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Department of Electrical and Electronics Engineering

SECURITY SYSTEM OF SPETRUM SHARING AUCTION

Master Thesis

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Supervisor
Asst. Prof. Dr. Halit YAHYA

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DECLARATION

I hereby declare that in the preparation of this thesis, scientific ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, there is no falsification in the used data, any part of the thesis has not been submitted to this university or any other university as another thesis.

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The thesis study of Ahmed Kanaan KADHIM titled as SECURITY SYSTEM OF SPETRUM SHARING AUCTION has been accepted as MASTER THESIS in the department of Electrical and Electronics Engineering by out jury.

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SUMMARY

The rise in mobile communication spectrum demand by 2025 necessitates addressing supply-demand imbalances for the Internet of Things (IoT). IoT spectrum-sharing solutions, such as Dynamic Spectrum Sharing (DSS) and Cognitive Radio (CR), improve spectrum usage and efficiency for 5G systems. However, energy consumption is a major issue, especially for long-operating nodes. Security of spectrum auctions is crucial for fair conduct, but maintaining integrity in complex network settings is challenging. A secure double spectrum auction architecture has been developed to address security concerns and challenges. In this thesis, a two-cascaded securing algorithm for the sharing auction system that selects appropriate base stations (BSs) to offer a low-complexity, secure, and efficient spectrum auction, with a focus on spectrum allocation and its auction is proposed. In the first step, a Paillier cryptosystem approach is provided to provide secondary users (SUs) with bidding methods to safeguard its data. To increase the security of every symbol in the data between the broker (auctioneer) and SUs (bidders), the second step encrypts each bidder's data using a single resolution wavelet transform. It can be structured based on a pyramid algorithm to perform private bases for every bidder. Thus, the data for every bidder will be encrypted with different codes. A better level of security will be achieved by double-encrypting each bidder's data between the broker and the SUs. The simulation result reveals that, the proposed double security increases the satisfaction, immunity, security, and utility. In addition, when applied to the 5G signal, the proposed approach produced graphical results that showed high bidder satisfaction and auction income for the BSs. The impact of Monte-Carlo simulation is also taken into consideration by trying different number of iteration. The results have a significant performance with the big number of iteration. Thus, a big number of Monte-Carlo simulation with doubled security process for the auction spectrum sharing system.

Key Words: CR, DSS, 5G, Paillier Cryptosystem, and Wavelet Transform

ÖZET

2025'e kadar mobil iletişim spektrum talebindeki artış, Nesnelerin İnterneti (IoT) için arz-talep dengesizliklerinin ele alınmasını gerektiriyor. Dinamik Spektrum Paylaşımı (DSS) ve Bilişsel Radyo (CR) gibi IoT spektrum paylaşım çözümleri, 5G sistemleri için spektrum kullanımını ve verimliliği artırmaktadır. Bununla birlikte, enerji tüketimi, özellikle uzun süre çalışan düğümler için önemli bir sorundur. Spektrum açık artırmalarının güvenliği adil bir uygulama için çok önemlidir, ancak karmaşık ağ ortamlarında bütünlüğü korumak zordur. Güvenlik endişelerini ve zorluklarını ele almak için güvenli bir çift spektrum açık artırma mimarisi geliştirilmiştir. Bu tezde, spektrum tahsisi ve açık artırmasına odaklanarak, düşük karmaşıklıkta, güvenli ve verimli bir spektrum açık artırması sunmak için uygun baz istasyonlarını (BS'ler) seçen paylaşımlı açık artırma sistemi için iki aşamalı bir güvenlik algoritması önerilmektedir. İlk adımda, ikincil kullanıcılara (SU'lar) verilerini korumak için teklif verme yöntemleri sağlamak için bir Paillier kriptosistem yaklaşımı sağlanmıştır. Broker (açık artırmayı düzenleyen) ve SU'lar (teklif verenler) arasındaki verideki her sembolün güvenliğini artırmak için, ikinci adımda her teklif verenin verisi tek çözünürlüklü dalgacık dönüşümü kullanılarak şifrelenir. Her teklif veren için özel tabanlar gerçekleştirmek için bir piramit algoritmasına dayalı olarak yapılandırılabilir. Böylece, her teklif sahibinin verileri farklı kodlarla şifrelenecektir. Broker ve SU'lar arasında her bir teklif sahibinin verileri çift şifrelenerek daha iyi bir güvenlik seviyesi elde edilecektir. Simülasyon.

Anahtar kelimeler: CR, DSS, 5G, Paillier Kriptosistemi, ve Dalgacık Dönüşümü

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ABBREDIVATIONS

IoT	Internet of Things
5G	Fifth Generation
DSS	Dynamic Spectrum Sharing
CR	Cognitive Radio
SU	Secondary User
SS	Spectrum Sensing
PU	Primary User
VMNO	virtual mobile network operator
VCG	Vickrey-Clarke-Groves Auction
DWT	Discrete Wavelet Transform
QoS	Quality of Service
DSA	Dynamic Spectrum Access
LSA	Licensed Shared Access
LTE	Long-Term Evolution
SAS	Spectrum Access System
PIR	Private Information Retrieval
AHP	Analytic Hierarchy Process
QoE	Quality of Experience

CRN	Cognitive Radio Network
DSM	Dynamic Spectrum Management
DoS	Denial of Service
MAC	Medium Access Control
ML	Machine Learning
HSTSNs	Hybrid Satellite–Terrestrial Sensor Networks
D2D	Device-to-Device
BS	Base Station
DF	Decode-and-Forward
AF	Amplify-and-Forward
UE	User Equipment
NOMA	Non-Orthogonal Multiple Access
TDMA	Time Division Multiple Access
CA	Cryptographic Authority
PBFT	Practical Byzantine Fault Tolerant
MOSS	Multi-Operator Spectrum Sharing
POW	Proof Of Work
IDE	Integrated Development Environment
PO	Primary Owner
SAMW	Sequential Auction-based Multi-Winner

SB	Spectrum Broker
RA	Resource Allocation
4G	Fourth Generation
MIMO	Multi-Input-Multi-Output
CPU	Central Processing Unit

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INTRODUCTION

By 2025, it is anticipated that the demand for mobile communication spectrum would have grown to 1,340–1,960 MHz worldwide. The mismatch between supply and demand for spectrum resources must be addressed beforehand in order to enable the Internet of Things (IoT) of the future. For the large number of IoT devices, which frequently produce substantial data streams while functioning under limitations like short battery life and computing power, IoT spectrum-sharing solutions present a viable way to improve spectrum usage. Because they make it possible to reallocate temporarily idle resources, these technologies are essential to 5G and future systems because they increase overall spectrum efficiency. Spectrum-sharing techniques fall into two categories: static and dynamic. Allocating spectrum resources to users in a predetermined way is known as static spectrum sharing. Despite being simple and quick to use, this approach is ineffective in using spectrum resources, which makes it unsuitable for contemporary applications that demand a great degree of flexibility, adaptability, and mobility among system users. As a result, dynamic spectrum sharing is becoming more widely accepted as the best strategy, enabling more efficient using of the scarce spectrum supply (Zhu, K et. al. 2022), (Rachakonda, L et. al. 2024).

A constantly changing technology, the Internet of Things (IoT) is changing a number of industries, including smart retail, healthcare, agriculture, communication, transportation, manufacturing, energy, and security systems. The number of IoT devices is expected to increase dramatically, reaching almost 30 billion by 2030, according to figures. These gadgets are made to gather enormous volumes of data, which are subsequently sent to the designated uses. However, the data passes through a number of steps, including as sensing, processing, and storage, before being transmitted. It is crucial to remember that IoT devices communicate via the radio spectrum, which is a valuable but finite resource. Therefore, the smooth functioning of IoT devices depends on the effective use of the radio spectrum (Choudhary, A 2024), (Rao, A et. al. 2023).

CHAPTER ONE

MOTIVATION AND THESIS CONTRIBUTIONS

1.1. Motivation

The demand for effective use of scarce frequency resources has increased due to the rising popularity of IoT devices. A solution to the limitations of available frequency resources in communication networks is Dynamic Spectrum Sharing (DSS), which is made possible by Cognitive Radio (CR). Network nodes are designated as Secondary Users (SUs) by CR inside DSS. Due to the energy-intensive nature of spectrum sensing (SS), these nodes monitor the Primary User (PU) channels, which imposes extra energy needs. Since nodes in IoT networks follow protocols intended to prolong their operational lives for several years, energy consumption is a major problem. There are a number of difficulties in integrating CR mechanisms into IoT networks, including figuring out which nodes should perform spectrum-sensing activities, implementing spectrum-sharing capabilities, and identifying suitable frequency ranges (Wu, Q et. al. 2023), (Sufyan, A et. al. 2023), (Nasser, A et. al. 2021).

The implementation of CR in IoT networks and the standardization of CR-based IoT systems have been the subject of several research. According on the findings of the sensing process, these studies describe the extra needs for putting CR mechanisms into practice, such as specific hardware and protocols that allow nodes to move between frequency bands. Since having numerous frequency channels makes channel switching easier and more efficient, multiband access has become crucial as a result of the growth of IoT devices. Cooperative spectrum sensing is frequently used to improve the energy-throughput performance of CR-IoT networks. Several SUs work together in the SS process with this method, which increases sensing precision but also presents energy consumption issues because of the constant sensing and reporting needs as shown in figure 1.1 that reveals the different needs for 5G bands. In the context of changing sensing settings, the decision between cooperative sensing and local sensing is also examined, with each strategy presenting unique trade-offs (Wu, Q et. al. 2023), (Sufyan, A et. al. 2023), (Nasser, A et. al. 2021).

Ensuring the security of spectrum auctions is crucial for conducting them in a fair and effective manner. However, maintaining the integrity of spectrum auctions is a difficulty for the current double spectrum auction techniques in open and complex network settings. For example, rival bidders can use past bid values to forecast future bids if a buyer's bidding information is disclosed, allowing them to manipulate the auction and obtain an unfair advantage. Sellers could also take use of this knowledge. Furthermore, bidders or sellers may bribe or breach spectrum auction servers to get private bidding information, which might distort auction results. The integrity of the process may be further compromised if dishonest agents sell past bidding data for their own benefit. In privacy-preserving auctions, confirming the legitimacy of transaction data is another crucial concern. Auction servers, for instance, usually compute and analyze transaction data from spectrum buyers and sellers. Nevertheless, there are weaknesses in the auction process as other participants are unable to confirm the veracity and correctness of the data produced and provided by the server (Wang, J et. al. 2021), (Wang, J et. al. 2024).

Figure 1.1. Needs of 5G bands (Sufyan, A et. al. 2023)

In order to handle data, calculate outcomes, and complete the auction process, spectrum auctions frequently depend on a semi-honest agent. Sensitive information might be leaked by such an agent, though. Researchers have suggested procedures employing two semi-honest actors, assuming they do not conspire, to improve the privacy of spectrum auctions. These techniques have significant drawbacks even though they somewhat increase security. In practical situations, it is difficult to guarantee that the agents properly follow the non-collusion assumption. Furthermore, these schemes are not appropriate for wider applications as they are limited to situations in which buyers request for a single spectrum channel (Dang, Y et. al. 2022), (Chen, Z et. al. 2014), (Huang, Q et. al. 2013).

For example, some mobile network operators may split their frequency bands into several sub-channels when they lease or sell spectrum to virtual mobile network operators (VMNOs). Multiple sub-channels are frequently needed by VMNOs depending on their service requirements. It may be possible to deduce rivals' trade secrets or manipulate the results of subsequent auctions if the quantity of spectrum channels that buyers have requested or their bid prices are revealed. The bid values of both buyers and sellers, as well as the quantity of spectrum channels that purchasers have requested, are examples of sensitive information in double spectrum auctions. Furthermore, there is insufficient validation of spectrum auction transaction data in the current security procedures, which allows for errors and manipulation. Auctions are vulnerable because current systems do not offer verification techniques to guarantee the accuracy of auction outcomes and do not secure the privacy of purchasers' channel requests (Akgül, Ö et. al. 2019), (Chen, Z et. al. 2019), (She, Z et. al. 2022), (Wang, J et. al. 2024).

