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Review

A Survey on Resource Management for 6G Heterogeneous Networks: Current Research, Future Trends, and Challenges

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Abstract: The sixth generation (6G) mobile communication system is expected to meet the different service needs of modern communication scenarios. Heterogeneous networks (HetNets) have received a lot of attention in recent years due to their potential as a novel structure for evolutionary networks. When compared to homogeneous networks, HetNets provide more potential for spatial spectrum reuse and higher quality of service (QoS). However, effective resource management (RM) solutions are essential to prevent interference and accomplish spectrum sharing due to mutual interference. This paper presents a comprehensive review of resource management in 6G HetNets. The study aims to give crucial background on HetNets to aid in the creation of more effective methods in this field of study. First, a detailed examination of recent work is presented in resource management aspects such as power allocation, user association, mode selection, and spectrum allocation. Second, we identify the most severe challenges associated with the current resource management methods and propose suitable solutions. Finally, several open issues and emerging areas of research are highlighted.

Keywords: heterogeneous networks; mode selection; power allocation; resource management; spectrum allocation; user association; 6G communications

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1. Introduction

The goals of both users and network operators have evolved with the development of mobile technologies from 1G to 6G. However, in the present era, communities are increasingly automating their processes, growing dependent on data, and being data-centric. Productivity will be significantly increased by the extensive use of automation in industrial production processes. Cities, houses, and factories will all have millions of sensors installed, and new applications will be made possible by systems run by artificial intelligence in the local cloud and fog settings [1]. These novel paradigms for smart systems will be powered by communication networks serving as their central nervous system. Nevertheless, the requirements are daunting. The need for rapid data transport through networks is expected to increase dramatically, as shown in Figure 1. Beyond individualized communication, the Internet of Things (IoT) paradigm will be fully realized in 6G connectivity, which will link not only humans but also computers, cars, wearables, sensors, and robots [2].

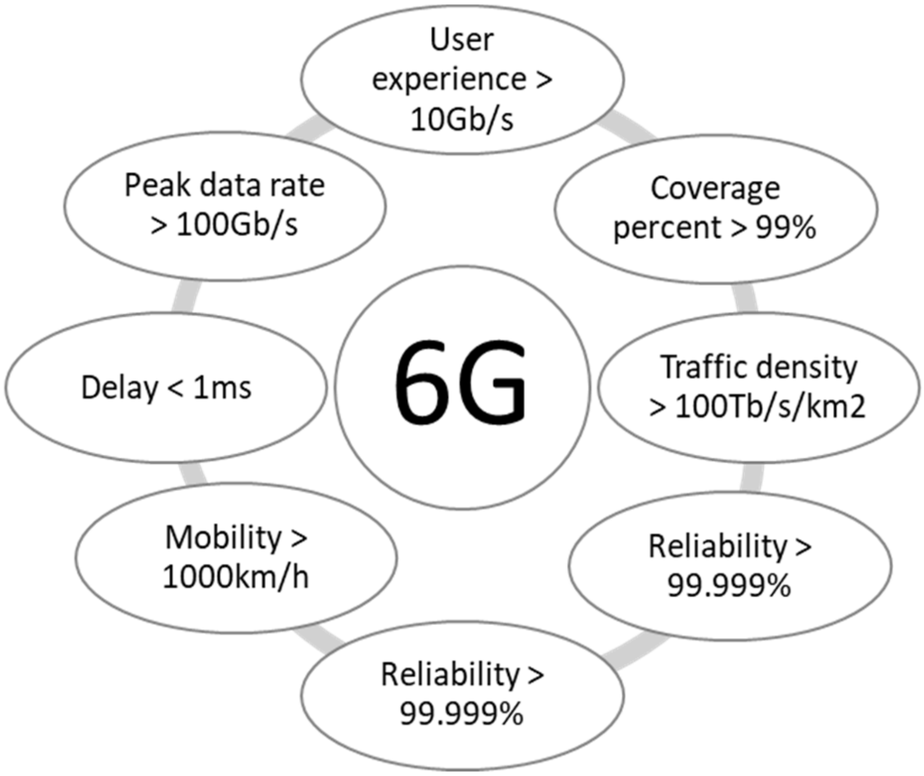

Figure 1. Possible capabilities of 6G.

When constructing the architecture of 6G networks, it is essential to consider resources with high bandwidth, spectral efficiency, and low power consumption [3,4]. It is anticipated that new radio (NR) 6G networks will be able to satisfy these needs with professionally managed spectrum resources to justify future data requirements and support various devices [5]. Researchers have determined that NR is a collection of radio access technologies that provide the required data with low latency, low power consumption, and high-spectrum efficiency [6,7]. With the efficient use of an unlicensed spectrum of Wi-Fi in a 5 GHz band and the integration of massive multiple-input–multiple-output (MIMO) technology in place of the traditional MIMO system, these devices can be broadly categorized as millimeter wave (mmWave) technology for low-power small cells [8]. The use of high-spectrum access, i.e., HetNet, ethernet passive optical networks (EPON) [9], IoT [10], device-to-device (D2D) communication, mobile ad hoc networks (MANETs) [11,12], wireless sensor networks (WSN) [13], coordinated multipoint operation (CoMP) [14], cooperative networks (CNs) using relay nodes (RNs) [15], massive-MIMO [16], cognitive radio (CR) [17], mmWave frequency band [18], and cellular cloud computing [19], provide methods that may be adapted to meet the needs of 6G networks. Ultimate outcomes may also be achieved by the ideal use of different power optimizations [20,21], interference cancellation [22], handover procedures [23], routing protocols [24,25], data security management [26], and scheduling algorithms [27]. Some interesting concepts for developing 6G networks are satellite communication in the mmWave band [28], machine learning-based communication [29], artificial intelligence (AI)-based micro base stations (BSs) [30], human-centric communication [31], and blockchain [32].

Recent research efforts have focused on finding ways to make cellular networks more power efficient. Since BSs account for 60–80% of total energy usage, several methods have been suggested for decreasing BS energy consumption [33]. These methods include cell switch-off, cell dispersion, and efficient power/channel allocation. Cell distribution for both heterogeneous and homogeneous cellular networks has been the subject of research [34,35]. None of these studies, however, seem to have examined the impact of cell dispersion on power allocation (PA). In addition, other studies investigate how to minimize cellular networks' power consumption by optimal utilization of resources [36–38]. However, they have not been given any special consideration for the distribution of the cells. In order to reduce power consumption and overall interference respecting the needs of user equipment (UEs), the current studies suggest a strategy to modify the transmission power of BSs on each of the channels after a cell distribution/switch-off event [39].

Significant challenges will arise in such a network environment due to the com-plexity of mobility management [40]. Provisioning seamless mobility with exceptionally low latency is a necessary aspect of the mobility management goal for 6G networks [41]. Nonetheless, 6G mobility management mechanisms must enable rapid handover techniques, efficient signaling during mobility events, optimum and fast user-to-BS associations, service migration, and reliable route re-configuration to guarantee latency and dependability [42]. User association approaches must be effective to meet an application's QoS, avoid frequent handovers, and respect network capabilities and capacity. User association strategies will have a tremendous problem accommodating the rapidly growing number of users that 5G networks will serve [43].

Proposing efficient mode selection schemes for HetNets is essential, especially with users' mobility scenarios [44]. For mobile users, the mode selection problem is posed as deciding which communication mode to use based on the quality of the channel [45]. Additionally, network performance and user experience would be dramatically impacted due to the different channel surroundings caused by user mobility [45–47]. Further improvements are possible in 6G and beyond by employing opportunistic HetNet. Connections in an opportunistic HetNet are made between network equipment based on the efficiency of the possible connections [48]. When a mobile device's connection is lost, it stores the data until it finds other BSs to forward the stored data [49]. Recently, research has expanded the idea of opportunistic HetNet to include fully connected networks. Here, connections are made between nodes only after their efficacy has been ensured. Resources opportunistic HetNet discussed this scenario [50], which utilizes non-real-time traffic to search for the most beneficial connectivity opportunities. Thus, it is essential to improve throughput further to have accurate system modeling and critical evaluation of mode selection with mobility.

The design of the current ultra-high frequency (UHF) wireless communication will not be able to meet the requirements of the 6G standard because the spectrums that are available in the range of 300 MHz to 3 GHz are almost fully used up and are close to reaching the Shannon limit [51–53]. Investigating the use of a high spectrum between 3 GHz and 300 GHz could be one solution to the problem of the insufficient spectrum being made available [22,54]. Except for the ranges from 57 GHz to 64 GHz and 164 GHz to 200 GHz, there are broad frequency bands that have the potential for development. Since signals at these frequencies can be absorbed by water vapor and oxygen, these frequency bands are not suitable for HetNet [55,56]. In addition, research is currently being conducted on THz frequency bands ranging from 300 GHz to 3 THz. These bands can offer even wider bandwidths, allowing them to accommodate future applications requiring high data rates [57,58]. Radio networking for mmWave, which operates in higher frequency bands, will be e different from current wireless networks. Due to the high path losses, signal penetration, and blocking effects of mmWave signals [59,60], Line of Sight (LoS) propagation, reflection, and scattering are especially important [61]. In order to improve mmWave connectivity, it is essential to limit the gap between users and BSs [62]. Because of the need for an ultra-dense network, small-cell networks can increase coverage in every unit area by being deployed in a highly concentrated manner [63–65]. Figure 2 shows the system structure of future HetNets [66].

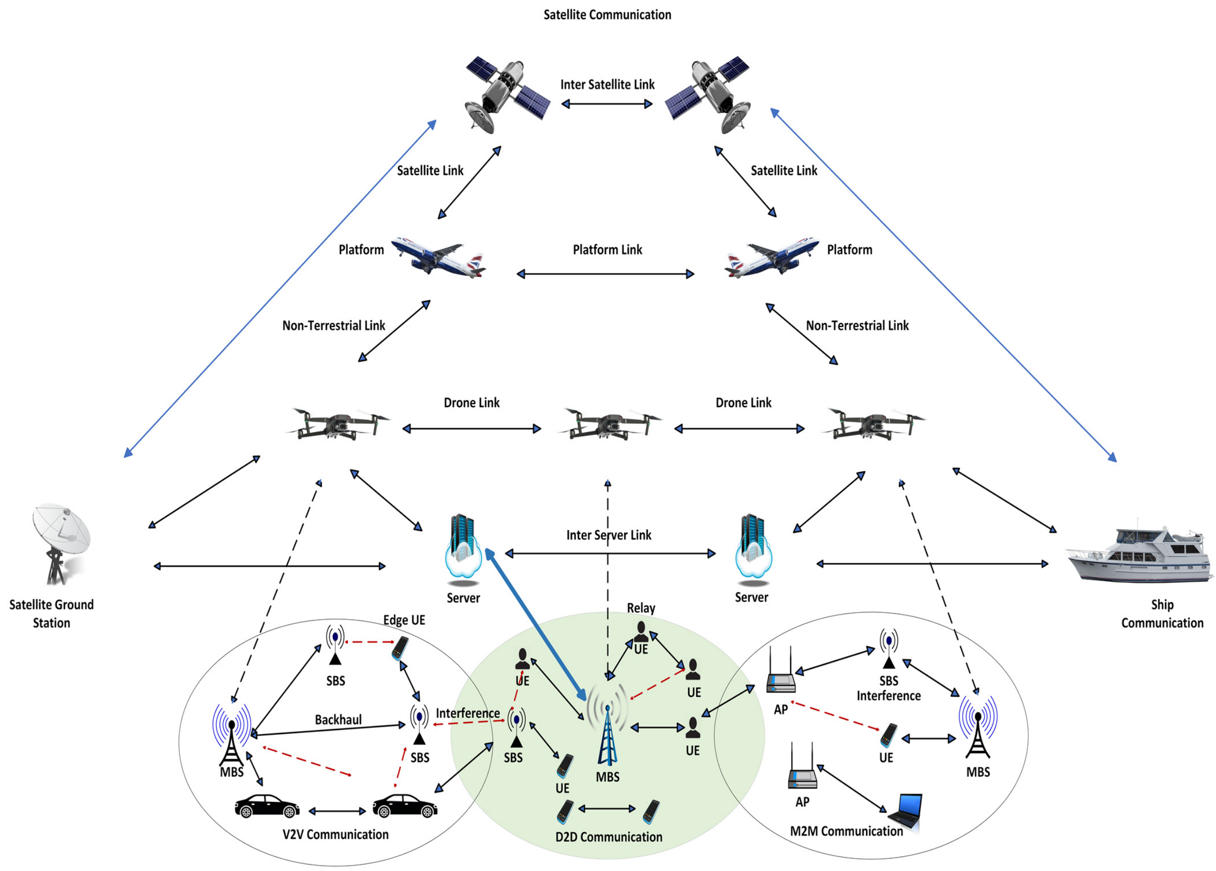

Figure 2. The system structure of future HetNets.

2. Motivation and Contributions

This article makes significant contributions by presenting the current state of the art in resource management for various scenarios of HetNets beyond 5G wireless networks, identifying and discussing potential solutions to resource management challenges, and introducing new research areas. This survey discusses many challenges in developing resource management methods caused by the extensive features of future wireless networks, the unpredictability of user deployment, the impractical deployment, and unique service requirements. The following are the most important contributions made by this article:

1. This article comprehensively analyzes the current work in resource management aspects such as power allocation, user association, mode selection, and spectrum allocation.
2. It highlights the most significant issues with the current resource management approaches and presents the best solution to overcome the existing problems.
3. It presents future directions and research challenges that have yet to be adequately addressed.

The remaining sections of the article are as follows: Section 3 briefly summarizes research on resource management in HetNets. In Section 4, a taxonomy to classify several resource management strategies is discussed in detail. In Section 5, various research challenges and future directions are explained. In Section 6, the conclusion is presented. The organization of this study is shown in Figure 3.

