# TX Diversity with Array-Interference Gain

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Abstract

- The objective of transmit (TX) diversity with array interference gain is to provide better link reliability than conventional techniques such as orthogonal space-time block codes (O-STBCs) [1]. Such scheme could be used to improve coverage area of IEEE 802.22b.
- Improvement over O-STBCs [1] comes from exploiting the energy contained in the MIMO array-interference.
- This can be achieved by designing the transmit vector in a way that interference is always constructive at the decoder side.
- We provide simulation results indicating significant performance improvements as compared to existing techniques.
Alamouti [2] – 2TX

\[ s = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} \quad G_2(s) = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad h = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} \quad w = \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \]

\[ r = \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = G_2 \cdot h + w \quad \text{(Received Open-Loop Alamouti signal)} \]

By doing the proper combination with “r” (skipped here for simplicity), the estimated symbol vector is:

\[ \hat{s} = D \cdot s + \bar{w} = \begin{bmatrix} |h_1|^2 + |h_2|^2 \\ 0 \end{bmatrix} \cdot \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} \bar{w}_1 \\ \bar{w}_2 \end{bmatrix} \]

Diversity factor

No Interference (Orthogonal)
Generating Interference by Spanning Alamouti over 4 TX antennas

\[ G_4(s) = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \]  
\[ h = \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \end{bmatrix} \]  
\[ w = \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \]

\[ r = \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = G_4 \cdot h + w \]

By doing the proper combination with “r” (skipped here for simplicity), the estimated symbol vector is:

Same Diversity factor of 4TX STBC + generated interference

\[ s = D \cdot s + \bar{w} = \begin{bmatrix} |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\ -(h_1^* h_3 + h_1 h_3^* + h_2^* h_4 + h_2 h_4^*) \end{bmatrix} \]

Orthogonal

\[ 0 \]

Same Diversity factor of 4TX STBC + generated interference
Generating Interference by Spanning Alamouti over 4 TX antennas

- The problem is that the generated interference bellow

\[-(h_1^*h_3 + h_1h_3^* + h_2^*h_4 + h_2h_4^*) = -(2\text{Re}\{h_1h_3 + h_2h_4\})\]

assumes “positives” and “negative” values with the same probability due to its pdf being:
Generating Interference by Spanning Alamouti over 4 TX antennas

- The interference causes the diversity gain below (which is always “positive”) to sometimes increase and reduce its value.

\[ |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \]

- The resultant is a final diversity similar to open loop Alamouti.
Alamouti with Array-Interference Gain
(4 TX Antennas)

- Since the interference is composed by channel values, and the receiver (RX) can estimate the channel with a high precision, the receiver knows when the interference is being “constructive” or “destructive”.
- The idea is to make the interference **ALWAYS constructive** (positive). In order to do it, we have to manipulate the transmit scheme in the following manner:

\[
\begin{align*}
\tilde{G}_4(s) &= \begin{bmatrix}
  s_1 & s_2 & s_1 & s_2 \\
  -s_2^* & s_1^* & -s_2^* & s_1^*
\end{bmatrix} & \text{Whenever interference is “+”} \\
\tilde{G}_4(s) &= \begin{bmatrix}
  s_1 & s_2 & -s_1 & -s_2 \\
  -s_2^* & s_1^* & s_2^* & -s_1^*
\end{bmatrix} & \text{Whenever interference is “-”}
\end{align*}
\]
Alamouti with Array-Interference Gain
(4 TX Antennas)

- Since 802.22b system supports TDD, both TX and RX obtain CSI due to channel reciprocity.
- By doing the necessary manipulations with the received signal (skipped here for the sake of simplicity), the estimated symbol vector is given by:

$$\hat{s} = D \cdot s + \bar{w} = \begin{bmatrix} |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\
+ \text{abs}(h_1^* h_3 + h_1 h_3^* + h_2^* h_4 + h_2 h_4^*) \\
0 \end{bmatrix} \cdot \begin{bmatrix} s_1 \\
s_2 \end{bmatrix} + \begin{bmatrix} \bar{w}_1 \\
\bar{w}_2 \end{bmatrix}$$
Alamouti with Array-Interference Gain (4 TX Antennas)

