Communication Through Fading Channels
Introduction

- When signals arrive at the receiving antenna having traversed different paths, they may combine destructively. This, multipath, phenomenon can induce signal fading.

- Fading
  - Frequency-Selective: The effects of the channel on the information signal are frequency-dependent.
  - Frequency-Nonselective

- Fading channels are multiplicative-noise channels and result in bursts of errors, as, for example, in
  - Wireless communication
  - Compact-disc players

- The multiplicative nature of the channel means increasing signal power may not yield a proportional improvement in performance.
Introduction (cont’d)

- Fading channels are not *memoryless*. Thus, sequence estimation is required for optimum detection.

- To ease implementation complexity, symbol-by-symbol detection is desirable. *Interleaving* is used (often with coding) to spread a number of errors in a burst over a larger number of bits (thus artificially yield a memoryless channel).

- In interleaving, (conceptually) bits are written row-wise into a matrix and read (and transmitted) column-wise. At the receiver, a *de-interleaver* reverses the process, and in doing so spreads burst of errors over a larger number of bits.
Often Used Channel Models

- **Rayleigh Fading**
  - The signal amplitude is Rayleigh distributed (no direct specular component is present, only diffused components)

- **Ricean Fading**
  - Besides the diffuse component, there is specular (line-of-sight) component

- **Gaussian Fading**
  - This corresponds to a Rayleigh distributed amplitude and a uniformly distributed phase (incoherent case)

- Fading is a correlated process
The Rayleigh Fading Channel (static fading)

\[ r(t) = a \cdot S_i(t) + n(t) \quad 0 \leq t \leq T \]

\[ p(a) = \frac{a}{\sigma^2} e^{-\frac{a^2}{2\sigma^2}} \quad a \geq 0 \quad \iff \quad \text{Rayleigh density} \]

If the signals have equal energy, \( E \), then the optimum receiver is:

\[ \max_i \int_0^T r(t) \cdot S_i(t) dt \]
Performance of Binary Signaling

\[ P(e) = \frac{1}{2} \cdot \left[ 1 - \sqrt{\frac{\text{SNR}}{1 + \text{SNR}}} \right] \approx \frac{1}{4 \cdot \text{SNR}} \]

**Coherent BPSK**

\[ P(e) = \frac{1}{2} \cdot \left[ 1 - \sqrt{\frac{\text{SNR}}{2 + \text{SNR}}} \right] \approx \frac{1}{2 \cdot \text{SNR}} \]

**Coherent FSK**

\[ P(e) = \frac{1}{2 + \text{SNR}} \approx \frac{1}{\text{SNR}} \]

**Incoherent FSK**

\[ P(e) = \frac{1}{2(1 + \text{SNR})} \approx \frac{1}{2 \cdot \text{SNR}} \]

**DPSK**

\[ \text{SNR} = \frac{E}{N_0} \cdot E(a^2) = 2\sigma^2 \cdot \frac{E}{N_0} \]
BER Comparison

![BER Comparison Graph](image-url)

- **BER Comparison**
  - **BER** (Bit Error Rate) vs. **SNR** (Signal-to-Noise Ratio)
  - **Error-Probability** on the y-axis
  - **SNR, dB** on the x-axis
  - **BPSK**, **DPSK**, **Coherent FSK**, **Incoherent FSK**

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Discussion on Performance

- Error probability decreases asymptotically as the inverse of SNR

- To improve performance, diversity techniques are used
  - Frequency diversity
  - Time diversity
  - Spatial diversity (i.e. multiple transmit/receive antennas)
  - Diversity through coding

- Diversity manifests itself on performance through a change in the slope of the BER curves

- An $L$-th order diversity approximately raises the diversity-1 BER to the $L$-th power.