Network Coding for Large Latency and/or Half-Duplex Channels

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• **Application:**
  - **Time-Division Duplexing or ‘Half-Duplex’ channels**
    - Node can transmit and receive, but not at the same time
    - Not necessarily half time for transmitter and half for receiver
    - How much should we talk before stopping to listen?
  - **Long latency channels**
    - Satellite and deep space communications
      - Very long distances (~10,000 km and up)
    - Underwater acoustic communications
      - Low propagation speed (~1500 m/s)
      - Long distances (~km)

• **Previous work**
  - ARQ schemes
  - FEC schemes: block-based (no feedback) or rateless
  - Hybrid schemes
Network Topologies Studied

1-to-all Broadcast

all-to-all Broadcast

Tx with M packets
Description of Scheme: one Rx – one Tx

- **Goal:** reliable transmission of a block of data packets

M data packets

Degrees of freedom needed by Rx:

- Generates $N_M$ random linear coded packets

Erasure Channel

- Header
- Coded Data $C_1 \ldots C_M$

$M$ data packets

ACK degrees of freedom required to decode (dofs req’d):

Not particular data packet

Degrees of freedom needed to decode:

$M$

Choice of $N_i$, $\forall i$ determines performance of scheme

$M$

Note: $N_i$
Minimizing Completion Time or Energy

TDD constraint

- Ni, ∀i chosen to minimize
  - Mean completion time
  - Mean completion energy (ICC’09)

Full Duplex Network Coding:

e.g: M = 10, round trip time = 250 ms, Rate = 1.5 Mbps
Throughput

- $N_i$, $\forall i$ chosen to minimize mean completion time for channel conditions
- e.g: $M = 10$, Rate = 10 Mbps

**Throughput Metric**

$$\eta = \frac{\text{#bits}}{\mathbb{E}[\text{Time}]}$$

- Increasing latency, favors network coding TDD scheme
- Better performance than Go-back-N (GBN) and Selective Repeat (SR) for TDD
• **Challenges:**
  • Optimal scheme: variables to optimize is too large
  • Good heuristics
Completion Time: Broadcast

- Outperforms TDD constrained Round Robin broadcast scheme (optimal, no coding)
- For high erasure probability: Outperforms full duplex Round Robin broadcast

0.8dB @ Pe = 0.8

Pe > 0.3 better than RR full duplex
Conclusions

• Tailoring feedback and coding can reduce mean delay for successful in-order transmission of packets

• Simple off-line optimization
  – Nodes need look-up tables

• Optimizing for completion time:
  – Mean completion time is close to Full Duplex
  – Mean completion energy:
    • Close to optimal
    • Considerably lower than full duplex
  – Throughput performance is equal or better than Go-back-N and Selective Repeat
Extra Slides
Random Linear Network Coding

• Generating a random linear network coded packet (CP)

\[ CP_j = \sum C_i P_i \]

• Operations over finite field of size \( q = 2^g \).
  
  e.g. \( g = 8 \) bits, \( q = 256 \)

\( P_1 \)

\( P_2 \)

\( h \) bits \hspace{2cm} n \) bits \hspace{2cm} \( g \) bits
Errors in estimate of probability of erasure

Over /Underestimate of $P_e$: similar results at low $P_e$

Underestimate of $P_e$: Better performance at high $P_e$
Variance of Completion Time

Variance is not continuous w.r.t packet erasure prob. Why?

As packet erasure prob. increases, number of coded packets sent $N_i$ increases.