Cost Sharing with Network Coding in Two-Way Relay Networks

Ertugrul N. Ciftcioglu and Aylin Yener

enc118@psu.edu, yener@ee.psu.edu

2009 School of Information Theory

PENNSTATE 1855

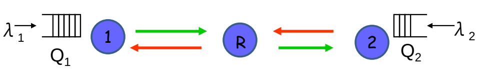
Wireless Communications & Networking Laboratory
WCAN@PSU

Objective

- Investigate the impact of stochastic arrivals on two-way traffic.
- Network coding can potentially reduce transmission cost for two-way networks: single transmission by relay to forward one packet from each source simultaneously
- Cost reduction may come with higher delays: each source must wait for packets to arrive at the other source to exploit network coding gain.

System Model

Two-way sources with arrival rates λ_1, λ_2 exchange packets via **relay** ***R*** immediately forwarding data received by sources at that slot.



Transmission rate $\tilde{\mu}_i(t)$ from node i to node j in slot t.

$$\tilde{\mu}_i(t) = \min(\mu_i(t),\ q_i(t)),\ i = 1,2$$

q_i : queue size
μ_i : service rate

Problem Statement

Unit cost for network coded data: $c_i(t)$
Unit cost for residual data: $d_i(t)$

e.g. $c_i(t)=1/2$, $d_i(t)=1$:

Cost for source i

$$J_i(\tilde{\mu}_1(t), \tilde{\mu}_2(t)) = (\tilde{\mu}_i(t) - \frac{1}{2}\min_{j=1,2}(\tilde{\mu}_j(t)))$$

Total cost of sources: $\max_{j=1,2}(\tilde{\mu}_j(t)))$

Determine source rates in the stability region to *minimize cost per packet.*

Methodology

- **Centralized** & **Decentralized** rate allocation:
  - Different levels of queue information within the network
  - *Decentralized: Non-cooperative* ***game***
  - *Threshold-based algorithms*
- Approach based on Lyapunov analysis for adaptive resource allocation in wireless networks with stochastic traffic.

Centralized Solution

- Full queue information
- Modified backpressure with trade-off parameter *V* given by

$$\max_{(\tilde{\mu}_1(t),\tilde{\mu}_2(t)\in\tilde{C}(t),t\geq 0)}(q_1(t)\tilde{\mu}_1(t)+q_2(t)\tilde{\mu}_2(t)-V\max(\tilde{\mu}_1(t),\tilde{\mu}_2(t)))$$

- Joint rate allocation for $(\tilde{\mu}_1(t), \tilde{\mu}_2(t))$ by **(A1)** depending on joint queue state and V:
- Transmission with either maximum rates, rates for only network coding or no transmission.

Individual Solution

Sources individually try to minimize their cost while ensuring stability for their queue

$$\max_{\tilde{\mu}_i:(\tilde{\mu}_1(t),\tilde{\mu}_2(t)\in\tilde{C}(t),t\geq 0)}(q_i(t)\tilde{\mu}_i(t)-V_iJ_i(\tilde{\mu}_1(t),\tilde{\mu}_2(t)))$$

Solved by source *i* with full queue information to determine $\tilde{\mu}_i(t)$.

Sources play a non-cooperative **game**.

Individual Solution (cont'd)

$\tilde{\mu}_i^*$ Nash equilibrium if $\tilde{J}_i(\tilde{\mu}_i^*, \tilde{\mu}_{-i}^*) \geq \tilde{J}_i(\tilde{\mu}_i, \tilde{\mu}_{-i}^*)$ for all $\tilde{\mu}_i \in \tilde{C}(t)$

Nash equilibrium depending on queue states and tradeoff parameters:

$$\tilde{\mu}_i(t) = \begin{cases} 0 & \text{if } q_i(t) < V_i/2 \\ u_i(t) & \text{if } q_i(t) \geq V_i \\ 0 & \text{if } V_i/2 \leq q_i(t) < V_i, q_j(t) < V_j/2\ i \neq j \\ u_c(t) & \text{if } V_i/2 \leq q_i(t) < V_i, q_j(t) \geq V_j, i \neq j \\ 0, i=1,2, or\ u_c(t) & \text{if } V_i/2 \leq q_i(t) < V_i, i=1,2 \end{cases} \quad \textbf{(A2)}$$

V_i and $V_i/2$ act like thresholds

Distributed Algorithms & Pricing

- Only Local queue information
- Assume worst case response (0) from other source:

$$\max_{\tilde{\mu}_i(t):(\tilde{\mu}_1(t),0)\in\tilde{C}(t),t\geq 0)}(q_i(t)\tilde{\mu}_i(t)-V_iJ_i(\tilde{\mu}_i(t),0))$$

Solution as **(A3)**: Threshold based transmission.

Relay can do pricing by adjusting coefficients: achieves centralized performance.

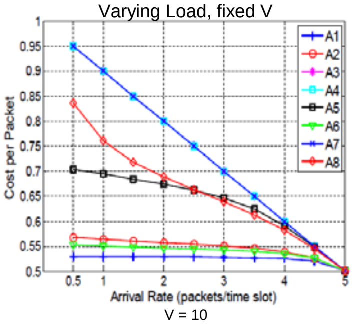
- Sources play the game with worst-case response with updated coefficients.

Algorithms with 1-bit Information

- ***(A6) Sources require*** *1-bit information to know whether other sources backlog exceeds a threshold (i.e. μ_{max}) or not.*
- Two-threshold operation, *V* & μ_{max}: *Reduce threshold if other source queue known to exceed μ_{max}*
- *Increases likelihood of cost-efficient operation with network coding without excessive delay.*

Simulation Results-Varying Load

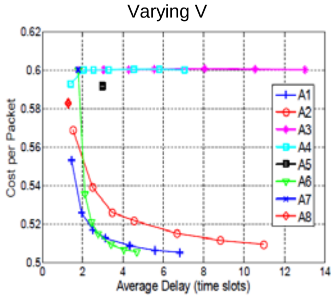
- Average costs decrease with with higher loads and increasing parameter *V*.



V = 10

Simulation Results-Cost-Delay Tradeoff

- Average cost per packet achieved by **(A6)** is very close to the centralized algorithm **(A1)** and the delay is reduced.



$\lambda = 4$, $\mu_{max} = 5$

Observations & Forward Look

- New cost-delay trade-offs based on policies depending on queue info availability in the network.
- 1-bit Queue info leads to asymptotically optimal cost, as the packet delay grows.
- Pricing by the relay for the worst-case response can achieve the optimal solution.
- Future work: Extend to arbitrary number of sources communicating through relays.

Sponsored by NSF