Distributed Space Time Block Coding

Slides Division:

- Introduction
- Space Time Block Codes
- Decode-and-forward distributed STBC
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- Amplify-and-forward distributed STBC
  - Performance analysis
- The synchronization problem
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  - Space-time spreading
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Introduction:

- What are STBCs & DSTBCs ?
- Way we use Distributed Space Time Block Codes?
- Problems / Drawbacks of Distributed Space Time Block Codes
  - Spreading
  - Design
- Solutions
  - Dis-Joint Time Slots
  - Different Frequency Bands
  - Decode and Forward & Amplify and Forward (will be discussed in next slides)

Two Phase Transmission Protocol Illustration:

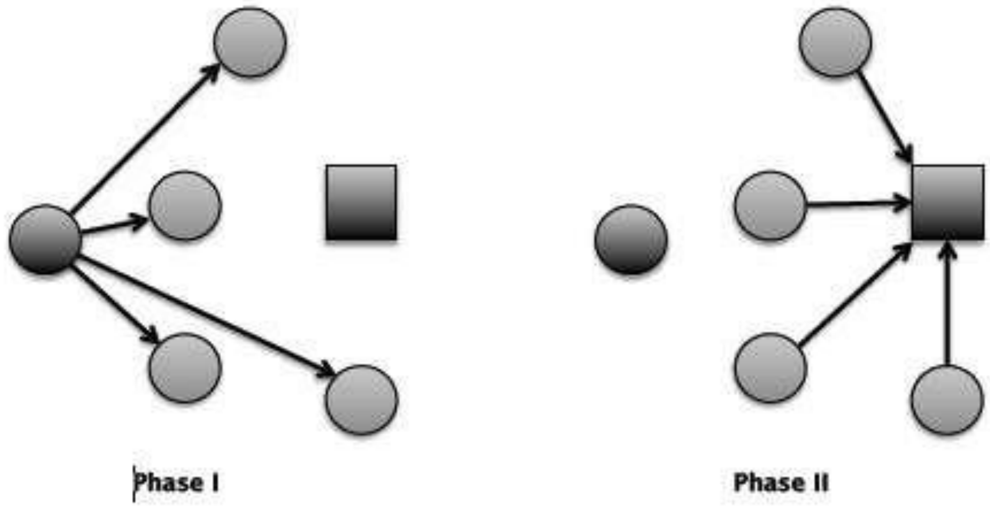

Figure 6.1: Illustration of the two-phase transmission protocol using a distributed space-time code. In the first phase (left subfigure) the source transmits to several relays, while in the second phase (right subfigure), the relays simultaneously transmit to the destination.

Space Time Block-Codes:

- What are Space Time Block Codes ?
  - One of the primary problems associated with forwarding information from relays to a destination in a cooperative wireless network is how information is transmitted from the relays over time, i.e., the space-time transmission scheme.

$$\text{time-slots}\downarrow\ \overset{\text{transmit antennas}\ \longrightarrow}{\begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n_T} \\ s_{21} & s_{22} & \cdots & s_{2n_T} \\ \vdots & \vdots & & \vdots \\ s_{T1} & s_{T2} & \cdots & s_{Tn_T} \end{bmatrix}}$$

- Linear Dispersion (LD) Space Time Block Codes
  - $t_i = A_i s + B_i \bar{s}$
- where $\bar{s}$ is the column vector containing the complex conjugates of s and the complex $T_2 \times T_1$ matrices A_i and B_i are called dispersion matrices.

STBCs Cont..

- Example of LD STBCs is:
  - One linear dispersion code that has been proposed for cooperative communication with R=2 relays is described by the dispersion matrices

$$A_1 = \begin{bmatrix} +1 & 0 \\ 0 & +1 \end{bmatrix}, A_2 = 0_{2\times2}, B_1 = 0_{2\times2}, B_2 = \begin{bmatrix} 0 & -1 \\ +1 & 0 \end{bmatrix}$$

where $0_{m\times n}$ is a $m \times n$ matrix of all-zeros. This code is simply a transpose of the well-known Alamouti space-time block code

Bit Error Rate Performance of 4 Systems:

