Review on Game Theory Based Spectrum Management in Cognitive Radio-WSN Applications

Vennila N. L.[1]* Dr. Sanjay Kumar[2] Dr. Jambi Ratna Raja Kumar[3]

[1] PhD Student, Kalinga University, Raipur

[2] PhD Guide, Kalinga University, Raipur,

[3] Principal, GSMCOE, Pune

Abstract – Wireless sensor network (WSN) is a powerful technology for disaster recovery, environmental monitoring, remote surveillance, non-destructive testing of buildings, military communication, and industrial automation. Radio spectrum is getting limited as wireless communication devices become more prevalent. The existing static spectrum management leads to poor spatial and temporal spectrum utilisation. The auction process is thought to be one of the most effective strategies to alleviate radio spectrum scarcity. However, building a workable spectrum auction system requires consideration of five important issues: rational user strategy, channel heterogeneity, reusability, and societal utility maximisation. Cognitive Radio Network (CRN) provides for opportunistic usage of licenced spectrum bands, provided that the licenced users' activities are not impacted. Due to their coupled observations, CR-based WSN nodes function independently of each other. They may detect a void in the spectrum. The CR-WSN must thus spread the available spectrum equitably and efficiently among the sensor nodes. CR-WSN also provides significant issues owing to its dispersed multihop design, changing network topology, and various QoS needs. CR-WSNs with low overhead and energy consumption have a difficult time using spectrum. To increase spectrum usage and accommodate unlicensed users, it was proposed that unlicensed devices/users be allowed to broadcast in the licenced band. In this research, we review the literature on spectrum management in WSN and discuss its shortcomings. Our latest work on heterogeneous spectrum management is also presented. We model spectrum allocation as a combinatorial auction.

Keywords – Wireless sensor network; Channel allocation, Cognitive radio, Game theory, Resource management.

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1. INTRODUCTION

WSNs are made up of tiny, resource-constrained wireless sensor nodes that are often deployed in large numbers for specific purposes. As a result of limited processing and communication power, traditional sensor nodes in WSNs have limited performance [1]. In recent years, applications such as multimedia wireless sensor networks have begun to challenge the traditional data-only, delay-tolerant design assumptions. With more commercial uses, sensors are being installed in densely populated locations, potentially increasing interference in unlicensed frequency bands [2]. WSN Cognitive Radio (CR) may pick their transmission spectrum, adjust their transmit power, and so offer high bandwidth applications with increased network lifespan [3], [4].

The past 20 years have witnessed the rapid development of wireless networks and mobile communication technologies [5]. However, limited frequency resources have become the bottleneck for the development of more and more wireless applications and services. The dynamic allocation of frequency is one of the basic technologies of mobile Internet. Most countries have special departments to manage the use of frequency, such as the Federal Communications Commission (FCC) in the United States, and the radio management of the country. Bureau (RAH) [6]. They statically allocate alternative resources to large wireless network providers in the form of long-term and large-scale use. This static allocation strategy results in the ineffective utilization of the scarce amount and general resources, which has two important aspects:

1) The static allocation of the amount and potential does not fully consider the spatial and temporal differences of the demand for the general public, resulting in In many regions and in many time periods, large-scale frequency resources are in an idle state;

2) Emerging wireless network applications cannot exert their application value due to the lack of sufficient spectrum resources.

This inefficient spectrum allocation mechanism is reflected in the Radio Utilization Report issued by the International Tele-communication Union (ITU) [7]. At present, frequency allocation is faced with the following two situations:

1) Many spectrum owners, also known as primary users, are willing to rent out their idle spectrum resources to obtain certain economic benefits;

2) Emerging wireless networks Service providers, also known as secondary users, hope to support their wireless services by renting general resources. Therefore, in order to effectively utilize the limited spectrum resources, the dynamic secondary allocation of general resources becomes particularly important, and the emerging cognitive radio technology makes the dynamic secondary allocation of spectrum resources possible.

Designing and researching a spectrum allocation mechanism based on market laws has become an unsolved problem in the field of communication networks. Open spectrum auction markets, already emerging, these markets further improve the utilization rate of spectrum resources by buying, selling, and leasing spectrum resources. In the quota allocation game [8], we abstract the dynamic secondary allocation of quota resources into the relationship between market supply and demand, and design an incentive mechanism to optimize potential allocation.

