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Performance Evaluation of Decoding Algorithms for Multi-Layered STBC-OFDM System

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Motivation

- Study of different decoding algorithms of High data rate architecture that combines spatial multiplexing and transmit diversity over frequency selective MIMO channels.
- This architecture is suitable for high data rate applications that can accommodate large number of antennas, such as WLANs.
- Decoding algorithms studied are based on group interference nulling/ cancellation (GINC) and on joint detection.
- We will concentrate on diversity tradeoffs among the different algorithms.

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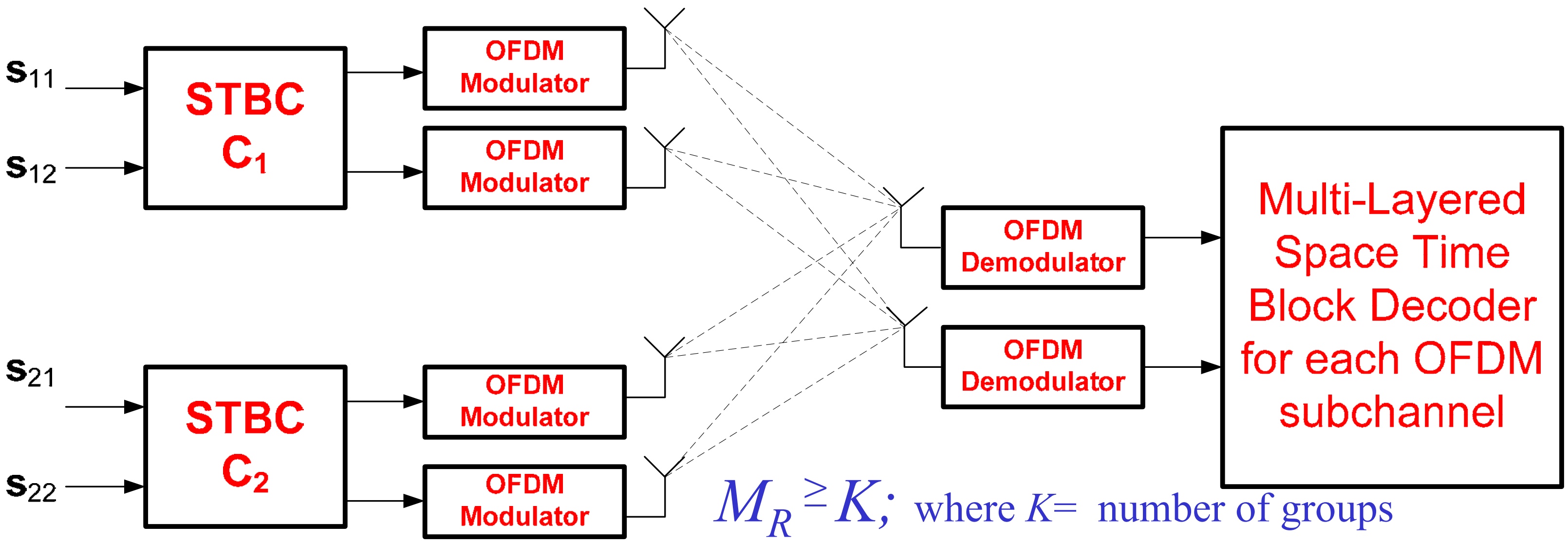
Architecture

- L point FFT (L subcarriers)
- Two Layered STBCs k=1,2

$$\mathbf{s}_{k1} = \begin{bmatrix} s_{k1,1} & s_{k1,2} & \cdots & s_{k1,L} \end{bmatrix}^T$$

$$\mathbf{s}_{k2} = \begin{bmatrix} s_{k2,1} & s_{k2,2} & \cdots & s_{k2,L} \end{bmatrix}^T$$

$$\mathbf{C}_k = \begin{bmatrix} \mathbf{s}_{k1} & \mathbf{s}_{k2} \\ -\mathbf{s}^*_{k2} & \mathbf{s}^*_{k1} \end{bmatrix}$$



