Cross-Layer Design & Optimization in Multimedia Wireless Networks

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Research Interests:

Mathematical Tools for Wireless Systems Design
Cooperative Communications
Adaptive & Cognitive Radios
Compressive Sensing
Modulation-Assisted UEP for Prioritized Packet Transmission

- Matching the "shape" of signal constellation to satisfy the distinct quality of service constraints

- developed an approximate but accurate BER formula that is readily invertible w.r.t. its SNR

\[
P^{(i)}_b(\gamma_s, \beta) = a^{(i)}_\beta e^{-b^{(i)}_\beta \cdot \gamma_s} + c^{(i)}_\beta e^{-2b^{(i)}_\beta \cdot \gamma_s}
\]

\[
y^{(i)}_\beta = -\frac{1}{b^{(i)}_\beta} \ln y^{(i)}_\beta, \quad i=1,2,3,\ldots,\log_2 M
\]

- criteria used to optimize \( \beta \)

\[
\arg \min_{\beta} \{ \max_i \{ y^{(i)}_{\text{req}} \} \}
\]

s.t. \( P^{(1)}_b \leq 10^{-5} \)

\( P^{(2)}_b \leq 10^{-4} \)

\( P^{(3)}_b \leq 10^{-3} \)

\( \beta \in (0, 0.5], \quad i \in \{1, 2, 3\} \)

Passive (receiver-oriented) rate-adaptation sustain the link/route path with graceful rate degradation
Joint-Design of PHY/MAC Layers: Multiresolution Modulation & Retransmission Diversity

\[ \frac{d_{i+1}}{d_i} = \beta, i = 1, 2, ..., m - 1 \]

\[ \beta^{k-m} = d_k/d_m \]

\[ \theta_i = \frac{\pi}{2} \beta^i, \ i = 1, 2, 3, ..., \left[ \log_2(M) - 1 \right], \ 0 < \beta \leq 0.5 \]
Comparison of packet loss probabilities (truncated SR-ARQ with $N_{\text{max}} = 3$ and 64-QAM) for three distinct data classes over Nakagami-m ($m=1.75$) fading.

Comparison of the average throughput performance of truncated conventional SR-ARQ ($\beta = 0.5$, 64-QAM), SR-ARQ-I and SR-ARQ-II for different values of $\beta$ in a Nakagami ($m=1.75$) channel.
Cross-Layer Optimization for H.264 over Fading Channels

[collaborative research with Dr. Kumar (SDSU) & Dr. Cosman (UCSD)]

Video Snapshots (I-frame): minimize error propagation

<table>
<thead>
<tr>
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<th>Variable NAL</th>
<th>Fixed NAL</th>
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Integrated Design of Link-Adaptive Cooperative Wireless Networks

Fig. 1: A “cooperative-diversity network” with link adaptation (adaptive source transmission) techniques.

Networked nodes in a tight cluster can coordinate both their transmissions and/or receptions to mimic a space-time processing system as if they were part of a single antenna array platform: exploit the broadcast nature of wireless transmissions, but there is a loss of spectral efficiency due to its inherent half-duplex operation.

- To overcome the practical implementation issue of packing many antenna elements in small-sized terminals (e.g., mobile handsets, sensor nodes).
- Built-in a flexible communication strategy for ensuring the connectivity and network stability needed in terms of throughput, latency, and error rates (QoS requirements) and enhancing platform endurance (longer battery life).

