Distributed Backlog-Driven Power Control in Wireless Networking

Aditya Dua and Nick Bambos

Information Systems Laboratory

Department of Electrical Engineering

Stanford University

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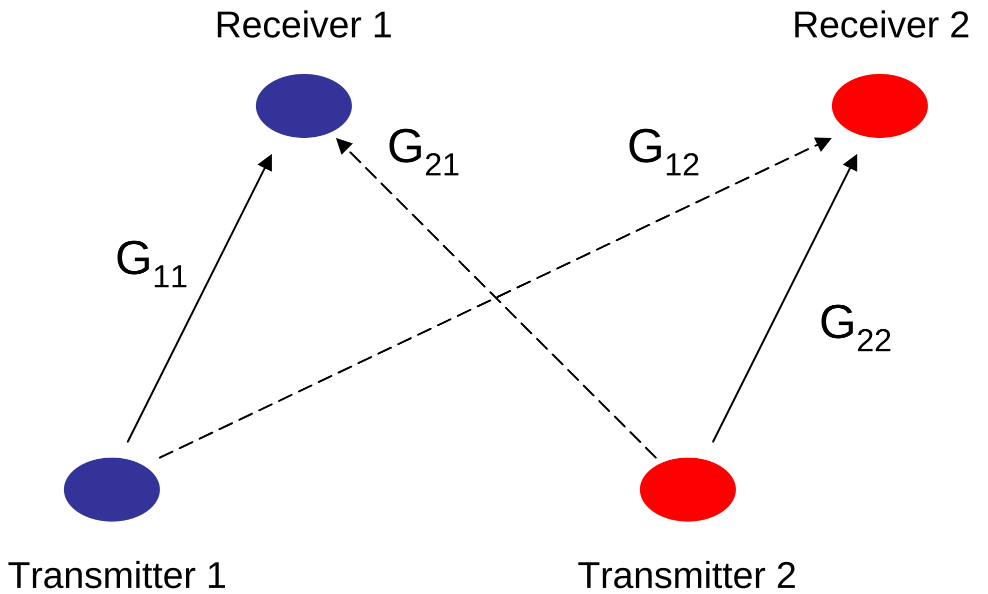
Introduction

- 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



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

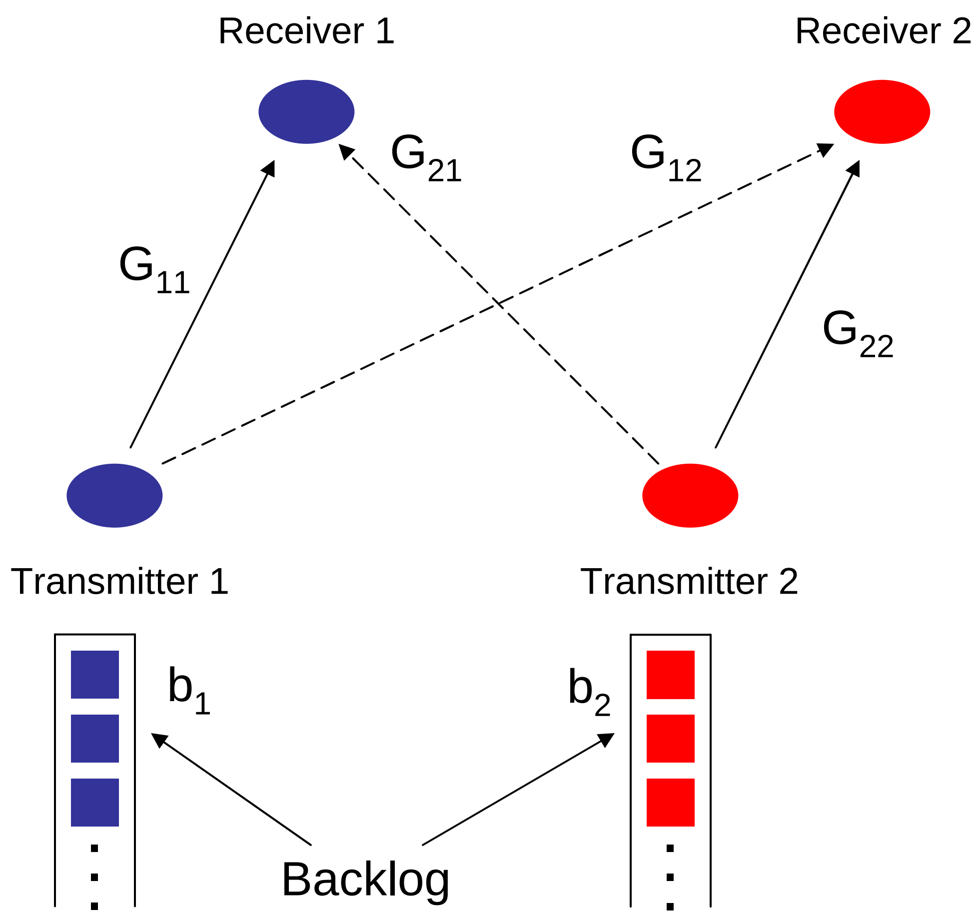
$$\gamma_2 = \frac{P_2 G_{22}}{P_1 G_{21} + \sigma^2}$$

