Performance Evaluation of Multi-Layered Space Frequency Time Codes for MIMO-OFDM Systems

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NCTT-MCP08

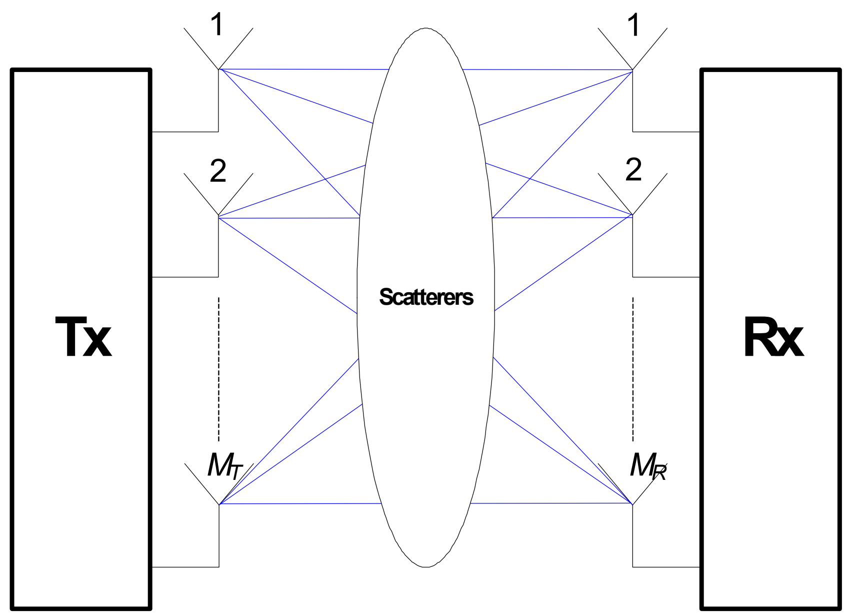
Aug, 2008

Outline

- Background and motivation
- IQ-Space Frequency Time codes
- Multi-Layered STBC vs VBLAST
- Multi-Layered SFT Codes

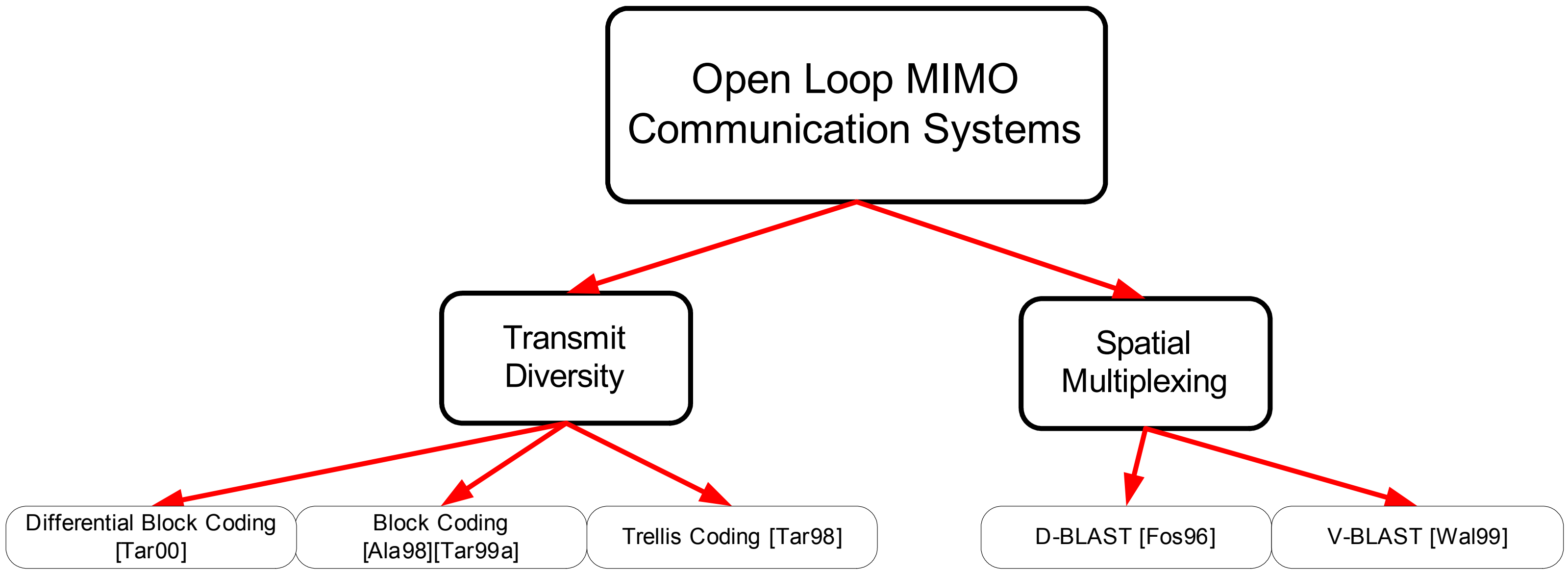
Introduction: Multiple Input Multiple Output (MIMO) Channels

