Modeling and Analysis of Generalized Slotted-Aloha MAC Protocols in Cooperative, Competitive and Adversarial Environments

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Outline

Background

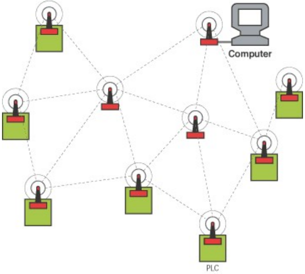
What is a slotted-Aloha type protocol?

- A medium access control (MAC) protocol.
- Transmissions synchronized into time-slots.
- Does not perform carrier sensing.

Motivation: Applications

Why is slotted-Aloha important?

- Renewal interests in wireless and sensor networks.
- Distributed control, easy to implement.
- Carrier sensing is complex (e.g. hidden terminal problem).



Motivation: Comparison

Prior Work

- Queueing models [Bertsekas, Gallager ’92], Instability [Hellman ’75][Schwartz ’88], Dynamic control [Rivest ’87][Lam, Kleinrock ’75].
- Homogeneous nodes (same parameters for all).

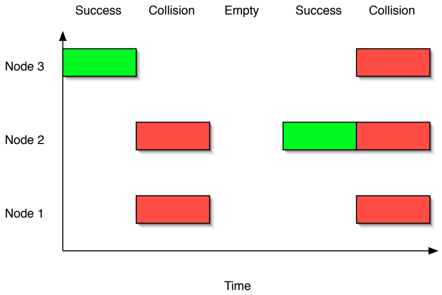
What is new about our study?

- Optimization and Game-theoretic approach.
- Performance under different user behaviors.
  - Cooperative (Welfare behavior)
  - Competitive (Selfish behavior)
  - Adversarial (Malicious behavior)

Slotted Aloha Algorithm: Review

The Slotted-Aloha Algorithm

- New packet ⇒ send in current time-slot.
- Successful transmission ⇒ send packet in next time-slot.
- Collision ⇒ retransmit with probability p until success.

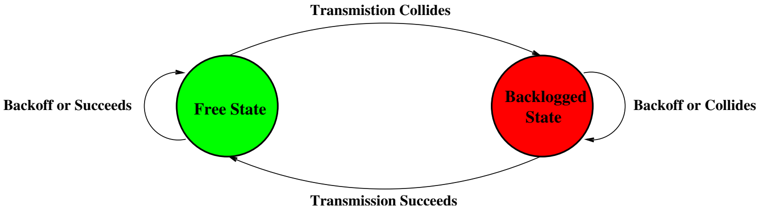


Our Model

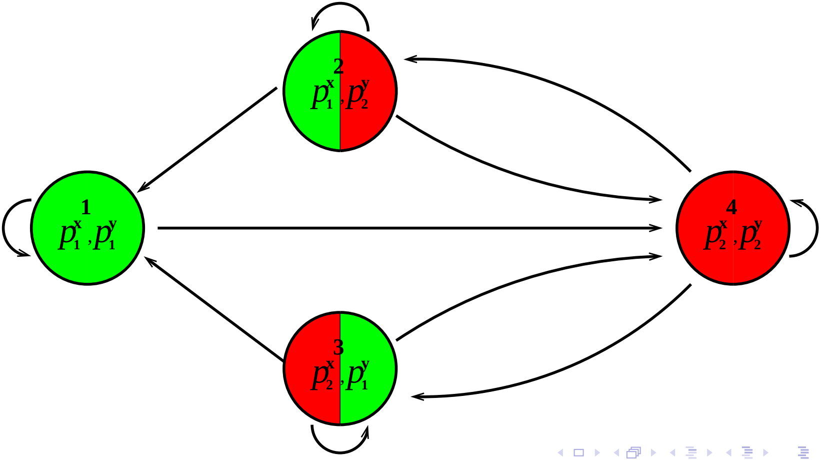
Bi-state Protocol: Generalization

Most recent transmission => Node's state:

- Success => Free state: Transmit probability $p_1[1]$.
- Collision => Backlogged state: Transmit probability $p_2[p]$.



