Game Theory in Wireless Networking

Prof. Howard Blum

Seidenberg School of Computer Science and Information Systems

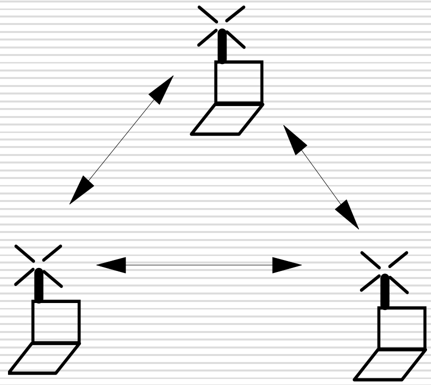
Outline

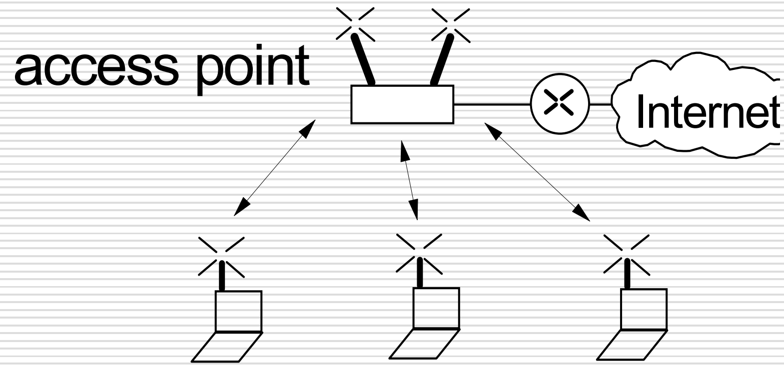
- Background
  - DPS Theses
- Wireless Data Networks
  - Contention for Shared-Channel
- Game Theory
  - Nash Equilibrium
  - Mixed Strategies
- Example – A Channel-Access Game
  - Game vs. Socially Optimal Solutions

Background

- Roli Wendorf (DPS student)
  - Interest in thesis in wireless data networks
    - Philips Labs
    - DARPA and FCC interest in Dynamic Spectrum Allocation
  - *"Channel-Change Games in Spectrum-Agile Wireless Networks"*
- Fred Dreyfus (DPS student)
  - *"Access-Control Games in Wireless Networks"*

Wireless Data Networks (e.g., 802.11)

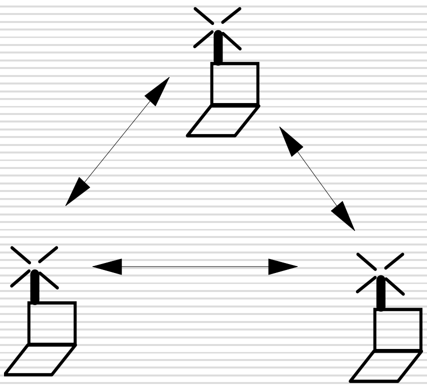


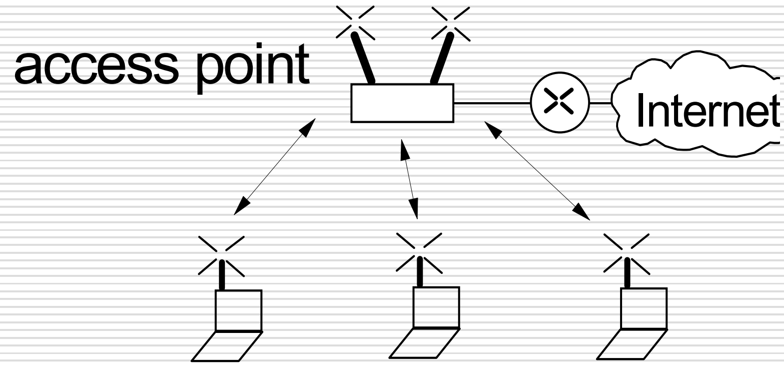


ad hoc mode **infrastructure mode**

- single, shared frequency channel per network
- **one at a time** or **collision -- who gets to transmit?**
- distributed, dynamic medium-access control
  → each station decides when to transmit, e.g., using CSMA/CA

