}}_1.\underline{\underline{C}}_0^H.\underline{\underline{Z}}_{k\ 1}^H$$

$$\underline{\underline{Z}}_{k\ 1}.\underline{\underline{C}}_0 \quad \underline{\underline{Z}}_{k\ 1}.\underline{\underline{C}}_1 \cdot \underline{\underline{Z}}_{k\ 1}.\underline{\underline{C}}_0 \quad \underline{\underline{Z}}_{k\ 1}.\underline{\underline{C}}_1 \quad ^H$$

$$\cdot\ \underline{\underline{Z}}_{k\ 1} \cdot \underline{\underline{C}}_0 \quad \underline{\underline{C}}_1 \cdot \underline{\underline{C}}_0 \quad \underline{\underline{C}}_1 \quad ^H .\underline{\underline{Z}}_{k\ 1}^H \quad \underline{\underline{A}}_{DIF}$$

Where, taking into account the orthogonal character of the received codewords and the commutative property of the determinant, results identical to the CSI at Rx case with 3dB loss.

Some examples of differential ST codes

For 1 bit rate only two matrixes

$$\begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix}$$

With initial matrix $\underline{\underline{D}}$

$$\begin{matrix} 1 & 1 \\ 1 & 1 \end{matrix}$$

BPSK as constellation and rate 0.25 and 2 antennas, Gain 4

2 bits, 2 antennas, rate 0.5→ four matrixes, BPSK, Gain 4

$$\begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix} , \quad \begin{matrix} 0 & 1 \\ 1 & 0 \end{matrix}$$

QPSK, 2bits/seg/Hz, 8 codewords, Code gain4, Rate 1

$$\begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix}, \quad \begin{matrix} j & 0 \\ 0 & j \end{matrix}, \quad \begin{matrix} 0 & 1 \\ 1 & 0 \end{matrix}, \quad \begin{matrix} 0 & j \\ j & 0 \end{matrix}$$

"quaternion" similar to Alamouti's code

For higher rates the codewords are formed as:

$$w_Q \quad \exp \quad j2 \quad / Q$$

$$\begin{matrix} 0 & w_Q \\ 1 & 0 \end{matrix}^{m} ; m \quad 0, \quad Q \quad 1$$

Q=8 Rate 2 Gain 1.531 // Q=16 Rate 2.5 Gain 0.7804

References

- S. Alamouti. A simple transmit diversity technique for wireless communications. IEEE JSAC, Vol. 16, pp. 1451-1458, Oct. 1998.
- V. Tarok, H. Jafarkhani, A.R. Calderbank. Space-time block codes from orthogonal designs. IEEE-IT, Vol. 45, pp. 1456-1467, July 1999.
- G.D. Forney, Geommetrically uni1998form codes. IEEE-IT, Vol. 37, pp. 1241-1260, Sept. 1991.
- B.M. Hochwald, T.L. Marzetta. Unitary space-time modulation for multiple antenna communications in Rayleigh flat fading. IEEE-IT. Also see from the same authors et al. Systematic design of unitary space-time constellations also on IEEE-IT, Vol.46, pp. 543-564, 2000.
- V. Tarok, A. Naguib, N. Seshadri, R. Calderbank. Space-time codes for high data rate wireless communications:Performance criterion and code construction. IEEE-IT, Vol. 44, pp. 744-765, Mar 1998. See also from Tarok and Calderbank papers on IEEE-IT Vol. 45, pp. 1456-1467, July 1999; IEEE-COM Vol. 47, pp. 199-207, Feb 1999.
- B. L. Hugues. Differential Space-Time Modulation. IEEE-IT, Vol. 46, No. 7, pp. 2567- 2578, Nov 2000.

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A compact formulation for two channel access:

Two data received $\underline{\underline{X}}_{R,k\ 1} \quad \underline{\underline{X}}_{R,k}$

New codeword $\underline{\underline{Z}}_{k\ 1} \quad \underline{\underline{Z}}_{k\ 1}.\underline{\underline{C}}_{k} \quad \underline{\underline{\overline{C}}}_{k}$

with

$$\underline{\underline{\overline{C}}}_{k}^{H}.\underline{\underline{\overline{C}}}_{k} \quad \begin{matrix} \underline{\underline{I}} & \underline{\underline{C}}_{k} \\ \underline{\underline{C}}_{k}^{H} & \underline{\underline{I}} \end{matrix} \quad y \quad \underline{\underline{\overline{C}}}_{k}.\underline{\underline{\overline{C}}}_{k}^{H} \quad 2.\underline{\underline{I}}$$

Optimum detector for no-CSI at Rx that arrives to the same result

$$Traza \quad \underline{\underline{X}}_{R,k\ 1} \quad \underline{\underline{X}}_{R,k} \quad \begin{matrix} \underline{\underline{I}} & \underline{\underline{C}}_{k} \\ \underline{\underline{C}}_{k}^{H} & \underline{\underline{I}} \end{matrix} \quad \begin{matrix} \underline{\underline{X}}_{R,k\ 1}^{H} \\ \underline{\underline{X}}_{R,k} \end{matrix} \qquad Traza \quad \underline{\underline{X}}_{R,k}\underline{\underline{C}}_{k}^{H}\underline{\underline{X}}_{R,k\ 1}^{H}$$