Resource Allocation in Wireless Ad-Hoc Networks - A Cross Layer Approach

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Outline

- Motivation
- The Cross Layer Approach
  - Joint Congestion and Power Control
- Problem Formulation
  - Optimization Framework
- Experimental Evaluation
  - Simulations
  - Discussion
- Discussions

Motivation

Wireless Ad-Hoc Networks

- Wireless Ad-Hoc Networks
  - Network of Self Configurable wireless mobile nodes
  - Can be of single-hop or multi-hop in nature
  - More complex than the wired network
- Nature of Wireless Networks
  - Broadcasting Nature
  - Mobility of Nodes
  - Time Varying Nature
    - Capacity of the channel Varies
    - Fading
- Limitations
  - Battery Power

Motivation

Resource Allocation

- Resources in Ad-Hoc Networks
  - Channel Share
  - Battery Power
- Wired Network
  - Layered Network Architecture
- Wireless Network
  - Can we use the same Layered Network Architecture?
    - No
      - Ans: Cross-Layer Approach

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Our Scheme

Congestion Control and Power Control

- It is a Joint TCP + PHY Layer
  - Joint Congestion Control and Power Control
- Congestion in the link
  - Aggregate demand exceeds the capacity of the link
  - Delay and Loss of packets in delivery
- What happens to the Packet loss due to channel error?
  - Increase the Transmission power
  - Better coding scheme

The Cross Layer Approach

- Why Cross Layer Approach?
  - The layered approach is not fully fit to wireless network
  - The knowledge of channel should be used by the upper layers
- How does it work?
  - As a joint congestion and power control problem
    - Power control to increase the capacity of the bottleneck link
  - As a joint power control and rate control problem
    - By considering both energy cost and congestion cost

Joint Congestion and Power Control

The Motivation

- Link capacity is a function of *SINR* of the link
- *SINR* can be controlled by a Tx power
  - To increase the capacity of the bottleneck link, one can increase the Tx power in the link
    - Results more interference
    - Tx power may not be optimal
- Can we obtain some solution to this?
    - Yes, by “message passing”
    - *Joint power and congestion control*

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Problem Formulation

- N Communicating source-sink pairs connected by L links
- c_l : Capacity of a link $l \in L$

$$R_{li} = \begin{cases} 1 & \text{if, source } i \text{ uses the link } l \\ 0 & \text{otherwise.} \end{cases}$$

- $x_i(t)$: Transmission rate of source-sink pair i
  - Aggregate flow at each link:

$$y_l(t) = \sum_i R_{li} x_i(t - \tau_{li}^f)$$

- Price of each link is λ_l
  - Total price between a source-sink pair:

$$q_i(t) = \sum_l R_{li} \lambda_l(t - \tau_{li}^b)$$

Problem Formulation

Optimization Framework

- Each source-sink pair i will maximize its profit

$$max_{x_i^*}\left[U_i(x_i^*) - q_i^* x_i^*\right]$$

- System needs to maximize the aggregate utility

$$\begin{aligned} max_{x>0} \sum_i U_i(x_i), \\ \text{s. t.,} \quad RX \leq C; \end{aligned}$$

- Modify the problem with variable capacity

$$\begin{aligned} max_{x>0} \sum_i U_i(x_i), \\ \text{s.t.,} \quad RX \leq C(P); \quad P = \{P_l\}, \\ P_l \leq P_{l-Max}, \quad \forall l, \\ P, X \geq 0 \end{aligned}$$

Joint Congestion and Power Control

- Using KKT, the Optimization Problem can be written as

$$\phi_{system}(X, P, \lambda) = \sum_i U_i(x_i) - \sum_l \lambda_l \sum_i R_{li} x_i + \sum_l \lambda_l c_l(P)$$

