symmetry

MDPI

Article

Joint Optimization Scheme of User Association and Channel Allocation in 6G HetNets

Hayder Faeq Alhashimi, Mhd Nour Hindia, Kaharudin Dimyati *, Effariza Binti Hanafi and Tengku Faiz Tengku Mohmed Noor Izam

Centre of Advanced Communication, Research and Innovation (ACRI), Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia; s2002239@siswa.um.edu.my (H.F.A.); nourhindia@um.edu.my (M.N.H.); effarizahanafi@um.edu.my (E.B.H.); tengkufaiz@um.edu.my (T.F.T.M.N.I.)

* Correspondence: kaharudin@um.edu.my

Abstract: The sixth-generation (6G) wireless cellular network integrates several wireless bands and modes with the objectives of improving quality of service (QoS) and increasing network connectivity. The 6G environment includes asymmetrical heterogeneous networks (HetNets) with the intention of making effective use of the available frequencies. However, selecting a suitable gNB and a communication channel that works for users in the network is an enormous challenge in 6G HetNets. This paper investigates a joint user association (UA) and channel allocation (CA) problem in two-tier HetNets by considering the downlink scenario to improve QoS. Our study presents an innovative scheme for user association and channel allocation, wherein the user can be connected to either the macro base station (MBS) or a possible small base station (SBS) in a direct or relay-assisted link. Furthermore, the proposed scheme identifies the optimal channel to be allocated to each user so that the overall network QoS can be maximized. A symmetric matching game-based user association is proposed to find the optimal association for users. Moreover, a modified auction game is applied to allocate the optimal channel by considering the quota of each gNB. Regarding connection probability, throughput, energy efficiency (EE), and spectrum efficiency (SE), the simulation results show that the proposed approach performs well over the state-of-the-art techniques.

Keywords: 6G; quality of service; heterogeneous networks; user association; channel allocation; sum-weighted strategy; matching game; auctions game

Citation: Alhashimi, H.F.; Hindia, M.N.; Dimyati, K.; Hanafi, E.B.; Izam, T.F.T.M.N. Joint Optimization Scheme of User Association and Channel Allocation in 6G HetNets. *Symmetry* **2023**, *15*, 1673. https://doi.org/10.3390/sym15091673

Academic Editors: Razvan Bocu, Sabin Tabirca, Daniel C. Doolanand and Sergei D. Odintsov

Received: 24 June 2023
Revised: 18 July 2023
Accepted: 26 July 2023
Published: 30 August 2023

1. Introduction

The growing demand for ultra-low-latency wireless connections is being driven by the proliferation of smart devices, including smartphones, wearable devices, and connected automobiles. Higher bandwidth, reduced latency, and more spectrum resources are just a few of the enormous challenges that the 5G and beyond fifth generation (B5G) network would have to overcome [1,2]. One of the most distinctive features of the next generation of cellular networks is the ultra-dense heterogeneous networks, which allow for the deployment of symmetric small base stations with low cost and low power consumption in hotspots and substantially boost the system capacity to meet the growing needs of wireless networks [3–5].

However, accommodating a wide variety of user equipment (UE) requires seamless integration of macro and small cells, which presents several issues because BSs will vary in transmission power, data rate abilities, and coverage area. Thus, it is challenging to design an appropriate user-base station association method for 6G HetNets. Such a suitable method must verify the QoS for each user's equipment and guarantee fairness among UE and base stations (BSs) [6]. Following the established understanding of service quality outlined in ITU-T E.800, QoS should encompass all desired performance levels and the service's capacity utilization to address both explicit and implicit security requirements of the user [7]. Moreover, determining the overall QoS is essential in heterogeneous networks as it enables service differentiation, facilitates traffic engineering, and enables resource optimization. By considering the diverse capabilities and limitations of network segments, operators can deliver better user experiences, efficiently utilize available resources, and effectively manage network traffic.

Maximum signal-to-interference-and-noise ratio (SINR)-based UE association algorithms may not ensure a fair load distribution, as they tend to allocate most UEs to high-power MBSs, which can result in low-power BSs being starved and undermine the advantages of having multiple tiers. As user association is crucial to enhancing the network's performance, research on user association schemes in HetNets has recently received attention as an integral aspect of radio resource allocation [8,9].

Furthermore, the cellular architecture of 6G HetNets, where SBSs are underlaid the MBS, is anticipated to boost overall cell throughput in addition to expanding coverage and capacity. Efficient resource allocation is one of the core research issues for HetNets since uncoordinated spectrum allocation for small cells has the potential to cause significant interference with the other receivers. Centralized solutions are computationally time-consuming and include substantial signaling overhead because of the nature of the resource allocation issue in multi-tier cellular networks. Consequently, it is preferable to have network nodes, such as SBSs, allocate resources autonomously or with minimum support from MBSs, using a distributed or semi-distributed method with low signaling overhead [10,11].

