Achievement report

**Achievement Description**

**Main Result:**
- Reduce UEP to degraded BC network
- Embed high priority message

**How it Works:**
- U → X → Y → Y

**Assumptions and Limitations:**
- Error probability measured in exponents
- Limited analytical solutions

**Status Quo**
- Physical links are viewed as equally reliable bit pipes.
- High priority control messages are sent over separated channels.
- No performance limits on UEP

**End-of-Phase Goal**
- Joint Source-Channel coding with layered codes
- Feedbacks and two-way channels
- Data driven network controls, Layering and QoS as interface

**Community Challenge**
- New protocols required to indicate, process, fuse, and prioritize heterogeneous data transmissions over networks

**New Insights**
- Embedding key messages over UEP: performance analysis by information geometry

**Embedding control messages/significant data with UEP**
Motivating Example: Yamamoto-Ito Scheme

- Burnashev exponent with Yamamoto-Ito schemes with 2 phases:
  - Data communication at full capacity
  - Confirm with binary ACK/NACK with high reliability

- Encode ACK/NACK with new data
  - Both Data and ACK/NACK occupy the entire block
  - Synchronizing sequential transmission
Embedding ACK/NACK

- Special case: embedding 2 bits over QPSK data symbols
- Performance metric for hierarchical error protections:
  - Throughput of data + Reliability of control
- Tradeoff between rate and reliability: controlling the distribution of the data codes
- Strictly out-perform is surprising: better than 2 bit repetition over QPSK
Control and Data Side-by-Side

- The feedback context is not important
  - Performance measured by large data and reliable control
  - Time sharing/orthogonal resource allocation between data and control
- Layered codes with UEP
  - Studied in CS under the name “priority coding”
  - Systematic design approach requires error exponents
UEP and Broadcasting Channel

- UEP can be thought as board casting

  \[ U \xrightarrow{\Phi} X \xrightarrow{W} Y \]

- Optimization problem easy to write, difficult to solve

  \[
  I(P_U, \Phi \circ V_1) > R_1 \]
  \[
  D(V_1 \| W | P_x) \leq E_1 \]
  
  For all \( V \)

  \[
  I(X; V_2 | U) > R_2 \]
  \[
  D(V_2 \| W | P_x) \leq E_2 \]

- Many other network information theory results look similar
The Very Noisy Approximation

• Definition **very noisy**: distributions involved in divergence optimization are close
  – Local approximation of distribution manifold
  – Euclidean approximation of information geometry
  – Normal approximation of the distribution of information quantity
  – Quadratic approximation of divergence

• Examples of very noisy cases
  – Very noisy channel codes
  – Source coding for nearly uniform source
  – Very low rate quantization
  – Good approximation to general cases

new canonical example?
UEP for Very Noisy Channel

• If the given channel has capacity $C \sim 0$

Optimal input $(U,X)$
- $P_x$ is capacity achieving
- $P_y|u$ proportional scaling

Achievable region

$$\frac{R_1}{(\sqrt{C} - \sqrt{E_1})^2} + \frac{R_2}{(\sqrt{C} - \sqrt{E_2})^2} \leq 1$$
Comparison and Insights

- Embedded UEP

\[
\frac{R_1}{(\sqrt{C} - \sqrt{E_1})^2} + \frac{R_2}{(\sqrt{C} - \sqrt{E_2})^2} \leq 1
\]

- Time sharing

\[
\frac{R_1}{(\sqrt{C} - \sqrt{\frac{E_1}{\alpha}})^2} + \frac{R_2}{(\sqrt{C} - \sqrt{\frac{E_2}{1-\alpha}})^2} \leq 1
\]

- Insights:
  - Very noisy is very nice
  - Combining control and data allows global optimization
  - Networking based on imperfect controls
  - Geometric approach for error exponent
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