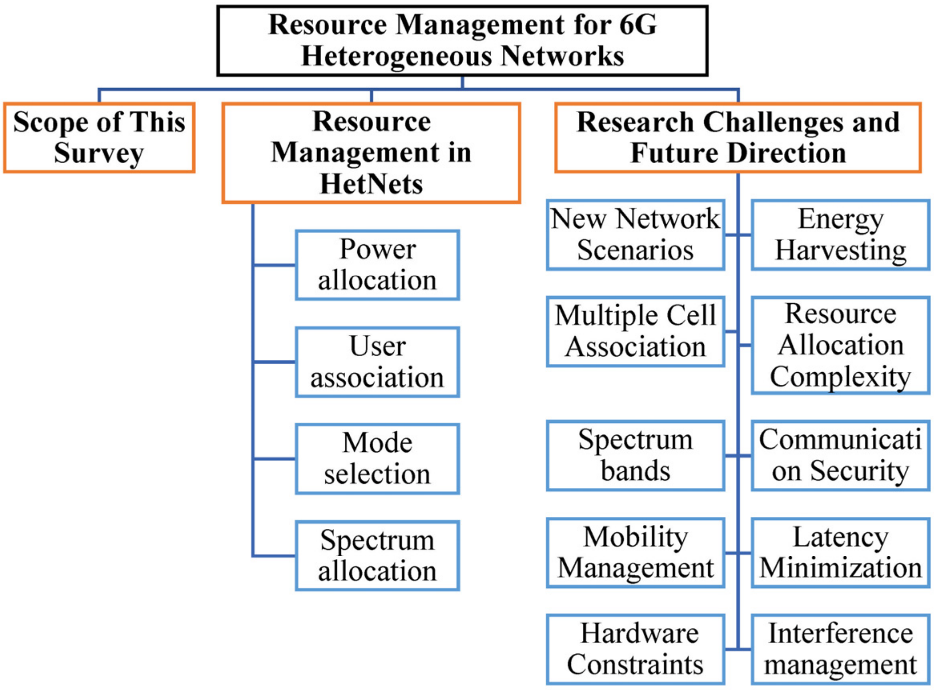

Figure 3. Organization of this study.

3. Scope of This Survey

The following are the findings of related surveys written by various authors covering different resource management aspects. Most of these research studies have focused on other aspects of resource management that are effectively enhance the network performance. However, to the best of our knowledge and understanding, there has not been a survey that has combined power allocation, user association, mode selection, and spectrum allocation. The proposed paper investigated HetNet resource management schemes for 5G networks and beyond, which each operates under a unique conceptual framework. This article provides a concise overview of the existing survey literature.

This article comprehensively reviews resource allocation methods in 5G networks and beyond [67]. In particular, this article introduces the resource allocation methods in ultra-dense for long-term evolution—unlicensed (LTE-U), HetNets, cognitive radio networks (CRNs), cloud radio access networks (C-RANs), D2D, and mmWave networks. Then, the resource allocation problem was classified using a taxonomy based on different methods, techniques, and optimization criteria. Finally, the emerging technologies, problems, and active research are illustrated and require the researchers' attention. In [68], a survey of HetNet resource management approaches is investigated with a focus on the strategies that optimize spectrum allocation with other mechanisms. Power allocation, complexity, fairness, user association, allocated capacity, and interference management are also important issues. These issues are categorized along with the techniques and strategies to handle related problems. For 5G systems, they provided a resource allocation (RA) survey in HetNets that discussed the various network scenarios [69]. Then, the current RA algorithms analysis is presented for the existing works. Finally, difficult problems and emerging areas of study are investigated. In order to address the RA issues of the 6G HetNets, they propose two possible structures for 6G communications: a control-based structure and a learning-based structure.

In [70], the authors summarized the key challenges such as resource allocation, user association, power allocation, co-tier interference, and cross-tier interference emerging in 5G HetNets and focused on their importance. They provided a comprehensive review of interference management-based radio resource management methods. They presented a taxonomy for individual and joint methods as a framework for systematically studying the existing approaches in terms of QoS, quality of experience (QoE), energy efficiency (EE), spectrum efficiency (SE), fairness, and coverage probability. Finally, the difficulties and potential benefits of radio resource management in 5G are discussed, and design guidelines with possible opportunities for advanced mechanisms are illustrated. In [71], the features of interference management for 5G networks from the aspect of HetNets and D2D communications are discussed. These aspects are approached through enabling techniques such as coordinated scheduling, coordinated multipoint, and inter-cell interference coordination. In addition, a critical analysis of several pertinent issues, with a focus on their strategies, advantages, and limitations, as well as the future work by the 3rd Generation Partnership Project (3GPP) for interference mitigation, is presented.

The study in [72] discussed the new radio resource control inactive cases, initial access, registration, and paging strategies. The literature survey also discusses connected state inter-radio access network handover methods and integrated mmWave cells with 5G HetNet. Finally, handover issues, power consumption, signaling overhead, latency, and security were addressed. This issue demonstrated some practical solutions to meet the 5G mobility management need. Approaches in spectrum sensing (SS) for CR were reviewed [73]. The two paradigms, half-duplex and full-duplex, were introduced, with an emphasis on the operating modes in the full-duplex. After that, they discussed the utilization of learning techniques to improve the performance of SS while considering both cooperative and local sensing strategies. In addition, they investigated the utilization of CR for 5G networks and beyond and its potential role in radio resource allocation. They also illustrated important future research in SS for CR based on wireless communications techniques.

An optimization taxonomy on different aspects of RM is provided, and a comprehensive survey of RM methods in a C-RAN is presented [74]. Spectrum management, user assignment, power allocation, remote radio heads (RRH) selection, and capacity maximization were the critical elements for efficient RM in C-RAN. In order to further demonstrate the benefits of C-RAN technology, they showed emerging use-cases technology: HetNets, mmWave, full-duplex, and Non-Orthogonal Multiple Access (NOMA). At last, the paper presents several suggestions for open issues and future research. The 5G vehicular network's resource allocation is outlined with the help of conventional optimization and advanced machine learning (ML) techniques, in particular, a deep reinforcement learning (DRL) approach [75]. Additionally, they proposed a vehicle-to-vehicle communication system based on federated deep reinforcement learning (FDRL). They discussed the problems and opportunities for future research into 5G and beyond into 6G in vehicular networks. Network slicing and a distributed federated learning method are investigated as multiaccess edge computing.

HetNet, carrier aggregation (CA), CR, mmWave, and massive MIMO are new technologies that must be used to achieve the desired results [76]. These methods are already used in 5G cellular networks, but their coexistence has created several spectrum management problems. This research provides a summary of these developing technologies. The study reviews cooperative communication across all spectrum management methods and potential issues with the proposed solutions. The future direction is also discussed to achieve the design of 6G networks. In [77], they presented different ML-based load-balancing approaches implemented in HetNets. This survey offers a roadmap for utilizing cost-effective and intelligent load-balancing strategies for future 6G networks. The available methods and solutions for the load balancing issue are investigated. The key performance indicators (KPIs) utilized in assessing the load balancing methods in HetNets are presented. Finally, the operational aspects of future load balancing are discussed, along with the existing challenges in implementing models.

The summary of relevant survey articles is presented in Table 1, which also focuses on the research gaps relative to the proposed survey. The current studies on resource management have concentrated their attention on more recent strategies and methods. This review contributes to the existing research by providing an overview of the latest improvements in the resource management aspects of HetNets. Moreover, up-to-date prospective research issues are discussed in addition to the fundamental principle and theoretical analysis. In this overview, we present a summary to investigate existing RM approaches.

Table 1. Summary of the related work for resource management.

Survey	Year	Summary
[67]	2021	• Presents resource allocation in ultra-dense LTE-U, HetNets, CRNs, C-RAN, mmWave, and D2D networks. • The resource allocation problem have classified according to Approaches, optimization criteria, and methods. • New technologies, difficulties, and existing research are described.
[68]	2020	• A survey of resource management schemes that optimize spectrum allocation with other mechanisms in HetNet is presented. • Power allocation, spectrum allocation, fairness, user association, and complexity are investigated. • Approaches and techniques for resolving related issues are described.
[69]	2021	• Different network scenarios of HetNets are discussed. • Provide a learning-based RA structure and a control-based RA process as two possible 6G communication structures for addressing RA issues in future-generation HetNets. • Challenges and future research are investigated.
[70]	2022	• Introduces the challenges in 5G HetNets, including user association, resource allocation, power • allocation, cross-tier interference, and co-tier interference. • Classifications for individual and combined approaches to analyze existing schemes for fairness, QoS, QoE, SE, EE, and coverage probability. • Challenges and opportunities in the 5G network are discussed, along with requirements and advanced mechanism solutions.
[71]	2019	• Introduces enabling techniques such as coordinated scheduling, coordinated multipoint, and inter-cell interference coordination to address interference management challenges in HetNet and D2D communication. • The methodologies, benefits, limitations, and future work of several important issues have been reviewed. • The 3rd Generation Partnership Project also outlined interference mitigation strategies as Future directions.
[72]	2020	• Described connected state inter-radio access network handover methods and integrated mmWave cells of 5G network. • Handover issues, power consumption, signaling overhead, latency, and security have been addressed. • 5G mobility management solutions have been shown.
[73]	2021	• Provided a spectrum sensing survey for cognitive radio by explaining the half-duplex and full-duplex approaches. • Discuss learning techniques to improve spectrum sensing and cognitive radio for 5G and beyond. • Highlight potential future research challenges based on emerging techniques.

Table 1. *Cont.*

Survey	Year	Summary
[74]	2020	• Provided a detailed optimization taxonomy for resource allocation in a C-RAN. • Spectrum management, user assignment, remote radio head selection, throughput maximization, network utility, and power allocation are the key elements of efficient resource management. • HetNet, mmWave, virtualized, NOMA, and full-duplex use cases were shown to improve performance. • Several open issues and future directions are discussed.
[75]	2021	• The 5G vehicular network's resource allocation is shown using traditional optimization and advanced machine learning methods, especially deep reinforcement learning. • Discussing 5G and 6G vehicular network problems, open issues, and future directions. • Network slicing and distributed federated learning are used to analyze multiaccess edge computing.
[76]	2020	• To achieve objectives, presented new methods and technologies such as CR, HetNet, mmWave, carrier aggregation, and massive MIMO. • Provides a detailed review of cooperative communication among all spectrum management techniques, and potential problems are addressed. • Research challenges are also discussed to achieve 6G wireless network design goals.
[77]	2022	• A survey of HetNets' machine learning (ML) and generic problem-based intelligent load balancing models. • Provides a guideline for developing cost-effective and intelligent load-balancing methods in future HetNets. • HetNet load balancing models and future key features are presented.
This survey	• This article comprehensively analyzes the current work in resource management aspects such as power allocation, user association, mode selection, and spectrum allocation. • Highlight the most significant issues with the current resource management approaches and present the best solution to overcome the current issues. • Presents future directions and research challenges that have yet to be adequately addressed.	

4. Resource Management in Heterogeneous Network (RM HetNet)

The demand for wireless communications services has increased due to the recent research of having mobile device connectivity at any time and everywhere, which has sped up the deployment of wireless networks with various service capabilities. Massive connectivity will be a key component of 6G systems in the future between devices via the cellular network, equipment via HetNet, and D2D features [78]. Effective resource management strategies are crucial to achieving these demands, especially in HetNets. Resource management, which dynamically allots available resources with different constraints, such as EE, SE, and QoS, is a popular strategy in resource management schemes. Artificial intelligence (AI) is a crucial enabler for the future generations of 6G mobile networks, and assuring effective resource management is a significant aspect of realizing the 6G vision [79]. The 6G networks powered by AI can provide robust and intelligent resource management solutions [80]. It is anticipated that 6G networks would efficiently handle high-quality services, new-and-emerging applications (such as virtual reality and augmented reality, holographic technology, and remote surgery), and infinite connection for the vast numbers of smart devices [81]. In this section, we go through the mechanisms used in recent RM methods, and we classify those methods further based on different concepts. The resource management aspects are illustrated in Figure 4.

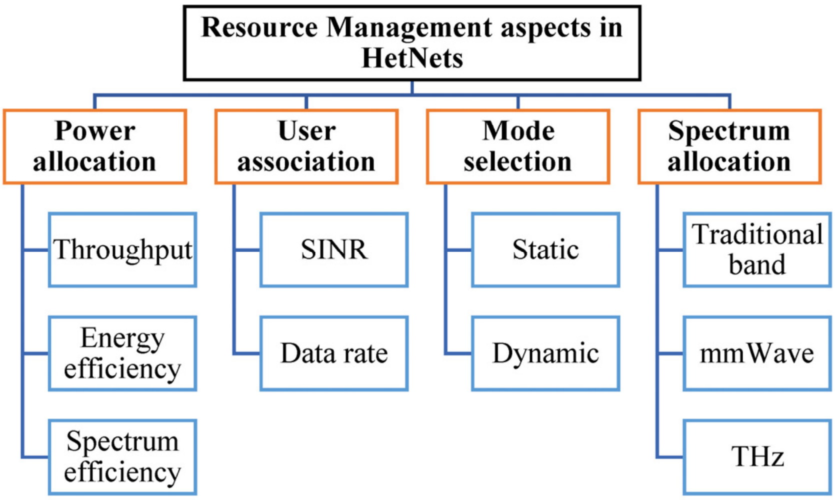

Figure 4. Resecures management aspects.

4.1. Power Allocation (PA)

Transmit power control is critical for beyond 5G network, as future communications will require EE with green technologies. The power allocation approach must be considered for these networks to ensure that the throughput, EE, and SE are at optimal levels. They are additionally modifying the power that, according to user requirements, can reduce interference, as shown in Figure 5. This section discusses the optimization parameters that were taken into consideration when allocating power, and a summary of those related works is listed in Table 2.

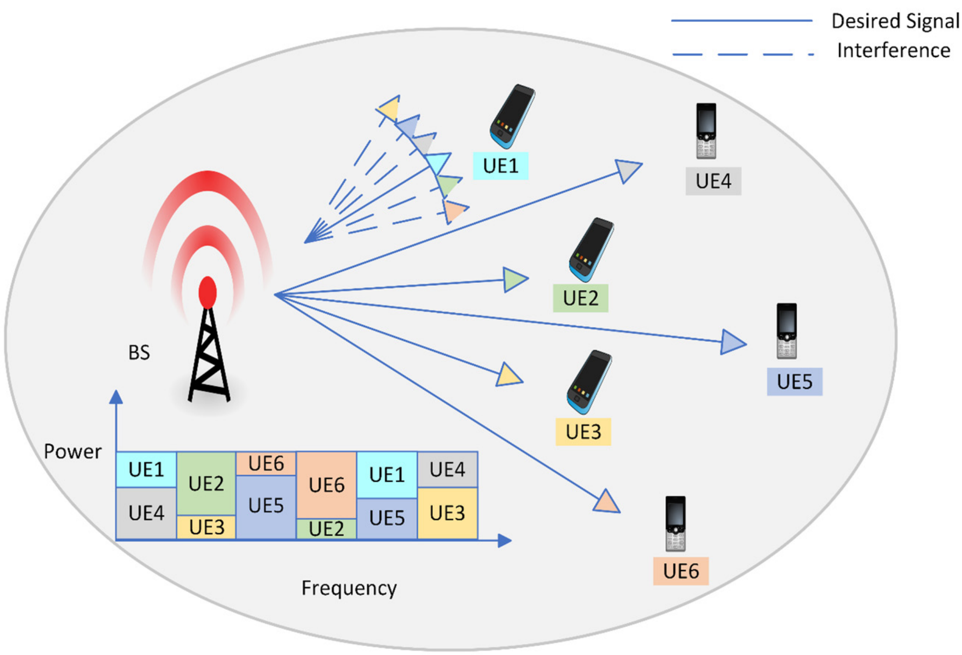

Figure 5. Power allocation in HetNet.

