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SURVEY

A Survey on Handover Optimization in Beyond 5G Mobile Networks: Challenges and Solutions

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ABSTRACT Handover (HO) management is essential in mobile cellular networks. It ensures seamless connectivity to the User Equipment (UE) while moving from one Base Station (BS) to another within the coverage area. HO optimization refers to the adoption of intelligent and automatic HO techniques in mobile networks. HO optimization is gaining more importance in Fifth-Generation (5G) and Beyond (B5G) systems because of the requirements and specifications that B5G targets. The requirements of B5G include global connectivity, ultra-low latency, big data analytics, extreme data rate transmissions, a massive number of devices in a small area, and new technologies that will support the B5G network, such as Millimeter Wave (mmWave), Terahertz (THz) communication, and Ultra-Dense Networks (UDNs). All these factors cause new HO optimization challenges and require new solutions for HO optimization techniques. This study comprehensively provides HO optimization challenges and solutions in B5G. First, it provides a research background and explanation of HO in legacy. It then investigates the HO optimization challenges in B5G, including future research directions. The paper then discusses the most prominent and recent techniques and technological solutions for HO optimization management in B5G. Finally, we highlight potential techniques for HO optimization in B5G.

INDEX TERMS Handover management, mobility management, HO, HO optimization, 5G, Beyond 5G, B5G, small cells, UDNs, mmWave, THz.

I. INTRODUCTION

The advancement of mobile and cellular systems has been extremely rapid, and new prospects are emerging. First-Generation (1G) and Second-Generation (2G) networks supply voice services, while Third-Generation (3G) and Fourth-Generation (4G) networks provide broadband Internet to consumers. The latest Fifth-Generation (5G) technology promises to offer consumers greater multi-Gbps peak data speeds, ultra-low latency, improved dependability, enormous network capacity, enhanced availability, and better consistency in user experience. The vision also includes expanding the coverage to more users that were not reachable via legacy technologies, such as in rural, remote, and disaster-prone areas. In addition, increased performance and efficiency enable new user experiences and business linkages. Although scenario identification for Sixth-Generation (6G) networks has not yet been accomplished, numerous studies, such as [1], [2], [3], [4], [5], [6], and [7], have provided studies on 6G and predicted the goal of linking everything globally via almost instantaneous, dependable, and inexhaustible wireless resources.

Furthermore, the 5G and 6G technological and architectural aspects that will form the future mobile system access,

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networking, and management domains offer limitless possibilities for service innovation and business efficiency, with tremendous influence on numerous vertical sectors [8]. 5G and Beyond-5G (B5G) network technologies can provide multiple options for various sectors, and new value chains and business models are ushering in a paradigm shift in the traditional communications service provider industry as it transitions to digital services [9].

Mobility management is considered a key function in B5G networks because it provides smooth access to wireless networks and mobile services. It ensures users' connectivity everywhere and at all times. Location and Handover (HO) management are two major functions of mobility management. Location management allows networks to track the whereabouts of the mobile nodes. On the other hand, HO management is the process through which User Equipment (UE) maintains its connection when traveling from one Access Point (AP) to another. The process of altering the UE's relationship with mobility such that the best-serving Base Station (BS) is always selected is referred to as HO. The average Received Signal Strength (RSS) level is a common and easy criterion for selecting the optimal serving BS. In other words, if another BS delivers a greater RSS than the serving BS, the UE changes its affiliation, which may occur when the user departs from the serving BS and moves toward another BS.

HO management in B5G is a significant part of a network that must be improved. Moreover, the requirements of enabling B5G, such as in 6G, ultra-high mobility of up to 1000 km/h, ultra-low latency of 10–100 μs, ultra-high peak data rate of up to 1–10 Tbps, and a massive number of connected devices per area of 10^7 devices/km^2 [10], [11] require efficient HO techniques to enable B5G to meet its requirements. Furthermore, utilizing new technologies such as Millimeter Wave (mmWave), Terahertz (THz), and a large number of small cells in a small area complicates the HO process, which makes the traditional HO techniques not applicable to the B5G system. In this regard, developers and researchers have begun investigating the challenges of HO management in B5G and have studied solutions that may help to address HO issues in B5G. Several researchers, such as [12], [13], [14], [15], [16], [17], [18], and [19], detailed in the related work section, have studied mobility management in 5G and B5G from different perspectives. However, there is still a lack of studies on HO's challenges and possible solutions in B5G considering innovative technologies and techniques such as blockchain, free cell networks, and Cell-Free massive Multiple-Input-Multiple-Output (CF-mMIMO).

Unlike the existing research in the literature, this survey comprehensively studies the challenges of HO in B5G that are caused by the new technologies and techniques to be implemented in B5G. On the other hand, this paper discusses the recent possible solutions of HO in B5G. The main contributions of this survey are summarized as follows:

- This survey presents background research on HO management in legacy systems and for different terminologies.
- Recent related works of this survey are also provided and summarized.
- The survey also comprehensively investigated the challenges of HO optimization in B5G systems. This explains the HO optimization issues in the most prominent B5G enabler technologies and is summarized in a table. For example, HO challenges interoperability, THZ Wave, high accuracy of data transmission, CF-mMIMO, The Non-Terrestrial Network (NTN), etc. Moreover, the challenges related to HO optimization emerging from B5G requirements are introduced. In addition, HO optimization research directions are illustrated.
- Most HO optimization technique solutions for B5G are discussed, along with how each technique can improve HO optimization in B5G. Also, the potential technologies that will help in enhancing the HO optimization in B5G, such as HO techniques based on: Blockchain, Artificial Intelligent (AI) techniques, RIS (Reconfigurable Intelligent Surface), Holographic Beamforming (HBF), cell-less network, etc., are highlighted. Moreover, their impact on enhancing HO optimization in B5G was summarized.
- This survey will help researchers, developers, and system designers interested in HO optimization in B5G systems to identify HO optimization issues facing the implementation of B5G. It also highlights the most recent and advanced HO optimization solution techniques for B5G. As a result, this survey can assist researchers and developers in designing robust and seamless HO optimization algorithms for B5G networks.

The remainder of this survey is organized as follows: Section II introduces the research background, including HO techniques in legacy systems. Related work is presented in Section III. The challenges of HO in B5G are discussed in Section IV. Section V discusses HO techniques and potential solutions in B5G. Finally, Section VI concludes the study.

II. RESEARCH BACKGROUND

This section provides a detailed background on the research. HO is explained in terms of several aspects, such as HO management and processes, HO decision types, HO network types, HO schemes, HO Control Parameters (HCPs), and HO in B5G.

A. HO MANAGEMENT

HO management is the primary function and process of mobile wireless systems. This enables the UE to be connected to the networks while moving within the network's coverage. In addition, HO management in mobile cellular networks aims to provide a fast and seamless transition of UE between the service and target BS.

In general, the HO process has three stages: commencement, preparation, and implementation. The report on the reference signal measurement by users from the nearby BS to the serving BS is included in the first stage. For example, in 4G Long Term Evolution (LTE), the signal measurement report consists of the Reference Signal Received Quality (RSRQ) and Reference Signal Received Power (RSRP), further HO processes of LTE was provided in [20]. Furthermore, HO may be conducted following the downlink and/or uplink signal measurement reports.

The second stage is preparation, where the signal exchange between the admission controller, target BS, and serving BS occurs. The admission controller determines whether to commence HO based on network-defined HO features. Once the HO requirements are fulfilled, the mobile user releases the serving BS, which then seeks to harmonize and obtain access to the target BS through the Random-Access Channel (RACH). When the target BS is synchronized, the UE sends a confirmation message to the network, indicating that HO is completed.

B. TECHNIQUE-BASED HO CLASSIFICATION

HOs can be of two types: hard HOs and soft. Both are also known as Break Before Connect (BBC) and Connect Before Break (CBB). The details can be found in [21] and are discussed further as follows:

Soft HO or CBB: CBB is a type of HO technique in which radio connections are included and relinquished so that the user consistently maintains one link connected to the system [22]. Soft and softer HOs were presented in Code Division Multiple Access (CDMA) designs [23]. A softer HO occurs when a mobile device is associated with two sectors/cells in the same BS [24]. Soft HO is reasonable for anticipating voice call dropping, maintaining a functioning session, and resetting a parcel session. This provides a smooth transition between BSs. However, soft HO can only operate between BSs with the same frequency. Moreover, it uses multiple channels simultaneously for a single mobile user, thereby increasing the network resources and reducing the network capacity.

Hard HO or BBC: Refers to the type of process in which the mobile device breaks the connection from the serving BS before connecting to the target BS [25]. Unlike soft HO, the mobile device drops the current radio connection in hard HO and then reconnects to a new BS. This causes communication interruptions. However, a hard HO can improve the network load resources by releasing the mobile user's resources and allocating them to another user. Table 1 compares hard HO with soft HO in terms of several essential characteristics.

C. NETWORK-BASED HO CLASSIFICATION

There are two types of HOs in terms of network and access technology: horizontal and vertical. The illustration provided in Figure 1 illustrates two HO types based on the network.

TABLE 1. Hard HO Vs. Soft HO.

Characteristic	Hard HO	Soft HO
HO speed	Fast	Slow
Reliability	High	Moderate
Service interruption	More	Less
Power consumption	High	High
Complexity	Low	High
Network resource	High	Moderate
Packet loss	More	Less

Horizontal HO is a type of HO that occurs between the same type of access technology, such as HO, within 5G networks. Moreover, when a UE moves and changes its BSs in the same network, this type of HO is called horizontal HO.

Vertical HO is a type of HO that occurs between the two access technologies. In addition, when the UE connection changes between mobile cellular networks and Wireless Local Area Networks (WLAN), this is a vertical HO.

D. HO CONTROL PARAMETERS (HCPs)

The HO decision technique comprises two HCPs: HO Margin (HOM) and Time-to-Trigger (TTT) [26]. The HOM refers to the threshold of two signals of the serving BS and target BS, which are adjusted with a specific value for the HO initiation decision. In addition, if the difference between the two signals (serving and target) is greater than the HOM value, then HO is initiated, and vice versa. Choosing the value of the HOM should be accurate to avoid HO issues, such as frequent HO, unnecessary HO, connection drop, and the ping-pong effect. For example, a low HOM may lead to an HO Ping-Pong (HOPP) effect and unnecessary HO, whereas a high HOM causes connection failure [27].

TTT represents the time it takes the mobile device with a poor signal to detect a better signal and initiate the HO. Similar to the HOM, the TTT should be adjusted carefully to avoid HO problems such as the abovementioned issues. Overall, the TTT and HOM should be appropriately selected to provide optimum HO performance.

E. HO DECISION SCHEMES

This subsection provides several HO schemes and algorithms implemented in legacy, current, and B5G mobile systems. This classification is shown in Figure 2.

1) RSS-BASED HO DECISION SCHEME

The HCP, HOM, is utilized to analyze the RSS of the serving cell to the RSS of the objective cells [28]. The HO decision utilizing this technique is based on measuring the RSS of the serving BS on the mobile device. Moreover, the mobile device keeps measuring the RSS and reports to the serving BS the measurement of both the serving and the target BSs. Considering the RSS measurement and HOM, which are predefined with a particular value, the HO decision is initiated. Additionally, the RSS-based HO decision technique

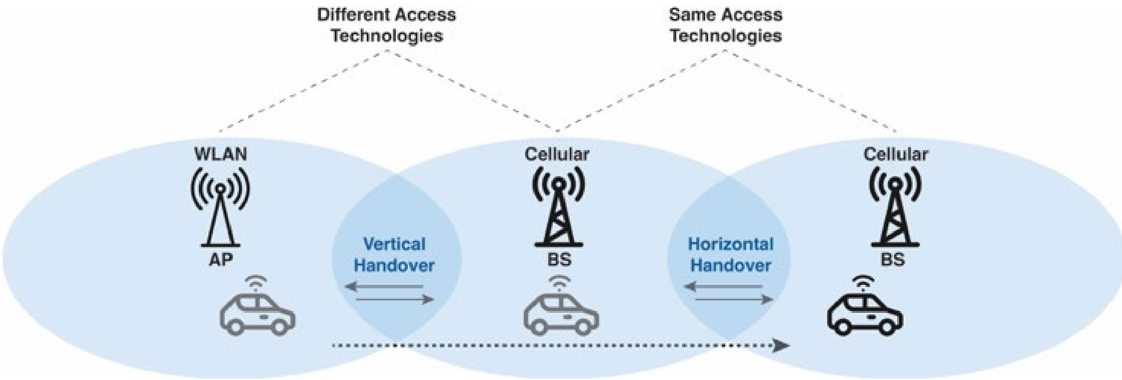

FIGURE 1. Horizontal and vertical HO.

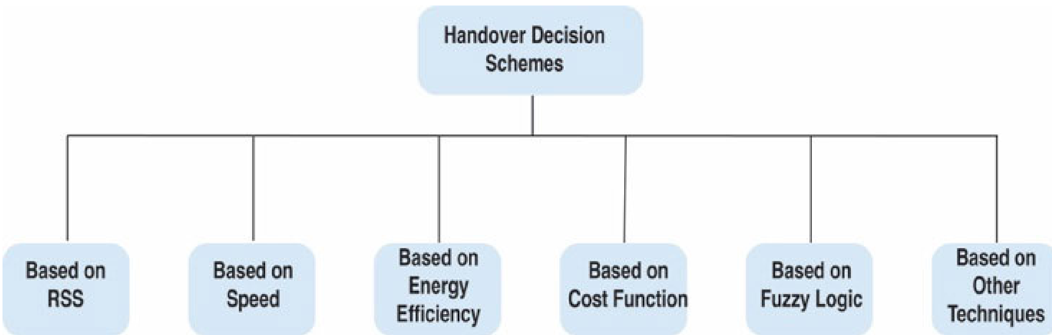

FIGURE 2. Classification of HO decision schemes.

is simple to implement. However, this technique has several limitations, such as its sensitivity to radio interference and mobile user mobility. Therefore, it increases the ping-pong effect and unnecessary HOs [29].

2) HO SCHEME BASED ON SPEED

One of the various HO decision schemes is HO based on UE's speed. In this scheme, the speed of the mobile device is utilized as an essential criterion to determine when HO needs to be initiated. The values of either one or both TTT and HOM are adjusted according to the level of UE. For example, when the mobile speed is high, the values of the TTT and HOM are set at low levels to avoid link failure. Furthermore, this type of HO scheme is usually combined with other HO decision factors, such as the RSS, UE's direction factor, and type of mobile data traffic, as in [30] and [31]. In addition, HO based on mobile speed is typically used in high-speed mobile scenarios, such as in vehicular networks or High-Speed Rail (HSR) [32], [33].

3) COST FUNCTION-BASED HO SCHEME

This type of HO decision technique is utilized to coordinate a wide range of HO choice parameters, such as the type of traffic, cell load, battery lifetime, user speed, and RSS, into one cost function. Moreover, this technique employs a cost function to analyze the quality of the current connection and prospective new connections and chooses the option with the lowest cost. Several studies, such as in [34], [35], [36], [37], considered cost-function-based HO schemes.

4) HO SCHEME BASED ON ENERGY EFFICIENCY

The energy-efficiency-based HO technique builds the framework's energy effectiveness by using small cells. In addition, it aims to reduce energy consumption during the HO process or switch from one BS to another. A few criteria can be set as the essential imperatives in this type of HO choice, for example, the power consumption of the mean TX (transmitter) of the user, UE, and system. Energy consumption can be reduced by decreasing the number of HOs and the signaling overhead. For example, many studies utilized energy-efficiency-based HO techniques, as published in [38], [39], and [40].

As the power utilization of the user and system are both emphatically reliant on the signal quality of interference, HO decision schemes based on energy efficiency are similar to those based on interference.

5) HO SCHEME BASED ON FUZZY LOGIC (FL)

Fuzzy Logic (FL) promptly leads to the HO choice issue because its adaptability in characterizing parameters obliges the dynamic nature of system conditions [41]. In a conventional HO situation, HO choice depends on whether the signal level (RSS) falls below a specific limit. When looking at various systems, an increasingly adaptable methodology, such as FL, would provide greater granularity in its portrayal. FL utilizes participation capacities that enable a parameter to simultaneously assume two unique states [42]. Taking the RSS model and utilizing a customary framework, the system's RSS is either above or below the limit. Furthermore, FL can depict how far a specific system's RSS is above or below the limit by appointing it as enrollment work for both states. For instance, a system with a participation capacity of 0.4 above and 0.6 underneath is less far beneath the edge than a system with a participation capacity of 0.2 above and 0.8 underneath.

6) HO BASED ON OTHER TECHNIQUES

The work in [43] advocates an all-SDN (Software-Defined Networking) system design with hierarchical system control abilities to consider various evaluations of execution and intricacy in offering central system administrations and provide administration separation for 5G frameworks. A dual-link soft HO plot for an HSR split system in HSR is introduced in [44]. By sending a train relay station and two reception apparatuses to the train, the HO blackout likelihood decreases. In addition, bi-throwing is performed to diminish the correspondence interference time and flagging progressions of the intra-macro-scale eNodeB (eNB) HO. Simulation results demonstrate that the introduced HO plan can essentially decrease the blackout likelihood and improve the HO achievement likelihood in HO among eNBs.

In [45], an enhanced HO technique was developed to merge the current UE trajectory and Home-eNB (HeNB) cell location. Additionally, a polynomial function is utilized to anticipate the future position of a user, whereas the cosine function, alongside separation, is utilized for the choice of a proper objective cell.

The authors in [46] presented an improved HO scheme that mitigates the rate of unnecessary HO probability in LTE-Advanced (LTE-A) by decreasing the number of objective femtocells and call blocking likelihood during HO. Two parameters, the speed and signal level of the UE, were considered before making the HO decision. However, in these studies, the effect of the call admission control scheme has not been verified for call dropping and blocking probability.

