Frequency-Offset Sensitivity of Resilient Microwave Links Applying the Alamouti Scheme

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1. Introduction

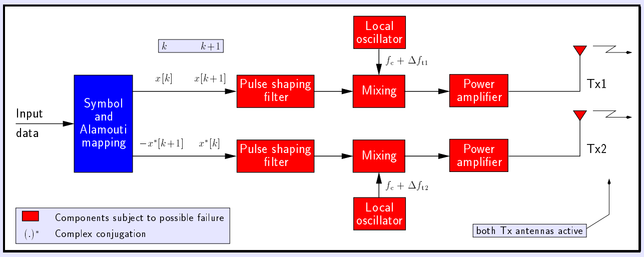
- **Space-time codes** were designed for fading environments in order to improve **system capacity** and/or to achieve a **diversity gain**.
  Here: Novel possible application of the **Alamouti scheme** to provide a **switchless alternative** in current **resilient** microwave radio links.
  - **Resilient link:** Transmitter (Tx) equipped with **two complete, independent** Tx chains; particularly, with **two Tx antennas**.
  - **Conventional design:** Only **one** Tx chain **active**; the other one is kept in a **'hot-stand-by'** mode as a back-up unit.
- **Proposed alternative:** Employ **Alamouti scheme** utilizing **both** Tx antennas at the same time $\Rightarrow$ **Diversity gain**.
  - **Rate** of the single Tx-antenna system is **retained** even if one Tx chain fails, since the Alamouti scheme is **backward compatible**.
  - One or two **Rx antennas** may be used, where a second Rx antenna yields an **additional** diversity gain.
- Due to the resilient structure, we do **not** want to **couple** the two **local oscillators (LOs)** in the transmitter

$\Longrightarrow$ Typically, two **different frequency offsets** occur, because both LOs may independently differ from the nominal carrier frequency f_c.

$\Longrightarrow$ **Orthogonality** of the Alamouti scheme is **lost** causing a **performance degradation**, even if the frequency offsets are **perfectly known**.

2. Proposed Resilient Transmitter Structure

- **Alamouti scheme:**
  Pairs $[x[k], x[k+1]]$ of M-ary data symbols are transmitted over the two antennas at time index k and $k+1$, according to a special **mapping rule**.
- **Frequency offset** at Tx antenna Txi is denoted as Δf_{ti}.



3. Application Example

- **Resilient microwave radio links** are, e.g., used to **interconnect base stations** within a cellular mobile radio network.
- Given **ideal LOs**, the **Alamouti scheme** yields **significant diversity gains** over the conventional 'hot-stand-by' scheme, even in the case of a **strong line-of-sight** signal component.

4. Orthogonality Loss due to Frequency Offsets

- **Preliminaries:**
  - **Frequency-flat block fading** $\Rightarrow$ Transmission path from Txi to Rxj characterized by channel coefficient h_{ij}.
  - A **single Rx antenna** is considered here.
  - At the **receiver** frequency offset Δf_r. **Overall** frequency offset for transmission path from Txi to Rx therefore given by

$$\Delta f_i \;=\; \Delta f_{ti} - \Delta f_r, \qquad i=1,2. \qquad (1)$$

$\Rightarrow$ **Time-varying** channel coefficients

$$\tilde{h}_{i1}[k] \;\doteq\; h_{i1}\exp(j\varphi_i[k]), \qquad (2)$$

where $\varphi_i[k] = 2\pi \Delta f_i kT$ (T symbol duration).

  - At the beginning of each data block ($k=0$), the channel coefficients are assumed to be **perfectly known** at the receiver.

- **Ideal oscillators:** $\Delta f_1 = \Delta f_2 = 0$
  - Utilizing the **orthogonal properties** of the Alamouti scheme, **maximum-likelihood (ML) detection** of the transmitted symbols $x[k]$ and $x[k+1]$ is enabled by the **combining rule**

$$\hat{\mathbf{x}}[k] \;=\; \mathbf{H}^{\mathrm{H}}\mathbf{y}[k] \;=\; \mathbf{H}^{\mathrm{H}}\mathbf{H}\,\mathbf{x}[k] + \mathbf{H}^{\mathrm{H}}\,\mathbf{n}[k]\,, \qquad (3)$$

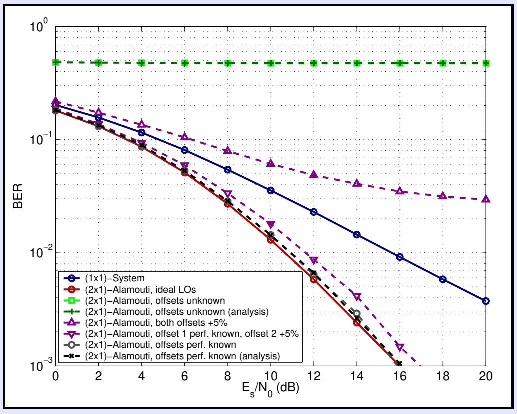
  - ▷ $\hat{\mathbf{x}}[k]$: (Soft) estimate of vector $\mathbf{x}[k] = [x[k]\;\; x^*[k+1]]^{\mathrm{T}}$
  - ▷ $\mathbf{H}$: Equivalent (2×2) channel matrix; $\mathbf{H}^{\mathrm{H}} = (\mathbf{H}^{\mathrm{T}})^*$
  - ▷ $\mathbf{y}[k]$: Received vector, $\mathbf{n}[k]$: Noise vector.
  - **Orthogonality:**

$$\mathbf{H}^{\mathrm{H}}\mathbf{H} \;=\; (|h_{11}|^2 + |h_{21}|)^2\,\mathbf{I}\,. \qquad (4)$$

- **Non-ideal oscillators:** Channel matrix $\tilde{\mathbf{H}}[k]$
  (a) Frequency offsets **unknown**: Receiver uses $\mathbf{H}^{\mathrm{H}}$ for combining.
  (b) Frequency-offset **estimates** available: Receiver uses $\tilde{\mathbf{H}}_{\epsilon}^{\mathrm{H}}[k]$ (perfect knowledge of frequency offsets: $\tilde{\mathbf{H}}^{\mathrm{H}}[k]$ used).
  - Orthogonality is **lost** in **any** case; if the frequency offsets are perfectly known at the receiver the effect is comparably **small**.

5. Analytical and Simulative Performance Results

- **Simulation parameters:**
  - Frequency-flat block fading, Rice factor $K=0$ dB.
  - Uncoded QPSK (Gray mapping used), $T=0.1\,\mu$s.
  - $\Delta f_1 = 15$ppm, $\Delta f_2 = -6$ppm w.r.t. $f_c = 20$ GHz
  - Frequency-offset estimates $\Delta f_i + 5\%$.
- **Analytical curves** developed in the paper are as well included.



6. Conclusions

- As a switchless alternative in a **resilient** microwave radio link, the Alamouti scheme yields **significant performance gains** (even in the case of a **strong** line-of-sight component), provided that the estimates of the individual **frequency offsets** are sufficiently accurate.

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