A Survey of Game Theoretical Approach in Cognitive Radio Network and 5G-6G Communications

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Abstract —The development of telecommunications, especially wireless communication, requires data transmission at high speed and wide bandwidth to support 5G-6G communication services. For this reason, it is necessary to have a network with adaptive capabilities in managing and improving performance parameters independently through an intelligent radio network system or better known as Cognitive Radio Network (CRN). The use of CRN in several implementations such as Cognitive Radio Ad Hoc Network (CRAHN), Cognitive Radio Vehicular Ad Hoc Networks (CR-VANET), Intelligent CRN and even 6G-CRN has also been widely used. Another method that is also used to optimize system performance independently is through the Game Theory (GT) approach. Game theory can be implemented on CRN as well as on 5G-6G communications. The use of GT in the CRN system provides improvements in terms of increasing system performance such as reducing interference and bit error rate (BER), increasing throughput and Signal to Interference plus Noise Ratio (SINR), power efficiency, increasing utility and resource capacity and being able to achieve convergence or reach the Nash equilibrium state more rapidly. Meanwhile, the use of GT in 5G-6G communication and other technologies are related to the power control, resource allocation, spectrum sharing, channel estimation, channel selection and Quality of Service (QoS) or Quality of Experience (QoE). In general, the use of GT can help to improve the overall performance of a system.

Index Terms—5G-6G communications, cognitive radio network, game theory, Nash equilibrium, SINR

I. Introduction

Wireless communication development requires high-speed data transmission, a large amount of bandwidth, and the ability to support services with varying levels of Quality of Service (QoS) in environments with high mobility. As it is known that the bandwidth is proportional to the data rate, where the wider the bandwidth, the higher the data rate. Due to the limited nature of bandwidth, spectral efficiency in bandwidth utilization is required. The maximum use of the frequency spectrum often affects interference between users, so we need a technology that can provide high bit rates, namely Multi Carrier Modulation (MCM). The principle of MCM is to divide the channel bandwidth into several subchannels. A form of MCM known as Orthogonal Frequency Division Multiplexing (OFDM) provides advantages such as high bandwidth spectrum efficiency, resistance to inter-symbol interference (ISI), and ease of data recovery through channel estimation methods [1].

To reduce spectrum usage density, we need a spectrum utilization technique that is not used by the Primary User (PU), but is used by the Secondary User (SU), thereby increasing the utility of the overall frequency spectrum usage. This concept is embodied in cognitive radio (CR) technology, also referred to as intelligent radio (smart radio). Additionally, cognitive radio can be integrated into an adaptive system, allowing it to be applied to a variety of operational parameters, including the frequency spectrum, transmit power, and modulation scheme [2]. Homogeneous and heterogeneous network technologies get more benefit from the use of cognitive radio networks (CRN) in the development of cellular communications.

The choice of game theory method is actually more motivated by the conflict between users who are self-organized in non-cooperative power control. Game theory is in accordance with the character of users who are distributed, self-organized and non-cooperative. Characteristics of non-cooperative game that applies strategic methods to users without having to get global information from all users, suitable if applied to femtocell networks with user characteristics as mentioned. Related to previous research that basically applied game theory also uses many players with incomplete information, this is because the players do not coordinate with each other and are not cooperative in strategy selection [3]. The implementation of the strategy method in this study was carried out at the user level and in the uplink direction. This is because strategy selection is more needed by users with mobility properties, so it is necessary to adjust parameters dynamically and independently.

In addition, because every user has the same goal, which is selfishly wanting to meet the SINR target which can result in harming other users, so a game theory method is needed for the user's independent strategy selection. Therefore, a research survey on the use of game theory approaches in CRN and 5G-6G communication systems is important and necessary to determine the effect of using the GT method on several wireless communication technologies.

This study gives a significant contribution by providing a comprehensive review of game theory applications in Cognitive Radio Networks and 5G

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communication, as well as an overview of previous performance in 4G communication (long term evolution, LTE) and for future implementations specifically in 6G communication and other implementations such as Machine Learning (ML), Blockchain (BC), and TeraHertz (THz) communications.

II. Game Theory

A. Why Game Theory?

Some theories like Selectorate theory [4] and Deterrence theory [5] only suitable for centralized, cooperative, or extensive systems [6]. Selectorate theory is widely used in political systems, where in the selectorate there will be several groupings of users, namely resident, selectorate and winning coalition which is then led by the leader. This condition is only suitable for systems that are centralized (centered on the leader of the winning coalition) and cooperative games. Meanwhile, Deterrence theory is applied to the defense system [4]. Deterrence is known as a situation where one party tries to prevent the other party from taking an action that has not been done. Literally, deterrence is a deterrence, rejection or prevention, which in this case is a strategy to prevent war by distracting the opponent (the other party) who tries to attack. The main goal is to convince the other party that the losses incurred due to war will far exceed the expected gains. Deterrence is a form of persuasion in military strategy. The strategy is a protection strategy, not only protecting the composition contained within the geographical boundaries of a country's sovereignty, but also preventing the opponent's attack on the alliance. There are several characteristics of deterrence theory that make this theory unsuitable to be applied to wireless communication systems, especially in the context of data transmission, namely extensive-form games, where this method is not suitable for femtocell networks that use Non-cooperative games. Deterrence theory also cannot be justified as a rational strategy [5]. Both of these theories are not suitable for use in wireless communication systems, especially for femtocell users who are self-organized with rational strategies. This has prompted research on game theory methods in economic theory when applied to cognitive femtocell networks for users with distributed, self-organized and non-cooperative characteristics.

B. Game Theory Concept

Game theory using mathematical approach that was developed to better understand competitive situations and how rational decision makers, in this case players or users, interact to accomplish goals. Because the fundamental concept of game theory is rationality, players will make decisions based on their interests [7]. The theory of rationality is based on two components, namely a group of actions or strategies in the same environment that are accessible to the decision maker, as well as the decision maker's specification of his or her preferences. According to rational choice theory, an action chosen by a decision maker is at least as good in terms of one's own preferences as it is in terms of the others preferences [8].

Game theory is used to find the best strategy in an activity. Each player in game theory is equally eager to achieve the highest utility competitively. The purpose of using game theory is to win the competition. One of the benefits of game theory is able to evaluate the optimization algorithms and help in selecting parameters that will make the game stable. There are numerous game models in game theory, and the model chosen is determined by the nature of the problem and its characteristics [9].

A game theory model has basic components in resolving a competition. Three major components comprise the game theory model, namely: (1) players, (2) game strategy, and (3) utility function (payoff). Generally, game theory modeling is expressed as the following equation [9]:

$$G = [P, S, U] \tag{1}$$

where:

$P = \{P_1, P_2, ..., P_N\}$ is the user who makes the decisions in the game model.

$s = \{s_1, s_2, ..., s_N\}$ is each player's game strategy in the game model.

$U = \{u_1(s), u_2(s), ..., u_N(s)\}$ is the game model's utility function.

C. Nash Equilibrium

Several concepts are used in game theory to determine which strategies or actions a player should take in order to win the game. The concept of a player's best response states that his action or strategy a_i* is the best response to the other players' strategies a_{-i} if it maximizes his payoff or utility [9]:

$$u_i(a_i^*, a_{-i}) \geq u_i(a'_i, a_{-i}) \forall a'_i \tag{2}$$

Profile of the strategy a_i* is a Nash equilibrium (NE) if no player can increase his payoff unilaterally. Thus, there is no incentive for any player to deviate from his strategy, assuming that the other players do not deviate, i.e., for each player [9]:

$$i : u_i(a_i^*, a_{-i}) \geq u_i(a'_i, a_{-i}) \forall a'_i \tag{3}$$

The players select equilibrium strategies in order to maximize their individual payoffs. The Nash Equilibrium is a solution concept in game theory for a game involving two or more players in which no player gains anything by unilaterally changing user's own strategy. If each player has chosen a strategy and no player benefits from changing his strategy while the other players maintain theirs, the current set of strategy choices and associated payoffs constitutes a Nash Equilibrium. Certain games can be solved through iterated dominance, which eliminates strategy profiles in a systematic fashion. A purely rational strategy in a Non-cooperative game, the Nash equilibrium exists [9]:

$$u_i(s_i^*, s_{-i}^*) \geq u_i(s_i, s_{-i}^*) \forall s_i \in S_i \quad (4)$$

It is a pure-strategic profile that is used. If no player has an incentive to unilaterally deviate from his or her current strategy, and all other players' strategies remain fixed, the situation is said to be in Nash equilibrium [10].

