

A SURVEY OF HANDOVER METHODOLOGIES IN COGNITIVE RADIOS FOR 5G NETWORKS

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DOI: <https://www.doi.org/10.58257/IJPREMS39949>

ABSTRACT

The advancement of 5G networks presents significant challenges in ensuring seamless connectivity, particularly in dynamic environments where cognitive radios are employed. The fifth-generation (5G) wireless communication system promises unprecedented levels of connectivity, high data rates, ultra-low latency, and massive device density. To achieve these goals, Cognitive Radio (CR) has emerged as a vital technology that enhances spectrum utilization by enabling dynamic access to underutilized frequency bands. One of the critical challenges in implementing CR in 5G networks is ensuring seamless and efficient handover between heterogeneous networks and frequency bands without compromising Quality of Service (QoS). Handover methodologies play a critical role in maintaining uninterrupted communication. This paper presents a comprehensive survey of handover methodologies in cognitive radio networks within the context of 5G. Various techniques, including spectrum sensing, decision-making algorithms, spectrum mobility, and predictive handover strategies are analyzed. Emphasis is placed on how these methods support uninterrupted service delivery, improve spectral efficiency, and reduce handover latency. Additionally, the survey identifies current challenges, such as interference management and energy efficiency, and explores emerging solutions driven by machine learning and artificial intelligence. This study aims to provide insights for researchers and developers working toward more adaptive and intelligent handover mechanisms in future 5G cognitive radio systems.

Keywords: Handover, Cognitive Radios, 5G, Methodologies, Network

1. INTRODUCTION

The rapid growth of wireless communication technologies has led to an increased demand for efficient spectrum utilization. With the advent of 5G networks, ensuring seamless connectivity, low latency, and high reliability has become a priority. However, traditional static spectrum allocation policies often result in spectrum underutilization and congestion. To address this challenge, Cognitive Radio (CR) has emerged as a key enabler of Dynamic Spectrum Access (DSA), allowing unlicensed users (secondary users) to opportunistically access underutilized spectrum bands without interfering with licensed users (primary users) (Mitola & Maguire, 1999).

One of the fundamental processes in Cognitive Radio Networks (CRNs) is handover, which ensures that secondary users can switch between different spectrum bands while maintaining an uninterrupted communication session. Handover methodologies in cognitive radio are significantly different from traditional cellular handovers, as they involve spectrum handover (switching between frequency bands) in addition to network handover (switching between different base stations or technologies) (Haykin, 2005). In the context of 5G, efficient handover mechanisms are essential for ultra-reliable low-latency communication (URLLC), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB) services. Existing handover methodologies in cognitive radios for 5G networks can be categorized into hard handover (break-before-make), soft handover (make-before-break), and hybrid handover (Yucek & Arslan, 2009). Advanced techniques such as machine learning-based handover, game theory-based spectrum handover, fuzzy logic-based handover, and blockchain-assisted handover have been proposed to enhance decision-making and improve spectrum mobility in dynamic 5G environments (Chen et al., 2019). This survey provides a comprehensive analysis of different handover methodologies in cognitive radios for 5G networks. It explores the strengths, limitations, and potential research directions in this field. The study also examines how emerging technologies such as artificial intelligence (AI), edge computing, and network slicing can further optimize spectrum handover processes, making 5G networks more adaptive and efficient. With the exponential growth in wireless communication, 5G networks have emerged as a transformative technology. Cognitive radios offer a promising solution to enhance spectrum utilization and dynamic access. However, handover management remains a fundamental challenge due to frequent mobility and dynamic spectrum allocation. This paper aims to survey handover methodologies, emphasizing their significance in maintaining Quality of Service (QoS) and spectrum efficiency.

2. CONCEPTUAL THEORY

Handover in wireless networks refers to the process of transferring an ongoing communication session from one network or frequency channel to another without disruption. In the context of Cognitive Radio (CR) for 5G networks, handover is a crucial mechanism that ensures seamless connectivity, improved spectrum utilization, and minimal latency. Cognitive radio enables dynamic spectrum access (DSA), allowing unlicensed users (secondary users) to intelligently detect and utilize unused spectrum bands while ensuring minimal interference with licensed users (primary users) (Mitola & Maguire, 1999). The theoretical foundation of handover in cognitive radio networks (CRNs) is based on three core concepts: spectrum sensing, spectrum decision-making, and spectrum mobility (Haykin, 2005). Spectrum sensing allows CR devices to detect available channels, spectrum decision-making selects the best available frequency bands based on network conditions, and spectrum mobility ensures efficient handover between different spectrum bands.

