Distributed Space-Time-Frequency Block Codes for MAC Channel with Relaying

Onur Oguz
Abdellatif Zaidi
Jerome Louveaux
Luc Vandendorpe

Université catholique de Louvain
Motivation

- Fading degrades communication
- **The key:** create *Diversity* with multiple links or branches that have uncorrelated fading
  - Ex: Antenna diversity
  - **Alternative:** Distributed approach
    = Cooperation
Distributed Array

- Different nodes in network act like a *virtual antenna-array*

**CHALLENGES**

- Array elements not physically connected
  ⇒ How to organize information transfer?
- Design of transmission for Diversity
  ⇒ Combining Techniques (MRC, EGC)
Cooperation through distributed arrays

- The relay channel
  - (Cover/El Gamal 1979)

- Cooperative diversity
  - (Sendonaris/Erkip/Aazhang & Laneman/Wornell 1998)

- Multiple relays/Multihop diversity
  - Gupta/Kumar 2001
Multiple Access Channel with Relaying

- **Different sources collaborate** to send different information to one destination
- Several criteria can be considered
  - Rate
    - of each source
    - Sum rate
  - Diversity gain
  - Error probability
    - of each source
    - Average
MAC with Relaying

- Examples of techniques available:
  - The relay node can operate in
    - Decode and Forward (DF)
    - Amplify and Forward (AF)
    - ...
  - Multiple access
    - time (TDMA)
    - frequency (OFDMA)
    - ...

Distributed STF Block Code for MAC with Relaying

- **Scenario**
  - Two user MAC with relaying
  - Frequency selective channel

- **Goal**
  - maximum diversity

- **Tools**
  - OFDM (with N subchannels)
  - Decode and Forward (NOT full duplex)
### D-STFBC Scheme

<table>
<thead>
<tr>
<th>Signaling Interval</th>
<th>Transmission</th>
<th>Number of Subchannels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U1 -&gt; U2, D</td>
<td>N1</td>
</tr>
<tr>
<td></td>
<td>U2 -&gt; U1, D</td>
<td>N2</td>
</tr>
<tr>
<td>2</td>
<td>U1 -&gt; D</td>
<td>N1 / N2</td>
</tr>
<tr>
<td></td>
<td>U2 -&gt; D</td>
<td>N1 / N2</td>
</tr>
</tbody>
</table>

- Achievable diversity?
  - Space/time/frequency
- How to achieve it?
D-STFBC Scheme

First signaling Interval

- Users transmit their private information
  - User 1: N1 sub channels
    - \([x_1, 0]\)
  - User 2: N2 sub channels
    - \([0, x_2]\)

- Both users obtained the complete information set
  - \(x = [x_1, x_2]\)
D-STFBC Scheme

- Second signaling interval
  - Users encode “x” via Alamouti scheme
    - User 1 transmits, over N sub channels
      - [ x(1), -x(2)*, x(3), -x(4)*, ... ]
    - User 2 transmits, over N sub channels
      - [ x(2), x(1)*, x(4), x(3)*, ... ]

- Assumption:
  - Neighboring sub channels are approximately equal
Combining for Alamouti

- Not straightforward (channels ≠)

\[ r_2(l) = \sqrt{E_a} \lambda_{ad}(l)x(l) + \sqrt{E_b} \lambda_{bd}(l)x(l + 1) + n_2(l), \]
\[ \bar{r}_2(l + 1) = -\sqrt{E_a} \bar{\lambda}_{ad}(l + 1)\bar{x}(l + 1) + \sqrt{E_b} \bar{\lambda}_{bd}(l + 1)\bar{x}(l) + n_2(l + 1). \]

- Zero Forcing (ZF)
- Maximum Ratio Combining (MRC)
- Enhanced Maximum Ratio Combining (E-MRC)
  - MRC + Decision Feedback Equalization
D-STFBC Scheme

During 1st signaling Interval

\[ r_1 = \sqrt{E_a} \Lambda_{ad} x_{a1} + \sqrt{E_b} \Lambda_{bd} x_{b1} + n_{r1}, \]

During 2nd signaling Interval

\[ r_2 = \sqrt{E_a} \Lambda_{ad} x_{a2} + \sqrt{E_b} \Lambda_{bd} x_{b2} + n_{r2}. \]

• And

\[
\begin{align*}
x_{a1} & = [x(1), x(2), \ldots, x(N1), 0, \ldots, 0], \\
x_{b1} & = [0, \ldots, 0, x(N1 + 1), x(N1 + 2), \ldots, x(N)] \\
x_{a2} & = [x(1), -\bar{x}(2), \ldots, x(N - 1), -\bar{x}(N)], \\
x_{b2} & = [x(2), \bar{x}(1), \ldots, x(N), \bar{x}(N - 1)].
\end{align*}
\]

If channel varies slowly: No additional Diversity
Key Idea: Frequency Shift

- First signaling interval
  - $x(i)$ : transmitted over sub channel, “i”
- Second signaling interval
  - $x(i)$ : transmitted over sub channel, “(i+C)mod N”
- If C is well chosen
  - Sub channels are nearly uncorrelated
  - 3$^{rd}$ order diversity
Simulation

- **OFDM**: 128 sub channels
  - \( N1 = N2 = 64 \)

- **Channel**
  - channels with 6 taps and different delay power spread (Channel 1 - ; Channel 2 --)
  - Tap gains: complex Gaussian
  - Minimally correlated at “C=N/2”

- 4-PSK mod.
Simulation

Effect of shift

![Graph showing the effect of shift on Bit Error Rate vs. SNR in dB. The graph compares different schemes including E-MRC D-STFBC, ZF D-STFBC, and Perfect Alamouti. The performance is compared with and without shift.](image-url)
Simulation

Effect of channel
Conclusion

- Proposed D-STFBC scheme exhibits
  - time-frequency diversity by carefully exploiting the correlation features of the channel
  - full spatial diversity established by use of the well known Alamouti scheme.
- The appropriate combination of these yields third-order diversity
- Transmission over the MAC with relaying with sufficiently low error rates is possible.
Conclusion

- Design for the MAC with relaying here could gain in performance by further exploiting
  - Resource allocation
  - Precoding techniques
- Performance analysis in terms of rate regimes