Cost Sharing with Network Coding in Two-Way Relay Networks

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Objective

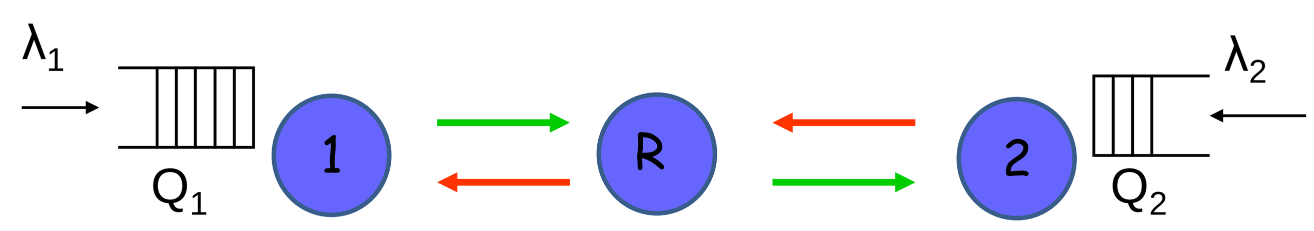
- Two-way traffic: ad-hoc and peer-to-peer systems.
Investigate the impact of stochastic arrivals on two-way traffic.

- 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.

Decentralized Solutions

Individual Solution

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

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

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

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

$\tilde{\mu}_i^*$ Nash equilibrium if

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

Nash equilibrium depending on queue states and tradeoff parameters:

(A2): Transmission with either maximum rate, rate for only network coding or no transmission, but might **differ from centralized** solution.

V_i and $V_i/2$ act like thresholds

Distributed Algorithms & Pricing

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

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.*

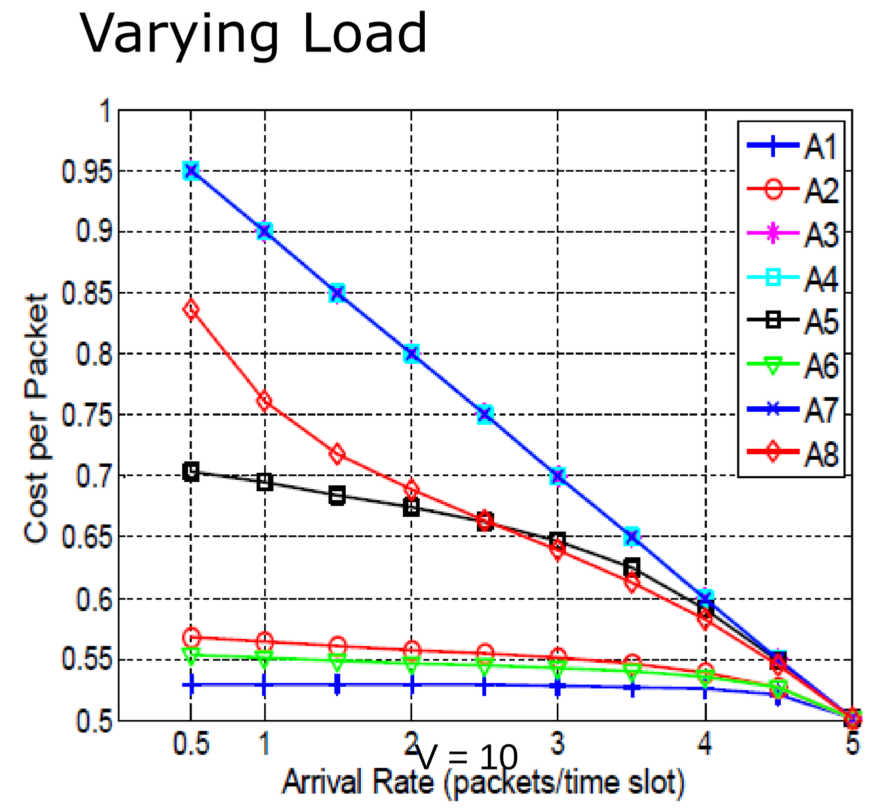
- Two-threshold operation, *V* & *μ_{max} : Reduce threshold if other source queue known to exceed μ_{max}*

- *Increases likelihood of cost-efficient operation with network coding without excessive delay.*

Simulation Results

Varying Load

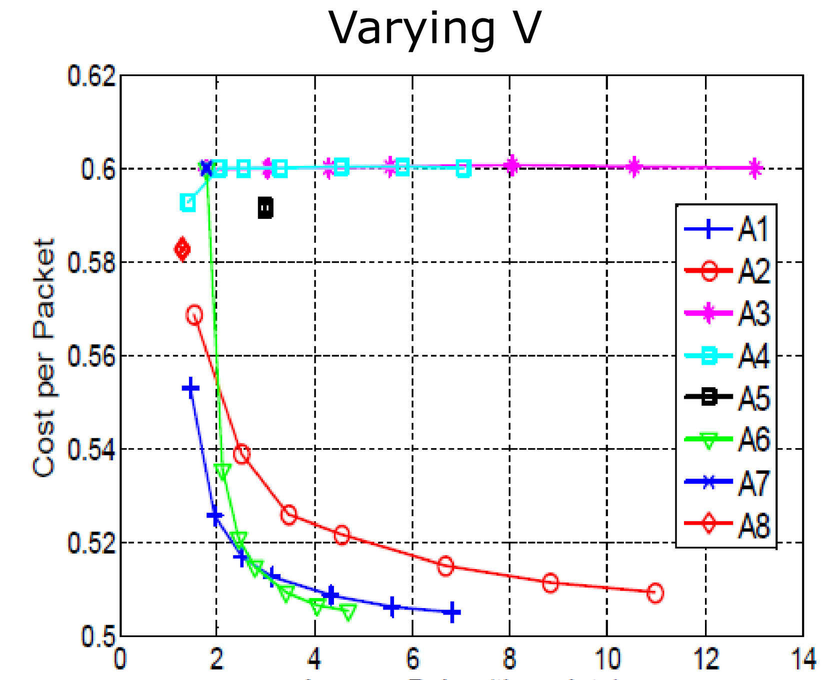
- Average costs decrease with with higher loads and increasing parameter *V.*



Cost-Delay Tradeoff

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

Varying V



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

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.

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