An Introduction to Network Games

Hoang D. Le

Computer Communications Laboratory

The University of Aizu, Japan

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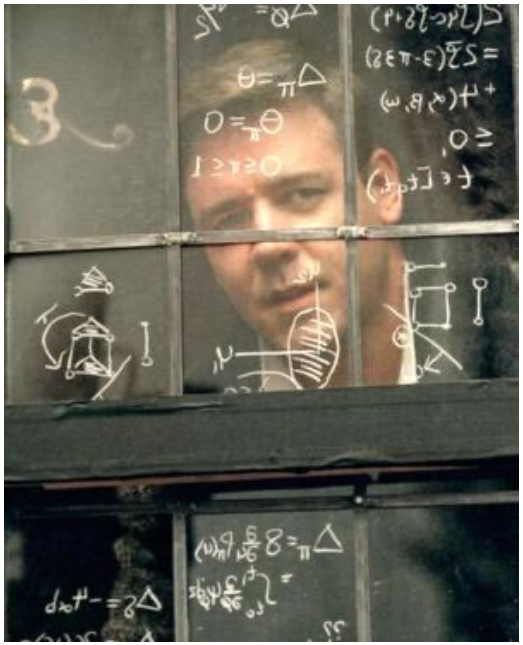
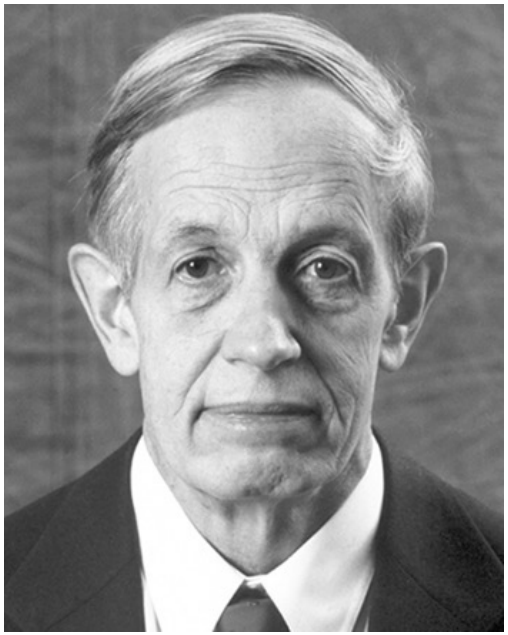
"A Beatiful Mind" (2001)

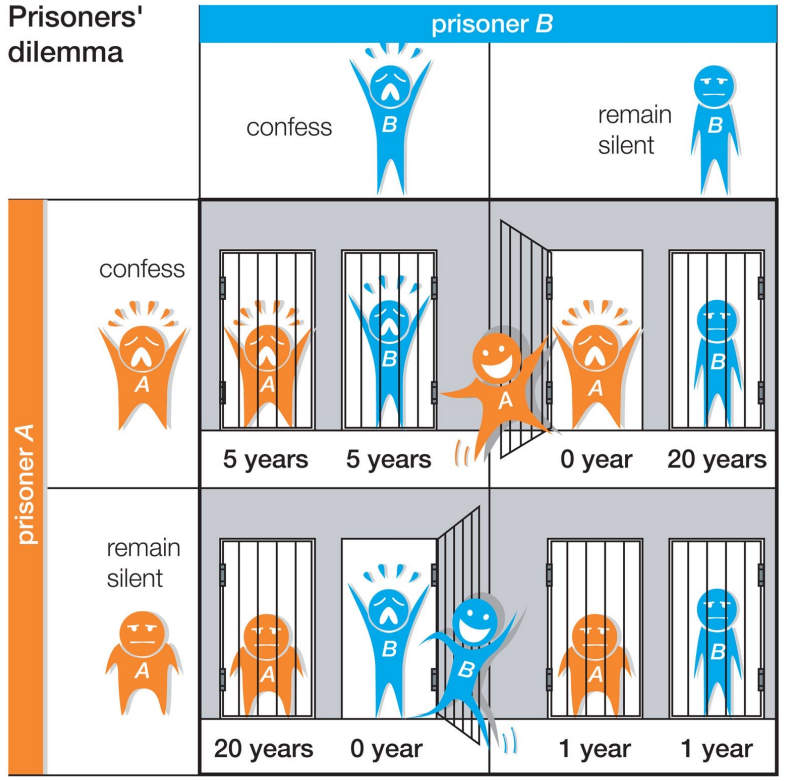
- An interesting film telling about John Nash who developed a key concept of Game Theory (Nash equilibrium) which initiated many subsequent results and studies





Prisoner's Dilemma: A typical example in Game Theory

- Two suspects in a major crime held for interrogation in separate cells
  - If they both stay quiet, each will be convicted with a minor offence and will spend **1 year** in prison
  - If one and only one of them confesses, he will be freed and used as a witness against the other who will spend **20 years** in prison
  - If both of them confess, each will spend **5 years** in prison



Outline

- Background of Game Theory
- Game Models

Why is the Game Theory?