Table 2. Summary of the related work for power allocation.

Characteristics	Issue	Methodologies	Advantages	Limitations/Future Work	Ref.
Throughput	Minimize the total power of HetNets as well to provide the network capacity and coverage.	Dynamic power optimization model.	• Significant power savings in different scenarios. • Data rates and energy efficiency are significantly improved.	The delay constraints of the proposed model are not considered.	[82]
	Find a user-specific optimum transmission power.	Game theoretic power control strategy.	• Increasing throughput, guaranteeing the quality of service, and reducing interference.	Imperfect channel state information impact requires attention and consideration.	[83]
	Mitigate the cell edge interferences.	Coordinated multi-point scenario.	• Improved the total sum rate by effectively decreasing the interference.	The system energy efficiency of the proposed scheme is not considered.	[84]
	Increase system throughput and decrease energy consumption.	Recurrent neural network-based iterative algorithm.	• Boosting energy efficiency, throughput, and reliability.	The handover effect requires attention and consideration.	[85]
	Increase the network total sum rate.	Energy harvesting and gain-based resource allocation (EHGRA) algorithm.	• Increase the sum rate of the entire network.	The proposed algorithm can only be used when only one cell and one BS exist.	[86]
	Find the optimum power of DUs.	Lagrangian dual multiplier approach and Karush–Kuhn–Tucker (KKT) conditions.	• Outperforms the state-of-the-art in terms of convergence performance and throughput.	UE interferences are not considered, and the network can only support a single cell.	[87]
Energy Efficiency (EE)	Maximize energy efficiency.	Dinkelbach method and the Lagrangian approach.	• It is superior performance in comparison to the baseline algorithms.	User association requires attention and consideration.	[88]
	Improve the capacity of indoor users.	Lagrange multipliers technique and a sub-gradient method.	• The system EE and the flying time of UAVs are significantly improved.	Interferences between UAVs are not considered.	[89]
	Optimize the downlink energy efficiency.	A novel parameterized deep Q-network (P-DQN) algorithm.	• Energy efficiency improvement.	Considered a limited number of users and small base stations.	[90]
	Maximize energy efficiency.	Gradients algorithm.	• EE of the system improved efficiently.	SBSs used a single band to provide users. Hence, inter-cell interference occurs.	[91]
	Maximize energy efficiency.	Combinatorial optimization algorithm and Dickelbach algorithm.	• The grid power consumption is reduced, and EE is increased.	User association requires attention and consideration.	[92]
	Enhance both network performance and energy efficiency.	Binary Particle Swarm Optimization algorithm.	• Energy Efficiency enhancement.	Multi-cell and multi-sharing resource in the HetNet is not considered.	[93]
Spectrum Efficiency (SE)	Determine the optimal power allocation.	Reinforcement learning power allocation algorithm based on graph signal processing.	• Achieve the best SE and high throughput of edge use.	Imperfect channel state information impact requires attention and consideration.	[94]
	Maximize the weighted sum of SE and EE.	Power allocation strategy based on a non-cooperative game.	• The tradeoff between SE and EE is enhanced by selecting the balancing parameters.	A limited number of users constrains the model that has been proposed.	[95]
	Achieve a higher EE and SE.	Dinkelbach technique.	• Guarantee higher EE and SE.	User mobility and imperfect CSI need to be considered.	[96]
	Maximize SE and EE.	A Lyapunov optimization model.	• Performed a good trade-off between SE, EE, and queue length.	A single band is used to provide users. Thus, inter-cell interference occurs.	[97]

Table 2. *Cont.*

Characteristics	Issue	Methodologies	Advantages	Limitations/Future Work	Ref.
	Enhance the SE and EE and minimize the total interference.	Heuristic algorithm.	• Demonstrates improvements in total interference, EE, SE, and total network throughput.	User association and mobility require attention and consideration.	[98]
	Maximize both the EE and SE.	Stochastic optimization problem.	• -SE and EE can be significantly enhanced.	A high amount of signaling overhead is to be expected.	[99]

4.1.1. Throughput

System throughput, measured in bits per second, is the aggregate data rate transmitted successfully across all nodes in a network. Throughput optimization methods are discussed in this section. In [82], the authors consider the power allocation problem in heterogeneous networks. They proposed a dynamic optimization model to minimize the total power of HetNets and provide network capacity and coverage. Energy consumption has been considered to balance capacity and power to ensure QoS constraints. The proposed model determines when small cells with the highest energy efficiency should be turned ON or OFF in order to optimize power utilization. The simulation results showed significant power savings in different scenarios while ensuring the throughput constraints for network users. Furthermore, data rates and energy efficiency are significantly improved. Nonetheless, the delay constraints of the proposed model are not considered.

In [83], the authors investigated a power optimization strategy for interference management in 5G HetNets comprised of macrocells and underlying femtocells. They proposed a game theoretic power control strategy to find a user-specific optimum transmission power. The user, acting as a player, selects a power level and is rewarded according to the signal-to-interference noise ratio (SINR) that is probably received. Users compete for the highest payoff while also meeting their quality-of-service demands. Then, they developed an algorithm based on iterative learning to integrate the power optimization game. In multiple iterations of the algorithm, the optimal power allocation for all users yields decreased interference. The proposed mechanism is effective in numerical simulations for increasing throughput, guaranteeing the quality of service, and reducing interference. Nevertheless, imperfect channel state information impact requires attention and consideration. In [84], the authors considered a coordinated multi-point scenario in HetNet, which is a cooperative technology between BSs to reduce interference. Furthermore, the investigated scenario prevents severe interference at the cell edges by forming links while considering each cell load. The channel gain between the user and the base station was used as a criterion for power allocation. In order to decrease interference power, this allocation scheme distributed subcarriers orthogonal to the nearby UEs and increased the distance between users who shared a single subcarrier. The simulation results demonstrated that the proposed method improved the total sum rate by effectively decreasing the interference between the neighboring clusters. However, the system energy efficiency of the proposed scheme is not considered.

In [85], to achieve joint optimization regarding throughput and EE for imperfect channels encountered in high-speed railway communication, the authors proposed a power allocation interference alignment algorithm based on game equilibrium. They developed a game model and demonstrated the existence of Nash equilibrium to increase system throughput and decrease energy consumption. Moreover, a recurrent neural network-based iterative algorithm for PA was proposed. When the optimal power matrix is calculated iteratively and combined with the maximal SINR interference alignment algorithm, interference management optimization is achieved. The algorithm is well-suited for a high-speed heterogeneous network, and simulation results demonstrate its effectiveness in boosting energy efficiency, throughput, and reliability in a realistic imperfect channel state information (CSI) scenario for a high-speed railway. Nonetheless, the handover effect requires attention and consideration. In [86], an investigation was conducted into a power allocation challenge for energy harvesting D2D communication in a downlink cellular network scenario. The authors intended to increase the network total sum rate by considering factors that include frequency reuse between D2D and cellular networks, quality of service, and energy harvesting for D2D links. Furthermore, the combined BS and sub-carrier power maximum were considered and formulated. For optimal power distribution to D2D and cellular users, it is recommended to use the energy harvesting and gain-based resource allocation (EHGRA) algorithm, which considers both BS power and energy harvesting. The simulation results show that the proposed algorithm performs better than the OJOA algorithm. In addition, a low-complexity method was developed to increase the sum rate of the entire network. Nevertheless, the proposed algorithm can only be used when only one cell and one BS exist.

In [87], the authors considered the power allocation problem in NOMA-based D2D communication in a cellular network with imperfect CSI, focusing on downlink single-cell scenarios. The focus is on determining the most efficient power of UEs. In order to achieve optimal power distribution, they introduce a convex programming-based approach. In the scenario where the CSI is not perfect, the authors make use of the Markov inequality and the Marcum Q-function to analyze the channel gains while considering the outage probability constraints. Subsequent convex programming transforms the probabilistic non-convex problem into a frequent convex problem. The proposed algorithm iteratively determines the optimal power allocation coefficients by employing a Lagrangian dual multiplier approach and Karush–Kuhn–Tucker conditions to solve this optimization problem. According to the simulation results, the proposed method outperforms the state-of-the-art in terms of convergence performance and throughput. Nonetheless, UE interferences are not considered, and the network can only support a single cell and base station.

4.1.2. Energy Efficiency (EE)

The EE in HetNet can be ensured by allocating bandwidth to users following their QoS requirements. Including EE in the allocation schemes for beyond 5G systems is essential, which calls for an increase in connections and services. In [88], we discussed the research that has been conducted on different approaches to resource distribution that consider EE as one of the optimization parameters. A NOMA-based heterogeneous network is deemed to support large-scale communications between different kinds of BSs and users in the 5G system. Data transmission using NOMA technology has been used to increase the access ratio and spectrum utilization. An NP-hard and nonconvex resource allocation optimization problem has been formulated to maximize energy efficiency. An iterative algorithm is proposed for joint power allocation and subchannel assignment in imperfect CSI, with maximum cross-layer interference, transmit power and quality-of-service requirements. Subsequently, the Lagrangian approach and the Dinkelbach method, both of which have guaranteed convergence and low computational complexity, can be used to solve optimization problems in a way that yields the best possible solution. The simulation results confirm the efficiency of the proposed algorithm and clearly demonstrate its superior performance in comparison to the baseline algorithms. Nevertheless, user association requires attention and consideration.

In [89], the authors examined the power allocation issue of three-tier HetNets in a downlink scenario. The goal was to improve the capacity of indoor users in cases where the terrestrial network is either insufficient or out of service, such as during disaster situations or temporary hotspot regions, by deploying unmanned aerial vehicles (UAVs) as flying BSs and small cells (SCs). UAVs are energy-constrained devices with relatively limited flying time. Consequently, they necessitate a two-layer optimization scheme in which they first optimize the power consumption of each tier for improving EE under a minimum QoS requirement and then optimize the average hover time of UAVs. The Lagrange multipliers technique is used to initialize the problem, and then a sub-gradient method is used to achieve convergence, yielding a solution to the nonlinearly constrained optimization problem. The simulation results show that both the system EE and the flying time of UAVs are significantly improved in contrast to the situation where the maximum amount of power was given to users. However, interferences between UAVs are not considered. In [90], we present a joint approach of power allocation and user association with the goal of optimizing downlink energy efficiency while satisfying backhaul link constraints and ensuring the quality of service. In order to maximize the average cumulative reward, they suggest updating the learning policy with the novel parameterized deep Q-network (P-DQN). Furthermore, both the QoS of each UE and the limitations of the wireless backhaul are considered in the learning process. The simulation results demonstrate that the proposed P-DQN achieves better energy efficiency than the conventional methods, such as the deep Q-network (DQN) and distance-based association, while still meeting the QoS and backhaul capacity restrictions. In a HetNet, the average energy efficiency improvement of the proposed P-DQN may reach 77.6%, and in some cases, 140.6% compared to the traditional DQN and distance-based association approaches. However, the authors considered a limited number of users and small base stations.

In [91], they examined the problem of maximizing energy efficiency throughout downlink transmissions in a two-tier heterogeneous network with multiple small cells by considering user association and power allocation simultaneously. First, they considered a system model that does not include the co-channel interference that occurs between small cells. The problem of maximizing energy efficiency is formulated with certain maximum power limit constraints and predetermined quality-of-service requirements. An algorithm based on gradients is utilized to find a solution to the power allocation problem. In order to achieve the highest possible level of energy efficiency, an algorithm for iterative joint user association and power allocation has been proposed. In the simulation results, as the number of small cell users increased, the EE of the system improved efficiently. Nonetheless, all the small base stations used a single frequency band to provide users. Hence, inter-cell interference occurs. The authors in [92] investigated the problem of maximizing EE in a hybrid-powered HetNet, where data and energy are coordinated between BSs. Intending to decrease grid power consumption (GPC), they propose a combinatorial optimization algorithm to increase EE in the system. Because of the formulation complexity, both the Lagrange dual decomposition and the metaheuristic method were incorporated into the solution to tackle the issue. In addition, the Dickelbach algorithm is used to guarantee rapid convergence. The simulation results demonstrate that during times of harvested energy scarcity when BSs are cooperating to share channel information and energy, the GPC is reduced by nearly 20%, and EE is increased by around 10%. However, user association requires attention and consideration. In [93], the authors investigate the power allocation-based interference mitigation issue of multi-hop D2D links and cellular users (CUs) to enhance the EE of the cell with guaranteeing the network QoS constraints. They suggested a joint power allocation and channel assignment scheme. Binary particle swarm optimization is used for power allocation. The proposed scheme determines unique power values for each multi-hop D2D link to enhance network performance and energy efficiency. The results show that the proposed scheme improves EE by providing the best possible channel and power allocation for the CUs and multi-hop D2D users. Both uplink and downlink scenarios have been modeled and analyzed using our scheme, with the uplink scenarios yielding consistently better results for the proposed schemes. Nonetheless, multi-cell and multi-sharing resource allocation in the HetNet are not considered.

4.1.3. Spectrum Efficiency (SE)

The SE is measured in bits per second per hertz and reflects the maximum number of services that can be derived from a particular spectrum. This measurement is helpful for users because it allows them to make informed decisions about who should have access to a given frequency range. Resource allocation techniques that include SE as a performance metric are discussed in this section. In [94], the authors considered a power control in downlink ultra-dense HetNet with different types of BSs. They suggest a reinforcement learning power allocation algorithm based on graph signal processing. At first, they developed a realistic model that operates within an ultra-dense HetNet environment, which includes the instantaneous rate and channel mode. After that, they used a graph signal processing tool to analyze network interference, and they obtained the interference analysis results to determine the optimal power allocation of reinforcement learning. According to the simulation results, the proposed algorithm enables more precise power allocation based on the interference results from a graph signal processing analysis. Therefore, the proposed algorithm can achieve better SE and higher throughput than the three baseline algorithms while simultaneously improving the throughput of edge UEs and guaranteeing a peak rate. However, imperfect channel state information impact requires attention and consideration.

