Distributed Space-Time Codes for Cooperative Wireless Networks in the Presence of Different Propagation Delays and Path Losses

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1. Distributed Space-Time Codes

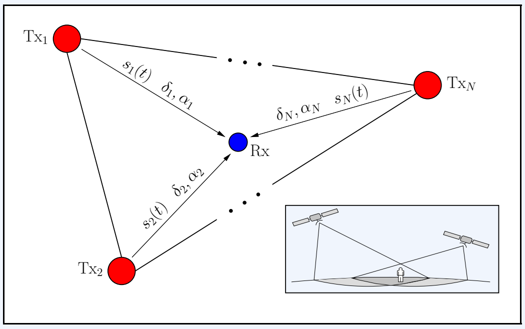
- Performance of wireless communication systems is often limited by **fading** and may be significantly improved by exploiting **diversity**.
- By means of **multiple antennas** in conjunction with a **space-time code (STC)**, **spatial diversity** can be exploited.
- Concept of multiple antennas may be transferred to **cooperative wireless networks** $\longrightarrow$ **Distributed STC**, 'cooperative diversity'.
- Consider a cooperative network with N **transmitting (Tx) nodes** and one **receiving (Rx) node** (all nodes employ a single antenna).

$\Longrightarrow$ Distributed STC should provide **diversity degree** of N if **no shadowing** occurs and **diversity degree** of $(N-n)$ if **any** subset of $n < N$ Tx nodes is obstructed due to **shadowing**.

Example: Orthogonal space-time block codes (OSTBCs); here focus on the **Alamouti scheme** $(N=2)$ and BPSK mapping.

2. Propagation Delays and Path Losses

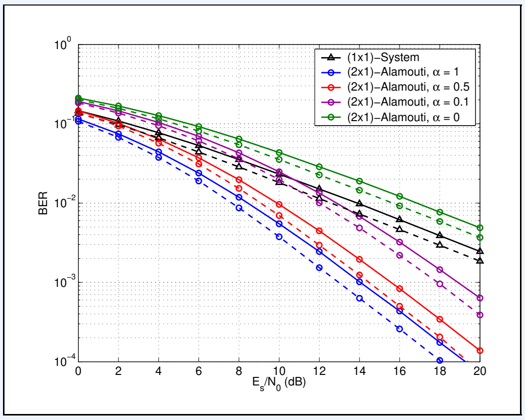
- **Key challenge** due to the **distributed nature** of the system: Transmitted signals $s_i(t)$, $i=1,\dots,N$, are typically subject to
  - ▷ Different **propagation delays** δ_i and
  - ▷ Different **average path gains** α_i (w.r.t. powers).



- **Counter measures:**
  - ▷ **Timing advance (TA)** $\longrightarrow$ Effective delays $\delta_1 \approx \delta_2 \dots \approx \delta_N$.
  - ▷ **Link adaptation (LA)** $\longrightarrow$ Effectively, $\alpha_1 \approx \alpha_2 \dots \approx \alpha_N$.

3. Perfect Timing Advance

- **Basic assumptions:**
  - ▷ **Propagation delays**: $\delta_1 := 0$, $\delta_2 := 0$ $(N=2)$.
  - ▷ **Average path gains**: $\alpha_1 := 1$, $\alpha_2 := \alpha \leq 1$, due to non-perfect LA.
  - ▷ Tx power of each Tx node **normalized** by a factor 1/2. $\longrightarrow$ Average **received SNRs** $E_s/2N_0$ and $\alpha E_s/2N_0$.
  - ▷ **Flat** Rayleigh fading/ Rice fading (Rice factor 0 dB).
- **Analytical** and **simulative** results for different values of α:



▷ **Bit error probability** for Rayleigh fading (solid lines):

$$P_b = \frac{1}{2}\left[\frac{1-\mu_1}{1-\alpha} + \frac{\alpha\,(1-\mu_\alpha)}{\alpha-1}\right], \quad \mu_\alpha = \frac{1}{\sqrt{1+\frac{2N_0}{\alpha E_s}}}.$$

▷ $\alpha = 1$: Diversity degree of 2 (corresponds to a system with colocated antennas).

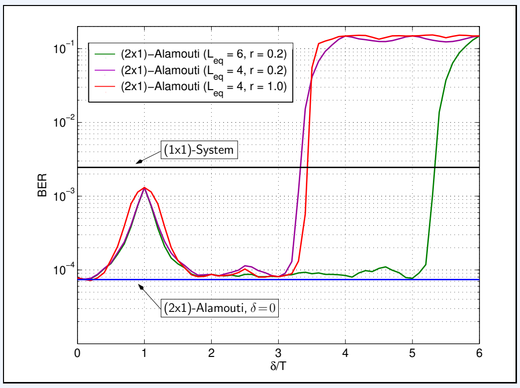
$\alpha = 0.5$: Still diversity degree of 2, but loss of $\approx$ 1.5 dB.

$\alpha = 0$: Diversity degree of 1 and loss of 3 dB compared to (1x1)-system, due to Tx power normalization.

▷ Corresponding curves for Rice fading (dashed lines) $\approx$ 1 dB better.

4. Non-Perfect Timing Advance

- **Basic assumptions:**
  - ▷ **Propagation delays**: $\delta_1 := 0$, $\delta_2 := \delta \geq 0$ $(N=2)$.
  - ▷ **Average path gains**: $\alpha_1 := 1$, $\alpha_2 := 1$ (perfect LA).
  - ▷ Tx nodes and Rx node employ **square-root Nyquist filter** with cosine roll-off (roll-off factor $0 \leq r \leq 1$).
- Propagation delay δ causes **intersymbol interference (ISI)**. $\longrightarrow$ Trellis-based **equalizer** for the Alamouti scheme.
- **Simulation results** for different delays δ ($E_s/N_0 = 20$ dB):



  - ▷ For MLSE, equalizer length L_{eq} must be sufficiently large (otherwise significant performance loss occurs).
  - ▷ Significant performance loss occurs also for $\delta \approx T$ (T: symbol duration), due to poor distance properties; for $\delta = T$ the diversity advantage is lost.
  - ▷ Influence of the roll-off factor r is comparably small.
- For **large** values of δ, the complexity of MLSE may be reduced by utilizing the equalizer concept for 'sparse' ISI channels.

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