In the context of 5G, handover methodologies in CRNs are categorized into:

1. Hard Handover (Break-Before-Make) – A secondary user releases the current channel before switching to another, which may cause temporary disconnection.
2. Soft Handover (Make-Before-Break) – The secondary user establishes a new connection before releasing the old one, ensuring seamless transitions.
3. Hybrid Handover – Combines elements of both hard and soft handover to optimize spectrum switching in highly dynamic 5G environments (Yucek & Arslan, 2009).

Several methodologies have been proposed to enhance handover efficiency in CR-based 5G networks, including:

- Machine Learning-Based Handover – Uses reinforcement learning and neural networks to predict optimal spectrum handover decisions (Chen et al., 2019).
- Game Theory-Based Handover – Models spectrum handover as a competitive game between secondary users to minimize interference (Wang et al., 2018).
- Fuzzy Logic-Based Handover – Implements intelligent decision-making based on uncertain and dynamic network conditions (Zhang et al., 2021).

The integration of these handover methodologies with 5G network slicing, ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC) is essential for achieving high efficiency in next-generation wireless networks. Future research focuses on AI-driven handover, blockchain-based spectrum management, and edge computing-assisted cognitive radio to further enhance spectrum mobility in 5G and beyond.

2.2 THEORETICAL FRAMEWORK

2.2.1. Hierarchical Mobility Management Model- The basic idea behind the domain-based mobility management scheme introduced in Section 2.2.1 is that the mobility management strategy should be based on a hierarchical mobility management scheme that localizes the management of mobility by introducing the concept of domain, in order to achieve the requirements on performance and flexibility especially for frequently moving hosts. With this in mind, two kinds of mobility can be defined as follows, according to the movement span

- a. Micro mobility, i.e. mobile node's movements inside a domain, to which intra-domain mobility management solutions are suitable, focusing mainly on a fast, efficient, seamless mobility support within a restricted coverage.
- b. Macro mobility, i.e. mobile node's movements between different domains, to which inter-domain mobility management schemes can be employed, acting as a global mobility solution with the advantages of flexibility, robustness, and scalability.

The figure below shows the hierarchical mobility management model.

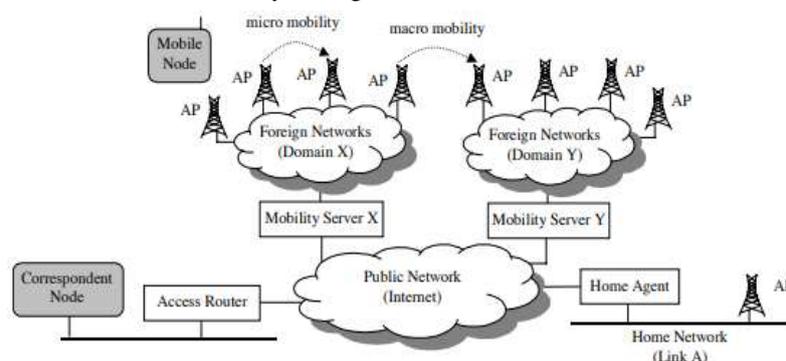


Figure 2.1: Hierarchical Mobility Management Model (Bhagwat et al., 1996).

2.2.2. Mobility Management for Femtocells in 5G- Support of femtocells is an integral part of the 5G system and a key enabler for its wide adoption in a broad scale. Femtocells are short-range, low-power, and low-cost cellular stations which are installed by the consumers in an unplanned manner. Even though current literature includes various studies towards understanding the main challenges of interference management in the presence of femtocells, little light has been shed on the open issues of mobility management (MM) in the two-tier macrocell-femtocell network.

Currently, one of the most challenging issues in mobile communications is the smooth integration of small-sized cells into the predominant macro-cellular network layout (Andrews et al., 2021). Small cells are short-range, low-power, and low-cost cellular access points that support fewer users compared to macrocells, embody the functionality of a regular base station and operate in the mobile operator's licensed spectrum. Small cells are considered a promising solution for improving cellular coverage, enhancing system capacity and supporting the plethora of emerging home/enterprise applications. Various small cell technologies have been deployed over the past few years, mainly including femtocells, picocells, and microcells, with broadly increasing radii from femtocells to microcells. Microcells and picocells are operator-managed, whereas femtocells are typically installed and managed by the consumer in an unplanned manner as shown below (Zahir et al.,2012).

