Two suggestions for Wideband OFDM Systems using frequency diversity

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Purpose: This presentation presents the concept for the proposed new diversity scheme feature.

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Two suggestions for Wideband OFDM Systems using frequency diversity

PanYuh Joo

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Objective

Idea
Efficient utilized methods
of frequency diversity
in OFDM system

Problem of STBC-OFDM
• Limitation in Performance
• Complexity increase
  as Number of Antenna increase
• Transmission rate decrease
  as Number of Antenna increase

Advantage of STFBC-OFDM
• enhancement in BER
  (using Frequency Diversity)
• simple structure
  (do not increase number of antennas)

STBC: space time block code
STFBC: space time frequency block code

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Introduction

• Diversity Techniques
  – Time Diversity : Channel Coding, Interleaving
  – Frequency(Path) Diversity : Coded-OFDM, Spread Spectrum
  – Space(Antenna) Diversity
    • Transmit Diversity
      – Space-Time Code (Space-Time Trellis Code, Space-Time Block Code)
    • Receiver Diversity
      – Rake Receiver, Selection Diversity

• MIMO Systems
  – Spatial Multiplexing
    • Capacity → increase in transmission rate (BLAST)
  – MIMO Diversity
    • Diversity gain → Performance Improvement (Transmit Diversity using Space-Time Code)
Space-Time Block Coding - I

• Space-Time Block Code
  – STBC is one of the simplest STC schemes.
    • Only simple linear processing at the receiver is required.
  – Maximum diversity gain
    • # of Tx antenna × # of Rx antenna

• Space-Time Block Coded OFDM (STBC-OFDM)
  – OFDM: robust in channel Environments
    + STBC: Diversity Gain
**Space-Time Block Coding - II**

- **Encoding Process**

  Transmitted Signal

  \[
  \begin{bmatrix}
  c_1 \\
  c_2
  \end{bmatrix}
  \rightarrow
  \begin{bmatrix}
  c_1^* \\
  c_2^*
  \end{bmatrix}
  \]

- **Decoding Process**

  Received Signal

  \[
  r_1 = h_1 c_1 + h_2 c_2 + n_1
  \]
  \[
  r_2 = -h_1 c_2^* + h_2 c_1^* + n_2
  \]

  \[
  r = \begin{bmatrix}
  r_1 \\
  r_2^* \end{bmatrix}^T = H c + n
  \]

  Channel Matrix

  \[
  H = \begin{bmatrix}
  h_1 & h_2 \\
  -h_2^* & h_1^*
  \end{bmatrix}
  \rightarrow
  H^H H = \rho \cdot I, \quad \rho = |h_1|^2 + |h_2|^2
  \]

  ML Decoder

  \[
  \hat{c} = \arg \min_{\hat{c} \in \mathcal{C}} \| r - H \cdot \hat{c} \|^2
  \rightarrow
  \hat{c} = \arg \min_{\hat{c} \in \mathcal{C}} \| \hat{r} - \rho \cdot \hat{c} \|^2,
  \]

  where

  \[
  \hat{r} = H^H r = \rho \cdot c + \hat{n}
  \]
Space-Time Block Coding - III

• Some STBC Examples for Multiple Transmit Antennas

• In the case of using more than three transmission antennas, simultaneously satisfy code orthogonality and transmission rate of STBC as 1, do not exists (Proved by V. Tarokh)

<table>
<thead>
<tr>
<th>Num. of Tx. Ant.</th>
<th>Space-Time Block Code</th>
<th>BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>• (2x2) Matrix: 2 symbol transmission in 2Ts (Proposed by Alamouti)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>• (8x3) Matrix: 4 symbol transmission in 8Ts (Proposed by Tarokh)</td>
<td>1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>• (8x4) Matrix: 4 symbol transmission in 8Ts (Proposed by Tarokh)</td>
<td>1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Space-Time and Frequency Block Coding for Wideband OFDM - I

• Motivation
  – Request More reliable system in next generation comm. system
    • Request of higher Diversity Gain $\rightarrow$ should increase the number of antennas
  – Diversity Gain of STBC Depends on number of Tx antennas
    • To improve in performance should increase number of tr antenna
    • Of number of antenna increase HW load seriously increases.
    • Especially, In the case of STBC-OFDM compare to single carrier system, operational complexity increases depends on sub-carrier number. $\rightarrow$ operational complexity greatly increases
      In OFDM, an STBC-OFDM system that have more than 3 tx antennas is not easy in implementation.
  – The STBC using more than 3 tx antennas transmission rate decreases.
  – OFDM can obtain frequency diversity in simple method.
Space-Time and Frequency Block Coding Wideband OFDM - II