SINR

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

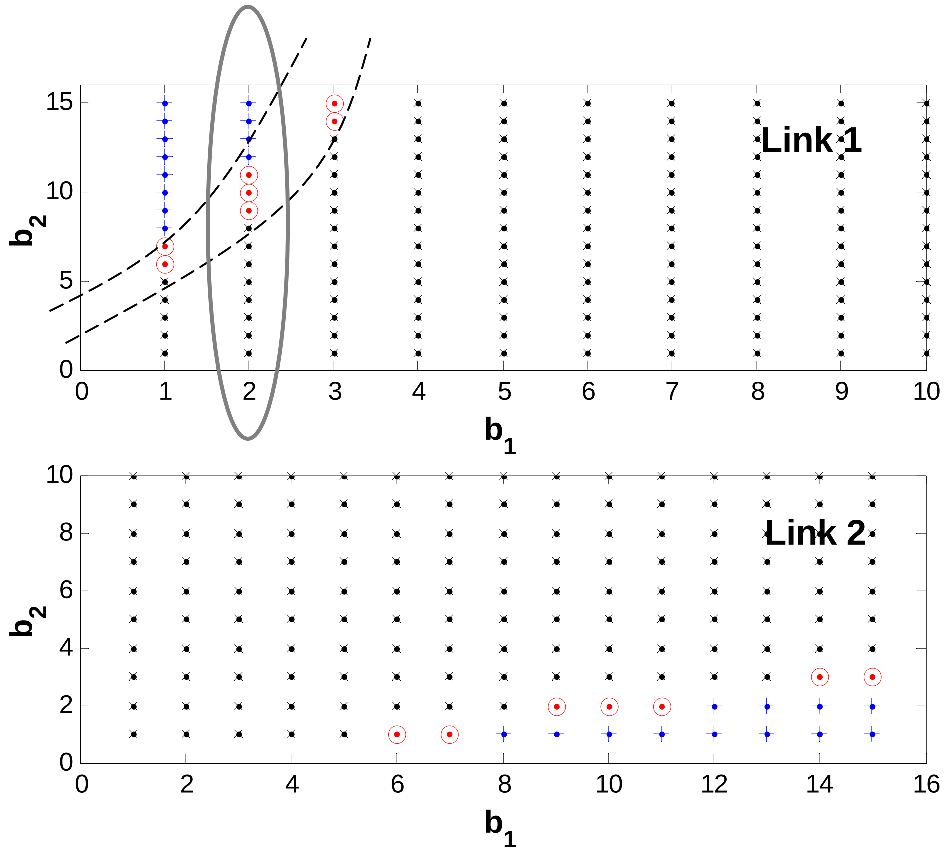
Practical considerations

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 …

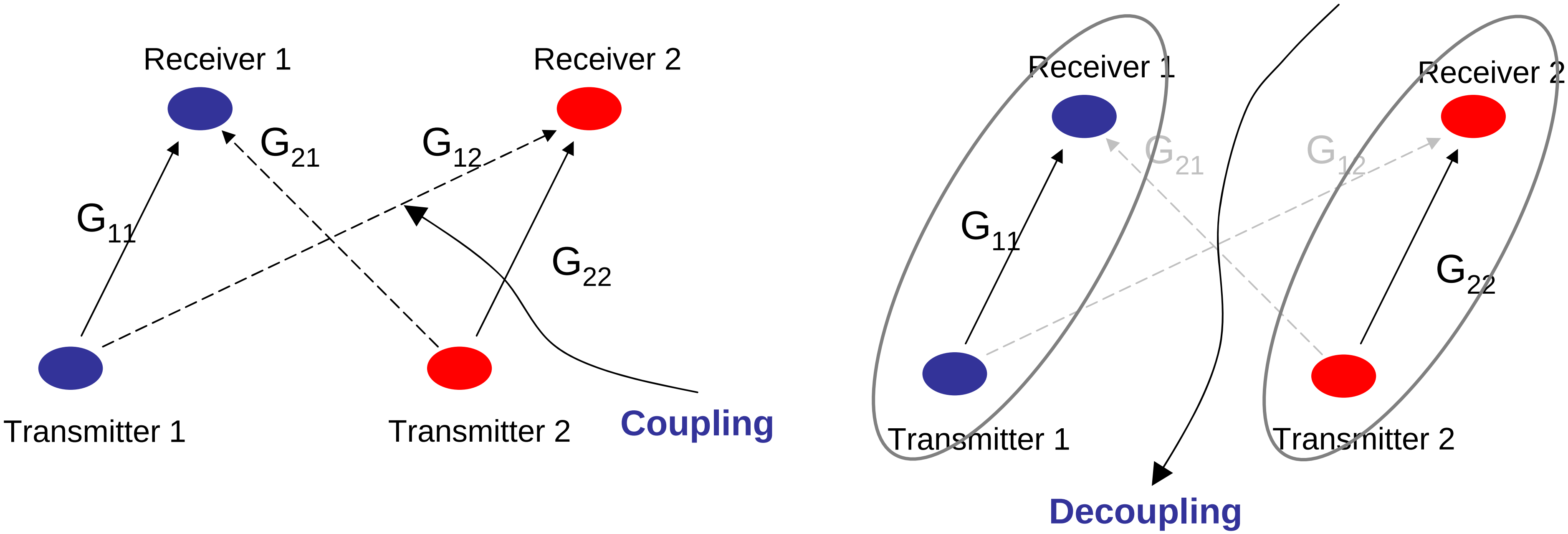


Snapshot of optimal policy (Oracle)

x increase o maintain + decrease

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

Distributed Power Control



- Coupling induced by broadcast nature of wireless medium
- Analysis / implementation does not scale with number of links

- *Decouple* – study every link in isolation
- Capture interaction through **power cost**
  - Penalty for "stressing" the shared wireless environment
  - Introduces ***power vs. backlog tradeoff***

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 $\begin{cases} \text{BACK} & w.p. \quad \beta_1 \\ \text{AGGR} & w.p. \quad \beta_2 \\ \text{STAT} & w.p. \quad 1-\beta_1-\beta_2 \end{cases}$

Decision step

- Observe interference (i) in current time slot

Update step

$i\downarrow$	$\beta_1\uparrow$	$\beta_2\downarrow$
$i\uparrow$	$\beta_1\downarrow$	$\beta_2\uparrow$
$i\leftrightarrow$	$\beta_1\downarrow$	$\beta_2\downarrow$

