

Lecture 7: Approaches to Channel Assignment

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EE529: Simulating Wireless Networks.

Channel Assignment Algorithms

- Several algorithms have been proposed in literature for channel assignment in CRNs, including centralized, distributed and cluster-based.
- Many algorithms follow one of three broad categories:
- Optimization
- Game Theory
- Heuristics



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Optimization Problem Formulation

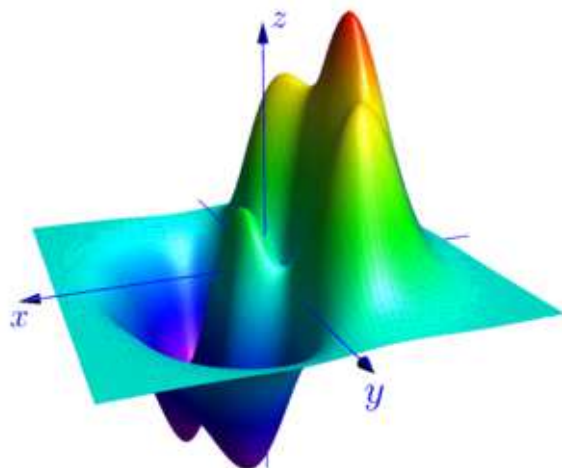
- **Maximize** Objective (or minimize)
 - **Such that** we maintain:
 - Constraint 1
 - Constraint 2
 - Constraint 3
 - etc
- Maximize $f(x, y)$
 - **Such that:**
 - $1 \leq x \leq 4$
 - $-5 \leq y \leq 20$
 - $x \leq 3.5y - 0.5$

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Find Maxima/Minima



Unless both the objective function and the feasible region are convex in a minimization problem, there may be several local minima.

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Example 1

minimize $P(\mathbf{h}_S)$

s.t. $C1: R_i(\mathbf{h}_S) \geq R_{\min} \cap C5, \quad \forall i \in \{1, \dots, n\}$

$C2: \mathbb{E}_{\mathbf{h}_S} [R_i(\mathbf{h}_S)] \geq R_{\min} \cap C5, \quad \forall i \in \{1, \dots, n\}$

$C3: \sum_i^n R_i(\mathbf{h}_S) \geq R_{\min} \cap C5$

$C4: \mathbb{E}_{\mathbf{h}_S} \left[\sum_i^n R_i(\mathbf{h}_S) \right] \geq R_{\min} \cap C5$

where $C5: Pr \{P(\mathbf{h}_S)|h_p|^2 \geq Q_{peak}\} \leq \epsilon$

and $R_i(\mathbf{h}_S) = \log(1 + P(\mathbf{h}_S)|h_{s,i}|^2)$ (16)

where $\mathbf{h}_S = \{h_{s,1}, h_{s,1}, \dots, h_{s,n}\}$ with $h_{s,i}$ the channel gain between the cognitive transmitter and i th cognitive sensor node,

- Minimize transmit power
- Constraints:
- Independent peak rate
- Sum of peak rates
- Independent average rate
- Sum of average rates
- Interference on PU Q_{peak}

Example 2

max $\frac{\sum_{k=1}^K C_k}{p_c + \gamma \sum_{k=1}^K p_k}$

s.t $\sum_{k=1}^K p_k g_{m,k} \leq I_m, \quad \forall m$

$p_k \geq 0, \quad \forall k$

- Maximize ratio of throughput to transmit power
- Constraint the transmit power of the SUs to keep the interference on PU below a certain threshold.
- I_m is the tolerable interference threshold on the m th PU.

Finding the Optimal Solution

- Optimization is best suited for centralized channel assignment, but can be used in other scenarios.
- Can be solved **Analytically**: extensive mathematical analysis.
- Or **Numerically**: A large number of algorithms proposed (see later).
- In numerical methods, it is difficult to distinguish between locally optimal solutions and globally optimal solutions.