Wireless Games





- **Access-Control Game**
  - each station decides when to transmit
  - **…** is **selfish**, but **rational**
  - **…** tries to maximize its own performance, rather than following dictated protocol rules.
- **Channel-Change Game**
  - multiple, interfering networks
  - each network decides whether to change channel

Game Theory

- mathematical models of interaction between two or more **rational** decision makers
- traditional applications -
  - economics and political science
    - J. Von Neumann and O. Morgenstern
    - **J. Nash** (1950 work, 1994 Nobel)
    - R. Aumann and T. Schelling (2005 Nobel)

Mathematical Game

$\mathbf{a_i}$ player i's action i = 1, … N

$\mathbf{A_i}$ player i's action space

$\mathbf{a}$ action profile = (a_i , a_{-i})

$\mathbf{u_i(a_i , a_{-i})}$ player i's utility

How should player i choose its action?

Need a **solution concept!**

- Saddle Point (Two-Person Zero-Sum)
- Nash Equilibrium

Nash Equilibrium (NE)

NE - *an action profile a* in which no individual player has incentive to deviate.*

i.e., a* is a NE if for every player i,

$$u_i(a_i , a^*_{-i}) \le u_i(a_i^*, a^*_{-i}) \quad \text{for all } a_i \in A_i$$

There may exist **0, 1 or multiple NEs** in a game.

Mixed Strategies and Existence of NE

- Mixed Strategy
  - probability distribution over the action set A_i (pure strategies)
  - enlarges the space of strategies
- Existence of NE (John Nash 1950)
  - In a finite game, introducing mixed strategies assures existence of a NE.

2-Player, Symmetric, Single-Stage Wireless-Access Game

Player 2

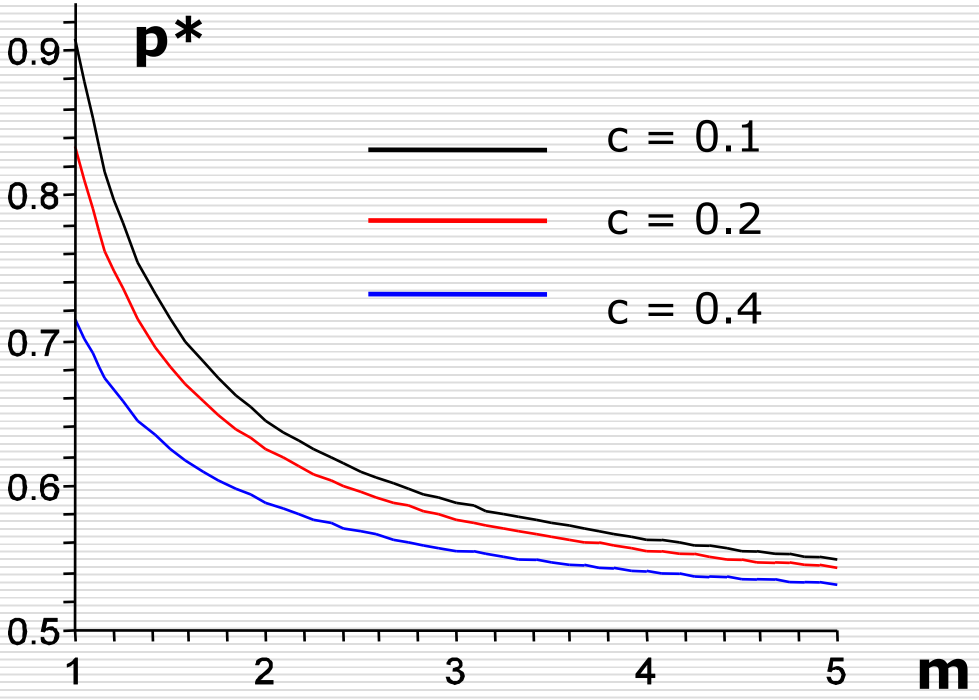
Player 1		**Transmit**	**Wait**
	Transmit	c+m, c+m	0, 1
	Wait	1,0	m, m