$M_R \geq K$; where K= number of groups

M_R= number of receive antennas

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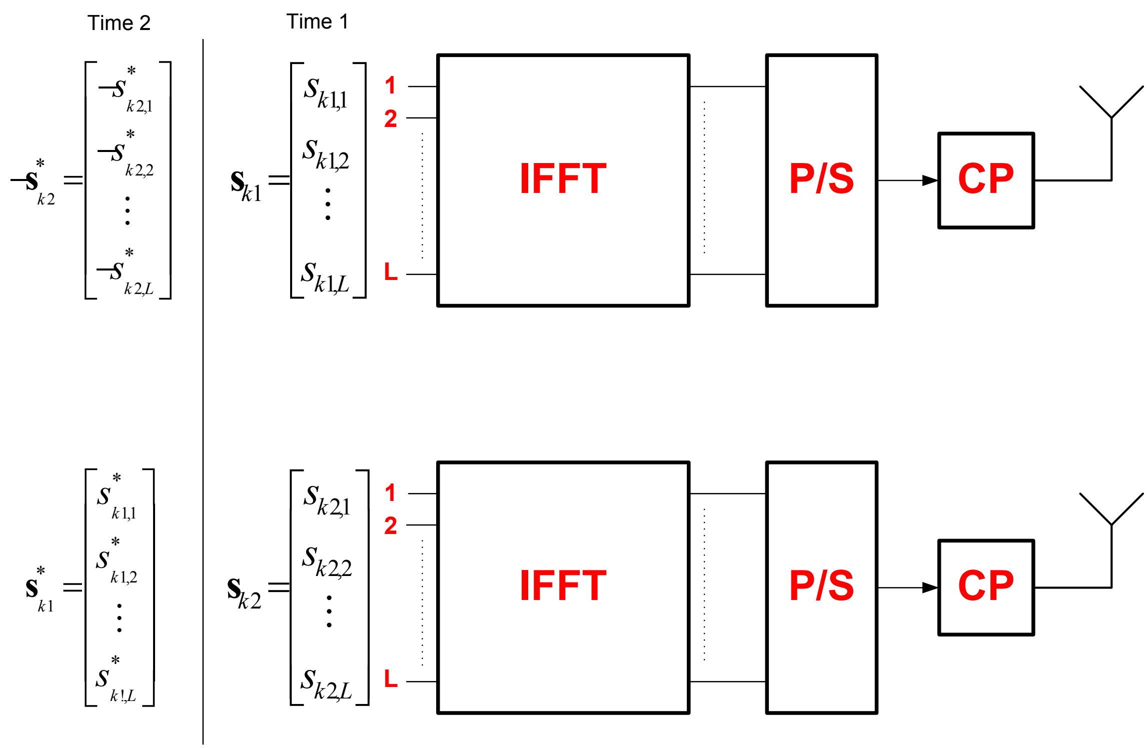
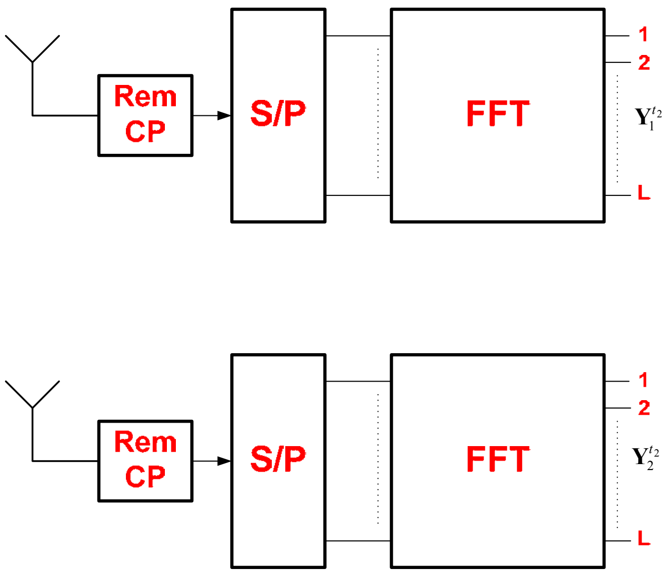
Transmitter

