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Game Theoretic Approaches to Modelling Cooperative and Competitive Dynamics for Enhanced Routing and Resource Allocation

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Abstract*: The goal of the field of game theory is to simulate scenarios in which decision-makers must choose between courses of action that may or may not conflict and in which the choices made by one element may affect the choices made by other elements. Techniques from game theory have been widely used to solve a variety of engineering design issues. Game theory may be applied to wireless networks to create cooperative strategies between nodes, terminals and network providers, among other organizations. The majority of the time, game theory has been used in networking to address routing and resource allocation issues in competitive settings. Because radio communication channels are typically shared in wireless networks, the actions of one wireless device may have an impact on the communication capabilities of a neighboring device. Game theory may be used to simulate situations such as these. A multi-layered viewpoint is presented in Applications of Game Theory in Wireless Networking, highlighting the domains in which game theory might find practical application. This explains how different wireless network interactions may be represented as games and how game-theoretical methods can accurately mimic or forecast genuine user behavior in cooperative or competitive settings. Because of these similarities, it is possible to grasp the intricate relationships between nodes in this highly dynamic and dispersed environment by using a strong mapping between classical game theory components and network parts*

Keywords: Game theory, wireless networks, physical layer, SINR, resource allocation, power control, spectrum management, FDMA, jamming game

I. INTRODUCTION

A mathematical technique for forecasting how people would act in strategically placed multiplayer games is called game theory. According to game theory, each player makes logical assumptions about what their other players (or associates) will do and then selects a response to those tactics in order to maximize its own rewards.[2]. Game theory presupposes that play will reach (or converge to) an equilibrium under the rationality assumption.

Rationality:

In the terminology of Game Theory, rationality indicates that each player seeks to maximize his or her payout regardless of what other players are doing[2][4]. In essence, each player must decide on a sequence of plays that are consistent with the game's rules and maximize his or her benefits.

Game Theory can be classified in two branches

Non co-operative game theory : In this game, every player operates on their own, trying to maximize their personal reward without explicitly collaborating or interacting with other players. The players decide what to do depending on their own plans and interests, which frequently results in aggressive conduct. Concepts like as Nash equilibrium, in which each player's approach is optimum given the strategies of others, are commonly used to represent non-cooperative games. When evaluating scenarios like competitive market scenarios or resource allocation in wireless networks, where entities have opposing interests and must strategy accordingly, this kind of game theory is helpful.

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Co-operative game theory: Cooperative game theory, on the other hand, enables players to organize into coalitions and cooperate to accomplish win-win situations. By negotiating and drafting legally binding agreements to share resources or prizes, players can develop a group strategy that can increase the group's total payout. Cooperative game analysis frequently makes use of ideas like the negotiating solution, Shapley value and the core. This method is especially helpful in situations where teamwork can produce better results and efficiency, such cooperative communication systems in wireless networks or network routing protocols. Understanding how to equitably allocate the rewards of collaboration among participants and how to promote cooperation are made easier with the aid of cooperative game theory.

Game Theory has found applications in Economic, Evolutionary Biology, Sociology, Political Science etc, now Its finding applications in Computer Science.

Game theory is the study of decision-making under con-icting interests. When the actions undertaken by a decision-maker affects the considerations of other 'players' there is a mathematical procedure to and the overall 'best choices' and also the rational choices from each player's perspective. Oftentimes, they dier; the overall best is never achieved because it it does not seem rational from an individual perspective. These insights are highlighted by game theory thanks to its simple rules. Although simple, game theory analyses are an essential part of modern decision-making. Today, agreements such as the Kyoto protocol (on reducing the climate footprint worldwide) undergo game theory analysis. Economy, negotiation, trade, resource management, ecology and physics are just some examples of applications of the modern game theory that was formalized during the 20th century. (Mazalov, 2014)

Components of game:
A game has the following

Set of players	$D = \{ P_i \mid 1 <= i <= n\}$
Set of rules	R
Set of Strategies	S_i for each player P_i
Set of Outcomes.	O
Pay off	$u_i(o)$ for each player i and for each outcome o *e* O

1.2 Example 1{*Coin Matching Game*}

Coin Matching Game : Two players choose independently either Head or Tail and report it to a central authority[6]. If both choose the same side of the coin , player 1 wins, otherwise 2 wins.

A game has the following :-

1. **Set of Players**.

Coin Matching Game form the set of players i.e. P={P1,P2}

2. **Set of Rules**: R

Each player can choose either Head or Tail. He has to act independently and made his selection only once. Player 1 wins if both selections are the same othrwise player 2 wins. These form the Rule set R for the *Coin Matching Game*.

3. **Set Strategies**: S_i for each player P_i

For example in Matching coins $S_1 = \{ H, T\}$ and $S_2 = \{H,T\}$ are the strategies of the two players. Which means each of them can choose either Head or Tail.

4. **Set of Outcomes**: O

In matching Coins its {Loss, Win} for both players. This is a function of the strategy profile selected.

In our example $S_1 \times S_2 = \{(H,H),(H,T),(T,H),(T,T)\}$ is the strategy profile.