D. Prisoner's Dilemma Strategy Concept

Prisoner's Dilemma is one of the best-known strategy games. [8]. The game stems from a story involving a suspect in a crime and what matters is when one of the suspects faces the same incentives as the other suspects. Consider the following scenario: two suspects in a serious crime are placed in different cells. However, there is insufficient evidence to convict either of the two suspects of a significant crime unless one of the suspects works as an informant against the other suspect, which is the situation in this instance under the *Fink* strategy. So that the behavior that occurs and the payoff that will be received can be grouped into:

- If both suspects remain *Quiet*, then each suspect will be found guilty of a minor offense and sentenced to one year in prison.
- If one of the two suspects *Fink*, then the suspect who fink is free while the other suspect gets a sentence of four years in prison.
- If both *Fink*, then each suspect will get a sentence of three years in prison.

From these issues, it is possible to model the situation as a strategy game with the following structure:

Players : The two suspects are Suspect 1 and Suspect 2

Strategy : Each player has 2 strategies, namely *Quiet* and *Fink*

Utility Function: $u_i(s_i, s_{-i})$ or utility player *i* (strategy player *i*, strategy player besides player *i*), so for the utility function $u_i(Fink,Quiet)$ means the utility function of player i with *Fink* strategy and other players with *Quiet* strategy.

Referring to the above conditions, the form of assessment of the utility function of player *i* can be determined as follows:

- $u_i(Fink,Quiet) = 3$ → player *i* free (not imprisoned)
- $u_i(Quiet,Quiet) = 2$ → Each player is jailed for 1 year
- $u_i(Fink,Fink) = 1$ → Each player is jailed for 3 years
- $u_i(Quiet,Fink) = 0$ → player *i* is jailed for 4 years

Hence the order of the utility function values of player *i* or $u_i(s_i, s_{-i})$ is:

$$u_i(Fink,Quiet) > u_i(Quiet,Quiet) > u_i(Fink,Fink) > u_i(Quiet,Fink) \quad (5)$$

which means that the condition of being free (not imprisoned) has the best utility ($u_i = 3$), and this is better than 1 year in prison ($u_i = 2$), especially compared to 3 years in prison ($u_i = 1$), while the worst condition is a sentence of 4 years in prison ($u_i = 0$).

The *Prisoner's Dilemma* simulates a situation that will provide utility value from a collaboration between suspects where each suspect in this case will always want to be free by choosing the strategy of *Fink* over *Quiet.* Because by choosing the *Fink* strategy, he can avoid the heaviest sentence, which is 4 years in prison, which means he also gets the smallest utility value ($u_i = 0$), no matter what strategy other suspects choose later.

TABLE I: GAME MATRIX OF PRISONER'S DILEMMA [8]

Player		**Suspect 2**	**Suspect 2**
	Strategy	*Quiet*	*Fink*
Suspect 1	*Quiet*	2, 2	0, 3
Suspect 1	*Fink*	3, 0	1, 1

Table I shows the possible strategy pairs and each player's utility value from the game *Prisoner's Dilemma.* From Table I, it can be seen that the strategy pair (*Fink, Fink*) is a *Nash equilibrium* condition because if Suspect 1 chooses *Fink*, then Suspect 2 is certain to also choose the *Fink* strategy so that he still gets a utility value of 1 compared to choosing the *Quiet* strategy with the smallest utility value of 0. The *Nash equilibrium* condition will be achieved if the two suspects are rationally no longer willing to change their strategy. want to change strategy. Nash equilibrium conditions will not be achieved in other strategy pairs, namely strategy pairs (*Fink, Quiet)*, (*Quiet, Quiet)* and (*Quiet, Fink*). This is because one or even both players will still want to change the strategy from *Quiet* to *Fink* in order to get a greater utility value or in other words to ease the punishment. As long as there are players who want to change their strategy, even if it is only one player, then it is certain that the *Nash equilibrium* condition has not been achieved.

Another example of the Prisoner's Dilemma case as introduced by Nicholas Milovsky is if there are two Suspects (Suspect 1 and Suspect 2) with two different strategies than before, namely *Fink* and *Quiet.* In this case, the behavior that occurs and the payoff that will be received can be grouped into:

- If no one *Finks*, then the two suspects can go free and share the booty.
- If one *Finks* and the other *Quiet*, then the *Fink* will be released with all the booty, and the other suspect will be imprisoned.
- If both *Fink*, then both can go to jail with a light sentence.

Thus the variation in Prisoner's Dilemma strategy choices can be seen in Table II as follows:

TABLE II: VARIATION OF STRATEGY CHOICES IN PRISONER'S DILEMMA [8]

Player		**Suspect 2**	**Suspect 2**
	Strategy	*Doesn't Confess*	*Confess*
Suspect 1	*Doesn't Confess*	3, 3	0, 5
Suspect 1	*Confess*	5, 0	1, 1

Based on Table II, the total payoff value for each action, which is seen from the position of Suspect 1, is as follows:

- If the two suspects *Do Not Confess* (meaning they are both free), then the outcome (3, 3)

- If Suspect 1 *Confesses* (but Suspect 2 *Doesn't Confess*), then Suspect 1 will be free and get a score of 5
- If Suspect 1 *Confesses* and then Suspect 2 also *Confesses*, then both are imprisoned and Suspect 1 gets a score of 1.

The safest way for Suspect 1 is when choosing *Confess* because It will be assigned a value of 5 in the best-case scenario and a value of 1 in the worst case scenario (but avoid a value of 0). However, if both of them act rationally for the common good in a compact way to choose the *Do Not Confess* strategy, then both will be free with a value of 3 each or with the highest number of outcomes, namely 6 so that satisfaction on both parties, namely Suspect 1 and Suspect 2 is achieved. The choice of this strategy is then called the Nash Equilibrium (NE) condition because all players are satisfied with getting the desired payoff.

E. Types of Game Theory

Game theory is a mathematical framework comprised of models and techniques for analyzing the repetitive behavioral decisions of individuals motivated by self-interest. Game models are developed for use in a wide variety of applications. The game model also aims to find equilibrium conditions and decide when these conditions are acceptable for the application and determine the best optimization parameters for bringing the system to its ideal equilibrium state.

There are two basic types of this game, namely Cooperative and Non-cooperative game [9]:

1. Cooperative Game

When playing this game, all players have a tendency to think about the overall benefit rather than their own individual gain. Consequently, players fully cooperate with one another to achieve the greatest possible overall benefit, just as players do in a football match. In practice, a solution based on these two elements may be more difficult to implement because cooperative games require additional signalling or agreement between decision makers.

2. Non-cooperative Game

In this game, every player tends to think about his personal outcome and therefore all decisions are made competitive and selfish. As a result, this game is referred to as a competitive game as well.

The selection of the type or model of game theory depends on the nature of the problem. In addition to the cooperative and non-cooperative game models previously mentioned, some of the game models include [9]:

a. Complete and Incomplete (information) Game

In a game where all of the information is available (complete information), the player knows the other players, the action sets of the other players and all possible outcomes or utility functions of the game. Apart from that the game is a game with incomplete information.

b. Static or Strategic Game

In static game, if a player consistently picks the same strategy, which dictates his or her behavior in all game situations, this is referred to as pure strategy. When a player adopts a different approach based on established probability, this is referred to as a mixed strategy.

c. Dynamic Game

Players act sequentially in dynamic games, making decisions based on their knowledge of the activities of other players. At least one player has multiple movements, and the sequence in which they are made is critical. When a player reaches a specific level in a game, his actions are determined by his decisions and the choices of other players at the previous stage, i.e. by his position in the game. In the game, the player strategy is a set of rules that govern the activities that the player must take.

d. Repeated Game

A repeated game is a dynamic game class in which multiple players make the same decisions frequently and periodically in the same setting.

e. Potential Game

The utility function in a prospective game is a hypothetical function that indicates the change in utility produced by each player unilaterally changing the other's strategy. Thus, a single function can be used to present the usefulness and behavior of all players. Typically, a potential game is given in its natural state. A potential game involving a selfish strategy is a specific desire because desire always reaches Nash Equilibrium, which is found in some local optima of potential functions.

f. Supermodular Game

Supermodular game characterized by characteristics that complement the strategy. In a nutshell, it means that when one player chooses a more advantageous action, the other player wishes to follow. Power control algorithms can learn a lot from this type of game because it has some interesting characteristics [11].