For HetNets utilizing non-orthogonal multiple access (NOMA), [95] explored the tradeoff between SE and EE concerning interference management and power allocation. The tradeoff between SE and EE is modeled as a non-convex multi-objective problem that is constrained by maximum power and QoS requirements. Combining a weighted sum strategy with the hypograph transformation can simplify the multi-objective problem into a convex single-objective problem. The single-objective problem can be solved in two different steps. First, they proposed a power allocation strategy for EE and SE in NOMA HetNets that is based on a non-cooperative game. To maximize the weighted sum of SE and EE, the macro base stations (MBSs) and small base stations (SBSs) compete in the proposed non-cooperative (NC) game by optimizing their transmit powers. Second, a closed-form formula is suggested to control the power allocation distributed to users while simultaneously considering the QoS and SIC constraints. The simulation results show that the tradeoff between SE and EE can be enhanced by appropriately selecting the EE threshold value and the balancing parameters. Nevertheless, the model that has been proposed is constrained by a limited number of users. In [96], the authors investigated an energy-efficient resource allocation of two-tier multi-carrier MIMO HetNet in a downlink scenario. The goal of this paper is to achieve a higher EE and SE. A massive MIMO transceiver design and antenna selection for macro and small cells are proposed to minimize power consumption. Furthermore, they proposed a joint resource block (RB) allocation algorithm, antenna selection, and a power optimization algorithm to enhance the EE and SE under constraints of minimal user rates and maximal capacity limits. The Dinkelbach technique was used to solve the power allocation problem successfully. The simulation result shows that the proposed algorithms guarantee higher EE and SE than the best-known benchmark algorithms while still being significantly easier to implement than an exhaustive search. Nonetheless, user mobility and imperfect CSI need to be considered.

In [97], they focused on the joint stochastic optimization problem of maximizing SE, EE, and queue length in downlink 5G HetNet. A Lyapunov optimization model is proposed and considers all aspects of the joint problem that simultaneously involves power control, resource allocation, and user association in complex networks. Particularly, this work focused on the NP-hard multiple resource allocation problem. They proved that a simplified version of the problem could be easily solved by applying a linear relaxation, and so they designed a distributed algorithm with low complexity to solve the original NP-hard problem. The simulation result showed that the proposed model performed an excellent tradeoff between SE, EE, and queue length. Furthermore, better results in terms of performance metrics than the state-of-the-art solutions based on the greedy algorithm are achieved. Nonetheless, all base stations used a single frequency band to provide users. Hence, inter-cell interference occurs.

In [98], the authors suggested a solution to modify the transmit power of BSs on each of the channels in the fractional frequency reuse scheme after a cell zooming/switch-off event. This is performed to reduce the energy that minimizes the total interference that occurs in relation to the requirements of UEs. After a cell switch-off/zooming event in the network, the fractional frequency reuse scheme requires a multi-objective optimization problem to be formulated to determine the radius of the cell-center region. Along with this, a heuristic algorithm for dealing with this issue is proposed. Adjusting the downlink transmission power of BSs to each user based on the required rate and the result of the heuristic algorithm leads to the formulation of a multi-objective optimization problem. Both EE, SE, and total interference are factors in this optimization problem. Additionally, a meta-heuristic algorithm for dealing with this issue is proposed. According to the research results of this investigation, its EE and SE are significantly superior to those of the previous studies. More specifically, the scheme's EE has increased by 41.95 and 36.60 percent compared to the earlier algorithm. Additionally, the method that has been proposed demonstrates improvements in total interference, SE, and, consequently, total network throughput. Nonetheless, user association and mobility require attention and consideration. To maximize both the EE and SE, [99] suggests an approach to allocating resources. Three strategies were modeled in their system: (1) a load balancing association schedule for the MBS and SBS that uses a range growth association scheme, (2) inter-cell and intra-cell interference management via fractional frequency reuse, and (3) allocating resources in a proportional manner to ensure users' fairness. The binary search algorithm was used to formulate the stochastic optimization problem and find an optimal solution that simultaneously maximized both the EE and the SE. The proposed method was evaluated with a variety of parameters, including power threshold, BS power usage, spectrum partition, and BS density. The results demonstrated that SE and EE could be significantly enhanced. In this method, the binary search algorithm was shown to reduce the amount of time needed to find the optimal value; consequently, the method is appropriate for use in real-life scenarios. However, because the MBS is allocating all of the system resources, a high amount of signaling overhead is to be expected.

4.1.4. Open Issues and Proposed Solutions

The UE capability has been investigated as one of the main factors in the next generation of mobile communications. Devices in 6G will be AI-guided and require substantial computational power to operate AI algorithms. Thus, new devices must be designed using new strategies and materials that support emerging networks. On the other hand, low-power SCs enhance the coverage and capacity of HetNets when SC locate underlying or overlaying MCs and utilize frequency reuse. There are still many problems the 5G networks to overcome. Cooperative and non-cooperative game theory can be modeled and analyzed in 6G networks. EE and SE are challenges in a 6G network, particularly in NOMA. An adaptive power allocation scheme is a key component of a 6G network, and NOMA has shown promise for improving system efficiency. This power allocation scheme enables developers to adjust transmit power levels to improve throughput, increasing system efficiency. Since BSs are implemented at fixed locations, the air–ground link distance mostly depends on the UAV position. UAV-assisted communication networks typically allocate more power when the UAV is close to the target to reduce path loss. Power allocation can be more productive in this way.

4.2. User Association (UA)

Each user in HetNet is associated with a single or multiple BSs, and a UA scheme is used to determine which BS provides the best service. Users are associated with a BS according to their data rate and SINR, as shown in Figure 6. UA is critical for enhancing the total sum rate as well as the EE and SE. In this section, we discuss the recent work that has been conducted on user association schemes, and the research is summarized in Table 3.

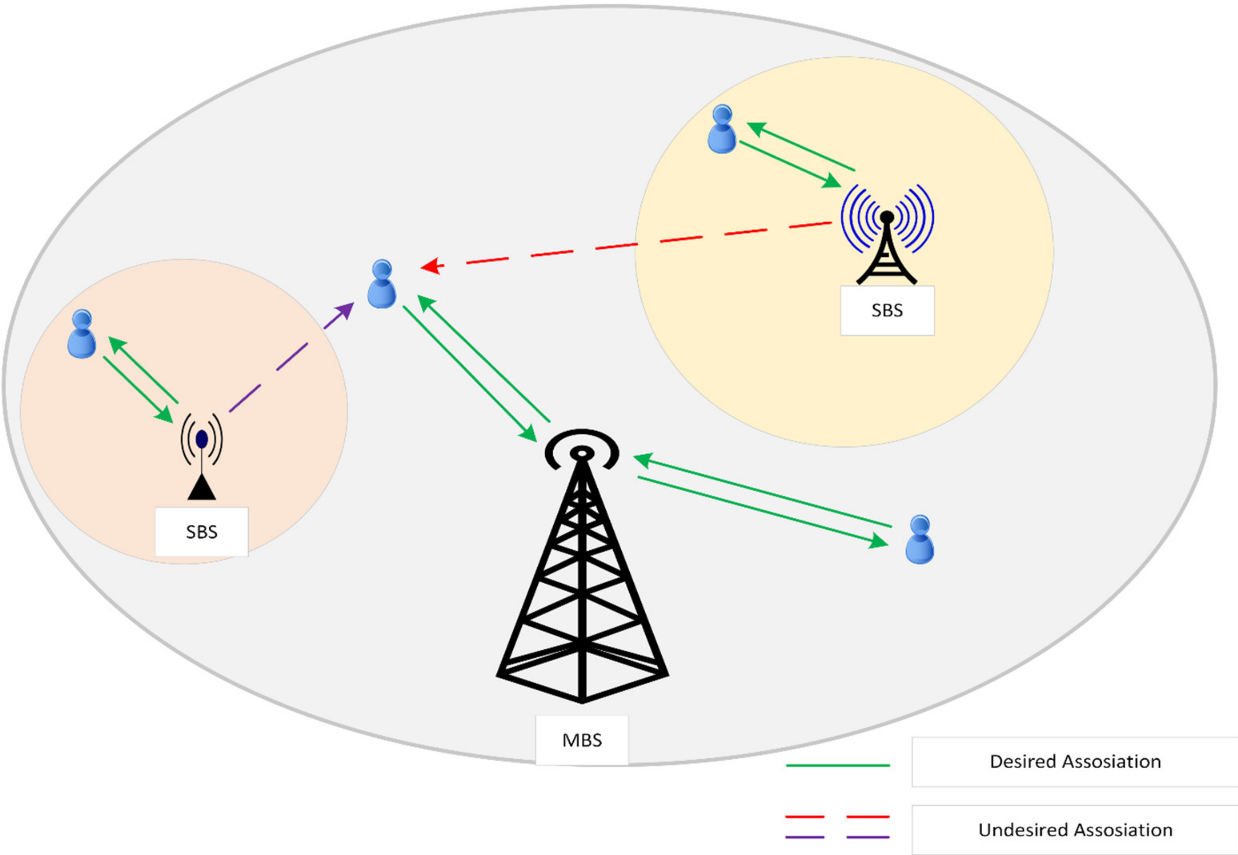

Figure 6. User association in HetNet.

Table 3. Summary of the related work for user association.

Characteristics	Issue	Methodologies	Advantages	Limitations/ Future Work	Ref.
SINR	Associate user devices with competing MBS and SBS	Cross-entropy algorithm	Maximizes data rate and sum rate	Power control and resource allocation need to be considered.	[100]
	Associate user devices with appropriate BS.	Centralized and distributed approaches	It enhanced the performance based on different scenarios.	The network energy efficiency is not taken into consideration.	[101]
	Associate user devices with appropriate BS.	Association schemes based on downlink uplink decoupled access	Downlink uplink decoupled access is superior in terms of UA, data rate, and SE.	EE is needed more attention and consideration.	[102]
	User association in HetNets	A distributed method based on deep reinforcement learning	Achieved a significant sum rate when considering the dynamic traffic.	The mobility of the user within a dynamic environment is not considered.	[103]
	Allocate users to SBS	A novel approach by employing second-order statistics of user data	Effective in reducing traffic load while also increasing data rate, average EE, and coverage.	The impact of imperfect CSI needs to be analyzed.	[104]
	Determine optimal associations in D2D HetNet	Evolutionary Game theory	Boost the performance of the network.	A distributed Open Radio Access Network controller needs to be considered.	[105]
	Find a more feasible user association	Developed semi-closed formulas	The coverage probability of the backhaul-aware UA scheme is outperformed.	Limited to a single MBS and single SBS scenario.	[106]

Table 3. *Cont.*

Characteristics	Issue	Methodologies	Advantages	Limitations/ Future Work	Ref.
Data Rate	User association in fog radio access HetNet	Joint UA and channel allocation scheme.	Effectively addressed statistical delay provisioning issues in HetNet.	EE needs more attention and consideration.	[107]
	Enhance the system EE and reduce the total interference	Lagrange multiplier approach	Improved the EE and minimized the total interference	The tradeoff between EE and SE is not considered.	[108]
	Find a more optimal user association	Non-cooperative game theory	Effective in ensuring dynamic user association, a higher total rate for all uses.	EE and frequency allocation is needed more attention and consideration.	[109]
	Associate users with BSs in an iterative and distributed way	Reinforcement Learning based technique	The achievable data rate, power consumption, and users' fairness.	The interference will rise with increasing the number of devices; hence the performance will degrade.	[110]
	User association in HetNets	User association approach	Boost the network throughput and system fairness in various HetNets.	Power consumption is not considered.	[111]
	UA in mmWave HetNet	Novel machine learning-based strategy	Capable of producing satisfactory results with a relatively small number of iterations.	The work relies on optimal UA schemes, which take time to collect.	[112]
	User association in HetNets	User-centric association algorithm	Enhance the average user rate.	As the number of users increases, the interference becomes unacceptable.	[113]

4.2.1. Signal to Interference Noise Ratio (SINR)

To evaluate these access schemes' ability to accommodate users, sum rate, EE, and SE, the following summarizes the current research on UA optimization schemes based on SINR in HetNets. In [100], the authors proposed a deep learning scheme based on ultra-dense networks to intelligently associate user devices with competing MBS and SBS. They considered user cell association in the downlink and assumed that each BS always transmits data to its associated UEs based on SINR. The problem of UA is formulated as a constrained optimization problem. A cross-entropy algorithm is employed to attain the optimal labeling solution in supervised learning. Through a combination of the mean squared errors (MSE) criterion and load balancing and fairness constraints, they define a differentiable loss function for the supervised deep learning framework. According to the results, the proposed schemes are comparable to the asymptotically optimal genetic algorithm scheme in terms of maximum data rate and sum rate. Moreover, the proposed schemes outperform the latter in terms of reduced computation time and robustness of the network. Nonetheless, it is important to control the power and allocate resources that need to be considered to improve the performance of the HetNet.

The authors tackled the issue of user association and spectrum allocation in 5G HetNets, which use both mmWave and sub-6GHz technology to deploy macro cells and small cells [101]. UA evaluation is based on the peak rate and SINR in BS for each user in the network. They unveiled a framework for associating users and allocating spectrum in a way that considers the number of users in the network. Specifically, they came up with an innovative approach to cell load estimation. This method was used to assign the spectrum to account for the users' distribution and strike a balance between spectral efficiency and frequency reuse. The UA discussed using two methods: a centralized approach that solved utilizing convex optimization techniques and a distributed method presented as an NC game. A fast-converging best response algorithm achieves the game's unique Nash equilibrium. The UA algorithms and spectrum allocation that were based on centralized, distributed, or relatively basic state-of-the-art approaches were all implemented in their coordinated framework. In simulation results, they evaluated the algorithms' performance based on BS density, traffic distribution, user density, global objective, and cluster size. In addition, they provided useful insights into the development of 5G HetNets. Nevertheless, the network energy efficiency is not taken into consideration. In [102], the authors considered both UA with HetNets consisting of large sizes, MBS, and relays operating in the microwave band as well as small sizes, SBS, and D2Ds operating in the mmWave band. UA optimization problems are formulated to compare the performance of user association schemes based on downlink uplink decoupled access with the performance of traditional downlink uplink coupled access in HetNets with respect to accommodating users and SE in mmWave and microwave bands. The formulated problems are NP-hard, meaning that the best possible algorithm is required to find a solution. In order to guarantee that users always associate with the BS in both the downlink and uplink, this access method uses the SINR as a criterion in the downlink. The simulation results showed that compared to downlink uplink coupled access, downlink uplink decoupled access is superior in terms of UA, data rate, and SE in the microwave and mmWave bands. In addition, simulation results gave an overview of the HetNets, showing that most users promote association with BSs operating in the untapped mmWave band rather than the scarce microwave band to meet higher data rate demands in the beyond 5G (B5G) HetNets. However, EE is needed more attention and consideration.

