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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

- 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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- **Discussions**
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 $\text{SINR}$ of the link
- $\text{SINR}$ 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
- \( c_i \): 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 \( \lambda_l \)
  - 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

$$\max_{x^*} \left[ U_i(x^*_i) - q^*_i x^*_i \right]$$

- System needs to maximize the aggregate utility

$$\max_{x \geq 0} \sum_{i} U_i(x_i),$$

s.t., $RX \leq C$;

- Modify the problem with variable capacity

$$\max_{x \geq 0} \sum_{i} U_i(x_i),$$

s.t., $RX \leq C(P)$; $P = \{P_l\}$,

$P_l \leq P_{l_{\text{Max}}}$, $\forall l$,

$x, P \geq 0$
Joint Congestion and Power Control

- Using KKT, the Optimization Problem can be written as

\[ \phi_{\text{system}}(X, P, \lambda) = \sum_i U_i(x_i) - \sum_i \lambda_i \sum_j R_{ij}x_i + \sum_i \lambda_i c_i(P) \]

- 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:

\[
P_l(t + 1) = P_l(t) + \delta \frac{\lambda_l(t)}{P_l(t)} - \delta \sum_{j \neq l} G_{lj} m_j \\
m_j(t) = \frac{\lambda_j(t) \text{SINR}_j(t)}{P_j(t) G_{jj}}
\]
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
  \[
  \lambda_i(t) = \max \left( 0, \frac{y_i(t) - c_i(t)}{c_i(t)} \right)
  \]
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 $\text{SINR}$)
Results

Without Power Control
Results

*With Power Control*

[Graph showing window size (cwnd) and normalized ping over time (in RTT).]
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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