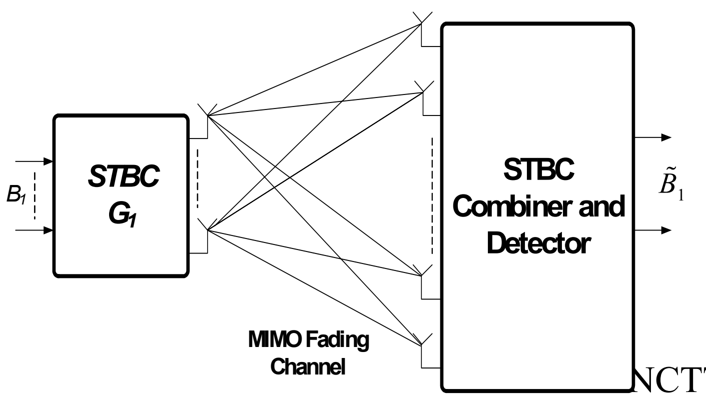
- A MIMO channel is a wireless link between M_T transmit and M_R receive antennas.
- MIMO channels boost the information capacity of wireless systems by order of magnitude [Telater95][Foschini98].

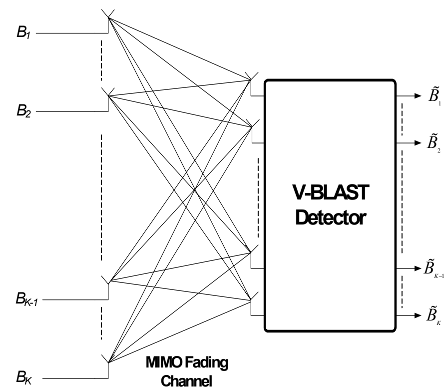


$$\mathbf{H}(t) = \begin{pmatrix} h_{11}(t) & \cdots & h_{1M_T}(t) \\ \vdots & \ddots & \vdots \\ h_{M_R1}(t) & \cdots & h_{M_RM_T}(t) \end{pmatrix}$$

Introduction: Open Loop MIMO Communication Systems

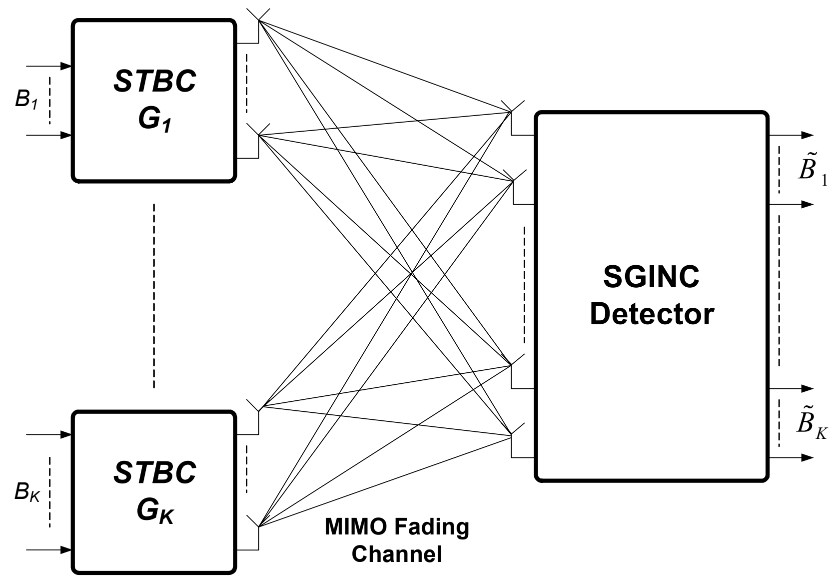






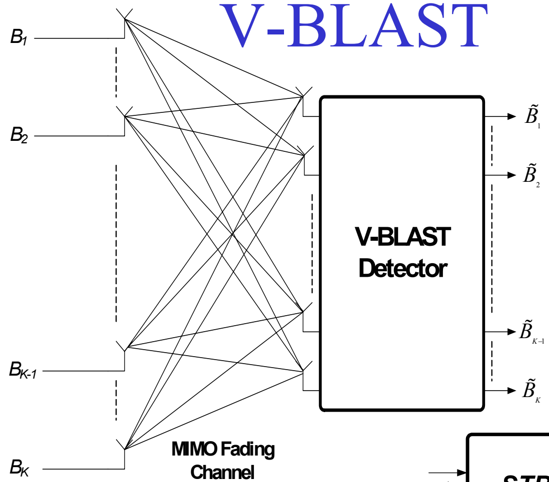
Multi-layered STBC is a single user system that consists of *K* parallel STBC

- It combines spatial multiplexing with transmit diversity.
- It is a V-BLAST system with STBC on each layer.

