TX Diversity with Array-Interference Gain

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Abstract

- **The objective the 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

$$\mathbf{s} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} \quad \mathcal{G}_2(\mathbf{s}) = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad \mathbf{h} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} \quad \mathbf{w} = \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$\mathbf{r} = \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \mathcal{G}_2 \cdot \mathbf{h} + \mathbf{w}$$ **(Received Open-Loop Alamouti signal)**

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

$$\hat{\mathbf{s}} = \mathbf{D} \cdot \mathbf{s} + \bar{\mathbf{w}} = \begin{bmatrix} \overset{\text{Diversity factor}}{|h_1|^2 + |h_2|^2} & \overset{\text{No Interference (Orthogonal)}}{0} \\ \underset{\text{No Interference (Orthogonal)}}{0} & \underset{\text{Diversity factor}}{|h_1|^2 + |h_2|^2} \end{bmatrix} \cdot \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} \bar{w}_1 \\ \bar{w}_2 \end{bmatrix}$$

Generating Interference by Spanning Alamouti over 4 TX antennas

$$\mathcal{G}_4(\mathbf{s}) = \left[\underset{\textbf{Alamouti}}{\boxed{\begin{matrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{matrix}}} \quad \underset{\textbf{Alamouti}}{\boxed{\begin{matrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{matrix}}} \right] \qquad \mathbf{h} = \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \end{bmatrix} \qquad \mathbf{w} = \begin{bmatrix} w_1 \\ w_2 \end{bmatrix}$$

$$\mathbf{r} = \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \mathcal{G}_4 \cdot \mathbf{h} + \mathbf{w}$$

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

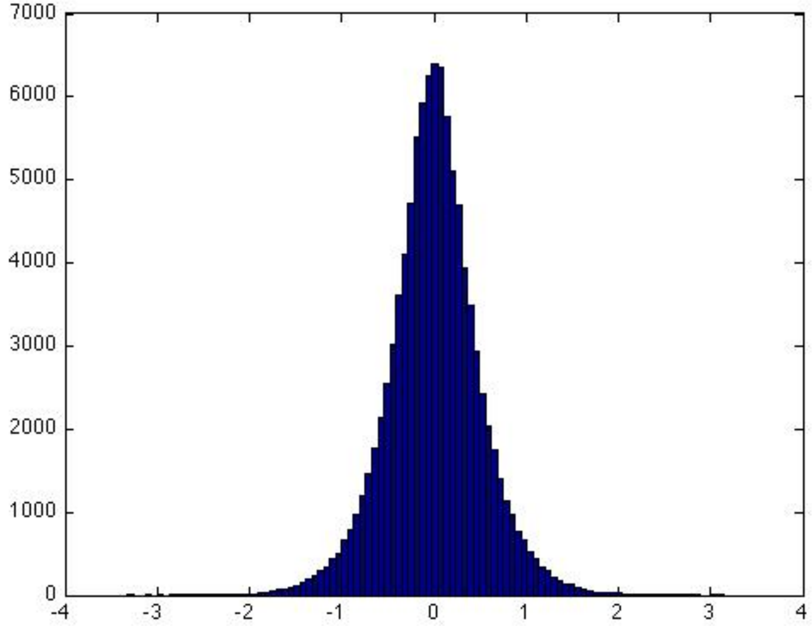
$$\hat{\mathbf{s}} = \mathbf{D} \cdot \mathbf{s} + \bar{\mathbf{w}} = \begin{bmatrix} \overset{\text{Same Diversity factor of 4TX STBC + generated interference}}{\boxed{\begin{matrix} |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\ -(h_1^* h_3 + h_1 h_3^* + h_2^* h_4 + h_2 h_4^*) \end{matrix}}} & \overset{\text{Orthogonal}}{0} \\ \underset{\text{Orthogonal}}{0} & \underset{\text{Same Diversity factor of 4TX STBC + generated interference}}{\boxed{\begin{matrix} |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\ -(h_1^* h_3 + h_1 h_3^* + h_2^* h_4 + h_2 h_4^*) \end{matrix}}} \end{bmatrix} \cdot \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} \bar{w}_1 \\ \bar{w}_2 \end{bmatrix}$$