An effective spectrum allocation [8] incentive mechanism should have two functions: Let spectrum resource owners be willing to provide their idle spectrum resources to spectrum resource demanders, and enable spectrum resource owners to obtain benefits when selling resources: Guide selfish spectrum resource demanders to orderly and efficiently using the available spectrum resources. Due to its fairness and effectiveness, the auction mechanism is considered to be an efficient resource allocation mechanism. The FCC has held a series of frequent license auctions. And received huge profits from the towel. In Europe, government departments have also held large-scale auctions for the use of UMTS' and ITE spectrograms. But these auction mechanisms are aimed at large-scale wireless network service providers, and our target is aimed at small-scale wireless service application providers. Such as community or home wireless network provider.

There are many challenges in designing a flexible and realistic spectrum auction mechanism [9]. The existing spectrum T mainly considers 5 challenges:

1) **Strategy-proofness:** The first major challenge comes from selfish users. strategic behavior. In the defense of the strategic spectrum auction mechanism, simply submitting real general demand information, including channel estimates and demand channel sets, can maximize the benefits of channel auction participants. Since auction participants are mostly rational and selfish, they always hope to increase their profits by strategically manipulating the auction. In the actual amount and price trading market. Selfish actors will not only lie about their channel valuations, but also their demanded channel sets. When both the offer and demanded channel sets are the buyer's private information, we call such a buyer a multi-strategy buyer. These selfish behaviors will inevitably affect the income of other participants. Therefore, if the pre-spectrum auction mechanism cannot guarantee the anti-tactics, it will greatly discourage the enthusiasm of real buyers to participate in the spectrum auction market. Most of the existing work does not consider auction models for multi-strategy buyers. The design of multi-strategy buyer auction mechanism belongs to the category of multi-parameter incentive mechanism design. The design of multi-parameter excitation is still an open research problem in the field of algorithmic game theory, and there is no effective solution yet. References [6-72] give the conditions that must be met in order to satisfy the anti-strategy in the multi-parameter incentive mechanism. Some papers also discuss negative results, such as the literature 8-s [pointing out that in the universal multi-parameter combinatorial auction model, there is no combinatorial auction mechanism that can satisfy both the anti-policy property and the positive system performance.

2) **Spatial reuse of channels:** Spatial reuse makes spectrum resources different from traditional auction commodities. If two wireless users are not in each other's interference area, they can use the same wireless channel at the same time. Using the spatial reuse of frequency potential can greatly improve the utilization of frequency potential.

3) **The heterogeneity of the channel:** The communication characteristics of the wireless spectrum resources make the auction items in the channel auction have heterogeneity. The heterogeneity of frequency distribution comes from two aspects: spatial heterogeneity and pre-rate heterogeneity in different regions. Channel availability and channel communication quality are different; on the other hand, channels with different heart rates also have different propagation and penetration characteristics.

4) **Diversity of bids:** It is possible for wireless devices to be equipped with multi-report antennas, so that wireless devices can operate on multiple different heterogeneous channels at the same time. Therefore, a wireless user reports this QoS requirements and can simultaneously clear multiple different channels. Furthermore, due to the heterogeneity of channels, buyers will have diverse preferences for different combinations of heterogeneous channels. For example, a secondary network user may have high estimates for some paired channels (used to provide WiMax services) and low estimates for other unpaired channels (used to provide WiMax services) value. Therefore the pre-spectrum auction mechanism allows buyers to have different valuations for different channel sets. Allowing the diversity of buyers' bidding can improve the opportunity of buyers to obtain channels, and make the spectrum redistribution mechanism more flexible and efficient.

5) **Maximizing social welfare:** The optimization goal of the most basic and well-rounded auctions is to maximize social welfare, that is, the sum of the valuations of the winners' assigned items.