- The interference is always constructive (positive) owing to the fact that choosing the proper transmit matrix, the interference pdf becomes:
Alamouti with Array-Interference Gain

- BER performance

16QAM, block fading (Rayleigh)

- Uncoded
- Alamouti (2 TX)
- Alamouti over 4TX
- O-STBC (4 TX)
- Alamouti with array-interference gain (4 TX)

About 1.5 dB better than the ideal 4TX

About 5 dB better than Alamouti

SNR (dB)

BER
Creating Further Interference Over 4TX Antennas

• In fact, Alamouti [2] is not the best scheme to span over TX antennas. The best scheme should be the one that generates more interference, so we can align then to increase the overall gain.

• In order to generate more interference, it is necessary to span a single symbol “s” over the TX antennas and do the proper received signal manipulation (skipped here for simplicity).

• Following the same line of thought, generate all possible dissimilar TX matrices:

\[
\begin{align*}
G_{41} &= \begin{bmatrix} s & s & s & s \end{bmatrix} \\
G_{42} &= \begin{bmatrix} s & -s & s & -s \end{bmatrix} \\
G_{43} &= \begin{bmatrix} s & s & -s & -s \end{bmatrix} \\
G_{44} &= \begin{bmatrix} s & -s & -s & s \end{bmatrix} \\
G_{45} &= \begin{bmatrix} s & s & s & -s \end{bmatrix} \\
G_{46} &= \begin{bmatrix} s & s & -s & s \end{bmatrix} \\
G_{47} &= \begin{bmatrix} s & -s & s & s \end{bmatrix} \\
G_{48} &= \begin{bmatrix} -s & s & s & s \end{bmatrix}
\end{align*}
\]
Creating Further Interference Over 4TX Antennas

• After doing the necessary manipulation (skipped for simplicity), each TX vector yields a specific estimated symbol:

\[
\hat{\mathbf{s}} = \begin{bmatrix}
|h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\
(h_1^* h_2 + h_1 h_2^* + h_1^* h_3 + h_1 h_3^* + h_1^* h_4 + h_1 h_4^* + h_2^* h_3 + h_2 h_3^* + h_2^* h_4 + h_2 h_4^* + h_3^* h_4 + h_3 h_4^*)
\end{bmatrix} \cdot \begin{bmatrix} s \\ \bar{\mathbf{w}} \end{bmatrix} 
\]

Interference (I₁)

\[
\hat{\mathbf{s}} = \begin{bmatrix}
|h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\
(-h_1^* h_2 - h_1 h_2^* + h_1^* h_3 + h_1 h_3^* + h_1^* h_4 + h_1 h_4^* + h_2^* h_3 + h_2 h_3^* + h_2^* h_4 + h_2 h_4^* - h_3^* h_4 - h_3 h_4^*)
\end{bmatrix} \cdot \begin{bmatrix} s \\ \bar{\mathbf{w}} \end{bmatrix} 
\]

Interference (I₂)

\[
\hat{\mathbf{s}} = \begin{bmatrix}
|h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\
(h_1^* h_2 + h_1 h_2^* - h_1^* h_3 - h_1 h_3^* - h_1^* h_4 - h_1 h_4^* - h_2^* h_3 - h_2 h_3^* - h_2^* h_4 - h_2 h_4^* - h_3^* h_4 + h_3 h_4^*)
\end{bmatrix} \cdot \begin{bmatrix} s \\ \bar{\mathbf{w}} \end{bmatrix} 
\]