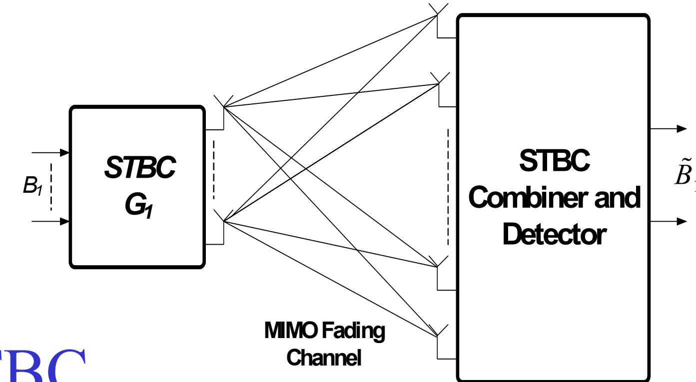


How does MLSTBC compare to V-BLAST and STBC?

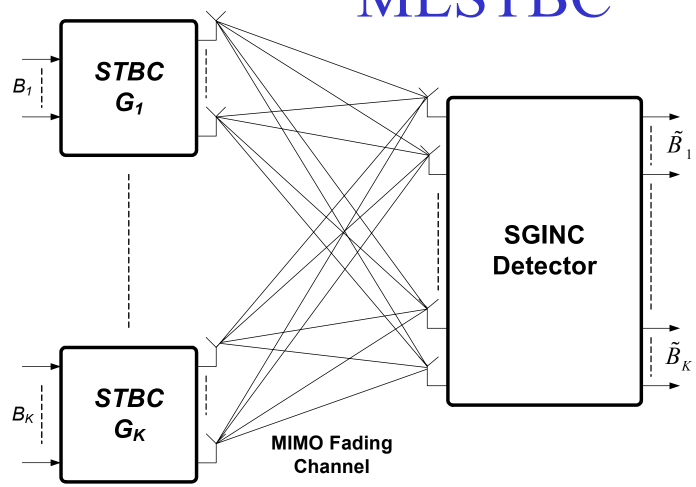
V-BLAST



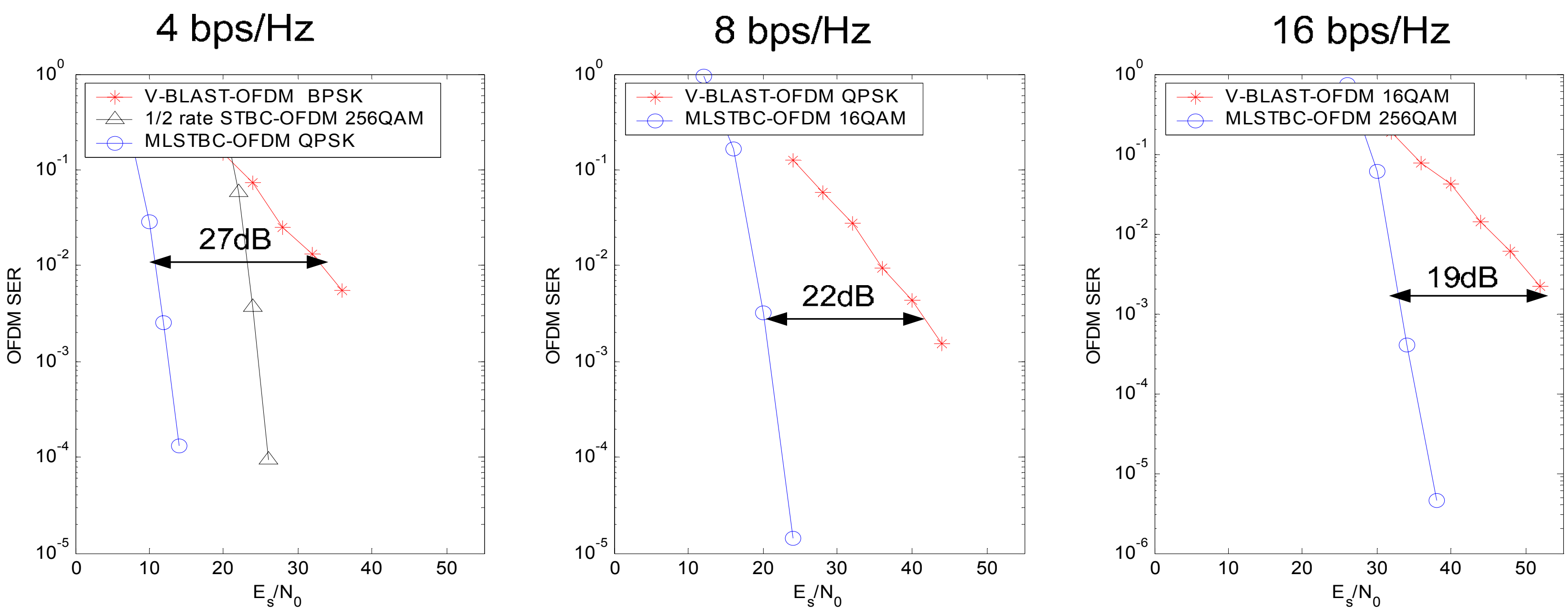
STBC



MLSTBC



Comparison of MLSTBC and V-BLAST over 4x4 MIMO-OFDM, N_c=64 and L=4



Motivation

- Pervious work on MLSTBC over MIMO-OFDM systems didn’t take advantage of the available frequency diversity.
- **Our Goal** is to design MLSTBC system that takes full frequency diversity advantage over MIMO-OFDM channels.
- **The solution** is to add space frequency time (SFT) codes at each layer.