Additional comparisons of the different HO decision schemes in terms of their advantages and disadvantages are summarized in Table 2.

F. HO IN B5G SYSTEMS

1) OVERVIEW

5G has been proposed as a solution for the rapid expansion of terminals, mobile data, current enterprises, and various phenomena and services. The rapid growth of the mobile Internet and rising corporate demand should contribute to 5G's safety, reliability, lower power consumption, and low cost. Furthermore, the transmission degree increased from 10 to 100 times, with the peak transmission degree reaching 10 Gbit/s. The one-way delay was reduced to the millisecond level. Additionally, the connection device density would expand by 10 to 100 times, whereas the traffic density would increase by 1,000 times. The spectrum's efficacy would be increased by five to ten times, with a guaranteed user experience speed of 500 km/h [47]. It can be concluded that 5G technology has the potential to significantly enhance communication and connectivity, resulting in a positive interactive experience among users, a significant reduction in the distance between objects and individuals, and rapid identification of a connection between objects and individuals [48].

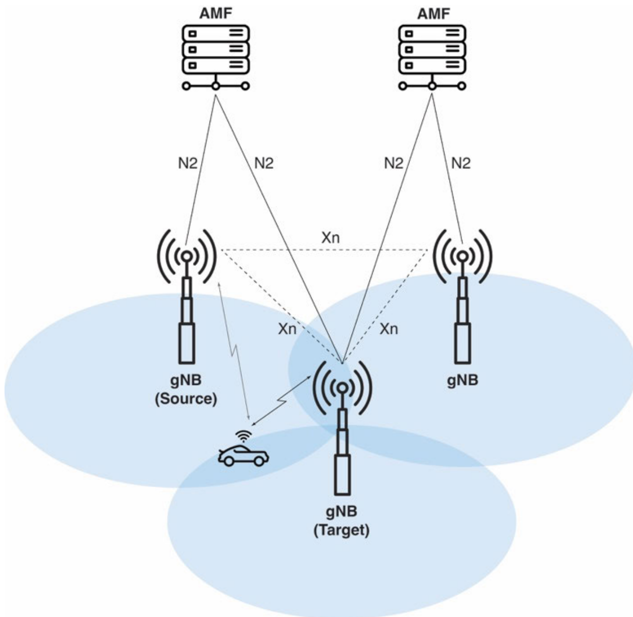

FIGURE 3. HO in the B5G network with the two HO procedure types.

HO is a key component of radio resource management, in which the optimal execution of HO results in a considerable increase in the overall system's efficacy and dependability, which is a critical function in modern wireless communication. In some cases, high bandwidth and transmission are essential for B5G mobile communication systems to accommodate various terminals. HO technology is critical for continuous responsiveness, service quality, and overall network execution.

2) HO PROCEDURES IN B5G

HO procedures are used in B5G systems to switch UE from source Next-Generation Radio Access Network (NG-RAN) nodes to target NG-RAN nodes. These procedures are used to maintain the connectivity of the UE service as it moves from one cell to another. Similar to the Evolved Packet System (EPS), HO methods are accessible even without a control-plane link between the source and target NG-RAN nodes. Two main types of HO procedures exist in B5G systems: Xn-based and N2-based procedures [49].

The Xn-based HO uses the Xn interface between the source and target NG-RAN nodes to handle the HO. This interface is

TABLE 2. Advantages and Disadvantages of the Different HO Decision Schemes.

Scheme	Advantages	Disadvantages
RSS-Based HO Decision Scheme	• Simple and easy to implement. • It is based on RSS, which is a commonly available measurement. • Low computational complexity.	• Susceptible to signal fluctuations and multipath fading. • May not consider other factors like user speed, network load, or energy efficiency. • May lead to frequent HOs (ping-pong effect).
HO Scheme Based on Speed	• Considers user mobility, which may reduce unnecessary HOs. • Can adapt to different user speeds for better performance. • May lead to better QoS for high-speed users.	• May not consider factors like signal strength, network load, or energy efficiency. • Requires precise user speed measurements, which may be challenging to obtain. • Less effective for low-speed users.
Cost Function-Based HO Scheme	• Considers multiple factors (e.g., signal strength, user speed, network load) in decision-making. • Can be tailored to specific network requirements or user preferences. • May lead to better overall network performance.	• Higher computational complexity. • Requires appropriate cost functions, which may be challenging. • Sensitive to parameter tuning and initial conditions.
HO Scheme Based on Energy Efficiency	• Focuses on energy consumption, promoting sustainable network operations. • May extend battery life for mobile devices. • Can help reduce network power consumption.	• May not consider factors like signal strength, user speed, or network load. • Potential trade-offs between energy efficiency and QoS. • May require additional monitoring and control mechanisms.
FL-Based HO Scheme	• Simple to implement. • Handles uncertain and imprecise input information. • Considers different factors for HO decisions. • Can be combined with other techniques. • Provides a more flexible HO decision-making process	• Requires designing fuzzy rules and membership functions precisely. • Higher computational complexity, in the case of a high number of rules and membership

responsible for transferring UE-related information between two gNodeB (gNB) nodes. This method allows for a smooth HO without service interruption, even without a control-plane link between the source and target NG-RAN nodes.

N2-based HO uses the N2 interface between the NG-RAN and the Access and Mobility Management Function (AMF) to handle the HO. The N2 interface is responsible for the transfer of UE-related information between the NG-RAN and AMF. This method also allows for seamless HO without interruption of service, but it is typically used when the UE is moving to a new coverage area managed by a different AMF.

Both the Xn- and N2-based HO methods are used to ensure continuity of service for the UE as it moves from one gNB coverage area to another gNB coverage area. These methods are important for maintaining a high-quality user experience and supporting the high-mobility requirements of B5G mobile networks. Figure 3 demonstrates the HO in B5G, including two types of HO procedures: Xn-based HO and N2-based HO.

III. RELATED STUDIES

This section presents several recent related studies that have been conducted in the same field as our study. The works are discussed and summarized in Table 3.

Zaidi et al. [12] pioneered a holistic survey in 2020 on mobility challenges in ultra-dense mobile networks and presented an in-depth tutorial on 5G mobility techniques with the pivotal mobility risks of legacy networks. This study reviewed key results from recent research and outlined the technical complexities and opportunities associated with mobility in emerging ultra-dense cellular networks.

Gures et al.'s comprehensive survey in 2020 [13] elaborated on 5G mobility management and its key elements (requirements, architecture, and challenges), which characterize mobility management in recent generations. Novel Radio Resource Control (RRC) inactive status, initial access, and registration and paging procedures are also highlighted. Inter-RAN HO protocols in a connected state and integrated mmWave cells with 5G technology have been thoroughly justified through literature reviews. Finally, the specific complexities entailing HO problems, signaling overhead, power consumption, security, and latency were addressed. Optimal solutions were highlighted to fulfill 5G mobility management prerequisites.

Ahmad et al. [14] conducted an inclusive study of HO decisions within two-tier 5G networks (eNB and HeNBs) in 2020. The first part of this survey provided a technical background for HO mechanisms. Essentially, the LTE-A architecture was discussed using recently released versions. The HeNB admission control and HO procedure phases in two-tier networks and HeNB HOM intricacies are subsequently highlighted. The integration of current modern HO algorithms into Heterogeneous Networks (HetNets) following primary techniques and input parameters was surveyed and classified in the second part of the survey, based on the HO challenges encountered by HO decisions in two-tier networks. The primary mechanism and input parameters in each category are employed in the HO decision to justify the benefits and drawbacks of the method. Notably, the representative algorithm in every category characterized its performance evaluation metrics. The aforementioned HO decision algorithms are then tabulated to present the decision parameters, key decision technology, and performance evaluation metrics. The article concludes with discussions on specific open issues involving 5G HetNet HO.

Jain et al.'s study in 2020 [15] presented a novel discussion on the functional requirements of mobility management strategies for these networks, with elaborations on the extent to which the current mechanisms were conceived by standardization bodies, such as IEEE (Institute of Electrical and Electronics Engineers), IETF (Internet Engineering Task Force), 3rd Generation Partnership Project (3GPP) (including the newly defined 5G standards), ITU (the International Telecommunication Union), and other academic and industrial research efforts fulfill these conditions. This was accomplished through a new qualitative evaluation that assessed every discussed mechanism following its capacity to fulfill the reliability, flexibility, and scalability criteria for future mobility management strategies. Research involving limitations in mobility management strategy design and implementation for 5G networks and beyond is also presented. Potential mobility management alternatives and their relevant capacities are outlined to manage persisting complexities. The study is summarized with a vision for mobility management mechanisms in 5G and B5G networks.

Mollel et al.'s survey study in 2021 [16] offered an extensive study on HOM in 5G networks with an emphasis on Machine Learning (ML) applications to HOM. A novel taxonomy based on the data source to be utilized in training ML algorithms was generated by following two broad divisions: visual and network data. The survey, which strived to divert the empirical focus from traditional methods to visual data sources following the potential of incorporating them into HOM, discussed how intelligent HOM could prove insightful in emergency scenarios involving mobile clinics, ambulances, and remote hospitals. Furthermore, advanced ML-aided HOM in cellular systems under every category is reviewed with recent research and elaboration on empirical issues and future study directions.

Tanveer et al.'s survey [17] on 5G mobility management in Ultra-Dense Small-Cell networks (UDSC) with Reinforcement Learning (RL) methods was published in 2022. The current surveys were first discussed before emphasizing HOM within the UDSC scenario. Likewise, this study explained how ML algorithms could facilitate multiple HO scenarios and outlined future directions and challenges involving 5G UDSC networks.

Khan et al.'s research in 2022 [18] presented a comprehensive review of HOM in future mobile ultra-dense HetNets. Various mobility and HOM methods have been developed to underscore their contribution towards seamless connection amidst user mobility. Specific intricacies, opportunities, and possible alternatives were also investigated to highlight the key complexities and ascertain appropriate solutions that may resolve mobility issues in future mobile networks.

The research in [19] examined various forms of flat and Distributed Mobility Management-based (DMM-based) Internet Protocol (IP) mobility management designs. Siddiqui et al., in 2022, identified and explored mobility management strategies for wireless networks from the viewpoint of network topologies, where traffic is primarily transferred locally at the RAN level rather than being routed over the primary network. The latest results were included in this study, along with the possible advantages of resilient mobility enablement in dynamic DMM 5G and B5G radio communication systems. Furthermore, the research thoroughly describes a wide range of recent and continuing investigations and difficulties, while outlining possible prospective study directions related to the planned flat DMM-based 5G and 6G networks. This article is a promising reference for designing wireless networks for 5G and B5G networks.

In summary, unlike the presented studies, from existing literature, which mostly focus on the existing HO challenges and omit critical expected HO optimization challenges and potential solutions of B5G networks, our survey extensively studies the HO optimization of B5G networks. This survey discusses the challenges and solutions of HO optimization techniques for future mobile wireless B5G. It examines most HO optimization challenges that may face the implementation of B5G networks, including the HO optimization issues of the potential technologies and techniques that will be implemented in B5G networks. In addition, future research directions are also discussed. Concurrently, this study provides the most prominent HO optimization techniques and explores the latest potential solutions for addressing HO optimization issues within the B5G context. Table 3 summarizes the existing related works regarding their motivations and contributions and is classified according to their published years and system focus.

IV. HO OPTIMIZATION CHALLENGES IN B5G

The challenges of HO management in B5G are increasing as new technologies are/will be designed for B5G systems to meet their requirements. This section discusses the most prominent HO optimization challenges in B5G networks by introducing new technologies to support the network.

A. ULTRA-DENSE NETWORK

In an Ultra-Dense Network (UDN) design, the cell radius is smaller than the initial radius [50]. A recurring HO is also generated by a decrease in the length of the mobile terminal remaining in the cell. Provided that the moving speed of the mobile terminal was 10 km/h, the cell radius speed was 25 m, and the overlap length amounted to 5 m, the mobile terminal initiated HO within 12 s, while the overlap area persisted for 4 s.

Various unresolved issues exist in the development of UDN, including many mobile node applications on the UDN

TABLE 3. Summary of Existing Related Works.

Ref.	year	System	Motivation	Contribution
[12]	2020	UDN	• The mobility management challenges in UDN • Few existing surveys are focused on ad hoc networks.	• Providing a comprehensive survey on mobility challenges in UDN. • Highlighting the mobility's technical constraints and possible prospects from the perspective of UDN.
[13]	2020	5G/ HetNets	• The importance of deploying intense small cells in 5G satisfies the demands and provides high coverage to the 5G network. • The mobility challenges, such as HOF, HOPP, HOL, etc. caused by the intense small cells.	• Providing a comprehensive survey in mobility management discussing RRC, the initial access and registration procedure of UE to the network, the paging procedure, connected mode mobility management techniques, beam level mobility, and beam management. • Addressing the challenges of mobility management and suggesting possible solutions for mobility management in the 5G.
[14]	2020	5G/ HetNets	• HO management decisions challenge facing in HetNets (femtocells).	• Presenting the challenges of HO management and highlighting modern HO decision algorithms between the eNB femtocells. • Providing a comprehensive study of HO procedure in LTE-A HetNets. • Categorizing the recent literature in HO's decision algorithms for eNB and femtocells in terms of the main decision technique.
[15]	2020	5G/ B5G	• The mobility management issues in 5G/B5G caused due to ultra-dense and HetNets to meet the users' data traffic requirements and ensure the QoS.	• Presenting discussion on 5G/ B5G mobility management functional requirements. • Developing qualitative analysis for the legacy mobility management techniques • Providing classification of the existing state-of-the-art techniques. • Discussing the research mobility management challenges. And discussing the potential solution.
[16]	2021	5G/ B5G	• ML HO management application in 5G/ B5G • HO challenges in the 5G requirements	• Updating the recent status of HO management in 5G. • Providing a comprehensive study on HO management in 5G, as well as a discussion on ML applications to HO management. • Producing taxonomy for the source of data used in training ML algorithms • Providing a revision of the state-of-the-art on ML-aided HO management
[17]	2022	5G/ UDSC	• The capability of the ML techniques enables the 5G to meet its requirements.	• Presenting HO RL-based techniques in 5G UDSC and showing how ML techniques impact HO management.
[18]	2022	5G/ B5G	• HO management over DC in 5G with UDN and HetNets.	• Various DC HO management techniques and mobility management strategies are examined and studied. • Describing the key concepts of the DC HO approaches in future UDN and HetNets. • Investigating the HO techniques based on ML and other emerging strategies to overcome mobility management issues. • Presenting and discussing several expected challenges and solutions for the future research direction.
[19]	2022	5G/ B5G	• The capability of DMM to solve the problems of unaided obstacles that destructively impact the current networks.	• Highlighting the possibilities and advantages of flat network architecture for efficient and fast traffic routing and providing the scheme's efficacy toward mobility management in B5G by outlining recent research efforts. • Discussing the existing constraints, problems, and future research path for seamless mobility to meet the requirements of current and future networks.

and small cells, which increases the number of HOs. This resulted in new recurrent HOs. In addition, UDNs may increase the HOPP effect that occurs when the UE frequently switches back and forth between two or more cells within a short period [51]. As a result of the control traffic surge, energy and network resources are consumed at a higher rate, thereby increasing the likelihood of HO Failure (HOF). In other words, increasing the number of cells increases the number of HOs, which increases the signaling overhead between the mobile node, serving, and target eNBs [52].

Recurrent and alternating HOs might arise from UDNs, leading to further problems such as increased latency and total error in the HO procedure [53]. Mobility management based on SDN and the current resource-estimation method

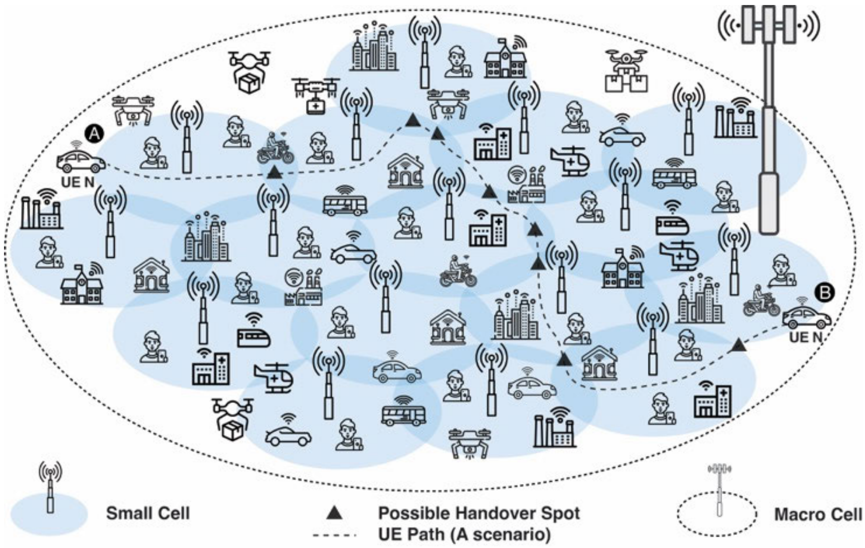

FIGURE 4. A UE HO scenario in UDN.

were proposed in [53] as solutions to the HO Latency (HOL) problem. A Markov chain-based HO management solution for software-defined ultra-dense 5G networks was also presented, which identified the optimal eNBs and conducted virtual allocation of the eNBs to the mobile node. Compared with the conventional method, the proposed solution reduced the HO errors and latency by 21% and 52%, respectively. In another study [54], a state-dependent HO selection algorithm was proposed that could notably reduce the rate of error in HO without decreasing the use of small cells and throughput user experience.