- Traditional Network Optimization
  - Focus on a single control objective in a network populated by obedient users and limited dispersion of information

$$\begin{aligned} \text{minimize} \quad & \sum_i u_i(x) \\ \text{subject to} \quad & x \in X \subset \mathbb{R}^n. \end{aligned}$$

- Challenging Issues
  - Large-scale with lack of access to centralized information
  - Consist of users with diverse requirements, and subject to dynamic changes
- These challenges make Game Theory natural tool for the analysis of large-scale networks

What is the Game Theory?

- It is a branch of applied mathematics used for describing and analyzing the strategic interaction among multiple decision-makers
- Strategic interation activities are refered to as games where each decision-maker chooses the action that
  - will give maximum possible outcome for self
  - at the same time predicting the rational decision taken by others
- Two views of game theory
  - As an analysis tool: model of a strategic situation and study what situation we will end up with having
  - As a control tool: development of a control mechanism that leads to a "good" conclusion

Fundamentals of Game Theory (1)

A game consists of

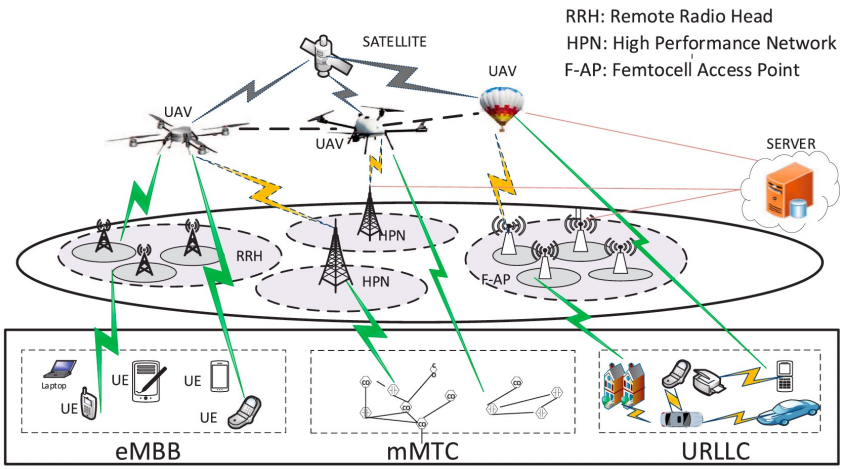
- At least two players
- A set of strategies for each player
- The payoff for the players

- Players
  - Entities or individuals who make decisions and perform the actions
- Strategies
  - actions which a player choose to follow
- Payoff
  - a reward is what a specific player receives at the end of the game
  - this reward is constrained by the decisions of other players

Fundamentals of Game Theory (2)

An example of UAV-based wireless networks

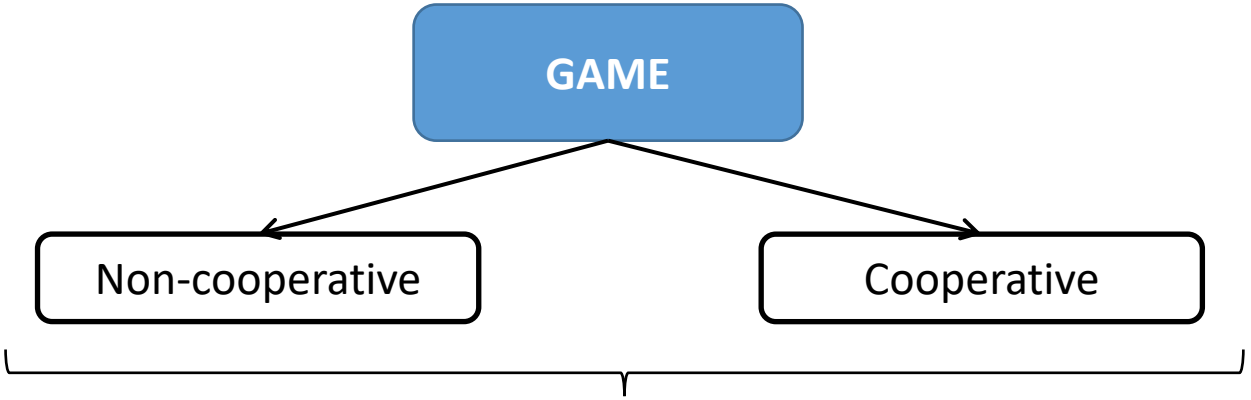
Game Component Set	Elements of a UAV wireless network	Comments
Players	UAV/drones and ground nodes	Players are assumed to be rational nodes aiming to maximize their utility function
Strategies	Beaconing periods scheduling, task servicing, relocating UAV coordinates, offloading or not offloading data, choosing the right channel, and evading an intruder	Action related to the functionality being studied.
Payoffs function	Performance metrics such as throughput, delays, encounter rates with ground node, number of nodes covered, and signal to noise ratio,	The players' objective which measures the outcome for the players strategies