Design criteria of SFT codes

- The maximum diversity available in MIMO-OFDM systems is $M_T L M_R$ [Ben Lu 2000].
- The design criterion is to maximize the minimum effective length and break up channel correlation in frequency domain by interleaving.
- To achieve this diversity, the minimum effective length of the SFT code should be equal to at least $M_T L$, which needs large number of states for practical values.
- For example, at $M_T=2$ and $L=3$, we need 1024 states. And at $L=4$, we need 16384 states

Design criteria of SFT codes

- **Our goal** is to simplify the design and reduce the number of states required to achieve the full spatial and frequency diversity.
- **Our approach** is based on concatenating trellis coded modulation (TCM) and space time block codes (STBC). [Lateif 2003]
- **Spatial diversity** is guaranteed by STBC and **frequency diversity** is provided by TCM.
- We further reduce the number of states of TCM by using **IQ-TCM** [AlSemari 97].

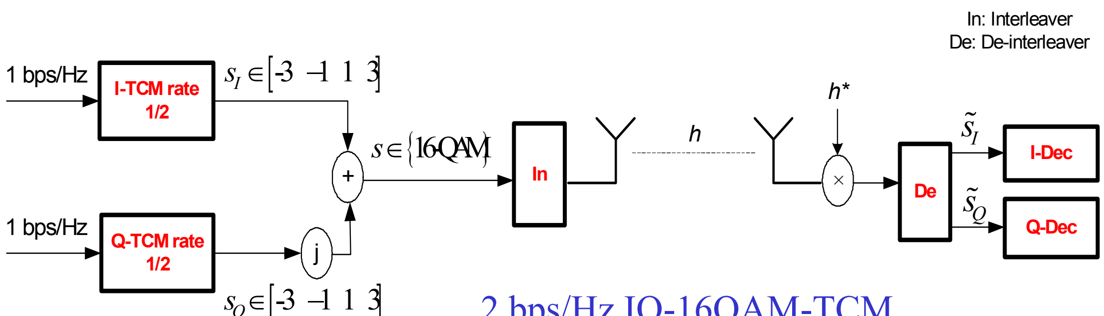
IQ-TCM [AlSemari97]

- The minimum effective length of TCM is upper bounded by:

$$l_{\min} \leq \lfloor v / k \rfloor + 1$$

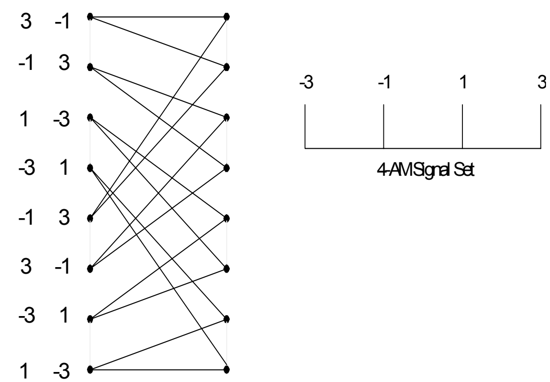
Where v is the number of memory elements and k is the number of inputs.

- Thus, when *k* is reduced by a half, l_{min} at most doubles and this is the reason behind the diversity increase of IQ-TCM.