Architecture of one STBC-OFDM group. Each group transmits one layer of information using Alamouti code with two transmit antennas



Receiver



$$\mathbf{Y}_1^{t_2} = \begin{bmatrix} y_{1,1}^{t_2} \\ y_{1,2}^{t_2} \\ \vdots \\ y_{1,L}^{t_2} \end{bmatrix} \quad \mathbf{Y}_1^{t_1} = \begin{bmatrix} y_{1,1}^{t_1} \\ y_{1,2}^{t_1} \\ \vdots \\ y_{1,L}^{t_1} \end{bmatrix}$$

$$\mathbf{Y}_2^{t_2} = \begin{bmatrix} y_{2,1}^{t_2} \\ y_{2,2}^{t_2} \\ \vdots \\ y_{2,L}^{t_2} \end{bmatrix} \quad \mathbf{Y}_2^{t_1} = \begin{bmatrix} y_{2,1}^{t_1} \\ y_{2,2}^{t_1} \\ \vdots \\ y_{2,L}^{t_1} \end{bmatrix}$$

Let $h_{mn,l}$ be the flat fading complex Gaussian RV in the frequency domain between the n^{th} TX and the m^{th} Rx at the l^{th} subcarrier, then the channel matrix for all subcarriers can be arranged as

$$\mathbf{H}_{mn} = \begin{bmatrix} h_{mn,1} & 0 & \cdots & 0 \\ 0 & h_{mn,2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & h_{mn,L} \end{bmatrix}$$

The received vectors over two time periods at the output of the FFT is

$$\begin{bmatrix} \mathbf{Y}_1^{t_1} & \mathbf{Y}_1^{t_2} \\ \mathbf{Y}_2^{t_1} & \mathbf{Y}_2^{t_2} \end{bmatrix} = \begin{bmatrix} \mathbf{H}_{11} & \mathbf{H}_{12} & \mathbf{H}_{13} & \mathbf{H}_{14} \\ \mathbf{H}_{21} & \mathbf{H}_{22} & \mathbf{H}_{23} & \mathbf{H}_{24} \end{bmatrix} \begin{bmatrix} \mathbf{s}_{11} & -\mathbf{s}_{12}^{*} \\ \mathbf{s}_{12} & \mathbf{s}_{11}^{*} \\ \mathbf{s}_{21} & -\mathbf{s}_{22}^{*} \\ \mathbf{s}_{22} & \mathbf{s}_{21}^{*} \end{bmatrix} + \begin{bmatrix} \boldsymbol{\eta}_1^{t_1} & \boldsymbol{\eta}_1^{t_2} \\ \boldsymbol{\eta}_2^{t_1} & \boldsymbol{\eta}_2^{t_2} \end{bmatrix}$$

Equivalent Channel Model per Subcarrier

At the l^{th} subcarrier,

$$\begin{bmatrix} y_{1,l}^{t_1} & y_{1,l}^{t_2} \\ y_{2,l}^{t_1} & y_{2,l}^{t_2} \end{bmatrix} = \begin{bmatrix} h_{11,l} & h_{12,l} & h_{13,l} & h_{14,l} \\ h_{21,l} & h_{22,l} & h_{23,l} & h_{24,l} \end{bmatrix} \begin{bmatrix} s_{11,l} & -s_{12,l}^{*} \\ s_{12,l} & s_{11,l}^{*} \\ s_{21,l} & -s_{22,l}^{*} \\ s_{22,l} & s_{21,l}^{*} \end{bmatrix} + \begin{bmatrix} \eta_1^{t_1} & \eta_1^{t_2} \\ \eta_2^{t_1} & \eta_2^{t_2} \end{bmatrix}$$