Generating Interference by Spanning Alamouti over 4 TX antennas

- **The problem is that the generated interference bellow**

$$-(h_1^* h_3 + h_1 h_3^* + h_2^* h_4 + h_2 h_4^*) = -(2Re\{h_1 h_3 + h_2 h_4\})$$

assumes “positives” and “negative” values with the same probability due to its pdf being:

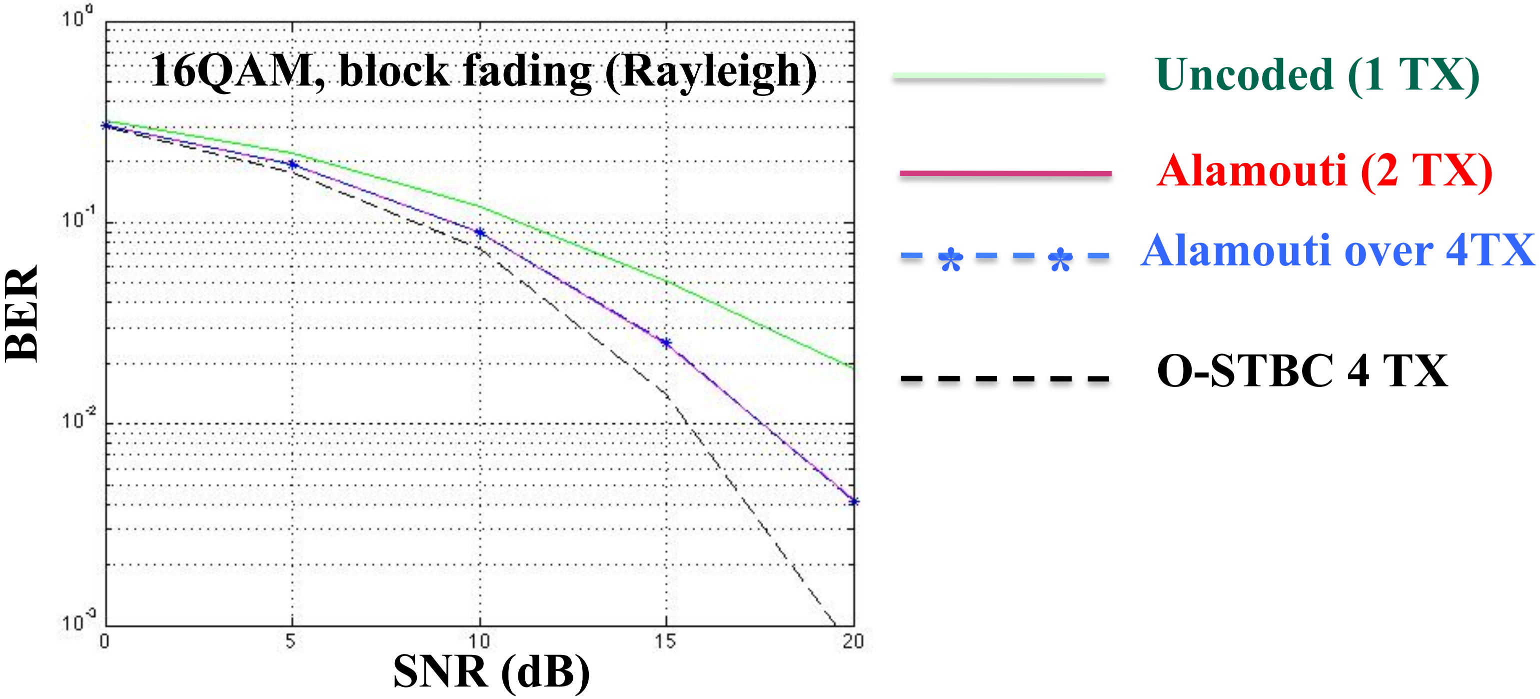


Generating Interference by Spanning Alamouti over 4 TX antennas

- **The interference causes the diversity gain bellow (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:**

$$\bar{\mathcal{G}}_4(\mathbf{s}) = \begin{bmatrix} s_1 & s_2 & s_1 & s_2 \\ -s_2^* & s_1^* & -s_2^* & s_1^* \end{bmatrix}$$