- β_1 = Fraction of time interfering links back off – interpret as probability

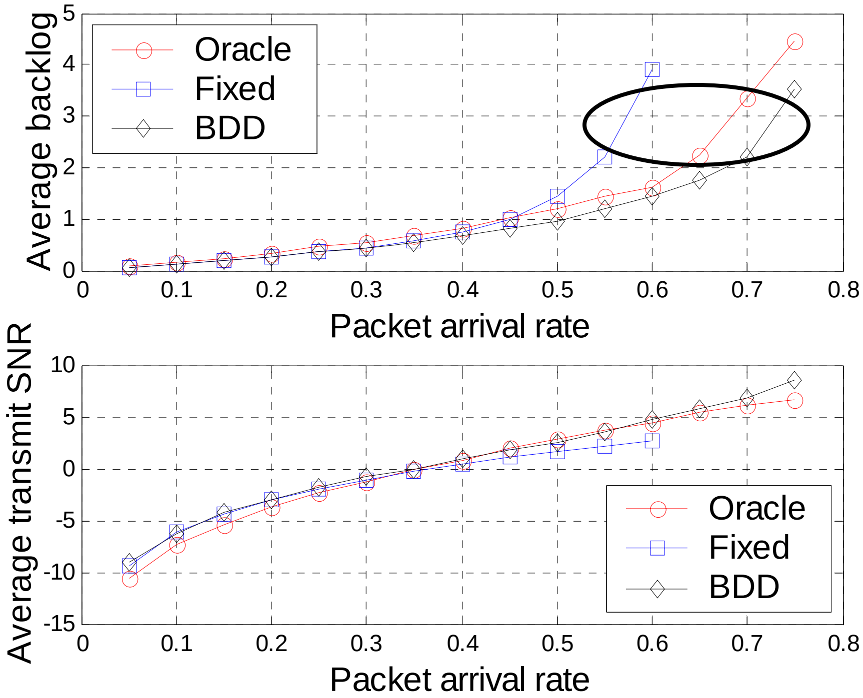
The BDD Power Control Algorithm …

- 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 β_1 and β_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

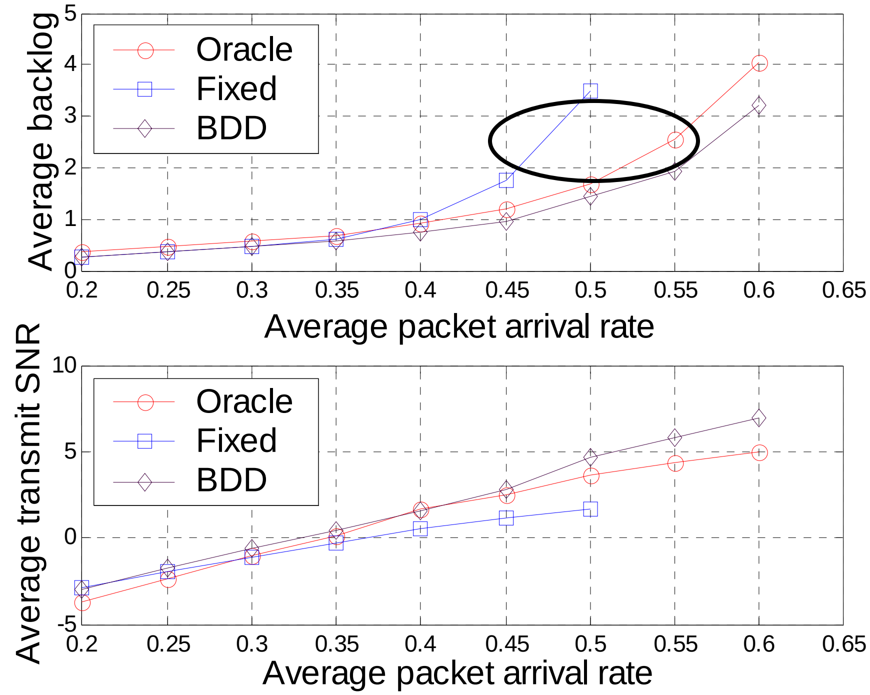
Performance Evaluation

Parameter	Value
Simulation length	10000 time slots
Channel gains	$G_{11} = G_{22} = 1$, $G_{12} = G_{21} = ½$
Success probability mapping	$s(\gamma) = 1 – \exp(-\gamma)$
Number of transmit power levels	$L = 8$
Backlog costs (Oracle and BDD)	$\phi(b) = b$
Power costs (BDD only)	$\zeta(l_1 - l_2) = l_1 - l_2$