Rearranging the received vector over two periods into one received vector

$$\begin{bmatrix} y_{1,l}^{t_1} \\ y_{2,l}^{t_1} \\ y_{1,l}^{t_2 *} \\ y_{2,l}^{t_2 *} \end{bmatrix} = \begin{bmatrix} h_{11,l} & h_{12,l} & h_{13,l} & h_{14,l} \\ h_{21,l} & h_{22,l} & h_{23,l} & h_{24,l} \\ h_{12,l}^{*} & -h_{11,l}^{*} & h_{14,l}^{*} & -h_{13,l}^{*} \\ h_{22,l}^{*} & -h_{21,l}^{*} & h_{24,l}^{*} & -h_{23,l}^{*} \end{bmatrix} \cdot \begin{bmatrix} s_{11,l} \\ s_{12,l} \\ s_{21,l} \\ s_{22,l} \end{bmatrix} + \begin{bmatrix} \eta_{1,l}^{t_1} \\ \eta_{2,l}^{t_1} \\ \eta_{1,l}^{t_2 *} \\ \eta_{2,l}^{t_2 *} \end{bmatrix}$$

$$\mathbf{y}_l = \begin{bmatrix} H_{1,l} & H_{2,l} \end{bmatrix} \mathbf{s}_l + \boldsymbol{\eta}_l$$

$$\mathbf{y}_l = \mathbf{H}_l \mathbf{s}_l + \boldsymbol{\eta}_l$$

Group Interference Nulling and Cancellation (GINC)

- Group interference nulling:

$$\mathbf{y}_l = \begin{bmatrix} H_{1,l} & H_{2,l} \end{bmatrix} \mathbf{s}_l + \boldsymbol{\eta}_l$$

-To detect group *k,* find the orthonormal bases ($\boldsymbol{\Theta}_{k,l}$)of the null space of H_l-{$H_{k,l}$}, then project y_l into this null space

$$\tilde{\mathbf{y}}_{k,l} = \boldsymbol{\Theta}_{k,l}\mathbf{y}_l = \tilde{H}_{k,l}\mathbf{s}_{k,l} + \tilde{\boldsymbol{\eta}}_{k,l}$$

source of Rx diversity reduction

- Group interference cancellation:

$$\tilde{\mathbf{y}}_l = \mathbf{y}_l - H_{k,l}\tilde{\mathbf{s}}_{k,l}$$

source of error propagation

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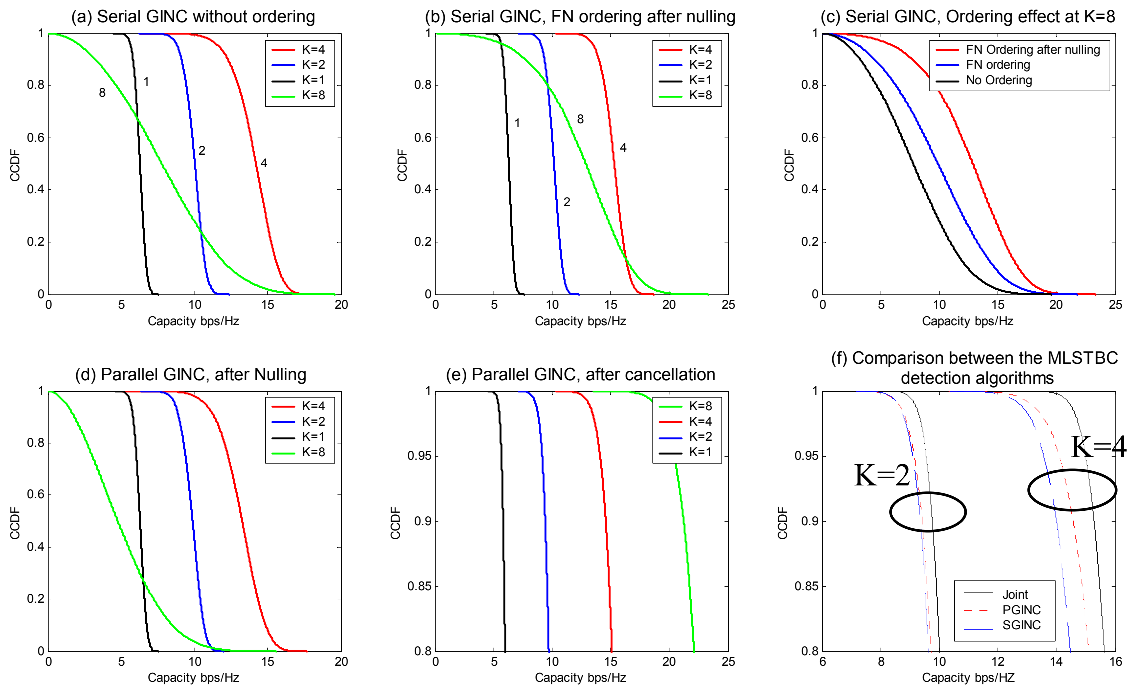
MLSTBC detection algorithms capacity