- time slots
- A_i = {Transmit, Wait}
- u_i = cost (delay + power) expended prior to start of successful transmission
- m > 1 = contention cost
- c = power expenditure penalty for a transmission

Two asymmetric NEs in pure strategies

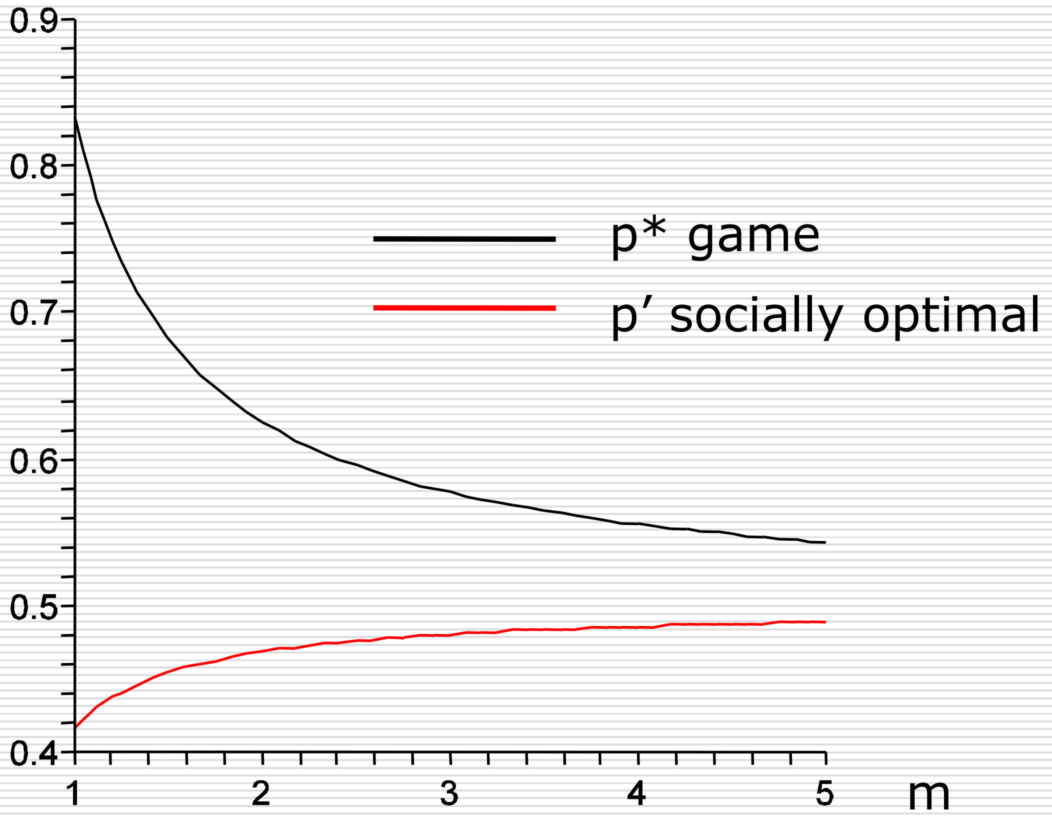
2-Player Wireless-Access Game (cont.)