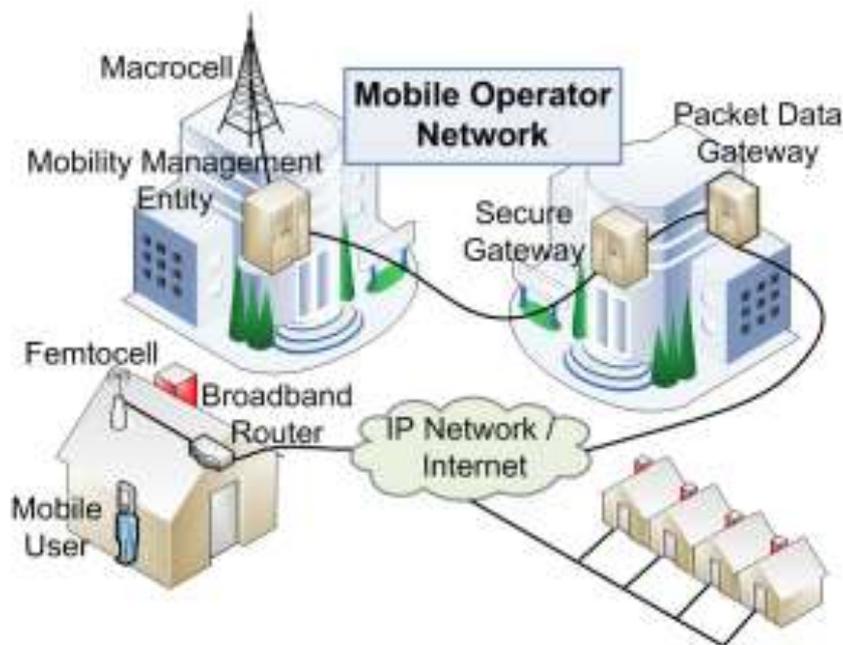


Fig 2.2 Example of Femtocell Deployment (Zahir et al.,2012).

Different from microcells and picocells, femtocells utilize the end user's broadband backhaul to reach the mobile operator network (Fig. 2.9). To cope with the comparably denser yet unplanned network layout, femtocells feature edge-based intelligence which spans over the implementation of enhanced self-x capabilities, such as self-configuration, self-optimization and self-healing, as well as advanced radio resource, interference, security, and mobility management. Other small cell technologies progressively incorporate femtocell features as well, aiming to enhance the user experience and reduce the mobile operator's maintenance and administration overhead.

Support of femtocells is an integral part of existing International Mobile Telecommunications (IMT)-Advanced standards and will play a key role in their wide adoption on a broad scale. One of these standards is the Release 10 of the 3rd Generation Partnership Project (3GPP) for the Long-Term Evolution (LTE) system, also known as LTE-Advanced (LTE-A), which surpasses the IMT-Advanced requirements set by the International Telecommunication Union (ITU). To achieve this, LTE-A incorporates a wide range of technical improvements for the LTE system, mainly including carrier aggregation, advanced multi-antenna techniques, relaying and enhanced support for heterogeneous deployments.

Current literature includes various surveys and studies on the key aspects of the LTE-A system and the technical challenges of femtocell support. The key differences between the LTE-A and LTE Release 8/9 systems, along with a short discussion on the technical improvements in LTE-A, are discussed in (Parkvall et al.,2011) and (Ghosh et al., 2010). The main challenges and the impact of using carrier aggregation in LTE-A are thoroughly investigated in (Iwamura et al.,2010), while the application of Multiple Input Multiple Output (MIMO) and relaying in IMT-Advanced standards are discussed in (Zheng et al, 2011) and (Xenakis et al., 2012), respectively. With the emphasis given to the

LTE system, various interference coordination and cancellation techniques are overviewed in (Xenakis et al., 2012), while focusing on the LTE-A system with multi-hop relaying, the performance of semi-static interference coordination schemes for radio resource allocation and power control is demonstrated in (Zheng et al., 2011).

