Power Optimization of Wireless Media Systems with Space-Time Code Building Blocks

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Distributing Multimedia Content over Hybrid Wired and Wireless Networks

- CCN
  - Resource Allocation
  - Error Control
  - Channel Modeling
  - Flow Control
  - Congestion Control

- SP & Comm
  - JSCC
  - Transmission and Space-Time Coding
  - Handoff
  - Power Optimization
CCN Scope

- **Work Done**
  - Rate Allocation & Partitioning (RAP)
  - Error Control (EC)
  - Flow Control (FC)

- **Future Work**
  - Congestion Control
  - Wireless Networks
  - Error Control
  - LMMC Dynamic Rate Analysis
  - Handoff & QoS
SP & Comm Scope

- **Work Done**
  - JSCC for Wireless Systems
  - Utilizing Multiple Transmit Antennas
  - Power Optimization of Wireless Media Systems w/ Memory

- **Future Work**
  - Analytical Channel Modeling
  - Delay-Controlled Power Optimization of Wireless Media Systems
  - Video Summarization
Important Issues

- Joint Source-Channel Coding
- Multiple Transmit Antennas
- Channel Loss Model
- Distortion Analysis
- Power Control vs QoS Tradeoff
Contributions

- Utilize Multiple Transmit Antennas with Space-Time Block Codes
- Consider Bernoulli, Gilbert, Gilbert-Elliott Channel Loss Models
- Minimize the Total Power of Source Coding, Channel Coding, and Transmission under Distortion and Rate Constraints
Apply a Slow Fading Rayleigh Channel with Fading Factor $\alpha : \quad S_o = \alpha S_i + N$

Demodulator Avg. SNR: $\overline{SNR} = E[|\alpha|^2] \frac{E_{sym}}{N_0}$

Symbol Transmission Energy, One-Sided Spectral Density of WGN
Transmission Analysis

- **Single-Transmit Single-Receive Antenna**
  
  L-PSK Symbol Error Rates
  \[
e_{\text{sym}} = \frac{L-1}{L} \left\{1 - \sqrt{\frac{ASNR}{1 + ASNR}} \frac{L}{L-1} \cdot \left[\frac{\pi}{2} + \arctan\left(\sqrt{\frac{ASNR}{1 + ASNR}} \cdot \cot\left(\frac{\pi}{L}\right)\right)\right]\right\}
  \]

  - **QPSK Formula**
    \[
e_{\text{sym}} = \frac{3}{4} \left\{1 - \frac{4}{3\pi} \sqrt{\frac{SNR}{2 + SNR}} \left[\frac{\pi}{2} + \arctan\left(\sqrt{\frac{SNR}{2 + SNR}}\right)\right]\right\}
  \]

- **Two-Transmit Multiple-Receive Antenna**
  
  L-PSK Symbol Error Rates
  \[
e_{\text{sym}} = \frac{1}{2} \left\{1 - \sqrt{\frac{2A}{1 + 2A}} \sum_{k=0}^{2M-1} \binom{2k}{k} \left[\frac{1}{4(1 + 2A)}\right]^k\right\}
  \]

  - **QPSK Formula**
    \[
e_{\text{sym}} = \frac{1}{2} \left\{1 - \sqrt{\frac{SNR}{1 + SNR}} \left[1 + \frac{1}{2(1 + SNR)}\right]\right\}
  \]
Utilize a Reed-Solomon Channel Coder with Rate $r = \frac{k}{n} = \frac{R_s}{R_s + R_c}$ allowing correction of $t_c = \frac{n-k}{2}$ symbols.

Residual Symbol Error Rate (Block Loss Probability) under Bernoulli Model

$$\Psi(n, t_c) = \sum_{i=t_c+1}^{n} \binom{n}{i} e_{sym}^i (1 - e_{sym})^{(n-i)}$$
Gilbert-Elliott Loss

- Residual Symbol Error Rate (Block Loss Probability) under GE Model

\[ \Psi(n, t_c) = 1 - \sum_{k=n-t_c}^{n} P(n, k) \]

where

\[ P(n,k) = P(n,k,G) + P(n,k,B) \]

\[ P(n,k,G) = e_G \left[ \gamma P(n-1,k,G) + (1 - \beta) P(n-1,k,B) \right] + (1 - e_G) \left[ \gamma P(n-1,k-1,G) + (1 - \beta) P(n-1,k-1,B) \right] \]

\[ P(n,k,B) = e_B \left[ (1 - \gamma) P(n-1,k,G) + \beta P(n-1,k,B) \right] + (1 - e_B) \left[ (1 - \gamma) P(n-1,k-1,G) + \beta P(n-1,k-1,B) \right] \]

Assuming \( N_{0,G} \ll N_{0,B} \)

\[ \overline{SNR}_G = E[|\alpha|^2] \frac{E_{sym}}{N_{0,G}} \]

\[ \overline{SNR}_B = E[|\alpha|^2] \frac{E_{sym}}{N_{0,B}} \]
Source Coding and Distortion Analysis

- **A Gauss-Markov Source Model**

\[
D_{\text{total}} = D_s + D_v = (1 - \Psi(n, t_c)) D_{tc} + \Psi(n, t_c) \sigma_{gm}^2
\]

\[
D_{tc}(R_s) = \xi \sigma_{gm}^2 (1 - \rho^2) \frac{k-1}{k} 2^{-2R_s}
\]

Variance: \(\sigma_{gm}^2\)  
Correlation coefficient: \(\rho\)

- **An Experimental H.263 Source Coder**

\[
D_{\text{total}} = D_s + D_v
\]

\[
D_s(\omega, R_s) = \frac{\theta(\omega)}{R_s - R_l(\omega)} + D_l(\omega) \quad D_v(\omega, \Psi) = \sigma_{u0}^2 \Psi(n, t_c) \sum_{t=0}^{T-1} \frac{1 - \omega t}{1 + \lambda t}
\]
Power Optimization

- **Power Optimization Formulation**

  \[
  \text{Minimize } P_{\text{total}} = \epsilon_s (a_s - b_s \omega + c_s R_s) \\
  + \epsilon_c \frac{n R_s R_c}{m (R_s + R_c)} + \epsilon_t \frac{E_{\text{sym}}}{m} (R_s + R_c)
  \]

  \[\text{Subject To: } \begin{align*}
  D_{\text{total}} &= D_s + D_v \leq D_0 \\
  R_{\text{total}} &= R_s + R_c \leq R_0
  \end{align*}\]

- **MINLP Complexity**

  \[O(I_p n \log n)\]

- **SQP Solution and KKT Equations**

  \[LG_p = P_s + P_c + P_t + \mu_1 (D_s + D_v - D_0) + \mu_2 (R_s + R_c - R_0)\]

  \[\nabla LG_p (\Omega^*) = 0\]

  \[\mu_1^* (D_s^* + D_v^* - D_0^*) = 0\]

  \[\mu_2^* (R_s^* + R_c^* - R_0^*) = 0\]

  \[\mu_1^*, \mu_2^* \geq 0\]
Gauss-Markov Simulations
H.263 Simulations