Whenever interference is "+"

$$\bar{\bar{\mathcal{G}}}_4(\mathbf{s}) = \begin{bmatrix} s_1 & s_2 & -s_1 & -s_2 \\ -s_2^* & s_1^* & s_2^* & -s_1^* \end{bmatrix}$$

Whenever interference is "-"

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:**

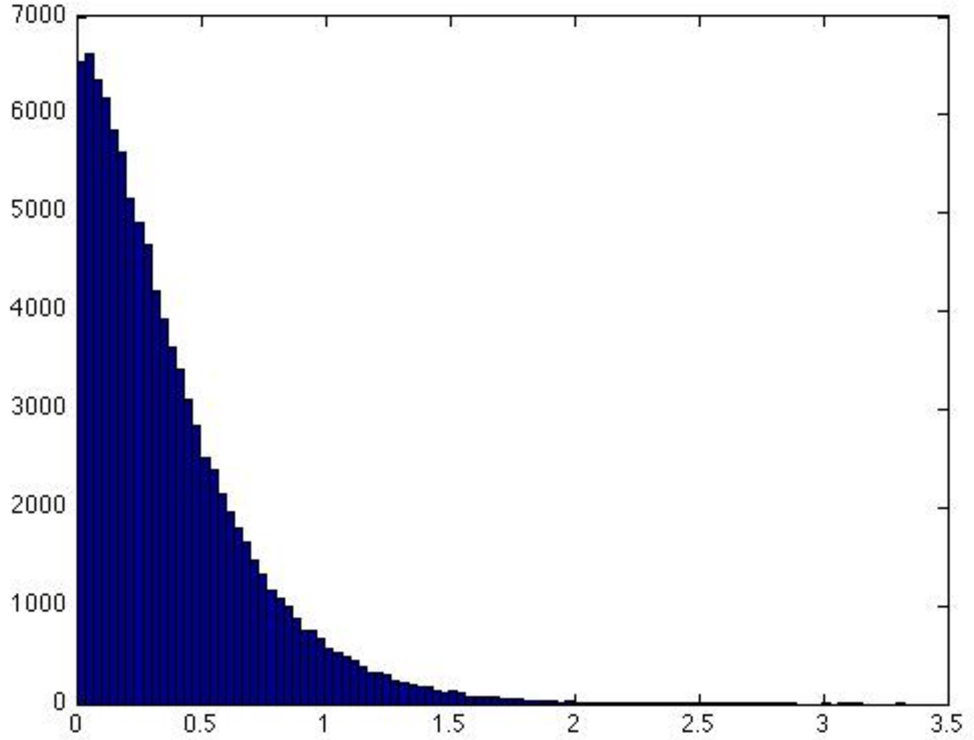
Diversity factor + absolute value of interference

$$\hat{\mathbf{s}} = \mathbf{D}\cdot\mathbf{s}+\bar{\mathbf{w}} = \begin{bmatrix} \boxed{\begin{array}{c} |h_1|^2+|h_2|^2+|h_3|^2+|h_4|^2 \\ +abs(h_1^*h_3+h_1h_3^*+h_2^*h_4+h_2h_4^*) \end{array}} & 0 \\ 0 & \boxed{\begin{array}{c} |h_1|^2+|h_2|^2+|h_3|^2+|h_4|^2 \\ +abs(h_1^*h_3+h_1h_3^*+h_2^*h_4+h_2h_4^*) \end{array}} \end{bmatrix} \cdot \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} \bar{w}_1 \\ \bar{w}_2 \end{bmatrix}$$