The key features and a number of open issues for femtocell support are summarized in (Chandrasekhar et al., 2018), while in a more recent studies (Andrews et al., 2021), the authors discuss the present market status, the recent advances in algorithmic design and the ongoing standardization efforts for femtocells. The authors in (Zahir et al., 2012) highlight the key challenges of femtocell deployment and survey current literature on interference management for femtocells. The technical impact and the business models of the various access control methods for femtocells are discussed in (Roche et al., 2020) and (Golaup et al., 2019), while a wide range of radio resource allocation and power control techniques for cross-tier interference mitigation are included in (Garcia et al., 2012)

Various studies have addressed the issues of energy saving (Conte et al., 2018). Interference mitigation (Simeone et al., 2010), discontinuous reception (DRX) (Wigard et al., 2019), cell search (Meshkati et al., 2009), cell selection/reselection (Lee et al., 2019), location management (Ferragut et al., 2012), handover (HO) decision (Xenakis et al., 2012), HO execution enhancements (Rath and Panwar, 2012), performance analysis and signaling cost evaluation, under the viewpoint of femtocell support. A noteworthy amount of work has also been engaged with the problem of admission control in hierarchical cellular networks, providing valuable insights for conducting performance analysis and designing advanced mobility and interference management techniques tailored to the femtocell network.

Mobility Management (MM), in the presence of femtocells, is one of the most challenging issues, owing to the dense network layout, the short cell radii and the potentially unplanned deployment. The key challenges of MM support for femtocells are posed during the phases of

- a) Cell identification,
- b) Access control

Cell identification is cumbersome due to the unplanned and dense reuse of the same physical cell identifiers (PCI) within small areas, a.k.a. the PCI confusion problem (Zhang et al., 2010). On the other hand, given that the use of femtocells is subject to access control, MM is further complicated in three aspects:

- a) The mobile terminals should be aware of the femtocells they can access
- b) The femtocell stations should enable the identification of the access type they support, and c) the membership status of the mobile terminals should be validated by a trusted network entity prior to accessing the femtocells.

Cell search should also be reassessed in the context of femtocells, given that the dense yet unplanned deployment dictates the use of autonomous rather than network-controlled cell search procedures, whereas the short cell radii may unpredictably augment the required energy consumption and delay overhead. Cell selection/reselection is another critical issue in large-scale deployments of femtocells, where the tracking area size has a major impact on the user equipment (UE) battery lifetime and the network signaling load. More sophisticated HO decision algorithms are also required, in the presence of femtocells, to mitigate the negative impact of user mobility and cross-tier interference on the Quality of Experience (QoE) and Signal to Interference plus Noise Ratio (SINR) performance at the UEs. Attaining a low service interruption probability for medium to high-speed users is another challenging issue for the HO decision phase. Certain network architectural and procedural enhancements are also required to lower the delay and signaling overhead of the HO execution to/from femtocells. Even though MM support and HO decision-making are of critical importance in the two-tier macrocell-femtocell LTE-A network, current literature lacks of surveys and comparative studies engaged with the matter.

The report in (Kwak et al., 2008) provides a brief discussion on the key aspects of MM support for femtocells in LTE Rel. 8, whereas the support of femtocells in the IMT-Advanced amendment of the Worldwide Interoperability for Microwave Access (WiMAX) system, i.e., the IEEE 802.16m standard, is discussed in (Zheng et al., 2011). The HO procedure in the LTE-A and IEEE 802.16m systems is overviewed in (Kim et al., 2010). The technical aspects and research challenges of the HO procedure in mobile WiMAX, i.e., the IEEE 802.16e amendment, are investigated in (Ray et al., 2010), with the emphasis given in the medium access control (MAC), network, and cross-layer related issues. Under the viewpoint of 60GHz-based wireless systems, the survey in (Quang et al., 2012) overviews the HO procedure for various radio access technologies (RATs) and discusses the suitability of existing horizontal and vertical HO decision algorithms. The survey in (Fernandes and Karmouch, 2012) provides a comprehensive overview of existing MM architectures in heterogeneous wireless networks and discusses the key design challenges for vertical MM. A novel architecture for seamless mobility is subsequently proposed, founded on the concept of context awareness.

A wide range of context-aware functionalities for mobile and wireless networking are surveyed in (Kwak et al., 2008), and a classification of current state-of-the-art proposals per functionality is also provided. The authors in (Kassar et al.,

2008) survey, classify and compare existing vertical HO decision (VHD) strategies, and propose their own approach for VHD algorithm for next-generation heterogeneous wireless networks. In a more recent study (Yan et al., 2010), the authors survey and classify VHD algorithms for the fourth generation (4G) heterogeneous wireless network and provide a detailed comparison with regard to their performance.