2. Related Work

Extensive research has been conducted on HetNet-based user association and channel allocation in B5G wireless networks. There are obstacles in the way of successful transmission of high-capacity data over the existing cellular network in terms of speed, quality of service, latency, and effective handover and mobility management [12]. Numerous difficulties connected to the scalability of QoS indicators have emerged as researchers attempt to solve the issue of establishing overall QoS in general telecommunication networks [13]. Furthermore, in [14], the authors address the issue of QoS-aware resource management in 5G and 6G networks. Recent works have focused on user association based on SINR while improving QoS [15–20]. In [15], a deep learning approach that is based on ultra-dense networks was presented in order to effectively associate users with an MBS or SBS in a downlink scenario. In supervised learning, the goal of finding the best labeling solution can frequently be achieved with the use of a cross-entropy algorithm. Nevertheless, it is essential to maintain power management and properly distribute the resources that need to be taken into account in order to enhance the efficiency of the HetNet. User association and channel allocation in HetNets, which deploy gNBs using both mmWave and sub-6GHz technologies, are addressed in [16]. The user association discussed two distinct methodologies, namely a centralized method that employed convex optimization methodologies and a decentralized method that was introduced as a non-cooperative (NC) game. The unique Nash equilibrium can be reached with the help of a fast-convergent best response technique. However, there is no consideration given to the energy efficiency of the network.

In [17], the UA problem that consists of an MBS with relays operating in the microwave band and the UA problem that consists of an SBS with device-to-device (D2D) running in the mmWave band are examined. The performance of UA methods based on downlink-uplink decoupled access is compared to the performance of conventional downlink-uplink coupled access by formulating UA optimization issues. Nevertheless, greater consideration and attention must be given to EE. The problem of user association in millimeter-wave HetNets is explored in [18], which explores the usage of several radio access methods. They presented a unique and decentralized approach to managing network dynamics using deep reinforcement learning. However, resource allocation needs more attention and consideration. In [19], the authors adopted a unique approach by utilizing second-order statistics of user data. The aforementioned statistics offer an additional, precise depiction of fluctuations in user rates. A novel approach was proposed for UA, incorporating the suitable BS by incorporating the standard deviation of the overall network load. Furthermore, novel expressions were developed to evaluate the system's performance in terms of EE and coverage probability. Nonetheless, the approach does not directly consider the partitioning of frequency bands.

In [20], the Nash equilibrium for game theory related to individual device pairs is determined by the authors in order to identify the optimal associations in D2D HetNets. They showcased the ability to establish the most favorable D2D connections between any two devices, ensuring the highest achievable QoS. Nonetheless, to facilitate devices in making optimal links, it is essential to take into account a distributed open radio access network controller. The conventional methods of UA that are dependent on SINR demonstrate an unfair advantage to the high-power MBS and result in a lack of resources for the low-power SBS.

Several recent studies have been investigated about user association based on rate while improving QoS [21–26]. In [21], a novel scheme for joint user association and channel allocation has been developed to achieve the objective of ultra-low latency. The scheme under consideration takes into account the impact of multiple-access interference and ensures a certain level of delay probability. Nevertheless, the access points employed elevated transmission power to provide services to the users. Therefore, it is essential that EE receives more attention and consideration. In [22], the researchers employed an improved clustering methodology that integrates the max-min distance clustering algorithm and the K-means clustering algorithm to ascertain both the cluster center and the overall quantity of clusters. The use of orthogonal resource allocation within the same cluster thereby minimizes intra-cluster interference. Ultimately, the combined data rate-based user association and resource allocation algorithm was introduced as a possible solution. Nevertheless, the trade-off between EE and SE has not been taken into account. In [23], the authors present an assessment of a non-cooperative game theory-based approach for joint power allocation and user association while taking into account QoS constraints. The approach reliably guarantees throughput stability across backhaul and access links, increased total rates for all UE, and dynamic UE association. However, there should be more attention and effort put into frequency allocation.

In [24], a collaborative optimization framework for a 5G UA HetNet was presented. To maximize thenetwork bandwidth, they organized the user association strategy as a mixed integer linear program. However, power consumption is not considered. The authors developed a new strategy that makes use of machine learning [25]. The UA scenario was developed utilizing a graphical model that incorporates the spatial distribution of users and the mmWave architecture in HetNets. The authors presented a new technique for extracting features that can effectively gather optimal user information, similar to the inference procedures employed in the graphical theory method. However, the effectiveness of the work is contingent upon the utilization of optimal UA strategies for gathering training samples, a time consumption process. The authors in [26] have proposed a user-centric association algorithm for HetNets in a downlink scenario. The algorithm is optimized for the maximum achievable value of the predicted long-term rate, which is subject to variation based on the specific multiantenna transmission methodology employed by the data communication system. Nonetheless, as the number of users grows, the interference becomes intolerable, leading to a drop in data rates.

Furthermore, there have been several recent studies about channel allocation based on rate while improving SE by properly allocating the best channel to the users. The authors in [27] constructed a utility-based prioritizing of the spectrum allocation (SA) algorithm to improve QoS for both its core users and its cell edge users. The utilization of Voronoi tessellation for cell user categorization reduces the SINR during instances of fluctuation. The implementation of the utility-based SA algorithm resulted in improved QoS for real-time applications with guaranteed delay-bound requirements, which were being managed by users located at the edge of the cellular network. Nevertheless, the BS became overloaded because of the centralized SA algorithm. In [28], the optimization problem of resource allocation was addressed by the authors through a scheme based on a two-step genetic algorithm. The initial stage involves the utilization of a normal genetic algorithm to address the SE component of the power allocation matrix for the resource blocks. The next procedure involves utilizing the newly obtained SA matrix in conjunction with the non-dominated sorting genetic algorithm for the purpose of assessing the power allocation matrix. However, the aspect of user association requires further attention and assessment.