In [103], the challenge of user association in HetNets millimeter-wave that employ different radio access technologies is investigated. They introduced a novel, distributed method based on deep reinforcement learning to manage network dynamics. In the suggested multi-agent reinforcement learning algorithm, agent decisions are made on the basis of partial and local observations. This reduces the signaling overhead and computational complexity in comparison to centralized approaches. The association of a specific UE to the BS is dependent on the SINR between them. Moreover, they proposed a robust solution to massive changes in the statistical dynamics of the environment by incorporating a distillation procedure. The proposed algorithm outperforms the exhaustive search algorithm in terms of network performance. Furthermore, the algorithm achieved a significant sum rate when considering the dynamic traffic. However, the user's mobility within a dynamic environment is not considered. The coexistence of high-power MBS and low-power SBS is challenging to guarantee the efficient utilization of radio resources for the benefit of users with QoS needs [104]. Conventional UA methods that rely on SINR unfairly prioritize the high-power MBS while starving the low-power SBS. In the research that has been conducted on this topic, numerous attempts to arbitrarily allocate users to SBS have met with only minimal levels of success. The authors take a novel approach by employing second-order statistics of user data. These statistics provide a more accurate representation of shifts in user rates. They suggested a new method for UA with the appropriate BS by adding the total network load standard deviation. In order to achieve this objective, they comprehensively search for the optimal user-equipment combinations that yield a global minimum in the standard deviation. This represents the optimal distribution of users across each MBS or SBS. In addition, they developed novel expressions for EE and coverage probability, both of which are useful for quantitatively assessing the system performance. The simulation results showed that the proposed methods effectively reduce traffic load while also increasing data rate, average EE, and coverage probability. Nonetheless, the impact of imperfect CSI needs to be analyzed.

In [105], the authors investigated the UA problem of D2D-enabled HetNet Based on parameters such as SINR, path loss, and remaining battery life for each device in the network acting as a node, they derive the Nash equilibrium for games involving each pair of devices to find optimal associations in D2D HetNet using game theory. They demonstrated that the best possible D2D linkages between any two devices could be formed, thereby maintaining the highest possible QoS. As a result of this, it was discovered that the proposed method achieves optimal results while simultaneously possessing a Jain fairness index that is able to compete with that of other methods of a comparable nature that have been illustrated. Thus, the current work demonstrates that a formulation for D2D link formation in 5G wireless networks based on an evolutionary game can aid in selecting suitable link pairs to boost the network's performance. Nonetheless, a distributed open radio access network controller needs to be considered to help devices make an optimal link. In [106], the authors developed semi-closed formulas of network key metrics such as rate coverage, coverage probability, and network latency in ultra-dense heterogeneous networks by using a backhaul-aware user association approach based on SINR. Specifically, the analytical findings of outage probability are minimized by considering all available access and backhaul connections within the user-connectable range of MBS and SBS. The user experiences an outage only if the access link or backhaul link, which together provides the highest possible throughput, fails. Moreover, to find a more feasible deployment of SBS, the theoretical analysis and numerical results examined the impact of the proportion of MBS and the SBS density ratio on network performance metrics. Simulation results revealed that, under backhaul constraints, the coverage probability of the backhaul-aware user association scheme outperformed that of the traditional user association method. Nonetheless, the proposed scheme is limited to a single MBS and single SBS scenario.

4.2.2. Data Rate

The data rate measures user association decisions as a performance indicator. By selecting one or more of the BSs to associate with, each UE received the required data rate from a BS, which can guarantee their minimum required rates. In [107], the authors investigated a joint UA and channel allocation problem of a fog radio access network in the uplink scenario. A novel joint UA and channel allocation scheme are developed in order to accomplish the ultra-low latency goal. Within this scheme, the BS is grouped with a user-centric perspective. The delay performance has been significantly enhanced in terms of the control signaling technique and the data transmission procedure. In particular, the multiple access interference between users is examined, and a closed-form equation for the effective rate of a typical user with several BS connections and arbitrary interfering users is developed. The proposed joint UA and channel allocation method considers multiple access interference and guarantees a delay probability. The proposed joint UA and channel allocation strategy effectively addressed statistical delay provisioning issues in HetNet scenarios through simulation. However, access points used high transmission power to serve the network users. Hence, EE needs more attention and consideration.

In [108], the authors investigated a joint UA and resource allocation problem of cluster-based energy efficiency in B5G HetNets. The authors aimed to enhance the system EE and reduce the total interference. First, to determine the cluster center and the total number of clusters, they used an enhanced clustering technique that combines the max–min distance clustering algorithm with the K-means clustering algorithm. The intra-cluster interference is then reduced using orthogonal resource allocation within the same cluster. A non-convex issue may be transformed into a convex optimization problem by iteratively optimizing and relaxing the variable. Finally, this article proposed a solution by introducing the joint data rate-based user association and resource allocation algorithm. They presented UA and derived the network utility function through the Lagrange multiplier approach, with users preferring to associate the SBS with the largest utility function result due to interference from SBSs in other clusters. The simulation results illustrated that the proposed algorithm improved the EE and minimized the total interference. However, the tradeoff between EE and SE is not considered. To maximize the total rate of users in the cell of different links while minimizing interference and guaranteeing QoS requirements, the authors in [109] evaluated a joint power allocation and user association using non-cooperative game theory under QoS constraints. The UA is based on the minimum QoS requirement and data rate. To accomplish this goal, they divided the problem into two sub-problems. The backhaul game is the first sub-problem, wherein leaders select their optimal power allocation strategies by finding the optimal strategies of their followers. The second game is called the access game, and its objective is for the followers to provide the best response possible to the leaders. Compared to the hierarchical game, their approach performs better in simulations. Numerical results show that the algorithm effectively ensures dynamic UE association, a higher total rate for all UEs, and throughput stability between backhaul and access links. Nonetheless, EE and frequency allocation is needed more attention and consideration.

In [110], the authors investigated a joint user association and power allocation problem of NOMA-based 5G HetNet. A theory-based contract method is presented to handle the imperfect CSI. In order to associate users with BSs in an iterative and distributed way, a reinforcement learning (RL) based technique is chosen, making use of the offered feedback from the communication environment. Since each user has its own unique set of communications characteristics and types, the optimum power is found by solving for the optimality of each BS's utility function while guaranteeing the utility function optimality for every associated user. After the contract-theoretic power distribution is completed, users may provide their subjective assessment of their actual data rate. Numerical results are presented to show how the proposed user association and power allocation architecture works and what advantages it provides to users in terms of achievable data rate, power consumption, and user fairness. Nonetheless, the level of interference will rise in direct proportion to the number of devices; hence the network performance will degrade. A joint optimization framework for UA of 5G HetNet was introduced in [111]. In order to achieve their goals, they modeled the user association approach as a mixed integer linear program that simultaneously optimized bandwidth allocation and UA across the network. They studied the performance of the UA by analyzing multiple active application profiles. These application profiles include massive machine-type communication (mMTC) and enhanced mobile broadband (eMBB). Moreover, they offer a novel investigation of the multiple dual connectivity modes, in which the user can be linked to either a single Macro Cell (MC) and a potential SC or with any two preferable candidates BSs. Dual connectivity constraints are defined, allowing users to choose between two BSs with a maximum data rate. They demonstrate that, compared to the baseline scenario, which is a traditional UA solution, the UA optimal solutions boost the performance of various HetNets in terms of total system throughput and fairness. In terms of the whole network throughput metric, the comparison between dual connectivity and single association revealed significant performance gains for the latter. However, power consumption is not considered.

To address the problem of UA in mmWave HetNet, the authors proposed a novel machine learning-based strategy [112]. The UA problem is formulated as a multi-label problem to accommodate multiple connections. The problem is decomposed into a set of single-label problems if efficient multi-label algorithms are used. The UA scenario is formulated with the assistance of a graphical model that is characterized by both the physical locations of users and the structure of the mmWave HetNet. The authors proposed a novel feature extraction approach to collect the best information about users, similar to the inference procedures used in the graphical theory approach. In a supervised manner, the parameters of the classifiers and the means of feature extraction for each simple-label problem are jointly learned to be optimized. The research results demonstrated that the proposed approach could produce satisfactory results with a relatively small number of iterations and without the utilization of CSI. Nonetheless, the work relies on optimal UA schemes of training samples, which take time to collect.

In [113], the authors developed a user-centric association algorithm based on data rate for HetNets in a downlink multi-antenna scenario. The algorithm improves for the maximum possible function of the predicted long-term rate, which changes depending on the multiantenna transmission technique used by the data communication system. Existing cellular networks need simple changes to their cell selection technique to use the proposed algorithm, which employs an overhead of the same order as max-power association. The user needs to assess the strength of the signals received from nearby BSs, run those assessments through a processing unit to estimate the anticipated rate from each BS, and then connect to the BS with the highest predicted value. As shown by the results of the simulations, the suggested approach, in contrast to the usual max power association, takes advantage of the multi-antenna transmission strategy to enhance the average user rate. However, as the number of users increases, the interference becomes unacceptable, resulting in data rate degradation.

4.2.3. Open Issues and Proposed Solutions

In 6G networks, continuous connectivity is a key to network automation and intelligence. However, UA plays a prominent role by ensuring that the load is distributed evenly between SBSs and MBSs. The user and BS association challenge will require additional consideration and attention in the future. The UA verification for each BS is the agent's operation, and the benefit is the network load balance. Because of urban traffic, the space-time dimension includes several patterns. The association patterns obtained during the training phase of reinforcement learning allow for simultaneous load balancing of BSs, considering both the dynamic changes in the environment and the space-time regularities. The reinforcement learning generates a UA matrix for each BS based on the similarities between the current situation and historical patterns. Although information such as channel quality, SINR, and backhaul capacity are essential characteristics of a UA, QoE of the user is of equal or higher priority. Users in the 6G system are assigned to specific cells according to their particular needs. Thus, the above method is best for 6G distributed UA schemes. Researchers are using dependent and independent due to network changes and more devices with different needs.

4.3. Mode Selection (MS)

MS methods to determine the best mode for each user are necessary due to the availability of multiple communication modes, as illustrated in Figure 7. To achieve the best connection of cellular and D2D networks, MS methods have been proposed. However, current MS methods cannot implement connections from opportunistic cellular networks into the selection method. We covered the most recent papers in MS methods and presented a summary of these studies in Table 4.

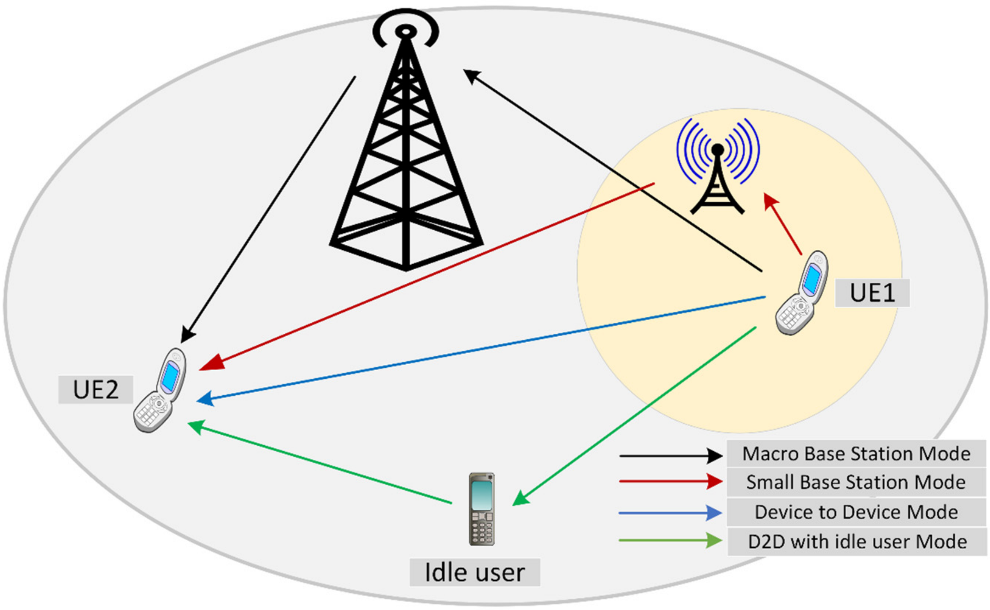

Figure 7. Mode selection in HetNet.

4.3.1. Static

When using a conventional method, the devices communicating with one another do not switch modes. We discussed static mode selection methods, wherein the communicating devices can select a mode of communication (ranging from cellular user and D2D). In [114], they considered the resource allocation problem in HetNets with multiple BSs, where an optimal solution can significantly enhance the system EE. The MS and UA are joined with each other in multiple BSs. They regarded the joint problem of the MS, UA, channel allocation, and power allocation in the multiple BSs networks, which remains an open problem. Each D2D pairs have its unique channel gain on its respective channels in a complicated form. Constraints such as total transmission power and BS load balancing are considered. An optimization problem involving mixed-integer variables is presented, and it is not convex. They proposed a joint MS, UA, power allocation, and channel allocation algorithm based on the particle swarm optimization algorithm. The simulation results demonstrate the feasibility of the proposed algorithm, which can effectively increase system EE by satisfying total transmit power and load balancing. However, the mobility of users needs to be considered.

In [115], the authors explore the MS problem for a HetNet in the uplink scenario to improve EE by focusing on QoS for D2D and CU. Each user transferred between regular cellular mode and D2D mode, presenting a Markov decision process problem. Deep deterministic policy gradient is a model-free deep reinforcement learning algorithm used by the authors to address the Markov decision process problem in continuous state and action space. The architecture of the suggested method consists of two networks: an actor-network and a critic network. Both the former and the latter use value function-based Q networks to analyze the performance of the actor-network, with the former employing a deterministic policy technique to construct deterministic activities for the agent. According to the simulation results, the proposed algorithm outperforms the benchmark algorithms in terms of convergence properties and EE. Nonetheless, the SE needs more attention and consideration. In [116], the authors discussed the possibility of using full-duplex radio in the access and backhaul links of SBSs. Specifically, they thought about the issue of how to distribute resources between SBSs that can use full duplex and users that can only use half-duplex. The solution divides the problem into two parts; user scheduling and MS, and power allocation to address the nonconvex of the underlying issue. They provided a decentralized and efficiently computed solution to each individual subproblem. According to the numerical results, the proposed algorithm effectively uses full duplex technology to boost the network sum rate compared to the network that only uses a half-duplex or full-duplex strategy. The research resource allocation method aimed to maximize SE by utilizing a mix of full-duplex and half-duplex modes of operation across access links and backhaul. In addition, the resource allocation algorithm distributed applied for full duplex HetNets without a centralized station. Nevertheless, the proposed scenario does not consider all possible transmission modes simultaneously.