- Solution to the above maximization equation can be done jointly
  - By controlling the x based on the link prices
    - Congestion control
  - By changing the Tx. Power in the link as:

$$P_l(t+1) = P_l(t) + \delta \frac{\lambda_l(t)}{P_l(t)} - \delta \sum_{j \neq l} G_{lj} m_j$$

$$m_j(t) = \frac{\lambda_j(t) SINR_j(t)}{P_j(t) G_{jj}}$$

Joint Congestion and Power Control

- Power Tx in the next slot is a function of
  - Congestion cost, message received from the neighboring links and present Tx. power
    - More the congestion cost, more the transmission power
    - If the transmission power in the congested link is already high, then, it should not be increased
      - *else, it will increase interference*
- Needs *SINR* updates and message passing
  - May not be scalable
- Comments
  - Increases the capacity of the bottleneck links
  - Capacity of some links gets decreased

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TCP Reno-2

- *cwnd* is halved if there is one or more mark in one RTT
  - Good for wireless networks
  - Multiple packet drops will not bring down the *cwnd* size
- Utility function is logarithmic and fully concave

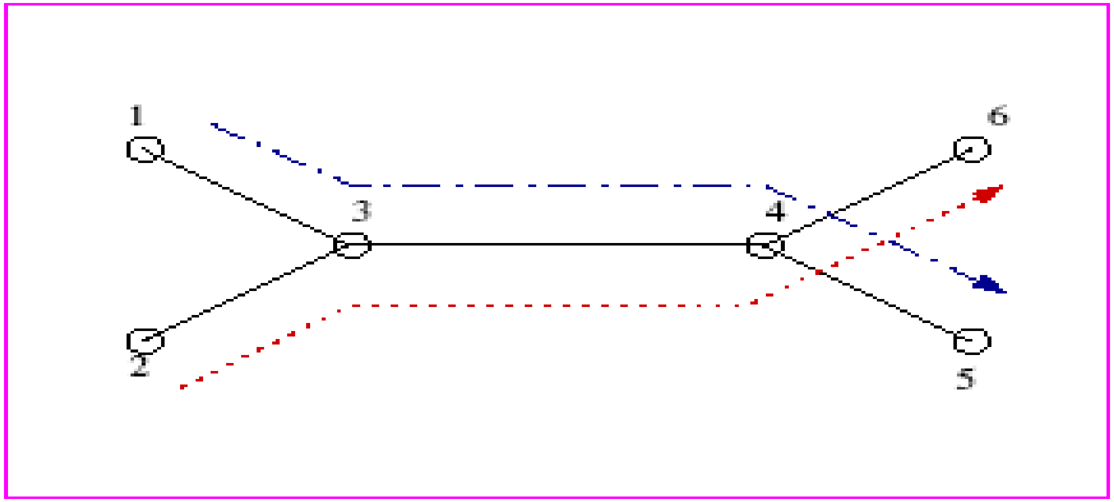
$$U_i(x_i) = \frac{1}{\tau_i} \log\left[\frac{x_i \tau_i}{2x_i \tau_i + 3}\right]$$

- Marking probability as a measure of congestion
  - Packet drop probability is modeled as *M/M/1/B* model

