Analysis of STFBC-OFDM for BWA in SUI channel

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

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Analysis of STFBC-OFDM for BWA in SUI Channel

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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)
• Range enhancement (due to Eb/N0 enhancement)

STBC: space time block code
STFBC: space time frequency block code
History of MIMO techniques

• Space-Time Trellis Code (STTC)
  – Guey et al. (1996) and Tarokh et al. (1998) independently derived design criteria for STTC

• Alamouti’s scheme with 2 Tx and Nr Rx antennas
  – Alamouti (1998) proposed a novel scheme to orthogonalize the channel with a very simple decoder

• Space-Time Block Code (STBC)
  – Tarokh et al. (1999) generalized Alamouti’s scheme with an orthogonal block coding structure
## Space-Time Block Coding

- **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>STBC Coder</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>(2×2)</strong> Matrix</td>
<td></td>
</tr>
<tr>
<td></td>
<td>: 2 symbol transmission in (2T_s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Proposed by Alamouti)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>STBC Coder</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>(8×3)</strong> Matrix</td>
<td></td>
</tr>
<tr>
<td></td>
<td>: 4 symbol transmission in (8T_s)</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td></td>
<td>1/2</td>
<td></td>
</tr>
<tr>
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<td>STBC Coder</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>(8×4)</strong> Matrix</td>
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<tr>
<td></td>
<td>1/2</td>
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</tbody>
</table>
Space-Time and Frequency Block Coding - OFDM - I

• Motivation
  – Request More reliable system in next generation comm. system
    • Request of higher Diversity Gain → 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. → **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**.

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Space-Time and Frequency Block Coding - 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 incorporate 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

\[
\begin{bmatrix} x_1 & x_2 \end{bmatrix} 
\rightarrow \begin{bmatrix} x_1 & x_2 \\ -x_2 & x_1 \end{bmatrix}
\]

\(X_2\) is replica symbol of \(X_1\)

Signal 1

Signal 2
Space-Time and Frequency Block Coding Wideband OFDM - IV

- STFBC Receiver

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

Channel state Information

Space-Time and Frequency Block Decoder

Channel state Information Needs only small amount Of data

\[ \hat{s} = \begin{bmatrix} \hat{s}(0) \\ \vdots \\ \hat{s}(N-1) \end{bmatrix} \]
Channel Covariance Matrix (CCM)

- Channel impulse response of L multi-path frequency selective fading can be modeled as L-Tap FIR filter as,

\[ g(t) = \sum_{i=0}^{L-1} h(i) \delta(t - \tau_i) \]

Then

\[ H(k) = \sum_{i=0}^{L-1} h(i) e^{-j2\pi ki/N}, 0 \leq k \leq N - 1 \]

\[ \rho_{\Delta k} = E[H(k)H^*(k + \Delta k)] = \sum_{i=0}^{L-1} \sigma_i^2 e^{j2\pi \Delta ki/N} = \frac{1}{L} \sum_{i=0}^{L-1} e^{j2\pi \Delta ki/N} = \frac{1}{L} \sin \left( \frac{\pi \Delta k}{N} \right) \sin \left( \frac{\pi \Delta k}{N} \right) e^{j\pi \Delta k (L-1)/N} \quad (1) \]

Channel covariance matrix is ..

\[ C_H = E[H H^H] = \begin{bmatrix} \rho_0 & \rho_1 & \cdots & \rho_{N-1} \\ \rho_{-1} & \rho_0 & \cdots & \rho_{N-2} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{-N+1} & \rho_{-N+2} & \cdots & \rho_0 \end{bmatrix} \]

\[ H = [H(0)H(1)\cdots H(N-1)]^T \text{ Is defined} \]

1. \[ \rho_{-\Delta k} = \rho_{\Delta k}^* \]
2. \[ |\rho_{-\Delta k}| = |\rho_{\Delta k}| \]
3. \[ \rho_{-\Delta k} = \rho_{N-\Delta k} \]

CCM has Cyclic Shift property

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To maximize the frequency diversity select optimum sub-carrier position

- Let $\rho_{\kappa_1\kappa_2}=0$, in Eq. (1), than
- 
  $$\sin\left(\frac{\pi \Delta k_{12} L}{N}\right) = 0$$

  (2)
- $\Delta k_{12}$ is function of the distance of 2 sub-carriers.
- $\Delta k_{12} = \frac{mN}{L}$ is general solution.
- \[ \frac{L}{N} \leq m \leq \frac{L}{N} - \frac{L}{N} \], m, N & L all positive integer
- \[ 1 \leq m \leq L - 1 \]

  (3)
- The optimum sub-carrier position in one of m.
- Find minimum channel covariance in m sub-carrier
Maximum frequency diversity achievable OFDM system structure

- 3 things shall be considered in the FD system.
  - Maximize diversity gain
  - Distance between all sub-carrier shall be maintained.
  - Robust property of channel correlation between sub-carrier.