In [29], the proposed architecture, that is subjected to a cross-layer optimization problem, aimed to optimize EE through the balancing of SA and mode selection. The problem has been successfully resolved by addressing and resolving two distinct subproblems in a sequential manner. The initial stage of the resource allocation problem revealed its non-convex nature, prompting the introduction of four stochastic algorithm-based solutions that incorporate a predetermined route selection. The second aspect of the routing problem was addressed by formulating it as a linear programming problem and subsequently utilizing an optimization toolbox to solve it. Notably, the resource allocation was maintained at a constant level throughout the process. However, the balance between SE and EE has not been taken into consideration. In [30], the authors presented two methodologies aimed at improving the efficiency of spectrum utilization. The primary methodology referred as static licensed SA, aims to optimize spectrum utilization by distributing the 28 GHz spectrum uniformly among all BSs. The second methodology, known as flexible licensed SA, aims to enhance spectrum utilization by allocating varying amounts of spectrum to each BS. Mathematical models are offered for both methodologies, enabling the computation of metrics such as SE, EE, and average capacity. However, it is imperative to take into account the network capacity.

In contrast, a number of recent research papers relating to user association have incorporated matching theory as a result of its relatively low level of complexity [31–35]. In [31], the authors presented two frameworks that use auction games and matching theory to facilitate the efficient admission of secondary users into the HetNet. In the next step, which is a repeated modified English auction, these base stations win access to the primary spectrum that is currently accessible on behalf of their respective UAs. To allocate secondary users to multiple SBSs that are randomly distributed, a many-to-one college admissions matching game is employed. Nonetheless, the system's energy efficiency under the suggested approach has not been taken into account. The study presented in [32] investigated a matching game for user association and identified a solution that is close to optimal. In [33], the authors presented a pair of many-to-one matching games aimed to achieve optimal association for users in both downlink and uplink scenarios. In [34], the authors propose algorithms for resource allocation in 5G HetNets that are based on stable matching and support many-to-many relationships. The objective of these algorithms is to maximize the revenue of service providers. Each service provider or resource has the freedom to construct its own preference list based on its utility function. Nevertheless, only a single framework has been taken into account in the proposed approach. In [35], the authors suggest a many-to-many matching game in order to provide the highest possible degree of dependability for the greatest number of users in multi-user and multi-cellular networks.

Moreover, the use of auction games to distribute spectrum in wireless communication networks has additionally sparked much discussion. In [36], the authors developed a multi-winner technique for allocating spectrum that used a single-sided, centralized sealed-bid auction in which secondary users made their bids in private. The auctioneer then created pricing and winning selection algorithms. In [37], a multi-winner double auction process was implemented, with secondary users placing bids and primary users asking for higher prices. Based on the bids and requests, the auctioneer sets the final selling price. In combinational auctions, secondary users may submit a bid for a specific set of channels that most effectively meet their needs. Primary owners will either approve the requests or reject them. In [38], to acquire a channel from a massive multiple-input, multiple-output

(MIMO) MBS, cognitive femtocells were seen as secondary base stations, and an auction game was used to choose the winner. In [39], an auction game is employed to optimize the attainable data rate by assigning resource blocks and power levels to underlay users. In [40], the advantages of the proposed overall model normalization techniques towards adequate prediction and presentation of QoE in conjunction with QoS are presented in the overall telecommunication systems. In [41], the authors focus on the network slicing issue, which involves allocating network resources to accommodate different QoS needs while mapping various specific virtual network services to a common shared infrastructure.

Nevertheless, to the best of our knowledge, there is limited research that has explored the distributed channel reuse between an MBS and SBSs in two-tier HetNets. None of the aforementioned literature used the sum-weighted strategy as a utility function for matching and auction games. In our presented scheme, the system is composed of MBSs, SBSs, and users operating in the terahertz band (95 GHz). The recent literature on distributed resource allocation considered reusing the resources once by the SBSs. In this paper, we propose a user association algorithm based on matching theory and a channel allocation algorithm based on modified auctions based on the sum-weighted strategy. In the modified auction game, multiple reuses of channel resources are considered. The present study involves the modification of the gNB's utility within the context of the matching game, with the aim of analyzing the impact of the matching stage on both EE and SE. Furthermore, the auction presented in reference [31] has been modified with the aim of enhancing channel utilization and improving user satisfaction.

3. Contribution and Motivation

Motivated by the previously mentioned potential advantages of utilizing matching and auction games, this paper investigates the terahertz band (94 GHz) using matching and auction games in 6G HetNets for QoS improvement. The 6G HetNet differentiates itself from existing HetNet studies by leveraging new spectrum resources, embracing ultra-dense deployments, promoting hyper-connectivity, and facilitating device cooperation. These differentiating factors contribute to the 6G HetNet as a transformative and revolutionary wireless network paradigm, catering to the diverse needs of industries and users. The current research addresses the problem of user association with multiple gNBs as well as the allocation of MBSs and SBSs in order to meet the needs of their respective associated users. A novel scheme is proposed to solve the joint user association and channel allocation problem, where the channel allocation phase is dependent on the outcomes of user associations with the gNBs. The scheme takes into account the number of users assigned to each gNB and their respective requirements, which determines the number of channels required by each gNB.