In order to avoid potential security concerns and address the aforementioned challenges, a new secure double spectrum auction architecture has been developed. This architecture's design relies on the following two fundamental presumptions: the anticipating of both buyers and sellers of spectrum would provide their accurate appraisals during the auction procedure, and the anticipating of buyers and sellers to compete with each other and avoid collusion (Wang, J et. al. 2021), (Watts, A et. al. 2024), (Balmann, A et. al. 2021).

A spectrum auction with several players from both sides has been created to satisfy the transaction needs of spectrum buyers and sellers, and it is becoming a common area of study for academics. Notwithstanding many developments, these auction methods may have security flaws due to the intricate network environment. Thus, some of related works are presented as follows. In order to solve the spectrum resource allocation issue and optimize system throughput, a multi-agent deep reinforcement learning-based system that improves the quality of service in heterogeneous vehicle networks was also presented by Tian et al. (Tian, J et. al. 2021). However, reinforcement learning struggles to converge in complicated contexts and needs big datasets for training. Some researchers have resorted to heuristic techniques for resource allocation in order to get beyond these restrictions.Zhu et al. (Zhu, R et. al. 2021) suggested a blockchain-based two-phase secure spectrum sensing and sharing auction method in order to solve this problem. This method greatly increases throughput and system utility. Qin et al. (Qin, P et. al. 2022) created a resource allocation mechanism for air–ground integrated power IoT networks, which greatly increased spectrum efficiency. In order to enhance spectrum multiplexing rates, decrease resource allocation delays, and speed up convergence, Hu et al. (Hu, X et. al. 2022) devised a hybrid approach that combines heuristic techniques with deep reinforcement learning. In order to maximize user experience. In order to increase overall efficiency, Su et al. (Su, P et. al. 2022) suggested a resource allocation system based on the Vickrey-Clarke-Groves (VCG) auction. Qin et al. (Qin, P et. al. 2022) created content-oriented and user-oriented resource allocation algorithms to improve the spectrum allocation efficiency of air–ground integrated networks. This method rely on conventional techniques, which is prone to converge at local optima since they frequently fail to acquire comprehensive information in real-world circumstances. While Katwe et al. (Katwe, M et. al. 2023) suggested a differential evolution-based meta-heuristic framework that cooperatively distributes resources among users, hence improving channel usage, Nguyen et al. (Nguyen, L et. al. 2023) created a meta-heuristic technique to reduce user delays and increase link transmission rates. Nevertheless, in complicated and large-scale contexts, heuristic approaches frequently suffer from sluggish convergence. Because of its efficiency and fairness, economics' auction theory has recently been used to allocate resources. Zhang et al. (Zhang, M et. al. 2023) presented a fuzzy logic-assisted Q-learning model for intelligent and dynamic resource allocation through centralized management. Torres et al. (Torres, F et. al. 2023) presented a dual-objective hyper-heuristic algorithm for allocating radio resources. Nevertheless, the abovementioned strategies frequently fall short in addressing the dynamic resource adjustment and synergy throughout the auction process, and they continue to have difficulties in effectively and precisely resolving the winner determination issue.

1.2. Problem Statement

Specifically, centralized spectrum allocation processes do not take into account the changing demands of different services or the dynamic nature of the radio spectrum when allocating static frequency bands for specified uses. Pre-assigned spectrum bands are frequently underutilized as a result of this strategy, and the quick growth of cellular services causes many commercial bands to become overcrowded. Governments have approved secondary spectrum markets to address this inefficiency, enabling primary license holders to rent their spare spectrum to secondary users. Spectrum auctions, which are based on microeconomic theories, have become a viable way to distribute unused spectrum to possible secondary users. However, conventional auction models cannot be used directly because the radio spectrum is inherently reusable. Bidders who are outside of each other's interference range must be able to share the same frequency at the same time during spectrum auctions. Consequently, while conventional auctions depend on reaching optimal allocations, attaining optimal spectrum allocation is categorized as an NP-complete task. Additionally, the possibility of fraud and collusion, including covert transactions between dishonest bidders and the auctioneer, complicates the design of a spectrum auction and can have a detrimental effect on the network as a whole. Safeguards against bid-rigging by participants and possible auctioneer fraud must be included in a secure spectrum auction.

1.3. Thesis Objectives

To design a framework for a multitier spectrum-sharing system to maximize the use of underused spectrum resources and preventing any fraud and bid-rigging are crucial steps in creating a highly secure spectrum auction that makes use of the Paillier cryptosystem. Cellular communication networks have limited spectrum, therefore in order to effectively distribute resources in the face of rising demand, an auction-based scheduling technique is required. Spectrum operators can prepare for expected future resource requirements and distribute network resources according to scheduled availability with the help of the suggested method. By serving as the auctioneer, this framework enables the cellular network operator to effectively and safely oversee the distribution of limited spectrum resources. Homomorphic encryption is used to guarantee auction security and safeguard user privacy since spectrum auctions are susceptible to bid-rigging and fraudulent activity by dishonest auctioneers.

1.4. Thesis Scope

Strengthening the security of auction systems throughout managing the 5G spectrum-sharing process is the main goal of this thesis. By detailing the steps required to accomplish its goals and pointing out topics that are outside its scope, Figure 1.2 provides an illustration of the research's broadness.

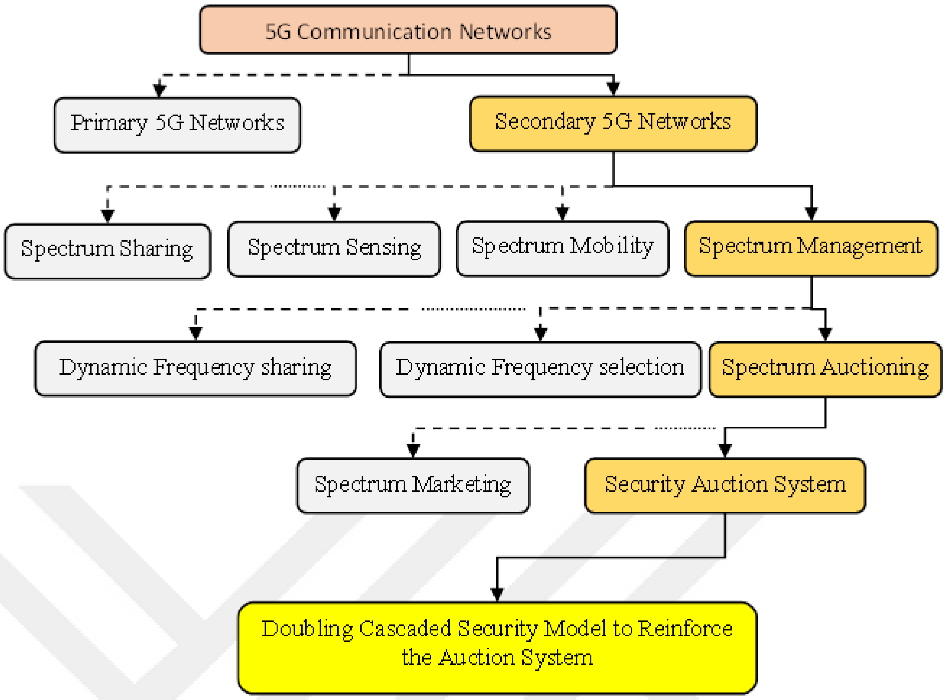

Figure 1.2. The Thesis Scope

1.5. Contributions of Thesis

In light of the aforementioned objective, this thesis offers the following concise contributions to the corpus of current research:

- The proposed architecture system supports a variety of 5G frequency bands, including government and commercial allotments, and considers spectrum reusability.
- The proposed system makes sure that bidders provide their accurate assessment of the spectrum during the auction process. By acting as a dominating tactic, this honesty stops the auction from being manipulated.
- To ensure the secrecy of bidding values, the proposed system uses doubled cascaded security model; the single resolution DWT and

Paillier cryptosystem to encrypt them. In order to conceal their true bids from the auctioneer, bidders send encrypted values across a safe buffer. The auctioneer may nevertheless safely decide the outcome of the auction and handle payments in spite of this encryption.

- The proposed system offers a secure spectrum auction that guards against bid-rigging and reduces the possibility of dishonest auctioneers engaging in fraudulent activity. It guarantees bidder satisfaction, produces income, and accomplishes effective spectrum usage.

1.6. Thesis Organization

This chapter included a summary of the significance and contributions of the thesis. There was also a succinct introduction. This thesis's remaining sections are organized as follows: The conventional auction of spectrum sharing idea, which is utilized in cellular communication networks, is introduced in Chapter 2. The auction mechanisms for spectrum sharing have been evaluated in related studies. The spectrum sharing security systems auction is introduced in Chapter 3. These systems' formulations are modeled analytically. The suggested security system-based auction is then determined and examined. The findings of the suggested security system were presented in Chapter 4 and are shown both visually and mathematically. Furthermore, the specifics of the inquiry into these findings are presented. The thesis summary, findings, and some recommendations for more research are provided in Chapter 5.

CHAPTER TWO

LITERATURE REVIEW

2.1. Preamble

5G mobile networks improve efficiency, throughput, and latency by providing better devices and communication capabilities. For mid- and long-range IoT, they are essential because they enable mobile firms to expand their communication capacity and offer more reliable and efficient services (Sharma, S et. al. 2021). In order to supply effective segments and improve Quality of Service (QoS) for IoTs, the scarce spectrum depends on appropriate spectrum auctioning. 5G IoT is becoming a key tool for digital transformation as a result of this trend, which is propelling cutting-edge IoT services including smart cities, e-healthcare, and smart agriculture (Allioui, H et. al. 2023). The number of segments, the effective distribution of segments, and the income for government authorities are all-important considerations in the design of a successful spectrum auction. An optimization model for balancing numerous objectives was created in a prior study, but it only implied quality in the number of throughput-related segments. Communication quality parameters like penetration rate and latency were disregarded. The optimization goal of the study was restricted to revenue and segment count, which is insufficient for 5G ecosystems. In order to maximize the equilibrium of 5G ecosystems, quality and value measurements have to be determined and displayed (Fister, J et. al. 2022), (Chiang, J et. al. 2021), (Chiang, J et. al. 2018).

2.2. Fundamentals of Dynamic Spectrum Access

The growth of mobile communication networks has increased the need for energy efficiency, coverage, connection, and capacity. However, the current spectrum is constrained, with higher frequencies being limited due to attenuation and air absorption. Frequency availability below 1 GHz is also restricted, hindering wireless network growth and user expansion. Furthermore, spectrum use remains inefficient, and as networks advance, efficiency improves at a slower pace. Resolving this issue is crucial for future improvements in spectrum efficiency (Chochliouros, I et. al. 2021). Regulatory bodies allocate spectrum statically, but a significant portion remains unused, resulting in underutilization of the limited resource. Dynamic Spectrum Access (DSA), also known as Cognitive Radio (CR) scheme, enables unlicensed users to opportunistically utilize licensed spectrum. This approach minimizes interference and security risks for licensed users by utilizing rapid sensing, coordination, and cooperation. DSA and CR are often used interchangeably in literature (Choi, J et. al. 2020). Cognitive Radio (CR) functionalities have been standardized across IEEE protocols like IEEE 802.22 WRAN, IEEE 802.11af, and IEEE 1900.x series to facilitate Dynamic Spectrum Access (DSA). IEEE 802.22 WRAN allows unlicensed TV frequency band use, while IEEE 1900.x series includes multiple standards for DSA. IEEE 802.11af uses CR techniques to identify white spaces. Licensed Shared Access (LSA) in LTE and 5G NR networks manages network parameters and minimizes interference, requiring licenses for secondary users. Other standards include IEEE 802.15.4m for Zigbee networks and IEEE 802.19.1 (Piran, M et. al. 2020). Briefly, the DSA has many benefits that can be summarized as follows (Raschellà, A et. al. 2019):

- Spectral Efficiency Enhanced: Secondary unlicensed networks can use underused or unused licensed spectrum through Dynamic Spectrum Access (DSA), allowing for a duty cycle as low as 10-40%. This can increase spectral efficiency by transferring data instead of acquiring more spectrum.