In addition, two intelligent HO skipping methods were proposed in [55], which enabled users to effectively skip future HO performance by considering the topological features of network deployment. In particular, the Cooperative (CO) skipping method is known as the BS collaboration advantage gained by the user, except when an HO is skipped. Meanwhile, in the Non-CO (NCO) skipping method, a single BS relation was used, and an HO was skipped according to three characteristics: (a) cell area, (b) path distance in the cell, and (c) BS distance from the cell boundary. For moderate user speeds, the NCO method provided the most significant average throughput.

Figure 4 illustrates a UE HO scenario for UDNs. As the figure shows, the network consists of a large number of small cells and a large number of different types of connected users. Thus, increasing the number of frequent HOs complicates the HO process and affects overall system performance. Additionally, assuming a scenario *UE N* moves from point *A* to point *B* through the UDN, as shown in the figure, a high number of HOs will occur; this increases as the UE speed increases.

B. ULTRA-LOW LATENCY COMMUNICATION (URLLC)

Mobility execution is one of the most crucial aspects of wireless interactions, and it also applies to Ultra-Low-Latency Communication (URLLC). URLLC services require high mobility, dependability, and latency [56], [57], [58], [59]. Seamless and quick HO approaches with no delay are essential for the activation of 5G capabilities, as well as various services and applications that demand a low-latency connection.

The effects of the HOF rate and HO Interruption Time (HIT) on reliability execution were investigated in [60]. The conditional make-before-break HO was then proposed, along with methods for simultaneously achieving zero HIT and zero HOF rates. In particular, zero HIT can be attained through make-before-break HO by suppressing the link from the source cell to the first or multiple downlink receptions from the chosen cell upon HO.

C. INTEROPERABILITY

Interoperability refers to the ability of different networks, devices, access technologies, or systems to communicate and work together smoothly [61]. Furthermore, in B5G, mobile users will be connected to different mobile wireless networks and access technologies to ensure connectivity and availability so that the mobile user can move and switch between other mobile wireless networks and access technologies freely and seamlessly. However, this increases HO management challenges by performing HOs between various wireless technologies [62]. Therefore, advanced HO techniques are required to support the mobile user when it sweeps within different wireless network accesses.

D. ULTRA HIGH MOBILITY

One of the major problems facing the advancement of B5G systems is ensuring dependable broadband wireless communication in high-speed mobility scenarios, such as HSR systems. In addition, the expected mobility speed that will be supported by the B5G system, such as 6G, is up to 1000 km/h. The major problems for HO in high-mobility systems were presented in [63]. In high-mobility scenarios, UEs often have a higher HO rate. Additionally, because UEs can quickly travel through the overlapping coverage area of the two BSs, the system may not have sufficient time to complete the HO operation. Consequently, more stringent delay control is required for HO in high-mobility systems. Moreover, fast-moving UEs might overlook the optimal HO position, increasing the chance of HOF. Furthermore, in HSR systems, HO may be required for many passengers aboard simultaneously, resulting in a group HO problem that requires a significant amount of network resources.

E. MMWAVE

5G mobile networks use a wide range of spectra in mmWave bands to significantly enhance the interaction volume. Significant differences exist between mmWave interactions and other current interaction systems in terms of substantial propagation loss, reactivity to blockage, and directivity. Moreover, when these features of mmWave interactions are fully utilized, they exhibit several problems [64]. In light of this situation, a thorough review of the new 5G mmWave wireless system ideas and a selection of the crucial mmWave radio propagation models developed globally to date were presented in [65].

Notably, mmWave interaction aided in the interaction of higher-frequency bands, significantly enhancing the volume of the interaction system. Nevertheless, high-band radio is only utilized within a restricted range owing to the low expansion around the barriers, atmosphere, rain absorption, and significant path loss [66]. Following rapid fading, a particular error in the measurement signal is present, resulting in a lower effective rate of HO and unnecessary HO. Overall, these phenomena have a significant impact on user interaction.

Accordingly, the problems associated with HO methods for radio-over-fiber networks at 60 GHz were discussed in [67]. In mmWave interaction systems, some problems in user mobility would lead to notable changes in channel conditions. User movement creates a distance variation from the receiver (RX) to the TX, including a wide range of channel conditions. The limited coverage of BSs also leads to a substantial and rapid rate of load shifts through user mobility in each BS, particularly in indoor areas [68]. Therefore, careful management of HOs between cellular APs and user relations is required to achieve optimum load stability.

In general, user mobility could lead to constant HOs between APs, while HO mechanisms could significantly impact network traffic, load stability, Quality of Service (QoS) guarantee, etc. For instance, smooth HOs are required to decrease the missing links and ping-pong, which refers to various HOs between similar pairs of APs. Nevertheless, more research is required on the HO mechanisms for mmWave interactions in the band of 60 GHz.

F. THZ WAVE

The core technology for 6G will be THz wave, which has an electromagnetic wave spectrum ranging from 0.1 to 10 THz with a wavelength of 30 to 3,000 microns [69]. The spectrum is in the transition region where macro-electronics and micro-photonics collide, especially between microwaves (from its lower band) and infrared light (up to its higher band) [70]. Despite the fact that the frequency band (from microwave to optical wave) of THz may not be fully operated, THz communication has abundant resources of the spectrum and an ultrahigh transmission rate, which provides precious broadband wireless access for future mobile networks [71]. THz communication also has a very large bandwidth range (up to 10 THz). In addition to its ability to visually penetrate non-transparent objects, THz communication also allows interactions with micro-scale objects (e.g., nanoscale networks or nanonetworks) owing to its scaled-down antennas (wavelength of approximately 1 mm for a frequency of 300 GHz). Consequently, the THz wave coverage is relatively limited, necessitating a large number of BS in a small area. Furthermore, the number of HO will be greatly increased because 6G employs ultra-mMIMO, which will affect the overall system performance. Consequently, 6G systems will experience significant challenges in terms of mobility management.

G. FAST AND SEAMLESS HO

A fast HO refers to the process of switching the UE from one BS to another with minimal disruption to ongoing communication. Simultaneously, a seamless HO is defined as an HO process that maintains the UE connection and data connected to the network without interruption when HO occurs [72]. Moreover, the goal of seamless HO is to ensure the uninterrupted delivery of end-to-end data in the case of a connection interruption or HO event [73].

In the B5G system, fast and seamless HO is a major challenge because B5G requires ultra-low latency and 100% connectivity to support different service cases, which require ultra-low latency and uninterrupted connection [74], [75]. Therefore, seamless and fast HO techniques are crucial for B5G mobile systems.

H. MASSIVE NUMBER OF DEVICES

The dramatically increasing number of devices connected to the Internet each year has likewise increased the volume of data. Billions of devices and sensors that are expected to be connected to the internet represent the main hurdle for 5G. Based on Huawei and Information Handling Services (IHS) forecasting analyses [76], [77], the number of connected devices will reach 75.4–100 billion devices by 2025. As such, 5G/B5G must be able to support massive amounts of data from an immense number of connected devices and sensors and process them in a very short time.

Overall, as the number of devices increased, the number of frequent HO also increased; thus, the HO challenge also increased. Therefore, ensuring HO techniques that can address the problem of increasing the number of HO is very important to meet the B5G requirements.

I. MULTI-RADIO ACCESS

To enhance the connection density, coverage, spectrum efficiency, and traffic capacity, B5G systems are promising for employing Multi-Radio Access Technology (multi-RAT) [78]. Multi-RAT refers to the ability of a UE to use multiple wireless communication technologies simultaneously. However, network diversity increases HO management challenges, such as interference, delay, and complexity. In the scenario of the multi-RAT network, the interference of frequency between networks may increase, affecting the signal quality and thus increasing the HO management challenges. Delay is another factor that increases the challenges of HO management in multi-RAT networks in B5G. In other words, as the number of mobile access technologies increases, the delay in HO can also increase, leading to a data communication delay. The complexity of managing HO in multi-RATs can be a significant challenge. With multiple networks and devices, it can be difficult to ensure that HO management is efficient and effective. Overall, managing HO in a multi-RAT network presents considerable challenges, necessitating efficient and effective HO techniques.

J. HIGH ACCURACY OF DATA TRANSMISSION

B5G must achieve high accuracy of data transmission without any error to satisfy its requirements and vision [79]. This is a considerable challenge, particularly with regard to the mobility of users and HO management. In the case of high data accuracy, the HO management task becomes more challenging, necessitating a fast and accurate HO decision to satisfy data communication accuracy. In addition, when the data are highly accurate, the UE is connected to the serving BS, even when it is the edge of the cell. This can increase the HO frequency as the UE moves in and out of the cell, creating an additional signaling overhead and reducing the overall system capacity. Therefore, this issue must be addressed efficiently to meet the demands and achieve the targets of the B5G system.

K. CARRIER AGGREGATION (CA)

Carrier Aggregation (CA) is an innovative technique that can increase the data rate in a B5G system [80]. In addition, CA enables the mobile terminal to be simultaneously linked with two or more cells of the providing BS, allowing the mobile terminal or UE to operate at various frequencies simultaneously. However, switching the UE from one cell to another in a short time may increase the complexity of HO management and cause difficulties during HO. One of the issues in carrier aggregation-related HO management is the requirement for coordinated HOs. For example, when a UE is connected to multiple carriers, it is critical to guarantee that HOs occur simultaneously across all carriers in order to maintain service continuity. If HO is not coordinated, it can cause service disruption, especially for real-time applications such as voice and live conferences with video calls. Furthermore, CA can result in a higher signaling overhead, influencing the total system capacity. The mobile device must exchange signaling messages with the network to perform HO as it moves from one carrier to another. This can result in a greater signaling overhead, particularly in densely populated areas, resulting in a lower system capacity. These issues will increase in the B5G system, as it uses enormous cells in a small area.

L. COGNITIVE RADIO (CR)

In wireless communication, Cognitive Radio (CR) is a technique used to utilize unused communication channels and allow users to dynamically switch between channels to evade user interference and congestion [81]. In addition, the CR intelligently detects which warless channels are in use and not in use. This is considered a type of spectrum allocation management.

In the B5G network, CR is an emerging technology that aims to increase spectrum utilization and satisfy massive data requirements by sharing the available spectrum intelligently, thus improving the QoS. However, HO management and switching between primary and secondary users are critical tasks [82]. Therefore, developing seamless and robust HO optimization schemes that can dynamically transfer users between section channels ensures a high QoS.

M. CELL-FREE MASSIVE MIMO (CF-mMIMO)

mMIMO is an extension of MIMO, a method in wireless systems that consists of many antennas for sending and receiving data from/to several users simultaneously [83]. CF-mMIMO [84] is a promising technology for B5G systems. On the other hand, CF-mMIMO is a system in which a large number of distributed APs coherently serve a large number of user terminals at the same time and frequency band. However, as investigated in [85], the users' serving clusters must be updated frequently in high-mobility scenarios. This generates a large number of signals, which affects the throughput. Furthermore, using CF-mMIMO may increase the HOL because each user can be served by several APs, which are themselves served by several Central Processing Units (CPUs).

Figure 5 (A and B) depicts HO in CF-mMIMO. As shown in the figure, each AP is connected to the CPUs, and multi-APs can serve each UE. Moreover, as shown in Figure 5 (B), *UE N* was simultaneously served by more than one AP and handed off to another AP/AP. Furthermore, the issue of HOL increased as UE speed increased.

N. PRIVACY AND SECURITY

Privacy and security are two of the biggest concerns in mobile wireless communication. In the B5G network, the importance of security and privacy is significantly higher than in the legacy because of the huge value of individuals' data that will be carried over different use cases and through the network [86], [87]. In addition, many applications that are not tolerant of security lack, such as autonomous and health-use cases [88], [89].

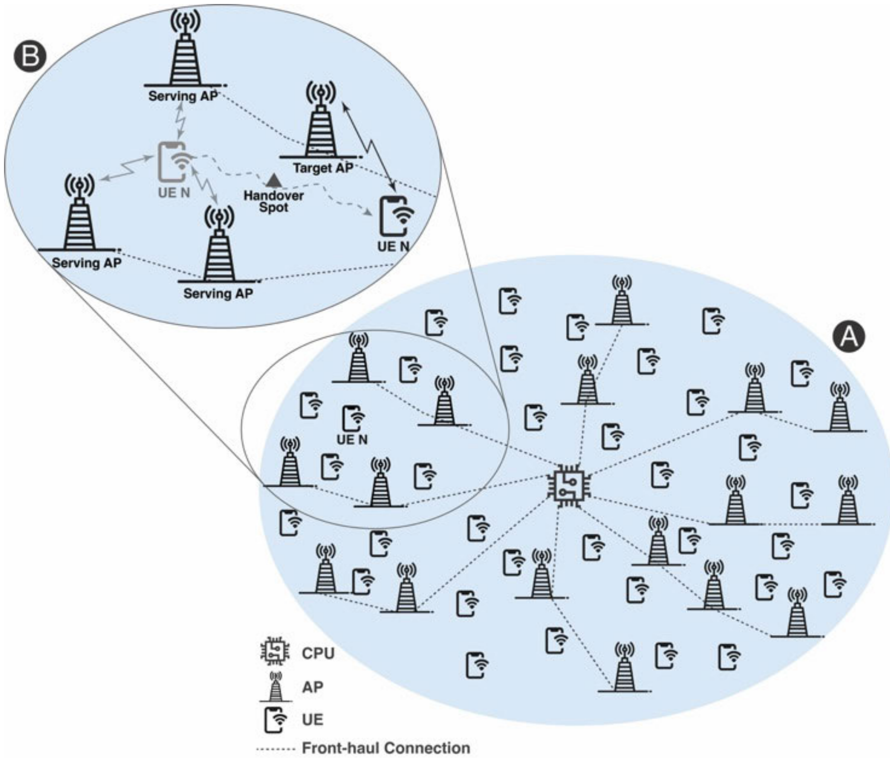

FIGURE 5. HO in CF-mMIMO.

In B5G HO, privacy and security are the main issues that must be addressed to ensure ultra-reliability. A comprehensive study on privacy and security was presented in [90]. This study outlined a complete set of security and privacy standards for 5G HetNet HOs to prevent possible threats and attacks. The study's findings and comparison show that state-of-the-art HO schemes fall short of fulfilling all security and privacy standards. Therefore, efficient HO techniques are required to satisfy the requirements of B5G networks.

O. NON-TERRESTRIAL COMMUNICATION NETWORK (NTN)

NTN is an important potential system that aims to satisfy the B5G system requirements of global connectivity and availability [91]. NTN aims to ensure connective and service availability for users anywhere and anytime [92]. Traditionally, NTN refers to the networks of satellite networks, Unmanned Aerial Vehicles (UAVs), and High-Altitude Platforms (HAPs), which are used in certain applications such as navigation, remote sensing, TV broadcasting, and disaster management [93]. In a B5G system, the NTN and Terrestrial Network (TN) will be integrated to ensure availability, scalability, and ubiquitous wireless coverage worldwide. However, the integration of TNs with NTNs may increase the complexity of the HO process, especially in the case of a Non-Geostationary-Satellite Orbit (NGSO) with moving cells, which causes cell pattern motion, thus increasing the frequency of HO. Furthermore, owing to the high speeds of satellites, the time that the UE is connected to the satellite is very short, which increases the rate of HO [94]. Therefore, new and robust HO techniques for NGSO are required to address the frequent HO caused by the movement of NGSO satellites. Table 4 summarizes the HO optimization challenges in B5G for each technology.

P. ADDITIONAL HO CHALLENGES IN MEETING THE 6G REQUIREMENTS

6G, which is expected to be released by 2030, is the most recent generation of mobile systems. Researchers, developers, and system designers have started to conduct experiments and identify roadmaps and standards, as well as 3GPP. 6G will make the most significant changes in the mobile system ever and will change the concept of the wireless system owing to the revolutionary technologies that will impact all life fields, people's lives, and industry domains.

The main 6G requirements and capabilities, as explained in our previous work [10], are as follows:

- User experience data rate of up to 1–10 Gbps.
- Extremely peak data rate of larger than 1Tbps.
- Spectrum efficiency is 5 to 10 times higher than in 5G.
- Ultra-high mobility speeds of 1000 km/h.
- Extremely low latency, about 1–10 μs.
- Massive connectivity density of 10^7 devices/ km^2.
- Network energy efficiency is 100 times higher than in 5G.
- Area traffic capacity of 1 Gbps/m^2.

TABLE 4. Summary of the HO Challenges in the B5G Network.

Technology	HO Related Challenges
UDN	High number of HO HOPP effect
URLLC	HOL HOL
Interoperability	High number of HO Different types of HO
High Mobility	HOF effect HOL
mmWave	High number of HO HOPP effect
THz Wave	High number of HO HOPP effect HOF effect HOL
Fast and Seamless HO	Fast HO Seamless HO
Massive Number of Devices	High number of HO
Multi-Radio Access	High number of HO Different types of HO
High Accuracy of Data Transmission	Fast HO Seamless HO HOL
CA	HO complexity
CR	Frequent HO
CF-mMIMO	High HOL
Privacy and Security	HO Privacy and security Cyber threats and attacks
NTN/ NGSO	Frequent HO

TABLE 5. Summary of the HO Challenges Face 6G Implementation.

Key Capability	Value	HO Optimization Challenges
Peak data rate	>1Tbps	Fast HO HOL
User experience data rate	1–10 Gbps	Frequent HO HOL
Spectrum efficiency	5x–10x of 5G	Frequent HO HOPP effect HOF
Ultra-high mobility speed	>1000 km/h	HOF Fast HO process HOL
Extremely low latency	1–10 µs.	HOL
Massive number of connected devices	10^7 devices/ km^2	Frequent HO HOL
Network energy efficiency	100x of 5G	Energy efficiency HO technique
Area traffic capacity	1 $Gbps/m^2$	Frequent HO HOL

To achieve these requirements, researchers and developers need to overcome the challenges of 6G implantation in all related fields. One of these fields is mobility management, specifically HO. Existing HO schemes may not be capable of being used in 6G systems. New optimization HO techniques must be developed to address HO issues, thus satisfying 6G requirements. Table 5 lists the HO management challenges that each distinct 6G requirement may face.