Interference (I₃)
Creating Further Interference Over 4TX Antennas

\[
\mathcal{G}_{44} = \begin{bmatrix} s & -s & -s & s \end{bmatrix} \\
\hat{s} = \begin{bmatrix} \left| h_1 \right|^2 + \left| h_2 \right|^2 + \left| h_3 \right|^2 + \left| h_4 \right|^2 \\
\left( -h_1^*h_2 - h_1h_2^* - h_1^*h_3 - h_1h_3^* + h_1^*h_4 + h_1h_4^* + h_2^*h_3 - h_2h_3^* - h_2^*h_4 - h_2h_4^* - h_3^*h_4 - h_3h_4^* \right) \end{bmatrix} \cdot \begin{bmatrix} s \end{bmatrix} + \begin{bmatrix} \bar{\mathbf{w}} \end{bmatrix}
\]

Interference (I₄)

\[
\mathcal{G}_{45} = \begin{bmatrix} s & s & s & -s \end{bmatrix} \\
\hat{s} = \begin{bmatrix} \left| h_1 \right|^2 + \left| h_2 \right|^2 + \left| h_3 \right|^2 + \left| h_4 \right|^2 \\
\left( h_1^*h_2 + h_1h_2^* + h_1^*h_3 + h_1h_3^* - h_1^*h_4 - h_1h_4^* + h_2^*h_3 + h_2h_3^* - h_2^*h_4 - h_2h_4^* - h_3^*h_4 - h_3h_4^* \right) \end{bmatrix} \cdot \begin{bmatrix} s \end{bmatrix} + \begin{bmatrix} \bar{\mathbf{w}} \end{bmatrix}
\]

Interference (I₅)

\[
\mathcal{G}_{46} = \begin{bmatrix} s & s & -s & s \end{bmatrix} \\
\hat{s} = \begin{bmatrix} \left| h_1 \right|^2 + \left| h_2 \right|^2 + \left| h_3 \right|^2 + \left| h_4 \right|^2 \\
\left( h_1^*h_2 + h_1h_2^* - h_1^*h_3 - h_1h_3^* + h_1^*h_4 + h_1h_4^* - h_2^*h_3 + h_2h_3^* + h_2^*h_4 + h_2h_4^* - h_3^*h_4 - h_3h_4^* \right) \end{bmatrix} \cdot \begin{bmatrix} s \end{bmatrix} + \begin{bmatrix} \bar{\mathbf{w}} \end{bmatrix}
\]

Interference (I₆)
Creating Further Interference Over 4TX Antennas

\[ \mathcal{G}_{47} = \begin{bmatrix} s & -s & s & s \end{bmatrix} \]

\[ \hat{s} = \begin{bmatrix} (-h_1^* h_2 - h_1 h_2^* + h_1^* h_3 + h_1 h_3^* + h_1^* h_4 + h_1 h_4^* - h_2 h_3^* - h_2^* h_4 + h_3^* h_4 + h_4 h_2^*) \end{bmatrix} \cdot [s] + [\bar{w}] \]

\text{Interference (I_7)}

\[ \mathcal{G}_{48} = \begin{bmatrix} -s & s & s & s \end{bmatrix} \]

\[ \hat{s} = \begin{bmatrix} (-h_1^* h_2 - h_1 h_2^* - h_1^* h_3 - h_1 h_3^* - h_1^* h_4 - h_1 h_4^* - h_2 h_3^* + h_2^* h_4 + h_3 h_2^* + h_3^* h_4 + h_4 h_3^*) \end{bmatrix} \cdot [s] + [\bar{w}] \]

\text{Interference (I_8)}
Conclusions

- Improved link reliability compared to the one of existing techniques can be earned by wisely exploiting the MIMO array interference. A natural consequence of utilizing such scheme is to increase of coverage area in IEEE 802.22b.

- The proposed scheme is full rate and full diversity + array interference gain, which results in improved link reliability even if compared to ideal 4TX antennas STBC.

- The proposed schemes makes use of the channel reciprocity inherent to TDD systems to as to estimate CSI and then design the transmit vector which yields the best constructive interference.
References