- Making New Services Possible: Acquiring dedicated spectrum is a significant hurdle for new services due to its scarcity and cost. DSA can ease access to this spectrum for new networks.

- Lower Expense: Opportunistic use of licensed spectrum would be significantly more economical for a new network than acquiring a specialized license.

- Profitability for Networks with Licenses: In times of idleness, DSA provides licensed networks with the opportunity to lease their spectrum bands and earn extra income.

On the other hand, the following categories can be used to group DSA approaches according to various parameters.

- In accordance with the system architecture category (Lin, Y et. al. 2021): DSA methods are categorized into centralized and distributed networks. Centralized networks have a designated authority controlling access, utilizing spectrum sensing data. This approach improves efficiency, reduces interference, and prioritizes critical devices, but also has high overhead, infrastructure requirements, and a single point of failure. Distributed networks, without a central controller, are ideal for ad-hoc networks without base stations. However, this decentralized model may lead to inefficiencies and security concerns due to the lack of a central authority. Spectrum-sharing methods, developed using distributed and centralized network architectures, offer efficiency and adaptability. Distributed methods, like the harmonized SDN-enabled approach, reduce errors due to inconsistent QoS. Research explores optimization strategies like interference graph and game-theoretic approaches to enhance decentralized spectrum sensing and adaptability. However, their limited flexibility remains a challenge.

- In accordance with the spectral sensing pattern category (Raymond, J et. al. 2023): DSA can be categorized into non-cooperative and cooperative networks based on spectrum sensing behavior. Non-cooperative networks allow individual devices to make decisions independently, reducing overhead and allowing faster detection. Cooperative networks involve multiple secondary devices sharing local sensing results, improving detection performance. However, cooperative sensing introduces complexity and implementation challenges, requiring a dedicated control channel and avoiding asynchronous and outdated information.

- In accordance with the spectrum access category (Badran, E et. al. 2024): DSA is a spectrum-sharing model that focuses on managing uplink interference in massive machine-type communication scenarios. It is divided into three types: interweave, overlay, and underlay networks. The Spectrum Access System (SAS) is gaining attention for efficient management. However, concerns about secondary user location privacy have been raised. A multi-server Private Information Retrieval (PIR) approach is proposed to protect SU location data. The Analytic Hierarchy Process (AHP) is applied to optimize spectrum sharing in 5G New Radio. The Dynamic Advanced Access Spectrum Sharing method is introduced to support both public and private telecommunication operators while ensuring high Quality of Experience (QoE). A hybrid spectrum access method is proposed, combining exclusive and pooled access.

2.3. Cognitive Radio Concept

Cognitive Radio (CR) is a real and practical invention for effective Dynamic Spectrum Access (DSA). A spectrum segment can be allocated to a Primary User (PU) as a DSA concept. The Secondary User (SU) does not receive all of the exploited spectrum when a PU requests its own spectrum. Furthermore, some SUs utilize the unused spectrum until PU wants to use it once again. The effectiveness of spectrum exploitation may therefore be significantly raised once the spectrum can be opportunistically utilized (Nasser, A et. al. 2021), (Fraz, M et. al. 2023).

SUs must be able to perceive the spectrum in order to support DSA. SUs can identify PUs and predict the degree of interference thanks to a variety of cognitive talents. These capabilities, which are essential elements of the CR idea, include sensing, learning, and measuring. These capabilities are, however, limited by a number of factors, including the radio channel's characteristics, the current radio environment, user needs and applications, and power availability. Furthermore, a number of jobs carried out by CR technology are essential for improving the dependability of detecting and adjusting the idle spectrum's radio properties. Spectrum sensing, spectrum sharing, spectrum mobility, and spectrum management are some ways to describe these duties (Zhang, Y et. al. 2023), (El-haryqy, N et. al. 2024), (Srivastava, A et. al. 2024).

The spectrum regulator, service provider, PUs, and SUs are the four stakeholders that require spectrum management and an economic model in a CRN. The service provider wants to boost profits with limited spectrum bands, the regulator wants to use spectrum bands to their fullest potential, PUs want to split the growing profits as incentives, and SUs want to expand their access to spectrum bands while guaranteed a certain level of quality of service. CRN wants to use primary networks as secondary users while paying less or no more than PUs since they have certain limitations when it comes to using their spectrum bands. Game theory is helpful for spectrum management in CRNs and may resolve issues with collaboration or conflict between parties. An extreme technique in game theory, auction theory can more effectively distribute resources and assess a community's worth (Parvini, M et. al. 2023), (Perera, L et. al. 2024), (Devi, M et. al. 2021).

2.4. Auction Fundamentals

The process of distributing resources and setting prices through participant bids is known as an auction. Auction theory is a subfield of economics that studies market behavior, analyzes auction results, and assesses their economic qualities. Efficiency, the best bidding tactics, equilibrium circumstances, and income production are all important aspects of an effective auction design. Furthermore, auction theory provides a theoretical foundation for organizing actual auctions, as those used to distribute telecoms spectrum or privatize public-sector businesses. Additionally, auctions are frequently used for resource allocation, task assignments, and multi-agent interactions (Kaltakis, K et. al. 2024), (Bingham, L et. al. 2024). The activity of purchasing and selling goods or services is the fundamental idea behind auctions. An auction often includes the following fundamental components as shown in the following table (Shi, Z et. al. 2022):

Table 1. Basic Components of Auction Process

Component	**Description**
Bidder	A bidder is a person who wishes to purchase goods at auction; in literature, the terms buyer and bidder are sometimes used interchangeably. In wireless communications, bidders engage in price competitions to compete for radio resources.
Seller	Spectrum holders, such as main license owners and regulators, are among the sellers in spectrum auctions who own commodities and are prepared to sell them for possible financial gains.
Auctioneer	A central manager and go-between for bids and sellers, an auctioneer is frequently a non-profit organization, a third-party broker, or the sellers themselves. They can also auction out radio resources, such as wireless network access points or base stations.
Commodity	Radio resource auctions can be used to trade commodities, or products exchanged between buyers and sellers. These commodities include periods of time, spectrum bandwidth, and spectrum licenses.
Valuation	Bidders have different values for the same commodity, and valuations are the financial assessment of assets. They can be either public or private, and the bidders' choices affect how much they are worth.
Price	In an auction, a buyer can place a bid to determine the bidding price for the item they want, and a seller can submit an ask to indicate the asking price for their commodity. The hammer price, which represents bidder payments and seller profits, is set by the auctioneer.

Thus, for many years, researchers have been examining radio resource auctions in wireless communications, particularly cognitive radio (CR). Three categories have been established for the sake of clarity (Devi, M et. al. 2021): single-seller auctions, multiple-seller auctions, and internet auctions.

- Single Seller-Spectrum Auction: This kind of auction is one-sided as there is no rivalry between the vendors. Furthermore, since the lone seller controls the radio resources and holds the auction among several purchasers, the roles of the auctioneer and the seller can be combined.

- Multiple Sellers-Spectrum Auction: Allocating various radio resources from multiple sellers to numerous bidders is made easier with a double spectrum auction. Both buyers and sellers provide their pricing (asks and bids) for exchanging resources throughout this procedure. A centralized controller usually acts as the auctioneer, supervising the sale by gathering pertinent data and coordinating bids and asks.

- Online-Spectrum Auction: Auctions are often conducted offline, with the auctioneer compiling all bid data in advance and rendering conclusions at a set time. However, the idea of temporal reusability has been examined in recent spectrum auction research, which has raised interest in online spectrum auctions. Buyers may bid at any moment during an online auction, and the auctioneer must distribute resources right away without being aware of subsequent bids.

On the other hand, numerous auction concepts have been put forth in theoretical studies and implemented in real-world marketplaces. Thus, a list of some common classifications is compiled that are frequently addressed in the literature (Perera, L et. al. 2024):

- Forward/Reverse: Buyers and bidders fight to purchase goods from vendors at forward auctions. In reverse auctions, on the other hand, vendors vie with one another to sell goods to purchasers.

- Single/Double-Sided: When just buyers or sellers are participating in the auction, it is referred to as a single-sided auction. The auction is designed to be double-sided if there are contests on both the buyers' and sellers' sides.

- Open-cry/Sealed-bid Auction: purchasers openly submit their offers in an open-cry auction, allowing all purchasers to be aware of each other's bids. Nonetheless, in a sealed-bid auction, bidders might covertly present their offers to the auctioneer.

- Single/Multi-Item: It makes sense because in a single-item auction, purchasers can only demand and bid on one commodity at a time, but in a multi-item auction, they can bid on several commodities.

To perform the auction process, many types may be used. The Vickrey auction process is another name for the second-price sealed-bid auction process, i.e., one of auction process types. Bidders are required to submit sealed bids using this method. The highest bidder wins, meaning they receive the commodity, while the second-highest bidder pays the same amount. Only the incentive concordance has to be investigated because the second-price sealed-bid payment rule seems to ensure individual rationality (Tu, X et. al. 2022). Other type, since multi-item combinatorial auction winner selection issues are typically non-deterministic Recent years have seen the proposal of several approximate winner determination techniques that are polynomial-time challenging. However, techniques for determining the approximate winner cannot be used with the VCG process (Abbass, O et. al. 2024). A broader variant of the Vickrey auction method is the Vickrey-Clarke-Groves (VCG) process. Assigning commodities in a way that is socially optimum is the goal of the VCG process. This approach makes sure that each bidder's best course of action is to offer their actual values and charges each individual for the harm they bring to other bidders. Additionally, it is a generalization of the Vickrey auction for combinatorial auctions with many items (Wagner, J et. al. 2023).

2.5. Security of Auction Management

Because spectrum sensing, access, trading, and mobility are all at risk from different types of assaults, it is imperative that security issues be addressed in Dynamic Spectrum Access (DSA) and Dynamic Spectrum Management (DSM). Deceptive node behavior in DSM systems can result in a number of security threats, including as malware infections, data manipulation, repudiation, spoofing, unauthorized access, Denial of Service (DoS), and system breaches. Other issues that DSM markets deal with include organized attacks, replay attacks, and interference in tradable spectrum bands. Because spectrum markets are susceptible to DoS and spoofing attacks, they require security mechanisms that are lightweight and appropriate for situations with limited resources. The Medium Access Control (MAC) layer is frequently the target of spectrum sensing (SS) attacks, and the growth of opportunistic DSA raises these dangers and necessitates the use of specific security measures. Specifically, attacks that impersonate primary users and falsify data jeopardize spectrum management, resulting in bad choices and secondary users passing for primary users. Additional dangers include service interruption attacks, message spoofing to find accessible spectrum bands, and denial-of-service attacks on spectrum sensing and sharing. Attacks that target secondary users with greedy resource occupation have a major effect on secondary users by delaying spectrum access, while attacks that target secondary users with overlap can cause network disruptions. Techniques like frequency hopping, spread spectrum approaches, data analysis based on Machine Learning (ML), and reputation-based trust models can be used to overcome these security issues. Through the detection and mitigation of harmful activity, these methods improve the resilience of DSA systems (Kumari, P et. al. 2023), (Ramezanpour, K et. al. 2023).

2.6. Literature Survey

The literature has several active strategies that addressed the issues with privacy or security of spectrum sharing. This section includes a few current, pertinent studies.