$$\lambda_l(t) = max\left(0, \frac{y_l(t) - c_l(t)}{c_l(t)}\right)$$

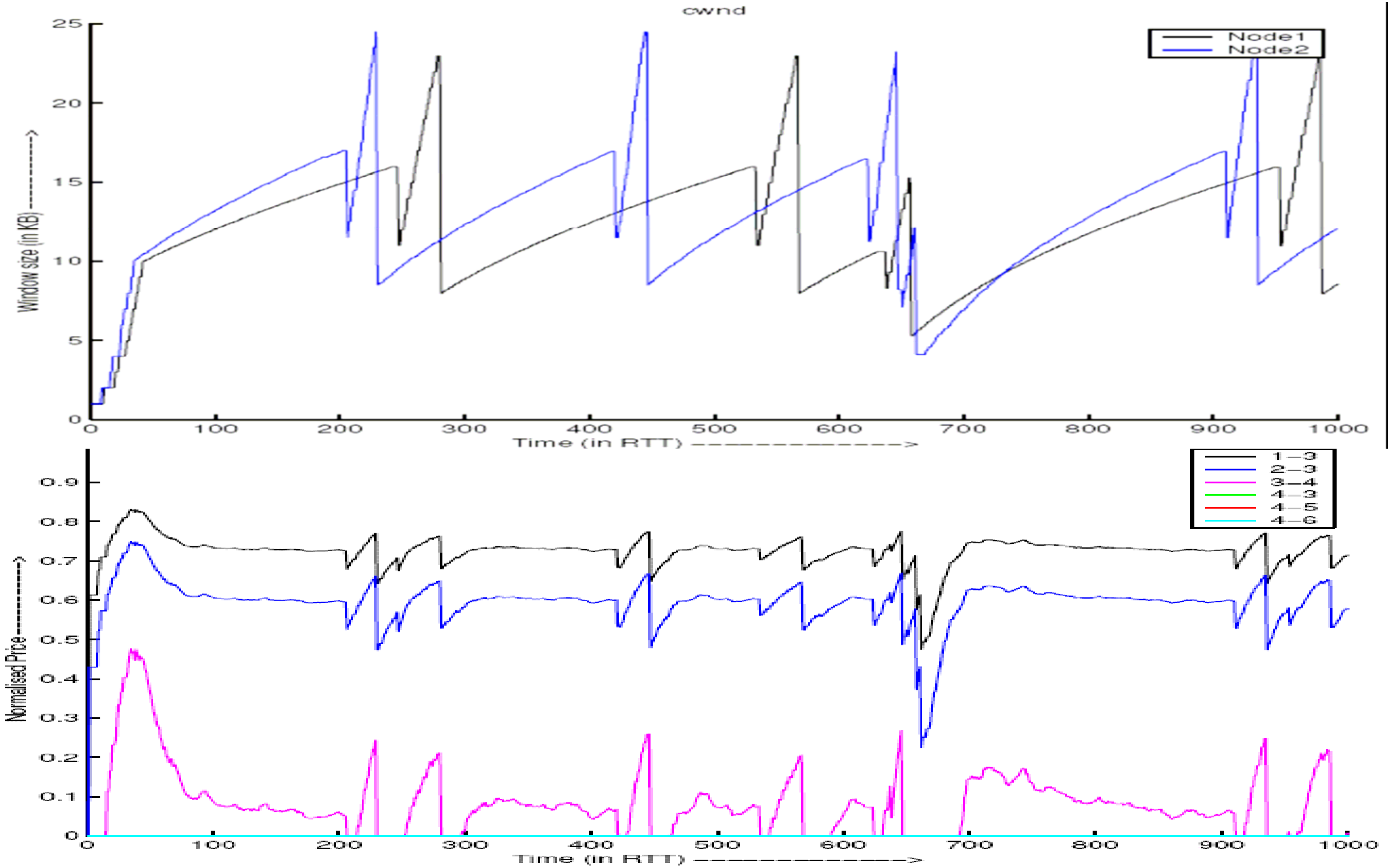
Simulation for TCP Reno-2

- Two source sink pairs (1-5) and (2-6)
- All nodes are TCP Reno-2 agents
- Routing tables at node 3 and 4 are static
- Capacity of the links are different (function of *SINR*)