Q. DISCUSSION AND FUTURE RESEARCH DIRECTIONS

This subsection discusses future research directions based on the outcomes of this study. The discussion is summarized as follows:

- **Dynamic network conditions:** In B5G networks, the environment is constantly changing because of several factors, such as the user's mobility, network load, capacity, and radio link conditions. Thus, HO optimization techniques must be adaptive and capable of working with these various dynamic conditions to preserve high QoS and user experience.
- **Complexity:** Owing to the B5G network comprising a high level of HetNets and high-density networks, designing HO optimization techniques requires a high level of complexity. This complexity poses a challenge for developing and implementing HO self-optimization techniques because advanced algorithms are required to fulfill the complexity of the networks.
- **Interference:** One of the major challenges facing the implementation of HO self-optimization techniques in B5G cellular networks. This is owing to the rapid increase in the number of connected devices, high-frequency bands, and an enormous number of small cells in a certain area. Interference can cause significant performance degradation, thereby affecting the effectiveness of HO decisions. Therefore, developing HO optimization techniques that can ensure seamless HO processes is crucial.
- **Scalability:** As B5G networks are expected to support a massive number of connected devices and high-speed data rates, it is critical that HO self-optimization techniques are scalable to meet the demands of the networks. This requires the development of scalable and efficient HO decision techniques to handle the large volume of data associated with B5G networks.
- **Real-time performance:** HO self-optimization techniques must operate in real-time to ensure that the HO process is performed efficiently and effectively because several applications require real-time connectivity. Thus, it is challenging to design HO techniques with fast decision processes to maintain network performance.
- **Energy efficiency and sustainability:** HO optimization techniques should also consider energy efficiency and environmental impact. Developing energy-aware HO techniques can help minimize energy consumption and extend the battery life of mobile devices. Energy efficiency and sustainability are essential global issues that must be addressed to ensure sustainability.

In short, this survey suggests several solutions for HO optimization techniques. However, various issues and challenges remain open to researchers and developers in the future.

V. HO OPTIMIZATION SOLUTIONS FOR B5G

As discussed in the previous section, many HO optimization challenges will face B5G implementation and limit its goals and requirements unless solutions that can overcome these challenges are found. The developers and researchers have come up with several solutions, techniques and technologies to enable the requirements of B5G. This section provides the main and most recent HO optimization solutions for B5G.

A. CONDITIONAL HO (CHO)

When one or more HO execution conditions are satisfied, a Conditional HO (CHO) is proposed to be executed by the UE. The UE begins to evaluate the execution condition(s) upon receiving the CHO configuration and stops once an HO is executed (legacy HO or CHO execution) [95]. CHO is a novel solution included in 3GPP Release 16 that seeks to increase the mobility robustness of mobile terminals [96]. New mobile services with minimal latency and high dependability are now available. Although the 5G standard has been devised from the beginning to deal with these services, 5G New Radio (NR) development must continually improve mobility robustness in these challenging contexts. Furthermore, CHO concentrates on lowering the number of HOFs while a user moves (e.g., when an HO between cells fails or when a link fails before an HO is triggered). In CHO, instead of preparing one target cell, as in the legacy case, the network prepares several potential target cells in advance. This method allows the HO order to be transmitted to the mobile terminal sooner than legacy HO when the radio circumstances are still good rather than when they start to decline.

Accordingly, [97] investigated the mobility performance, disruption, and signaling overhead of CHO in 5G NR. According to this study, CHO could offer mobility robustness and outage gain, but at the same time, improper parametrization could notably increase signaling (overhead). Furthermore, the optimization of Self-Organizing Networks (SON) for CHO and CHO triggering based on source quality was found to considerably enhance performance without increasing signaling. In another study, [98] examined the merits and limitations of CHO by comparing it to 5G baseline HO. The study proposed utilizing more preparations to improve the robustness of CHO, resulting in significant signaling overhead. This study also proposed a revolutionary Prediction-based CHO (PCHO) strategy that employs Deep Learning (DL) technology to address CHO weaknesses and produce more intelligent preparation selections. Performance evaluation showed that PCHO could enhance the success rate of early preparation and decrease signaling overhead compared to existing CHO strategies.

The authors in [99] recommended the 'ZEro HOF with unforced and automatic time-to-execute Scaling' (ZEUS) algorithm in 2022 for seamless HO parameter optimization in CHO and the minimization of HOF to near 0 to fulfill the 5G network prerequisites, which necessitates HIT at 0 ms in various scenarios. In line with the analysis and simulation outcomes, ZEUS potentially attains a '0' HOF rate without elevating the HOPP rate. Although both metrics assessed an HO algorithm following a tradeoff between them, the two metrics proved inadequate with CHO, which resolved the tradeoff. Hence, a novel integrated HO performance metric, Mobility-Aware Average Effective Spectral Efficiency (MASE), was used to assess the HO algorithm optimality. Based on the simulation outcomes, ZEUS offered a higher MASE than LTE and other CHO variants. Figure 6 shows the CHO and the stages of the CHO procedure [100].

B. MACHINE LEARNING (ML) HO TECHNIQUES

ML is a collection of computational methods that emerged from powerful AI techniques that enable computers to self-learn, find patterns, and create models from past data without being explicitly programmed [101]. ML aims to find data collection characteristics that are likely to impact an outcome of interest given the input and then utilize those learned features to forecast the outcome in new circumstances [102].

By minimizing delays, computational overhead, and frequent HOs, ML techniques can significantly contribute to HO optimization and BS selection. These techniques aid in forecasting the target BS and ensuring that sufficient resources are accessible at the target BS before HO to guarantee a smooth HO [16].

A detailed explanation of HO management in 5G systems, including a discussion of ML applications for HO management, was presented in [16]. A unique taxonomy was developed for the data source used in training ML algorithms, with two broad categories considered: (i) visual and (ii) network data. The current state-of-the-art ML-aided HO management in cellular networks was thoroughly examined, including the latest studies, obstacles, and potential study areas.

An example of utilizing ML is the study in [103], which proposed and explored an ML method for learning the best timing and location for HOs in 5G radio networks, as well as how to utilize the learned model to trigger HOs depending on forecasted radio circumstances. The entire solution was analyzed and compared to modern mobility methods to evaluate its efficacy in minimizing total system outages.

The following subsection discusses several important ML-based HO techniques that are promising for enhancing HO management in mobile wireless networks, especially in future B5G networks.

1) DEEP LEARNING (DL)

The DL HO technique is an important ML HO technique that improves HO performance in B5G networks [104]. DL can significantly improve HO performance in B5G systems.

DL is expected to significantly improve mobility management in future networks by leveraging its ability to analyze vast amounts of data and generate effective mobility management models. This powerful ML technique will assist in the development of intelligent algorithms capable of predicting user mobility patterns and adapting network resources accordingly. As a result, HO processes are optimized to reduce latency and enhance the Quality of Experience (QoE). Furthermore, DL-based HO optimization techniques will facilitate more efficient load balancing among cells and seamless integration of HetNets, such as 5G/6G, Wi-Fi, Device-to-Device (D2D), and satellite systems.

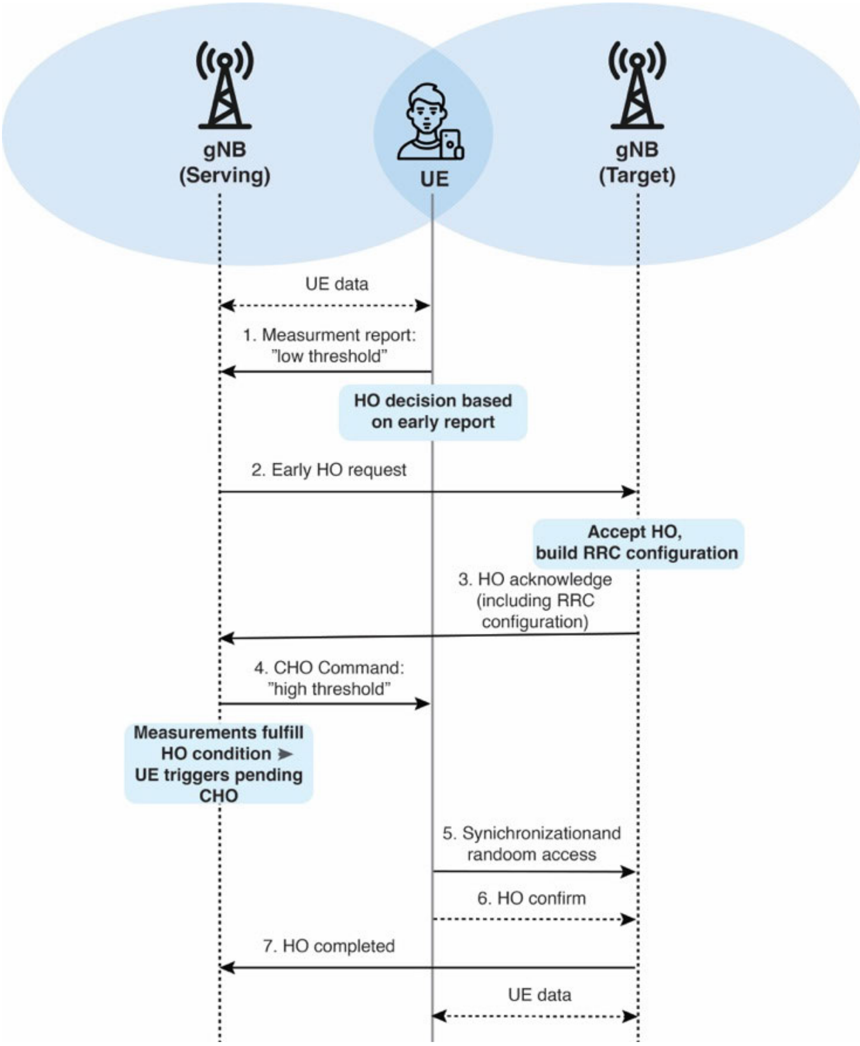

FIGURE 6. CHO procedures.

In [105], the authors suggested a hybrid user-mobility prediction method for HOM in mobile networks. User mobility patterns were first extracted using a mobility model with statistical models and DL algorithms. User future trajectories were forecasted using a Vector Autoregression (VAR) model and Gated Recurrent Unit (GRU). The number of unnecessary HO signaling messages was mitigated, and the HO procedure was optimized with the derived prediction outcomes. The mobility data generated from actual users were used in this experiment. All simulations were conducted with an Intel core i7-6700k CPU using 4.00 GHz and 32 GB RAM (Random-Access Memory). Keras, a renowned Python library, was used for the simulations. Based on the simulation outcomes, the suggested VAR-GRU mobility model demonstrated a minimal prediction error compared with the current approaches. HO processing and transmission costs were also examined for predictive and non-predictive scenarios. As a result, HO-oriented expenditure significantly reduces post-network predictions. The processing and transmission costs for vertical HO improved by 57.14% and 28.01%, respectively.

2) REINFORCEMENT LEARNING (RL)

Reinforcement is a subset of ML that can achieve a high HO performance [106]. It has demonstrated its ability to provide robust HO algorithms in B5G systems.

A study in [107] recommended an autonomous mobility management control method to enhance UE mobility robustness and mitigate operational mobility management expenses. The proposed technique relies on RL to learn an optimal HO control policy autonomously through environmental interactions. The function approximation technique enables RL for large state and action-space processing. A linear function approximator was employed to approximate the state-action value function. Finally, the semi-gradient State-Action-Reward-State-Action (Sarsa) approach is updated to the approximated function, and the optimal HO control policy is learned. The COST-Hata model simulated the LTE channel with the Urban Macro (UMa) and Urban Micro (UMi) propagation models from [108] incorporated for 5G channel simulation. Both Additive White Gaussian Noise (AWGN) and Rayleigh noise represent channel noise. Parallel to the simulation outcomes, the recommended approach could efficiently enhance UE mobility robustness under varying speeds and minimize unnecessary HOs and latency by approximately 20% and 58%, respectively, while attaining a near-0 HOF rate and increasing throughput by 12% compared to the conventional RSRP-based method.

In [109], the authors suggested an HO scheme following a Jump Markov Linear System (JMLS), which accounts for abrupt system dynamic shifts, and Deep-RL (DRL), an AI approach for learning highly dimensional and time-varying behaviors, to alleviate HO intricacies, maintain connectivity, and prevent unnecessary HO 5G mmWave mobile networks. Both methods were integrated to ascertain time-varying, abrupt, and incongruent shifts in mmWave link behavior by forecasting possible target-link deterioration patterns. As this prediction was enhanced by meta-training methods that minimized the training sample size, the JMLS-DRL platform formulated astute and flexible HO policies for 5G. The Dual-Connectivity (DC) LTE mmWave model presented by New York University and the University of Padova was employed in the current study simulation [110]. The LTE BSs in the DC model managed the mmWave BS. Reportedly, this HO scheme proved to be more reliable in target link selection than the Signal-to-Noise Ratio (SINR) and DRL-based HO schemes. The proposed scheme, which supports a longer dew time between HOs and high sum rates by avoiding unnecessary HOs with almost half the HOs, could reduce wasteful HO to less than 5% in 200 training episodes instead of the DRL-based HO counterpart, which required over 200 training episodes.

3) Q-LEARNING

Q-Learning is an RL model-free algorithm that does not require an environment model, given the current state, to determine the next-best action. It randomly selects the action and seeks to maximize the reward [111].

In B5G HO, the Q-Learning HO base technique is another type of AI HO technique that significantly improves B5G HO performance, as several studies have shown.

The authors of [112] introduced a technique based on Q-Learning for LTE. The method selects the TTT and HOM values according to the best performance by testing different values of the HCPs. The proposed method was compared with other HO optimization algorithms from the literature to evaluate its performance at various scenario speeds. According to the results, the method effectively enhanced HO optimization for several HO Key Performance Indicators (KPIs). Furthermore, the technique reduced the number of HO, increased the system throughput, and reduced the latency.

The authors in [113] proposed a novel QoE-aware Mobility Robustness Optimization (MRO) algorithm based on a multi-service scenario. In this study, optimization enhanced the cell edge QoE while simultaneously increasing the successful HO probability throughout the network, unlike previous methods that aimed to improve successful HO rates. Defined by the pair of HCPs (HOM and TTT), the HO trigger point was tuned per adjacency basis in line with QoE and HOF assessments. Essentially, a performance assessment was conducted in an authentic LTE scenario that was integrated with a dynamic LTE simulator embedded in MATLAB [114]. Consequently, QoE-aware MRO simultaneously enhances the cell edge QoE throughout the network and the successful HO probability compared to conventional techniques.

In [115], an intelligent scheme based on the AHP-TOPSIS (Analytic Hierarchy Process-Technique For Order Of Preference By Similarity To Ideal Solution) method and Q-Learning approach was proposed for HO optimization. The proposed scheme was analyzed numerically and via simulation using MATLAB. According to the results, the method performed better in delay-sensitive and speed-sensitive applications. However, this method aims to improve the HO performance by reducing the HOF rate and HOPP effect in the LTE-A system caused by deploying ultra-densification and small eNBs. In addition, this method is applicable to NG 5G networks. The results showed that the method reduced the HOF rate and HOPP by 28% and 25%, respectively. The method outperformed the conventional method and Fuzzy Multiple-Criteria Cell Selection (FMCCS) scheme, with reductions of 35% and 33% in HOF and HOPP, respectively.

4) DATA-DRIVEN

The Data-Driven technique is another crucial HO technique that can improve HO performance.

In [116], HO optimization was studied in NG networks. The study also introduced an HO optimization technique utilizing Data-Driven HO (DHO) to overcome the problem of HO management, such as unnecessary HO, wrong HO, too-late HO, too-early HO, and HOPP effects. The DHO technique is composed of four main steps: (a) identifying mobility management issues, (b) designing HO KPIs, (c) estimating the HO KPI function, and (d) optimizing HCPs (TTT and HOM). To evaluate the system, LTE-Sim was used considering LTE networks. This technique aimed to adjust the HCPs, including the TTT and HOM. The simulation results showed that the DHO could effectively reduce mobility management issues.

The research in [117] developed a DHO optimization model for femtocells based on data gathered from the measurement results of the mobile communications network to evaluate the association between the collected dataset features and KPIs represented as the weighted average of the mobility problem ratios. The proposed DHO approach addresses mobility problems such as HO delay, early HO, erroneous target cell selection, and prevalent HO. Furthermore, the KPI was improved by optimizing HO design parameters, such as the TTT and HOM. The neural network multilayer perception method was used to estimate the KPI based on TTT and HOM design parameters. MATLAB is used to test and simulate the proposed model. According to the simulation findings, a KPI increase of 12%–15.4% was achieved for a transmission power of 40–15 dBm. Based on these positive results, the study concluded that the proposed DHO scheme could effectively address mobility issues.

The transmit power Tuning-Based HO Success Rate Improvement Scheme (TORIS), a new Data-Driven alternative to mitigate inter-frequency HOFs and inter-frequency HOF prediction in 5G, was introduced and assessed in [118]. TORIS was developed through the establishment and combination of two sub-solutions. The first counterpart constitutes an AI-based model to forecast inter-frequency HOFs, which attained higher accuracy than its advanced counterparts by leveraging the two techniques. A new feature set was initially created by manipulating the domain knowledge derived from the in-depth drive test data evaluation. An extensive set of data augmentation approaches, such as the Chow-Liu Bayesian Network and generative adversarial network, was then exploited to resolve the class imbalance in HOF prediction model training. These approaches were further optimized with an emphasis on borderline sampling. The performance of the advanced AI model was also compared to predict HOFs with and without augmented data. SyntheticNET, an advanced 3GPP-compliant system-level simulator, was used for data generation [119]. The simulator was calibrated against actual network measurements for data validity. Consequently, AdaBoost demonstrated an optimal performance for HOF prediction. The second counterpart involves a heuristic technique for tuning the transmit power of the serving and target BSs. Notably, TORIS focused on the primary causes of HOFs, such as low signal quality and propagation conditions, by proactively varying the TX power of the cells in anticipation of HOF, unlike the advanced HOF mitigation methods that Tune Cell Individual Offset (CIO). Overall, TORIS outperformed the advanced HOF reduction solution, with a 40–75% reduction in HOFs.