The main contributions of this study can be expressed as follows:

1. We examine a joint optimization problem involving user association and a decentralized two-tier channel allocation scheme. The proposed optimization scheme takes into account the distinct characteristics and demands of the two tiers, namely MBS and SBSs, within 6G HetNets. Additionally, the user has the capability to establish a connection with either the MBS or a potential SBS through a direct or relay-assisted link. It is assumed that an MBS has a higher transmission power and can accommodate a larger user capacity. The SBS endeavors to achieve the rate of the associated small base station user (SU) by utilizing the underlay scheme for the purpose of accessing the symmetry MBS channels, thereby enhancing the QoS.
2. We present a quick convergence many-to-many matching game that considers a two-tier framework in the downlink association of users to a number of gNBs. Based on the user's proposal to the SBS, the SBS will guarantee the user an appropriate data rate. The utility function of the SBSs, which considers the substantial interference experienced by the users, is evaluated through a sum-weighted strategy that depends on the EE and SE.

3. A modified auction game is proposed for the allocation of multi-tier channels, wherein a predetermined number of macro channels are allocated for each SBS. The utility function is a linear combination of the EE and SE with appropriate weights assigned to each, encompassing both the MBS and SBSs.

Simulations show the effectiveness of the sum-weighted strategy based on the EE and SE after the matching and the modified auction games. The simulations support the idea that modified auctions yield a high degree of satisfaction with respect to gNBs requirements as well as an overall improvement in the system throughput, provided that the number of available channels is sufficiently large. In cases where the number of channels is relatively small, modified auctions result in fullychannel occupation. A comparative analysis is performed between the repeated auction approach presented [31] and the proposed scheme, with the aim of evaluating the efficiency of the latter in meeting the QoS demands of gNBs as well as assessing its impact on channel occupancy and connection probability. A many-to-many matching game is employed to address the user association problem based on the sum-weighted strategy. This study shows the effectiveness of matching games, modified auctions, and a maximum sum-weighted strategy. The modified auction game was successfully demonstrated to produce higher rates of connectivity in gNBs and more effective utilization of MBS channels. In addition, the use of modified auction procedure ensures an equitable distribution of workload between MBS and SBSs usage. This is achieved through the implementation of channel-specific pricing, which is not a feature of the matching game approach.

The subsequent sections of our paper are structured in the following manner: Section 4 of the document outlines the system and channel models, followed by the problem formulation. In Section 5, the proposed user association and channel allocation are explained in detail. Section 6 shows the simulation results and discussion. The paper's conclusion is stated in Section 7.

4. System Model and Problem Formulation

4.1. System Model

In this paper, one MBS that is outfitted with M antennas and a number of SBSs make up the model of the 6G two-tier HetNet system that has been taken into consideration. Furthermore, a number of users (U) are present, and inactive users serve as relays (R) within its scope, as shown in Figure 1. An MBS has been assigned a set of macro base station users (MUs). We focus on model development in the context of the downlink scenario, wherein the utilization of orthogonal frequency-division multiple access (OFDMA) is taken into account. Consequently, a singular macro channel is allocated to every MU at any given time. Nevertheless, the proposed study has the potential to be expanded to accommodate multiple users within a single channel. Let N = (1, 2, . . ., N) be a set composed of positive integers, which denote the collection of SBSs. On the other hand, SUs are a set of users that are paired with any SBS. The set U = (1, 2, . . ., U) denotes a set of users that are randomly distributed, while the set R = (1, 2, . . ., R) represents a set of idle relays, and each user is to be matched with either an MBS or SBS. The quota (Q) denotes the maximum number of users that can be allocated to a single gNB, thereby limiting the number of users associated with it. It is assumed that the quotas of distinct base stations are non-identical. The paper considers the allocation of bandwidth resources, where the total bandwidth of the system is represented by the variable W and the bandwidth splits into a set K = (1, 2, . . ., K) of symmetrical sub-channels. Different types of propagation issues, such as pathloss and shadowing, might affect the wireless channels. It is posited that SBSs are linked to an MBS through a backhaul connection, which may be implemented through a wired medium such as fiber.

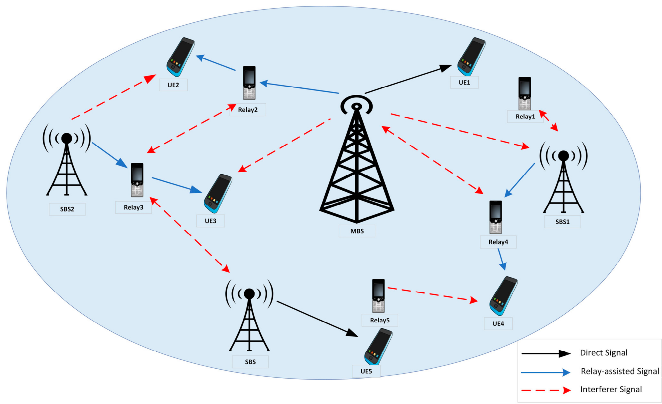

Figure 1. System model.