Assuming equal rate transmission from each group, the capacity of the MLSTBC system is:

$$C_{MLSTBC}^{GNIC} = K \cdot \min_{i=1,2,\ldots,K} \left\{ r_c \log_2 \left(1 + \frac{\rho}{K \cdot N_T} \left\| \tilde{\mathbf{H}}_i \right\|_F^2 \right) \right\}$$

- K groups
- M_R=8
- N_T=2 transmit antennas per group
- Each group uses Alamouti STBC
- SNR=10dB



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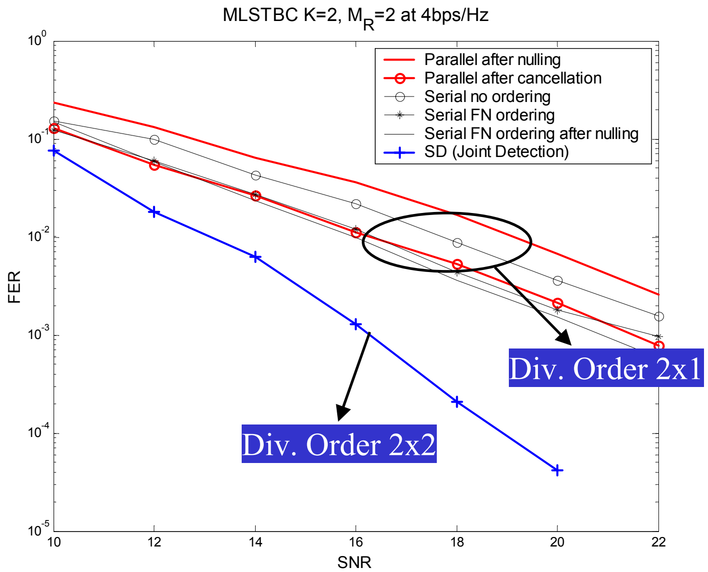
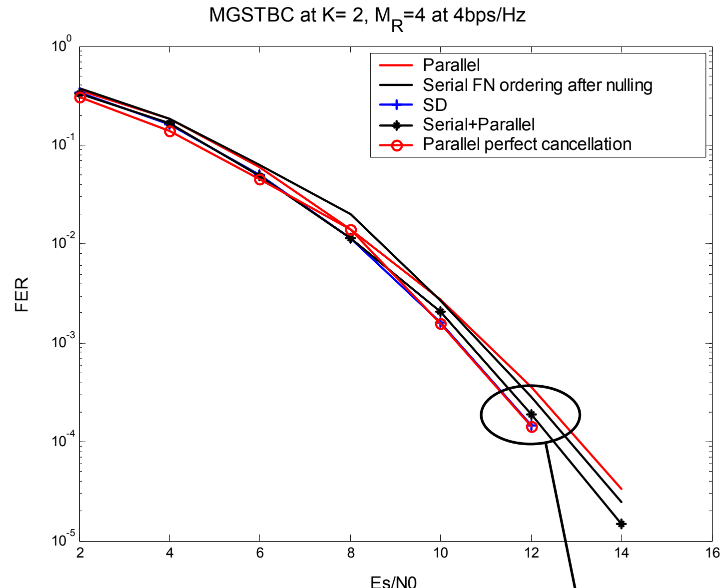
Simulation Results GINC algorithms verses joint detection (Sphere Decoder) at 4bps/Hz





For SGINC, although each layer has different diversity order, the system performance is dominated by the weakest group which is usually the first detected group. Similarly, the PGINC performance is dominated by the weakest group after parallel nulling.