The literature contains several active strategies that address privacy and security issues within spectrum sharing as highlighted below with a few recent and relevant studies. In 2019, the authors have proposed an auction system for secondary relay selection on overlay spectrum sharing (Zhang, X et. al. 2019). They applied the system on the Hybrid Satellite–Terrestrial Sensor Networks (HSTSNs). They focused on the potential relay that would be the base stations (BS) of the 5G, device-to-device (D2D) nodes or other ad-hoc networks, which are capable of applying the unlicensed frequency band. The authors analyzed first both the decode-and-forward (DF) and amplify-and-forward (AF) relay protocols on the spectrum sharing mechanism for primary user’s (PU’s) message in HSTSNs. Then, they applied the Vickery auction mechanism that achieves the efficient and fairness secondary relay selection by one shot in a distributed manner, where the bids of the potential relay are the assistance transmission capacity by the different sub-time slot allocation in the entire time slot. The obtained results are compared the proposed auction-based algorithm with the maximum satellite-relay and relay-destination link and maximum satellite-relay link, which validate the effectiveness of the auction mechanism on cooperative spectrum sharing in HSTSNs for secondary relay selection. Besides, the effects of key factors on the performance of the auction mechanism are analyzed.

Although the proposed system has many advantages, the security level is very low since the key is public. In the same year, a trading of spectrum for D2D communication in cellular networks (Farshbafan, M et. al. 2019). The D2D pair can buy its required bandwidth from three types of service providers (SPs) that are willing to share or resale their spectrum. The D2D pair can use the spectrum of the SPs that are willing to resale their resource in an overlay manner where all UEs use orthogonal resources. The D2D pair bids a demand curve and each supplier offers a supply curve. In order to have a practical and more realistic system model, it is assumed that each player is not aware of the strategy of the other player and can just be aware of the bandwidth price. Thus, the game is modeled as an incomplete information game. They proposed to utilize a best response based learning method in a repeated manner as the solution of the incomplete information game. It is shown that the proposed algorithm converges to the NE point of the game iteratively. The proposed method converges rapidly and quicker than the state-of-the-art proposed method formerly. However, the proposed system is unsecure. Also in 2019, the authors in (Wang, Q et. al. 2019) proposed a double auction system for heterogeneous spectrum. The proposed system enables truthful double auction over heterogeneous spectrum while ensuring full privacy protection. It has addressed the following challenges. First, they applied efficient additive homomorphic encryption to bidders' data before sending them to the auctioneer so that leveled/linear computations can be performed over ciphertexts. Next, they designed a secure multiplication protocol, expedited by packing and concurrent computing techniques. Third, they proposed a novel algorithm for minimum/maximum value selection among multiple ciphertexts. Finally, they introduced a new obfuscation approach by constructing tailored sorting matrices. The proposed system introduced well benefits, yet its privacy protection is easy to break. Next year (2020), the authors have proposed an auction system for cooperative spectrum sharing in hybrid satellite-terrestrial IoT networks (Zhang, X et. al. 2020). They have used satellite-IoT network as the primary network sharing the spectrum resource and the terrestrial-IoT network as potential secondary network sharing the infrastructure. They also proposed an auction-based optimization problem to maximize the sum transmission rate of all primary satellite-IoT receivers with the appropriate secondary network selection and the corresponding profile of radio resource allocation by the distributed implementations while meeting the minimum transmission rate of secondary receivers of each terrestrial-IoT network. Due to the incentive compatibility of VCG, the secondary terrestrial-IoT cluster yields the true bids of each channel, where both the NOMA and time division multiple access (TDMA) scheme are implemented in the cooperative transmission. Besides, the average allocation and proportional allocation methods are proposed to reallocate the extra payoff from the VCG auction to the secondary network. Unfortunately, the proposed system depended on the moderate level of security since it uses a traditional VCG. In the same year, a framework of privacy preserving for spectrum sharing thorough IoT has been proposed (Wang, X et. al. 2020). The proposed framework intends to reveal the winners' identities and the group bids, but keeps the individual user's bid confidential. To this end, the proposed spectrum sharing framework consists of three parties, i.e., an auctioneer, multiple bidders and a Cryptographic Authority (CA). Here, CA is a third party to generate public keys. Regarding the bidding processes, firstly the bidders send their homomorphic encrypted sealed bidding vectors (e.g., using ElGamal encryption) to the auctioneer by using the ElGamal public key generated by the CA. Then, the auctioneer constructs a mixed sealed group matrix and sends it to CA, who will decrypt the group bids by using his ElGamal private key. Finally, the auctioneer derives the winning groups and their charges. As regarding of authors assumptions, either the auctioneer or CA could be untrusted, but they would not collude. The proposed framework guarantees that no bidder's bidding price would be exposed, as long as the auctioneer and CA do not collude with each other. They have performed extensive evaluations to show that the proposed framework achieves good spectrum utilization efficiency and user satisfactory ratio, at the cost of acceptable communication and computation overheads. The ElGamal private key has been used but it may easy to face by the eavesdropper. Also in 2020, the authors constructed a permissioned blockchain for the spectrum sharing in multi-operator wireless communication networks (Zheng, S et. al. 2020). The practical byzantine fault tolerant (PBFT) consensus algorithm instead of proof of work (POW) is adopted in the permissioned blockchain, which can greatly realize the high throughput and short delay. In the proposed system, the Multi-Operator Spectrum Sharing (MOSS) smart contract is designed on the blockchain for spectrum sharing in wireless communication networks. The proposed system also is decentralized and secure with double auction and free-trading market, and it is compiled on the Remix integrated development environment (IDE). Nonetheless, its cryptography system is not significant. In 2021, the authors have proposed a sequential auction-based multi-winner (SAMW) spectrum allocation framework where the primary owner (PO) serves as the auctioneer and decides a non-cooperative auction game among SUs (bidders) (Devi, M et. al. 2021). In the proposed system, the authors considered the channels that offered for auction are homogeneous, due to which sequential bidding becomes favourable for bid submission. Moreover, this work enabled multiple noninterfering bidders to share a single idle channel at a time. Such a condition facilitates an increase in spectrum utilization along with the revenue earned by the auctioneer. Furthermore, the proposed model ensures truthfulness for preventing any kind of manipulation of the bid values. This makes every SU bid a true valuation, while the SU is completely unaware of any other bidder's bidding strategy. The proposed system has many benefits as shown above but the securing level is too bad. In the same year, a multi-channel multi-winner sealed-bid double auction mechanism is proposed to model the spectrum allocation problem in CRN (Devi, M et. al. 2021). In the proposed model, primary owners (POs) participate in the game to obtain a monetary profit where they report ask values to the spectrum broker (SB) for leasing their vacant channels. SB acting as the auctioneer collects asks from POs, bids from SUs, and consequently decides a clearing price with the winner determination and pricing strategies to achieve an efficient allocation. Both multi-channel allocation and multi-winner allocation for spectrum reuse have been applied in this model. Since the channels are considered as heterogeneous with respect to their maximum allowable transmission power, so every SU can decide a different bid value for each channel according to the channel availability of the SU. In the seller side, a PO can lease multiple channels, which are kept idle. To enable spectrum reuse, a channel-specific bidder group formation algorithm is proposed where for every channel groups of non-interfering SUs are formed. Then, the winning group for each channel is determined using a spectrum allocation algorithm. The developed auction model guarantees truthfulness and individually rationality at the auctioneer. However, its secure level is not significant. In (Zhu, R et. al. 2021), the authors proposed a secure spectrum intelligent sensing and sharing auction mechanism to prevent selfish auctioneers and improve the utility of SUs while guaranteeing the security of spectrum resource auctions. The proposed system included a blockchain-based two-stage secure spectrum intelligent sensing and sharing auction mechanism. The completed auction records are formed as new blocks and added to the consortium blockchain. The proposed system also allocated the spectrum resources of PU auctions to SUs to maximize the utilities of SUs with low complexity, which takes into account the preference of auctioneers. The optimal allocation of limited spectrum resources is realized while ensuring the utilities of SUs, stimulating more SUs to participate in spectrum sharing. However, the security of the proposed system is too weak. In 2022, the authors have proposed a new pragmatic spectrum trading model (Abozariba, R et. al. 2022). This model is non-contiguous channel aggregation for each bidder is used to achieve its aggregate demand. This leads to maintain the quality of the spectrum resources and information on the utilization history that extracted from past allocations to bidders is used for the fair allocation. The proposed system obtained also optimal total reserve cost for adversaries bidding on auctions while minimizing the winning costs to bidders. It also provided to choose the optimal auctions that maximize monetary return after winning a set of auctions. Nevertheless, the proposed system has a bad security. In the same year, the authors have proposed a framework to utilize the consensus and computing resource consumption to perform convenient tasks closely related to the system application (Zhu, K et. al. 2022). The proposed method has the advantage of exploiting the decentralized computing power of the blockchain network, which is consistent with distributed architectures of general IoT systems and applications. In addition, an autonomous double auction mechanism is designed for distributed spectrum users to optimally share spectrum resources. Furthermore, a differential privacy-based privacy-preserving approach is proposed in the spectrum resource auction to prevent potential user information leakage in the presence of blockchain. In addition, the practical time-dependent valuation of the spectrum is considered in the system design. However, the securing level of the proposed system is not significant. In the last year, blockchain-based spectrum trading mechanisms is proposed to enable intra-CxG and inter-CxG spectrum trading (where CxG is abbreviation of coexistence group) (Cheng, Z et. al. 2023). The proposed system can balance the interference to incumbents and resource requirement by introducing a new parameter termed “network feature”. When considering the network feature as the priority of transaction queuing, the aggregated interference to incumbents can be reduced by spectrum trading. In addition, the proposed system characterized the radio environment, which is considered in the queuing rule of spectrum transaction. The simulation results show that the proposed system can effectively reduce the queuing time of important transactions and improve the satisfaction of users. Although the proposed system has many benefits, its big drawback is bad securing level. In the current year (2024), there are also many related works that have been proposed to address the issue of auction security for spectrum sharing. In the research, which is referenced in (Xu, J et. al. 2024), a new mobile broadband IoT architecture is proposed. It focused on the cloud-enabled double auction model. Implemented within the mobile broadband IoT framework, this mechanism optimizes spectrum resource sharing, resulting in improved performance of the IoT infrastructure. The approach is thoroughly validated through detailed discussions of its theoretical foundation, algorithmic implementation, simulation results, and user satisfaction analysis. Other related work (Ye, L et. al. 2024) is proposed based on blockchain by utilizing the ERC4907 standard. A smart contract for Non-Fungible Spectrum Tokens auctions has been developed. The security level results have met the requirements of dynamic spectrum sharing, however, the complexity of the proposed system has a high level. In (Cariappa, K et. al. 2024), a novel optimal spectrum auction mechanism is proposed. It enables the primary user of a channel to oversell it with an intelligent-manner. This helps the system to choose a set of unlicensed users carefully while collecting suitable payments from them. It also demonstrates the proposed overselling methodology to improve the key performance metrics. The analytical characterization of essential properties has been supported by the mechanism along with computationally efficient techniques for implementing the method. Nevertheless, the security level is low. On the market perspective, the aim of research is to study the protection on the market for secondary spectrum services (Mu, K et. al. 2024). The study proposed service providers must reduce their traffic when the incumbent is present. The finding is that while consumers consistently benefit from relaxing incumbent protection, the impact on service providers' revenue and social welfare is more complex. The market response can be negative depending on the level of relaxation, suggesting that regulators must carefully consider such policies. In (Ma, K et. al. 2024), a proposed system is highlighted the shortcomings of the current spectrum resource management approach. Using the Taguchi quality assessment theory, a cost model for a utility company was developed, employing a decode-and-forward cooperative relay strategy to transmit downlink horizontal propagation to a data aggregation unit. The proposed system analyzed the bilateral auction process between the utility company and licensed users. Thus, a maximizing social welfare and identifying the optimal spectrum transaction enhanced spectrum resource utilization. Other related work presented an initial work toward creating a roadmap for federal agencies to modernize their spectrum usage by conducting practical analyses and utilizing emerging spectrum sharing technologies (Kaminski, N et. al. 2024). Using the example of design of experiments spectrum usage examines the key factors federal agencies must consider to enable spectrum sharing. Additionally, it provides a preliminary review of the most relevant spectrum sharing models and technologies for federal applications, particularly focusing on the emerging capabilities of 5G, such as New Radio Unlicensed, to enable spectrum sharing and unlicensed access. This effort aims to bridge the gap between academic discourse on spectrum sharing and a practical implementation roadmap for federal agencies. The last but not least, a study developed a consortium blockchain for secure dynamic spectrum sharing in Internet of vehicles environments (Li, Q et. al. 2024). To address signal instability in these scenarios, an enhanced asynchronous Byzantine fault-tolerant algorithm is introduced. Additionally, spectrum resource allocation and management between vehicles and base stations are optimized using the Stackelberg game, with deployment automated through smart contracts. Simulation results demonstrated that this approach significantly improves system response time, ensures communication quality, and maintains efficient performance even under high network delays and complex conditions.