Overall, the choice of HO management technique depends on the specific application and requirements of the system as well as the available data and computational resources. Essential comparisons of the different ML-based HO optimization methods, including Supervised/ Unsupervised Learning (SVL/USVL), DL, RL, Q-Learning and Data-Driven methods, are presented in Table 6.

C. MULTI-CRITERIA DECISION SUPPORT

Multi-Criteria Decision Making (MCDM) is a process used to evaluate and rank multiple alternatives based on multiple criteria or objectives. It helps decision-makers select the best option by considering different factors, often by assigning weights to each criterion and aggregating the scores [120]. In general, the MCDM method has two categories: (1) Multi-Objective Decision-Making (MODM) and (2) Multi-Attribute Decision-Making (MADM). Specifically, the first manages a continuous decision space, whereas the other deals with a discrete decision space [121].

The study in [122] presented an entropy-based simple additive weighting decision-making method for multicriteria HO in SDN-based 5G small cells to address the challenges highlighted earlier. The proposed HO method enables the mobile node to connect with the best-suited eNB by utilizing the bandwidth, user density, and SINR characteristics. Furthermore, the method was contrasted with the traditional LTE HO and distributed approaches considering latency, block ratio, HOF, and throughput based on the differing number of mobile users. In addition, the HO scalability for both methods (dependent on the number of users) was investigated. The simulation results showed that the proposed method improved the HOL, blocking probability, and throughput by 15%, 48%, and 22%, respectively, compared with conventional LTE HO.

In another study, [123] presented an intelligent mobility management system for HO optimization based on the Enhanced Multi-Objective Optimization Method by Ratio Analysis (E-MOORA) and the Q-Learning technique. E-MOORA combines the modified entropy weighting approach with the Multi-Objective Optimization Method by Ratio Analysis (MOORA), which includes vector normalization. Furthermore, the E-MOORA method employed performance parameters while selecting an HO target cell, reducing the ranking abnormality. The Q-Learning technique was utilized to determine the best-triggering locations to mitigate the effect of frequent needless HOs while still satisfying user QoS requirements. Compared to other current MCDM methods, the performance analysis demonstrated a substantial enhancement in avoiding unnecessary HO, Radio Link Failure (RLF), and user throughput.

D. FUZZY LOGIC (FL)

FL is a variable processing technique that allows numerous values to be processed through the same variable and seeks to solve issues using an open, imprecise data spectrum and heuristics that allow for an array of accurate conclusions [124]. Furthermore, FL was created to solve problems by accounting for all accessible information and making the most feasible decision, given the input. Recently, FL has been widely utilized in HO for 5G systems because it can significantly enhance HO performance in 5G systems, making this technique one of the best solutions for HO issues in 5G systems [125], [126].

Many studies have applied FL to their algorithms to develop HO techniques for 5G systems. For instance, [127] presented an FL-based method that utilizes a user's speed and radio channel quality to self-optimize a HOM for HO decisions. The goal of the proposed algorithm is to reduce the number of duplicate HOs and the HOF ratio while allowing users to reap the advantages of deploying dense small cells. Simulation results revealed that the proposed method effectively suppressed the HOPP effect and maintained it at

TABLE 6. Comparison of the Different ML-Based HO Optimization Techniques.

Criterion	SVL/ USVL	DL	RL	Q-Learning	Data-Driven
Learning Method	Supervised/Unsupervised learning.	Neural networks, including deep architectures.	Agent-environment interaction, reward-based learning.	Special case of RL, learning by trial and error.	Analyzing and discovering patterns in existing data.
Complexity	Relatively low to medium.	High, due to multiple layers and complex architectures.	Medium to high, depending on the environment and learning algorithm.	Medium, depending on state and action space.	Varies based on the method used and dataset complexity.
Training Data	Labelled or unlabeled data.	Large amounts of labelled data.	Cumulative reward from the environment.	Q-value table or function approximator.	Large volumes of data, structured or unstructured
Computational Requirements	Relatively low to medium.	High, due to deep networks.	Medium to high, depending on the learning algorithm.	Medium, depending on state and action space.	Varies based on the method used and dataset complexity.
Applicability in HO	Analyzing HO patterns, prediction.	Complex pattern recognition, feature extraction.	Dynamic environment adaptation, optimal decision-making.	Adaptive control of the HO process.	Discovering hidden patterns, feature extraction, modeling HO behavior.
HO Optimization Use Case and Suitability	When a simple and fast model is required. Suitable for less complex networks	When there is a need to learn complex HO patterns. Suitable for more complex networks and large-scale applications.	When HO optimization needs to adapt to changing conditions. Suitable for highly dynamic networks.	When a discrete representation of HO optimization is sufficient. Suitable for smaller-scale network.	When large amounts of historical data are available. Suitable for networks with limited dynamics or when historical data is highly representative.
Adaptability to Changing Networks	Moderate, may require retraining.	Moderate to high, depending on the architecture.	High, can learn new policies as the environment changes.	High, adaptive learning based on Q-values.	Moderate, may require additional data analysis and updates.
Generalization & Robustness	Moderate, depending on the model.	High, due to deep architectures.	Moderate to high, depending on the learning algorithm.	Moderate, depends on state and action space representation.	Moderate, depends on data quality and model selection.

a minimal level (below 1%) under all circumstances studied. Furthermore, the HOF ratio and overall number of HOs were significantly reduced compared with those of previous schemes, particularly in cases with many small cells.

An Auto-Tuning Optimization (ATO) method that adjusts the HOM and TTT based on the velocities of the UE and RSRP was presented in [128]. The proposed method mitigated the number of HOs and HOF ratios. Simulations with two-tier 4G and 5G system models were used to assess the performance of the proposed algorithm. Simulation results indicated that the proposed algorithm considerably decreased the average rates of HOPP and HOF compared to other state-of-the-art schemes.

E. PREDICTIVE HO

In mobile wireless networks, HO prediction is a simple technique for efficiently allocating radio resources and increasing QoS. For instance, [129] presented a Line-of-Sight (LOS) blockage forecast tool for small and dense mmWave cellular networks that can eradicate unnecessary HO and make essential HO smoother by accurately predicting the blockage time and duration of the mmWave channel LOS component.

The study in [130] proposed a unique approach for choosing the best network from the available networks to which a UE may be handed over to improve QoS performance. AHP acquired the aggregation of several criteria for calculating the overall network ranking, which was coupled with the history of previously visited cells and regression analysis of Layer 1 (L1) and Layer 3 (L3) filtered RSS data to predict future values. AHP was used to determine the weights of the system properties and rank the available networks based on numerous criteria MADM. Compared to the conventional AHP, the findings revealed that the developed algorithm decreased the number of HO and needless HO, as well as the threshold crossing rate and average fading time.

In another study, [131] introduced a unique algorithm based on RSRP, RSRQ, and various UE parameters, such as movement direction and femtocell location, utilized as HO decision criteria. The proposed algorithm selects the most appropriate target femtocell from many candidates and eradicates redundant HO in femtocell-based cellular networks. MATLAB was used to assess the performance of the proposed network in terms of user mobility in HO regions with a success/failure HO Probability (HOP). The findings showed that the developed approach performed better than the usual procedure in predicting the best target femtocell AP for HO. The overall network QoS was also improved owing to a lower failure likelihood rate and nearly steady ping-pong impact.

F. BLOCKCHAIN-BASED HO

Blockchain is one of the most recent revolution technologies that impact life in different applications [132], [133], [134]. One of its famous applications is cryptocurrency, such as Bitcoin [135]. It was created to allow Bitcoin users to execute safe financial transactions without using a go-between such as a bank. Mobile service providers, corporations, telecom providers, government regulators, and infrastructure suppliers may benefit from 5G's unique features, which can enable new business models and services that require uninterrupted interactions among numerous parties. Meanwhile, blockchain technology has emerged as a transformative, disruptive, and enabling technology that has begun to be used across various vertical industry sectors [136]. In addition, in 5G and B5G, blockchain (i) facilitates full-forward key separation for HO, (ii) provides innate security features to complement HO security, and (iii) improves network performance for HO [137].

To enhance the performance and security of 5G, [137] evaluated the existing LTE system's key management system in the HO process for reference. This assessment enabled us to pinpoint places that fundamentally threatened the efficiency and security of mobile communication. This study offers a solution to this problem by employing blockchain technology to boost throughput and security during the intra-HO phase of 5G networks. In addition to enhancing HO efficiency, PB-KDF (Parallel Blockchain Key Derivation Function) fixes structural flaws to help 5G reach its maximum capacity. In 5G, PB-KDF with a secure and quick HO would address the large BSs densification problem.

Similarly, [138] suggested using blockchain for key sharing and generation to increase the security and efficiency of the HO process. A novel technique called the Blockchain Key Derivation Function (BKDF) allows for increased protection and faster HO between the BSs. Because of the blockchain's additional element of protection, the network can securely produce the HO key and distribute it to the BSs and mobile devices in the pre-HO stage, greatly decreasing the number of transactions required during the intra-HO phase. The simulation findings showed that BKDF improved network reliability, reduced intra-HO packet loss, and reduced the HOL.

A summary of the different existing HO optimization techniques from the literature in terms of mobile systems, problems, solutions, used techniques, HO's KPIs, strengths, and weaknesses is provided in Table 7. Table 8 lists the strengths and weaknesses of various HO optimization techniques in B5G.

G. OTHER POTENTIAL SOLUTION TECHNIQUES

In order to satisfy the requirement of the B5G network and address the issues that may occur because of new demand in the form of mmWave and THz communication, several techniques and technologies can play essential roles in improving the HO performance and QoS for the users.

The following subsections discuss several techniques that are considered potential techniques and solutions for HO management in B5G systems.

1) DUAL CONNECTIVITY-AIDED (DC)

DC enables each user to connect to more than one BS at the same time [142], hence reducing HIT [143]. It has been demonstrated in [144], [145] that the HIT can be reduced to near zero using this approach.

Considering mobile consumers who demand real-time communication with minimal data rate demands, the authors in [139] developed a proactive mobility management system that uses a DC to assist. A proactive HO strategy and predictive resource reservation method comprise proactive mobility management. With the projected aggregate channel gains and the estimated list of linked BSs for each user, the predictive resource-reservation method is improved to increase the transmission rate or user impartiality. By dividing the cell-center and cell-edge users and selecting varying sets of linked BSs for the two classes of users, the proactive HO system attempts to prevent repeated and prolonged HOs and minimize the computing overhead. According to the simulation findings, the proposed methodology performs better than its reactive equivalents. It can substantially lower service interruptions while supporting a higher transmission rate when the traffic volume is high, or it can enhance user fairness while causing fewer service interruptions when the traffic load is low.

2) RIS-ASSISTED

The RIS is a new concept in wireless systems that aims to extend coverage over blockage areas [146]. RIS consists of a large surface area over a wall or flat surface [147], [148]. It is composed of many low-cost reflecting electronic components with programmable variables, such as traditional reflect-arrays and varactor diodes or micro-electrical-mechanical systems, the resonance frequency of which may be electrically adjusted. In HO management, using RIS has great potential to reduce blockages, thus minimizing the number of unnecessary HO. This is because the RIS strengthens the weak signals (mmWave or THz), which are attenuated or blocked because of the Non-LOS (NLOS) transmission, obstacles, and other environmental factors, such as rain and unclear space.

A study in [140] suggested an HO technique that uses RIS by utilizing DRL. By concurrently modifying the beamformers and RIS phase shifts, the DRL agent can lower the accumulated HO costs under various channel occlusion circumstances. The RIS-assisted HO system dramatically decreases the number of HO and provides improved spectrum utilization compared to previous systems that do not consider RIS. Additionally, the researcher suggests a simple technique to detect the blockage state to reduce the effects of the constrained views of rapidly fading channels. The findings of this study can be used to enhance the effectiveness of model development. The efficacy of the DRL agent can be further enhanced by integrating it with a blockage-status sensing algorithm according to numerical data.

Figure 7 demonstrates an HO scenario in the RIS system and how RIS may help to enhance mobile cellular coverage and HO issues caused by blockages and signal weaknesses.

3) HOLOGRAPHIC BEAMFORMING (HBF)

In general, Beamforming (BF) [149] is a method for transmitting and receiving antenna arrays using a focused narrow beam with a very high gain. This is accomplished by

TABLE 7. Summary of Existing Works in HO Optimization Management.

Ref.	Year	System	Problem	Solution	Technique	HO's KPIs	Strength	Weakness
[98]	2020	5G/ mmWave	Undesired early HO preparations due to the weakness of the mmWave signal affect the CHO's robustness.	Develop a novel PCHO scheme.	CHO/ DL	Early preparation success rate, number of early preparations and total resource reservation time	High prediction accuracy.	Computational complexity due to using the DNN model.
[99]	2022	5G	The problem of the accordance of HOF, which leads to an increase in the interruption time.	Introduce the "ZEro HOF with Unforced and automatic time-to-execute Scaling" (ZEUS) technique to optimize HO parameters easily in the CHO.	CHO/	HOP, HOF, and HOPP	Decreasing the HOF as well as decreasing HOPP.	Further HO reliability is required.
[103]	2021	5G	Minimize radio link failures while avoiding unnecessary HOs.	Propose an ML technique for learning the optimal time and destination for HOs.	ML	Outage	Simplicity.	No major HO KPIs (such as HOF, HOPP, etc.) are validated.
[105]	2021	Mobile Network	Problems of unnecessary HO affect the network capacity and increase the latency.	Develop VAR-the GRU mobility model, which is a hybrid user mobility prediction approach for HO management in mobile systems.	DL/ Prediction	Prediction error, HO processing cost and transmission cost	Predicts future user trajectory.	No HO's KPIs evaluated
[107]	2021	5G UDN/ HetNets	The problem of frequent HOs and HOF is caused by small cells and HetNets.	Propose RL-based with tile coding function approximation.	RL	HO rate, HOF rate, Throughput, HOPP and HOL	Better convergence and high computational efficiency as compared to the completive approaches.	Conflict of the trade-off between HOF and HOPP.
[109]	2022	5G/ mmWave	The problem of too early, too late, or wrong HOs is caused by utilizing mmWave, which is easily blocked.	Propose an HO scheme based on JMLS and DRL (JMLS–DRL).	DRL	Wasteful HO, and unnecessary HOs	Using fewer training episodes.	No main HO KPIs were validated.
[112]	2018	LTE	The problem of inappropriately adjusting HOM and TTT affects the HO performance.	Propose a Q-Learning optimization technique to learn the best TTT and HOM values.	Q-Learning	Throughput and number of HO.	Optimizing both HCPs (TTT and HOM).	Low HO robustness in complex network deployment scenarios.
[113]	2021	LTE	The problem of HOF impacts the QoS and QoE.	Propose a novel QoE-aware MRO algorithm considering a multi-service scenario.	Q-Learning	Too-late HO, too-early HO, successful HO, HOPP and QoE throughput.	Improve cell edge QoE while improving successful HOP.	Not suitable for applications that require extremely high throughput and ultra-reliable low-latency communications.
[115]	2019	LTE-A	The problem of optimizing the triggering time and selection of eNB impacts the QoS.	Develop a HO scheme based on the AHP-TOPSIS technique and Q-Learning.	AHP-TOPSIS Q-Learning	HOF and HOPP.	The technique provides more accuracy and low complexity. The method provides better performance for both delay-sensitive and speed-sensitive applications.	Needs further improvement in terms of energy computation.
[116]	2016	4G	The problems of mobility management include too-late HO, too-early HO, HO to the wrong cell, HOPP and unnecessary HO that is caused due to the deployment of dense small cells and UDSCs.	Present a DHO optimization approach.	Data-Driven	Too-late HO, too-early HO, HO to the wrong cell, HOPP, and unnecessary HO.	Improves mobility performance by reducing mobility management problems, including too-early HO, too-late HO, HO to the wrong cell, unnecessary HO and HOPP.	Computational complexity.