3. METHODOLOGY

This survey systematically reviews recent literature, categorizing handover methodologies into signal-based, mobility-based, and machine-learning-based approaches. Performance metrics such as handover latency, packet loss, and spectrum efficiency are analyzed to evaluate each method's effectiveness.

3.1. Material Used

The materials used are:

- CISCO RFSS – This is used to extract data which was used as a baseline for our simulation.
- LAPTOP – 64-bit operating system, 8GB RAM, 7 Generation. It will serve as a workstation for simulation and experiment.
- MATLAB 19.2 - used to implement all written programs and serve as a simulation environment
- JAVA - High-level programming language used to write MILP with respect to variables in the developed algorithm.
- CORBA – This is the gateway with which MILP was used to interact with the kernel of CISCO packer tracer.
- CISCO PACKET TRACER – This is used to build a virtual network for simulation purposes.
- MICROSOFT EXCEL – This was used to tabulate the variables and also used to generate graphs.

3.2. Design Method

The method was to develop a mixed integer linear programming model for cognitive radio resources that reduces spectrum sensing energy dissipation using an energy detection method. The energy detection method is a non-coherent detection method that detects the PU signal based on the sensed energy. An existing MTN network is based on the CISCO RFSS network controller was characterized to determine the energy usage and the throughput, which was the key performance indicator that enhanced mobility management. The mixed integer programming was formulated to tackle the problem of deciding the SUs to use for the available spectrum. The problem of selecting the spectrum for allocation is tackled using MILP which is implemented in Java program. Spectrum analysis is tackled using a log - distance path loss model and adaptive modulation code (AMC) to estimate the minimum bandwidth of the SUs. In applying the above MILP technique to the underlay 5G radio network, connections existing between each of the secondary users can be represented mathematically in a linear equation inform of matrix which represents the minimum connectivity path for allocating resources for connected secondary users. This MILP model focuses on minimizing the power losses during spectrum sensing of the secondary user in other to avoid interference to the secondary user in other to maintain the mobility of the 5G. Due to simplicity and the no requirement on prior knowledge of PU signal, energy detection (ED) is the most common method in cognitive radio sensing. Advanced Cisco packet tracer software is used to build a virtual radio environment used for testing and validation of the developed spectrum allocation technique. 5G traffic is simulated within the virtual basic software environment. Poisson distributions are used to model the PUs and SUs traffic. The cognitive radio users (PUs and SUs) transmission arrivals are taken to be Poisson distribution. The proposed solutions for bandwidth estimation and allocation and energy issues are shown in figure 3.1 below.

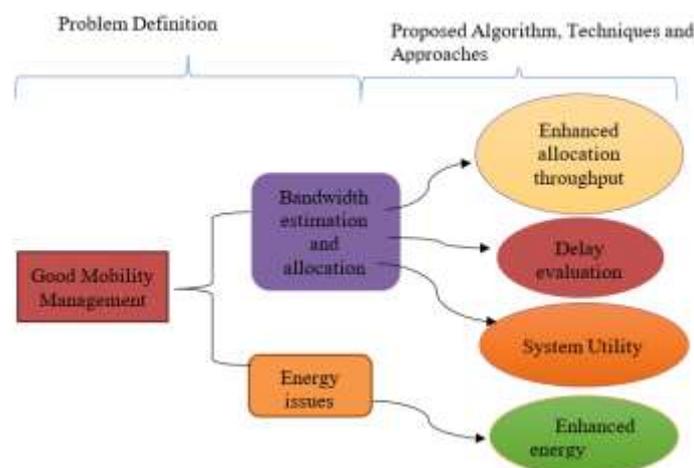


Figure 3.1: Proposed Solutions for Bandwidth Estimation and Allocation and Energy issues

3.2.1. Characterization of Energy Usage

This study characterized the MTN 5G base stations located at Polo Park Shopping Mail Enugu with serial number 219095560016 and power rating of -48W/h, 10A, cell range is 46meter, and transmission strength is 22dBm. The Operating frequency UL; 2500MHz – 2570MHz, DL 2620MHz – 2690MHz. ZTE ZXSDR R8862A S2601 Macro radio remote unit. Data was collected on 17th June 2022. The diagram of the based station is presented as shown in Figure 3.2 with the antennas, RRU, and other materials interconnected to it. The result is presented in Table 3.1;4