Scenario examples of the UAV applications in 5G wireless communications networks

Source: *2019. A survey of Game Theory in Unmanned Aerial Vehicles Communications*

Game Models



- Non-cooperative:
  - the modeling unit is the individual player, including her/his knowledge about the game status, expectations, and possible static strategies
- Cooperative:
  - the modeling unit is a group of several players sharing a common goal but in competition with other groups

Non-Cooperative Model(1)

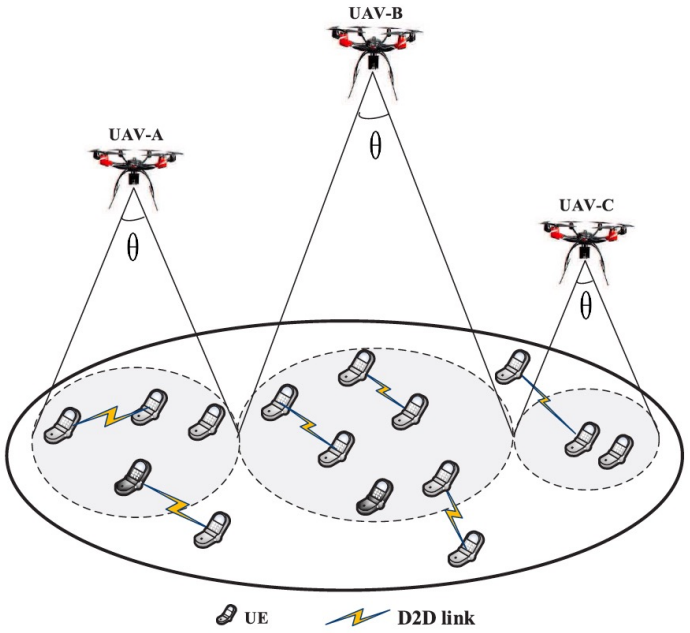
- The main goal of this model is to evaluate whether there exists a reasonable solution for that game
- This solution implies a set of strategies that the players would rationally select for maximizing their own payoff
- A well-known solution concept for this model is Nash equilibrium
  - it is a set of strategies for the players such that no player has any intention to change his/her strategy to gain a higher payoff given that none of the other players changes his/her strategy

Non-Cooperative Model(2)

Example of optimal height and coverage

- if UAVs are approproately positioned, the number of UAVs required to provide coverage can be significantly reduced
- proper mechanisms are needed for positioning of UAVs to provide maximum coverage to the ground nodes with satisfactory quality

Non-cooperative game is used to find the optimal positions of UAVs



Source: *2019. A survey of Game Theory in Unmanned Aerial Vehicles Communications*

Cooperative Model(1)

- The main aim behind this model is that several players share a common objective and they can do better as a group than working alone
- Players can coordinate strategies and agree on how the total payoff is to be divided among players in a coalition
- Nash bargaining is one of typical solution of this model
  - players maximize the product of their gains given what each player would receive without cooperation

$$\mathbf{s}^* = \arg\max_{\mathbf{s}} \prod_{i \in \mathbb{I}} (u_i(s_i) - u_i^{\mathrm{d}})$$

where $u_i(\cdot)$ is the payoff function of player i, s_i is a strategy of player i, and $\mathbf{s}^*$ is a Nash bargaining solution strategy vector of all players, and u_i^{d} is the threat point (i.e., the utility gained if player i decides not to cooperate and bargain with the other players).