- The maximum separation of sub-carrier is N/2. And in general, the optimum
  \[ \Delta k = d = \left[ \frac{N}{L} \right] \cdot \left\lfloor \frac{L}{2} \right\rfloor \]
  \[ \rho_{-\Delta k} = \rho_{N-\Delta k} \]

- According to channel covariance matrix property 3 the correlation vector is cyclically rotate to each other. So the maximum separable sub-carrier spacing \( k' \) is

- \( k' = (k + d) \mod N \)
Optimum Position of Sub-carrier of Symbol $X_1$

- Put the 0$^{th}$ sub-carrier of the replica symbol here!!
- Frequency Diversity Maximized

Put replica symbol of $X_1$

[Graph showing correlation amplitude against subcarrier index]
What is Replica Symbol?

EX) If d=8 in 16 FFT, then . . .

\[ X_1 \]
\[
\begin{array}{cccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7
\end{array}
\]

\[ X_2 = X_1 \]
\[
\begin{array}{cccccccc}
0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\
8 & 9 & 0 & 1 & 2 & 3 & 4 & 5
\end{array}
\]

\[ X_1 = \text{Tx symbol} \]
\[ X_2 = \text{replica symbol} \]
\[ \sim \text{means cyclic shift in frequency domain} \]
MIMO system performance

For the quasi-static flat fading channel with $N_t$ transmit and $N_r$ receive antennas, the pairwise error probability is

$$P(c \rightarrow e) \leq \left( \frac{E_S}{4N_0} \right)^{-LN_r} \left( \prod_{t=1}^{L} d_H^t(c, e) \right)^{-N_r}$$

where $L \leq N_t$ is the number of nonzero Hamming distances per branch $d_H^t(c, e)$

**diversity gain**: slope of BER curve

**coding gain**: horizontal shift of BER curve
Symbol (frequency) Interleaving

Original

Interleaved $X_1$

Interleaved Cyclic Shift of $X_1$

Cyclic shift of symbol
Do not effect Coding & Interleaving Gain
Analysis in SUI channel model

• In L path frequency selective fading,
  – Assumed Uniform delay spread

• But, It is different in SUI model
  – Ricean
    – Delay spread is Not uniform

• Two model is analysed
  – SUI 1 terrain Type C
  – SUI 3 terrain Type B
SUI channel model

### SUI-3 Channel

<table>
<thead>
<tr>
<th>Tap1</th>
<th>Tap2</th>
<th>Tap3</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.4</td>
<td>0.9</td>
<td>µs</td>
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- **Delay**: 0<br>- **Power (omni ant.)**: 0<br>- **Doppler (omni ant.)**: 0.4

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### SUI-1 Channel

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- **Delay**: 0<br>- **Power (omni ant.)**: 0<br>- **Doppler (omni ant.)**: 0.4

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- **Delay**: 0<br>- **Power (omni ant.)**: 0<br>- **Doppler (omni ant.)**: 0.4

### Antenna Correlation

- **SUI-3 Channel**: $\rho_{ENV} = 0.4$
- **SUI-1 Channel**: $\rho_{ENV} = 0.7$
CCM is Still Cyclic Shift in SUI model

Channel Covariance Matrix
Still Cyclic Shifting
Not in amplitude
But also in Delay.
Performance Evaluation I

• Channel Order : 10
• Compares,
  • STBC 3x1,16QAM
  • STBC 4x1,16QAM
  • STFBC 2x1,16QAM
• Independent Rayleigh Fading Channel
• Perfect Channel & Order Information
Performance Result I

- In uniform delay spread Rayleigh Fading

- Simulation environments
  - 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 approx. 2.5dB SNR gain
Performance Evaluation II

- Channel Order : 10
- Independent Rayleigh Fading Channel
- Perfect Channel & Order Information
- To match the Spectrum Efficiency
- Compares, 2bits/sub-carrier
  - QPSK (STBC) : 2 tx antennas & 1 rx antenna
  - 16QAM (STFBC) : 2 tx antennas & 1 rx antenna
Performance Result II

- In uniform delay spread Rayleigh Fading

- Simulation environments

  - In $10^{-5}$ BER more than 5dB
  performance improvements.
Performance Evaluation III

- SUI 1
  - 2 bits/sub-carrier
    - QPSK (STBC) with 2 antenna
    - 16QAM (STFBC) with 2 antenna
- Ricean Fading Channel
- Perfect Channel & Order Information
Performance Result III

- Simulation environments SUI 1
  - STFBC in $10^{-5}$ BER shows approx. 4.5dB $\text{Eb/N0}$ gain

![Graph showing BER vs. $\text{Eb/N0}$ for STFBC-OFDM (QPSK) and STFBC-OFDM (16-QAM)]
Performance Evaluation IV

- SUI 3
  - 2bits/sub-carrier
    - QPSK (STBC) with 2 antenna
    - 16QAM (STFBC) with 2 antenna
  - Ricean Fading Channel
- Perfect Channel & Order Information
Performance Result IV

- Simulation environments SUI 3
  - **STFBC in** $10^{-5}$ BER shows **approx. 5dB** Eb/N0 gain

![Graph showing BER vs. Eb/N0 for STBC-OFDM and STFBC-OFDM]
Comparison of diversity Gain

- Blue: OFDM only
- Red: STC-OFDM
- Black: STFC-OFDM
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 increasing the number of tx antenna is not required.
  – Compatible to existing STBC-OFDM

• **Tx diversity scheme for OFDM system is desirable to use the STFBC is strongly requested.**
References