In [117], the authors explored the MS issue for uplink scenario two-way D2D communication enabled with full duplex to improve SE in a cellular network. Four types of communication are considered: full-duplex underlay, full-duplex overlay, half-duplex underlay, and half-duplex overlay. They optimized the SE for each mode to ensure that both cellular users and D2D can meet the minimum data rate requirements and the maximum power transmission. In the full-duplex underlay mode, the optimization model has converted into a programming problem; the difference between convex functions and the concave–convex procedure method can be applied to solve the problem efficiently. The optimization problem is then solved using a search plus concave–convex procedure algorithm for both full and half duplex overlay modes. Lastly, in half-duplex underlay mode, all that remains is to locate the best solution. The MS can be chosen according to the highest SE among the four modes. The simulation results illustrated the effects of interference cancellation capabilities and channel gain on four transmission modes with maximum SE and MS. Moreover, the full-duplex mode is preferred when interference cancellation is satisfactory, while the underlay mode is preferred when the interference connection is poor. Nevertheless, the EE and imperfect channel state information are not considered.

In [118], the authors proposed an MS scheme that uses a distance-based mechanism to select between different communication modes and a non-orthogonal scheme for sharing resources. The proposed mechanism derives the formulas of throughput and the policy for utilizing resource blocks, two crucial metrics for evaluating the efficiency of the network. A user's equipment can select its communication mode based on the MS condition, such as the distance and threshold SINR between machine-to-machine (M2M) users. The MS prior to data rate has potentially improved the network's performance. The traffic load on the BS can be reduced through the strategic design of distance-assisted suggested resource block utilization policies. The system's performance is evaluated in relation to a number of different parameters that can be altered, including throughput, MS threshold SINR, threshold distance, and resource blocks. The proposed mechanism also improved network performance and decreased the proposed network traffic load. Nevertheless, EE needs more attention and investigation.

4.3.2. Dynamic

There are multiple possible modes in a B5G network. The users are in their proximity area, and they select D2D mode; otherwise, they select cellular mode to help BS. In the dynamic network, the users are free to move in any direction and change their mode when their information is substituted. In [119], the authors considered the MS problem of D2D multi-tier HetNets for a downlink scenario in terms of improving EE. A mathematical representation of the MS problem describes it as an NP-hard problem. The complexity of the optimization problem is reduced and solved using various optimization techniques, all of which are selected based on a load of traffic passing through the network. This paper proposes a novel method for dynamic mode selection based on fuzzy clustering. Depending on the network resource block availability, the proposed model allows D2D users to switch between dedicated and reuse modes in real time dynamically. Based on the received signal strength and the level of interference, the method selects D2D users for dedicated and reuse mode operations. Further, whenever there is a shift in resource block availability, users automatically transition to the mode that best manages the network's optimum performance. The new method's effectiveness is evaluated compared to the traditional methods. The simulation results demonstrate that the proposed approach is superior to the conventional methods in terms of EE and the number of connected D2D users. In addition, the EE of downlink transmission is improved by deploying the D2D underlying multi-tier HetNet. Nevertheless, the greater physical distance between devices leads to a user being banned.

In [120], the authors explored the MS issue in the downlink scenario of multi-hop cellular communication and D2D communication over HetNets. They propose a new approach for MS in HetNets that makes use of greedy multi-hop cellular networks. The proposed system selects a mode of communication after weighing its advantages and disadvantages. In addition, the proposed approach switched between the conventional cellular mode, the multi-hop cellular mode, and the greedy multi-hop cellular mode. Further, the proposed approach combines the selection of the optimum number of hops into the MS process. Multi-hop cellular and single-hop cellular modes are contrasted with the proposed approach. The simulation results demonstrate that opportunistic multi-hop cellular network communications significantly improve the performance of future networks.

Further, the proposed approach selects the best MS to maximize system throughput, EE, and network capacity. Nonetheless, signaling overhead is not considered. In [121], to enhance the performance of cellular networks, the authors explored an MS problem for D2D communication for each uplink and downlink scenario. A new MS scheme is proposed to reduce the network signaling overhead at each BS in which the D2D mode is stimulated based on the distance between users. MS in mobile D2D scenarios is further facilitated by a tractable analytical approach that accounts for relative motion. They formulated the threshold distance for D2D communication, the successful transmission probability, the probability of using D2D mode, and the minimum amount of time spent in D2D mode. The evaluation of the D2D performance while considering mobility primarily focuses on these parameters. Monte Carlo simulations were performed to verify the analytic results and evaluate the proposed method's advantages. As evidenced by the determined minimum for D2D residence time, the results confirmed the importance of the system's dynamic performance regarding user mobility. However, the interference between the D2D and CU is not considered in the proposed scheme.

In [122], the authors discussed the MS issue in the downlink scenario of D2D and multi-hop cellular communication over HetNets. They suggested a context-aware MS strategy that can identify and select the optimal mode for each device in various deployment and operating conditions. The number of user devices and the distance between the BS and the user device are considered when determining the various communication modes. The proposed MS technique significantly improves user throughput over baseline cellular systems, especially in the presence of medium or high UE densities and for users close to the cell edge. The research results of the simulation demonstrated the importance of incorporating accurate information regarding the context of users into the decision-making process to enhance the system's performance. In addition, the results showed that the proposed method could adapt the MS choice it makes in response to different and varying operational conditions within the cell. Nevertheless, user association requires attention and consideration. In [123], the authors discussed the MS problem for D2D communication that is underlaid in a cellular network to improve the system's throughput while simultaneously maximizing user access. They suggested a probabilistic integrated resource allocation approach as well as a quasi-convex optimization technique depending on the probability of channel characteristics. The simulation results demonstrated the efficiency of the communication strategy by showing that the proposed approach can significantly improve system throughput and user experience and eliminate interference between users. In order to maximize system capacity while guaranteeing a fair user experience, all modes consider users' varying channel quality, dynamically choose MS in each scheduling period, and resource allocate blocks. However, the equilibrium between user experience and channel utilization in the proposed approach is not considered.

In [124], the authors demonstrated direct D2D communication for 5G and 6G networks operating in dynamic scenarios in which the D2D network topology is subject to the mobility of users. In particular, they thought about a situation where multiple users are located within the coverage area of a single BS and where differences in speed and direction cause changes in the D2D network topology, either through direct connections or via single-hop or multi-hop D2D paths. They formulated a problem to minimize the power consumption of the D2D devices while maximizing the total SE by choosing the optimal transmission mode. In order to solve the above issue, they proposed a distributed AI solution plan that takes into account the mobility of the D2D to create efficient clusters and stable and better backhauling links dynamically. The results showed that an improved distributed AI solution outperformed its related counterparts in terms of SE and power consumption. These alternatives included the distributed sum rate, the distributed random, and the single-hop relay approach. Nonetheless, signaling overhead due to a large number of relays and users is not considered.

In [125], the authors proposed a sum-rate maximization model for D2D communication underlaid cellular networks, which simultaneously depends on MS and power control. Joint optimization was utilized to determine the optimal MS and power control, which is a nonconvex problem with both linear and nonlinear requirements. Sub-optimal solutions to the joint optimization method were derived from the Lagrange dual function. They proposed the deep neural network algorithm, which uses the Lagrange dual function as its loss function. The proposed model for a deep neural network is learned in such a way as to reduce the loss function. Deep neural network performance compared to exhaustive search and other suboptimal methods. The results justify the proposed MS model to select the optimal mode (D2D or device–infrastructure–device) for user pairs to improve system performance. Moreover, the results demonstrated that the proposed deep neural network method outperforms the Lagrange duality approach and finds a near-global optimal solution at a much lower computational complexity than an exhaustive search. Nevertheless, imperfect channel state information is not considered in the proposed scenario.

Table 4. Summary of the related work for mode selection.

Characteristics	Issue	Methodologies	Advantages	Limitations/ Future Work	Ref.
Static	Enhance the system EE	Particle swarm optimization algorithm	Effectively increase system EE by satisfying total transmit power and load balancing	The mobility of the user needs to be considered.	[114]
	Improve EE by focusing on QoS for D2D and CU	A deep deterministic policy gradient algorithm	Outperforms the benchmark algorithms in terms of convergence properties and EE	SE needs more attention and consideration.	[115]
	Maximize SE by utilizing a mix of full-duplex and half-duplex modes	Decentralized user scheduling and MS scheme	boost the network sum rate in comparison to the network that only uses half or full duplex	All possible transmission modes do not consider simultaneously.	[116]
	Utilize an effective capacity to evaluate the statistical QoS of a D2D link.	A novel multiple features-based MS mechanism	MS with the best possible weights performs better than the conventional MS.	Imperfect channel state information is not considered in the proposed scenario	[126]
	Maximize system throughput	Greedy strategy and convex optimization theory.	Significantly improve system throughput	Does not consider the interference between D2D and CU.	[127]
	Improve SE in a cellular network.	Search plus concave–convex procedure algorithm	Illustrated the interference cancellation capabilities and channel gain with maximum SE.	EE and imperfect channel state information are not considered	[117]
	Select between different communication modes	MS distance-based mechanism	Improved network performance and decreased network traffic load.	EE needs more attention and investigation.	[118]
Dynamic	Improve the network EE	A novel dynamic MS based on fuzzy clustering	The EE of downlink transmission is improved through the deployment of the D2D users.	The greater physical distance between devices leads to a user being banned.	[119]
	Selects the best mode of communication	Novel MS approach with multi-hop cellular network communications.	Maximize system throughput, EE, and network capacity	Signaling overhead is not considered.	[120]
	Enhance the performance of cellular networks	Novel MS scheme	Confirmed the importance of the system's dynamic performance.	The interference between the D2D and CU is not considered in the proposed scheme.	[121]
	Identify and select the optimal mode for each device.	Context-aware MS strategy	Demonstrated the ability to adapt the MS within the cell	User association requires attention and consideration.	[122]
	Improve the throughput of the system while simultaneously maximizing user access.	Probabilistic integrated resource allocation approach	Significantly improve system throughput and user experience, and eliminate user interference.	The equilibrium between user experience and channel utilization in the proposed approach is not considered.	[123]
	Minimize the power consumption of the D2D devices while maximizing the total SE	Distributed AI algorithm	Outperformed its related counterparts in terms of SE and power consumption	Signaling overhead due to many relays and users is not considered.	[124]
	Maximize the network sum rate	The deep neural network algorithm	Outperforms the Lagrange duality approach and finds an optimal solution with low complexity	Imperfect channel state information is not considered in the proposed scenario.	[125]

4.3.3. Open Issues and Proposed Solutions

D2D communication is considered a challenging and dynamic environment; consequently, a comprehensive evaluation of the distributed artificial intelligence solution (DAIS) mode selection algorithm is needed to be investigated. The SE and power consumption of the network have been analyzed and considered various factors. Two parameters, the data rate threshold and the device battery threshold, notably impact the EE and SE. In addition, a blockchain technology-based D2D network that addresses security and privacy concerns in a decentralized manner will be beneficial for safe communication. Under the D2D communication network, blockchain technology is crucial for establishing smart contracts between the D2D relay and the direct D2D.

4.4. Spectrum Allocation (SA)

The SE and EE enhancement is a significant research problem in designing appropriate transmission strategies and SA methods in a HetNet. Allocating the capacity of the links with distributed network nodes efficiently requires optimal utilization of spectrum resources in a HetNet. The SA schemes that are typically involved in a HetNet are listed in Table 5. Figure 8 shows the spectrum ranges in HetNet.

Table 5. Summary of the related work for spectrum allocation.

Characteristics	Issue	Methodologies	Advantages	Limitations/ Future Work	Ref.
Traditional Band	Improve QoS for the cell center users and cell edge users.	Utility-based SA algorithm	Effective solutions for the real-time application of cell edge users.	A centralized SA method is presented. Hence, the burden on the BS increased.	[128]
	Improve the network SE	Cooperative bargaining solution.	Attain significant performance improvements over other existing schemes	The tradeoff between SA and the power allocation problem is not considered.	[129]
	Improve the SE	Genetic algorithm-based EE SA scheme	Showed a tradeoff between EE and throughput	The transmitted power increased, and the EE and SE decreased.	[130]
	Match secondary users with randomly distributed SBSs.	Many-to-one college admissions matching game	Evaluate the proposed repeated auction in comparison to the matching theory and the single auction.	The system EE of the proposed scheme is not considered	[131]
	Enhance EE and SE	Lyapunov optimization algorithm	Achieved an outstanding overall performance with low complexity.	User mobility and imperfect CSI need to be considered.	[132]
Millimeter Wave (mmWave)	Maximize the sum-rate	The joint optimization problem of UA, subcarrier allocation, power control, and SA	-Perform better transmission performance in terms of the total rate and power efficiency.	Users' fairness needs more attention and consideration.	[133]
	Optimize EE by balancing SA and route selection	Stochastic algorithm	-EE and SE are improved by optimizing resource allocation and path selection.	User mobility is not considered.	[134]
	Allocate the entire 28 GHz mmWave spectrum to each BS	Novel licensed SA approach	Provide similar performance improvements in average capacity, SE, EE, and cost efficiency.	Load balance is not considered.	[135]
	Enhance spectrum utilization	Static-licensed SA and flexible-licensed SA	Demonstrated that the spectrum reuse method enhanced SE and EE results.	User mobility needs to be considered.	[136]
	Improve HetNet backhaul capacity	The centralized SA algorithm	showed that the proposed algorithm boosts HetNet performance.	EE needs more attention and consideration.	[137]
Terahertz (THz)	To enhance the available spectrum utilization	A decentralized resource allocation strategy based on deep reinforcement learning and federated learning	Effectively optimizes network performance in terms of power consumption and throughput.	Realistic mobility models need to be considered.	[138]
	Optimize the effective capacity in the THz band	Energy harvesting-based THz -band nano-communication systems model	Verify and assess the proposed THz band schemes over HetNets.	Network energy consumption needs more consideration and investigation.	[139]
	Perform high data transmission	A novel multi-sub band quasi-perfect (MS-QP) sequence	Outperforms the existing methods in terms of communication and sensing performance.	Imperfect channel state information needs to be investigated.	[140]
	Determine sub-band bandwidth, sub-band assignment, and optimum transmit power	Iterative algorithms using the successive convex approximation approach	- Increase the network throughput by enabling and optimizing adaptive sub-band bandwidth	The use of adaptive sub-band bandwidth is limited to situations in which the sub-bands have a relatively narrow bandwidth.	[141]
	Optimize the SE while simultaneously fulfilling the data rate needs of users.	Long user central window principle and the bipartite graph matching approach.	Achieved greater system spectrum efficiency.	The proposed THz system is limited to a small number of users.	[142]

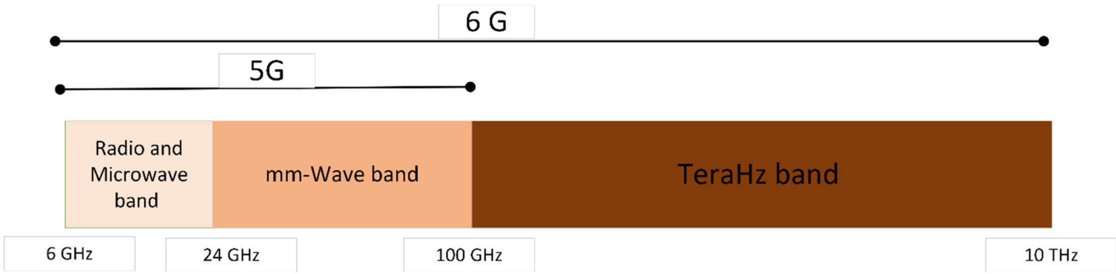

Figure 8. Spectrum ranges in HetNet.