III. Cognitive Radio Network (CRN)

A. Concept of CRN

As a promising paradigm for optimizing the use of frequency resources by allowing the coexistence of licensed (primary users, PU) and unlicensed users (secondary users, SU) in the same spectrum band, the concept of cognitive radio (CR) has recently gotten a lot of attention from the scientific community [12]. Mitola [13] defined cognitive radio as a radio system that understands the context of existence in a communication environment and can set parameters optimally in carrying out the communication process. Smart radio is a simple way to describe cognitive radio.

The term CR can also refer to an intelligent communication system that can sense its surroundings and use the understanding methodology by studying the environment, and then adjust its internal state by changing its state in accordance with specific operating parameters [14]. From this definition, it can be concluded that the task of cognitive radio can be divided into three parts: (1) listening, thinking, and acting. Analysis of the radio environment (both outside and inside); (2) channel estimation (including capacity and condition estimation); (3) resource management; and a variety of other tasks (power control and spectrum allocation) [2]. Cognitive radio is a system that has several inputs, namely the results of environmental sensors, the need for quality of service (QoS) from the system itself (both from users and applications), and also predictive models or results from experiments that have been carried out. Some of these inputs are taken into consideration by the cognitive system to take an action independently and provide an output in the form of a system configuration to adapt to the existing demands. The output given by the system can be in the form of an adaptation command which will be sent to the hardware [15]. The applicable regulatory policies are also a consideration for the implementation of a smart radio system.

B. Implementation of CRN

Utilization of cognitive radio technology on cellular networks strongly encourages the advance mobile communication technology, particularly femtocell network technology. Development of cognitive femtocell network (CFN) can provide cost-effective improvement solutions in several scenarios related to spectrum scarcity [16]. In research [17] mentioned that the effect of increasing the number of users on the femtocell communication network also affects system performance. Conversely, expanding the number of users reduces the achieved SINR even though the decrease is not significant because the addition of users can be accommodated by the system, as in this case, the system is feasible and can be implemented.

In addition to CFN, other CRN implementations are on cognitive radio ad hoc networks (CRAHN). CR networks can be divided into two categories based on their network architecture: infrastructure-based CR networks and CRAHN [18]. The infrastructure-based CR network is comprised of a central network element, such as a base station in cellular networks or a wireless local area network (LAN) access point. On the other hand, the CRAHN lacks a backbone in terms of infrastructure. As a result, a CR user can communicate with other CR users via ad hoc connections over both licensed and unlicensed spectrum bands. The primary problem with CRAHN is to integrate these services into the protocol stack layers in such a way that CR users can communicate successfully in a distributed way, over a multi-hop/multi-spectrum environment, without the support of infrastructure [19]. We consider a decentralized and self-configuring CRAHN [20]. Because of their ability to rapidly configure networks without the need to use existing infrastructure and to efficiently use frequency resources while responding to changes in dynamic radio resource demand CRAHN have been used in various fields, including disaster emergency networks and military tactical communications [21]. The latest implementation of CRAHN is to use machine learning or often referred to as the intelligent CRAHN system, aimed at using spectrum more efficiently. This research provided a model for network planning, learning, and dynamic configuration based on a learning-based distributed autonomous CRAHN network system. This research also proposed machine learning based optimization techniques for spectrum sensing, cluster-based ad hoc network design, and context-aware signal classification based on the system model. The result can provide stable network services while adapting to dynamic network environment changes, the intelligent system model and learning algorithms, so it can be applied to a variety of wireless ad-hoc network applications, including emergency disaster communications and military tactical networks [22].

Another implementation of CR is the communication system of vehicular ad hoc networks (VANET) or often called CR-VANET. This implementation of CR-VANET has several problems and solutions [23] [24]. The moving vehicles in the CR-VANET network are all equipped with CR. The system becomes dynamic as a result of the channel responses changing in response to the movement of the cars. CR adoption in the vehicle network necessitates effective spectrum detection and a proper distribution of power. Different spectral detection techniques over a correlated Rayleigh fading channel have been presented in the literature in this circumstance [25], taking into account both earlier and subsequent knowledge regarding the availability of channels [26], in the scientific and medical field [27] and so forth. In particular, the CR users in the vehicles in the CR-VANET are battery powered. Maximizing energy efficiency (EE) should be given equal weight, which extends battery life and decreases the need for frequent battery replacement. In the vehicle to infrastructure (V2I) scenario [28], total energy consumption was reduced by optimizing the sensing time and transmission power allocation to the SU within the restrictions of minimal attainable throughput and interference to the PU.

In the usage of device to device (D2D) approaches in vehicle to vehicle (V2V), a novel cognitive radio-based resource allocation policy is more efficient. This allocation policy will regulate the amount of interference that occurs between cellular devices and D2D automobiles. Furthermore, the decision on the communication mechanism for the vehicles should take into consideration a viable range under a variety of V2V and e-Node B (eNB) distances. By utilizing D2D, it is feasible to both reduce latency and create a solution that is functional even when no cellular network coverage is available. In D2D mode, vehicles in close proximity interact directly with one another, resulting in a reduction in latency and the offloading of traffic from the eNB. D2D will be a viable solution for local data sharing between automobiles in the future [29].

The CR technology allows for opportunistic spectrum utilisation in vehicle networks and communications [19]. CR-VANET is a rapidly expanding application field of CR technology [30]. CR-enabled vehicles can utilise additional spectrum in TV bands to meet application QoS requirements. However, general-purpose CR network research solutions cannot be directly applied to CR-VANET. Because the CR-spectrum VANET's management activities must take into account the specific characteristics of the vehicular environment, such as mobility and cooperation opportunities. Unlike static CR, CR-VANET allows many collaborating vehicles to communicate spectrum information to determine spectrum availability. This allows other vehicles to anticipate the road's spectrum characteristics and respond accordingly. V2V communication, entertainment and information systems, and public safety communication will all benefit from CR-VANET [31]. To avoid interference from other users or jammers, the experiments were carried out in a real-world setting, using the elaborated testbed, and the results show that the use of sensing and cognitive management mechanisms enables more efficient spectrum use while maintaining reasonable overhead values related to management procedures [32]. However, the licensed spectrum is already crowded, limiting effective vehicle communication. Thus, CR systems emerged as a solution to the spectrum scarcity issue. This research discusses the previous detection strategies and proposes an enhanced energy detection based cooperative spectrum sensing scheme for automobile VANET. The proposed system improved network performance, allowing for more efficient spectrum utilization [33].

To assure CR-VANET's applicability, a framework that solves the concerns addressed should be developed. The database addresses the issue of spectrum allocation in cognitive radio VANET by utilizing parameters such as vehicle locations, power models, and SINR. The suggested integrated paradigm is based on the make-before-break principle, which ensures that transmission quality is not compromised during a spectrum handover [34]. There is also research on cross-layer design in CR-VANET communication [35]. The CRN will also be implemented on 6G communications and is referred to as 6G CRN. Potential critical problems in 6G CR network communication as well as crucial enabling technologies that are critical to the accomplishment of 6G and beyond. The different technologies may prove beneficial for 6G CRN communications [36].

IV. Game Theoretical Approach in CRN

When centralized control is unavailable or a flexible self-organized approach is required, such an approach becomes indispensable [3]. Several other studies on game theoretical approach in CRN are applied to interference adjustment [37], [38], increased throughput [39], power efficiency [40]–[44], fulfillment of QoS requirements [39], [45], increased network capacity [40], [46], etc. The use of game theory as a power control technique has also been widely used in research on conventional wireless networks [47], cognitive radio networks [48], two-tier femtocell networks [49], and heterogeneous networks [50], [51].

In cognitive radio communication, several power control studies using a game theory approach discuss the pay-off or utility function in the form of SINR, QoS, link rate, throughput, and others. Power control aims not only to minimize the power consumed by the cognitive radio network but also to maximize utility. Utilities can be in the form of increasing throughput and network capacity according to power limits and total interference through the selection of strategies carried out by each user as a player who will compete with other users in controlling their power [39]. Combining power control with interference mitigation algorithms is also able to overcome QoS and energy efficiency trade-offs [3]. In addition, research on power control using game theory is also aimed at increasing the speed in achieving the convergence condition (or high convergence rate) [49], [50],[52]–[56], low complexity algorithm [45], algorithms with reduced iterations so that SU accelerates in reaching Nash Equilibrium conditions [48], [57]. For more details, the implementation of GT on CRN can be shown in Table III.

V. Game Theoretical Approach in 5G-6G Communications

Prior to its implementation in 5G communications, GT was widely used in 4G (LTE) communications, as demonstrated in previous studies for focusing on interference minimization [58], network selection [59], [60], quality of service (QoS) enhancement [61], resource allocation in LTE [62], and security and privacy [63].