2 bps/Hz IQ-16QAM-TCM

8-states 4AM-TCM

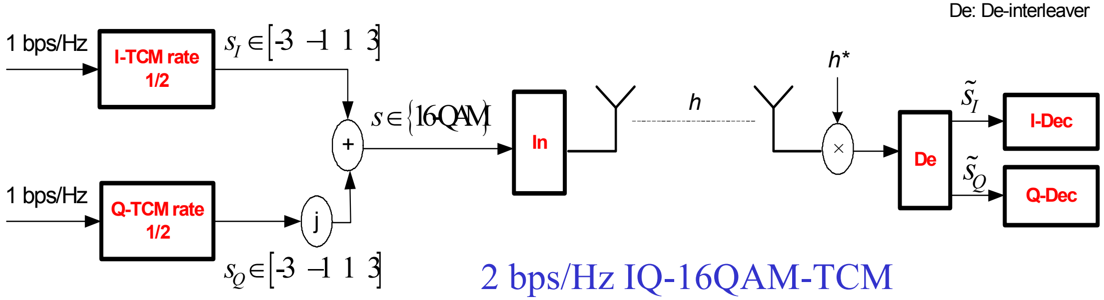


2 bps/Hz Comparison

- 8-states 8PSK-TCM:
  v=3, k=2 → l_{min}=2

$$l_{\min} \leq \lfloor v / k \rfloor + 1$$

- 8-states IQ-16QAM-TCM:
  v=3, k=1 → l_{min}=4



2 bps/Hz IQ-16QAM-TCM

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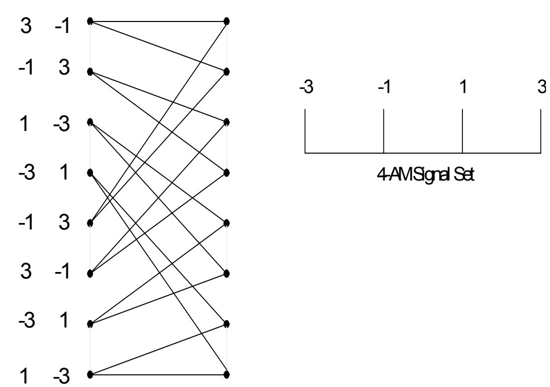
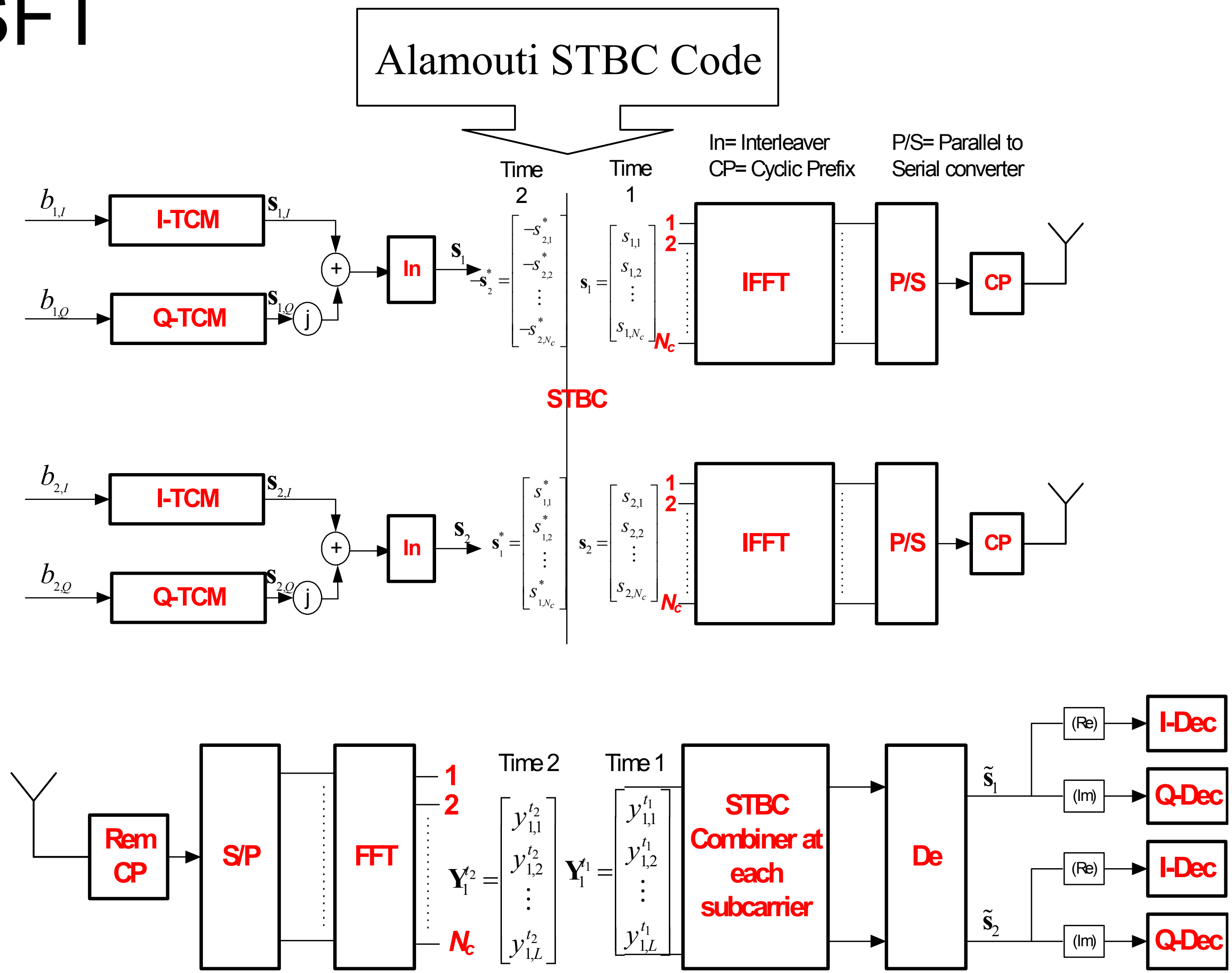