Diversity factor + absolute value of interference

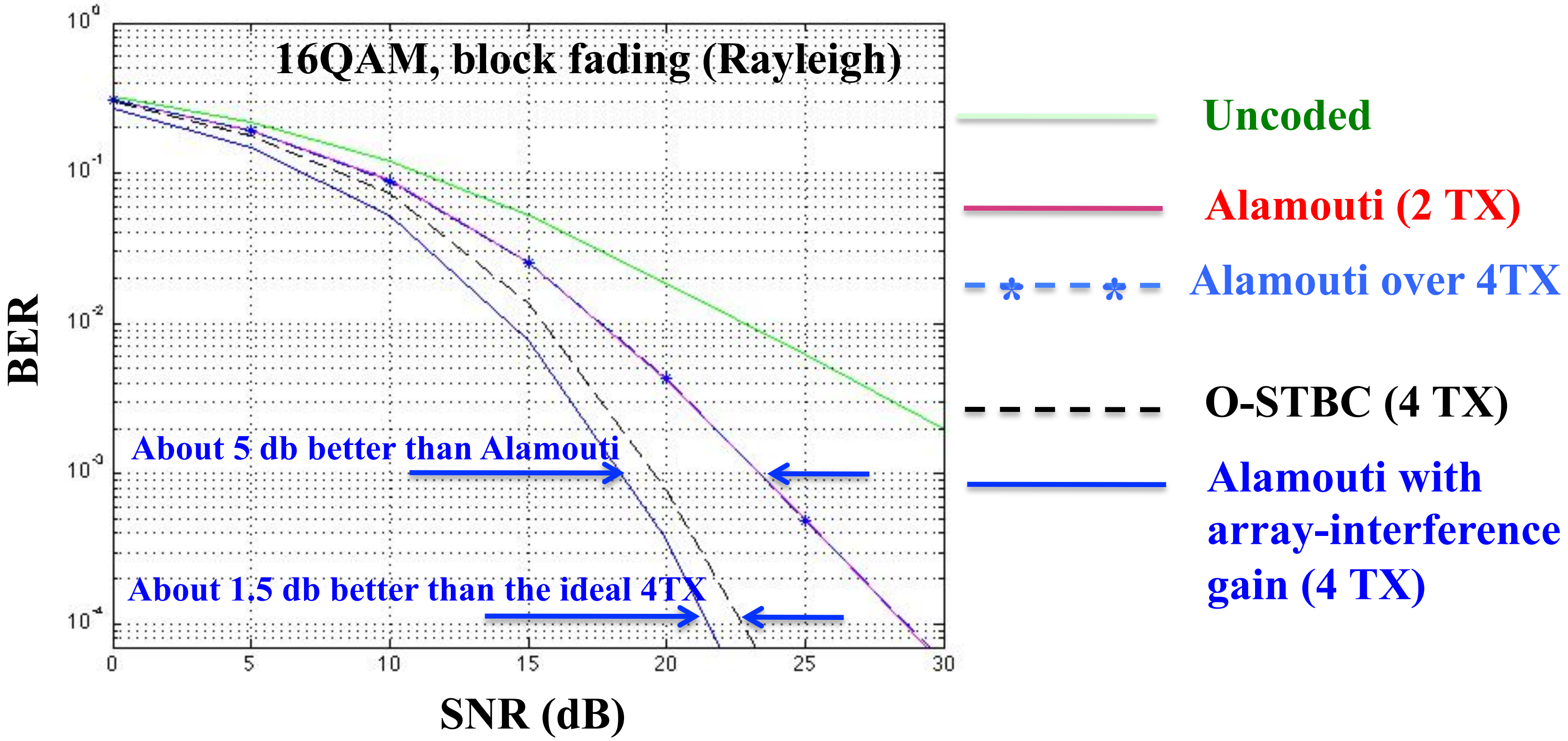
Alamouti with Array-Interference Gain (4 TX Antennas)