Very close performance at low number of layers and at additional receive diversity. The weakest group has a diversity of 2x3

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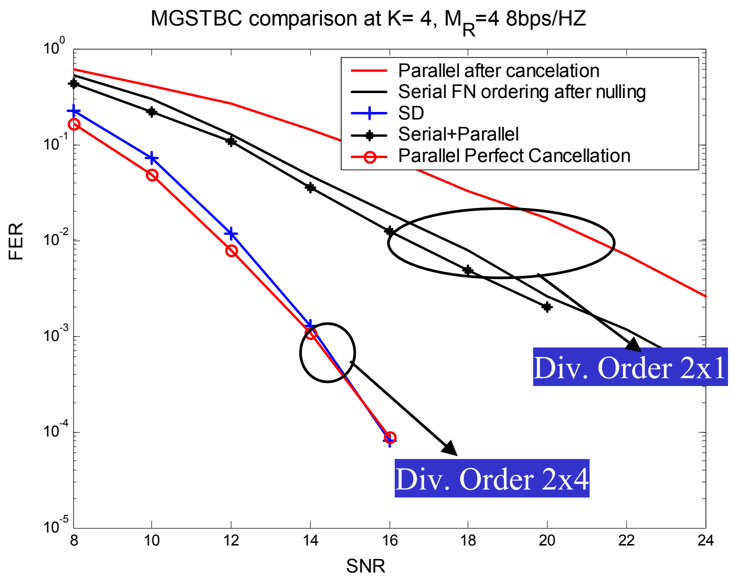
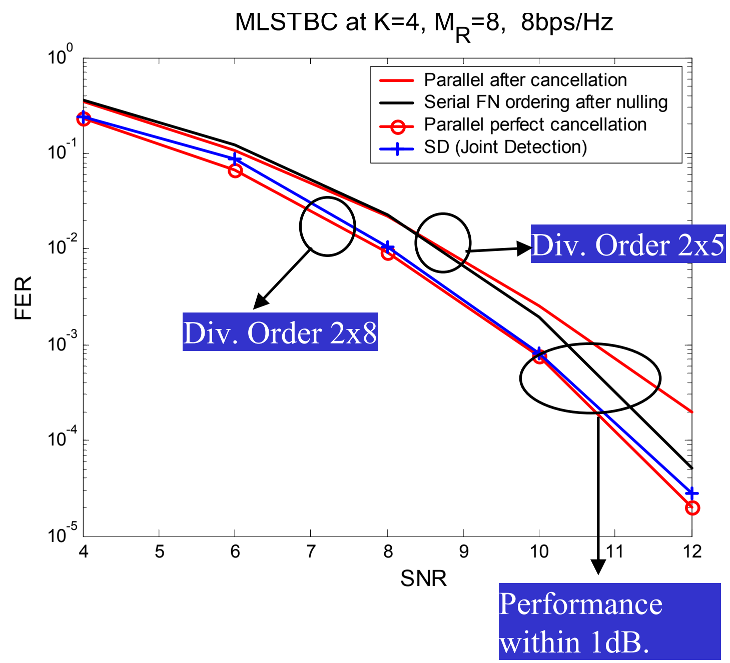
Simulation Results at 8bps/Hz





Conclusion

- We have presented a Multi-layered STBC system over frequency selective (FS) MIMO Channels.
- The OFDM transforms the FS MIMO channel into L parallel flat fading MIMO channels.
- Group interference nulling/ cancellation (GINC) and joint detection algorithms are applied on each subcarrier to decode the MLSTBC system.
- The SD performs the best. The serial algorithm with optimum ordering outperforms the parallel at high number of layers and with minimum number of receive antennas.

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Conclusion

	Diversity, Alamouti Code for each group	Complexity per subcarrier	Comments
Sphere Decoder (Joint Detection)	$2\times M_R$	At high SNRs, average complexity $O(K^3)$	ML detector but with random complexity which is an exponential in worst case scenario
Serial GINC	Dominated by the minimum Div. of $2\times(M_R-K+1)$	$O(K^3)$	Ordering improves the performance and adds more gain
Parallel GINC	Dominated by the minimum Div. of $2\times(M_R-K+1)$	$O(K^3)$	Parallel cancellation adds more gain to the performance