2.7. Research Gap

Overall, a number of networks have investigated the security of spectrum sharing using well-known techniques that are either computationally costly or lack a robust cryptographic methodology. The suggested methods have been dispersed over many projects. Nevertheless, no low-complexity, strong security method has been put forth.

2.8. Overview

An overview of the security auction concept used by spectrum sharing to control power consumption in different IoT-based networks is given in this chapter. Measurement kinds are characterized by details like as protection, sensing, sharing, and management. However, several disadvantages and undesirable results persisted in spite of attempts to resolve the problems related to these methods. Many process types have handled the distribution process without any problems, but they have not been able to efficiently manage different frequency bands in accordance with their individual requirements. To overcome these obstacles, security auction of spectrum sharing utilizing IoT should use a new, simple security approach to increase the robustness of the auction system.

CHAPTER THREE

THE PROPOSED SECURITY AUCTION SYSTEM FOR SPECTRUM SHARING

3.1. Prelude

As aforementioned, the FCC, a central government agency, traditionally manages radio spectrum by assigning static frequency bands without considering dynamic service demands. This leads to inefficiencies, with some bands underutilized and commercial bands overcrowded. To improve spectrum utilization, the FCC introduced secondary markets, allowing license holders to lease unused spectrum. Spectrum auctions, inspired by microeconomic principles, have emerged as a promising method for reallocating underutilized spectrum. Spectrum auctions are unique due to the reusability of radio frequencies and the need for bidders outside each other's interference range to share the same frequency simultaneously. Optimal spectrum allocation is an NP-complete problem, and secure auctions must prevent fraud by the auctioneer and eliminate bid-rigging to maintain fairness and transparency (Abbasi, M et. al. 2021), (Iqbal, A et. al. 2023). The growing number of mobile subscribers and data usage has led to increased demand for bandwidth and strain on carrier resources. Network providers offer services like multimedia telephony and mobile TV, but a single frequency band is insufficient due to limited radio frequencies. Aggregating frequency bands from different carriers optimizes radio resources, enabling scalable bandwidth expansion and inter-band noncontiguous carrier aggregation (CA) (Alimi, I et. al. 2024). CA is a crucial feature in 5G rather than 4G systems, including LTE-Advanced, to address spectrum scarcity by aggregating component carriers of different bandwidths. This enables wider transmission bandwidths between Node B and user equipment. Network operators are implementing CA across both macro and small cells to improve capacity and performance in small cells while ensuring strong mobility management (Ye, W et. al. 2024). The National Broadband Plan recommend repurposing underutilized federal spectrum for secondary use to improve network capacity, data rates, and user experience. It report emphasizes expanding small cell network deployment and implementing spectrum-sharing technology for wireless broadband.

To fully leverage additional spectrum, it must be integrated with existing commercial mobile networks. A resource allocation strategy based on CA is proposed to optimize both permanent and underutilized spectrum resources. Noncontiguous CA presents challenges in hardware design and resource allocation due to multiple oscillators, RF chains, enhanced signal processing, and extended battery life. A distributed resource allocation algorithm is needed for efficient allocation among mobile users (Gomes, M et. al. 2018), (Sudhamani, C et. al. 2023). Multistage resource allocation (RA) algorithms incorporating CA have been proposed for efficient resource distribution among mobile users. These algorithms use a utility-proportional fairness approach, with the primary carrier distributing resources and the secondary carrier assigning optimal rates based on user applications. An RA optimization model is introduced for LTE-Advanced and MIMO radar carriers, and a price-selective centralized RA algorithm with CA is presented. However, these algorithms do not guarantee optimal pricing (Trabelsi, N et. al. 2024).

This chapter enables a spectrum-sharing framework for effective use of unused spectrum and presents a secure spectrum auction that uses the Paillier cryptosystem cascaded 2D-single resolution Discrete Wavelet Transform (DWT) to avoid fraud and bid-rigging. Additionally, an ideal bidding mechanism is suggested to provide a safe and honest auction, in which BSs compete for temporary extra resources. In simple words, a secure spectrum sharing auction technique is presented that uses a customized cryptosystem to improve security and distribute the limited resources of a frequency band during peak demand. To efficiently allocate these resources across participating SUs, an effective band scheduling method is created. The Paillier based 2D-DWT cryptosystem is used in the proposed encryption system to safeguard bidding values and guard against manipulation by SUs, guaranteeing security and privacy in the spectrum auction. The band operator can plan for future availability and charge smart grids for frequency band resources that have been allotted by using this method. Through the use of homomorphic encryption, the system offers a safe and effective framework for the BSs band operator, acting as an auctioneer, to distribute limited spectrum resources while protecting user privacy and preventing fraud or bid-rigging.

3.2. System Model Considerations

A proposed model is introduced in this chapter, a secure spectrum auction framework that uses spatial reuse to efficiently allocate spectrum resources. This double-secure auction mechanism, exploiting the cascaded Paillier cryptosystem and pyramid-wavelet algorithm, allows the auctioneer to secure frequency bands from PUs to 5G wireless communication providers' BSs. The benefits of the proposed system are many as follows. The proposed model considers spectrum reusability and diverse frequency bands. It establishes a dynamic spectrum-sharing framework, ensuring optimal use of underutilized spectrum by 5G wireless communication providers. The model enforces honesty by requiring bidders to submit their true spectrum valuations, preventing auction manipulation. It follows economic principles like incentive compatibility and individual rationality. The secure bidding process uses the cascaded of Paillier cryptosystem and pyramid-wavelet algorithm, ensuring bid confidentiality. The model reduces computational and communication costs, preventing fraudulent activities like dishonest auctioneering and bid-rigging.

The spectrum holder, a network operator, rents its 5G spectrum to a broker for an extended period of time in a spectrum trading scenario that is examined. As an agent for the spectrum holder and cellular communication networks, the broker oversees spectrum holdings. Due to this, the spectrum holder, the broker, and the user equipment (UE) are the three main levels of the system. The broker occupancies 5G frequency bands from the spectrum holder in accordance with certain rules. The broker auctions these frequency bands to cellular communication networks, acting as a secondary marketplace. Last but not least, cellular communication systems' base stations (BSs) provide 5G spectrum to user equipment (UE).

Assuming that a single auctioneer, or broker, is holding a spectrum auction where bidders or nodes that represent base stations (BSs) $\mathcal{N}$ = {1, 2... N}, in the same geographic area, are competing for a set of 5G frequency bands $\mathcal{M}$ = {1, 2… M}. Different 5G cellular communication platforms are represented among these bidders. The number of cellular communication systems operating within the selected geographic region of the auction is denoted by L. Multiple cellular cells are served by each cellular communication system (I-th system), which offers mobile wireless services. Depending on its need, each base station (BS) may bid for one or more frequency bands from the available set, $\mathcal{M}$, in a spectrum auction. The broker becomes the owner of the unused frequency bands in $\mathcal{M}$ after leasing them from the spectrum owner for a period *T*. The broker receives offers from interested BSs throughout this time. Suppose that $\kappa = \{\alpha^1, \alpha^2 \ldots\}$ represents the collection of all potential frequency band allocations. The closed bids of Every BS is represented by $\mathbf{b_n} = [b_n(\alpha^1), b_n(\alpha^2), \cdots]$. The evaluation value $v_n(\alpha)$ can be considered a true with nth BS for a certain allocation α. Supposed that Un represents the utility of n BS and can be formulated as

$$U_n = v_n(\alpha) - p_n \qquad (3.1)$$

where p_n denotes the entity responsible for distributing the frequency bands in the auction.

For every more than one cellular communication networks (L > 1) operating in the same terrestrial area, the broker has its spectrum auction. Such networks engage in the auction by attempting to get access to the auctioneer's frequency bands ($\mathcal{M}$). Each system has a number of cells under the control of its operators within its coverage region. In order to compete for underused governmental spectrum bands, base stations (BSs) that need more spectrums send sealed bidding vectors to the auctioneer over a secure intermediary gateway. Each BS has a set coverage radius that is thought to be equal to the radius of the cell in accordance with the frequency reuse concept. No interfering BS can use the same frequency bands as the nth BS at the same time within this radius. The model may make effective use of the spectrum since a noninterfering base station (BS) outside of this radius can reuse the same frequency band without creating interference. The auctioneer creates an interference conflict area that maps each participating BS in order to control interference. In this area, each BS is linked to other BSs within its coverage radius, which shows mutual interference. These links (edges) indicate that interference limits prevent the connected BSs from using the same frequency bands at the same time. One subnet at a time, the spectrum auction procedure is carried out in a sequential fashion. With the exception of previously allocated root BSs, a subnet is a collection of BSs made up of a root BS (n) and every other BS linked to it by interference edges. An outline of the suggested spectrum auction concept is shown in Figure 3.1. First, every BS sends in encrypted bidding vectors over a governmentally managed intermediary gateway. Then, one subnet at a time, the auctioneer processes a secure spectrum auction. The winning BSs are then given frequency bands, and charges are applied appropriately for the resources that have been allotted.