2. REVIEW OF WORKS

The problem of zygomatic spectrum resource allocation [10] is a typical challenge mechanism design problem in the mobile Internet. In the wooden section, we will briefly review the research background of mobile Internet stimulation mechanism. Through the introduction of this research background, we can more clearly understand the research motivation and research significance of the dynamic frequency redistribution problem. The rapid development and wide application of the mobile Internet has changed the way of life of modern human beings, and its efficient operation can be saved by the cooperation among the user nodes of each network. The previous wireless communication equipment solidifies the network protocol in the hardware to ensure that the user node faithfully follows the network protocol. But with the rapid development of wireless communication equipment, and software, for example, in the free-rider problem, the user node only asks for resources or services without contributing resources or services; adverse selection problem, the user node misleads the system by revealing wrong information Develop in a direction that is beneficial to oneself; the collusion problem (collusion problem), user nodes form small groups to seek greater benefits. Research shows that the distributed autonomous system represented by Gnu tella [11] has nearly 70% of free riders Node. In the mobile Internet towel. Such selfish behavior can compromise network connectivity, reduce network availability.

Cognitive radio (cognitive radio) technology [11] provides an effective way to effectively utilize idle spectrum resources, and mobile Internet nodes equipped with cognitive radio can share the detection. "Empty hole" for communication. In order to obtain greater communication flow, selfish user nodes tend to modulate their cognitive radio equipment to the widest possible communication bandwidth, or shorten the back-off waiting delay when the channel is connected to obtain longer channel usage time. These selfish behaviors will increase the signal interference of wireless ad hoc networks, destroy the fairness of communication media access control protocols, and thus damage the robustness of mobile Internet networks visible. If there is no effective mechanism to ensure the cooperation between user nodes, the selfish behavior of user nodes will make the mobile Internet into a state of anarchy and chaos. Lead to a sharp decline in network availability and robustness. However, the highly dynamic nature of the mobile Internet and the discontinuity of connection determine that we cannot simply use the existing technologies of distributed autonomous systems to solve the problem of autonomous coordination in the emerging mobile Internet. Therefore, we need to set up an effective mechanism for the mobile Internet network to encourage the user nodes of the mobile Internet network to cooperate with each other and ensure the efficient operation of the mobile Internet network. The interaction between selfish user nodes in mobile internet can be naturally abstracted as a game model. Therefore, Muwen [12] will use game theory as the main tool to study the interaction behavior of user nodes in the mobile Internet network. Game theory studies the interaction of competition among multiple decision makers. And the mathematical theory and method of seeking optimal behavior strategy. Using game theory as a tool to carry out research on the incentive mechanism of mobile Internet cooperation has three advantages:

1) By formalizing the problems in the mobile Internet network into strategies, we can use rich game theory tools to analyze the

interactive behavior strategy of user nodes and their impact on the network.

2) Game theory provides us with the theoretical basis and feasible methods to achieve single-objective and multi-objective optimization in a competitive environment.

3) Many strategic game models, including non-cooperative games, conform to the characteristics of distributed dynamic decision-making in mobile internet networks, and their research results provide strong support for our design of cooperative incentive mechanisms in wireless networks.

The collaborative incentive mechanism [13] of mobile Internet users is set to H problem from 200. Over the years, it has been paid more and more attention by researchers at home and abroad. A climax has been formed since 2008. Several international journals have launched relevant special issues, and a number of high-level specialized academic conferences initiated by famous universities and scientific research institutions in North America and Europe have emerged. Several major academic conferences in the field of network and communication have also opened branches on related topics, and the number of academic papers collected by Chuanguan is also on the rise.

Spectrum management and efficient utilization in CR networks [14] is widely studied research problem since from last two decades by considering the networks like ad hoc and sensor. The game theory based approach gained researchers attentions due to promising outcomes for CR-Networks spectrum management. This section presents the literature related to spectrum allocation methods for CR networks.

“Local self-organized groups” regularly negotiate spectrum assignment with “CR users” in [15]. The concept utilises a poverty threshold to ensure minimal channel consumption and fairness for all users. However, most of these spectrum management models have been proved to be difficult to implement. The authors in paper [16] presented an energy-efficient CSS to handle the sensor node selection issue. The authors in paper [17], presented an energy-efficient SUs selection method is presented to reduce energy and increase detection performance. Due of the openness, dynamism, and unpredictability of the wireless environment, the authors in paper [18] presented a correlation-aware node selection technique for CSS. The authors in paper [19] further investigated and produced generic criteria for decision-approach selection where real channel propagation effects exist. The authors in paper [20] defines spectrum management as the practise of managing radio frequency use to maximise efficiency and net societal benefit. The Nigerian government assigned the Nigerian Communications Commission (NCC) with creating and enacting policies that would guarantee that this rare resource is adequately managed under its jurisdiction.