Figure 3.2 Base Transmitter Station

Figure 3.3 Particulars of a Remote Radio Unit Transmitter Station

Table 3.1: Data for characterization

Time (sec.)	Allocation Throughput Kbytes/sec	Power (Energy Usage)
3	1.7238	148
6	15.9034	148
9	18.6789	135
12	20.5678	132
15	30.6789	146
18	32.5678	157
21	38.9087	166
24	39.7950	178
27	43.8976	179
30	45.8956	182
33	50.5467	183
36	52.8906	188
39	55.7890	193
42	58.9876	205
45	60.8907	212
48	65.7865	216
51	67.8654	215
54	73.5678	204
57	76.9056	196
60	80.4657	185
Total	932.3131	3568

The data in Table 3.1 presented the power consumption performance of the 5G Radio station within sixty seconds.

Average throughput = $932.3131/20 = 46.6156$

Average power consumption = $3668/20 = 183.4$

3.3.1. Experimental Measurement and Data Collection

Data sampling window: 3secs

No of channel radio frequency channel: 13

Channel bandwidth: 0.1MHZ

Transmission power: 15watts

Bus (slots) duration: 625secs

The table below shows network data collected from 5G Radio MTN Network as shown in Fig 3.2 and Fig 3.3

Table 3.2 5G network traffic statistics data

Records# (interval 3secs)	Occupied channel	Unoccupied Channel	No of Sus	No of Pus	Average spectrum sensing duration (seconds)	Wait Queue	Active radio session
1	118	2	45	73	4.56	3	113
2	120	-	40	80	8.86	16	109
3	116	4	59	57	6.42	8	116
4	111	9	25	86	4.98	4	106
5	114	6	34	80	3.97	7	108
6	120	-	70	50	8.27	18	118
7	120	-	30	90	7.98	12	117
8	110	10	40	70	5.98	8	104
9	120	-	18	102	9.06	20	116
10	109	10	60	49	5.65	13	104

4. RESULTS

Table 4.1: Comparative Summary of Handover Methodologies in Cognitive Radios for 5G

Handover Methodology	Key Features	Advantages	Challenges	Suitability
Reactive Handover	Triggered by degradation in current link	Simple implementation	High delay, risk of call drops	Low-mobility environments
Predictive Handover	Uses ML/AI to anticipate handover before link fails	Reduced latency, proactive response	Requires training data and computational power	High-mobility, dense networks
Spectrum Sensing Based	Uses signal detection techniques (energy, cyclostationary)	Good spectrum awareness	Accuracy depends on method used	Dynamic spectrum environments
Make-Before-Break (MBB)	Establish new link before breaking the old one	Seamless transition, minimal service disruption	Resource-intensive	Critical communication systems
Break-Before-Make (BBM)	Disconnects first, then connects to new spectrum	Simple logic, resource-saving	High risk of dropped connections	Non-critical, low-traffic areas
MCDM (e.g., AHP, TOPSIS)	Evaluates multiple handover criteria simultaneously	Informed decision-making	Complexity in weight assignment	Adaptive and smart networks
SDN/NFV Based Handover	Centralized control with programmable network functions	Dynamic, scalable, flexible	Requires SDN infrastructure	Urban, heterogeneous networks

5. DISCUSSION

The evolution of 5G networks, characterized by ultra-high data rates, low latency, and dense device connectivity, necessitates more intelligent and efficient handover mechanisms, especially within Cognitive Radio (CR) environments. The survey highlights that traditional handover techniques, while foundational, are insufficient to meet the dynamic and heterogeneous demands of 5G networks. As such, newer and more adaptive methodologies are gaining traction. Predictive handover approaches, particularly those leveraging machine learning (ML) and artificial intelligence (AI), are becoming prominent due to their ability to anticipate link degradation and initiate proactive switching. These methods reduce handover latency and improve overall Quality of Service (QoS). However, their performance is highly dependent on the availability and quality of training data, as well as the computational capabilities of the network. In contrast, reactive handover methods remain relevant for simpler, low-resource scenarios but often suffer from higher latency and increased risk of dropped connections—factors that can critically affect real-time applications like autonomous driving and remote surgery. The use of Multi-Criteria Decision-Making (MCDM) techniques, such as TOPSIS and AHP, brings a structured approach to selecting the optimal handover candidate by considering multiple parameters (e.g., signal strength, latency, interference levels). While this enhances decision accuracy, the increased computational complexity can be a limitation in highly dynamic environments. Spectrum sensing-based techniques, which enable dynamic access to underutilized bands, remain integral to cognitive radio functionality. Among the sensing methods, cyclostationary detection offers higher accuracy but requires more processing power, making it less suitable for mobile or low-power devices.