- Introduce mixed strategies
  - yields a symmetric NE in mixed strategies
  - p* = NE probability of transmitting

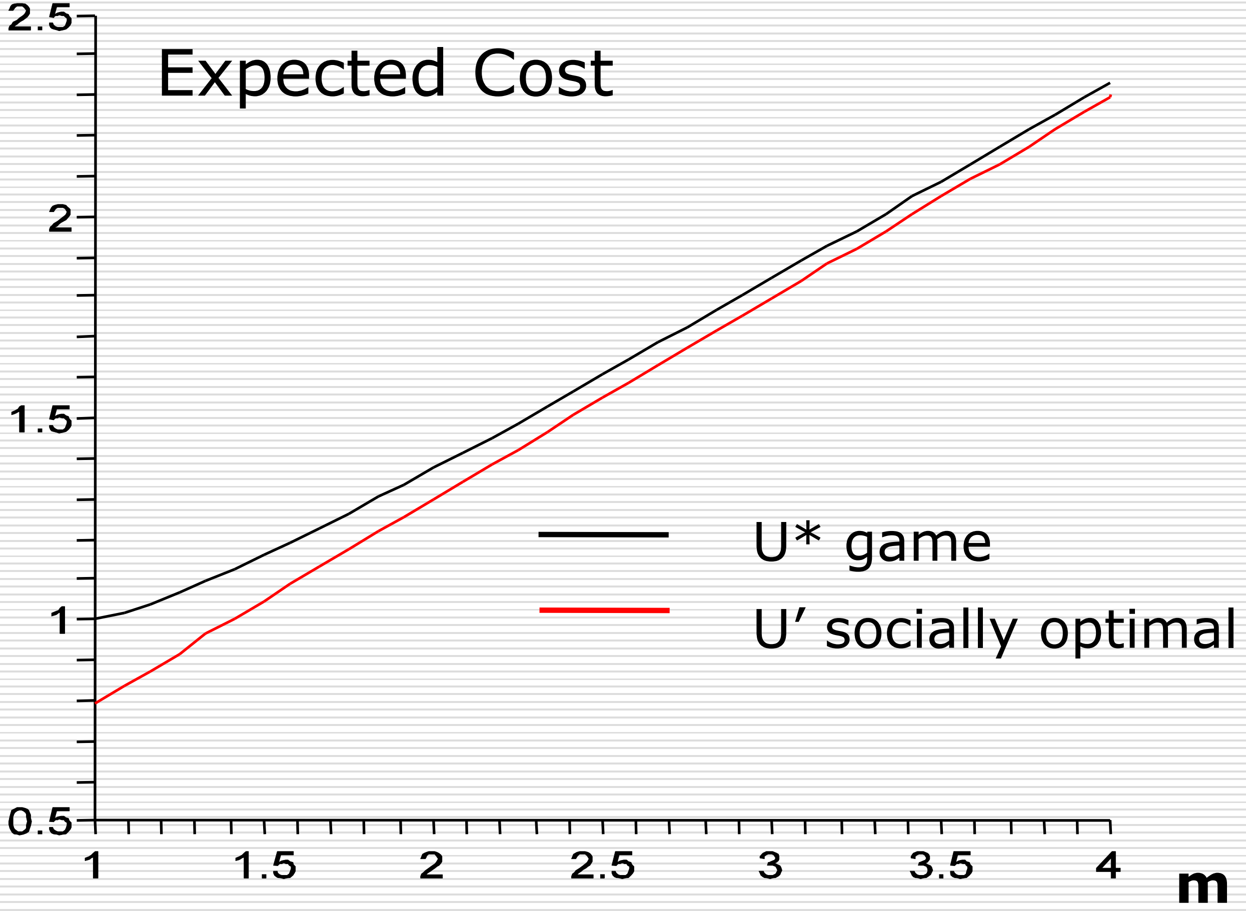


Consider Cost of Non-cooperation

- Choose transmission probability p′ to minimize total expected cost for all players, i.e., **Socially Optimal!**



Cost of Non-cooperation (cont.)



Summary

- Many extensions and variations
  - > 2 players
  - multistage
  - dynamic number of players
  - varying the players' information
- Techniques
  - analytical
  - numerical
  - simulation
- Acknowledge DPS students

References

- D. Fudenberg and J. Tirole, *Game Theory*, The MIT Press, Cambridge, Massachusetts, 1991.
- A. MacKenzie and S. Wicker, "Game Theory and the Design of Self-Configuring, Adaptive Wireless Networks", *IEEE Communications Magazine*, November 2001, pp. 126-131.