TABLE 7. ***(Continued.)*** **Summary of Existing Works in HO Optimization Management.**

[117]	2019	Small Cells	The challenges of the HOL, early HO, wrong HO, and frequent HO that caused by the deployment of the dense cells or UDNs.	Propose a DHO optimization technique.	Data-Driven	HOL, early HO, wrong HO, and frequent HO.	Optimizes both HCPs, HOM and TTT.	Introduces additional latency in the HO decision-making process due to data processing and model training.
[118]	2022	5G	The issues of the inter-frequency HOFs due to UDN.	Introduce a novel Data-Driven solution, which is referred to as TORIS.	Data-Driven	HOF.	Enhances the inter-frequency HO success rate by tuning the transmitter power using AI.	The approach omits the intra-frequency HOs and only focuses on inter-frequency HOs.
[122]	2021	SDN/ 5G Small Cell	The issues of HOF, HOPP, HOL and frequent HO that caused by the deployment of UDNs.	Introduce an Entropy-based simple additive weighting MCDM method HO in SDN based 5G small cells.	Multi-criteria HO	HO blocking probability, HOL, HOF and Throughput.	Provides better allocate resources within the network, improving network utilization and efficiency. Uses several parameters to make the HO decision, which improves the HO optimization accuracy.	The HOF probability is still relatively high. Computational Complexity.
[127]	2018	Dense Small-Cell Networks	A high number of HOs in dense small cell networks.	Self-optimization algorithm based on FL exploiting the velocity of the users and radio channel quality to adjust HOM.	FL	The number of HO, HOF, and HOPP.	It is simple and provides good HO decision-making accuracy.	The technique may suffer from computational complexity.
[128]	2019	4G/5G HetNets	The increase in the number of HOs increases the HOPP effect and HOF due to deploying a large number of BSs.	Introduce a self-optimization method based on WFSO to adjust HOM and TTT.	FL	RLF, HOPP, and HOF.	Besides its simplicity, it offers better performance with different mobile speeds due to considering the speed as a system input.	Effaced to sensitivity to noise and interference due to considering only two parameters, speeds and RSRP.
[130]	2020	HetNets	HO Optimization in HetNets.	Present a HO algorithm that considers the history of visited cells for target selection combined with AHP.	Prediction-based/ AHP-MADM	The number of HO and HOL.	Improves the QoS performance by selecting the optimal network.	The technique may suffer from computational complexity due to combining multiple schemes.
[131]	2019	LTE/ Femtocells	The challenges of deploying a large number of femtocells which leads to an increase in the frequent initiation of an HO procedure.	Propose a novel HO algorithm utilizing RSRP, RSRQ and several UE parameters, such as moving direction and the position inside the femtocell.	Prediction-based	HOP, HOF, and number of successful HO.	The technique considers multiple parameters for the HO decision, including RSRP, RSRQ, cell capacity and bandwidth availability.	The algorithm was not compared with any other advanced HO optimization technique to show its robustness.
[137]	2020	5G	The issues of the HOL and security in 5G network.	Introduce a novel approach to improve 5G experience by adopting blockchain.	Blockchain	HOL, Packet loss in the intra-HO phase.	Enhances the security and latency of the HO process.	Increases the computational complexity.
[138]	2019	LTE	The challenges of the HO process and security in LTE and Beyond networks.	Propose a method BKDF.	Blockchain	HOL, Packet loss in the intra-HO phase.	Improves the security of the HO process, as the technique utilizes blockchain technology.	Blockchain-based HO optimization techniques may consume more energy than traditional methods due to their computational intensity.
[139]	2021	DC	The issues of frequent HO, HOL, and computational complexity in the DC.	Develop a DC-aided proactive HO and resource reservation scheme for mobile users requesting real-time service.	DC-aided	Outage probability, average network rate and average minimal rate.	Offers dynamically balanced network performance by reducing service outages and boosting throughput during heavy traffic while	The technique may suffer from interference management.

TABLE 7. ***(Continued.)*** **Summary of Existing Works in HO Optimization Management.**

							enhancing user fairness and minimizing outages during light traffic.	
[140]	2021	5G/ mmWave	The weakness of the links caused by the high directivity and attenuation of mmWave signals causes frequent mmWave channel blockages, thus triggering excessive HOs.	Present a RIS-assisted HO technique by leveraging DRL.	RIS-assisted/ DRL	Prediction accuracy, number of HO and spectrum efficiency.	Reduces the HOP and achieves higher spectrum efficiency.	The technique may suffer from HOL and computational complexity.
[141]	2017	5G/ UDN	The requirement of ubiquitous service and support the users in smart cities.	Introduce 5G converged cell-less communication networks.	Cell-less	Coverage probability and energy saving.	Reducing the HOP.	High complexity and security concerns.

TABLE 8. **Summary of the Strengths and Weaknesses of the Different HO Optimization Techniques.**

Technique	Strengths	Weaknesses
CHO	• Simple to implement. • Reduces the number of HOF.	• May not be suitable for complex scenarios. • Undesired early preparations in the scenario of mmWave.
ML-Based HO	• Adapts to network changes. • Continuously learns and improves. • Can handle complex scenarios	• Requires a large dataset for training. • May suffer from overfitting or model bias
Multi-Criteria Decision HO	• Considers multiple factors for HO decisions. • Suitable for complex scenarios. • Flexibility. • Enhances the QoS.	• Higher computational complexity. • HO decision-making overhead.
FL-Based HO	• Simple to implement. • Handles uncertain and imprecise input information. • Considers different factors for HO decisions. • Can be combined with other techniques. • Provides a more flexible HO decision-making process.	• Requires designing fuzzy rules and membership functions precisely. • Higher computational complexity, in the case of a high number of rules and membership.
Predictive HO	• Simple to implement. • Reduces HOL. • Optimizes network resource utilization.	• Can be computationally intensive. • May suffer from prediction errors. • Complexity
Blockchain-Based HO	• Enhances security and privacy. • Enhances reliability. • Improves the user's experience.	• Scalability issues. • Implementation complexity. • Increases energy consumption.

focusing on power in a restricted angular range. In addition, BF enhances coverage and throughput while boosting the SINR, which may be utilized to monitor individuals. The HBF [150] is a more sophisticated BF method that employs a Software-Defined Antenna (SDA). On the other hand, HBF tracks the user with a narrow coverage, providing strong signals, thus reducing the unnecessary HO, Ping-Pong effect, and HOF.

Figure 8 shows a scenario of HO in HBF and gNB BSs, the scenarios of HO between the BSs, and how the HBF system serves each UE with a directive and narrow signal.

4) CELL-LESS NETWORK

A cell-less network is a promising technology that will be enabled in B5G systems. It provides seamless communication between various technologies, such as mmWave THz communication and Visible-Light Communication (VLC) [151]. Moreover, in cell-less networks, a single UE can be automatically connected to any available radio network. In other words, cell-less networks target avoid HO issues such as frequent HO, thus improving user experience and QoS [152].

Contrary to a typical cellular network, UE is not limited to establishing an association with a single standard BS or AP. The authors in [141] described a convergent cell-less communication network that utilizes collaborative communications to enhance traditional HO. The UE can be connected to several BSs or APs. This can be obtained using coordinated multi points. Additionally, SDN controllers are set up in 5G convergent cell-less communication systems to manage traffic and distribute resources. Consequently, the connectivity can be enhanced while reducing delays caused by HO.

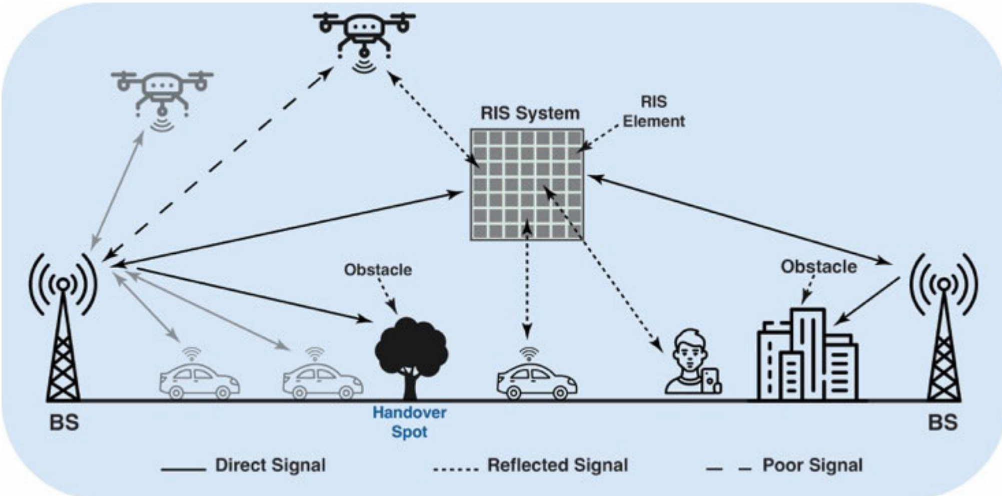

FIGURE 7. RIS System.

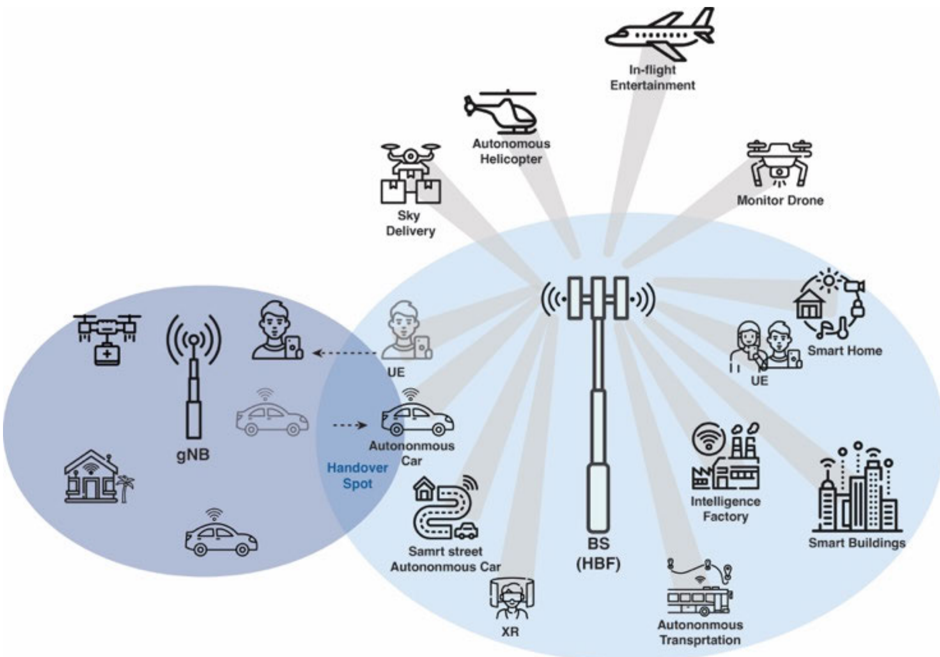

FIGURE 8. HO in HBF and gNB BSs.

TABLE 9. Impact of the Potential Technologies on HO Optimization in B5G.

Ref.	Technology	Impact on HO Optimization
[60, 139, 144, 145]	DC	Reduce: unnecessary HO, Reduce: HOPP effect, and HOF failure.
[140, 146]	RIS	Reduce unnecessary HO and HOF.
	HBF	Reduce HIT.
[141, 152, 153]	Cell-less network	Decrease: HO frequent, HOPP effect, HOF and HOL.

The simulation findings also reveal that the proposed method increases the likelihood of coverage and both the BS/AP and UE energy usage. Table 9 summarizes the impact of the potential techniques on HO optimization in B5G.

VI. CONCLUSION

HO management plays a significant role in mobile cellular systems, particularly in 5G and forthcoming generations (B5G). Therefore, researchers and developers must take substantial consideration in providing studies to improve HO techniques that are suitable for B5G systems. Moreover, HO optimization is considered a crucial topic because of its importance in enabling B5G networks. Furthermore, this survey paper presents extensive research on the challenges and solutions of HO management in B5G. It first presents background research on HO management in current systems. Next, we introduce recent related studies. The survey also examined the HO optimization challenges faced by implementing the B5G system. In addition, the most prominent HO optimization issues in B5G networks are discussed. Finally,

TABLE 10. List of Abbreviations in Alphabetical Order.

Acronym	Definition
1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	The 3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
6G	Sixth Generation
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AMF	Access And Mobility Management Function
AP	Access Point
ATO	Auto-Tuning Optimization
AWGN	Additive White Gaussian Noise
B5G	Beyond Fifth Generation
BBC	Break Before Connect
BCC	Break Before Connect
BF	Beamforming
BKDF	Blockchain Key Derivation Function
BS	Base Station
C-RAN	Cloud- Radio Access Network
CA	Carrier Aggregation
CBB	Connect Before Break
CDMA	Code-Division Multiple Access
Cf-MIMO	Cell-Free Multiple Input Multiple Output
CHO	Conditional Hanover
CIO	Cell Individual Offset
CO	Cooperative
CoMP	Coordinated Multiple Points
CPU	Central Processing Unit
CR	Cognitive Radio
CRE	Cell Range Extension
D2D	Device-to-Device
DC	Dual Connectivity
DHO	Data-Driven Handover
DL	Deep Learning
DMM	Distributed Mobility Management Train Relay Station
DRL	Deep Reinforcement Learning
E-MOORA	Enhanced Multi-Objective Optimization Method by Ratio Analysis
eNB	eNodeB
EPS	Evolved Packet System
FL	Fuzzy Logic
FMCCS	Fuzzy Multiple-Criteria Cell Selection
GB	Gigabyte
Gbps	GigaBit Per Second
GHz	Giga Hertz
gNB	gNodeB
GRU	Gated Recurrent Unit
HAPs	High-Altitude Platforms
HBF	Holographic Beamforming
HCPs	Handover Control Parameters
HeNB	Heterogenous Home-eNB
HetNets	Heterogenous Networks
HIT	Hanover Interruption Time
HO	Handover
HOF	Hanover Failure
HOL	Hanover Latency
HOM	Hanover Margin
HOPP	Hanover Ping-Pong
HSR	High-Speed Railway
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IHS	Information Handling Services
IP	Internet Protocol
ITU	International Telecommunication Union
JMLS	Jump Markov Linear System
Km/h	Kilo Metre Per Hour
KPI	Key Performance Indicator
LOS	Line-of-Sight
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MADM	Multi-Attribute Decision-Making
MASE	Mobility-Aware Average Effective Spectral Efficiency
MBS	
MCDM	Multi-Criteria Decision-Making
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MLP	Multi-Level Perceptron
mMIMO	Massive Multiple-Input-Multiple-Output
mmWave	Millimeter Wave
MODM	Multi-Objective Decision-Making
MOORA	Multi-Objective Optimization Method by Ratio Analysis
MRO	Mobility Robustness Optimization
multi-RAT	Multi-Radio Access Technology
NCO	Non-Cooperative
NG	Next-Generation
NG-RAN	Next-Generation Radio Access Network
NGSO	Non-Geostationary-Satellite Orbit
NLOS	Non-Line-of-Sight
NR	New Radio
NRN	Radio Access Network
NTN	Non-Terrestrial Network
PB-KDF	Parallel Blockchain Key Derivation Function)
PCHO	Prediction-Based CHO
QoE	Quality of Experience
QoS	Quality of Service
RACH	Random Access Channel
RAM	Random-Access Memory
RAN	Radio Access Network
RIS	Reconfiguration Intelligent Surface
RL	Reinforcement Learning
RLF	Radio Link Failure

TABLE 10. ***(Continued.)*** **List of Abbreviations in Alphabetical Order.**

RNC	Radio Network Controller
RRC	Radio Resource Control
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSS	Received Signal Strength
RX	Receiver
Sarsa	State-Action-Reward-State-Action
SCeNBs	Small Cells eNBs
SCNs	Small Cell Networks
SDA	Software-Defined Antenna
SDN	Software-Defined Networking
SINR	The Signal-to-Noise Ratio
SON	Self-Organizing Networks
SVL/ USVL	Supervised/ Unsupervised Learning
TCP	Transmission Control Protocol
THz	Terahertz
TN	Terrestrial Network
TOPSIS	Technique For Order of Preference by Similarity to Ideal Solution
TORIS	Tuning-Based Handover Success Rate Improvement Scheme
TTT	Time-to-Trigger
TX	Transmitter
UAVs	Unmanned Aerial Vehicles
UDNs	Ultra-Dense Networks
UDSC	Ultra-Dense Small Cell Networks
UE	User Equipment
UMa	Urban Macro
UMi	Urban Micro
URLLC	Ultra-Low Latency Communication
VAR	Vector Autoregression
CF-mMIMO	Cell-Free Massive Multiple-Input-Multiple-Output
VLC	Visible Light Communication
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network
ZEUS	Zero HOF With Unforced and Automatic Time-to-Execute Scaling

candidate solutions for HO optimization techniques in B5G are provided. As a result, this survey paper will contribute to helping researchers and developers interested in HO optimization in B5G technologies by comprehending HO optimization challenges and potential solutions, thus developing robust, seamless, and consistent HO techniques with B5G systems.

APPENDIX

See Table 10.

REFERENCES

[1] M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions," *IEEE Open J. Commun. Soc.*, vol. 1, pp. 957–975, 2020.

[2] P. Porambage, G. Gür, D. P. M. Osorio, M. Liyanage, A. Gurtov, and M. Ylianttila, "The roadmap to 6G security and privacy," *IEEE Open J. Commun. Soc.*, vol. 2, pp. 1094–1122, 2021.

[3] W. Jiang, B. Han, M. A. Habibi, and H. D. Schotten, "The road towards 6G: A comprehensive survey," *IEEE Open J. Commun. Soc.*, vol. 2, pp. 334–366, 2021.

[4] S. Zhang, C. Xiang, and S. Xu, "6G: Connecting everything by 1000 times price reduction," *IEEE Open J. Veh. Technol.*, vol. 1, pp. 107–115, 2020.

[5] C. D. Alwis, A. Kalla, Q.-V. Pham, P. Kumar, K. Dev, W.-J. Hwang, and M. Liyanage, "Survey on 6G frontiers: Trends, applications, requirements, technologies and future research," *IEEE Open J. Commun. Soc.*, vol. 2, pp. 836–886, 2021.

[6] H. Tataria, M. Shafi, A. F. Molisch, M. Dohler, H. Sjöland, and F. Tufvesson, "6G wireless systems: Vision, requirements, challenges, insights, and opportunities," *Proc. IEEE*, vol. 109, no. 7, pp. 1166–1199, Jul. 2021.

[7] Y. Lu and X. Zheng, "6G: A survey on technologies, scenarios, challenges, and the related issues," *J. Ind. Inf. Integr.*, vol. 19, Sep. 2020, Art. no. 100158.

[8] A. Pouttu, "6G white paper on validation and trials for verticals towards 2030's," *6G Res. Visions*, vol. 4, pp. 1–23, Jun. 2020.

[9] S. S. Yrjölä, P. Ahokangas, and M. Matinmikko-Blue, "Value creation and capture from technology innovation in the 6G era," *IEEE Access*, vol. 10, pp. 16299–16319, 2022.