5. **Pay off** :$u_i(o)$ for each player i and for each outcome o *e* O

In general its different for different players.

Let the payoffs in *Coin Matching Game* be,

$u_1(Win) = 100$

$u_1(Loss) = 0$ similar for u_2

Solving and analyzing the games

A. Iterated Dominance

Once the game is expressed in strategic form, it is usuallyinteresting to *solve* it. Solving a game means predicting thestrategy of each player, considering the information the gameoffers and assuming that the players are rational[1][7]. There areseveral possible ways to solve a game; the simplest oneconsists in relying on *strict dominance.*

Strategy S **strictly dominates** a strategy T if every possible outcome when S is chosen is better than the corresponding outcome when T is chosen.

Dominance Principle

Rational players never choose strictly dominated strategies.

Idea: Solve the game by eliminating strictly dominated strategies!

iterated removal

Example packet forwarding game in network layer[1].

Limitation :

Removal of strictly dominates strategies does not always work.Consider a game :

	A	B	D
A	12	-1	0
C	5	2	3
D	-16	0	-1

Rows=Player1 set of strategies{A,C,D}

Columns = Player2 set of strategies{A,B,D}

NEITHER PLAYER HAS DOMINATED STRATEGIES HERE!

B. Weakely dominance:

B weakely dominates A : There is atleast one set of opponent's action for which B is superior and all other sets of opponent's action gives B atleast the same payoff as A.

One can perform an elimination based on iterated weak dominance, which results in a strategic profile.

JAPANESE

KENNEY		North	South
	North	2 , -2	2 , -2
	South	1 , -1	3 , -3

C. Mixed strategies:

Each player associates a probability distribution over its set of strategies

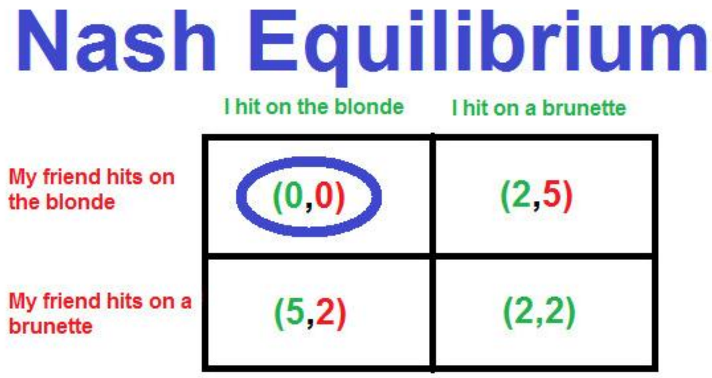
Payoffs are computed as expectations.

We should players choose prob. distribution that cannot be exploited by other player i.e.payoff should be equal independent of the choice of strategy of other player.

D. Nash theorem:

An outcome o* of a game is a NEP (Nash equilibrium point) if no player can unilaterally change its strategy and increase its payoff.

Every two person game has *at least one* equilibrium in either pure or mixed strategies.



II. GAME THEORY IN NETWORKING

Game theory techniques have widely been applied to various engineering design problems. In the context of wireless networks, game theory may be used as a tool for forming cooperation schemes among entities such as nodes, terminals or network providers[8].

This describe how various interactions in wireless networks can be modeled as a game and how game-theoretic solutions may effectively predict/simulate realistic user behaviour in competitive or cooperative scenarios.

2.1 LAYERED PERSPECTIVE

2.1.1 PHYSICAL LAYER:

Performance is often determined by the estimated signal-to-interference and noise ratio (SINR) that players or nodes receive. This leads to an interactive decision-making process at the physical layer.Game theory may be used to solve allocation issues involving resources like electricity and spectrum in this context[6].For instance, we may create a non-cooperative game to manage frequency allocation in frequency control within an FDMA (Frequency Division Multiple Access) system. The jamming game, a zero-sum game in which the gain of one player equals the loss of the other, is a simpler form of this concept. Nodes fight for frequencies in this situation, and the main tactics are to minimize interference and maximize signal quality. A mixed strategy Nash equilibrium may be used to find the solution to this game, in which each node probabilistically chooses its transmission method to maximize its performance in spite of any external interference.

2.1.2 DATA LINK LAYER

Game theory applications regarding the data link layer involve the medium access control problem. In these games, selfish users seek to maximize their utility by obtaining an unfair share of access to the channel. Multiple Access Game[1], introduces the problem of medium access. Suppose that there are two players $p1$ and $p2$ who want to access a shared communication channel to send some packets to their receivers $re1$ and $re2$. We assume that each player has one packet to send in each time step and he can decide to access the channel to transmit it or to wait. Assume that $p1$, $p2$, $re1$ and $re2$ are in the power range of each other, hence their transmissions mutually interfere.

2.1.3 NETWORK LAYER

It does establishment of routes and the forwarding of packets along those routes. Game theory may be applied to aid a node in determining which the optimal route is or deciding whether it should forward a received packet or not.