4.4.1. Traditional Band

Frequency bands for B5G networks are separated into different frequency ranges. The frequency bands are traditionally used by previous standards but have been extended to include potential new spectrum offerings. In [128], the authors developed a utility-based prioritization of the SA algorithm to improve QoS for the cell center users and cell edge users of HetNet. Voronoi tessellation-based cell user categorization reduces the SINR at the instantaneous fluctuation. The user requests should be prioritized according to the utility of the quality of service and the delay-bound budget in terms of improving fairness among users. In the centralized SA method, the designed utility-based SA algorithm optimized the sharing of resources mechanism to satisfy the QoS and delay bound of the users. Utility-based SA algorithm provided a higher quality of service to guaranteed delay-bound and real-time applications managed by cell edge users when compared to conventional scheduling algorithms. The SA algorithm was implemented to improve the throughput, fairness, average delay, and SE of the users and network. The simulation results prove that the designed utility-based SA algorithm offers superior and more effective solutions for the real-time application of cell edge users in HetNets. However, the centralized SA method is presented. Hence, the burden on the BS increased.

In [129], the author proposed a joint SA scheme that integrates NOMA and orthogonal multiple access (OMA) modes into a unified strategy. They utilized cooperative bargaining solution concepts to analyze multiple access methods performed together efficiently. The proposed algorithm considered the hybrid OMA-NOMA system platform and was inspired by the Nash bargaining solution and group bargaining solutions. In the suggested method, users within the same channel form a group, and the SA process for BSs and channels follows the OMA mode. The NOMA mode determines which power level to use for users in each group. Traditional Nash bargaining solution is used in OMA mode SA. The NOMA mode operates on the group bargaining solution in both individuals and across groups. The limited SA is managed and distributed at each period to effectively adapt to the current network changes while ensuring consistent system performance. Simulation results demonstrate that the proposed method attains significant performance improvements over other existing two-tier based NOMA spectrum allocation, locally cooperative game, and NOMA-based HetNet SA schemes when the NOMA and OMA exist in the HetNet system. Nevertheless, In the NOMA model, the tradeoff between SA and the power allocation problem is not considered. In [130], the authors developed a genetic algorithm-based energy-efficient SA scheme in downlink orthogonal frequency division multiple access (OFDMA) HetNets. In order to improve the SE of 5G mobile networks, frequency reuse is used. An intractable mixed-integer nonlinear fractional programming problem is formulated to address the EE optimization problem based on coordinated scheduling. To discuss this, they proposed a two-step genetic algorithm-based scheme to address the optimization problem. In the first step, a standard genetic algorithm is used to solve the SE aspect of the power distribution matrix for the resource blocks. The second step is to use the obtained SA matrix and the non-dominated sorting genetic algorithm to evaluate the power distribution matrix. The simulation results showed a tradeoff between EE and throughput. Nonetheless, as the transmitted power increased, the EE and SE decreased accordingly.

In [131], the authors proposed two frameworks based on auction games and matching theory to accept secondary users into the HetNet efficiently. In this paper, they considered a practical scenario in which primary channels can have a variety of characteristics. The characteristics include MC channels with the active primary transmission, macro channels with the primary user absent, and SC channels with limited use when the SC transmission is pending and a higher price than the macro channels. In the subsequent stage, a repeated modified English auction, these BSs gain access to the available primary spectrum on behalf of its UA. In order to match secondary users with a number of randomly distributed small base stations, a matching game that is many-to-one college admissions is utilized. As demonstrated by the research results, both a stable matching point for a Walrasian equilibrium point and the users' admission game of the repeated auctions are effective. Furthermore, comprehensive simulations are performed to evaluate the proposed repeated auction compared to the matching theory and the single auction. However, the system energy efficiency of the proposed scheme is not considered. In [132], the authors evaluated the energy minimization queue-aware challenge offloading, and SA issue for air–ground integrated clustered-NOMA HetNets. They utilized Lyapunov optimization to convert the origin problem to three sub-problems: assignment splitting and local computational SA for the users, frequency reusing and offloading optimization, and edge SA for BS. Accordingly, they developed assignment splitting and local computational SA algorithm, energy minimization frequency reusing algorithm, and energy minimization greedy-based edge SA algorithm to solve the three subproblems sequentially. In addition, they investigated the optimality, convergence, and complexity of the approach. The results of the simulation show that the proposed scheme is capable of achieving outstanding overall performance with low complexity of power control, SE, queuing delay, and task backlog. Nevertheless, user mobility and imperfect CSI need to be considered.

4.4.2. Millimeter Wave (mmWave)

Beyond 5G and 6G networks will need to be able to handle massive amounts of data, and both cellular network densification and mmWave communications hold great promise as possible solutions. In addition to improving the SE and EE of the next-generation wireless networks, HetNet can enable network densification in a cost-efficient manner. HetNet architecture and mmWave bands can be integrated to realize the goals of massive bandwidth and network densification. Furthermore, mmWave communications are more susceptible to blockages such as shadows and building walls and are also affected by atmospheric conditions compared to communications in low-frequency bands. In [133], the author identified transmission scheduling for downlink transmission OFDMA-based mmWave in HetNet. Specifically, a different SA can use the data rate on each subcarrier. Consideration of the impact of mmWave beam directivity on resource optimization is incorporated into the derivation of signal power and interference. They formulated a joint optimization problem of UA, subcarrier allocation, power control, and SA to maximize the sum rate. This joint optimization problem is partitioned into two subproblems for a more effective solution. Joint optimization of users, SA, and subcarrier allocation for fixed power allocation is the first subproblem to be addressed. The second subproblem addressed power allocation for a fixed number of users, SA, and a subcarrier. They suggested a novel multiple SAs cooperative-based method to achieve optimal scheduling by solving the two subproblems. The simulation results demonstrated that compared to the standard algorithms, the proposed multi-SAs cooperative algorithm has better transmission performance regarding the total rate and power efficiency. The optimal iteration number for the proposed algorithms is shown to be relatively low. Nevertheless, user fairness needs more attention and consideration.

In [134], the joint optimization problem of resource allocation in a cellular network with mmWave and traditional wave has been investigated. A cross-layer optimization problem is formulated for this innovative architecture to optimize EE by balancing SA and route selection. Two subproblems have been identified and addressed individually, allowing this problem to be resolved. In the first part of the resource allocation problem, they discovered it was non-convex and introduced four solutions using stochastic algorithms with a given route selection. According to the new model specifications, both SA and power allocation are coded independently. Then, the four resource allocation methods, including the genetic algorithm and the differential evolution algorithm, are discussed, through which the SA and power allocation jointly enhance the SE and EE. Regarding the second component of the routing issue, they developed it as a linear programming problem and solved it with an optimization toolbox while managing to keep the resource allocation constant. The simulation results show that the EE and SE of the mmWave network can be improved by simultaneously optimizing resource allocation and path selection on a cross-layer basis. Furthermore, network throughput can be increased by perfectly locating the route without overloading any of the BSs. Nonetheless, user mobility is not considered. In [135], they proposed a new approach for licensed SA to allocate the entire 28 GHz mmWave spectrum to each BS to perform its small cells for each building to avoid co-channel interference. Hence, increasing spectrum availability and utilization. Because most data are produced inside, the full mmWave SA provided to a BS is regarded as being reused for small indoor cells. They introduced a frequency-domain and time-domain method for avoiding co-channel interference and deriving its optimality conditions. They determine the average capacity, SE, EE, and cost efficiency for licensed SA and carry out extensive numerical and simulation results. It was demonstrated that licensed SA with both frequency-domain and time-domain co-channel interference avoidance approaches provide similar performance improvements in average capacity, SE, EE, and cost efficiency. Nonetheless, load balance is not considered.

In [136], based on the licensed 28 GHz mmWave, or other spectrum is allocated equally to each BS, they proposed two approaches to enhance spectrum utilization. Principally, the first approach, known as static licensed SA, is on maximizing spectrum utilization by allocating the 28 GHz spectrum equally to all BSs. The second approach, flexible licensed SA, is concerned with increasing spectrum utilization through the spectrum allocated unequally to each BS. Since sharing and reusing the licensed SA to each BS using either static licensed SA or flexible licensed SA can be abused, secondary spectrum trading is essential in the case of static licensed SA to redistribute the spectrum assigned to the BSs. They provide mathematical models for both approaches, allowing the calculation of metrics such as SE, EE, and average capacity. The results demonstrated that the average SE and EE requirements for 6G mobile networks could be achieved using both the first and second approaches. Nevertheless, user mobility needs to be considered.

In [137], to improve HetNet backhaul capacity, the author suggested resource allocation algorithms and used geometric analysis to evaluate network efficiency. First, they suggested a centralized SA algorithm for the case that BS is available to collect traffic load information and CSI of each user's equipment. In order to improve the high propagation loss of the mmWave band, densification of BS is necessary. This may induce high computational complexity and require a massive channel state information feedback load for the centralized SA scheme. They discussed the distributed SA scheme that can be individually managed at each BSs to solve this problem. However, they applied geometric analysis to the investigation of the HetNet to gain insights into the system design. They considered stochastic geometry and hybrid beamforming in the mmWave band to arrive at a manageable approximation of co-channel interference. This expression is possible to obtain the insights necessary to avoid the impact of interference co-channels. Numerical results evaluated the strength of the geometric analysis and showed that the proposed algorithm could boost system performance. However, the EE needs more attention and consideration.

4.4.3. Tera Hertz (THz)

In this section, we provide a summary of the THz frequency bands. We also highlight the exceptional characteristics of the THz frequency region. While the bands above the THz band have been extensively investigated, the THz band remains one of the least studied zones in the SA. In [138], the authors investigated the resource allocation problem in D2D-based underlay 6G HetNets in an uplink scenario. The purpose of this article is to enhance the available spectrum utilization. A decentralized resource allocation strategy based on deep reinforcement learning and federated learning is proposed to increase the network throughput and reduce power consumption while guaranteeing both cellular and D2D users' QoS. For a more realistic simulation of the dynamic network nature, they considered cellular and D2D users equally when allocating transmission resources under a decentralized paradigm and considered users' mobility inside the base station's coverage area. Simulations are performed to evaluate the suggested schemes' effectiveness in the 5G mm-wave and 6G THz scenarios and compared with the baseline methods. Simulation results demonstrate that the proposed approach effectively optimizes network performance in terms of power consumption and throughput. However, realistic mobility models need to be considered.

The authors proposed optimum resource allocation methods to optimize the effective capacity in the THz band over energy harvesting-based HetNets in the limited block length scenario for the delay and error-rate constrained QoS provisioning in [139]. They developed models of energy harvesting-based THz-band nano-communication systems within the finite block length range. Afterward, they used the finite block length coding method to analyze the interference, channel dispersion functions, and channel capacity in the THz-band. In order to support massive ultra-reliable low latency communications over finite block length coding energy harvesting based HetNets, they developed and tackled the effective capacity maximization problem. Attenuation is often attributed to the transmission medium's spreading loss and shadow-fading properties. Detailed simulation results are provided to verify and assess their proposed THz band schemes over HetNets. Nevertheless, the network energy consumption needs more consideration and investigation.

In [140], the authors investigated the waveform design for ultra-broadband combined radar sensing and communication systems operating in the mmWave and THz bands. For target sensing, they presented a novel Multi-Sub band Quasi-Perfect (MS-QP) sequence comprised of several perfect subsequences on various sub-bands; this allows for precise target range and velocity estimates with just a cost-effectively low rate for sequence detection. In addition, each perfect subsequence's root index is created to minimize the effect of high Doppler shift on radar detection. Lastly, a data-embedded MS-QP (DE-MS-QP) waveform is built by extending the MS-QP sequence in the time domain, which creates null frequency points on each sub-band for data transmission. The suggested DE-MS-QP waveform, which inherits all the benefits from MS-QP sequences, allows for simultaneous interference-free sensing and communication, unlike the co-existence-based joint radar sensing and communication system in the time-domain duplex (TDD) approach. In the simulations, the suggested waveforms were numerically shown to be better than existing methods in terms of communication and sensing performance, implementation cost, and flexibility of spectrum allocation between the functions. Nonetheless, imperfect channel state information needs to be investigated.