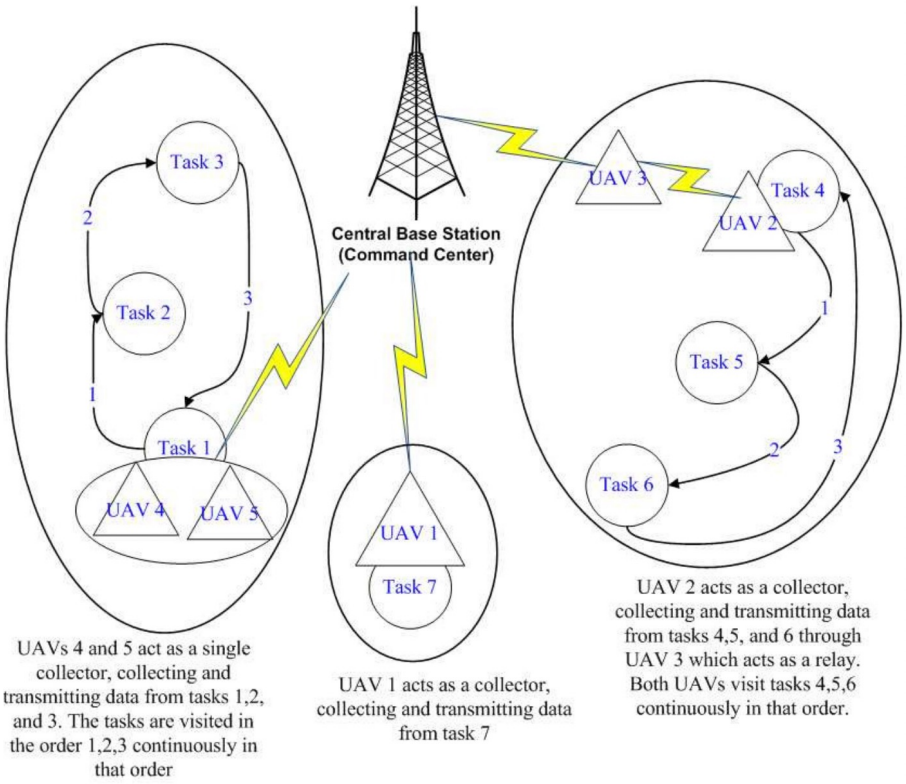
Source: *2011. Game Theoretic Approaches for Multiple Access in Wireless Networks: A Survey*

Cooperative Model(2)

Example of task allocation among UAV-assisted networks

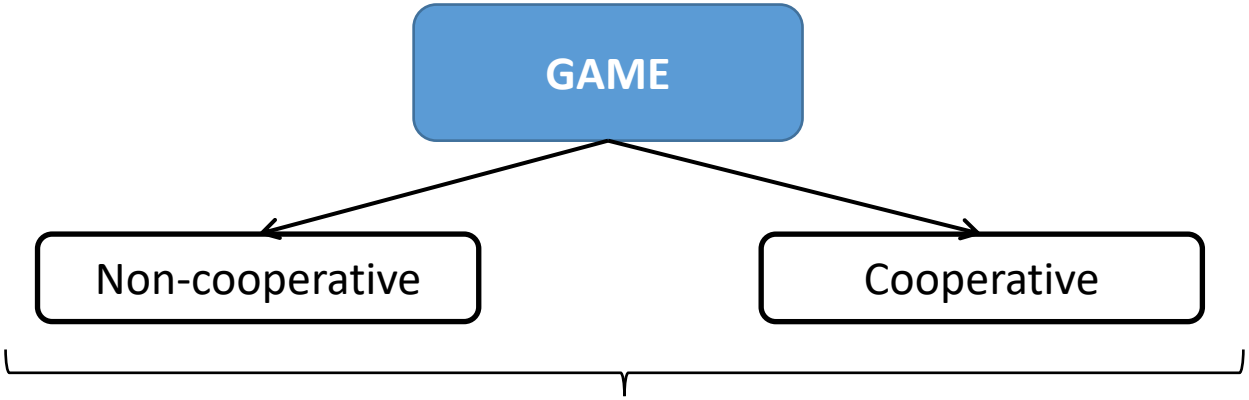
- a number of UAVs controlled by a BS and belonging to a single operator are required to collect data from arbitrarily located areas
- tasks represent queues of data packets that need collection and transmission by a UAV to BS

Game theory was applied and yields a better performance of more than 30.26 % on average compared to equal allocation of task strategy



2009. A Selfish Approach to Coalition Formation among Unmanned Air Vehicles in Wireless Networks

Game Models: Further Classifications



Strategy

- **Static game**: an one-short game where all players make decisions without the knowledge of the strategies that are being chosen by other players
- **Dynamic game**: a player chooses an action in the current stage based on the knowledge of the actions chosen by other players in current or previous stages
- **Repeated game**: a special kind of dynamic game where the same set of players plays the same stage game or one-shot game repeatedly over a long time period

Information

- **Complete game**: payoffs and strategies of the players are observable to all players
- **Incomplete game**: information is unknown by other players

Thank you for your listening!