Low-power small cells (picocells and femtocells) enhance the coverage and capacity of wireless networks when overlaid on top of macrocells in heterogeneous small cell networks by utilizing spatial spectrum reuse. The 5G networks continue to face numerous challenges and issues. Cooperative and Non-cooperative games are two types of game theory that can be modeled and analyzed in 5G wireless communications. Different game theories are applicable in interference reduction, resource allocation, spectrum access, economic analysis, and other aspects of 5G wireless networks [64].

TABLE III: COLLECTIVE INFORMATION OF NON COOPERATIVE GAME APPLICATIONS IN CRN

Game modeling scheme	Objectives	Implemented Environment	References
non-cooperative game	interference minimization	CRN	[65]
non-cooperative game	increasing throughput	CRN	[33]
non-cooperative game	minimizing power consumption (increase power efficiency)	CRN, *two-tier femtocell networks*, MIMO-CRS	[66]–[70]
non-cooperative game	ensuring the fulfillment of QoS requirements and overcome the trade-off between QoS and power efficiency	CRN	[71]
non-cooperative game	maximizing network capacity	CRN	[72]
non-cooperative game	maximizing utility	CRN, *two-tier femtocell networks, single cell* CDMA	[67], [72]–[75]
non-cooperative game	low complexity	CRN	[76]
non-cooperative game	more effective against noise	CRN	[76]
non-cooperative game	pricing to increase efficiency	*single-cell* CDMA, CRN, *two-tier femtocell networks*	[73], [77]–[80]
non-cooperative game	fast Nash equilibrium convergence (increasing Nash equilibrium efficiency) and ensuring more users to reach target SINR	CRN, *two-tier femtocell networks*, MIMO-CRS, *single cell* CDMA	[70], [73]–[75], [78], [81], [82],
non-cooperative game	efficient use of resources	MC-CDMA *cognitive radio system*	[83]
non-cooperative game	overcoming the near-far effect	CRN	[68]
non-cooperative game	ensuring fairness in user power control system	CRN	[69]
non-cooperative game	ensuring the target SINR is achieved for variations in the number of users	CRN	[17]
non-cooperative game	ensuring target SINR is achieved for user macro and user femto	CRN heterogeneous network	[51]

The application of the game theory approach to 5G communication has been widely carried out. In addition, energy efficiency and spectral efficiency are challenges in a 5G network, particularly in non-orthogonal multiple access networks (NOMA). NOMA is a promising technique for increasing system efficiency in a 5G network through adaptive power control (PC). For uplink power-domain NOMA systems, an efficient PC scheme based on Evolutionary Game Theory (EGT) model has been proposed.

This PC scheme enables users to adjust their transmit power level adaptively in order to improve their payoffs or throughput, resulting in an increase in system efficiency. A successive interference cancellation (SIC) receiver is installed at the base station (BS) site to separate the user signals. In terms of energy efficiency and spectral efficiency, the simulation results show that the proposed EGT-based PC scheme outperforms traditional game theory-based PC schemes and orthogonal multiple access (OMA) [84], [85]. Study of CR-NOMA networks using a game-theoretic approach is compared to the orthogonal multiple access (OMA) method as well. The sum utilities of SU with NOMA improve by up to 37.5%. As a result, an additional 5.6% of SU can now be used in the system in energy efficient mode [86].

For cellular downlink NOMA networks, a new power allocation algorithm based on the Glicksberg game is proposed. Price-based utility functions are proposed and shown to be effective while also being restrictive. Hessian matrix is used to derive an expression for the price of electricity based on transmission capacity and number of customers served in a cell. The uniqueness of the Nash equilibrium is then demonstrated, and the optimal solution to maximize the utility function is presented. It has been shown that, in terms of sum and average data rates, the proposed power allocation mechanism outperforms existing algorithms [87]. Cooperative NOMA (C-NOMA) is an effective technique for preventing performance degradation of distant users by allocating the least amount of power possible to users with favorable channel conditions. This research proposed a fair power and channel allocation scheme for multi carrier (MC) NOMA based on the Nash bargaining solution (NBS) game solution in full-duplex, cooperative beamforming (BF). The proposed NBS scheme allocates power and channels optimally based on channel conditions while ensuring a fair rate for cooperative users. NBS is the most equitable and optimal method for increasing the total rate of C-NOMA. The results indicate that the proposed NBS power allocation scheme improves SNR by 2 dB when compared to the non-cooperative scheme and by 3 dB when compared to the multiple-input multiple-output NOMA (MIMO-NOMA). In terms of fairness, the proposed NBS scheme achieved a score of 0.8401, which is significantly higher than previous research [88].

The 5G communication technology is also determining how D2D communication network can offer significant benefits in urban metropolitan environments. D2D networks can thus provide an effective means of supplementing standard cellular communication networks, reducing the load on the standard cellular networks while maintaining or improving service quality. The purpose of this work is to discuss a user association scheme for determining the optimal association in a D2D wireless network using game theory. This is accomplished by deriving Nash Equilibrium for games involving each pair of devices using parameters such as SINR, path loss, and remaining battery power for each device as a network node. Additionally, an evolutionary game theory model is developed to simulate the formation of D2D links in a network when nodes are dynamically added, with the goal of identifying the evolutionary stable strategy (ESS) [89]. A power control technique based on Nash equilibrium and game theory is utilized to reduce interference between the mobile user device and the D2D link. Via D2D, power control is treated as a non-cooperative game with the goal of achieving stable connectivity while consuming the least amount of energy possible in wireless communication. Each device is free to pick and transmit its own power in order to increase (or limit) usefulness for the user. The convergent algorithm used with the Nash Equilibrium rate is relatively quick. It ensures that user devices can meet the needed QoS by changing the residual cost coefficient and residual energy factor. The power control reduces power consumption significantly [90].

The cognitive D2D communication technology used in the 5G network can establish a direct communication link between two established communication equipment, allowing them to communicate directly, maximizing communication resources and finally meeting growing traffic demand. To increase the efficiency of D2D communication equipment's operation, a communication channel allocation method and resource optimization based on spectrum grouping and non-cooperative games is proposed. The effectiveness of communication can be increased 1.5 times above the original [91]. A load shedding coefficient, that is, the proportion of requested data that can be transferred via a D2D link, is used to send user equipment (UE) data down to another UE in a D2D link pair. Each link operates as a player in cooperative play, with the Nash bargaining solution (NBS) determining the ideal solution for the game. This research discusses a strategy for controlling various UE parameters, such as harvested energy stored in rechargeable batteries with limited capacity and the offload coefficients of D2D link pairs, in order to optimize network performance in terms of throughput and energy efficiency while maintaining network fairness. The results show that the suggested gaming scheme effectively offloads mobile data, improves energy economy, and increases throughput while retaining a high level of justice, when compared to offloading schemes based on the maximized fairness index (MFI) and no-load schemes [92].

The Internet of Things (IoT) is a critical component of 5G wireless communication's smart environment. The proposed IoT is based-on power and spectrum efficient D2D communication via the Stackelberg game. IoT devices communicate directly with one another without using the base station, and when they need to send data to another network, they use the femtocell base station. The article proposes a utility function for selecting the lead IoT device from each cluster based on the IoT device's minimal distance to the femtocell base station. As a result, the proposed network's power consumption is decreased by around 35%, while SINR and spectral efficiency are raised by approximately 6% and 4%, respectively, over the present technique [93]. Channel allocation problem for IoT uplink communications in a 5G network with the goal of enhancing the quality of experience (QoE) of smart objects (SO) has been investigated. The modified optimization problem is formulated mathematically using a game-theoretic model in which the designed potential function approximates the optimization objective. It was demonstrated that the best NE existed in the exact potential game, as a near-optimization solution to the channel allocation problem [94]. While the implementation on 6G communications, the use of GT is also mostly done for the purpose of spectrum sharing [95], network slicing [96], digital processing [97], optimizing 6G network performance [98], and resource management [99].