IQ-SFT

Encoder

Decoder



Advantages of concatenated IQ-TCM-STBC at 2bps/Hz

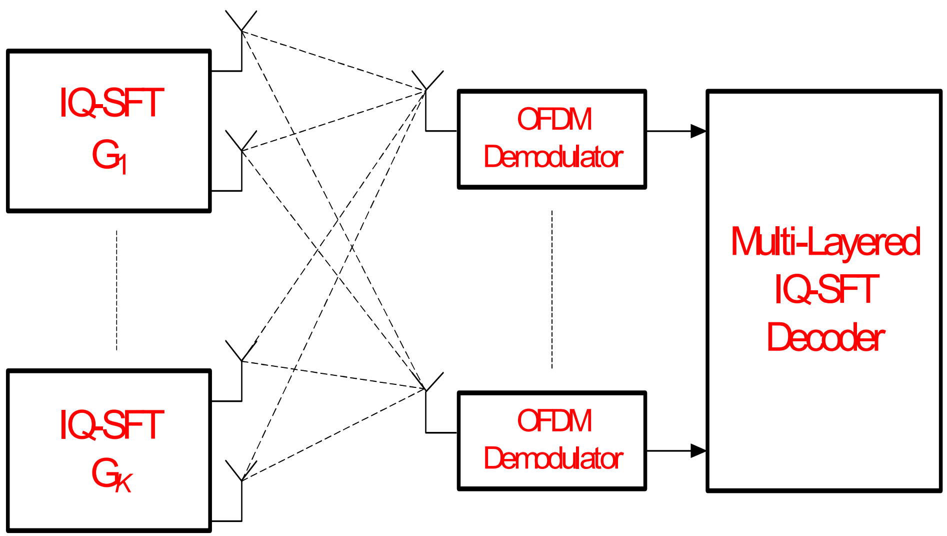
FCS Length	Minimum number of states to achieve full diversity ($M_T L M_R$)		
L	Tarokh STTC QPSK	8PSK-STBC	IQ-16QAM-STBC
2	64	4	2
3	1024	16	4
4	16384	64	8
5	262144	256	16
6	4194304	1024	32
7	67108864	4096	64

The discrete received signal over *T* time slots at the i^{th} subcarrier is

M_R: total number of receive antennas
N_G: number of transmit antennas per group
M_T: total number of transmit antennas

$$\mathbf{Y}_i = \mathbf{H}_i \mathbf{S}_i + \mathbf{V}_i$$

$$= \begin{bmatrix} \mathbf{H}_{1,i} & \mathbf{H}_{2,i} & \cdots & \mathbf{H}_{K,i} \end{bmatrix} \begin{bmatrix} \mathbf{S}_{1,i} \\ \mathbf{S}_{2,i} \\ \vdots \\ \mathbf{S}_{K,i} \end{bmatrix} + \mathbf{V}_i$$

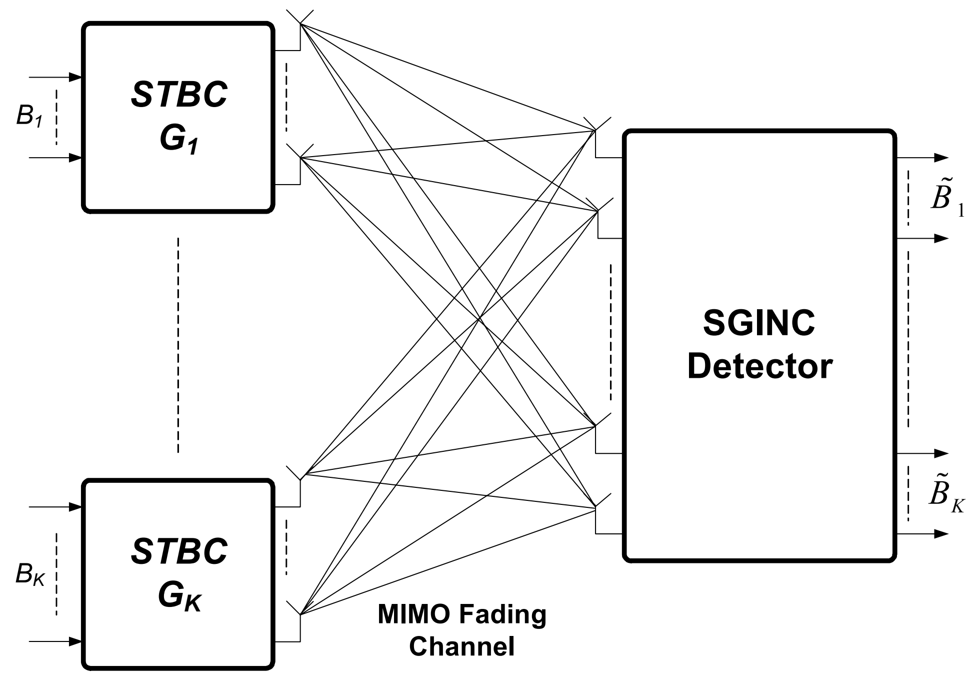


$\mathbf{S}_{k,i}$ is the k^{th} STBC at the i^{th} layer.
$\mathbf{H}_{k,i}$ is the $M_R \times N_G$ MIMO matrix from group *k* to the receiver at the i^{th} subcarrier.

Due to the short code length of STBC, the received signals over *T* slots are rearranged into a vector

$$\mathbf{y} = \hat{\mathbf{H}}\mathbf{x} + \boldsymbol{\eta}$$

$$= \begin{bmatrix} \hat{\mathbf{H}}_1 & \hat{\mathbf{H}}_2 & \cdots & \hat{\mathbf{H}}_K \end{bmatrix} \begin{bmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_K \end{bmatrix} + \boldsymbol{\eta}$$



$\mathbf{x}_k$ is the symbols of the k^{th} layer.