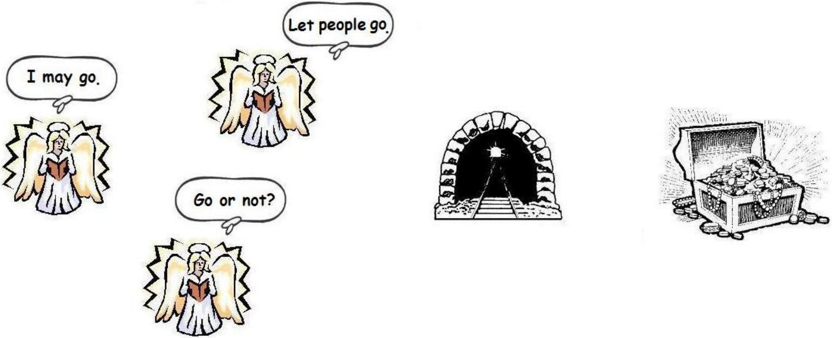
A two node Markov chain



Problem Formulation: Welfare Behavior

Objective

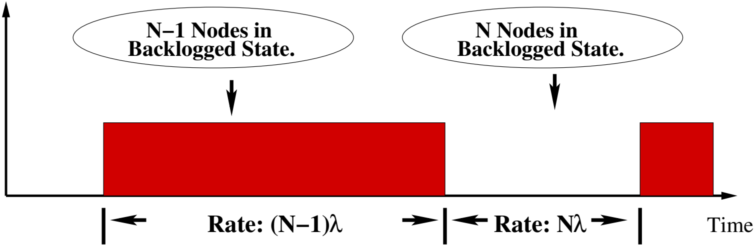
Find (p_1, p_2) for all to maximize throughput.



Limiting behavior: multi-node case

Multi-user limiting throughput

If $p_1 = 1$ and $p_2 \to 0$, aggregate throughput $\rho \to N/(2N-1)$.



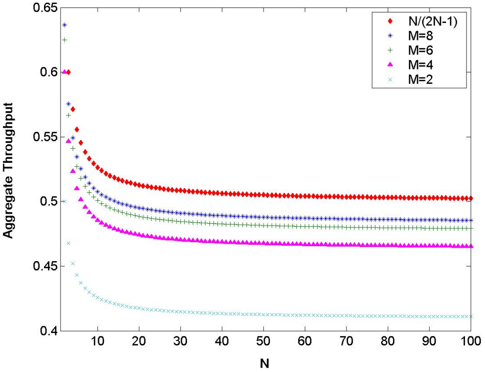
$$\rho = \frac{Busy}{Busy+Idle} = \frac{\frac{1}{(N-1)\lambda}}{\frac{1}{(N-1)\lambda}+\frac{1}{N\lambda}} = \frac{N}{N+(N-1)}.$$

Short-term Unfairness

Long term average $\frac{N}{2N-1}$; How about short term?

- X_b: r.v. = # of slots a node holds channel.
- $p_1 = 1$ and $p_2 \searrow 0$ ==> Channel capture ==> $X_b \nearrow \infty$.
- Short-term unfairness measure: $M(p_2) = E[X_b]$.

Short-term Fair Throughput



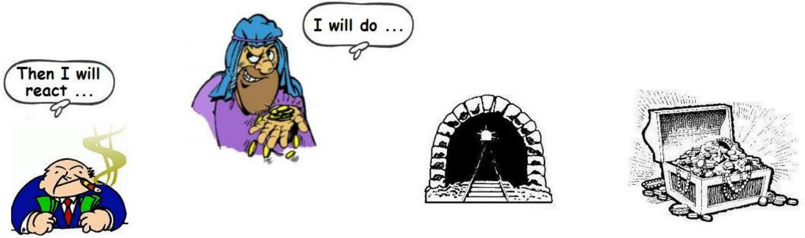
Tradeoff

Throughput Vs. Fairness

Problem Formulation: Selfish Behavior

Stackelberg Game (Leader-follower Game)

Find (p_1, p_2) to maximize own throughput. Take turns.



Problem Formulation: Budget Constraint

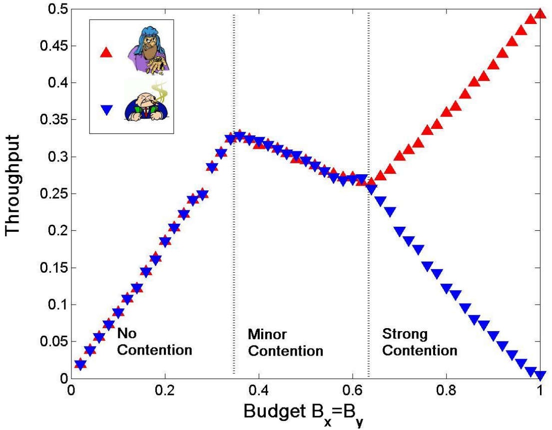
In addition to Throughput, what else?

- Power consumption.
- Transmission frequency.