In addition to the use of GT in 4G, 5G and 6G communications, GT in wireless communication is also widely combined with Machine Learning (ML), Blockchain, THz communication, Big data, etc. Regarding the combination of using GT and Machine Learning, this research is also implemented with Artificial Intelligence (AI) to perform critical application tasks, low-latency, high-reliability and scalable AI along with a reliable infrastructure [100], increased desire for reliable UAVs-assisted wireless communication systems and privacy protection [101] and for spectrum sharing in CR networks [102]. While the combination of the use of GT and Blockchain in wireless communication, namely: for network slice (NS) brokering mechanism [96], for spectrum sharing enhancement in 5G-enabled IoT Dense Network which results in increasing spectrum sharing by more than 55.1% [103] and even for resources management and distribution in blockchain network [104]. Applications of GT in THz communication is used to improve communication effectiveness [105] and for energy efficiency by reducing the computational complexity [106]. Based on the 4G, 5G, and 6G comparisons in Table IV, the motivation for using GT in 5G/6G is that it can improve performance in terms of increasing energy efficiency, increasing convergence speed, channel optimization, increasing SNR, selecting the right network combination, sharing bandwidth resources, increasing throughput or capacity, and reducing complexity while maintaining conditions at the target SINR. Table VI also shows how GT is is combined with other technologies like Machine Learning, Blockchain, and THz communication.

VI. Conclusion

Based on the results of each paper's analysis of the application of GT to CRN, it is possible to conclude that the adoption of GT can increase the overall performance of the system under consideration.

TABLE IV. GAME THEORETICAL APPROACH IN 4G, 5G, 6G COMMUNICATION AND OTHER TECHNOLOGIES

Technology	Reff	Game Theoretical Approach	Game Theory Model	Performance Measures
4G	[58]	Interference minimization	Dynamic game	higher cell throughputs
	[60]	Network selection, resource allocation, admission control	Cooperative, Non-Cooperative, Auction, Bayesian, Evolutionary game	comprehensive classification of related game theoretic approaches
	[59]	Network selection	Non-Cooperative and Cooperative game	networks security
	[61]	Quality of service (QoS) enhancement	Non-Cooperative and Cooperative game	low latency
	[63]	Security and privacy	Coalitional game	peer discovery, proximity services, and location privacy
	[62]	Resource allocation in LTE	Game Theory in general	energy efficiency, data rate, power, number of supported user
5G	[95]	Spectrum sharing	Coalitional game	low cost interaction
	[107]	Spectrum sharing	Coalitional game	high throughput
	[108]	Resource allocation in mmWave and D2D	Coalitional game	fast convergence rate, maximize the system sum rate
	[109]	Resource allocation in Hetnet	Non-Cooperative game	efficient and flexible system
	[110]	Resource allocation in D2D	Stackelberg, Non-Cooperative, Coalitional, NBS, Auction game	minimum Interference and high throughput
	[111]	Frame to model D2D underlay communication	Stackelberg game	achieve rate and achievable secrecy rate
	[112]	Power control and channel allocation	Nash Bargaining Solution (NBS) game	energy efficiency (EE), high convergence rate, fairness, BER, SNR
	[113]	Energy efficiency (EE) and throughput improvement	Nash Bargaining Solution (NBS) game	effective offload mobile data, energy efficiency (EE) and improved throughput
	[114]	Energy efficiency (EE)	All Game Theory model	energy efficiency (EE)
	[115]	Channel selection and power control	Non-Cooperative game	less energy consumption
	[116]	Quality of service (QoS) enhancement	All Game Theory model	routing selection, power control, and spectrum resources allocation
	[117]	Quality of service (QoS) enhancement	Game Theory in general	routing selection, power control, and spectrum resources allocation
	[118]	Quality of Experience (QoE)	Coalitional game	maximizing the overall average quality of the clients
	[119]	Channel estimation	Coalitional game	normalized mean square error (NMSE) and bit error rate (BER)
6G	[120]	Replacing the classical probabilities of game theory	Quantum Game Theory (QGT)	enabling technologies for network-infrastructure, network-edge, air interface, and user-side of the proposed 6G framework
	[95]	Spectrum sharing	Coalitional game	low cost interaction
	[97]	Digital processing	Game Theory in general	efficient system
	[98]	Optimizing network performance	All Game Theory model	low complexity and high efficiency
	[99]	resource management in network virtualization	Game Theory in general	overcome the ossification problem and traditional architecture limitations
Machine Learning (ML)	[100]	GT, ML and AI-based self-sustaining network (SSN)	Game Theory in general	low latency, high-reliability and scalable AI
	[101]	GT and ML in UAVs-assisted wireless communication	Game Theory in general	reliable wireless communications and privacy protection
	[102]	GT and ML for spectrum sharing in CR networks	Static and Dynamic game	a self-organizing inventive scheme for spectrum sensing
THz Communications	[105]	GT and THz for effectiveness	Fractional Evolutionary game	memory effect of the users can achieve a higher utility
	[106]	GT and THz for energy efficiency (EE)	Mean-Field Game (MFG) theory	reducing the computational complexity and EE
Block Chain (BC)	[96]	GT and BC for Network Slice (NS) brokering mechanism	Stackelberg game	end to end (E2E) creation and selection latency
	[103]	GT and BC for Spectrum Sharing in 5G-IoT Dense Network	Game Theory in general	increasing spectrum sharing
	[104]	GT and BC for resources management and distribution	Game Theory in general	balancing resources management and distribution
	[121]	GT and BC for security, mining management and blockchain applications	Game Theory in general	efficient system

Improved system performance can be achieved by reducing interference, boosting power efficiency, increasing throughput and utility, achieve rapid Nash equilibrium convergence, provide fairness in the power control system, and ensuring that the SINR target can be fulfilled by all users, are all important goals of implemented GT. Meanwhile, the use of GT in 5G-6G communication and other technologies are related to the power control, resource allocation, spectrum sharing, channel estimation, channel selection and quality of service (QoS) or quality of experience (QoE). In general, the use of GT can help to improve the overall performance of a system.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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REFERENCES

[1] W. Zhou and W. H. Lam, "A fast LMMSE channel estimation method for OFDM systems," *EURASIP Journal on Wireless Communications and Networking*, vol. 2009, pp. 1–13, 2009.

[2] S. Haykin, "Cognitive radio: brain-empowered wireless communications," *IEEE Journal on Selected Areas in Communications*, vol. 23, no. 2, Art. no. 2, Feb. 2005.

[3] B. Wang, Y. Wu, and K. J. R. Liu, "Game theory for cognitive radio networks: An overview," *Computer Networks*, vol. 54, no. 14, Art. no. 14, Oct. 2010.

[4] B. Bueno de Mesquita, *The Logic of Political Survival*, Cambridge, Mass.: MIT Press, 2003.

[5] R. Powell, "Nuclear deterrence theory, nuclear proliferation, and national missile defense," *International Security*, vol. 27, no. 4, Art. no. 4, 2003.

[6] F. C. Zagare and B. L. Slantchev. (2010). *Game Theory and Other Modeling Approaches*. [Online]. Available: http://slantchev.ucsd.edu/incollection/pdf/IRCompend-W02F.pdf

[7] D. Niyato and E. Hossain, "Cognitive radio for next-generation wireless networks: An approach to opportunistic channel selection in IEEE 802.11-based wireless mesh," *Wireless Communications, IEEE*, vol. 16, no. 1, Art. no. 1, 2009, Accessed: Apr. 20, 2014.

[8] M. J. Osborne, *An Introduction to Game Theory*, California: Oxford University Press, 2002.

[9] E. Pertovt, T. Javornik, and M. Mohor, "Game theory application for performance optimisation in wireless networks," pp. 287–292, 2011.

[10] H. A. Shyllon and S. Mohan, "A game theory-based distributed power control algorithm for femtocells," in *Proc. IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, New Delhi, India, Dec. 2014, pp. 1–6.

[11] X. Deng, W. Xia, Q. Guan, S. Lin, and S. Jiang, "A novel distributed power control based on game theory in cognitive wireless network," in *Proc. IEEE/CIC International Conference on Communications in China (ICCC)*, Shanghai, China, Oct. 2014, pp. 59–63.

[12] G. Scutari and D. P. Palomar, "MIMO cognitive radio: A game theoretical approach," *IEEE Transactions on Signal Processing*, vol. 58, no. 2, Feb. 2010.

[13] J. Mitola and G. Q. Maguire Jr, "Cognitive radio: Making software radios more personal," *Personal Communications, IEEE*, vol. 6, no. 4, 1999.

[14] M. Tran, G. Zaggoulos, A. Nix, and A. Doufexi, "Mobile WiMAX: Performance analysis and comparison with experimental results," in *Proc. Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th*, 2008, pp. 1–5.

[15] Y. Zhang, J. Zheng, and H. H. Chen, *Cognitive Radio Networks: Architectures, Protocols, and Standards*, CRC Press, 2010.