A non-convex game was introduced by the authors in paper [21] presented to study the presence and uniqueness of a typical Nash equilibrium. Their algorithm works in both cooperative and non-cooperative cognitive radio networks.

It was proposed in the paper [22] that a Primary User (PU) and several Secondary User (SUs) sharing the spectrum may be solved using cooperative game theory. This game started with all SUs adopting starting strategies and mutual information, then having to alter their tactics iteratively based on the latest state observations.

A innovative rate-based pricing mechanism for PU was developed by the authors in the paper [23]. This method reduces communication signalling overhead. Furthermore, both the PU and the SU can transmit at high speeds, improving spectrum efficiency.

Authors suggested a network-assisted cooperative game theory in the paper [24]. In their suggestion, the authors propose that a group of SUs access the spectrum of PUs in a cellular OFDMA network. The proposal states that PUs and SUs provide power restriction and channel condition information to the PU base station, which calculates the optimal sub-channel and power allocation for all users.

In the paper [25], the authors assume that the players are selfish (players that strive to maximise their personal earnings) and that the PU are oblivious of the existence of SUs, allowing SUs to exploit the spectrum.

The authors in paper [26] developed dynamic spectrum management for CR-WSNs. They solved the question of how many SSNs are needed. They initially looked at the impact of SSN ratio on spectrum sensing accuracy in terms of network energy efficiency. By improving the cooperative detection probability, the ideal SSN ratio was found (CDP).

The authors in paper [27] described a new energy-efficient game-theory-based spectrum decision (EGSD) strategy for CR-WSNs. The EGSD system uses two spectrum selection algorithms: random and game-theory-based. With the EGSD technique, you can additionally coordinate cluster member clustering. Individual sensors may adjust and learn from their prior decisions and those of their neighbours, as suggested in [28]. In order to meet the data needs from source to sink, they presented a multi-agent distributed and adaptive approach.

3. SPECTRUM ALLOCATION INCENTIVE MECHANISM

In this section, we will revisit the frequency distribution incentive mechanism. The allocation incentive mechanism is mainly based on two models: strategic game and auction.

Spectrum Allocation Incentive Mechanism Based on Strategy Game Model. The study of this mechanism begins with the analysis of Nash equilibrium. Halldorsson et al. [29]. Felegyhazi et al. [30] analyzed the problem of multiple wireless application service providers (service providers) competing to use spectrum resources to compete for users. Felegyhazi et al. [31] also studied the existence of Nash equilibrium in the channel allocation game. Channel allocation game convergent Nash equilibrium set-type and distributed algorithm. Subsequently, Wu Fan et al [32] jointly proposed a channel allocation.

1. Fan Wu et al. [32] jointly proposed a channel allocation incentive mechanism, so that the channel allocation game can gradually converge to a strongly dominant strategy equilibrium (strongly dominant strategy equilibrium). And maximize the throughput of each system in this equilibrium state. Wang Xinbing et al. [33] proposed a kind of anti-towel conspiracy Nash equilibrium. And proved its existence in the spectrum allocation game. Zhang Qian et al. [34] took the lead in studying the existence of a Nash equilibrium in a one-layer spectrum allocation market model. Kasbekar and Sarka [35]: Using a repeated game model to study the channel paid assignment problem in cognitive radio networks. And the construction method of Nash equilibrium is clearly given. In 2011, Wu Fan et al. [32] proposed a spectrum allocation incentive mechanism that adapts to dynamic tunable channels. (dominant strategy equilibrium) and maximize the throughput of a wireless network. The problem of resource allocation among selfish actors has been extensively studied in different network environments, such as wireless mesh networks, OFDMA cellular Network Corpse and LTE Network.