Fixed transmission methods that are designed to provide the required QoS in the ‘worst-case’ are inefficient when better channel conditions prevail.
The art of adaptive link layer in CRNs has not been fully explored

- Most existing studies assume fixed signaling rate & equal transmit power for all distributed nodes.
- How link adaptation could be performed on individual links in the absence of complete CSI?
- “Although the performances of wireless relaying systems over fading channels have been extensively evaluated in terms of outage probability and error rate, there have been few studies on ergodic capacity of fading relay channels…” [Farhadi & Beaulieu, IEEE Trans. Wireless Communications, May 2009, pp. 2286]
- “… there is a lack of significant contributions to the analysis of channel capacity of distributed MIMO systems over fading channels…, where only bounds are so far available for channel capacity computation.” [Di Renzo, Graziosi & Santucci, IEEE Sarnoff Symposium, April 2009]
- Most of existing results restricted to the Rayleigh fading environment.
On Ergodic Capacity of Non-Regenerative Cooperative Wireless Networks

TDMA
Phase 1: S transmits, R₁, R₂, …, Rₙ listen
Phase 2:
Time Slot 2: R₁ transmits, D listens
…..
Time Slot (N+1): Rₙ transmits, D listens

Only partial CSI (i.e., effective SNR) is required at the source, which adapts its rate and/or power according to the prevailing channel conditions.

\[ \gamma_{jk} = \left|h_{jk}\right|^2 \frac{E_s}{N_o} \] denotes the instantaneous SNR between node j and node k

\[ \gamma_T = \gamma_{SD} + \sum_{k=1}^{N} \frac{\gamma_{SR_k} \gamma_{R_kD}}{\gamma_{SR_k} + \gamma_{R_kD} + 1} \leq \gamma_{SD} + \sum_{k=1}^{N} \gamma_k \]

\[ \frac{1}{2} \min\{\gamma_{SR_k}, \gamma_{R_kD}\} \leq \gamma_k \leq \min\{\gamma_{SR_k}, \gamma_{R_kD}\} \]
Equal Power Allocation vs Optimal Power Allocation

\[ P_R = cP_T d^{-L_p} \]
\[ L_p = 4, \ c = 10^{-2} \]
\[ d_{s,l} = 400m, \ d_{l,d} = 600m, \ d_{s,d} = 1000m \]
\[ m_{s,l} = 4, \ m_{l,d} = 2, \ m_{s,d} = 1 \]
\[ \Omega_{s,l} = \left( \frac{d_{l,d}}{d_{s,d}} \right)^{-L_p} c \delta_{s,l} E_T / N_o \]
\[ \Omega_{l,d} = \left( \frac{d_{l,d}}{d_{s,d}} \right)^{-L_p} c \delta_{l,d} E_T / N_o \]
\[ \Omega_{s,d} = \left( \frac{d_{s,d}}{d_{s,d}} \right)^{-L_p} c \delta_{s,d} E_T / N_o \]
\[ \delta_{s,d} = \frac{P_{s,l}}{P_T} \]

Optimum Power Allocation:
\[ \delta_{s,l} = \delta_{s,d} = 0.28, \ \delta_{l,d} = 0.72 \]

Ergodic capacities (for “Upper Bound Case”) of cooperative relay network with ORA, OPRA and TCIFR policies in an i.n.d Nakagami-m fading channel consisting of \( N \) relays (\( N = 0, 1 \)).
Relay Node Placement/Selection

Ergodic capacity (for “Upper Bound Case”) of CRNs consisting of \( N \) relays \((N = 0, 1)\) with ORA policy as a function of ratio of distances in Nakagami-m channels.
Discrete-Rate Adaptive M-QAM vs Continuous-Rate Adaptive Modulation

\[ \Omega_{s,d} = 0.2E_s/N_0, \quad \Omega_{s,1} = E_s/N_0, \quad \Omega_{s,2} = 0.8E_s/N_0, \quad \Omega_{1,d} = 0.3E_s/N_0, \quad \Omega_{2,d} = 0.56E_s/N_0 \]

Case 1: \( m_{s,d} = m_{s,1} = m_{s,2} = m_{1,d} = m_{2,d} = 1 \)
Case 2: \( m_{s,1} = 4, \quad m_{s,2} = 4, \quad m_{1,d} = 2, \quad m_{2,d} = 2, \quad m_{s,d} = 1 \)
Case 3: \( m_{s,1} = 2, \quad m_{s,2} = 2, \quad m_{1,d} = 4, \quad m_{2,d} = 4, \quad m_{s,d} = 1 \)