All of the users in the system are aware of their locations, as well as the EE and SE. Each user is supposed to be assigned to the gNB that offers them the maximum EE and SE. In the context of the time division multiple access (TDMA) mode, it can be observed that each gNB is responsible for serving its respective users in distinct time slots. It is notable that the number of slots allocated for each gNB corresponds to the number of users that are associated with it. A SBS's function is proposed as that of cognitive radio units, whereby they are involved in the sensing of the transmission of the MBS prior to the matching and auction games. This sensing activity is undertaken to enable the calculation of the EE and SE for all users before the matching process takes place. The power transmitted by the n-th SBS to downlink (DL) users is represented by P_n, which is a value within the range of [0, P_{maxN}]. Here, P_{maxN} refers to the maximum power that can be transmitted by each SBS. The abbreviations P_{maxM} and P_{maxR} represent the upper limit of power output for the MBS and each individual relay, respectively.

4.1.1. User Association

In the process of cell search and association, the gNB broadcasts reference signals that carry the cell identity at maximum power through a single-antenna port, employing an omnidirectional transmission approach [42]. In order to mitigate the handover occurrence, the user conducts a measurement of the received reference signal power while basically considering the impact of large-scale fading. The conventional user association approach involves the user's reception of reference signals from BSs in the surrounding area. Subsequently, the user connects to the gNB that meets their requirements [43]. Four association relationships are considered based on various gNBs. Let the set $\mathring{A}_{m,mu}(t)(m \in MBS,\ mu \in U)$ represent the association relationships between users and base stations at a given time slot t, with $\mathring{A}_{m,mu}(t) = 1$ and $\mathring{A}_{m,mu}(t) = 0$ otherwise. Likewise, the set $\mathring{A}_{m,r}(t)(\mathrm{m} \in \mathrm{MBS},\ \mathrm{r} \in \mathrm{R})$ denotes the relationships of the associations between relays and base stations if the r-th relay user associates with the m-th base station at time slot t; $\mathring{A}_{m,r}(t) = 1$ and $\mathring{A}_{m,r}(t) = 0$ otherwise. Furthermore, the set $\mathring{A}_{n,su}(t)(n \in \mathrm{SBSs},\ \mathrm{su} \in \mathrm{U})$ denotes the relationships of the user association if the su-th user associates with the n-th base station without relay at time slot t; $\mathring{A}_{n,su}(t) = 1$ and $\mathring{A}_{n,su}(t) = 0$ otherwise. Similarly, the set $\mathring{A}_{n,r}(t)(\mathrm{n} \in \mathrm{SBSs},\ \mathrm{r} \in \mathrm{R})$ represents the association relationships of users if the r-th user associates with the n-th base station at time slot t; $\mathring{A}_{n,r}(t) = 1$ and $\mathring{A}_{n,r}(t) = 0$ otherwise.

4.1.2. Channel Association

In the context of cellular communication, the spectrum allocation W is subdivided into K channels, with each user being restricted to accessing a single channel during a given time slot t. The binary channel allocation variable is defined as $v_{mu,k}(t)(mu \in U,\ k \in K)$ for the macro base station users, specifically, if the mu-th user occupies the k-th cellular channel at time slot t; $v_{mu,k}(t) = 1$, and $v_{mu,k}(t) = 0$ otherwise. Similarly, a binary channel allocation variable is defined as $v_{su,k}(t)(su \in U,\ k \in K)$ for the small base station users, specifically, if the su-th user occupies the k-th cellular channel at time slot t; $\nu_{su,k}(t) = 1$, and $\nu_{su,k}(t) = 0$ otherwise.

The channel model described above yields an expression for the SINR received by the m-th user in the k-th channel from the transmitter of the m-th MBS during time slot t.

$$\gamma_{mnk}^{mu} = \frac{(\mathring{A}_{m,mu}(t)p_m(t)g_{m,mu}(t) + \mathring{A}_{m,r}(t)p_r(t)g_{mu,r}(t))\nu_{mu,k}(t)}{\sum_{su\in U\setminus mu}(\mathring{A}_{n,mu}(t)p_n(t)g_{n,mu}(t) + \mathring{A}_{n,r}(t)p_r(t)g_{mu,\bar{r}}(t))\nu_{su,k}(t) + \delta} \tag{1}$$

where $p_m(t)$, $p_n(t)$, and $p_r(t)$ denote the transmission power of the m-th MBS, the n-th SBS, and the r-th relay in the k-th channel at time slot t, respectively. $g_{m,mu}(t)$ and $g_{mu,r}(t)$ denote the channel gain of the m-th MBS and the r-th relay to the receiver of the mu-th user in the k-th channel at time slot t, respectively. $g_{n,mu}(t)$ and $g_{mu,\bar{r}}(t)$ denote the interferer signal channel gain of the n-th SBS and the r-th relay to the receiver of the mu-th user in the k-th channel at time slot t, respectively. It should be noted that the gain of the channel between any two transmitters and receivers is composed of a pathloss that is dependent on the distance as well as shadowing. The variable δ represents the power of noise.