$\hat{\mathbf{H}}_k$ is the $M \cdot T \times N_G$ MIMO matrix from group *k* to the receiver.

Serial Group Interference Nulling and Cancellation (SGINC)

- *Group interference nulling*: Based on an ordering criterion, assume that the first detected group is the k^{th} group. Then, the algorithm calculates the orthonormal bases of the null space of:

$$\mathcal{H}_k = \begin{bmatrix} \hat{\mathbf{H}}_1 & \cdots & \hat{\mathbf{H}}_{k-1} & \hat{\mathbf{H}}_{k+1} & \cdots & \hat{\mathbf{H}}_K \end{bmatrix}$$

- Denote the orthonormal bases of the null space of $\mathcal{H}_k$ by $\mathcal{N}_k$, then the received signal for the i^{th} group after nulling is:

$$\tilde{\mathbf{y}}_k = \mathcal{N}_k \mathbf{y} = \tilde{\mathbf{H}}_k \mathbf{x}_k + \tilde{\boldsymbol{\eta}}_k$$

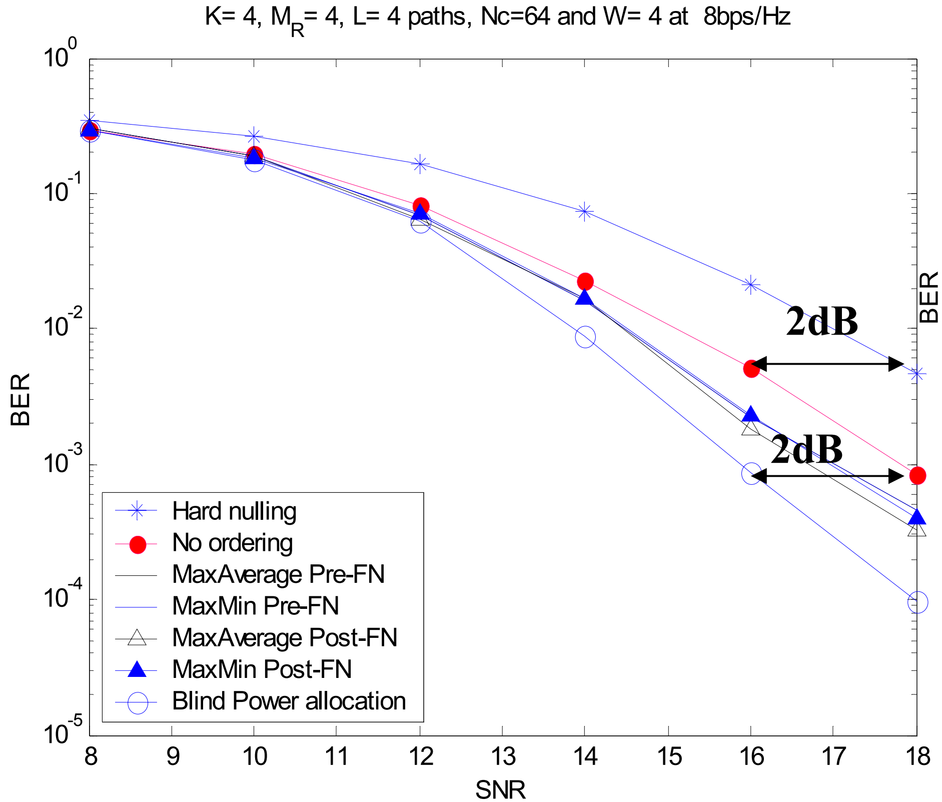
Where $\tilde{\mathbf{H}}_k$ is the post-processing channel matrix.