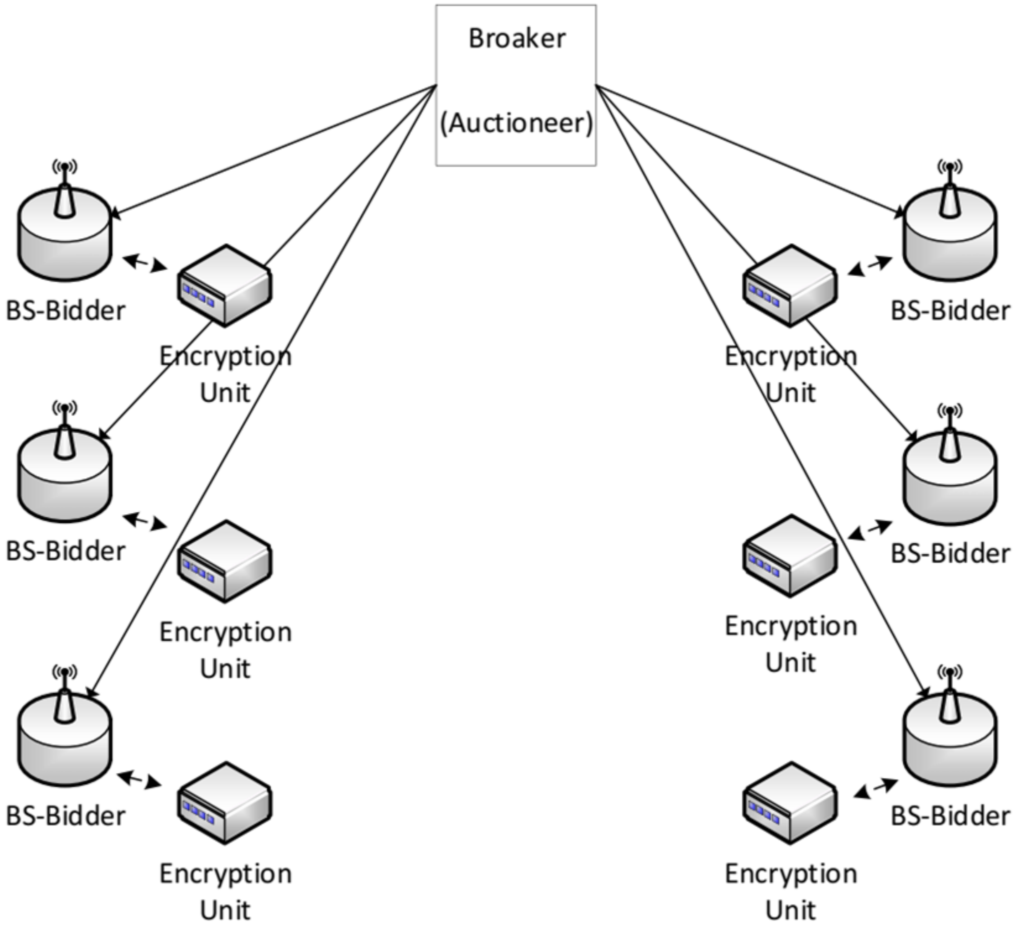

Figure 3.1. The Structure of the Proposed Security Auction System

When creating a spectrum auction, honesty is an important consideration. Since they guarantee bidders submit their accurate value, sealed-bid second-price auctions and VCG auctions are strongly recommended. As was already established, the VCG auction has a number of important characteristics that are necessary for a spectrum auction. However, because of the spectrum's spatial reusability, it necessitates figuring out an optimal allocation, which is NP-complete. Additionally, VCG is vulnerable to bid-rigging by dishonest auctioneers and profit-seeking bidders. Therefore, precautions against these dangers are necessary when using VCG in a spectrum auction. When a greedy bidder and an auctioneer collude to manipulate the process for their own gain, this is known as bid-rigging. The auctioneer can reveal the winning bid value to a preferred bidder since they have access to the valuation information of every bidder. For a single frequency band, the auctioneer may also hold a VCG auction, which is comparable to a sealed-bid second-price auction. A dishonest auctioneer may also commit fraud if they overpay the winner in order to boost their own earnings, causing the successful bidder to suffer unjust losses. Because bid prices are sealed and bidders cannot see each other's bids, this is possible. A well-designed spectrum auction must provide security by enabling the auctioneer to distribute frequency bands without knowing the bidders' true valuations in order to prevent fraud and bid-rigging. To avoid collusion and preserve a safe and equitable spectrum auction, this measure is crucial.

3.3. Proposed Doubled Secure Auction Model

Designing a safe spectrum auction with a high degree of security, privacy, and misdirection is essential to guaranteeing the effective use of the shared spectrum under a broker's management. This guarantees spectrum use efficiency and dependability. A system that enables the auctioneer to choose the highest offer among all bidders without knowing their true bid values is required to stop backroom transactions. The Paillier cryptosystem cascaded with wavelet single resolution are used by the suggested double-secure algorithm to reduce the possibility of fraud and bid-rigging. The suggested method and the frequency band allocation process are mathematically described in this section.

The proposed safe spectrum auction solution is based on several essential features of the Paillier cryptosystem rather than wavelet single resolution. As a probabilistic public-key encryption strategy, the Paillier cryptosystem generates distinct ciphertexts when the same plaintext is encrypted several times. Important properties like self-blinding, indistinguishability, and homomorphic addition are made possible by this trait and are essential for maintaining anonymity and security during the auction process.

The Paillier cryptosystem has a major benefit due to its homomorphic features. $C(m)$ stands for its encryption function, which is additively homomorphic ($C(m_1 +$

m_2) = $C(m_1)C(m_2)$). Furthermore, if the same plaintext m is encrypted again, the ciphertexts that emerge are different because to the indistinguishability feature, which makes it difficult to identify the original plaintext without decryption apart from speculating. Additionally, ciphertext alteration is possible without changing the underlying plaintext because to the self-blinding characteristic. This implies that a new randomized ciphertext $C'(m)$ may be created from a given ciphertext $C(m)$ without needing to know the original plaintext or the decryption key.

On the other hand, since the pyramid method is a single resolution, it serves as the foundation for the suggested algorithm for the Haar-Wavelet single resolution. Manual trial-and-error selection is used to choose the optimal quality for recovered streams, increase security for scrambled streams, and manage time for quick computations.

Bid values are submitted by all base stations (BSs) that are interested in taking part in the auction and are owned by cellular communication networks in the specified geographic area. The auctioneer creates an interference conflict graph based on the locations of these BSs and their corresponding cellular communication networks. One subnet at a time, the auction is held. The auctioneer determines the associated subnet, which is made up of the linked nodes (BSs), for each subnet by randomly choosing a BS n as the current root BS. The auctioneer chooses a new BS, one that has never been a root BS before, as the next root BS when the auction for the current subnet is over. The new subnet does not include any previously selected root BS or its assigned frequency bands. The auctioneer conducts the auction subnet by subnet until all BSs have taken part in this iterative procedure. The auctioneer charges each root BS according to the frequency bands that are assigned to them based on the outcomes of the subnet auctions. A local conflict table is also kept up to date by every BS taking part in the auction.

To perform the suggested secure band auction, the auctioneer creates the public and private keys for the Paillier-Haar cryptosystem and distributes element x and his public key to the UEs in the band grid. Next, Every UE i in N sends its true evaluation bidding values in $w_i = v_i$ to a buffer, which uses the Paillier-Haar cryptosystem to encrypt the values and produce ciphertexts.

Allow $w(\beta)$ of allocation β for a given UE to be equal to m such that $1 \leq m \leq s$, where s is one integer big sufficient to include all potential bidding prices for the EPU allocation, that is, any real bidding price does not beat s. Let $E(x)$ represents the Paillier-Haar encryption of the public element. For each bidding value m, the buffer generates a vector of cipher-texts $e(m)$, where $e(m)$ is determined as

$$e(m) = (e^1, \dots, e^s) = (E(x), \dots, E(x), E(0), \dots, E(0)) \tag{3.2}$$

The selfblinding feature of the Paillier-Haar cryptosystem makes it impossible to discover m without first decrypting the components in $e(m)$. Without knowing m, the secure gateway randomly selects the encrypted bids. The encrypted vector $e(m)$ is given a constant r added to it, and the remaining elements are randomly generated. The resulting vector is as follows

$$e'(m + r) = (E(x), \dots, E(x), e'_1, \dots, e'_{s-r}) \tag{3.3}$$

The proposed algorithm for the Wavelet Transform-Haar type is constructed from the pyramid algorithm as it is a single resolution. The bases are choosing manually by trial and error way to produce best quality for recovered speech signal, more security for scrambled speech signal and manipulate the time for fast calculation. The proposed Haar Wavelet Transform is created in the proposed algorithm to increase the security.

$$H = \begin{bmatrix} 1 & -2 & -1 & 0 \\ 2 & 1 & 0 & 1 \\ 1 & -2 & 1 & 0 \\ 2 & 1 & 0 & -1 \end{bmatrix} \tag{3.4}$$

As it can be seen the basis vectors of the Haar wavelet transform are also orthogonal, and

$$H = \begin{bmatrix} 0.1 & 0.2 & 0.1 & 0.2 \\ -0.2 & 0.1 & -0.2 & 0.1 \\ -0.5 & 0 & 0.5 & 0 \\ 0 & -0.5 & 0 & -0.5 \end{bmatrix} \tag{3.5}$$

For this four elements modified Haar wavelet transform the scaling function and the three-wavelet coefficients are calculated as follows.

$$S = (a_1 + 2a_2 + a_3 + 2a_4)/(5N/4) \tag{3.6}$$

$$w_1 = (-2a_1 + a_2 - 2a_3 + a_4)/(5N/4) \tag{3.7}$$

$$w_2 = (-a_1 + a_3)/(N/2) \tag{3.8}$$

$$w_3 = (a_2 - a_4)/(N/2) \tag{3.9}$$

As mentioned *N* equals to four elements, but in the proposed the number is equal to 64 elements, therefore *H* which becomes 64×64 matrix, and the scaling function and the wavelet coefficients are calculated as follows

$$s = (\textstyle\sum_{k=odd(1)}^{N} a_k + 2\sum_{k=even(1)}^{N} a_k)/(5N/2) \tag{3.10}$$

$$w_1 = (-2\textstyle\sum_{k=odd(1)}^{N} a_k + \sum_{k=even(1)}^{N} a_k)/(5N/2) \tag{3.11}$$

$$w_2 = (-\textstyle\sum_{k=odd(1)}^{N/2} a_k + 2\sum_{k=odd\left(\left(\frac{N}{2}\right)+1\right)}^{N} a_k)/(N/2) \tag{3.12}$$

$$w_3 = (\textstyle\sum_{k=even(1)}^{\frac{N}{2}} a_k - \sum_{k=even\left(\left(\frac{N}{2}\right)+1\right)}^{N} a_k)/(N/2) \tag{3.13}$$

Next, from $w_4 - w_7$ it is shown in one equation with two parameters *i* and *j*, where *i* have 4 numbers and *j* have 2 numbers. Substitution each 2 numbers from *i* with number from *j* (or each number from *j* using two times) to produce the equations, *i* is depending on n_1 and *j* is depending on n_2 where $n_1 = 0,1,2,3$ and $n_2 = 0,1$

$$i = n_1 + 4 \tag{3.14}$$

$$j = 2n_2 \tag{3.15}$$

$$w_i = (-\textstyle\sum_{k=odd(j+1)}^{(j+1)N/4} a_k + \sum_{k=odd(\left(\frac{(j+1)N}{4}\right)+1}^{(j+2)N/4} a_k)/(N/4) \tag{3.16}$$

$$w_i = (\textstyle\sum_{k=even(j+1)}^{\frac{(j+1)N}{4}} a_k - \sum_{k=even(\left(\frac{(j+1)N}{4}\right)+1}^{(j+2)N/4} a_k)/(N/4) \tag{3.17}$$

Next, from $w_8 - w_{15}$ it is also shown in one equation. However, *i* have 8 numbers and *j* have 4 numbers, note that equation of *j* is the same in (3.72), $n_1 = 0,1,2,\ldots,7$ and $n_2 = 0,1,2,3$

$$i = n_1 + 8 \tag{3.18}$$

$$w_i = (-\sum_{k=odd(j+1)}^{(j+1)N/8} a_k + \sum_{k=odd\left(\frac{(j+1)N}{8}\right)+1}^{(j+2)N/8} a_k)/(N/8) \qquad (3.19)$$

$$w_i = (\sum_{k=even(j+1)}^{\frac{(j+1)N}{8}} a_k - \sum_{k=even\left(\frac{(j+1)N}{8}\right)+1}^{(j+2)N/8} a_k)/(N/8) \qquad (3.20)$$

Next, from $w_{16} - w_{31}$ it is also shown in one equation. However, *i* have 16 numbers and *j* have 8 numbers, note that equation of *j* is the same in (3.72), $n_1 = 0,1,2,\ldots,15$ and $n_2 = 0,1,2,\ldots,7$

$$i = n_1 + 16 \qquad (3.21)$$

$$w_i = (-\sum_{k=odd(j+1)}^{(j+1)N/16} a_k + \sum_{k=odd\left(\frac{(j+1)N}{16}\right)+1}^{(j+2)N/16} a_k)/(N/16) \qquad (3.22)$$

$$w_i = (\sum_{k=even(j+1)}^{\frac{(j+1)N}{16}} a_k - \sum_{k=even\left(\frac{(j+1)N}{16}\right)+1}^{(j+2)N/16} a_k)/(N/16) \qquad (3.23)$$

Next, from $w_{32} - w_{63}$ it is also shown in one equation. However, *i* have 32 numbers and *j* have 16 numbers, note that equation of *j* is the same in equation (14), $n_1 = 0,1,2,\ldots,31$ and $n_2 = 0,1,2,\ldots,15$

$$i = n_1 + 32 \qquad (3.24)$$

$$w_i = (-\sum_{k=odd(j+1)}^{(j+1)N/32} a_k + \sum_{k=odd\left(\frac{(j+1)N}{32}\right)+1}^{(j+2)N/32} a_k)/(N/32) \qquad (3.25)$$

$$w_i = (\sum_{k=even(j+1)}^{\frac{(j+1)N}{32}} a_k - \sum_{k=even\left(\frac{(j+1)N}{32}\right)+1}^{(j+2)N/32} a_k)/(N/32) \qquad (3.26)$$

Furthermore, the auctioneer creates *N* + 1 representing vectors $E_T = E(O)$, $E_1 = E(O)$,...,$E_N = E(O)$ (i.e. *N* is the number of bidders). The size of *E* equals |*A*| and the initial *O*(*β*) equals 0; i.e. *E*(*O*) = {*e*(0), *e*(0), .., *e*(0)}. Each UE; i.e. the *j*th UE in *N* keeps its encrypted bidding vector w_j secret by adding it to all representing vectors except E_j. Once performing this addition process by each UE in *N*, the auctioneer obtains

$$E_T = \left(\prod_i e(w_i(\beta_1)), \ldots, \prod_i e(w_i(\beta_{|A|}))\right) \qquad (3.27)$$

Next, using the following formula, the auctioneer establishes the maximum aggregate value of the disguised bids

$$k = \max_{\beta \in A}\left(\textstyle\sum_i w_i(\beta) + \theta(\beta)\right) = \max_{\beta \in A}\left(\textstyle\sum_i w_i(\beta)\right) + r \qquad (3.28)$$

where k can be obtained by the auctioneer by taking the product of the encrypted values in E_T, and finding the maximum element in that product which is equivalent to k in previous equation.