[16] X. Li, L. Qian, and D. Kataria, "Downlink power control in co-channel macrocell femtocell overlay," in *Proc. 43rd Annual Conference on Information Sciences and Systems*, Baltimore, MD, USA, Mar. 2009, pp. 383–388.

[17] A. F. Isnawati, W. Pamungkas, and J. Hendry, "Power control game performance in cognitive femtocell network," *JCM*, vol. 14, no. 2, pp. 121–127, Feb. 2019.

[18] I. F. Akyildiz, W. Y. Lee, M. C. Vuran, and S. Mohanty, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey," *Computer Networks*, vol. 50, no. 13, pp. 2127–2159, Sep. 2006.

[19] I. F. Akyildiz, W. Y. Lee, and K. R. Chowdhury, "CRAHNs: Cognitive radio ad hoc networks," *Ad Hoc Networks*, vol. 7, no. 5, pp. 810–836, Jul. 2009.

[20] N. Mansoor, A. K. M. M. Islam, M. Zareei, S. Baharun, T. Wakabayashi, and S. Komaki, "Cognitive radio ad-hoc network architectures: A survey," *Wireless Pers Commun*, vol. 81, no. 3, pp. 1117–1142, Apr. 2015.

[21] T. Braysy, *et al.*, "Network management issues in military cognitive radio networks," in *Proc. International Conference on Military Communications and Information Systems (ICMCIS)*, Oulu, Finland, May 2017, pp. 1–6.

[22] K. E. Lee, J. G. Park, and S. J. Yoo, "Intelligent cognitive radio ad-hoc network: Planning, learning and dynamic configuration," *Electronics*, vol. 10, no. 3, p. 254, Jan. 2021.

[23] A. A. Ahmed, A. A. Alkheir, D. Said, and H. T. Mouftah, "Cooperative spectrum sensing for cognitive radio vehicular ad hoc networks: An overview and open research issues," in *Proc. IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, Vancouver, BC, Canada, May 2016, pp. 1–4.

[24] R. Kaur, "Cognitive radio for vehicular ad-hoc network (CR-VANET): Problems and solutions," 2018.

[25] X. Qian and L. Hao, "Spectrum sensing with energy detection in cognitive vehicular ad hoc networks," in *Proc. IEEE 6th International Symposium on Wireless*

Vehicular Communications (WiVeC 2014), Vancouver, BC, Canada, Sep. 2014, pp. 1–5.

[26] X. L. Huang, J. Wu, W. Li, Z. Zhang, F. Zhu, and M. Wu, "Historical spectrum sensing data mining for cognitive radio enabled vehicular ad-hoc networks," *IEEE Trans. Dependable and Secure Comput.*, vol. 13, no. 1, pp. 59–70, Jan. 2016.

[27] K. Baraka, L. Safatly, H. Artail, A. Ghandour, and A. El-Hajj, "An infrastructure-aided cooperative spectrum sensing scheme for vehicular ad hoc networks," *Ad Hoc Networks*, vol. 25, pp. 197–212, Feb. 2015.

[28] C. Yang, Y. Fu, Y. Zhang, S. Xie, and R. Yu, "Energy-Efficient hybrid spectrum access scheme in cognitive vehicular ad hoc networks," *IEEE Commun. Lett.*, vol. 17, no. 2, pp. 329–332, Feb. 2013.

[29] S. Mumtaz, K. M. Saidul Huq, M. I. Ashraf, J. Rodriguez, V. Monteiro, and C. Politis, "Cognitive vehicular communication for 5G," *IEEE Commun. Mag.*, vol. 53, no. 7, pp. 109–117, Jul. 2015.

[30] M. Di Felice, R. Doost-Mohammady, K. Chowdhury, and L. Bononi, "Smart radios for smart vehicles: Cognitive vehicular networks," *IEEE Veh. Technol. Mag.*, vol. 7, no. 2, pp. 26–33, Jun. 2012.

[31] K. D. Singh, P. Rawat, and J.-M. Bonnin, "Cognitive radio for vehicular ad hoc networks (CR-VANETs): Approaches and challenges," *J Wireless Com Network*, vol. 2014, no. 1, p. 49, Dec. 2014.

[32] A. Kaszuba-Chęcińska, R. Chęciński, P. Gajewski, and J. Łopatka, "Cognitive radio MANET waveform design and evaluation," *Sensors*, vol. 21, no. 4, p. 1052, Feb. 2021.

[33] K. V. Rop, P. K. Langat, and H. A. Ouma, "Spectrum sensing on high density cognitive radio vehicular ad hoc network," *Journal of Communications*, vol. 16, no. 7, p. 8, 2021.

[34] J. M. Y. Lim, Y. C. Chang, M. Y. Alias, and J. Loo, "Cognitive radio network in vehicular ad hoc network (VANET): A survey," *Cogent Engineering*, vol. 3, no. 1, p. 1191114, Dec. 2016.

[35] A. Shaw, "Cross-Layer design in vehicular ad-hoc network with cognitive radio," p. 11.

[36] M. M. Aslam, L. Du, X. Zhang, Y. Chen, Z. Ahmed, and B. Qureshi, "Sixth Generation (6G) Cognitive Radio Network (CRN) application, requirements, security issues, and key challenges," *Wireless Communications and Mobile Computing*, vol. 2021, pp. 1–18, Oct. 2021.

[37] I. W. Mustika, K. Yamamoto, H. Murata, and S. Yoshida, "Potential game approach for self-organized interference management in closed access femtocell networks," in *Proc. Vehicular Technology Conference (VTC Spring), IEEE 73rd*, 2011, pp. 1–5.

[38] N. Nie, C. Comaniciu, and P. Agrawal, "A game theoretic approach to interference management in cognitive networks," in *Wireless Communications*, Springer, 2007, pp. 199–219.

[39] J. Duan, J. Liu, S. Leng, and Q. Wang, "A game-based power control scheme for cognitive radio networks," in *Proc. International Conference on Computational Problem-Solving*, 2012, pp. 76–79.

[40] Z. Lu, Y. Sun, X. Wen, T. Su, and D. Ling, "An energy-efficient power control algorithm in femtocell networks," in *Proc. 7th International Conference on Computer Science & Education*, 2012, pp. 395–400.

[41] X. Wang, G. Yang, X. Tan, and B. Li, "Adaptive power control algorithm in cognitive radio based on game theory," *IET Communications*, vol. 9, no. 15, Art. no. 15, Oct. 2015.

[42] V. Chandrasekhar, J. G. Andrews, Z. Shen, T. Muharemovic, and A. Gatherer, "Distributed power control in femtocell-underlay cellular networks," in *Proc. Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, 2009, pp. 1–6.

[43] X. Xie, H. Yang, A. V. Vasilakos, and L. He, "Fair power control using game theory with pricing scheme in cognitive radio networks," *Journal of Communications and Networks*, vol. 16, no. 2, Art. no. 2, Apr. 2014.

[44] M. Cui, B. Hu, X. Li, and H. Chen, "A novel power control algorithm for massive MIMO cognitive radio systems based on game theory," in *Proc. Vehicular Technology Conference (VTC Spring), 2015 IEEE 81st*, 2015, pp. 1–5.

[45] J. Jiao, L. Jiang, and C. He, "A novel game theoretic utility function for power control in cognitive radio networks," in *Proc. Fifth International Conference on Computational and Information Sciences*, Jun. 2013, pp. 1553–1557.

[46] Y. Zhang and S. Shao, "Effective of power control game algorithm for cognitive radio," in *Proc. IEEE 3rd International Conference on Communication Software and Networks*, 2011, pp. 236–240.

[47] C. U. Saraydar, N. B. Mandayam, and D. Goodman, "Efficient power control via pricing in wireless data networks," *Communications, IEEE Transactions on*, vol. 50, no. 2, Art. no. 2, 2002.

[48] Z. Junhui, Y. Tao, G. Yi, W. Jiao, and F. Lei, "Power control algorithm of cognitive radio based on non-cooperative game theory," *Communications, China*, vol. 10, no. 11, Art. no. 11, 2013.

[49] J. Liu, W. Zheng, W. Li, X. Wang, Y. Xie, and X. Wen, "Distributed uplink power control for two-tier femtocell networks via convex pricing," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, Shanghai, Shanghai, China, Apr. 2013, pp. 458–463.

[50] Y. Ma, T. Lv, and Y. Lu, "Efficient power control in heterogeneous femto-macro cell networks," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC): PHY*, 2013, pp. 4215–4219.