- **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**



About 5 db better than Alamouti

About 1.5 db better than the ideal 4TX

Creating Further Interference Over 4TX Antennas

- **In fact, Alamouti [2] is not the best scheme to span over TX antennas. <u>The best scheme should be the one that generates more interference, so we can align then to increase the overall gain.</u>**
- **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 though, generate all possible dissimilar TX matrices:**

$$\mathcal{G}_{4_1} = \left[\begin{array}{cccc} s & s & s & s \end{array}\right] \qquad \mathcal{G}_{4_5} = \left[\begin{array}{cccc} s & s & s & -s \end{array}\right]$$

$$\mathcal{G}_{4_2} = \left[\begin{array}{cccc} s & -s & s & -s \end{array}\right] \qquad \mathcal{G}_{4_6} = \left[\begin{array}{cccc} s & s & -s & s \end{array}\right]$$

$$\mathcal{G}_{4_3} = \left[\begin{array}{cccc} s & s & -s & -s \end{array}\right] \qquad \mathcal{G}_{4_7} = \left[\begin{array}{cccc} s & -s & s & s \end{array}\right]$$

$$\mathcal{G}_{4_4} = \left[\begin{array}{cccc} s & -s & -s & s \end{array}\right] \qquad \mathcal{G}_{4_8} = \left[\begin{array}{cccc} -s & s & s & s \end{array}\right]$$

Creating Further Interference Over 4TX Antennas

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

① $\mathcal{G}_{4_1} = \begin{bmatrix} s & s & s & s \end{bmatrix}$

$$\hat{\mathrm{s}} = \begin{bmatrix} |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\ \underline{(h_1^*h_2 + h_1h_2^* + h_1^*h_3 + h_1h_3^* + h_1^*h_4 + h_1h_4^* + h_2^*h_3 + h_2h_3^* + h_2^*h_4 + h_2h_4^* + h_3^*h_4 + h_3h_4^*)} \end{bmatrix} \cdot \begin{bmatrix} s \end{bmatrix} + \begin{bmatrix} \bar{w} \end{bmatrix}$$

Interference (I_1)

② $\mathcal{G}_{4_2} = \begin{bmatrix} s & -s & s & -s \end{bmatrix}$

$$\hat{\mathrm{s}} = \begin{bmatrix} |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\ \underline{(-h_1^*h_2 - h_1h_2^* + h_1^*h_3 + h_1h_3^* - h_1^*h_4 - h_1h_4^* - h_2^*h_3 - h_2h_3^* + h_2^*h_4 + h_2h_4^* - h_3^*h_4 - h_3h_4^*)} \end{bmatrix} \cdot \begin{bmatrix} s \end{bmatrix} + \begin{bmatrix} \bar{w} \end{bmatrix}$$

Interference (I_2)

③ $\mathcal{G}_{4_3} = \begin{bmatrix} s & s & -s & -s \end{bmatrix}$

$$\hat{\mathrm{s}} = \begin{bmatrix} |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\ \underline{(h_1^*h_2 + h_1h_2^* - h_1^*h_3 - h_1h_3^* - h_1^*h_4 - h_1h_4^* - h_2^*h_3 - h_2h_3^* - h_2^*h_4 - h_2h_4^* + h_3^*h_4 + h_3h_4^*)} \end{bmatrix} \cdot \begin{bmatrix} s \end{bmatrix} + \begin{bmatrix} \bar{w} \end{bmatrix}$$

Interference (I_3)

Creating Further Interference Over 4TX Antennas

④

$$\mathcal{G}_{4_4} = \begin{bmatrix} s & -s & -s & s \end{bmatrix}$$

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

Interference (I_4)

⑤

$$\mathcal{G}_{4_5} = \begin{bmatrix} s & s & s & -s \end{bmatrix}$$

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

Interference (I_5)

⑥

$$\mathcal{G}_{4_6} = \begin{bmatrix} s & s & -s & s \end{bmatrix}$$

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

Interference (I_6)

Creating Further Interference Over 4TX Antennas

⑦

$$\mathcal{G}_{4_7} = \begin{bmatrix} s & -s & s & s \end{bmatrix}$$

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

Interference (I_7)

⑧

$$\mathcal{G}_{4_8} = \begin{bmatrix} -s & s & s & s \end{bmatrix}$$

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

Interference (I_8)

