Rate Control for Random Access Networks: The Finite Node Case

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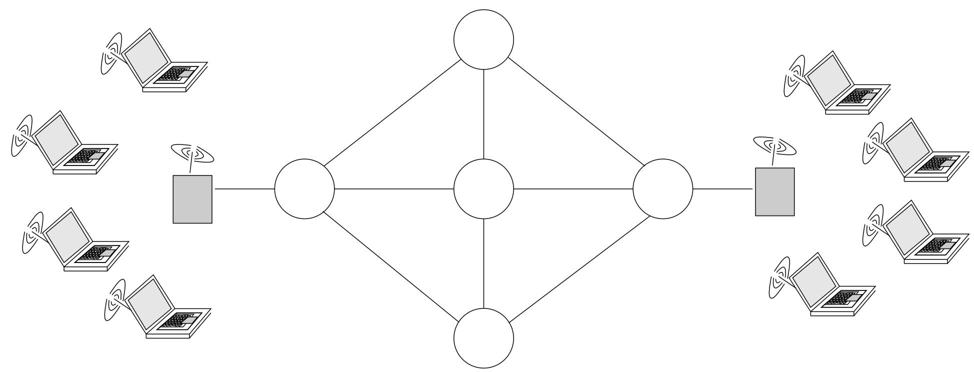
Price-Based Rate Control



- Point-to-Point Wide Area Networks
  - Price-Based Rate Control
    (F. Kelly, S. Low, etc.)
- Local Area Networks
  - Random Access

Point-to-Point Networks: Price-Based Rate Control

Problem Formulation

$$\max_{x_r \geq 0} \sum_r U_r(x_r)$$

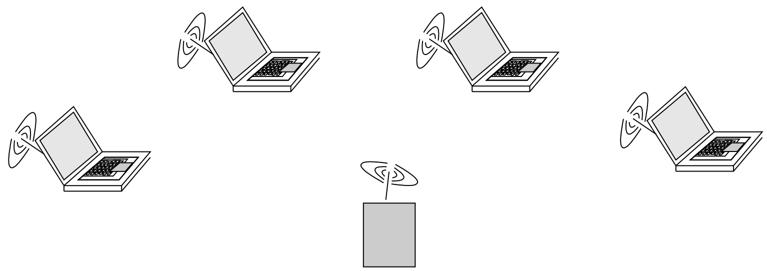
subject to

$$Ax \leq C$$

Rate Control

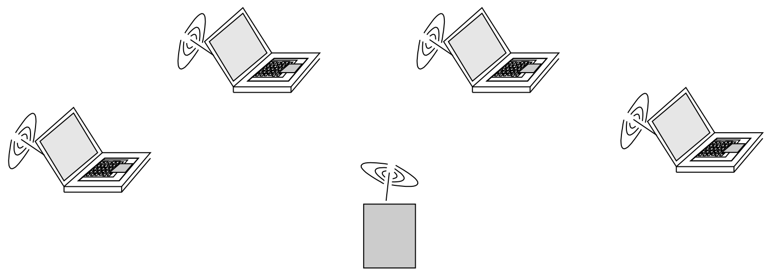
- Lagrange Multipliers
- "Link Price"
  - Input Rate
  - Backlog
- Rate: $x_r = D_r(u_r)$, $u_r = \sum_{l \in r} \mu_l$

Random Access Networks



- Collisions - Backlog - Stability
- Retransmission Strategies for Backlogged Packets
- Rate Control
  - Input Rate?
  - Backlog?
- Channel Feedback
  - Idle/Transmission/Collision

Random Access Networks



- Rate Control
  - Collision: Reduce Rate
  - Idle: Increase Rate
- Questions
  - Stable?
  - Operating Point?
  - Packet Scheduling?

Approach

- Channel Model: Slotted Aloha
  - CSMA, CSMA/CD
- Use Channel Feedback to Modulate Rate
  - Idle, Successful, Collision Slot
- Markov Chain Formulation
  - Stability
- Infinite Node Model: Operating Point
- Finite Node Model: Packet Scheduling

Rate Control and Slotted Aloha

- Poisson Arrival Rate
- Fixed Retransmission Probability q, $0 < q < 1$
- Price (Control) Signal u
- Aggregated Transmission Rate $\lambda(u)$
  - Continuous, Strictly Decreasing
  - $lim_{u \to \infty} \lambda(u) = 0$
- Collision: Increase Price
- Idle Slot: Decrease Price
- Price Adaptation: $\alpha < 0, \gamma > 0$

$$u_{t+1} = \Big[u_t + \alpha I[Z_t = 0] + \beta I[Z_t = 1] + \gamma I[Z_t \geq 2]\Big]^+$$

Infinite Node Model: Results

- Markov Chain (n_t, u_t)
- System is stable.
- (Under suitable conditions) There exists a unique operating point (n^*, u^*)
- We can set $S^* = \lambda(u^*)$ and $D^* = n^*/S^*$ by choosing α,β,γ.

Finite Number of Nodes

- Finite Number of Nodes

$$\lambda(u) = \sum_{m=1}^{M} \lambda_m(u).$$

- Nodes can have several backlogged packets
- Backlog-Dependant Retransmission Probabilities

$$q_m(n_m) = \begin{cases} n_m q_m, & n_m q_m \leq 1 - \epsilon, \\ 1 - \epsilon, & \text{otherwise,} \end{cases}$$

- Backlog-Independent Retransmission Probabilities, q_m.

Finite Number of Nodes: Results

- "Scheduling" is important
- Service differentiation
  - Rate

$$\lambda(u) = \sum_{m=1}^{M} \lambda_m(u).$$

  - Delay

$$q_m(n_m) = \begin{cases} n_m q_m, & n_m q_m \leq 1 - \epsilon, \\ 1 - \epsilon, & \text{otherwise,} \end{cases}$$

Backlog-Dependant Retransmission Probabilities

Assumption: "Price tends to increase when all nodes are saturated and retransmit with probability $1 - \epsilon$."

Case Study

Node	Bandwidth	Delay
1	low	high
2	low	low
3	high	high
4	high	low

Results

Node m	S_m	D_m
1	0.021	186.7
2	0.021	19.9
3	0.206	116.5
4	0.210	11.8

Overview

- Point-to-Point vs. Random Access Networks
- Markov Chain Model
- Operating Point
- Delay and Throughput Differentiation
- End-to-End Rate Control

Related Work

- Price-Based Rate Control
  - Frank Kelly, Steven Low,.....
- Rate Control and Slotted Aloha
  - Kleinrock and Lam
  - Mittal and Venetsanopoulos
- TCP over 802.11
  - Cali *et al.*
- Price-Based Rate Control for Random Access Networks
  - Jin and Kesidis
  - Battiti *et al.*