Performance Evaluation …



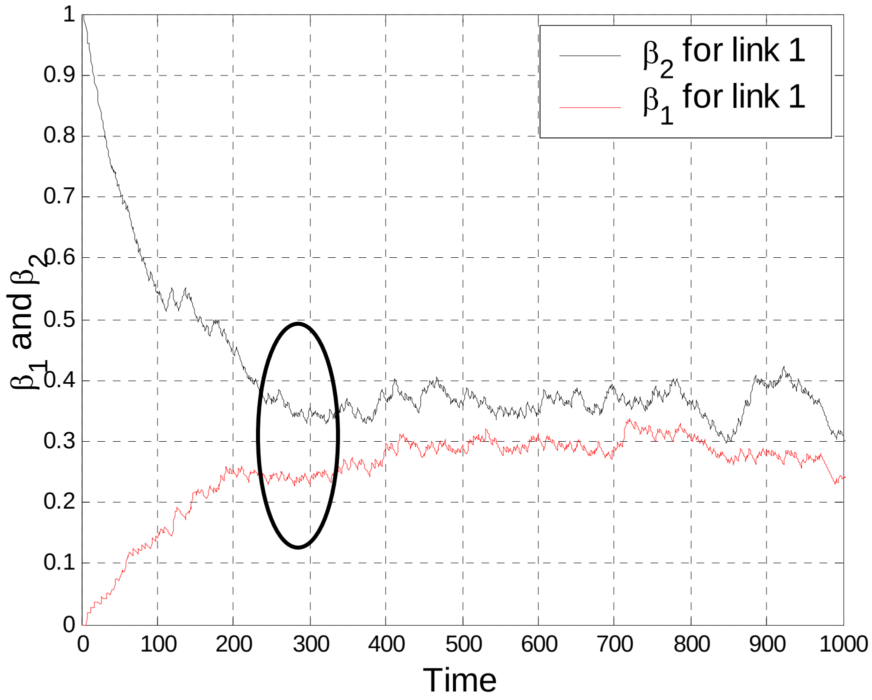
Bernoulli traffic

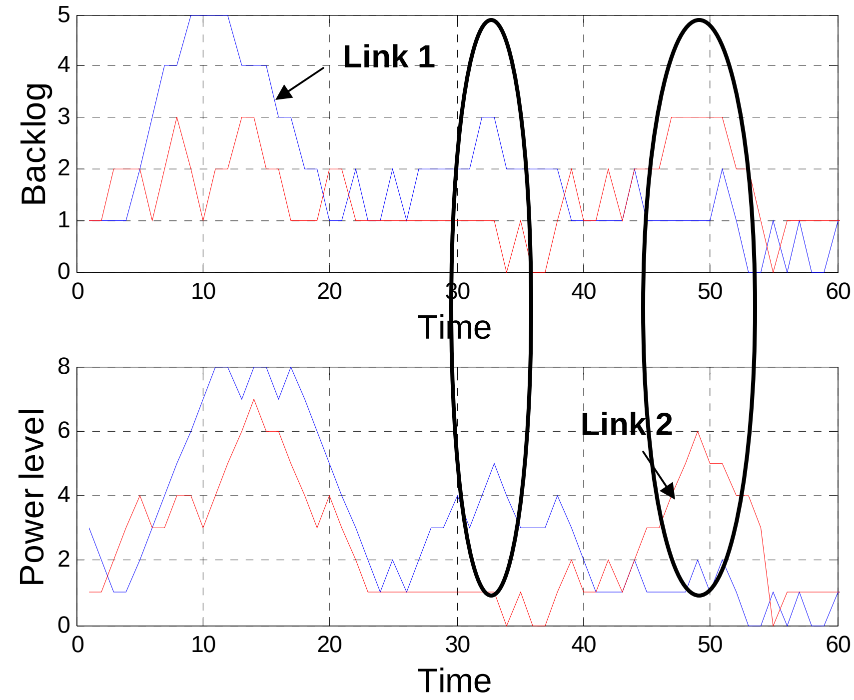


Markov modulated Bernoulli traffic (bursty)

- 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

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 !

Contact: {dua,bambos}@stanford.edu

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