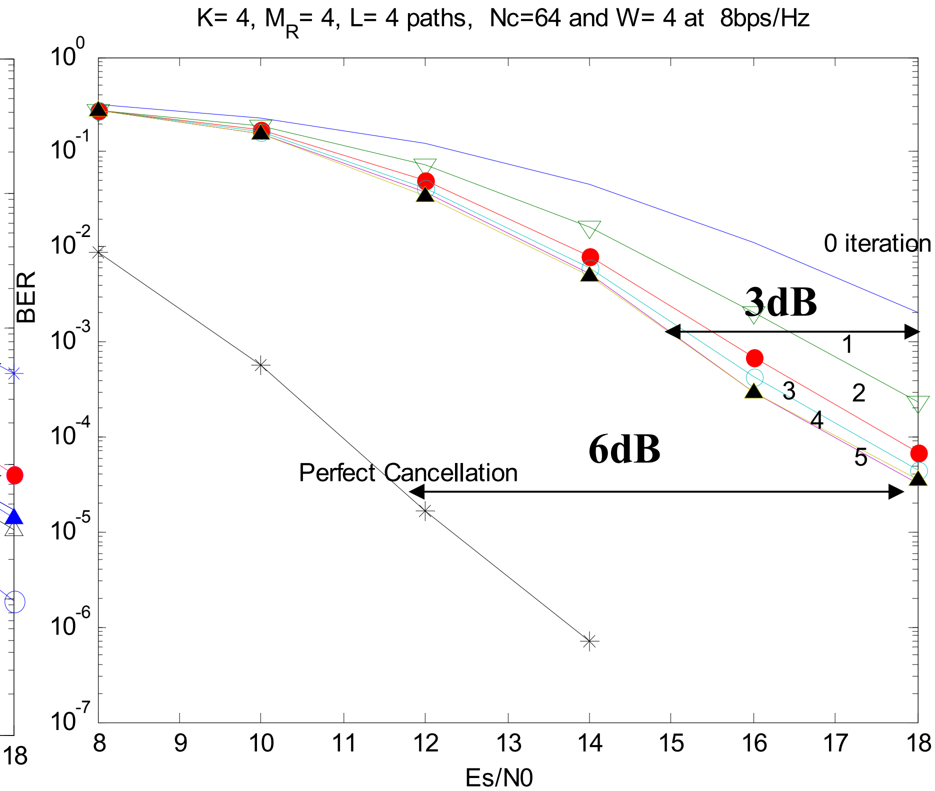
SGINC

- *STBC Combiner:* $\tilde{\mathbf{x}}_k = \tilde{\mathbf{H}}_k^H \tilde{\mathbf{y}}_k$
- *IQ-SFT Decoder*
- *Group interference cancellation*: After Decoding the k^{th} Layer, its contribution is subtracted from the received signal and the processing is repeated serially for each group.
- *Ordering:*
  - *MaxMin FN*
  - *MaxAverage FN*
  - *Blind power allocation*
- Number of receive antennas should be greater than or equal to number of layers.

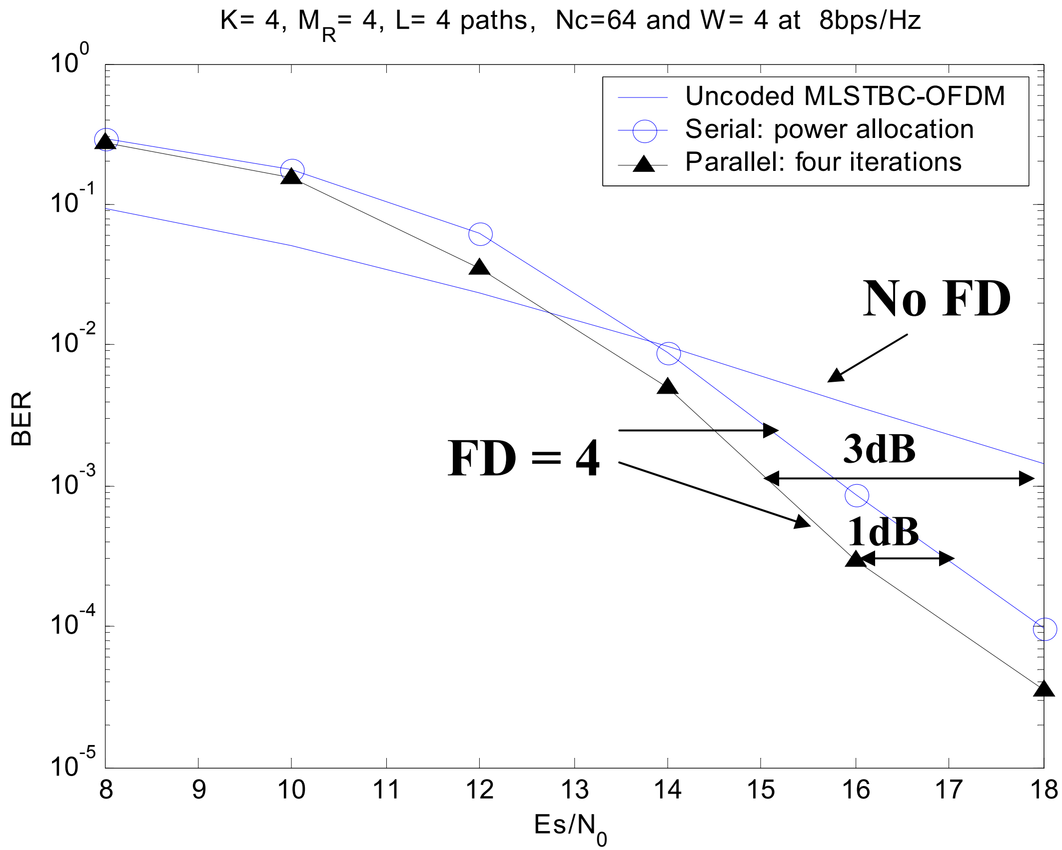
Serial Interference cancellation/ decoding algorithm

Parallel Interference Cancellation/ Decoding Algorithm





Comparison


K= 4, M_R= 4, L= 4 paths, Nc=64 and W= 4 at 8bps/Hz
Uncoded MLSTBC-OFDM
Serial: power allocation
Parallel: four iterations
No FD
FD = 4
3dB
1dB
BER
Es/N_0
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
8
9
10
11
12
13
14
15
16
17
18

Conclusion

- Multi-layered Space frequency time codes were designed and evaluated over MIMO-OFDM channels.
- The code design is simplified with IQ-TCM.
- Serial and parallel algorithms were proposed and evaluated for MIMO-OFDM systems.