[51] A. F. Isnawati and M. Aly Afandi, "Game theoretical power control in heterogeneous network," in *Proc. 9th International Conference on Information and Communication Technology (ICoICT)*, Yogyakarta, Indonesia, Aug. 2021, pp. 149–154.

[52] X. Deng, W. Xia, Q. Guan, S. Lin, and S. Jiang, "A novel distributed power control based on game theory in cognitive wireless network," in *Proc. IEEE/CIC*

International Conference on Communications in China (ICCC), Shanghai, China, Oct. 2014, pp. 59–63.

[53] Z. Junhui, Y. Tao, G. Yi, W. Jiao, and F. Lei, "Power control algorithm of cognitive radio based on non-cooperative game theory," *Communications, China*, vol. 10, no. 11, Art. no. 11, 2013.

[54] M. Cui, B. Hu, X. Li, and H. Chen, "A novel power control algorithm for massive MIMO cognitive radio systems based on game theory," in *Proc. IEEE 81st Vehicular Technology Conference (VTC Spring)*, Glasgow, United Kingdom, May 2015, pp. 1–5.

[55] J. Zhang, Z. Zhou, H. Yao, Y. Zhou, and K. S. Kwak, "A novel non-cooperative power control game for cognitive radio networks," in *Proc. 9th International Symposium on Communications and Information Technology*, 2009, pp. 115–118.

[56] F. Benedetto and D. Izzo, "A joint modulation, rate, and power control game-theoretic approach for uplink CDMA communications," *JCM*, vol. 9, no. 3, pp. 271–278, 2014.

[57] J. Zhang, Z. Zhou, H. Yao, Y. Zhou, and K. S. Kwak, "A novel non-cooperative power control game for cognitive radio networks," in *Proc. 9th International Symposium on Communications and Information Technology*, 2009, pp. 115–118.

[58] G. Alnwaimi, S. Vahid, and K. Moessner, "Dynamic heterogeneous learning games for opportunistic access in LTE-Based macro/femtocell deployments," *IEEE Trans. Wireless Commun.*, vol. 14, no. 4, pp. 2294–2308, Apr. 2015.

[59] M. M. Cherian and M. Chatterjee, "Game theory based network selection in 4G," *Information Technology*, vol. 1, no. 4, p. 5, 2015.

[60] R. Trestian, O. Ormond, and G. M. Muntean, "Game theory-based network selection: Solutions and challenges," *IEEE Commun. Surv. Tutorials*, vol. 14, no. 4, pp. 1212–1231, 2012.

[61] K. Ahmad and G. Kumar, "A novel coalesce model of game theory to enhance QoS of cell edge user," in *Proc. IEEE International Conference on Signal Processing, Computing and Control (ISPCC)*, Solan, India, Sep. 2013, pp. 1–6.

[62] S. Oulaourf, A. Haidine, and H. Ouahmane, "Review on using game theory in resource allocation for LTE/LTE-Advanced," in *Proc. International Conference on Advanced Communication Systems and Information Security (ACOSIS)*, Marrakesh, Morocco, Oct. 2016, pp. 1–7.

[63] M. Haus, M. Waqas, A. Y. Ding, Y. Li, S. Tarkoma, and J. Ott, "Security and privacy in Device-to-Device (D2D) communication: A review," *IEEE Commun. Surv. Tutorials*, vol. 19, no. 2, pp. 1054–1079, 2017.

[64] H. Zhang, C. Jiang, J. Cheng, M. Peng, and V. C. M. Leung, "Editorial: Game theory for 5G wireless networks," *Mobile Netw Appl*, vol. 22, no. 3, pp. 526–528, Jun. 2017.

[65] J. Duan, J. Liu, S. Leng, and Q. Wang, "A game-based power control scheme for cognitive radio networks," in *Proc. International Conference on Computational Problem-Solving (ICCP)*, Leshan, China, Oct. 2012, pp. 76–79.

[66] Z. Lu, Y. Sun, X. Wen, T. Su, and D. Ling, "An energy-efficient power control algorithm in femtocell networks," in *Proc. 7th International Conference on Computer Science & Education*, 2012, pp. 395–400.

[67] V. Chandrasekhar, J. G. Andrews, Z. Shen, T. Muharemovict, and A. Gatherer, "Distributed power control in femtocell-underlay cellular networks," in *Proc. Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, 2009, pp. 1–6.

[68] X. Wang, G. Yang, X. Tan, and B. Li, "Adaptive power control algorithm in cognitive radio based on game theory," *IET Communications*, vol. 9, no. 15, pp. 1807–1811, Oct. 2015.

[69] X. Xie, H. Yang, A. V. Vasilakos, and L. He, "Fair power control using game theory with pricing scheme in cognitive radio networks," *Journal of Communications and Networks*, vol. 16, no. 2, pp. 183–192, Apr. 2014.

[70] M. Cui, B. Hu, X. Li, and H. Chen, "A novel power control algorithm for massive MIMO cognitive radio systems based on game theory," in *Proc. IEEE 81st Vehicular Technology Conference (VTC Spring)*, 2015, pp. 1–5.

[71] B. Wang, Y. Wu, and K. J. R. Liu, "Game theory for cognitive radio networks: An overview," *Computer* Networks, vol. 54, no. 14, pp. 2537–2561, Oct. 2010.

[72] J. Duan, J. Liu, S. Leng, and Q. Wang, "A game-based power control scheme for cognitive radio networks," in *Proc. International Conference on Computational Problem-Solving*, 2012, pp. 76–79.

[73] J. Liu, W. Zheng, W. Li, X. Wang, Y. Xie, and X. Wen, "Distributed uplink power control for two-tier femtocell networks via convex pricing," in *Proc. Wireless Communications and Networking Conference (WCNC), 2013 IEEE*, 2013, pp. 458–463.

[74] F. Benedetto and D. Izzo, "A joint modulation, rate, and power control game-theoretic approach for uplink CDMA communications," *Journal of Communications*, vol. 9, no. 3, pp. 271–278, 2014.

[75] X. Deng, W. Xia, Q. Guan, S. Lin, and S. Jiang, "A novel distributed power control based on game theory in cognitive wireless network," in *Proc. IEEE/CIC International Conference on Communications in China*, 2014, pp. 59–63.

[76] J. Jiao, L. Jiang, and C. He, "A novel game theoretic utility function for power control in cognitive radio networks," Jun. 2013, pp. 1553–1557.

[77] A. W. Sun and H. Zhang, "An improved power control algorithm in cognitive radio system," in *Proc. IEEE 14th International Conference on Proc. Communication Technology*, 2012, pp. 1193–1197.

[78] Z. Junhui, Y. Tao, G. Yi, W. Jiao, and F. Lei, "Power control algorithm of cognitive radio based on non-cooperative game theory," *Communications, China*, vol. 10, no. 11, pp. 143–154, 2013.

[79] C. U. Saraydar, N. B. Mandayam, and D. Goodman, "Efficient power control via pricing in wireless data networks," *IEEE Transactions on Communications*, vol. 50, no. 2, pp. 291–303, 2002.

[80] Q. Zhou, Z. Chen, F. Gao, J. C. Li, and M. Lei, "Pricing and power allocation in sensing-based cognitive femtocell networks," in *Proc. IEEE International Conference on Communications*, 2014, pp. 5342–5347.

[81] Y. Ma, T. Lv, and Y. Lu, "Efficient power control in heterogeneous femto-macro cell networks," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC): PHY*, 2013, pp. 4215–4219.

[82] J. Zhang, Z. Zhou, H. Yao, Y. Zhou, and K. S. Kwak, "A novel non-cooperative power control game for cognitive radio networks," in *Proc. 9th International Symposium on Communications and Information Technology*, 2009, pp. 115–118.

[83] Y. Chen, "The research on non-cooperative power control game algorithm for cognitive radio," in *Proc. 6th IEEE International Conference on Software Engineering and Service Science*, 2015, pp. 633–636.

[84] S. Riaz, J. Kim, and U. Park, "Evolutionary game theory-based power control for uplink NOMA," *KSII TIIS*, vol. 12, no. 6, Jun. 2018.

[85] S. Riaz and U. Park, "Power control for interference mitigation by evolutionary game theory in uplink NOMA for 5G networks," *Journal of the Chinese Institute of Engineers*, vol. 41, no. 1, pp. 18–25, Jan. 2018.

[86] S. S. Abidrabbu and H. Arslan, "Energy-Efficient resource allocation for 5G cognitive radio NOMA using game theory," *arXiv:2101.00225 [eess]*, Jan. 2021.