2. Spectrum allocation excitation mechanism based on auction model. This mechanism is represented by VERITAS' and TRUST, proposed by Zhou et al. [36]. VERITAS adopts an auction model similar to cRay. Let network nodes bid for spectrum resources, and decide the winning bidder and the fees to be paid according to the bidding situation. AS under VERI not only maintains the anti-tactical nature of frequency auctions, but also improves the space utilization of frequency auctions to a certain extent. TRUST creatively combines spectrum allocation and double auction to effectively prevent selfish behavior in both the sale and demand of spectrum resources, but there is a problem of low utilization rate of spectrum resources. Subsequently, Wu Fan et al. [32] proposed a new type of reserve price auction machine, SMALL-SMAI.L, which can not only ensure the anti-tactical nature of frequent sneak auctions, but also make up for the low utilization rate of VERITAS and TRUST deficiency also. Zhang Qian et al. [37] proposed a spectrum auction mechanism based on VCG (named after the pioneering work of Vickrey. Zheng [38] also studied the spectrum auction mechanism the problem of conspiracy and fraud, and proposed that Athena provides a conspiracy prevention mechanism with adjustable strength for pre-book auctions. Recently, Wang Xinbing and others [39] creatively proposed a channel allocation mechanism based on combination auction (coml, inatorial auction). In addition, there are some other works in the channel auction, such as the online channel auction mechanism 39-, the profit maximization problem in the channel auction 32-test. The higher time complexity of solving the optimal solution For different channel interference models and different valuation function forms of buyers, researchers have proposed a variety of effective approximation algorithms [40]. We have also made some creative works in this regard, such as the heterogeneous spectrum auction algorithm Tide 3, one, spectrum auction algorithm with privacy protection function. In recent years. Researchers have begun to pay attention to the spectrum access incentive mechanism based on online auction. Illinois, United States.

The WINET research group led by Li Xiangyang [41] of the University has made in-depth research on the design of online frequent auctions and incentive mechanisms. Online frequency distribution and charging mechanism. Maximize the total social benefit. When users arrive at a Poisson distribution, TODA', an online auction mechanism can obtain 80% of the social benefits of the offline (off-line) VCG auction mechanism and 70% of the frequent use rate. Under two user arrival models (semi-random arrival model and random arrival model), the synchronous approximate maximization of social benefit and expected income is achieved. SOFA imposes restrictions on the bidding time of the bidders and the decision-making time of the auctioneers after their arrival, and stipulates that the winning party can only obtain a single channel, so that the auction system can achieve Nash equilibrium in the case of preemption. TOFU, on the basis of SOFA. It makes selfish users unable to benefit from low-price bidding, and the ratio of the total revenue obtained compared to the offline VCG auction mechanism is greater than 95%. They also consider multi-channel online auctions. Yang Yaoyu, Long Chengnian, etc. [42], considering the reusability of time and space, used the online market clearing method to set up a settlement rule for the dynamic conflict graph. The Topaz' designed by Deck et al. [43] uses the 3D bin packing technology to allocate time, space and rate distribution at the same time, and adopts a threshold-based charging method to ensure the availability of media access to online auctions credibility.

4. PROBLEMS WITH THE CURRENT SPECTRUM AUCTION

Although there have been many research results on the redistribution of conventional resources in recent years, we believe that these T wells have four major problems: model distortion, equilibrium loss, mechanism untrustworthy, and distribution loss of control [44].

4.1 Model Distortion

The game model is the basis for dynamic spectrum resource reallocation, but in order to make the problem solvable, most of the existing work has introduced too many idealized flaws in the construction process of the game model. processing capacity, transmission rate, transmission power consumption, etc.; another example, assuming that the communication channel is homogeneous, with the same bandwidth, noise and interference intensity. This kind of research method that adapts the problem to the solution will inevitably lead to a greatly reduced practicability of the research results.

4.2 Balance loss

Most of the existing work stops at analyzing the existence of Nash equilibrium. However, given a game model, Nash equilibrium is often not unique, and the performance of the system brought by different Nash equilibrium is often different. When there are multiple Nash equilibria. The pros and cons of different Nash equilibria of Liubie need to be further studied. The existence of Nash equilibrium does not mean that the system can converge to Nash equilibrium in a limited time, so the convergence of Nash equilibrium is also a problem that we need to study.

