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# Mechanism Design for Efficient Decentralized Network Control: Power Allocation in Wireless Networks

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# Why decentralized control?

- complexity
- lack of local information at a central controller
- signaling overhead
- New communication/computing paradigms
  - peer-to-peer computing
  - adhoc nets

# Case Study: Power Control

Why is power control important?

- CDMA, the technology of 3G cellular, is interference limited
- Power employed by a terminal becomes interference to another
- Power control increases the capacity of a CDMA system by limiting interference
- It also extends battery life, which is important to user

# The free market as an algorithm

- A free economic market often produces “efficient” results with little centralized control
- Microeconomic theory and game theory provide a great body of relevant scientific work
- This body can provide a solid foundation for the decentralized control of engineering systems
- Power control among data terminals has been fruitfully formulated as a “game”

# What is a Game?

- A game: each of several players chooses a "strategy" in order to receive a "payoff".
- Payoffs depend on the choices of ALL players
- Each player is "selfish"
- Key solution concept: Nash equilibrium.
  An allocation (a strategy per player) such that no player would gain by unilaterally changing strategy ("deviating")
- Nash equilibria are generally "inefficient"

# Power Control Game

- Players: CDMA data transmiting terminals.
- Strategy: transmission power level
- Payoff : number of bits successfully transmitted per unit energy (bits/Joule)
- Signal-to-interference ratio determines bits/Joule
- A Nash equilibrium generally exists
- Equilibrium power levels are “too high”
- Challenge: how to get selfish terminals to choose lower power levels “on their own”

# Toward efficient decentralization

- To induce lower power levels : "tax" power
  - Original: terminal chooses power $p$ to maximize its "utility" $u(p;I)$ given interference, $I$.
  - New terminal maximizes $u(p;I) - cp$ with $c$ chosen by network administrator
- Problems
  - Resulting allocation is "better" but still inefficient
  - Unnatural restrictions become necessary

# Efficiency via a mechanism

- "mechanism" : a set of procedures, penalties and rewards designed to guide selfish entities toward a desired outcome
- Example: Vickery's Second Price Auction
  - Each player chooses an amount of money to bid for an object and highest bidder gets object
  - But highest bidder pays second-highest bid
  - Each player's best response is to bid its true valuation of object: "truth-telling" is optimal

# A Compensation mechanism

- Proposed by Varian in a general context
- Applies whenever a choice by an entity adversely affects another entity (“externality”)
- Requires a “transferable good”, say money, with which agents compensate each other
- Agents must be “well-informed”; but “naive” agents can reach the desired equilibrium by successive adjustments.
- Agents “fairly” compensate each other at equil.

# Mechanism–Basic Idea

With only 2 terminals, suppose terminal 1 interferes with terminal 2 but not vice-versa. (SIC decoding)

- Terminal 2 declares the amount money (or transferable good) it wishes to charge terminal 1 as compensation for each unit of interference.
- Terminal 1 (interferer) declares the price it offers to pay terminal 2 as compensation.
- The interferer (#1) must pay penalty if its offered price is different from terminal 2's price

# What is the ‘right thing’ to do?

- Because of the interference, terminal 2 suffers a “disutility”; i.e., it transmits fewer bits per Joule.
- This disutility has a value to terminal 2 (in terms of the transferable good)
- This value is the “fair” compensation to terminal 2
- This is exactly what terminal 2 gets at equilibrium.

# Why does the mechanism work?

- To avoid the penalty, generally the interferer will offer to pay the exact amount terminal 2 wants.
- But why doesn't terminal 2 ask "too much"?
- If price paid to terminal 2 exceeds its "true cost", then it "makes a profit" per unit of interference.
- But then, it would want more interference!
- To get the interferer to produce more, terminal 2 must lower its price. At equilibrium, terminal 2 price equals its true cost.

# Two mutually interfering terminals

- Terminal 1 needs to choose three values: $c_{12}^{1}$ : unit compensation to be paid to terminal 2; $c_{21}^{1}$ : unit compensation to be charged to terminal 2; transmission power, $p_1$
- Equivalently, terminal 2 chooses $c_{21}^{2}$, $c_{12}^{2}$ , $p_2$
- "Payoff" to terminal 1:

$$\underbrace{u_1(p_1;p_2)}_{\text{bits/Joule}} + \underbrace{c_{21}^{2}p_2}_{\text{paid BY 2}} - \underbrace{c_{12}^{1}p_1}_{\text{paid TO 2}} - \underbrace{\left(c_{12}^{1}-c_{12}^{2}\right)^2}_{\text{Penalty}}$$

- Terminal 2 faces an identical situation

# Procedure

- Announcement:
  - Terminal 1 announces $c^1_{12}$, $c^1_{21}$.
  - Terminal 2 announces $c^2_{21}$, $c^2_{12}$
- Each terminal chooses its power level to solve

$$\max_{p_i} \underbrace{u_i(p_1;p_2)}_{\text{bits/Joule}} + \underbrace{c^j_{ji}p_j}_{\text{paid BY j}} - \underbrace{c^i_{ij}p_i}_{\text{paid TO j}} - \underbrace{\left(c^i_{12} - c^j_{12}\right)^2}_{\text{Penalty}}$$

- It can be shown that the equilibrium values of this game are efficient ("Pareto optimal")

# Re-cap-1

- Decentralized control may offer many advantages
- Some new communication/computing paradigms are inherently decentralized
- The free economic market is a practical example of decentralized control
- Microeconomics and game theory provide useful analytical and conceptual tools
- Mechanism design can guide selfish entities toward efficient choices in a decentralized fashion

# Re-cap-2

- A mechanism has been applied to power control, but it also applies to many situations
- Each terminals must choose 2 compensation prices:
  - one to be paid out to others
  - one to be charged to others
- At equilibrium, these prices are “fair”
- An adjustment algorithm exists that leads “naive” terminals to the desired equilibrium

THANK YOU!!!

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