Introduction

- Transmit power control in wireless networks
  - Mitigates multiple access interference
  - Conserves battery life in mobile terminals
- Distributed power control for ad hoc networks
  - Classical algorithm by Foschini & Miljanic’93
    - Fully distributed, but not backlog aware
  - PCRA by Bambos & Kandukuri’00
    - Backlog aware, but assumes unresponsive interference
- This talk … distributed, backlog aware power control, responsive to interference
  - Focus on stochastic control aspects
System Model

\[ \gamma_1 = \frac{P_1 G_{11}}{P_2 G_{21} + \sigma^2} \]

\[ \gamma_2 = \frac{P_2 G_{22}}{P_1 G_{21} + \sigma^2} \]

- Slotted time
- \( L \) transmit power levels
- Probability of successful transmission – function of SINR
- Change power by at most one level in every time slot

Practical considerations
Centralized Power Control

- Buffer draining problem
  - Can incorporate Markovian arrivals
- Backlog costs per time slot (convex)
- **Objective** – Minimize total backlog cost incurred in draining queues
- Power assignment based on
  - Backlog information
  - SINRs from previous time slot
- Stochastic shortest path problem
  - Dynamic programming
Centralized Power Control …

- **Provable** structural properties
- **Load balancing effect**
  - Opportunistic behavior
- **What is missing?**
  - Distributed decision making
  - Scalability
- **Oracle** is a benchmark for performance evaluation

Snapshot of optimal policy (Oracle)

x increase  o maintain  + decrease
Distributed Power Control

- **Coupling** induced by broadcast nature of wireless medium
- **Decouple** – study every link in isolation
- Capture interaction through **power cost**
  - Penalty for “stressing” the shared wireless environment
  - Introduces **power vs. backlog tradeoff**

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Distributed Power Control …

- Solve three different buffer draining problems for single link under the assumptions:
  - Interference will always decrease – BACK (back-off)
  - Interference will always increase – AGGR (aggressive)
  - Interference will stay fixed – STAT (static)

- **Objective** – Minimize total backlog cost plus power cost incurred in draining queue
- Dynamic programming formulation
- One look up table for each problem
The BDD Power Control Algorithm

- Compute 3 look up tables BACK, AGGR, and STAT offline at each link.

- Given current backlog and interference from previous time slot:
  
  - Choose action from table:

    \[
    \begin{align*}
    \text{BACK} & \quad w.p. \quad \beta_1 \\
    \text{AGGR} & \quad w.p. \quad \beta_2 \\
    \text{STAT} & \quad w.p. \quad 1 - \beta_1 - \beta_2 \\
    \end{align*}
    \]

- Observe interference \((i)\) in current time slot:

  \[
  \begin{array}{ccc}
  i \downarrow & \beta_1 \uparrow & \beta_2 \downarrow \\
  i \uparrow & \beta_1 \downarrow & \beta_2 \uparrow \\
  i \leftrightarrow & \beta_1 \downarrow & \beta_2 \downarrow \\
  \end{array}
  \]

- \(\beta_1\) = Fraction of time interfering links back off – interpret as probability.
The BDD Power Control Algorithm …

- Generalizes to multiple links
- Only aggregate interference from other links matters
  - Conceptually, other links behave as one *mega link*
- Can adapt to changes in topology through $\beta_1$ and $\beta_2$
  - No need to re-compute look up tables as other links come and go
- Look up tables re-computed only when self link gain changes
  - Reasonable under slow mobility
**Performance Evaluation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation length</td>
<td>10000 time slots</td>
</tr>
<tr>
<td>Channel gains</td>
<td>$G_{11} = G_{22} = 1, G_{12} = G_{21} = \frac{1}{2}$</td>
</tr>
<tr>
<td>Success probability mapping</td>
<td>$s(\gamma) = 1 - \exp(-\gamma)$</td>
</tr>
<tr>
<td>Number of transmit power levels</td>
<td>$L = 8$</td>
</tr>
<tr>
<td>Backlog costs (Oracle and BDD)</td>
<td>$\phi(b) = b$</td>
</tr>
<tr>
<td>Power costs (BDD only)</td>
<td>$\zeta(l_1 - l_2) = l_1 - l_2$</td>
</tr>
</tbody>
</table>
Performance Evaluation …

Bernoulli traffic

- 20-30 % gain in throughput over power control with fixed SINR targets
- Similar results for other traffic types (e.g., Poisson)
- Performance of BDD and Oracle similar

Markov modulated Bernoulli traffic (bursty)
Performance Evaluation ...

Convergence
Bernoulli – $p_1 = 0.8$, $p_2 = 0.4$

Power vs. Backlog tradeoff
Bernoulli – $p_1 = 0.6$, $p_2 = 0.6$
Conclusions

- Centralized power control – Oracle
  - Load balancing effect

- Distributed power control – BDD
  - Decouple links for analysis – capture interaction through “power costs”
    - More generally applicable (e.g., buffer management for media streaming)
  - Mimics load balancing effect
  - Scalable

- Ongoing work – multilink simulations, theoretical aspects, protocol aspects
Thank You!

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Introduction …

- A distributed PC algorithm – FM’93
  - Fixed SINR targets
  - Infinitely backlogged sources
  - “Fights” the interference

- Another distributed PC algorithm – BK’00
  - Probability of success – function of SINR
  - Backlog aware
  - Assumes unresponsive interference
  - “Befriends” the interference

- This talk … *distributed, backlog aware power control, responsive to interference*
  - Focus on structural / control aspects