In the game called the Forwarder's Dilemma[1][7],we assume that there exist two devices as players, $p1$ and$p2$. Each of them wants to send a packet to his destination6,$dst1$ and $dst2$ respectively, in each time stepusing the other player as a forwarder.

If player $p1$ forwards the packet of $p2$, it costs player$p1$ a fixed $cost$ $0 < C <<1$, which represents theenergy and computation. Each player is tempted to drop the packet heshould forward, as this would save some of his resources;but if the other player reasons in the same way, then the packet that the first player wanted to send will also be dropped. They could, however, do better by mutually forwarding each other's packet. Hence the dilemma.

2.1.4 TRANSPORT LAYER:

At the transport layer, game-theoretic models have been mainly developed to analyze the effectiveness of congestion control .Congestion avoidance control refers to controlling the load of the network by restricting the admission of new user's sessions and resolving the unwanted overload situations.Admission control takes place each time a new session request is received and decides whether it should be allocatedresources or be rejected due to lack of resources.Its basic goal in cellular networks is to control the admissionof new sessions within the network with the goal of maintaining the load of the network within some boundaries.

Example

1. Provider v/s Provider:
In this kind of games the networks constitute the players.
As individual players in the game, the access networks
will try to choose the request that best fits their characteristics[8].
2. Customer v/s Provider:The main goal of such schemes is to maximize not only the QoS offered to customers, but also the provider's gain,therefore balancing the interests of both parties[8].

2.2 Challenges in the use of game theory

The use of game theory in wireless networks unfortunately comes with a set of challenges, the most important of which are the following ones:

2.2.1 Assumption of rationality

Game theory is founded on the hypothesis that eachplayer plays rationally and thus seeks his best interestin a rational manner. When dealing with nodes or terminal showever this behavior cannot be always guaranteed.

2.2.2 Assumption of willingness to cooperate

In cooperative games it is assumed that players will collaborate in order to maximize their profits. A significant problem is that players sometimes choose to behave selfishly or even cheat in order to optimize their own profit. For this reason, in certain occasions, incentive mechanisms for cooperation, as well as disincentives against cheating need to be formulated.

2.2.3 Not guaranteed existence of equilibrium

In game-theoretic formulations an analysis is often required to check if they reach a nash equilibrium. Evenif an equilibrium is reached however, the existence of multiple equilibria is not always excluded. In such casethe most efficient and stable one has to be sought.

2.3 FUTURE SCOPE

Advanced Techniques for Cooperation:

Enhancing cooperative game models with greater complexity in order to maximize network performance. This involves developing innovative algorithms for resource sharing, coalition development and equitable benefit distribution among collaborating entities. Looking at the application of cooperative game theory to new network paradigms, such 5G and beyond, where effective cooperation mechanisms are needed because of dense networks and diverse devices.

Combining Machine Learning with Integration:

Using machine learning and game theory to enable flexible and wise decision-making in wireless networks. This might entail utilizing reinforcement learning to dynamically modify methods according on past data and current network circumstances. Utilizing computer learning to forecast network circumstances and user behavior, improving the precision and efficiency of game-theoretic models.

Privacy and Security:

Investigating game-theoretic methods to improve wireless network security and privacy. Creating plans to counteract risks like eavesdropping, jamming and illegal access is part of this. Looking at how game theory may be used to ensure safe cooperation between network nodes while protecting user privacy.

Resource Distribution in Edge Computing and IoT:

Maximizing resource allocation using game theory in edge computing and Internet of Things (IoT) contexts, where several devices vie for few resources.

Creating game-theoretic frameworks to control how edge devices and cloud services interact, guaranteeing equitable and effective resource allocation.

Adaptive Spectrum Distribution:

Building on game-theoretic models, dynamic spectrum sharing aims to decrease interference in wireless networks and increase spectrum efficiency. This involves investigating novel approaches for cooperative spectrum access and spectrum auctions.

Examining how regulatory actions affect game-theoretic spectrum sharing models and making suggestions for policy based on theoretical conclusions.

Virtualization with Network Slicing:

Network slicing and virtualization in next-generation networks are managed through the use of game theory, allowing numerous virtual networks to coexist and effectively share physical network resources. Constructing models to handle the issues of dynamic reconfiguration, quality of service (QoS) assurances and resource separation in virtualized settings.

Energy Effectiveness:

Concentrating on game-theoretic approaches to increase wireless network energy efficiency, especially for battery-constrained devices and green networking projects.

Looking into cooperative energy-saving techniques amongst network nodes to prolong battery life and lessen wireless network's negative environmental effects.

2.4 CONCLUSION

Using a layered approach, we have shown in this study how game theory may be applied to networking. We have outlined how game-theoretic formulations of networking issues might be used to capture them, emphasizing the ideal kind of game for each application domain and how to build the utility functions that go along with it.

This work aimed to provide the fundamentals of cooperative and non-cooperative game theory in the context of computer science. We think that the creation and examination of network protocols greatly benefit from the use of game theory. Game theory is a potent conceptual and analytical tool that may be used to generate deeper insights and better solutions when applied to the analysis of real-world problems.

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