Constraint

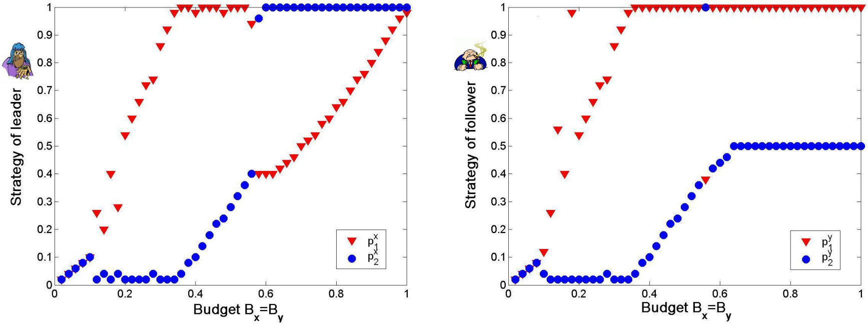
- Cost = $\frac{\#\text{ of trials}}{\#\text{ of slots}} \leq$ Budget $\in (0, 1]$.
- Throughput = $= \frac{\#\text{ of successes}}{\#\text{ of slots}}$.
- Cost - Throughput = $\frac{\#\text{ of collisions}}{\#\text{ of slots}}$.

Stackelberg Game: Throughput



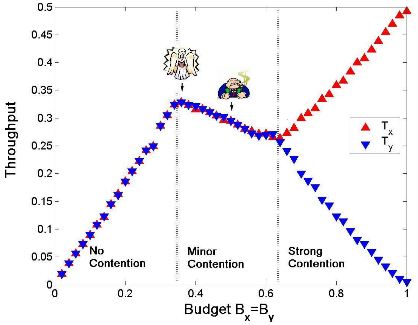
- Large Budget: Leader's advantage.
- Small Budget: Similar throughput.

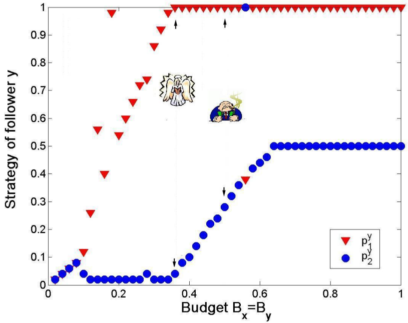
Stackelberg Game: Strategies



- Small Budget: Similar strategies.
- Large Budget: Leader's aggressiveness.

Two Strategies





-  $T = 0.331, p_1 = 1, p_2 = 0.02.$
-  $T = 0.285, p_1 = 1, p_2 = 0.28.$

Prisoner's Dilemma

		
	(0.331,0.331)	(0.002,0.941)
	(0.941,0.002)	**(0.285,0.285)**

-  is better than , regardless of the other's action.
- Equilibrium (, ) is worse than (, ) for both.

Problem Formulation: Adversarial Behavior

Stackelberg Game

Leader minimizes Follower's throughput.

Devil's Advocate

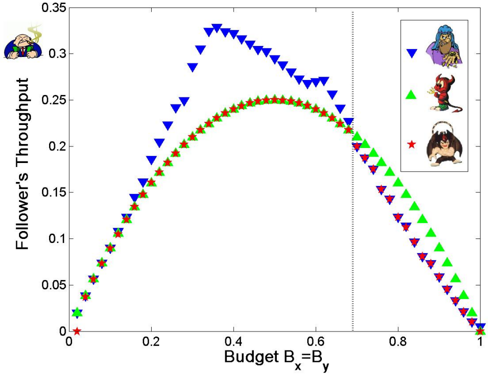
Pure Random Attack Strategy

$p_1 = p_2 = B \Leftrightarrow$ send with probability B independently in each time-slot.

Property

As if a lossy channel with dropping probability B.

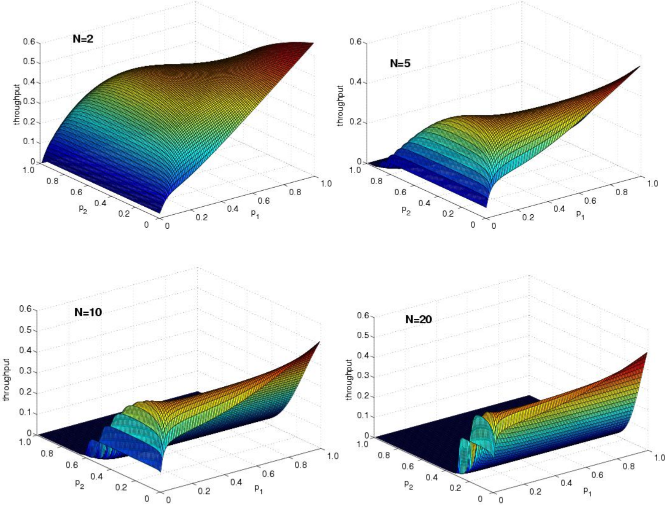
Throughput: A Comparison



- Small Budget:
   as good as 
- Large Budget:
   as good as 

Conclusions

1. Generalized slotted-Aloha (two-state protocol) and its Markov model
2. User behaviors: Cooperative, Selfish and Adversarial
    - Throughput bound: $N/(2N-1)$
    - Short-term fairness
    - Prisoner's Dilemma
    - Random attack is optimal for small budget.
    - Selfish behaves as if strategic attack for large budget.


N=2
N=5
N=10
N=20
throughput
p1
p2