Creating Further Interference Over 4TX Antennas

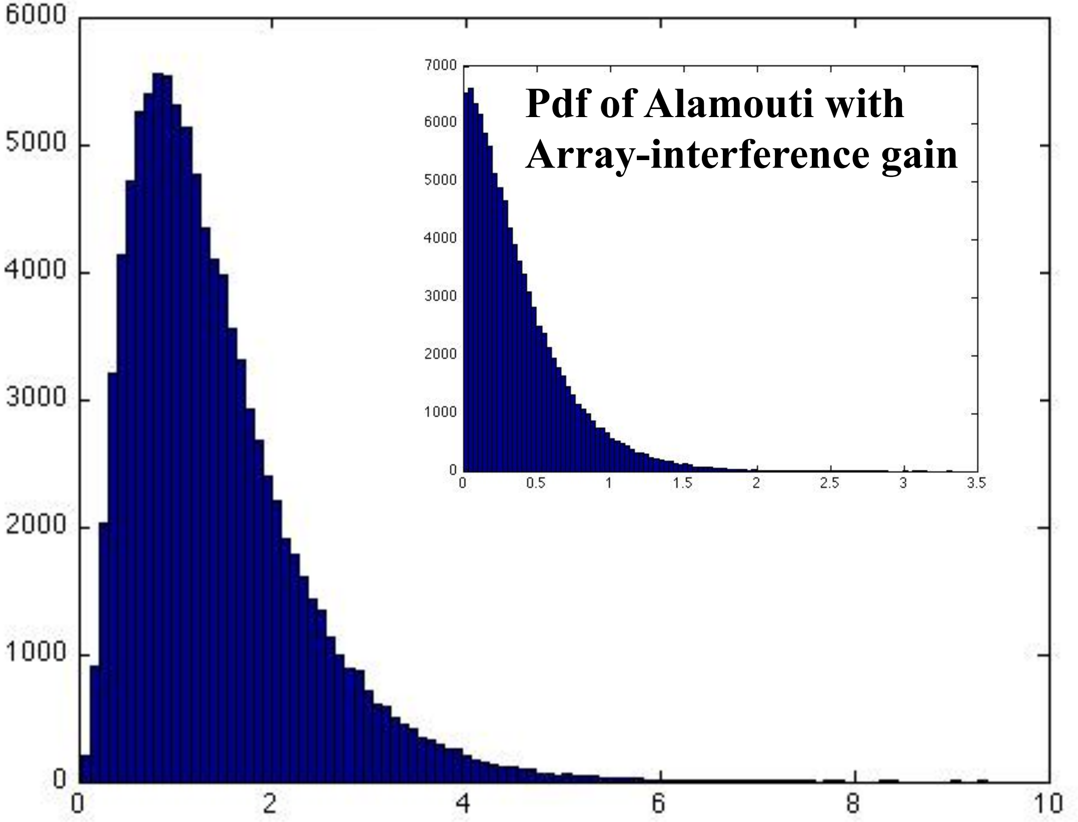
- **In order to find out which transmit vector to use, the following operation must be performed:**

$$max(I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8)$$

- **Then the transmit vector which yields higher interference is selected among all vectors ① ~ ⑧.**
- **This scheme is expandable to any number of TX antennas.**
- **When multiple antennas are available at the receiver, maximum ratio combining (MRC) can be employed in order to further improve link reliability.**