Design consideration

- **Maximum Frequency Diversity Gain**
  - # of Tx antenna × # of rx antenna × frequency gain

- **Simple Structure**
  - Should not increase number of transmission antenna.
  - To earn frequency Diversity Gain in Decoding process it should be incorporated with Linear Processing

- Compatibility with **STBC-OFDM system**

- **Minimize complexity increase**
- **Maximize Diversity Gain**

→ **Space-Time and Frequency Block Coding Technique**
Space-Time and Frequency Block Coding Wideband OFDM - III

- STFBC Transmitter

\[ s = \begin{bmatrix} s(0) & \cdots & s(N-1) \end{bmatrix}^T \]

Frequency Coder: Frequency diversity enabling part in STBC-OFDM system
**Frequency Coder**

- Replicate original signal
- Cyclically shift sub-carrier $X_1$ produce $X'_1$
- $X_1$ and $X_1'$ is get into the original STC symbol mapping such as

  - $X_1 = s = [s(0), \ldots, s(N-1)]^T$
  - $X_2 = X_1' = [s(N-d), \ldots, s(N-1), s(0), \ldots, s(N-d-1)]^T$
  - The shift term $d$ can be obtained as following

$$\Delta k = d = \left\lfloor \frac{N}{L} \right\rfloor \cdot \left\lfloor \frac{L}{2} \right\rfloor$$
Correlation of sub-carriers with $0_{th}$ sub-carrier

\[ \Delta k = d = \left\lfloor \frac{N}{L} \right\rfloor \cdot \left\lfloor \frac{L}{2} \right\rfloor \]
Space-Time and Frequency Block Coding Wideband OFDM - IV

• STFBC Receiver

\[
\tilde{r} = \frac{1}{\rho} H^H r
\]

\[
\begin{bmatrix}
\hat{s}(0) \\
\vdots \\
\hat{s}(N-1)
\end{bmatrix}
\]

_\text{Space-Time and Frequency Block Decoder}_
Frequency Decoder

• Inverse cyclically shifted sub-carrier of the estimated symbol \( X_2 \) to produce the “replication” of symbol \( X_1 \).
• \( X_1 \) and \( X_2’ \) is combined as frequency diversity manner such that
  \[
  X_1 = s = [s(0), \ldots, s(N-1)]^T
  \]
  \[
  X_2’ = X_1(k-d) \mod N = [s(0), \ldots, s(N-1)]^T
  \]
• The inverse shift term \( d \) can be obtained from channel estimation process, proportional to Channel impulse response \( L \).
Space-Time and Frequency Block Coding Wideband OFDM - V

• Performance Result (1)

• Simulation environments
  – Channel Order : 10
  – 16-QAM
  – Independent Rayleigh Fading Channel
  – Perfect Channel & Order Information
  – 4 tx antenna using STBC and 2 tx antenna using STFBC shows same performance
  – Compare to 3 tx antenna using STBC in $10^{-4}$ SER shows approximate 2.5dB SNR gain
Space-Time and Frequency Block Coding Wideband OFDM - VI

- Performance Result (2)

- Simulation environments
  - Channel Order : 10
  - Independent Rayleigh Fading Channel
  - 2 tx antennas and 1 rx antenna
  - Perfect Channel & Order Information
  - 2bits/sub-carrier
  - $\ln 10^{-5}$ BER approx. 5dB performance improvements.
  - If correlation between tx antennas increases, the performance improves impressively.
Closing Comment

• **Space-Time Block Coding (STBC)**
  – Simple structure and Full space diversity gain
  – But there are many problem when using more than 3 antennas in OFDM system (HW and operational complexity, decrease in tx rate)

• **Space-Time and Frequency Block Coding (STFBC)**
  – Overcome the problem of STBC-OFDM
  – A scheme, Not only Maximize Space Diversity but also frequency Diversity gain
  – Using frequency diversity so that increase the number of tx antenna is not required.
  – Compatible to existing STBC-OFDM

• **Two suggestion**
  – **Tx diversity scheme for OFDM system is desirable to use the STFBC is strongly requested.**
  – **The code combining in H-ARQ is also desirable to adapt the frequency diversity in this proposal.**