IQ Space Frequency Time Codes for MIMO-OFDM Systems

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Outline

• Background and motivation
• IQ-SFT code description and performance
• Effect of interleaving
Introduction: Multiple Input Multiple Output (MIMO) Channels

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

\[ \mathbf{H}(t) = \begin{pmatrix} h_{11}(t) & \cdots & h_{1M_R}(t) \\ \vdots & \ddots & \vdots \\ h_{M_T,1}(t) & \cdots & h_{M_T,M_R}(t) \end{pmatrix} \]
OFDM

- Wide bandwidth and high data rates result in frequency selective channels (FSC) which cause ISI.
- OFDM is robust against FSC. It transforms FSC to parallel flat fading channels.
- WLANs such as IEEE 802.11a and Hyperlan2 are based on OFDM
OFDM Channel Model in the Frequency Domain

\(N_c\) subcarriers
\(L\) taps (FSC length)

Let \(h_{mn} = [h_0, h_1, \cdots, h_{L-1}]^T\)

The OFDM channel in the frequency domain is
\(h^f_{mn} = F h_{mn}\)

\[F_{k,l} = \frac{1}{\sqrt{N_c}} \exp \left[ -i \frac{2\pi}{N_c} (k - 1)(l - 1) \right];\]
\(k = 0,1,\ldots,N_c-1\)
\(l = 0,1,\ldots,L-1\)

Let \(h \sim N_c(0, \mathbf{C}_h)\)

The covariance matrix in the frequency domain is
\(\mathbf{C}_{h^f} = \mathbf{F} \mathbf{C}_h \mathbf{F}^H\)
Background on Space Frequency Time (SFT) Codes

• SFT codes apply spatial coding across multiple antennas, frequency coding across OFDM subcarriers, and temporal coding across successive OFDM symbols.

• [Agrawal98]: STTC-OFDM, not optimized for OFDM channels, designed for quasi-static channels.
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.
Design criteria of SFT codes

• Our goal in this work is to simplify the design and reduce the number of states required to achieve the full spatial and frequency diversity.
• Our approach is to concatenate trellis coded modulation (TCM) and STBC.
• 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:

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

2 bps/Hz IQ-16QAM-TCM

8-states 4AM-TCM
IQ-SFT

Encoder

Decoder

05/16/2006
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>
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<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>
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<tr>
<td>4</td>
<td>16384</td>
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<td>5</td>
<td>262144</td>
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<td>6</td>
<td>4194304</td>
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<td>7</td>
<td>67108864</td>
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</tbody>
</table>
Channel Model

• The channel is a MIMO-FSC of length $L$ with equal power paths and each path experience an independent Rayleigh fading.
• We assume that the channel is constant over two OFDM symbols.
Performance results over 2x1 MIMO-OFDM channels at 2 bps/Hz 8-state TCM, $N_c=64$, $W=4$

\begin{figure}
\centering
\includegraphics[width=\textwidth]{performance_results}
\caption{BER vs. SNR for different modulation schemes and STBC-OFDM configurations.}
\end{figure}
Interleaving effect over 2x1 MIMO-OFDM channels at 2bps/Hz 8-state TCM
Effect of interleaving on subcarrier correlation

(a) Correlation No Interleaving at L= 4 paths and Nc=64

(b) Correlation with Interleaving at L= 4 paths and Nc=64 and W= 4
SFT coding conclusions

- Concatenated IQ-TCM-STBC-OFDM achieves full spatial and frequency diversity at much lower complexity than other codes.
- Appropriate block interleaver design is essential to maintain the performance and diversity of the code. Best performance is at \( W=L \) and \( W=2L \).