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

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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].

$$H(t) = \begin{pmatrix} h_{11}(t) & \cdots & h_{1M_R}(t) \\ \vdots & \ddots & \vdots \\ h_{M_T1}(t) & \cdots & h_{M_TM_R}(t) \end{pmatrix}$$
Introduction: Open Loop MIMO Communication Systems

Open Loop MIMO Communication Systems

Transmit Diversity
- Differential Block Coding [Tar00]
- Block Coding [Ala98][Tar99a]
- Trellis Coding [Tar98]

Spatial Multiplexing
- D-BLAST [Fos96]
- V-BLAST [Wal99]
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

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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:

\[ l_{\text{min}} \leq \left\lfloor \frac{v}{k} \right\rfloor + 1 \]

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

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

In: Interleaver
De: De-interleaver

2 bps/Hz IQ-16QAM-TCM

8-states 4AM-TCM

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2 bps/Hz Comparison

- **8-states 8PSK-TCM:**
  \( v=3, k=2 \rightarrow l_{min}=2 \)

- **8-states IQ-16QAM-TCM:**
  \( v=3, k=1 \rightarrow l_{min}=4 \)

\[
l_{min} \leq \left\lfloor \frac{v}{k} \right\rfloor + 1
\]
IQ-SFT

Alamouti STBC Code

Encoder

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

<table>
<thead>
<tr>
<th>FCS Length</th>
<th>Minimum number of states to achieve full diversity ( (M_TLM_R) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L ) ( )</td>
<td>Tarokh STTC QPSK</td>
</tr>
<tr>
<td>2</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>1024</td>
</tr>
<tr>
<td>4</td>
<td>16384</td>
</tr>
<tr>
<td>5</td>
<td>262144</td>
</tr>
<tr>
<td>6</td>
<td>4194304</td>
</tr>
<tr>
<td>7</td>
<td>67108864</td>
</tr>
</tbody>
</table>
The discrete received signal over $T$ time slots at the $i^{th}$ subcarrier is

\[ Y_i = H_i S_i + V_i \]

\[
= \begin{bmatrix}
H_{1,i} & H_{2,i} & \cdots & H_{K,i}
\end{bmatrix}
\begin{bmatrix}
S_{1,i} \\
S_{2,i} \\
\vdots \\
S_{K,i}
\end{bmatrix} + V_i
\]

$S_{k,i}$ is the $k^{th}$ STBC at the $i^{th}$ layer.

$H_{k,i}$ is the $M_R \times N_G$ MIMO matrix from group $k$ to the receiver at the $i^{th}$ subcarrier.

$M_R$: total number of receive antennas
$N_G$: number of transmit antennas per group
$M_T$: total number of transmit antennas
Due to the short code length of STBC, the received signals over $T$ slots are rearranged into a vector

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

where

$$\hat{H}_k = \begin{bmatrix} \hat{H}_1 & \hat{H}_2 & \cdots & \hat{H}_K \end{bmatrix}$$

$y$ is the received signal vector,

$x_k$ is the symbols of the $k^{th}$ layer.

$\hat{H}_k$ 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:

$$\mathcal{H}_k = \left[ \hat{H}_1 \quad \cdots \quad \hat{H}_{k-1} \quad \hat{H}_{k+1} \quad \cdots \quad \hat{H}_K \right]$$

- 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:

$$\tilde{y}_k = \mathcal{N}_k y = \tilde{H}_k x_k + \tilde{\eta}_k$$

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

- **STBC Combiner:** $\tilde{x}_k = \tilde{H}_k^H \tilde{y}_k$
- **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

K = 4, M_r = 4, L = 4 paths, N_c = 64 and W = 4 at 8 bps/Hz
Comparison

K = 4, M = 4, L = 4 paths, Nc = 64 and W = 4 at 8bps/Hz

BER vs Es/N0

Uncoded MLSTBC-OFDM
Serial: power allocation
Parallel: four iterations

FD = 4
No FD

3dB
1dB
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.