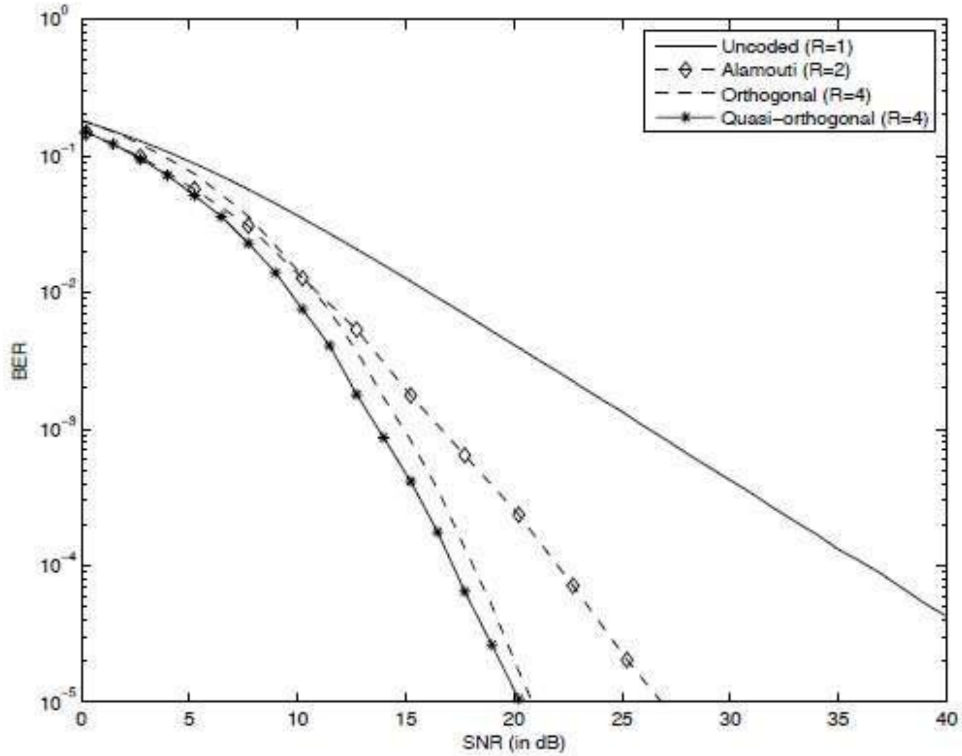

Figure 6.2: Bit error rate (BER) performance of four systems: An uncoded system with $R = 1$ transmit antenna, an Alamouti-coded system with $R = 2$ transmit antennas, an orthogonal STBC with $R = 4$ transmit antennas, and a quasi-orthogonal STBC with $R = 4$ transmit antennas. In each case, the spectral efficiency is 3 bps/Hz and the signals are transmitted over independent Rayleigh fading channels.

Decode-and-forward distributed STBC

- Consider Two Phase Relay Network
- Assume First Channel Transmission is corrupted by noise
- Guarantee of data loss
- This Problem is solved by using *decode-and-forward* protocol
- Each node decodes the received signal and only passes it to next phase if the signal received is correct
- Work of *DSTBCs* started in second phase
- It requires each relay to fully decode the signals received

Performance Analysis

- Performance depends on error control code
- If LDPC code is used for measuring performance then performance is mentioned by *information-outage probability* of the link
  - the probability that the conditional mutual information between the channel input and output is below some threshold.
  - Final Expression for end-to-end outage probability

$$p_D = p^R + \sum_{k=1}^{R} \binom{R}{k} (1-p)^k p^{R-k} \left(1 - \sum_{n=0}^{\min\{k, K_{max}\}-1} \frac{\Gamma_2^n}{n!} e^{-\Gamma_2}\right).$$

Numerical Analysis:

- We can determine the outage probability for a network comprised of R relays that uses a particular space-time code by the expression given below:

$$p_D = p^R + \sum_{k=1}^{R} \binom{R}{k} (1-p)^k p^{R-k} \left(1 - \sum_{n=0}^{\min\{k, K_{max}\}-1} \frac{\Gamma_2^n}{n!} e^{-\Gamma_2} \right).$$

Amplify-and-Forward distributed STBC:

- Each relay using this protocol simply converts the received signal to baseband
- And then passing it through a pair of filters matched to the in-phase and quadrature basis functions.
- The Matched signals are sampled
- Which gives T1 complex samples that are placed into the vector ri
- Finally the relay transmits a linear combination of the samples in ri and its conjugates at power P2
- The normalized signal transmitted by node Ni in vector form is given by

$$\mathbf{t}_i = \sqrt{\frac{1}{P_1 + 1}} (A_i \mathbf{r}_i + B_i \bar{\mathbf{r}}_i)$$

Performance Analysis:

- The achievable diversity in this case can also be find by the technique used in point-to-point space-time coded system
  - By bounding the pairwise error probability
- The main result or achieved diversity is given by the expression given below:

$$d = R\left(1 - \frac{\log \log P}{P}\right)$$

The Synchronization Problem:

- Delay Diversity:
  - The point-point communication over multiple channels provide diversity
  - The Following Scheme is used:
    - in the first time slot, the symbol x[1] is transmitted on antenna 1 and all other antennas are silent. In the second time slot, x[1] is transmitted from antenna 2 and x[2] is transmitted by antenna 1 and all other antennas remain silent. At time slot m, $x[m - l]$ is transmitted on antenna $l + 1$ for $l = 0, 1, . . . L - 1$.
- This transmission scheme yields a received signal that is identical to that received in a SISO frequency selective channel with L paths. This special point-point space-time coding scheme is called delay diversity

Delay Tolerant Space-Time Codes

- Another approach is Delay Tolerant is used whose performance in insensitive to delays among each relay
- Let S be a code word matrix from a synchronized space-time block code and let ΔS be the code matrix received at destination due to transmission or propagation delay.
- The ΔS can be given by the expression:

$$\Delta S = \begin{bmatrix} 0^{\Delta_1} & 0^{\Delta_2} & \cdots & 0^{\Delta_R} \\ C_1\mathbf{s}^{(1)} & C_2\mathbf{s}^{(2)} & \cdots & C_R\mathbf{s}^{(R)} \\ 0^{T-\Delta_1} & 0^{T-\Delta_2} & \cdots & 0^{T-\Delta_R} \end{bmatrix}.$$

Space Time Spreading:

- Assign the source and each relay a unique spreading code.
- When Relays are not synchronized the signal received at the destination will be similar to that obtained in a conventional asynchronous CDMA uplink
- Which allows the separation of transmission from the source and the relays
- Requires the synchronization of the relays

Conclusion:

- Distributed STBC are good to use in multiple relay networks
- With this technique each relay transmits a particular column of space-time code word
- The decode-and-forward is used when the number of relays is greater then the no of columns in code word
- DF requires the relays to be connected to each other
- When the number of relays are equal to the no of columns then in this case we use Amplify-and-forward protocol
- In AF it is not necessary that the relays are interconnected

Cont..

- In addition to the implementation challenges that are common to conventional MIMO systems, the lack of synchronization at the destination receiver imposes additional challenges to systems that use distributed space-time codes.
- The synchronization problem can be alleviated by using delay diversity, space - time spreading, or delay-tolerant space-time codes.

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