In [141], they investigated the spectrum allocation for THz band communication systems in HetNets while considering THz channels' frequency and distance dependence. They investigated multi-band-based spectrum allocation with adaptive sub-band bandwidth by dividing the desired spectrum into subbands with uneven bandwidths. Furthermore, they evaluated the influence of sub-band assignment on multi-connectivity-enabled THz communication systems, which allow users to associate and interact with several access points concurrently. To determine sub-band bandwidth, sub-band assignment, and optimum transmit power, they formulated resource allocation problems with a major emphasis on spectrum allocation. Moreover, they provided appropriate approximations and transformations for solving the stated issues analytically and developed iterative algorithms using the successive convex approximation approach. The results of simulations demonstrated that a large increase in throughput could be obtained by enabling and optimizing adaptive sub-band bandwidth compared to adopting equal sub-band bandwidth, with the throughput increase being most noticeable when the power budget restriction is more severe. They further demonstrated that the proposed approach outperforms the traditional sub-band assignment strategies, with the greatest performance improvement seen when allocating spectrum based on the average molecular absorption coefficient. However, the use of adaptive sub-band bandwidth is limited to situations in which the sub-bands have a relatively narrow bandwidth. They investigated the problem of resource allocation in THz downlink networks to optimize the system's spectral efficiency while simultaneously fulfilling users' data rate needs. Based on the indoor Terahertz channel model, an optimization issue to maximize SE is proposed in [142]. In order to tackle the optimization problem, it is first divided into two sub-problems, PA and sub-band allocation. First, bub-bands are distributed using the long user central window principle and the bipartite graph matching approach. Second, using an iterative procedure, the power is optimized via the sequential quadratic programming (SQP) approach. When compared to other conventional schemes, simulation results illustrated that the proposed algorithm achieved greater system spectrum efficiency. Nevertheless, the proposed THz system is limited to a small number of users.

4.4.4. Open Issues and Proposed Solutions

To meet the stringent requirements of modulating THz signals, novel schemes that can provide spectral efficiency of at least 14 bits/s/Hz are essential. However, this is not possible with current modulation techniques, though research into this area is recommended. The development of THz transceivers and power amplifiers for frequencies between 500 and 750 GHz presents a significant challenge for the industry. However, redesigning antennas to accommodate increasingly dense arrays is necessary because of the shortness of these radio waves. A system that operates at mmWave or THz frequencies is more efficient than in the sub-6 GHz networks, which makes it a perfect field for the EE of future 6G networks. The consumption factor theory provides a power trade-off metric for communication systems. This spectrum method is necessary to avoid interference between new THz-operating systems and established satellite communication systems. Finally, the cooperation between different bands (tradition band, mmWave, and THz) has to be modeled in the best scenario to mitigate the interference and increase the SE.

5. Research Challenges and Future Directions

5.1. New Network Scenarios

Both the terrestrial mobile system and the mobile satellite system were two-dimensional network designs in the past. Each of these systems was independent of the other. With 6G, there is an ability to seamlessly communicate over shorter distances via direct connections to nearby devices, medium orbit and low orbit satellite mobile communications, and terrestrial wireless mobile communications [143]. Furthermore, 6G also includes new computation, navigation, and sensing technology. Consequently, 6G will develop a new three-dimensional (3D) core network architecture capable of integrating these technologies and providing ubiquitous worldwide coverage of high-speed mobile communications through the use of intelligent mobility management and control techniques [144]. A number of obstacles must be overcome before this 3D core network design can be made widely accessible, even though it has the potential to overcome conventional coverage constraints and ultimately create extraordinary universal coverage. Consequently, developing and implementing resource management and optimization methods regarding the routing protocol, mobility support, and multiple access is crucial. A redesigned network architecture is required for scheduling.

Various techniques have been suggested in recent years, such as carrier aggregation, mmWaves, intelligent reflecting surfaces, and Terahertz. New HetNets may emerge from combining these methods with HetNets, adding complexity to the RA problems. The predictable direction of HetNet development in 6G will solve this issue by combining the upcoming technology with HetNets [145]. For instance, an intelligent reflecting surface-aided HetNet may increase capacity while decreasing energy usage. However, finding a solution to the issue is difficult because of the linked transmit power and the phase shift that intelligent reflecting surface causes. An essential research objective is figuring out how to create a network model with a low level of complexity and a high degree of adaptability, with the end goal of achieving even greater gains in network performance.

5.2. Energy Harvesting

The total energy that is consumed by a network will ultimately decide how much it will cost its operators to set up the network. Consequently, it is essential to manage the EE of a network at the optimum level to fulfill a user's QoS and QoE requirements. The use of renewable energy sources for both MBSs and SBSs has the potential to lower the total power consumption of the HetNet, and it is anticipated that 6G will make more use of green technologies [146]. SBSs and MBSs should be able to generate their own power from the surrounding environment. Investigating the possibility of BSs working together to build a network with increased EE is yet another area of research.

The use of collaborative task execution strategies allows for a reduction in the total energy that mobile applications in a HetNet consume. In this approach, exploring the tradeoff between the application's performance and energy consumption is vital while simultaneously implementing a power allocation and saving mode on mobile devices [147]. Nevertheless, in order to further improve energy efficiency and prevent inter-cell interference, a coordinated BS system is necessary. This plan calls for BSs to share transmission cycles with each other. In order to enhance the functionality of ultra-dense HetNets in terms of energy efficiency, considerable research must be conducted on the use of energy harvesting from renewable energy sources. During periods of low traffic, a significant number of BSs can be underutilized since they cater to relatively few users while still using a considerable amount of power. As a result, it is essential to figure out research efficient BS switching-off techniques to decrease the energy used during periods of low traffic [148]. In energy efficiency, a system that runs in THz and mmWave frequencies is superior to networks that operate at sub-6 GHz regarding future 6G networks and beyond. The theory of consumption factors supports this idea by providing a measurement for the power-to-information exchange in each communication system.

5.3. Multiple Cell Association

Network distribution, load balancing, optimization metrics, and traffic models are all crucial to the success of user association schemes in HetNets. As a newer approach, multicell user association allows users to associate with numerous SBSs simultaneously, increasing their potential for both data throughput and system efficiency. Hence, more study into multicell association methods is required. Classifying users before and then associating them with the MBS or SBS to increase the efficacy of UA is another exciting study field [149]. Joint optimization with additional characteristics such as interference minimization, load distribution, and fairness are another research area where user association techniques may be improved.

Implementing and conducting field testing of the suggested methods is crucial for determining their viability in real-world contexts. The appropriate technique may be used to implement the UA scheme. The field testing results also provide light on the real performance of HetNet in real-world applications and the actual performance improvement that a user may obtain by using coordinated multipoint transmission based on HetNet [150]. Moreover, in the case of actual situations where the network characteristics are unknown and alter over time, UA strategies and machine learning methods for online learning-based policies might be explored. Furthermore, real-world experiments should be used to prove the effectiveness of the queue-aware resource allocation strategy with hybrid coordinated multipoint under fronthaul constraints. Based on those mentioned above, further work is needed to construct experimental prototypes and real-world measurement-based analyses to verify the results of most theoretical investigations.

5.4. Resource Allocation Complexity

In order to allocate resources effectively and in a manner that is suitable for implementation, attention must be taken to properly manage the computational complexity of resource allocation [147,151]. Most of the approaches, however, have considerable computational and implementational complexity, which extends the processing time and indirectly raises the cost of deployment. More cautious approaches with reduced complexity and quick algorithms are needed to prevent a negative impact on performance [152]. These methods may speed up computation while decreasing complexity; however, the complexity of the underlying algorithm was not evaluated. Therefore, measuring algorithm complexity to ascertain implementation ability is an exciting future study subject. Joint clustering with resource allocation and coordinated multipoint-enabled HetNets are two examples of approaches that have been studied to decrease overhead signals, which are a key cause of the network's implementational complexity. In order to minimize the overhead and computational complexity of potential 6G HetNets, prospective radio RM can use computational intelligence approaches.

5.5. Spectrum Bands

Due to its unique propagation properties, Terahertz systems will replace current ultrahigh frequency networks in future communications. Massive amounts of spectrum in the mmWave and Terahertz ranges (300 GHz to 3 THz) will be used in 6G networks and beyond to support applications requiring 100 Gbps or more [153]. Nevertheless, paradigm changes in operating these systems are required to make use of these frequency ranges since the properties of these signals are substantially different from standard ultrahigh frequency communications. The attenuation caused by the atmosphere is more severe at higher frequencies (over 800 GHz) due to their physical properties. Nonetheless, narrow beams and directional antennas can compensate. Eavesdropping on communications may be avoided, and secure communication is feasible [154]. However, a greater study of THz signals is required in transceiver designs and the physical layer to provide a viable component. To meet the demanding data rate requirements of THz signals, new modulation techniques are needed that can provide spectral efficiency of at least 14 bits/s/Hz. However, this is not possible with current modulation methods, so additional research into this field is required [155]. To ensure the long-term viability of the spectrum utilization plan, regulatory authorities such as ETSI and ITU are hard at work on the THz spectrum strategy. A spectrum policy that prioritizes their safety and efficiency is needed to keep satellites and other space-based communication systems from being disrupted by new devices operating in the THz spectrum. Lastly, because additional applications employing THz signals may be accessible in the future, it is important to thoroughly investigate the effects of radiation from THz broadcasts on human health.

5.6. Communication Security

Since there are numerous possible risks from the neighboring RF frequencies, such as pseudo-BSs and eavesdroppers, figuring out how to enhance communication security is crucial for the next generation of HetNets. Consideration of secure communication in advance RA problem models might make current RA algorithms useless [156]. Therefore, a study of communication security in HetNets is essential.

Among the various 6G applications, human-centric communications stand out as the most crucial. Therefore, 6G networks must prioritize secrecy, privacy, and security. The physical security of a 6G network cannot be ensured using the same approaches that have been used up to this point in regulation and privacy and security procedures. Security and secrecy in 5G networks are provided by accepted encryption methods based on the Rivest–Shamir–Adleman (RSA) public-key cryptosystems. Nonetheless, big data and artificial intelligence have made RSA cryptosystems insecure [157]. Therefore, a novel physical-layer privacy approach must be created for future 6G communication based on big data and AI. The 6G standard requires the use of a physical-layer security architecture and encrypted interactions with upper layers. Solutions for providing security in 6G networks include physical security technologies and the distribution of quantum keys using visible light communication (VLC) [158]. Because of the vast growth of edge and cloud infrastructures, it is anticipated that large-scale quantum computing will expand, which might raise asymmetric cryptography's study interest in this field. Network virtualization and software-defined networking might greatly benefit from using machine learning in automated security in order to identify better and prevent attacks.

5.7. Mobility Management

A critical component of mobility is a reliable and constant connection, which may be achieved using a variety of wireless communication methods [159]. Based on user-centric or network operator needs, utility functions and efficient algorithms should be designed with reduced complexity while mobile call patterns became closely correlated with connectivity patterns in the service area of the same BS at the same time, HetNet optimization should integrate user mobility data to improve performance in the context of large-scale user mobility [160]. An interesting area for further study is the development of mobility-aware adaptive approaches for the efficient optimization of HetNet system parameters, as well as the investigation of acceptable mobility models for various traffics (human, machine). In order to make HetNets more compatible with 6G NR networks, future research may combine NR and HetNet technologies [161]. HetNet might benefit from the introduction of new dual-connectivity processes and innovative vertical handover methods to enhance global network coverage, seamless mobility, and service continuity. To further facilitate changeover and paging operations, solutions for user geolocation are needed to identify the belonging beam, the next-to-switch beam, and the beam belonging time.

5.8. Latency Minimization

As the number of BSs increases, the possibility of transmission delay increases. Real-time processing capabilities of suggested methods may be significantly assisted by understanding the effect of transmission and scheduling delays. Further research is required in this area to analyze the theoretical implications of delay-sensitive traffic for hybrid coordinated multipoint in a HetNet. The performance-delay tradeoff due to coding across several fades should also be investigated. Offloading tasks and resources to the edge of the network using appropriate edge computing and proactive caching technologies is an attractive approach to reducing network latency in a HetNet [162]. Furthermore, collaborative user processing may reap the benefits of the Bs processing and the user processing, allowing for the real-time operation of delay-sensitive applications while also managing the enormous volume of data at the HetNet.

One of the biggest obstacles for mission-critical communications is the propagation delay, which has a major effect on the system performance in HetNet communications. The time it takes for a signal to travel from a BS to a user is known as the propagation delay. In addition, while deciding on transmission settings, the propagation delay must be considered. As the user radio channel in HetNet communications is subject to fast oscillations over time, the user may be unable to decode the sent data or may experience an undesirable QoS after the propagation time has gone [163]. Imperfect channel estimation over cellular networks has been the subject of numerous recent publications. The effects of these variables on the user channel and strategies for dealing with sudden changes in the channel by taking propagation delay into account may need to be explored in future studies to guarantee uninterrupted service.

5.9. Hardware Constraints

Many kinds of communication systems, including frequency bands, network topologies, and service delivery, will need to work together to implement 6G [164]. Hardware configurations for access points and mobile terminals will also vary greatly. The transition from 5G to 6G will include an update to the massive MIMO technology, which might need a more intricate network design. This adds another layer of complexity to the design of the underlying communication protocol and algorithms. However, AI and machine learning will be incorporated into communication [165]. Furthermore, many forms of communication devices have diverse structural designs. Hardware implementation difficulties might also arise from using unsupervised and reinforcement learning [166]. As a result, bringing together disparate forms of communication into a unified system will be difficult. There is active research on power amplifiers with a frequency threshold of 500 GHz to 750 GHz, and developing future transceivers that can function in the THz range is a key problem for the industry [167]. Nonetheless, redesigning antennas to accommodate extraordinarily dense arrays is necessary because of the shortwave lengths involved.

5.10. Interference Management

Since spectrum resources are limited and interference might occur, it is crucial to effectively manage the 6G spectra, which requires new approaches to spectrum management and sharing [168]. Maximizing resource utilization while maintaining or improving the quality of service requires effective spectrum management. Issues such as spectrum sharing and managing spectrum mechanisms in heterogeneous networks that synchronize broadcasts on the same frequency must be investigated in depth for 6G [169]. Additionally, researchers must look at how common interference cancellation techniques, including parallel interference cancellation and consecutive interference cancellation, may be used to eliminate the interference.

6. Conclusions

This paper has provided a comprehensive survey of RMs in advanced HetNets. A detailed evaluation of the current resource management strategies for HetNets is introduced. By focusing on PA, US, MS, and SA, this article addresses research gaps by analyzing recent work in these areas of RM. Methods, criteria, approaches, strategies, and architectures organize the presented RM aspects for each network scenario. Each section includes a summary and review of the relevant literature, followed by an investigation of the benefits and limitations of the current methods. This survey well-defined the associated challenges and future research that need in-depth exploration. Furthermore, the efficient methods in HetNets to overcome the difficulties of big wireless data and intelligent communications are presented. This survey aims to encourage more researchers into this area, as the RM in HetNets will play an essential role in the 6G communication for developing a seamless connection, high system throughput, reduced latency, massive connectivity, etc.

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