[87] R. Aldebes, K. Dimyati, and E. Hanafi, "Game-theoretic power allocation algorithm for downlink NOMA cellular system," *Electron. lett.*, vol. 55, no. 25, pp. 1361–1364, Dec. 2019.

[88] M. Fadhil, A. H. Kelechi, R. Nordin, N. F. Abdullah, and M. Ismail, "Game theory-based power allocation strategy for NOMA in 5G cooperative beamforming," *Wireless Pers Commun*, Aug. 2021.

[89] J. Sanyal and T. Samanta, "Game theoretic approach to enhancing D2D communications in 5G wireless networks," *Int J Wireless Inf Networks*, Aug. 2021.

[90] S. Abdu, K. A. Noordin, and K. Dimyati, "An efficient game theory-based power control algorithm for D2D communication in 5G networks," *KSII TIIS*, vol. 15, no. 7, Jul. 2021.

[91] S. Zhao, Y. Feng, and G. Yu, "D2D communication channel allocation and resource optimization in 5G network based on game theory," *Computer Communications*, vol. 169, pp. 26–32, Mar. 2021.

[92] H. T. Thien, V. H. Vu, and I. Koo, "Game Theory-Based Smart Mobile-Data Offloading Scheme in 5G Cellular Networks," *Applied Sciences*, vol. 10, no. 7, p. 2327, Mar. 2020.

[93] S. Ghosh and D. De, "Power and spectrum efficient D2D communication for 5G IoT using stackelberg game theory," in *Proc. 2020 IEEE 17th India Council International Conference (INDICON)*, New Delhi, India, Dec. 2020, pp. 1–7..

[94] H. Dai, H. Zhang, W. Wu, and B. Wang, "A game-theoretic learning approach to QoE-driven resource allocation scheme in 5G-enabled IoT," *J Wireless Com Network*, vol. 2019, no. 1, p. 55, Dec. 2019.

[95] P. Yang, L. Kong, and G. Chen, "Spectrum sharing for 5G/6G URLLC: Research frontiers and standards," *IEEE Comm. Stand. Mag.*, vol. 5, no. 2, pp. 120–125, Jun. 2021.

[96] T. Hewa, A. Kalla, D. P. M. Osorio, and M. Liyanage, "Blockchain and game theory convergence for network slice brokering," *Computer*, p. 9, Feb. 2022.

[97] G. Gui, M. Liu, F. Tang, N. Kato, and F. Adachi, "6G: Opening new horizons for integration of comfort, security, and intelligence," *IEEE Wireless Commun.*, vol. 27, no. 5, pp. 126–132, Oct. 2020.

[98] B. T. Tinh, L. D. Nguyen, H. H. Kha, and T. Q. Duong, "Practical optimization and game theory for 6G ultra-dense networks: Overview and research challenges," *IEEE Access*, vol. 10, pp. 13311–13328, 2022.

[99] J. Bennaceur, H. Ahmadi, and S. Souhi, "Game-Theoretical approaches for service provisioning in network virtualization: Survey, taxonomies and open challenges," *Telecom*, vol. 2, no. 3, pp. 232–254, Jun. 2021.

[100] W. Saad, M. Bennis, and M. Chen, "A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems," *IEEE Network*, vol. 34, no. 3, pp. 134–142, May 2020.

[101] M. Zhou, Y. Guan, M. Hayajneh, K. Niu, and C. Abdallah, "Game theory and machine learning in UAVs-assisted wireless communication networks: A survey," *arXiv:2108.03495 [cs]*, Aug. 2021, 2022.

[102] M. S. Gupta and K. Kumar, "Progression on spectrum sensing for cognitive radio networks: A survey, classification, challenges and future research issues," *Journal of Network and Computer Applications*, vol. 143, pp. 47–76, Oct. 2019.

[103] Y. Choi and I. G. Lee, "Game theoretical approach of blockchain-based spectrum sharing for 5G-Enabled IoTs in dense networks," in *Proc. IEEE 90th Vehicular Technology Conference (VTC2019-Fall)*, Honolulu, HI, USA, Sep. 2019, pp. 1–6.

[104] C. H. Tran, D. T. Le, and T. H. Huynh, "Game theory application resources management and distribution in blockchain network," *IJNSA*, vol. 13, no. 1, pp. 65–78, Jan. 2021.

[105] N. T. T. Van, *et al.*, "Dynamic network service selection in intelligent reflecting surface-enabled wireless systems: Game theory approaches," *IEEE Trans. Wireless Commun.*, pp. 1–1, 2022.

[106] Y. Zhang, H. Zhang, and K. Long, "Energy efficient resource allocation in cache based terahertz vehicular networks: A mean-field game approach," *IEEE Trans. Veh. Technol.*, vol. 70, no. 6, pp. 5275–5285, Jun. 2021.

[107] A. B and P. M. Jose, "A survey of spectrum sharing techniques in 5g communication network," *Turkish*

Journal of Computer and Mathematics Education, vol. 12, no. 7, pp. 1722–1734, Apr. 2021.

[108] Y. Chen, B. Ai, Y. Niu, K. Guan, and Z. Han, "Resource allocation for device-to-device communications underlaying heterogeneous cellular networks using coalitional games," *IEEE Trans. Wireless Commun.*, vol. 17, no. 6, pp. 4163–4176, Jun. 2018.

[109] M. Gharam and N. Boudriga, "Game theoretical model for resource allocation in 5G hybrid HetNets," in *Proc. 2nd International Conference on Networking, Information Systems & Security - NISS19*, Rabat, Morocco, 2019, pp. 1–7.

[110] R. Rathi and N. Gupta, "Game theoretic and non-game theoretic resource allocation approaches for D2D communication," *Ain Shams Engineering Journal*, vol. 12, no. 2, pp. 2385–2393, Jun. 2021.

[111] Y. Luo, L. Cui, Y. Yang, and B. Gao, "Power control and channel access for physical-layer security of D2D underlay communication," in *Proc. International Conference on Wireless Communications & Signal Processing (WCSP)*, Nanjing, China, Oct. 2015, pp. 1–5.

[112] M. Fadhil, A. H. Kelechi, R. Nordin, N. F. Abdullah, and M. Ismail, "Game theory-based power allocation strategy for NOMA in 5G cooperative beamforming," *Wireless Pers Commun*, Aug. 2021.

[113] H. T. Thien, V. H. Vu, and I. Koo, "Game theory-based smart mobile-data offloading scheme in 5G cellular networks," *Applied Sciences*, vol. 10, no. 7, p. 2327, Mar. 2020.

[114] A. Mughees, M. Tahir, M. A. Sheikh, and A. Ahad, "Energy-Efficient ultra-dense 5G networks: Recent advances, taxonomy and future research directions," *IEEE Access*, vol. 9, pp. 147692–147716, 2021.

[115] A. Benamor, O. Habachi, I. Kammoun, and J. P. Cances, "Game theoretical framework for joint channel selection and power control in hybrid NOMA," in *Proc. 2020 - 2020 IEEE International Conference on Communications (ICC)*, Dublin, Ireland, Jun. 2020, pp. 1–6.

[116] Z. Sun, *et al.*, "Applications of game theory in vehicular networks: A survey," *IEEE Commun. Surv. Tutorials*, vol. 23, no. 4, pp. 2660–2710, 2021.

[117] Z. Sun, Y. Liu, J. Wang, C. Anil, and D. Cao, "Game theoretic approaches in vehicular networks: A survey," *arXiv:2006.00992 [cs]*, Jun. 2020.

[118] O. E. Marai, M. Bagaa, and T. Taleb, "Coalition Game-based approach for improving the QoE of DASH-based streaming in multi-servers scheme," in *Proc. GLOBECOM 2020 - 2020 IEEE Global Communications Conference*, Taipei, Taiwan, Dec. 2020, pp. 1–6.

[119] S. Dhanasekaran and J. Ramesh, "Channel estimation using spatial partitioning with coalitional game theory (SPCGT) in wireless communication," *Wireless Netw*, vol. 27, no. 3, pp. 1887–1899, Apr. 2021.

[120] S. J. Nawaz, S. K. Sharma, S. Wyne, M. N. Patwary, and M. Asaduzzaman, "Quantum machine learning for 6g communication networks: State-of-the-Art and vision for the future," *IEEE Access*, vol. 7, pp. 46317–46350, 2019.

[121] Z. Liu, *et al.*, "A survey on applications of game theory in blockchain," *arXiv:1902.10865 [cs]*, Mar. 2019.

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