[10] S. Alraih, I. Shayea, M. Behjati, R. Nordin, N. F. Abdullah, A. Abu-Samah, and D. Nandi, "Revolution or evolution? Technical requirements and considerations towards 6G mobile communications," *Sensors*, vol. 22, no. 3, p. 762, Jan. 2022.

[11] *IMT Vision Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond*, document Recommendation ITU, 2083, M. Series, 2015.

[12] S. M. A. Zaidi, M. Manalastas, H. Farooq, and A. Imran, "Mobility management in emerging ultra-dense cellular networks: A survey, outlook, and future research directions," *IEEE Access*, vol. 8, pp. 183505–183533, 2020.

[13] E. Gures, I. Shayea, A. Alhammadi, M. Ergen, and H. Mohamad, "A comprehensive survey on mobility management in 5G heterogeneous networks: Architectures, challenges and solutions," *IEEE Access*, vol. 8, pp. 195883–195913, 2020.

[14] R. Ahmad, E. A. Sundararajan, and A. Khalifeh, "A survey on femtocell handover management in dense heterogeneous 5G networks," *Telecommun. Syst.*, vol. 75, no. 4, pp. 481–507, Dec. 2020.

[15] A. Jain, E. Lopez-Aguilera, and I. Demirkol, "Are mobility management solutions ready for 5G and beyond?" *Comput. Commun.*, vol. 161, pp. 50–75, Sep. 2020.

[16] M. S. Mollel, A. I. Abubakar, M. Ozturk, S. F. Kaijage, M. Kisangiri, S. Hussain, M. A. Imran, and Q. H. Abbasi, "A survey of machine learning applications to handover management in 5G and beyond," *IEEE Access*, vol. 9, pp. 45770–45802, 2021.

[17] J. Tanveer, A. Haider, R. Ali, and A. Kim, "An overview of reinforcement learning algorithms for handover management in 5G ultra-dense small cell networks," *Appl. Sci.*, vol. 12, no. 1, p. 426, Jan. 2022.

[18] S. A. Khan, I. Shayea, M. Ergen, and H. Mohamad, "Handover management over dual connectivity in 5G technology with future ultra-dense mobile heterogeneous networks: A review," *Eng. Sci. Technol., Int. J.*, vol. 35, Nov. 2022, Art. no. 101172.

[19] M. U. A. Siddiqui, F. Qamar, M. Tayyab, M. N. Hindia, Q. N. Nguyen, and R. Hassan, "Mobility management issues and solutions in 5G-and-beyond networks: A comprehensive review," *Electronics*, vol. 11, no. 9, p. 1366, Apr. 2022.

[20] K. Dimou, M. Wang, Y. Yang, M. Kazmi, A. Larmo, J. Pettersson, W. Müller, and Y. Timner, "Handover within 3GPP LTE: Design principles and performance," in *Proc. IEEE 70th Veh. Technol. Conf. Fall*, Sep. 2009, pp. 1–5.

[21] B. Zhang, *Handover Control Parameters Optimisation in LTE Networks*. Sheffield, U.K.: Univ. Sheffield, 2018.

[22] S. Ferretti, V. Ghini, and F. Panzieri, "A survey on handover management in mobility architectures," *Comput. Netw.*, vol. 94, pp. 390–413, Jan. 2016.

[23] R. A. Saeed, "Handover in a mobile wireless communication network—A review phase," *Int. J. Comput. Commun. Informat.*, vol. 1, no. 1, pp. 6–13, May 2019.

[24] J. Kumawat and S. Tailor, "Soft and softer handover in communication netwoks," *Int. J. Recent Innov. Trends Comput. Commun.*, vol. 1, no. 6, pp. 558–562, 2013.

[25] I. Chattate, J. Bakkoury, A. Khiat, and M. El Khaili, "Overview on technology of vertical handover and MIH architecture," in *Proc. 4th IEEE Int. Colloq. Inf. Sci. Technol. (CiSt)*, Oct. 2016, pp. 31–34.

[26] R. Ahmad, E. A. Sundararajan, N. E. Othman, and M. Ismail, "Handover in LTE-advanced wireless networks: State of art and survey of decision algorithm," *Telecommun. Syst.*, vol. 66, no. 3, pp. 533–558, Nov. 2017.

[27] S. Alraih, R. Nordin, I. Shayea, N. F. Abdullah, A. Abu-Samah, and A. Alhammadi, "Effectiveness of handover control parameters on handover performance in 5G and beyond mobile networks," *Wireless Commun. Mobile Comput.*, vol. 2022, pp. 1–18, Mar. 2022.

[28] H. T. Yew, A. Chekima, A. Kiring, A. I. Mbulwa, J. A. Dargham, and S. K. Chung, "RSS based vertical handover schemes in heterogeneous wireless networks: Past, present & future," in *Proc. IEEE 2nd Int. Conf. Artif. Intell. Eng. Technol. (IICAIET)*, Sep. 2020, pp. 1–5.

[29] E. M. Malathy and V. Muthuswamy, "State of art: Vertical handover decision schemes in next-generation wireless network," *J. Commun. Inf. Netw.*, vol. 3, no. 1, pp. 43–52, Mar. 2018.

[30] W. Huang, J. Yu, P. Wang, and K. Sun, "A speed-based and traffic-based handover algorithm in LTE heterogeneous networks," in *Proc. TENCON IEEE Region 10 Conf.*, Oct. 2018, pp. 925–930.

[31] D. Yao, X. Su, B. Liu, and J. Zeng, "A speed-adjusted vertical handover algorithm based on Fuzzy logic," in *Proc. Int. Conf. Ad Hoc Netw.* Cham, Switzerland: Springer, 2018, pp. 167–176.

[32] S. Meghana and P. Jain, "Vehicle-to-vehicle communication.A vertical handover algorithm based on vehicle speed," in *Optical and Wireless Technologies*. Cham, Switzerland: Springer, 2018, pp. 481–489.

[33] B. Duan, C. Li, J. Xie, W. Wu, and D. Zhou, "Fast handover algorithm based on location and weight in 5G-R wireless communications for high-speed railways," *Sensors*, vol. 21, no. 9, p. 3100, Apr. 2021.

[34] D.-W. Lee, G.-T. Gil, and D.-H. Kim, "A cost-based adaptive handover hysteresis scheme to minimize the handover failure rate in 3GPP LTE system," *EURASIP J. Wireless Commun. Netw.*, vol. 2010, no. 1, pp. 1–7, Dec. 2010.

[35] R. M. Abdullah, A. Z. Abualkishik, and A. A. Alwan, "Improved handover decision algorithm using multiple criteria," *Proc. Comput. Sci.*, vol. 141, pp. 32–39, Jan. 2018.

[36] N. Salawu, S. H. S. Ariffin, and S. K. Adnan, "Adaptive cost-based handover decision algorithm for user equipment battery-life aware load balancing in LTE network," Tech. Rep., 2016.

[37] S. Goutam, S. Unnikrishnan, S. S. Prabavathy, and A. Karandikar, "Algorithm for vertical handover decision using least cost function," *IEIE Trans. Smart Process. Comput.*, vol. 10, no. 1, pp. 44–54, Feb. 2021.

[38] G. Araniti, J. Cosmas, A. Iera, A. Molinaro, A. Orsino, and P. Scopelliti, "Energy efficient handover algorithm for green radio networks," in *Proc. IEEE Int. Symp. Broadband Multimedia Syst. Broadcast.*, Jun. 2014, pp. 1–6.

[39] K. Zhang, C. Yin, and J. Xu, "Energy efficient handover algorithm in OFDMA systems," in *Proc. IEEE Int. Conf. Comput. Commun. (ICCC)*, Oct. 2015, pp. 295–299.

[40] P. Satapathy and J. Mahapatro, "Energy-efficient vertical handover in heterogeneous networks," in *Proc. IEEE Int. IoT, Electron. Mechatronics Conf. (IEMTRONICS)*, Apr. 2021, pp. 1–7.

[41] C. W. De Silva, *Intelligent Control: Fuzzy Logic Applications*. Boca Raton, FL, USA: CRC Press, 2018.

[42] F. M. McNeill and E. Thro, *Fuzzy Logic: A Practical Approach*. New York, NY, USA: Academic, 2014.

[43] V. Yazici, U. C. Kozat, and M. O. Sunay, "A new control plane for 5G network architecture with a case study on unified handoff, mobility, and routing management," *IEEE Commun. Mag.*, vol. 52, no. 11, pp. 76–85, Nov. 2014.

[44] J. Zhao, Y. Liu, Y. Gong, C. Wang, and L. Fan, "A dual-link soft handover scheme for C/U plane split network in high-speed railway," *IEEE Access*, vol. 6, pp. 12473–12482, 2018.

[45] R. Ahmad, E. A. Sundararajan, N. E. Othman, and M. Ismail, "An efficient handover decision in heterogeneous LTE–A networks under the assistance of users' profile," *Telecommun. Syst.*, vol. 68, no. 1, pp. 27–45, May 2018.

[46] O. O. Omitola and V. M. Srivastava, "An enhanced handover algorithm in LTE-advanced network," *Wireless Pers. Commun.*, vol. 97, no. 2, pp. 2925–2938, Nov. 2017.

[47] S. K. Ray, K. Pawlikowski, and H. Sirisena, "Handover in mobile Wimax networks: The state of art and research issues," *IEEE Commun. Surveys Tuts.*, vol. 12, no. 3, pp. 376–399, 3rd Quart., 2010.

[48] N. Shanjin and Z. Junhui, "Key technologies in physical layer of 5G wireless communications network," *Telecommun. Sci.*, vol. 31, no. 12, pp. 40–45, 2015.

[49] S. Rommer, P. Hedman, M. Olsson, L. Frid, S. Sultana, and C. Mulligan, *5G Core Networks: Powering Digitalization*. New York, NY, USA: Academic, 2019.

[50] M. Kamel, W. Hamouda, and A. Youssef, "Ultra-dense networks: A survey," *IEEE Commun. Surveys Tuts.*, vol. 18, no. 4, pp. 2522–2545, 4th Quart., 2016.

[51] D. Zidic, T. Mastelic, I. N. Kosovic, M. Cagalj, and J. Lorincz, "Analyses of ping-pong handovers in real 4G telecommunication networks," *Comput. Netw.*, vol. 227, May 2023, Art. no. 109699.

[52] W. Sun, Q. Wang, N. Zhao, H. Zhang, C. Shen, and L. W.-C. Wong, *Ultra-Dense Heterogeneous Networks*. Boca Raton, FL, USA: CRC Press, 2022.

[53] T. Bilen, B. Canberk, and K. R. Chowdhury, "Handover management in software-defined ultra-dense 5G networks," *IEEE Netw.*, vol. 31, no. 4, pp. 49–55, Jul. 2017.

[54] J. Moon, J. Jung, S. Lee, A. Nigam, and S. Ryoo, "On the trade-off between handover failure and small cell utilization in heterogeneous networks," in *Proc. IEEE Int. Conf. Commun. Workshop (ICCW)*, Jun. 2015, pp. 2282–2287.

[55] E. Demarchou, C. Psomas, and I. Krikidis, "Mobility management in ultra-dense networks: Handover skipping techniques," *IEEE Access*, vol. 6, pp. 11921–11930, 2018.

[56] D. Feng, L. Lai, J. Luo, Y. Zhong, C. Zheng, and K. Ying, "Ultra-reliable and low-latency communications: Applications, opportunities and challenges," *Sci. China Inf. Sci.*, vol. 64, no. 2, pp. 1–12, Feb. 2021.

[57] S. Mumtaz, V. G. Menon, and M. I. Ashraf, "Guest editorial: Ultra-low-latency and reliable communications for 6G networks," *IEEE Commun. Standards Mag.*, vol. 5, no. 2, pp. 10–11, Jun. 2021.

[58] B. Hassan, S. Baig, and M. Asif, "Key technologies for ultra-reliable and low-latency communication in 6G," *IEEE Commun. Standards Mag.*, vol. 5, no. 2, pp. 106–113, Jun. 2021.

[59] H. H. H. Mahmoud, A. A. Amer, and T. Ismail, "6G: A comprehensive survey on technologies, applications, challenges, and research problems," *Trans. Emerg. Telecommun. Technol.*, vol. 32, no. 4, Apr. 2021, Art. no. e4233.

[60] H. Park, Y. Lee, T. Kim, B. Kim, and J. Lee, "Handover mechanism in NR for ultra-reliable low-latency communications," *IEEE Netw.*, vol. 32, no. 2, pp. 41–47, Mar. 2018.

[61] S. Kharche and P. Dere, "Interoperability issues and challenges in 6G networks," *J. Mobile Multimedia*, p. 1445, Apr. 2022.

[62] P. Agbaje, A. Anjum, A. Mitra, E. Oseghale, G. Bloom, and H. Olufowobi, "Survey of interoperability challenges in the Internet of Vehicles," *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 12, pp. 22838–22861, Dec. 2022.

[63] J. Wu and P. Fan, "A survey on high mobility wireless communications: Challenges, opportunities and solutions," *IEEE Access*, vol. 4, pp. 450–476, 2016.

[64] Y. Niu, Y. Li, D. Jin, L. Su, and A. V. Vasilakos, "A survey of millimeter wave communications (mmWave) for 5G: Opportunities and challenges," *Wireless Netw.*, vol. 21, no. 8, pp. 2657–2676, Nov. 2015.

[65] T. S. Rappaport, Y. Xing, G. R. MacCartney, A. F. Molisch, E. Mellios, and J. Zhang, "Overview of millimeter wave communications for fifth-generation (5G) wireless networks—With a focus on propagation models," *IEEE Trans. Antennas Propag.*, vol. 65, no. 12, pp. 6213–6230, Dec. 2017.

[66] A. N. Uwaechia and N. M. Mahyuddin, "A comprehensive survey on millimeter wave communications for fifth-generation wireless networks: Feasibility and challenges," *IEEE Access*, vol. 8, pp. 62367–62414, 2020.

[67] B. Van Quang, R. V. Prasad, I. Niemieeger, and N. T. V. Huong, "A study on handoff issues in radio over fiber network at 60 GHz," in *Proc. Int. Conf. Commun. Electron.*, Aug. 2010, pp. 50–54.

[68] M. Xiao, S. Mumtaz, Y. Huang, L. Dai, Y. Li, M. Matthaiou, G. K. Karagiannidis, E. Björnson, K. Yang, C. I, and A. Ghosh, "Millimeter wave communications for future mobile networks," *IEEE J. Sel. Areas Commun.*, vol. 35, no. 9, pp. 1909–1935, Sep. 2017.