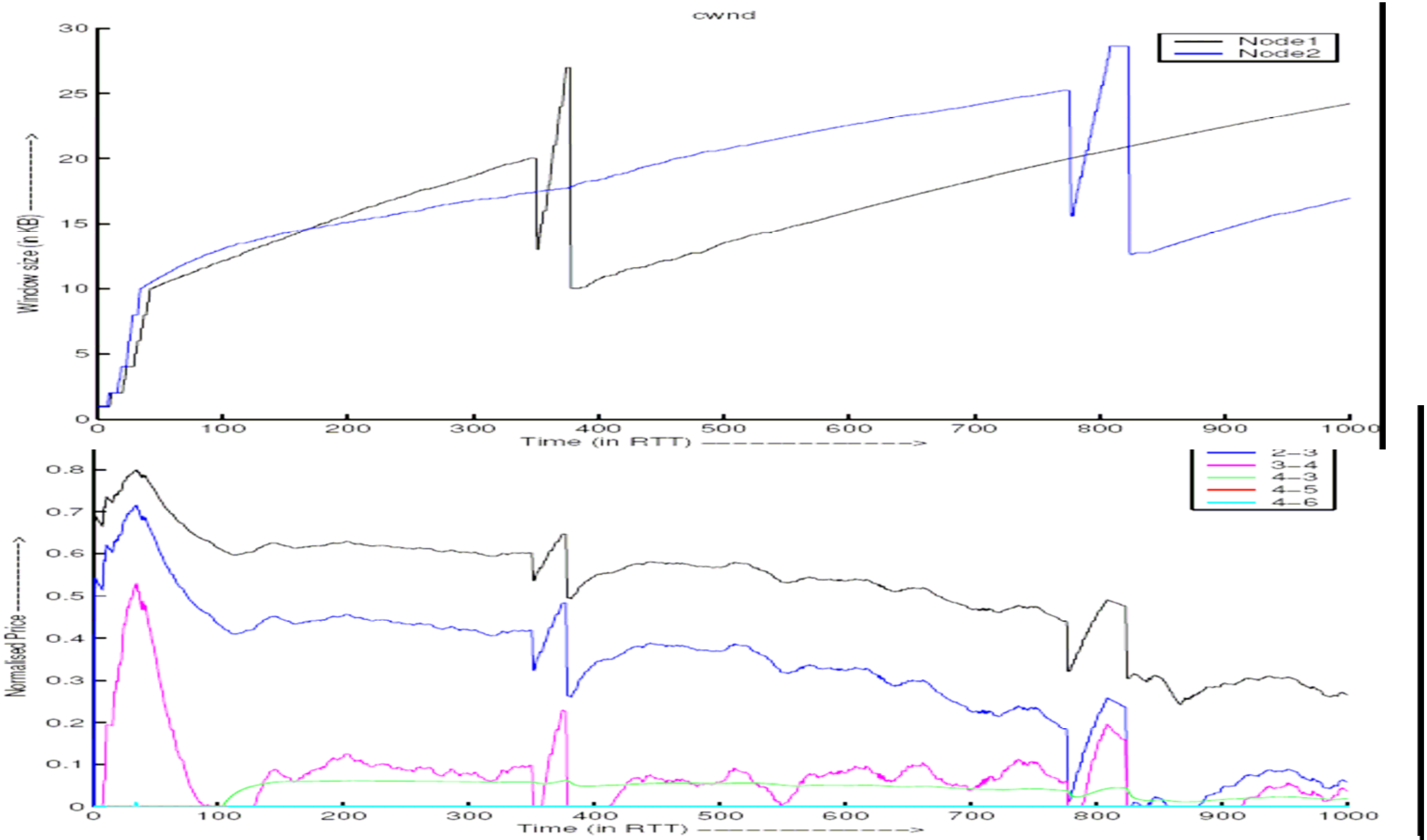
Results

Without Power Control



Results

With Power Control



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Discussions

- Algorithm converges very fast
- Robust algorithm
  - Tested with fading in the channel
  - More and stabilized throughput
- Window size variation is not frequent
- Power transmission is also optimal
  - May transmit at a power level less than P_{Max}
- Needs message passing
  - May not be scalable

Discussions

Present Research

- Design a new Transmission Control Protocol for wireless ad-hoc networks
  - Should be similar to present TCP
  - Should distinguish packet loss due to fading and congestion
  - Energy cost can be included
- AE/CM (Active Energy/Cost Management) for wireless ad-hoc networks

Discussions

Present Research

- Use of Dual Perturbation Theorem
  - Sensitiveness of Lagrange multiplier for a small perturbation in the right hand side
    - Small change in capacity of the link and its effect in the congestion
    - Rate of change of the Lagrange multiplier
  - The Message passing can be minimized

Thanks