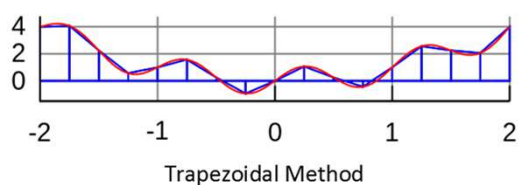
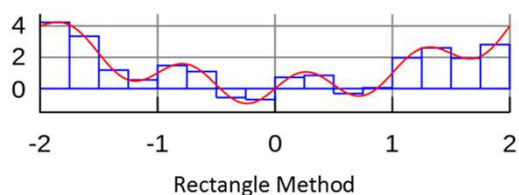
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Similar to...

- Analytical vs. Numerical solution of integrals and differential equations.



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Optimization Numerical Methods

- Linear programming (LP): used when the objective function is linear and the constraints are specified using only linear equalities and inequalities.
- Geometric programming.
- Fractional programming: optimization of ratios of two nonlinear functions.
- Nonlinear programming (NLP): the objective function or the constraints or both contain nonlinear parts.
- Stochastic programming: some of the constraints or parameters depend on random variables.



Iterative/Heuristics Optimization

- Coordinate descent methods
- Quasi-Newton methods
- Evolutionary algorithms
- Genetic algorithms
- Particle swarm optimization
- Simulated annealing
- Stochastic tunneling
- etc



Game Theory

- The channel assignment problem is formulated as strategic interaction between individuals (**players**) in situations called **games**.
- Suitable for cooperative and non-cooperative distributed channel assignment.
- Many optimization methods can be re-formulated into game theory in order to be solved iteratively.
- **Nash equilibrium** is the solution in which each player is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing **only** his or her own strategy.



Classic Games

- Peace war game
- Prisoner's dilemma
- Princess and monster game
- Public goods
- Traveler's dilemma
- Cake cutting
- Diner's dilemma
- Nash bargaining game



Example: Prisoner's Dilemma

- A classic game that shows why two rational individuals might not cooperate, even if it appears that it is in their best interests to do so.
- Problem: Two members of a criminal gang are arrested and imprisoned.
- Each prisoner is in solitary confinement with no means of communicating with the other.
- The prosecutors lack sufficient evidence to convict the pair on the principal charge.
- They can, however, get both sentenced to a year in prison on a lesser charge.



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Reward/Punishment

- The prosecutors offer each prisoner a bargain. Each prisoner is given the opportunity either to: betray the other (**defect**) by testifying that the other committed the crime, or to remain silent (i.e., **cooperate** with the other gang member).
- If A and B each betray the other, each of them serves 2 years in prison.
- If A betrays B but B remains silent, A will be set free and B will serve 3 years in prison (and vice versa)
- If A and B both remain silent, both of them will only serve 1 year in prison (on the lesser charge).



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Payoff Matrix

Canonical Prisoner's Dilemma payoff matrix

	Cooperate	Defect
Cooperate	Reward = -1, Reward = -1	Sucker = -3, Temptation = 0
Defect	Temptation = 0, Sucker = -3	Punishment = -2, Punishment = -2

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Player Strategy

- Defecting offers a greater payoff than cooperating.
- All purely rational self-interested prisoners would betray the other.
- So, pursuing individual reward logically leads both of the prisoners to defect (called **dominant strategy**).
- If both pursue cooperation (both keep silent) both would get a better reward.

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Useful in Economic Theory

- Mutual defection is the only strong **Nash equilibrium** in the game (i.e. the only outcome from which each player could only do worse by unilaterally changing strategy).
- The dilemma then is that mutual cooperation yields a better outcome than mutual defection but it is not the rational outcome because from a self-interested perspective, the choice to cooperate, at the individual level, is irrational.



Heuristics

- A heuristic is any algorithm which is not guaranteed (mathematically) to find the solution, but which is nevertheless useful in certain **practical** situations.
- Heuristics make few or no assumptions about the problem being optimized.
- Heuristics are used to find approximate solutions for many complicated optimization problems.
- Intuition and logical thinking is utilized more than mathematical analysis.
- Examples include contention resolution (CSMA/CD & CSMA/CA), and papers #1 & #2.