[69] H. Elayan, O. Amin, R. M. Shubair, and M. Alouini, "Terahertz communication: The opportunities of wireless technology beyond 5G," in *Proc. Int. Conf. Adv. Commun. Technol. Netw. (CommNet)*, Apr. 2018, pp. 1–5.
[70] Y. Zhao, G. Yu, and H. Xu, "6G mobile communication network: Vision, challenges and key technologies," 2019, *arXiv:1905.04983*.
[71] J. Wells, "Faster than fiber: The future of multi-G/s wireless," *IEEE Microw. Mag.*, vol. 10, no. 3, pp. 104–112, May 2009.
[72] S. Sesia, I. Toufik, and M. Baker, *LTE-the UMTS Long Term Evolution: From Theory to Practice*. Hoboken, NJ, USA: Wiley, 2011.
[73] M. Al-Khalidi, R. Al-Zaidi, and M. Hammoudeh, "Network mobility management challenges, directions, and solutions: An architectural perspective," *Electronics*, vol. 11, no. 17, p. 2696, Aug. 2022.
[74] E. Hong, I. Lee, B. Shim, Y. Ko, S. Kim, S. Pack, K. Lee, S. Kim, J. Kim, Y. Shin, Y. Kim, and H. Jung, "6G R&D vision: Requirements and candidate technologies," *J. Commun. Netw.*, vol. 24, no. 2, pp. 232–245, Apr. 2022.
[75] S. Jun, Y. Choi, and H. Chung, "Considerations on ultra broadband, high reliable and low latency services in 6G system," in *Proc. Int. Conf. Inf. Commun. Technol. Converg. (ICTC)*, Oct. 2021, pp. 1552–1554.
[76] Forbes. (2016). *Roundup Of Internet of Things Forecasts Market Estimates*. [Online]. Available: https://www.forbes.com/sites/louiscolumbus/2016/11/27/roundup-of-internet-of-things-forecasts-and-market-estimates-2016/#1931adfe292d
[77] Huawei. (2018). *GIV 2025 Unfolding the Industry Blueprint of an Intelligent World*. [Online]. Available: https://www.huawei.com/minisite/giv/Files/whitepaper_en_2018.pdf
[78] Z. Zhao, Q. Du, D. Wang, X. Tang, and H. Song, "Overview of prospects for service-aware radio access towards 6G networks," *Electronics*, vol. 11, no. 8, p. 1262, Apr. 2022.
[79] C. Yeh, G. D. Jo, Y.-J. Ko, and H. K. Chung, "Perspectives on 6G wireless communications," *ICT Exp.*, vol. 9, no. 1, pp. 82–91, Feb. 2023.
[80] F. Qamar, M. U. A. Siddiqui, M. N. Hindia, R. Hassan, and Q. N. Nguyen, "Issues, challenges, and research trends in spectrum management: A comprehensive overview and new vision for designing 6G networks," *Electronics*, vol. 9, no. 9, p. 1416, Sep. 2020.
[81] A. S. Buttar, "Fundamental operations of cognitive radio: A survey," in *Proc. IEEE Int. Conf. Electr., Comput. Commun. Technol. (ICECCT)*, Feb. 2019, pp. 1–5.
[82] H. Anandakumar and K. Umamaheswari, "Supervised machine learning techniques in cognitive radio networks during cooperative spectrum handovers," *Cluster Comput.*, vol. 20, no. 2, pp. 1505–1515, Jun. 2017.
[83] M. S. J. Singh, W. S. W. Saleh, A. T. Abed, and M. A. Fauzi, "A review on massive MIMO antennas for 5G communication systems on challenges and limitations," *Jurnal Kejuruteraan*, vol. 35, no. 1, pp. 95–103, Jan. 2023.
[84] S. Elhoushy, M. Ibrahim, and W. Hamouda, "Cell-free massive MIMO: A survey," *IEEE Commun. Surveys Tuts.*, vol. 24, no. 1, pp. 492–523, 1st Quart., 2022.
[85] H. A. Ammar, R. Adve, S. Shahbazpanahi, G. Boudreau, and K. V. Srinivas, "User-centric cell-free massive MIMO networks: A survey of opportunities, challenges and solutions," *IEEE Commun. Surveys Tuts.*, vol. 24, no. 1, pp. 611–652, 1st Quart., 2022.
[86] R. Khan, P. Kumar, D. N. K. Jayakody, and M. Liyanage, "A survey on security and privacy of 5G technologies: Potential solutions, recent advancements, and future directions," *IEEE Commun. Surveys Tuts.*, vol. 22, no. 1, pp. 196–248, 1st Quart., 2020.
[87] I. Ahmad, S. Shahabuddin, T. Kumar, J. Okwuibe, A. Gurtov, and M. Ylianttila, "Security for 5G and beyond," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 4, pp. 3682–3722, 4th Quart., 2019.
[88] P. Porambage, G. Gür, D. P. M. Osorio, M. Livanage, and M. Ylianttila, "6G security challenges and potential solutions," in *Proc. Joint Eur. Conf. Netw. Commun. 6G Summit (EuCNC/6G Summit)*, Jun. 2021, pp. 622–627.
[89] V. Nguyen, P. Lin, B. Cheng, R. Hwang, and Y. Lin, "Security and privacy for 6G: A survey on prospective technologies and challenges," *IEEE Commun. Surveys Tuts.*, vol. 23, no. 4, pp. 2384–2428, 4th Quart., 2021.
[90] D. Zhao, Z. Yan, M. Wang, P. Zhang, and B. Song, "Is 5G handover secure and private? A survey," *IEEE Internet Things J.*, vol. 8, no. 16, pp. 12855–12879, Aug. 2021.
[91] F. Rinaldi, H. Maattanen, J. Torsner, S. Pizzi, S. Andreev, A. Iera, Y. Koucheryavy, and G. Araniti, "Non-terrestrial networks in 5G & beyond: A survey," *IEEE Access*, vol. 8, pp. 165178–165200, 2020.
[92] *Study on Using Satellite Access in 5G*, document TR 22.822, Release 16, 3GPP, 2018. Accessed: October Oct. 17, 2022. [Online]. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspxspecificationId=3372
[93] M. M. Azari, S. Solanki, S. Chatzinotas, O. Kodheli, H. Sallouha, A. Colpaert, J. F. M. Montoya, S. Pollin, A. Haqiqatnejad, A. Mostaani, E. Lagunas, and B. Ottersten, "Evolution of non-terrestrial networks from 5G to 6G: A survey," *IEEE Commun. Surveys Tuts.*, vol. 24, no. 4, pp. 2633–2672, 4th Quart., 2022.
[94] Q. Ye, C. Lo, J. Jeon, C. Tarver, M. Tonnemacher, J. Yeo, J. Cho, G. Xu, Y. Kim, and J. Zhang, "5G new radio and non-terrestrial networks: Reaching new heights," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops)*, May 2022, pp. 538–543.
[95] *NR; NR and NG-RAN Overall Description; Stage-2*, document TS 38.300, Release 16, 3GPP, 2021. [Online]. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3191
[96] Ericsson. *This is the Key to Mobility Robustness in 5G Networks*. [Online]. Available: https://www.ericsson.com/en/blog/2020/5/the-key-to-mobility-robustness-5g-networks
[97] H. Martikainen, I. Viering, A. Lobinger, and T. Jokela, "On the basics of conditional handover for 5G mobility," in *Proc. IEEE 29th Annu. Int. Symp. Pers., Indoor Mobile Radio Commun. (PIMRC)*, Sep. 2018, pp. 1–7.
[98] C. Lee, H. Cho, S. Song, and J. Chung, "Prediction-based conditional handover for 5G mm-wave networks: A deep-learning approach," *IEEE Veh. Technol. Mag.*, vol. 15, no. 1, pp. 54–62, Mar. 2020.
[99] H. Park, Y. Lee, T. Kim, B. Kim, and J. Lee, "ZEUS: Handover algorithm for 5G to achieve zero handover failure," *ETRI J.*, vol. 44, no. 3, pp. 361–378, Jun. 2022.
[100] *3GPP. R2-1710850*. [Online]. Available: https://www.3gpp.org/ftp/tsg_ran/WG2_RL2/TSGR2_99bis/Docs/?sortby=date
[101] M. Frank, D. Drikakis, and V. Charissis, "Machine-learning methods for computational science and engineering," *Computation*, vol. 8, no. 1, p. 15, Mar. 2020.
[102] P. V. Klaine, M. A. Imran, O. Onireti, and R. D. Souza, "A survey of machine learning techniques applied to self-organizing cellular networks," *IEEE Commun. Surveys Tuts.*, vol. 19, no. 4, pp. 2392–2431, 4th Quart., 2017.
[103] A. Masri, T. Veijalainen, H. Martikainen, S. Mwanje, J. Ali-Tolppa, and M. Kajo, "Machine-learning-based predictive handover," in *Proc. IFIP/IEEE Int. Symp. Integr. Netw. Manage. (IM)*, May 2021, pp. 648–652.
[104] *What is Deep Learning? | IBM*. [Online]. Available: https://www.ibm.com/cloud/learn/deep-learning
[105] N. Bahra and S. Pierre, "A hybrid user mobility prediction approach for handover management in mobile networks," in *Telecom*, vol. 2, no. 2. Basel, Switzerland: Multidisciplinary Digital Publishing Institute, 2021, pp. 199–212.
[106] J. M. Carew. *What is Reinforcement Learning? A Comprehensive Overview*. [Online]. Available: https://www.techtarget.com/searchenterpriseai/definition/reinforcement-learning
[107] Q. Liu, C. F. Kwong, S. Zhou, T. Ye, L. Li, and S. P. Ardakani, "Autonomous mobility management for 5G ultra-dense HetNets via reinforcement learning with tile coding function approximation," *IEEE Access*, vol. 9, pp. 97942–97952, 2021.
[108] 3GPP. *Study on Channel Model for Frequencies From 0.5 to 100 GHz*. Accessed: Nov. 16, 2021. [Online]. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3173
[109] M. Chiputa, M. Zhang, G. G. M. N. Ali, P. H. J. Chong, H. Sabit, A. Kumar, and H. Li, "Enhancing handover for 5G mmWave mobile networks using jump Markov linear system and deep reinforcement learning," *Sensors*, vol. 22, no. 3, p. 746, Jan. 2022.
[110] M. Rebato, M. Polese, and M. Zorzi, "Multi-sector and multi-panel performance in 5G mmWave cellular networks," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2018, pp. 1–6.
[111] Simplilearn. *What is Q-Learning: Everything you Need to Know | Simplilearn*. Simplilearn. [Online]. Available: https://www.simplilearn.com/tutorials/machine-learning-tutorial/what-is-q-learning

[112] A. Abdelmohsen, M. Abdelwahab, M. Adel, M. S. Darweesh, and H. Mostafa, "LTE handover parameters optimization using Q-learning technique," in *Proc. IEEE 61st Int. Midwest Symp. Circuits Syst. (MWSCAS)*, Aug. 2018, pp. 194–197.

[113] M. L. Marí-Altozano, S. S. Mwanje, S. L. Ramírez, M. Toril, H. Sanneck, and C. Gijón, "A service-centric Q-learning algorithm for mobility robustness optimization in LTE," *IEEE Trans. Netw. Service Manage.*, vol. 18, no. 3, pp. 3541–3555, Sep. 2021.

[114] P. Muñoz, I. de la Bandera, F. Ruiz, S. Luna-Ramírez, R. Barco, M. Toril, P. Lázaro, and J. Rodríguez, "Computationally-efficient design of a dynamic system-level LTE simulator," *Int. J. Electron. Telecommun.*, vol. 57, no. 3, pp. 347–358, Sep. 2011.

[115] T. Goyal and S. Kaushal, "Handover optimization scheme for LTE-advance networks based on AHP-TOPSIS and Q-learning," *Comput. Commun.*, vol. 133, pp. 67–76, Jan. 2019.

[116] P.-C. Lin, L. F. G. Casanova, and B. K. S. Fatty, "Data-driven handover optimization in next generation mobile communication networks," *Mobile Inf. Syst.*, vol. 2016, pp. 1–11, Jul. 2016.

[117] S. Kumari and B. Singh, "Data-driven handover optimization in small cell networks," *Wireless Netw.*, vol. 25, no. 8, pp. 5001–5009, Nov. 2019.

[118] M. Manalastas, M. U. B. Farooq, S. M. A. Zaidi, A. Abu-Dayya, and A. Imran, "A data-driven framework for inter-frequency handover failure prediction and mitigation," *IEEE Trans. Veh. Technol.*, vol. 71, no. 6, pp. 6158–6172, Jun. 2022.

[119] S. M. A. Zaidi, M. Manalastas, H. Farooq, and A. Imran, "SyntheticNET: A 3GPP compliant simulator for AI enabled 5G and beyond," *IEEE Access*, vol. 8, pp. 82938–82950, 2020.

[120] P. A. Alvarez, A. Ishizaka, and L. Martínez, "Multiple-criteria decision-making sorting methods: A survey," *Expert Syst. Appl.*, vol. 183, Nov. 2021, Art. no. 115368.

[121] H. Taherdoost and M. Madanchian, "Multi-criteria decision making (MCDM) methods and concepts," *Encyclopedia*, vol. 3, no. 1, pp. 77–87, Jan. 2023.

[122] M. Cicioğlu, "Multi-criteria handover management using entropy-based SAW method for SDN-based 5G small cells," *Wireless Netw.*, vol. 27, no. 4, pp. 2947–2959, May 2021.

[123] M. R. Palas, M. R. Islam, P. Roy, M. A. Razzaque, A. Alsanad, S. A. AlQahtani, and M. M. Hassan, "Multi-criteria handover mobility management in 5G cellular network," *Comput. Commun.*, vol. 174, pp. 81–91, Jun. 2021.

[124] T. J. Ross, *Fuzzy Logic With Engineering Applications*. Hoboken, NJ, USA: Wiley, 2009.

[125] S. Alraih, R. Nordin, A. Abu-Samah, I. Shayea, N. F. Abdullah, and A. Alhammadi, "Robust handover optimization technique with fuzzy logic controller for beyond 5G mobile networks," *Sensors*, vol. 22, no. 16, p. 6199, Aug. 2022.

[126] S. Alraih, R. Nordin, I. Shayea, N. F. Abdullah, and A. Alhammadi, "Ping-pong handover effect reduction in 5G and beyond networks," in *Proc. IEEE Microw. Theory Techn. Wireless Commun. (MTTW)*, Oct. 2021, pp. 97–101.

[127] K. D. C. Silva, Z. Becvar, and C. R. L. Frances, "Adaptive hysteresis margin based on fuzzy logic for handover in mobile networks with dense small cells," *IEEE Access*, vol. 6, pp. 17178–17189, 2018.

[128] A. Alhammadi, M. Roslee, M. Y. Alias, I. Shayea, S. Alraih, and K. S. Mohamed, "Auto tuning self-optimization algorithm for mobility management in LTE–A and 5G HetNets," *IEEE Access*, vol. 8, pp. 294–304, 2020.

[129] J. Bao, T. Shu, and H. Li, "Handover prediction based on geometry method in mmWave communications—A sensing approach," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops)*, May 2018, pp. 1–6.

[130] S. A. ELWahab M. Ibrahim and M. A. H. Abbas, "A new vertical handover prediction method for heterogeneous wireless networks," *Univ. Khartoum Eng. J.*, vol. 10, no. 2, Oct. 2022.

[131] M. Mandour, F. Gebali, A. D. Elbayoumy, G. M. Abdel Hamid, and A. Abdelaziz, "Handover optimization and user mobility prediction in LTE femtocells network," in *Proc. IEEE Int. Conf. Consum. Electron. (ICCE)*, Jan. 2019, pp. 1–6.

[132] M. N. M. Bhutta, A. A. Khwaja, A. Nadeem, H. F. Ahmad, M. K. Khan, M. A. Hanif, H. Song, M. Alshamari, and Y. Cao, "A survey on blockchain technology: Evolution, architecture and security," *IEEE Access*, vol. 9, pp. 61048–61073, 2021.

[133] M. Krichen, M. Ammi, A. Mihoub, and M. Almutiq, "Blockchain for modern applications: A survey," *Sensors*, vol. 22, no. 14, p. 5274, Jul. 2022.

[134] T. Hewa, M. Ylianttila, and M. Liyanage, "Survey on blockchain based smart contracts: Applications, opportunities and challenges," *J. Netw. Comput. Appl.*, vol. 177, Mar. 2021, Art. no. 102857.

[135] M. Kouhizadeh and J. Sarkis, "Blockchain practices, potentials, and perspectives in greening supply chains," *Sustainability*, vol. 10, no. 10, p. 3652, Oct. 2018.

[136] A. Chaer, K. Salah, C. Lima, P. P. Ray, and T. Sheltami, "Blockchain for 5G: Opportunities and challenges," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, Dec. 2019, pp. 1–6.

[137] H. Lee and M. Ma, "Blockchain-based mobility management for 5G," *Future Gener. Comput. Syst.*, vol. 110, pp. 638–646, Sep. 2020.

[138] H. Lee and M. Ma, "Blockchain-based mobility management for LTE and beyond," in *Proc. Int. Conf. Secur., Privacy Anonymity Comput., Commun. Storage*. Cham, Switzerland: Springer, 2019, pp. 36–49.

[139] K. Qi, T. Liu, C. Yang, S. Suo, and Y. Huang, "Dual connectivity-aided proactive handover and resource reservation for mobile users," *IEEE Access*, vol. 9, pp. 36100–36113, 2021.

[140] L. Jiao, P. Wang, A. Alipour-Fanid, H. Zeng, and K. Zeng, "Enabling efficient blockage-aware handover in RIS-assisted mmWave cellular networks," *IEEE Trans. Wireless Commun.*, vol. 21, no. 4, pp. 2243–2257, Apr. 2022.

[141] T. Han, X. Ge, L. Wang, K. S. Kwak, Y. Han, and X. Liu, "5G converged cell-less communications in smart cities," *IEEE Commun. Mag.*, vol. 55, no. 3, pp. 44–50, Mar. 2017.

[142] M. Agiwal, H. Kwon, S. Park, and H. Jin, "A survey on 4G–5G dual connectivity: Road to 5G implementation," *IEEE Access*, vol. 9, pp. 16193–16210, 2021.

[143] M. Polese, M. Giordani, M. Mezzavilla, S. Rangan, and M. Zorzi, "Improved handover through dual connectivity in 5G mmWave mobile networks," *IEEE J. Sel. Areas Commun.*, vol. 35, no. 9, pp. 2069–2084, Sep. 2017.

[144] I. Viering, H. Martikainen, A. Lobinger, and B. Wegmann, "Zero-zero mobility: Intra-frequency handovers with zero interruption and zero failures," *IEEE Netw.*, vol. 32, no. 2, pp. 48–54, Mar. 2018.

[145] M. Tayyab, X. Gelabert, and R. Jäntti, "A survey on handover management: From LTE to NR," *IEEE Access*, vol. 7, pp. 118907–118930, 2019.

[146] C. Pan, H. Ren, K. Wang, J. F. Kolb, M. Elkashlan, M. Chen, M. Di Renzo, Y. Hao, J. Wang, A. L. Swindlehurst, X. You, and L. Hanzo, "Reconfigurable intelligent surfaces for 6G systems: Principles, applications, and research directions," *IEEE Commun. Mag.*, vol. 59, no. 6, pp. 14–20, Jun. 2021.

[147] S. Hao and H. Zhang, "Performance analysis of PHY layer for RIS-assisted wireless communication systems with retransmission protocols," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 34, no. 8, pp. 5388–5404, Sep. 2022.

[148] M. Jian, G. C. Alexandropoulos, E. Basar, C. Huang, R. Liu, Y. Liu, and C. Yuen, "Reconfigurable intelligent surfaces for wireless communications: Overview of hardware designs, channel models, and estimation techniques," *Intell. Converged Netw.*, vol. 3, no. 1, pp. 1–32, Mar. 2022.

[149] L. Rao, M. Pant, L. Malviya, A. Parmar, and S. V. Charhate, "5G beamforming techniques for the coverage of intended directions in modern wireless communication: In-depth review," *Int. J. Microw. Wireless Technol.*, vol. 13, no. 10, pp. 1039–1062, Dec. 2021.

[150] J. H. Kim, "6G and Internet of Things: A survey," *J. Manage. Anal.*, vol. 8, no. 2, pp. 316–332, Apr. 2021.

[151] L. U. Khan, I. Yaqoob, M. Imran, Z. Han, and C. S. Hong, "6G wireless systems: A vision, architectural elements, and future directions," *IEEE Access*, vol. 8, pp. 147029–147044, 2020.

[152] M. Giordani, M. Polese, M. Mezzavilla, S. Rangan, and M. Zorzi, "Toward 6G networks: Use cases and technologies," *IEEE Commun. Mag.*, vol. 58, no. 3, pp. 55–61, Mar. 2020.

[153] A. N. Devi and P. S. Mali, "6G technology," *Int. J. Res. Publication Rev.*, vol. 2582, pp. 1477–1480, Jul. 2022. [Online]. Available: www.ijrpr.comISSN

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