For every allocation in A, the auctioneer decrypts the kth element of every vector in E_T. It will have a decrypted value of x or zero. The allocation that maximizes w_i is the one with a decryption value equal to x, or β^*. The auctioneer schedules its resources to the respective UEs based on β^*, which it regards as the winning allocation.

The auctioneer decrypts e of E_z (i.e., UE_z is a winning one) and determines the value θ in order to determine its charging price for each winning UE. The highest value of the product of the encrypted components, maxi, is then determined by the auctioneer.

Using the following formula, the auctioneer determines the charging price that each of the winning UEs must pay for the planned Sectors in order for the winning bidder (UE_z) to pay a price of p_z for its scheduled Sectors.

$$p_z = \left(\textstyle\sum_{i \neq z} w_i(\beta^*_{-z}) + r\right) - \left(\textstyle\sum_{i \neq z} w_i(\beta^*\ ) + r\right) \qquad (3.29)$$

3.4. Brief

This chapter provides a detailed and methodical analysis of a secure auction system for spectrum sharing. The proposed algorithm focuses on making sure that the auction process is efficient, secure, and private, especially in settings where important bidding data has to be shielded from manipulation and unwanted access. Additionally, a thorough mathematical model of the suggested system is provided, integrating the single resolution Haar code, which uses a private key and is based on the Paillier cryptosystem. By guaranteeing safe encryption and decryption of bidding values, this approach guards against any unapproved release of private auction information. The distinctions between public and private key-based security techniques in spectrum auctions are further highlighted by introducing the traditional secure auction system, which uses a public key encryption method for comparison. Three cascading security steps make up the suggested secure auction system, which is intended to improve protection and stop bid-rigging and fraud. The Paillier cryptosystem, a probabilistic public-key encryption technique that supports homomorphic encryption characteristics and guarantees bid secrecy, is used in the first step. By changing the encrypted data into a different mathematical domain, the second stage's single resolution Haar Wavelet Transform procedure provides an extra degree of security and increases the data's resistance to unwanted access. In order to further safeguard the outputs from the first two stages and guarantee that only authorized organizations may access and handle the encrypted bidding information; the third stage lastly uses a private key. By combining these three phases, the suggested auction approach reduces the possibility of bid-rigging, fraud, and illegal data access while ensuring improved security, resilience, and privacy in spectrum distribution.

CHAPTER FOUR

SIMULATION RESULTS

4.1. Initiation

The outcomes of modeling using MathWorks® that include the suggested cryptosystem are shown in this chapter. To evaluate the performance of the suggested auction cryptosystem and compare it with other cryptosystems, different algorithms are used to different metrics, depending on the number of spectrum sharing. Monte Carlo trials, cellular communications income, cryptosystem efficiency, and bidder satisfaction are the four main performance measures that are examined. For a spectrum sharing auction to be successful, several metrics are necessary. The suggested secure spectrum sharing auction's security structure is also assessed, emphasizing its capacity to thwart any fraud and bid-rigging. Optimizing certain performance parameters is essential for a safe and effective spectrum auction. Additionally, the suggested auction system's security and privacy procedures are investigated, guaranteeing defense against unethical behavior by the cellular communications operator or spectrum sharing trying to rig the auction.

Suppose that two cellular networks run in the same area, and a spectrum auction is examined that is held by an auctioneer (broker) inside a square geographical region in terms of squares of meters. Since each network is owned by a separate cellular communication networks, the auction is being contested by more than one cellular communication network ($L > 1$). A specific number of base stations (BSs) are owned by each cellular communication network. Within the auction area, the BSs are dispersed at random. It is thought that the distance between any two BSs determines the degree of mutual interference between them. Bid values are randomly assigned in our simulation scenario, with each frequency band having a monotonically declining pattern. In other words, a business is bidding more for the first frequency band than the second, the second band than the third, and so on.

4.2. Impact of Monte-Carlo Trials

The Averaging several separate simulation runs yields the findings, where two important performance metrics are assessed and the auction prices allocated to SUs are chosen at random. Monte Carlo simulations are performed with 1000 and 5000 trials, taking into account-varied numbers of SUs vying for the auctioneer's resources, in order to examine the effects of different degrees of competition. Five different situations with 2-6 as the number of participating a number of BSs are shown in the simulation results. It is assumed throughout the simulations that there is no bid-rigging, collusion, or fraudulent activity and that the auction process runs fairly and openly.

4.3. Impact of Auction Revenue

The sum of the billing prices for each winning UEs is used to calculate the cellular communication network's overall revenue. The auctioneer's revenue fluctuates with the number of UEs in relation to the number of services demand that are accessible, as shown in Figures 4.1 and 4.2. The cellular communication network's revenue is shown on the y-axis in these figures, while the x-axis shows the number of spectrum. Furthermore, each curve represents a certain quantity of users, which serve as bidders throughout the auction procedure. The numbers show that the auctioneer's revenue rises in tandem with the number of participating UEs. This result is in line with predictions since more UEs increase competition for resources, which heats up the bidding process and eventually boosts the auctioneer's earnings. Furthermore, compared to Figure 4.1, the curves in Figure 4.2 seem smoother. This is explained by Figure 4.2's larger trial count, which minimizes volatility, lowers statistical noise, and produces more reliable and consistent findings.

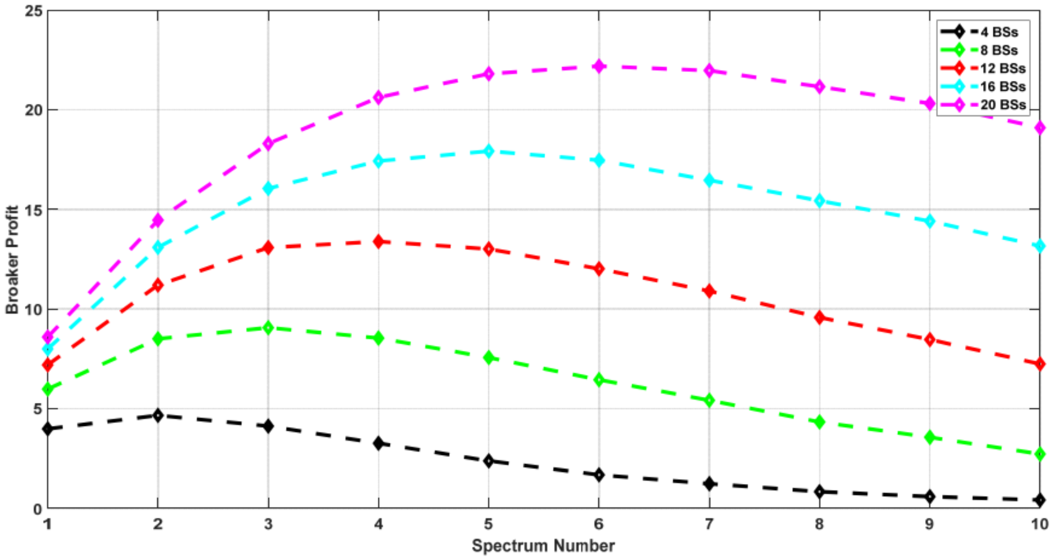

Figure 4.1. Broker Profit with 1000 Trials

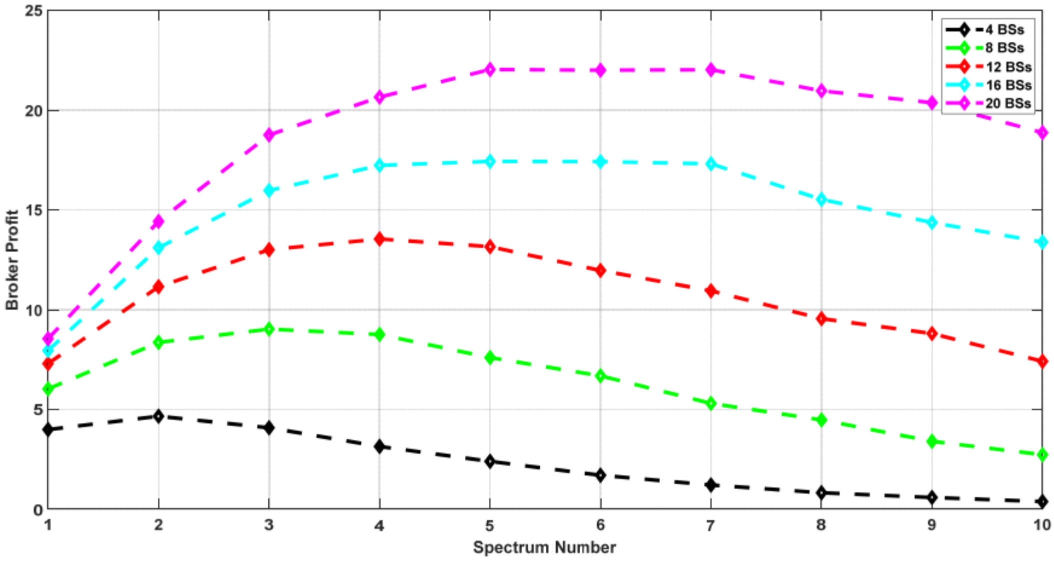

Figure 4.2. Broker Profit with 5000 Trials

4.4. Impact of Bidders Satisfaction

As The Figures 4.3 and 4.4, show that UEs satisfaction levels climb in tandem with the number of accessible users. Each UE gets exactly the quantity of services demand it has bid for when this trend reaches a saturation point. The y-axis in these graphs shows the bidders' percentage of auction satisfaction, while the x-axis shows the number of spectrum that are offered. Furthermore, each curve represents a certain quantity of meters, which act as bidders throughout the auction procedure. Additionally, Figures 4.3 and 4.4 show that individual UEs get better satisfaction levels for a given quantity of the auctioneer's available resources when fewer UEs take part in the spectrum auction. This happens because each UE has access to a greater portion of the resources allotted when there are fewer bids vying for the same proposal. Because there is less rivalry for the same pool of services demand, each UE may more successfully complete its bid, raising customer satisfaction levels overall.

