Lecture 7: Approaches to Channel Assignment

Dr. Mohammed Hawa
Electrical Engineering Department
The University of Jordan

EE529: Simulating Wireless Networks.

Channel Assignment Algorithms

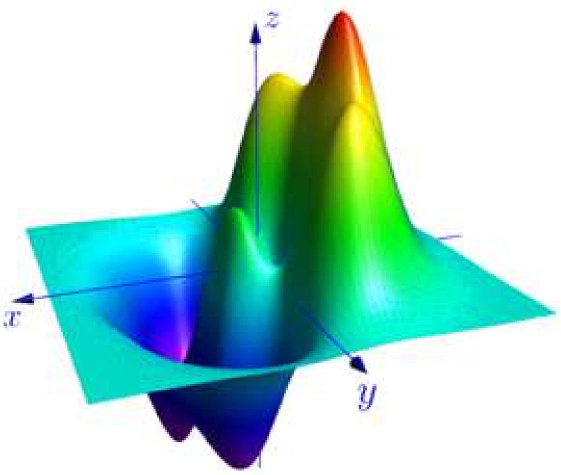
- Several algorithms have been proposed in literature for channel assignment in CRNs, including centralized, distributed and cluster-based.
- Many algorithms follow one of three broad categories:
- Optimization
- Game Theory
- Heuristics

Optimization Problem Formulation

- **Maximize** Objective (*or* minimize)
- **Such that** we maintain:
- Constraint 1
- Constraint 2
- Constraint 3
- etc

- Maximize $f(x, y)$
- **Such that**:
- $1 \leq x \leq 4$
- $-5 \leq y \leq 20$
- $x \leq 3.5y - 0.5$

Find Maxima/Minima



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

Example 1

$$\begin{aligned}
&\text{minimize} \quad P(\mathbf{h_S})\\
&\text{s.t.} \quad C1: \quad R_i(\mathbf{h_S}) \geq R_{\min} \cap C5, \quad \forall i \in \{1,\dots,n\}\\
&\qquad C2: \quad \mathbb{E}_{\mathbf{h}_S^2}\left[R_i(\mathbf{h_S})\right] \geq R_{\min} \cap C5, \quad \forall i \in \{1,\dots,n\}\\
&\qquad C3: \quad \sum_i^n R_i(\mathbf{h_S}) \geq R_{\min} \cap C5\\
&\qquad C4: \quad \mathbb{E}_{\mathbf{h}_S^2}\left[\sum_i^n R_i(\mathbf{h_S})\right] \geq R_{\min} \cap C5\\
&\text{where } C5: \quad Pr\left\{P(\mathbf{h_S})|h_p|^2 \geq Q_{peak}\right\} \leq \epsilon\\
&\quad \text{and} \quad R_i(\mathbf{h_S}) = \log\left(1 + P(\mathbf{h_S})|h_{s,i}|^2\right) \qquad (16)
\end{aligned}$$

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 ith 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

$$\begin{aligned}
\max \quad & \frac{\sum_{k=1}^{K} C_k}{p_c + \gamma \sum_{k=1}^{K} p_k}\\
\text{s.t} \quad & \sum_{k=1}^{K} p_k g_{m,k} \leq I_m, \quad \forall m\\
& p_k \geq 0, \quad \forall k
\end{aligned}$$

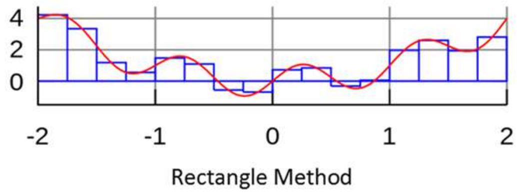
- Maximize ratio of throughput to transmit power
- Constraint the transmit power of the SUs to keep the interference on PU below a certain threshold.
- I_m is the tolerable interference threshold on the *m*th PU.

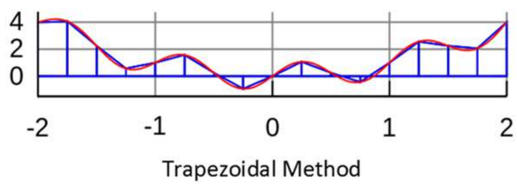
Finding the Optimal Solution

- 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.

Similar to…

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





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.

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).

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*

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.

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).