The SINR from the n-th SBS transmitter to the su-th user in the k-th channel at time slot t is calculated using the previously explained channel model as follows:

$$\gamma_{nmk}^{su} = \frac{(\mathring{A}_{n,su}(t)p_n(t)g_{n,su}(t) + \mathring{A}_{n,r}(t)p_r(t)g_{su,r}(t))\ \nu_{su,k}(t)}{\sum_{mu\in U\setminus su}(\mathring{A}_{m,mu}(t)p_m(t)g_{m,su}(t) + \mathring{A}_{m,r}(t)p_r(t)g_{su,\bar{r}}(t))\ \nu_{mu,k}(t) + \delta} \tag{2}$$

where $p_m(t)$, $p_n(t)$, and $p_r(t)$ denote the transmission power of the m-th MBS, the n-th SBS, and the r-th relay in the k-th channel at time slot t, respectively. $g_{n,su}(t)$ and $g_{su,r}(t)$ denote the channel gain of the n-th SBS and the r-th relay to the receiver of the su-th user in the k-th channel at time slot t, respectively. $g_{m,su}(t)$ and $g_{su,\bar{r}}(t)$ denote the interferer signal channel gain of the m-th MBS and the r-th relay to the receiver of the su-th user in the k-th channel at time slot t, respectively.

The attainable data rate for the transmission from the m-th MBS transmitter to the mu-th user in the k-th channel during time slot t can be represented as follows:

$$R_{mnk}^{mu} = W\log_2(1 + \gamma_{mnk}^{mu}) \tag{3}$$

The attainable data rate for the communication between the n-th SBS transmitter and the su-th user in the k-th channel during time slot t can be represented as:

$$R_{nmk}^{su} = W\log_2(1 + \gamma_{nmk}^{su}) \tag{4}$$

The EE of each user denotes the ratio of data transmitted to the energy expended per unit. The expression of the EE for the MU and SU can be provided as follows:

$$EE_{mu} = \frac{R_{mnk}^{mu}}{p_m + p_c} \tag{5}$$

$$EE_{su} = \frac{R_{nmk}^{su}}{p_n + p_c} \tag{6}$$

where p_c is the circuit's power consumption.

On the other hand, SE refers to the effective utilization of the available spectrum with respect to the attained data rate within a designated bandwidth, W. The SE for the MU and SU can be expressed as follows:

$$SE_{mu} = \frac{R_{mnk}^{mu}}{W} \tag{7}$$

$$SE_{su} = \frac{R_{nmk}^{su}}{W} \tag{8}$$

4.2. Problem Formulation

We present a mathematical formulation of the joint user association and channel allocation problem. Within the context of a two-tier HetNet, we investigate network utility for the downlink scenario. Conventional user association techniques typically rely on the max-SINR principle. However, it has been observed that this approach may not be suitable in scenarios where users with poor channel quality are unable to access radio resources. Therefore, in the current research, we have achieved a satisfactory balance between the EE and SE. The optimization of the aggregate throughput is a crucial aspect in the context of HetNets. The utilization of the sum-weighted strategy is considered appropriate for pairing the users with the gNB in a network utility, wherein the EE and SE are put through a weighted summation. By controlling the weights, it is possible to attain a committed equilibrium between the EE and SE that aligns with the system requirements. The proposed network utility function is given by:

$$\vartheta_u = \beta\, EE_u + (1-\beta)\, SE_u \tag{9}$$

where β is a partition factor that determines the effect of the EE and SE, where $\beta \in [0, 1]$.

In addition to the cellular MUs, there are numerous SUs present within the cell. The gNB will utilize a matching algorithm to determine the appropriate association for each user and subsequently allocate the corresponding channel resource based on the user association and the rate between the gNB and users. This allocation process will be optimized through the use of a modified auction algorithm, with the ultimate goal of enhancing system performance. In [16], the Shannon capacity formula below was used to determine the instantaneous data rates that can be achieved by the u-th user in a downlink scenario.

$$\max_{P,\vartheta,\mathring{A},\nu,} \sum_{t}^{m,n,k} R_{mnk}^{mu} + R_{nmk}^{su} \tag{10}$$

$$s.t.\quad \mathring{A}_{m,mu}(t), \mathring{A}_{m,r}(t),\ \mathring{A}_{n,su}(t), \mathring{A}_{n,r}(t) \ \in \{0,1\}, \qquad \forall m,\ \forall n,\ \forall mu,\ \forall su,\ \forall r \tag{10a}$$

$$\textstyle\sum_{m,n} \mathring{A}_{m,mu}(t) + \mathring{A}_{n,su}(t) = 1 \qquad mu, su\ \in U \tag{10b}$$

$$\textstyle\sum_{k\in K} \nu_{mu,k}(t) = 1 \qquad mu\ \in U \tag{10c}$$

$$\textstyle\sum_{k\in K} \nu_{su,k}(t) = 2 \qquad su\ \in U \tag{10d}$$

$$\textstyle\sum_{k\in K} \nu_{mu,k}(t) + \nu_{su,k}(t) \leq 3 \qquad \forall U \tag{10e}$$

$$0 \leq P_n\ \leq P_{max} \qquad \forall U,\ \forall K \tag{10f}$$

$$R_{mnk}^{mu}, R_{nmk}^{su} \geq R_{min} \qquad \forall mu,\ \forall su \tag{10g}$$

The main objective of this research is to collaboratively address the issues of user association and channel allocation with the goal of optimizing the overall network sum rate while observing specific limitations. Constraint (10a) denotes the relationship between the gNBs and the users in terms of association relationships. Constraint (10b) ensures that each user is restricted to establishing a connection with only one gNB within a given time slot. Constraints (10c) and (10d) ensure that each MU or SU accesses a distinct cellular channel. According to constraint (10e), the channel of a MU can be shared twice by a SU. Constraint (10f) restricts the range of SBS transmission power. The constraint (10g) delineates the QoS requirements of the users. In the following section, we intend to convert the optimization issue into a joint user association and channel allocation problem.