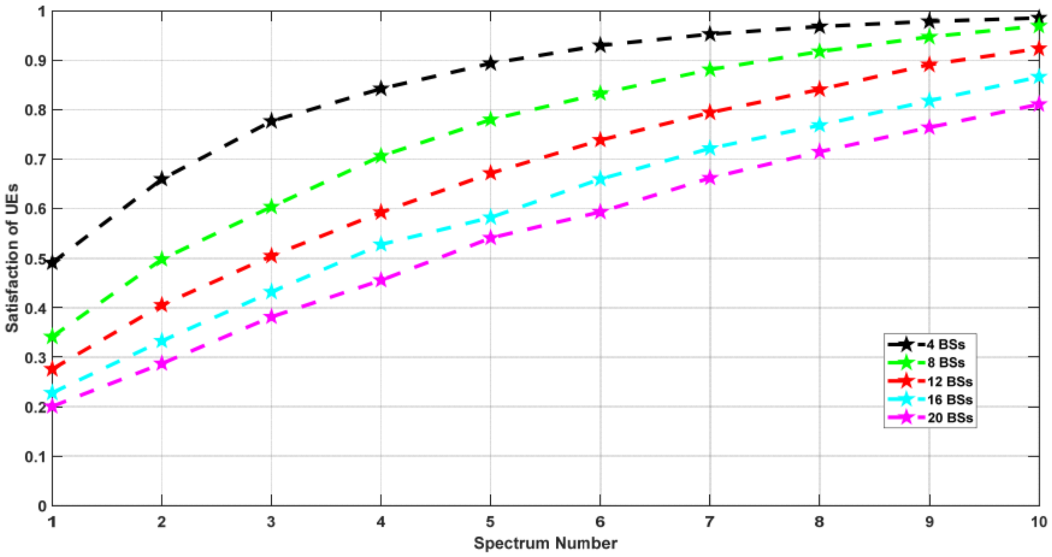

Figure 4.3. Users Satisfaction with 1000 Trials

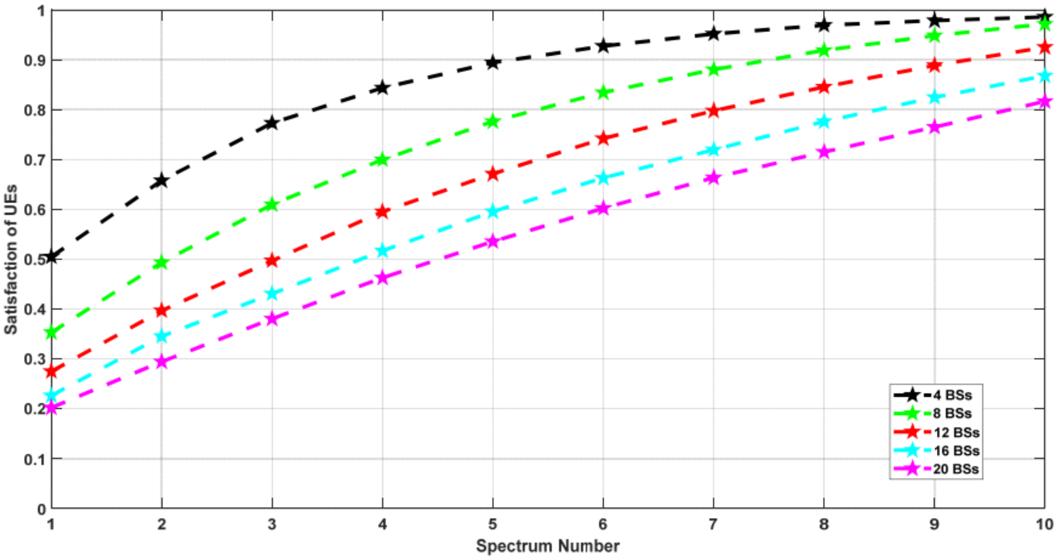

Figure 4.4. Users Satisfaction with 5000 Trials

4.5. Impact of Cryptosystem Measurements

The power and endurance of the cryptosystem are influenced by a number of elements, which makes decryption extremely difficult. These elements consist of the transformation method used, the cryptographic algorithm selected, and the particular weighting of these changes. Together, these components improve security by making it impossible for an interceptor to access or alter them. Furthermore, the suggested security technique has a number of benefits over related studies in the sector. It has a straightforward yet efficient architecture, keeps computing costs down, makes it simple to generate and retrieve cryptographic codes, and exhibits robust defense against assaults. The low memory required of Wavelet weights is an additional advantage. The method is still quite effective because it simply uses averages and differences and requires a minimal amount of calculations. The total security of the cryptosystem may be further improved by modifying the ratio of Wavelet weights as necessary, offering a strong and adaptable protection against any attacks.

4.6. Discussion

The simulation results were acquired using a PC with 8 GB of RAM and a 512 GB SSD. These outcomes were assessed for different bidder counts. When evaluating the computational cost and execution time of the Paillier cryptosystem and the suggested DWT single-resolution technique, the time required for each bid is a crucial consideration. Although the Paillier cryptosystem generally has a minimal computing cost, it generates ciphertext that is weaker and so more vulnerable to decoding. On the other hand, earlier research has used methods with a lot more computing overhead, which frequently leads to longer processing times. By depending only on fundamental operations like addition, subtraction, and averaging, the suggested DWT single-resolution method, which is based on the pyramid algorithm that maintains extremely low computing complexity. As a consequence, it doesn't need a lot of processing time and can produce robust encryption with little computational cost. In contrast, current techniques typically entail intricate calculations that, while providing different degrees of cryptographic strength, significantly lengthen the time needed for bidding procedures. The evaluation of the encryption/decryption time of Paillier cryptosystem is shown in following table.

Table 4.1. Encryption/Decryption Time of Paillier Cryptosystem

Number of Bidders	Encryption Time / sec	Decryption Time / sec	Usage of CPU / packet	Usage of Memory / MB
0	0.0002674	6.27e-05	10	20
50	0.03557	0.026445	11	22
100	0.044167	0.022707	12	24
500	0.22129	0.11643	20	40
1000	0.47429	0.27878	30	60

As shown in table 4.1, the encryption time increases as the number of bidders increases. In addition, the usage of CPU and memory increase too. However, the decryption time is less than the encryption time for same amount of bidders number, usage of CPU, and usage of memory. Furthermore, the computational overhead of Paillier cryptosystem is equal to *log*(*length of data stream*), thus, it is non-linear complexity.

On the other hand, table 4.2 reveals the consumed time for encryption and decryption of single-resolution DWT.

Table 4.2. Encryption/Decryption Time of Single-Resolution DWT

Number of Bidders	Encryption Time / sec	Decryption Time / sec	Usage of CPU / packet	Usage of Memory / MB
0	4.73e-05	2.94e-05	10	20
50	0.028672	0.036806	11	22
100	0.03435	0.070233	12	24
500	0.17151	0.37484	20	40
1000	0.32876	0.65412	30	60

The decryption time of single-resolution DWT is greater than the encryption time for same amount of bidders number, usage of CPU, and usage of memory. In addition, the number of bidders, and usage of CPU/memory increase as the encryption/decryption time increase too. Besides, the computational overhead of single-resolution DWT is equal to (*length of data stream*/2), thus it is half of linear complexity.

The cascaded system of Paillier cryptosystem and single-resolution DWT consume a time bigger than that of Paillier cryptosystem, or single-resolution DWT, separately, as shown in table 4.3.

Table 4.3. Encryption/Decryption Time of Paillier Cryptosystem and Single-Resolution DWT

Number of Bidders	Encryption Time / sec	Decryption Time / sec	Usage of CPU / packet	Usage of Memory / MB
0	0.0001415	3.36e-05	10	20
50	0.16717	0.064812	11	22
100	0.090168	0.070441	12	24
500	0.49127	0.3499	20	40
1000	0.9915	0.7921	30	60

In addition, the computational overhead of the cascaded system is summing of both previous algorithms.

Overall, Discrete Wavelet Transform (DWT) bases are used to analyze each bidder's data in order to create a new encoded representation known as a fusion. Multi-resolution analysis is made possible by this transformation, which improves data security and compression. Each bidder's DWT base is individually created to guarantee individual uniqueness and to stop possible adversaries from identifying patterns. Following the creation of the DWT fusion, the data is further encrypted using the Paillier cryptosystem. Sensitive bid information is protected during processing and transmission thanks to this two-pronged strategy, which also improves the bidding process's secrecy and integrity. Each bidder's data is encrypted using a different encryption key, which adds an extra degree of protection and customization. Each bidder's data is transformed using manually produced unique bases of the single-resolution Discrete Wavelet Transform (DWT), as explained throughout this thesis. This method strengthens the system's resilience against unwanted access by offering a high level of resistance in the early cryptographic stage. The Paillier cryptosystem is then used to add a second layer of cryptographic security. The bidders' DWT-transformed data is used by this homomorphic encryption approach, which enables safe calculations on encrypted values. A pseudocode implementation is added to further increase cryptographic security, making the system more resistant to cryptanalytic assaults and eavesdropping as shown in the following steps.

i. Choose two random prime p and q, with $p, q \in Z_N$;

ii. Set $N = p.q$;

iii. Set $\lambda = lcm(p\text{-}1,q\text{-}1)$;

iv. Choose $g \in Z^{*}_{N^2}$;

v. Plaintext $d < N$;

vi. Choose a random number $r < N$;

vii. Calculate ciphertext: $c = g^{d}r^{N}modN^{2}$;

viii. Plaintext $d = F(c^{\lambda}modN^{2})\mu modN$;

where *lcm*(.) presents greatest common divisor, the order of *g* introduces a multiple of *n*, and *F*(.) presents $F(\mu)= \mu\text{-}1/N$, and $\mu = F(g^{\lambda}modN^{2})$. When combined, these two encryption and transformation layers guarantee that bidder information is private and impenetrable during the auction process.

4.7. Investigation

In this chapter, the proposed spectrum auction is guaranteed to function satisfactorily and to maintain privacy and security during the bidding process. The winner and their charge price are still determined by the auctioneer, who uses the Homomorphic Encryption using Paillier Haar cryptosystem to conceal the UEs' bidding values. The Paillier-Haar cryptosystem's self blinding feature and indistinguishability make it impossible to determine the true bidding value. It takes a look at a safe gateway, which is crucial to keeping the auction secure. The encrypted bids that the UEs send to the secure gateway are randomly generated by a random constant. Because the federal gateway randomized the bidding, even if a particular bidder conspires with the auctioneer, it will not be able to get any real bidding value. Then, without being aware of the real bidding prices, the auctioneer may decide which UEs will win and how much to charge for them. In other words, an effective spectrum scheduling system may arrange the cellular communication network's limited resources during peak hours time slots thanks to the proposed secure spectrum scheduling auction. The potential for the auctioneer to act dishonestly was taken into account, and a spectrum auction was created to guard against potential frauds and bid-rigging between dishonest auctioneers and avaricious buyers. In order to prevent the auctioneer from knowing the bidding prices of the successful UEs, the proposed spectrum auction uses homomorphic encryption using the Paillier-Haar cryptosystem. Through simulations, it demonstrated how the proposed power auction offers a safe spectrum scheduling auction against any insider transactions, while still generating enough money for the cellular communication networks and satisfying utilities for the UEs.

CONCLUSION AND RECOMMENDATIONS

In order to prevent dishonest auctioneers and greedy bidders from participating in fraudulent bid-rigging, this thesis aims to provide a secure auction mechanism for the spectrum sharing management. This chapter summarizes the major contributions, concentrates on the most important findings, and makes recommendations for more research.

This thesis primarily introduces an online auction technique that improves spectrum sharing management for secondary users by ensuring individual rationality, budget balance, and facilitating demand response through the cellular networks. Additionally, it presents a privacy-focused online auction method that protects secondary users' sensitive bidding data, effectively ensuring security and privacy for band demand, its frequency rate, and kind of waveform. Furthermore, the study examines the proposed mathematical models to achieve significant security outcomes for spectrum management system. Simulation results confirm that the proposed security system enhances resilience within cellular networks.

- **Conclusion**

The results of the investigation support the following conclusions:

- Discrete wavelet transform with single resolution structure was used in a spectrum sharing management system based on the security auction algorithm.
- The security system's architecture creates a special code to improve data security in cellular networks settings.
- Even when there are many secondary users, the system performs effectively.
- It uses cryptographic code generation, which limits computation to addition and subtraction operations, to decrease computational complexity.

- **Recommendations**

Although the main focus of this thesis is on cellular networks, secondary users, spectrum sharing, and security auction process, a number of issues and suggestions come to light.

- Investigating Different Wavelet Transform Families: Examining several kinds of wavelet transformations may improve denoising and data reduction in smart grid systems.
- Achieving Efficient Consumption Management: Energy efficiency, cost-effectiveness, and resource optimization may all be greatly enhanced by putting cellular networks-based spectrum management systems into place.
- Extension of the suggested techniques to other network setups, such as 6G, may enable more complete and integrated energy management systems.

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