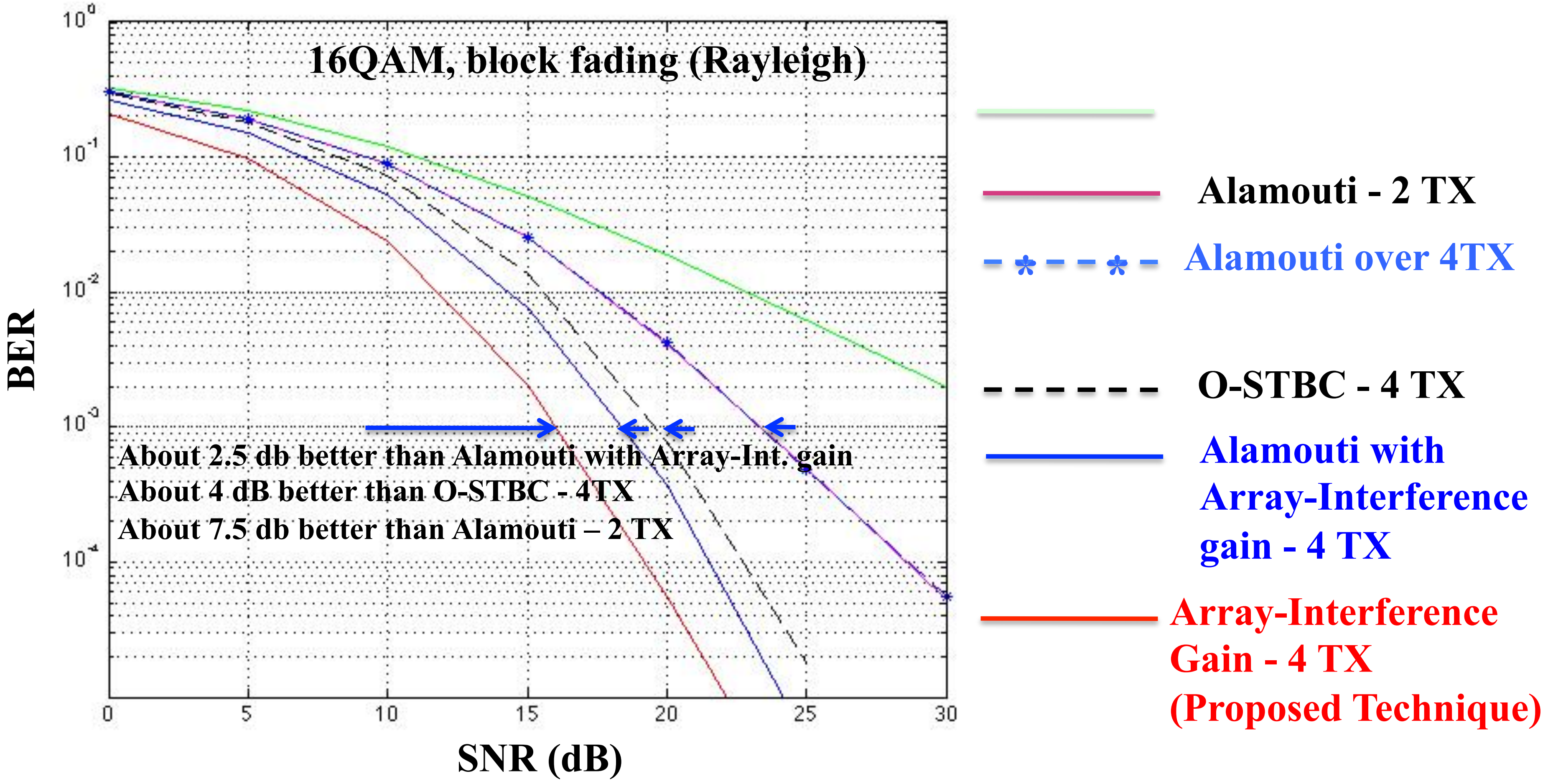
Creating Further Interference Over 4TX Antennas

- The pdf of $max(I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8)$ compared to Alamouti with array-interference gain:



Pdf of Alamouti with Array-interference gain

Creating Further Interference Over 4TX Antennas



About 2.5 db better than Alamouti with Array-Int. gain
About 4 dB better than O-STBC - 4TX
About 7.5 db better than Alamouti – 2 TX

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

[1] V. Tarok, H. Jafarkhani. and A.R. Calderbank, ”Space-time block codes from orthogonal designs," IEEE *Trans. on Information Theory,* vol. 45. no. *5.* pp. 1456-1467, July 1999

[2] S.M. Alamouti. “A simple Transmitter diversity scheme for wireless communications,” *IEEE Journal on Selected Areas in Communications,* vol. SAC-16, pp. 1451-1458, October 1998.