4.3 Mechanism is untrustworthy

Nash Equilibrium is a relatively fragile solution concept in game theory (solution concept). When there are multiple Nash equilibria, players may still manipulate the game process to make the system converge to a more favorable Nash equilibrium state. However, there are not many high-intensity incentive mechanisms that can achieve a dominant policy-post equilibrium or an anti-strategy.

4.4 Out of control distribution

Most of the existing excitation mechanisms rely on a trusted party (or core control) to ensure the reliability of the mechanism. Such as the central bank responsible for virtual currency settlement and the reputation center for recording reputation scores. This centralized control method is not suitable for the distributed network environment, resulting in the only feasible solution in the distributed network is the exchange of things and things. Obviously, barter is not conducive to the flexibility of network information dissemination and service delivery. Most of the existing spectrum auction mechanisms require a credible core node to be responsible for the orderly conduct of the auction.

5. KEY SUBJECT ISSUES IN SPECTRUM DYNAMIC MANAGEMENT

Aiming at the four major problems of model distortion, equilibrium loss, mechanism failure, and distribution loss control, the research on dynamic spectrum management will focus on the following key scientific issues:

1. The game model is a mathematical model that is highly abstracted from the real network environment. The game model describes the interest trend of the participants (user nodes) and the rational behavior strategies in the game, and determines the final game results generated by the participants' behavior strategies. Building a game model that can accurately reflect the complex spectrum management system is the basis for the research and design of spectrum auction mechanisms. A game model consists of two main parts: the payoff/utility function and the set of strategies. The utility function reflects the interest trend of the players in the game; the strategy set reflects the behavior space of the players. Accurate selection of utility functions and strategy sets is crucial for accurate behavioral goals of participants, analyzing game equilibrium and designing effective incentive mechanisms.

2. The existence, uniqueness and convergence of Nash equilibrium (research on the problem of equilibrium misjudgment). Given a wireless network game problem or a specific redistribution problem, our first concern is whether there is a Nash equilibrium in the game without the influence of external factors. If there is, whether the Nash equilibrium is unique, when there are multiple Nash equilibria, it is necessary to judge the pros and cons of each Nash equilibrium. Given the evaluation criteria, whether there is an optimal Nash equilibrium. When there is an optimal Nash equilibrium, how the system converges to an optimal Nash equilibrium, and how to evaluate the convergence time and communication costs will be important issues

3) Existence and design of strong incentive mechanism

Nash Equilibrium is a kind of weak solution concept, and there are 3 reasons for it:

i. The incentive effect of Nash equilibrium on a player to follow its equilibrium strategy is based on the assumption that all other players follow their corresponding equilibrium strategies. When the above assumptions cannot be guaranteed, the Nash equilibrium cannot produce any stimulating effect on the participants.

ii. When the network system reaches the Nash equilibrium, its performance often cannot reach the optimization. E.g. The system throughput is not maximized, or the route selected is not the lowest power path. Because the Nash equilibrium state of the network system is often not unique, some selfish nodes will deliberately guide the network system to converge to the favorable Nash equilibrium state in order to maximize their personal interests, resulting in the loss of network performance.

iii. The process of the network system converging to Nash equilibrium is often very slow and long. In some cases, the network system cannot even converge to a Nash equilibrium state. while oscillating back and forth between multiple states

4) The dependability of trusted parties (the problem of out-of-control distribution of research) Most of the existing incentive mechanisms depend on the reliability of a trusted third party

5. CONCLUSION

The problem of spectrum distribution has been systematically studied, the problems existing in the existing work are pointed out, and feasible solutions are proposed. In the secondary spectrum market, we assume that the nodes of the wireless network are strategic players, have their own interests, and obtain limited spectrum resources through mutual competition. We use the auction mechanism to design an efficient and orderly allocation plan for the total amount. We point out that a flexible and efficient spectrum auction mechanism needs to consider five main design difficulties: user selfish policy behavior, channel heterogeneity, channel spatial reuse, user preference diversity and social welfare maximization. Improving the spectrum management does not alone solve the problem of energy efficiency in CR-WSNs; it required the energy efficiency based spectrum management algorithms for CR-WSNs. In this research, we have studied the approaches to improve the energy efficiency and QoS of CR-WSNs using the novel energy efficient game theory algorithm.

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Corresponding Author

Vennila N. L.*

PhD Student, Kalinga University, Raipur