Using Packet Timings to Communicate through Computer Networks

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Background

- '48: Shannon [1] showed theoretically communication is possible over noisy memoryless channels. Capacity:
  \[
  C = \max_{P(x)} I(X;Y)
  \]
  \(\text{bits/sec}\log_2(2^{l_m}) = C\)

- '93: practical capacity-achieving codes developed for memoryless channels [2]

- '94: capacity expression found in complete generality (even channels with memory) [3]

- Queuing Timing Channels: non-memoryless channels where packet timings randomly altered due to queuing.

- '96: Capacity found in [4]:
  \[
  C(\lambda) = h(\lambda) - \frac{1}{\mu} h(\mu) \text{ bits/slot}
  \]

  \[
  C(\lambda) = \log_2 \frac{\mu}{\lambda} \text{ bits/sec}
  \]

- '08: Coleman, Kiyavash developed practical codes for queuing channels [5]

Goals

- Understand basics of information theory and queuing theory for timing channels
- Learn and understand Forney Factor Graphs and Belief Propagation
- Optimize the existing code parameters in [5] for improved performance/complexity trade-offs
  - Optimize shaping for reduced symbol error rate
  - Exploit queuing theory for better complexity

Fundamental Questions/Challenges

- How do we improve symbol error rates by mapping bits to timings in more clever manners?
- How do we reduce decoding complexity without suffering significant performance loss?

Research Plan

- Encoding: use low-density parity-check codes (LDPCs) over \(F_Q\), followed by shaping to map bits timings

- Decoding: study the Forney Factor graph for \(P(a|x|d)\)

Developed clever ways to map uniform code symbols to non-uniform timings to approach capacity

- Little’s law [6]: \(E[S] = E[d_i-a_i] = g(\lambda, \mathcal{Q})\). So when calculating \(P(a|x|d)\), if \(d_i - a_i >> cE[S]\), approximate it by a small number. This is accurate and reduces complexity from \(O(n^2)\) to \(O(n)\)

Research Results

Performance for an LDPC with \(Q=4\), using 1000 packets, over a DT queuing channel

Order of magnitude improvement in performance-complexity trade-off over scheme introduced in [5]

References