The integration of Software Defined Networking (SDN) and Network Function Virtualization (NFV) has shown promising improvements in managing handover processes by enabling centralized control and dynamic reconfiguration. These technologies allow for more scalable and flexible handover decisions but demand advanced infrastructure and robust network orchestration. Importantly, despite these advancements, handover failures, ping-pong effects, and QoS degradation remain open challenges—especially in scenarios involving high-speed mobility or dense urban deployments. Future research should focus on hybrid approaches that combine the strengths of various methodologies and incorporate context-awareness, user behavior prediction, and real-time analytics.

6. CONCLUSION

The integration of Cognitive Radio (CR) technology into 5G networks represents a significant advancement toward achieving efficient spectrum utilization and seamless connectivity. This survey has reviewed various handover methodologies employed in CR-enabled 5G systems, highlighting their strengths, limitations, and suitability for different network conditions. While traditional reactive handover methods offer simplicity, they fall short in meeting the ultra-low latency and high-reliability demands of 5G. In contrast, intelligent approaches—particularly those incorporating machine learning, predictive algorithms, and multi-criteria decision-making—demonstrate substantial potential in optimizing handover performance. Additionally, the incorporation of SDN and NFV technologies adds a layer of programmability and flexibility, enabling real-time network adjustments and improved scalability. Despite these innovations, challenges such as increased computational complexity, energy efficiency, and reliable spectrum sensing remain. Therefore, future research should focus on developing hybrid, lightweight, and context-aware handover strategies that can adapt to highly dynamic environments without compromising Quality of Service (QoS). Ultimately, enhancing handover efficiency in cognitive radio systems is crucial for the realization of robust, intelligent, and sustainable 5G networks.

6.1 Contribution to Knowledge

This study will advance the field of mobility management in cognitive radio networks (CRNs) for secondary users (SUs) in motion by:

- 1. Optimizing Mobility Management:** Developing a novel algorithm to enhance spectrum handoff efficiency and reduce service interruptions.
- 2. Adaptive Spectrum Handoff:** Proposing strategies to minimize latency and improve connectivity using real-time data and predictive models.
- 3. Predictive Spectrum Availability Algorithm:** Creating algorithm to anticipate spectrum availability based on mobility patterns and primary user activity.
- 4. Quality of Service Improvements:** Enhancing network performance by reducing latency, packet loss, and connectivity disruptions.
- 5. Simulation and Evaluation:** Providing new benchmarks through performance evaluations and simulations for CRNs in dynamic environments.

6.2 Recommendation

For the effective administration of the Nigeria radio spectrum space and to stimulate an increase in the availability of radio spectrum and thus the reduction in the telecommunication cost, it is important that the Nigeria Communication Commission (NCC) lead the way in the opportunistic reuse of radio spectrum that has been allocated for TV and radio broadcast for data network usage. This work strongly recommendation here is that the NCC should use the findings of this work in terms of throughput, resource utilization, delay, and sensing energy achieved using the MILP as the baseline in the regulation of newer radio communication equipment

To improve mobility management for secondary users (SUs) in cognitive radio networks (CRNs), the following recommendations are proposed:

1. Adaptive Spectrum Handoff Mechanism using Predictive Modelling: Implement dynamic, low-latency handoff strategies using predictive models to anticipate spectrum availability and optimize handoff decisions based on mobility patterns and primary user activity to ensure seamless connectivity for mobile secondary users.
2. Quality of Service (QoS) Enhancements: Focus on reducing energy loss, handoff delays, and increasing throughput to improve overall network performance.
3. Integration of Real-World Scenarios: Nigeria Communication Commission (NCC) leads the way in the opportunistic reuse of radio spectrum that has been allocated for TV and radio broadcast for data network usage. They should also use the findings of this work in terms of throughput, resource utilization, delay, and sensing energy achieved using the MILP as baseline in the regulation of newer radio communication equipment.

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