5. Proposed Joint UA and CA

The proposed scheme is based on the maximum sum-weighted utility in a coexisting network. The scheme clusters users to every gNB with/without relay existence and selects an appropriate channel to communicate. The proposed research introduces a two-phase framework that utilizes matching and auction games to optimize the aggregate data rate of wireless network users.

5.1. Matching Game-Based User Association

In order to facilitate user enrollment into the system, assigning them to a specific gNB that can effectively meet their needs while minimizing interference is necessary. Considering a finite number of gNBs relative to the number of users, allocating multiple users to a singular gNB is advisable. Nonetheless, it is notable that every gNB is constrained by a maximum threshold of users that it is able to serve, which is denoted by its quota Q. The Q depends on the user's location, with a maximum value (Q_{max}). The gNBs and users demonstrate distinct utility functions. The current research investigation employs a many-to-many matching game. Each user implies that it will receive a singular channel allocation and subsequently computes a utility function that is dependent upon both the EE and SE as follows:

$$\vartheta_{u,r} = \beta(EE_{m,u}, EE_{n,u}, EE_{m,r}, EE_{n,r}) + (1-\beta)(SE_{m,u}, SE_{n,u}, SE_{m,r}, SE_{n,r}) \tag{11}$$

where $\vartheta_{u,r}$ is the sum-weighted utility function of the users and relays. $EE_{m,u}$ and $EE_{n,u}$ are the energy efficiency of users that are in direct communication with the MBS and SBS, respectively. $EE_{m,r}$ and $EE_{n,r}$ are the energy efficiency of relays that are associated with the MBS and SBS, respectively. On the other hand, $SE_{m,u}$ and $SE_{n,u}$ are the spectrum efficiency of users that are in direct communication with the MBS and SBS, respectively. $SE_{m,r}$ and $SE_{n,r}$ are the spectrum efficiency of relays that are associated with the MBS and SBS, respectively.

The user association is conceptualized as a many-to-many matching problem, wherein a group of users is allocated to a singular gNB based on its quota. Each of the users exhibits varying utility levels with respect to different gNBs, which subsequently update their respective preferences as outlined before. The problem at hand has been addressed through the utilization of a stable matching algorithm, as proposed in [31].

Algorithm 1 outlines the scenario in which users submit proposals to the gNBs, and the gNBs make the determination of whether to accept or decline the stated proposals. A stable matching point that is optimal for gNBs can be achieved through a matching process that is oriented toward gNBs. The process of gNB-oriented matching commences with the creation of preference lists by gNBs, which are based on the utility functions of users. Then, gNBs extend proposals to their most favored users, who subsequently accept or decline the offers. The proposals put forth by a given gNB are dependent on its allocated quota, Q.

Algorithm 1 Matching user association algorithm

Input: $\vartheta_{u,r}$, and Q_{max}
Output: $\mathring{A}_{m,mu}$, $\mathring{A}_{n,su}$, $\mathring{A}_{m,r}$, and $\mathring{A}_{n,r}$

```
Initialization: initialize the proposing users set τ containing all unmatched users, and gNBs
sort the utilities in (11) in descending order to form the preference lists.
While τ ≠ ∅
for U ∈ τ do
   U proposes the first gNB in its reference list.
   if that gNB is matched to its quota number of users
   then
      gNB keeps the best-quoted users and rejects the worst users.
         if user u was chosen then
            Remove u from τ
            Return the worst user to U
            Update the associated matrices Å_{m,mu}, Å_{n,su}, Å_{m,r}, and Å_{n,r}
         end if
      else if that gNB is available then
         Remove u from τ and match it with that gNB
         Update the associated matrices Å_{m,mu}, Å_{n,su}, Å_{m,r}, and Å_{n,r}
      end if
end for
end while
```

5.2. Auction Game-Based Channel Allocation

The initial step in the framework involves matching the users to various cognitive gNBs. The outcome of this matching process can be represented using the sets $\mathring{A}_{m,mu}$, $\mathring{A}_{n,su}$, $\mathring{A}_{m,r}$, and $\mathring{A}_{n,r}$, which define the users associated with the gNBs in relay-assisted and direct scenarios. SBSs demonstrate determined channel utilization, irrespective of the existence of MBS communication. The proposed scheme involves using the maximum power level of the SBS transmission when the MBS transmission is present in order to protect the MBS transmission from undesirable interference. Similarly, the maximum power level of the MBS transmission is used to protect the SBS transmission from inappropriate interference. When applied to the MBS channels, the data rate of the SBS for providing service to the SU through channel k is given by:

$$\Theta_{nmk}^{su,\,\mathring{A}} = W \log_2\left(1 + \frac{\mathring{A}_{n,su}(t)p_{max}^{n}(t)g_{n,su}(t) + \mathring{A}_{n,r}(t)p_r(t)g_{su,r}(t)}{\sum_{mu\in U\setminus su}\mathring{A}_{m,mu}(t)p_{max}^{m}(t)g_{m,su}(t) + \mathring{A}_{m,r}(t)p_r(t)g_{su,\bar{r}}(t) + \delta}\right) \tag{12}$$

where p_{max}^{n} and p_{max}^{m} are the maximum power of SBSs and MBSs, respectively.

The EE and SE of each SBS user denote the ratio of data transmitted to the energy expended per unit and the effective utilization of the available spectrum with respect to the attained data rate within a designated bandwidth W, respectively. The expressions of the EE and SE for the SU can be provided as follows:

$$v_{su} = \frac{\Theta_{nmk}^{su,\mathring{A}}}{p_{max}^{n} + p_c} \tag{13}$$

$$\varsigma_{su} = \frac{\Theta_{nmk}^{su,\mathring{A}}}{W} \tag{14}$$

Each SBS user assumes that it will be allocated a single channel and subsequently formulates a utility function that is contingent upon both the EE and SE, as follows:

$$\vartheta_{u,r} = \beta\, v_{su} + (1-\beta)\, \varsigma_{su} \tag{15}$$

In the TDMA model, the utility function considers the aggregate number of SUs associated with each SBS by demonstrating it as an expression of the time slots. The data is then reported as a bit rate for each time slot. The utility function of SBSs, taking into account the MBS sub-channels, can be expressed as follows:

$$\psi_{k,n}^{SBS} = \frac{1}{S_n^{su}} max \vartheta_{u,r} \tag{16}$$

where S_n^{su} represents the availability of time slots, which is proportional to the number of users accessing a single SBS.

In order to mitigate the potential interference caused by the SBSs, the MBS data rate $\Theta_{k,n}^{MBS}$ is utilized. The formulation of the MBS is expressed as a function of the data rate, as stated below:

$$\Theta_{k,n}^{mu,\AA} = W \log_2\left(1 + \frac{\AA_{m,mu}(t) p_{Max}^m(t) g_{m,mu}(t) + \AA_{m,r}(t) p_r(t) g_{mu,r}(t)}{\sum_{mu \in U \setminus su} \AA_{n,su}(t) p_{Max}^n(t) g_{n,mu}(t) + \AA_{n,r}(t) p_r(t) g_{mu,\bar{r}}(t) + \delta}\right) \tag{17}$$

The EE and SE of each MBS user indicate the ratio of data transmitted to the energy expended per unit and the effective utilization of the available spectrum with respect to the attained data rate within a designated bandwidth W, respectively. The expressions of the EE and SE for the MU can be provided as follows:

$$v_{mu} = \frac{\Theta_{mnk}^{mu,\AA}}{p_{max}^m + p_c} \tag{18}$$

$$\varsigma_{mu} = \frac{\Theta_{mnk}^{mu,\AA}}{W} \tag{19}$$

Each user of the MBS operates on the assumption that it will be provided with a single channel and subsequently formulates a utility function that is contingent upon both the EE and SE in the following manner:

$$\psi_{k,n}^{MBS} = \beta(v_{mu}) + (1-\beta)(\varsigma_{mu}) \tag{20}$$

In order to facilitate the auctioning process of sub-channels, the combined utilities of the MBS and SBS are expressed as a single weighted-sum utility function, as outlined below:

$$\psi_{k,n}^{joint} = \zeta \, \psi_{k,n}^{MBS} + (1-\zeta) \, \psi_{k,n}^{SBS} \tag{21}$$

where ζ is used as a weight parameter that can be utilized to boost the priority of one utility in relation to the other. $\psi_{k,n}^{MBS}$ and $\psi_{k,n}^{SBS}$ are the utilities of the gNBs using communication sub-channels.

A modified auction is implemented. The communication sub-channels are the commodities that are exchanged, with the MBS serving as owners and the SBSs acting as purchasers. In initialization, the SBSs possess a monetary gain denoted as $G_{k,n}^{(0)}$. This gain is determined by subtracting the initial channel prices $\rho_n^{(0)}$ from the joint utility $\psi_{k,n}^{joint}$.

$$G_{k,n}^{(0)} = \psi_{k,n}^{joint} - \rho_n^{(0)} \tag{22}$$

If there is a simultaneous demand for a channel by multiple SBSs, a certain value ϵ is added to the price of the channel. Consequently, the monetary gain denoted by $G_{k,n}^{(0)}$ undergoes modification in every iteration.

Algorithm 2 describes the proposed mechanism as follows:

1. Each SBS sorts its utility function $\psi_{k,n}^{joint}$ in descending order to obtain the pricing information and record the channels that correspond to the highest $\psi_{k,n}^{joint}$ in K. Q is the number of channels stored in K for each SBS.
2. The bidder set is assessed by considering the demand sets of all SBSs and includes only those channels that are requested by more than one SBS.
3. The channel prices within the bidder set have been subjected to an increment of ε. Consequently, a different transmission power level of SBSs exhibits a need for the channels in the bidder set, leading to a scenario where a high transmission power level SBS is capable of connecting more users.

Algorithm 2 Auction channel allocation algorithm

Input: $\psi_{k,n}^{joint}$, Q_n, and ε
Output: $\nu_{mu,k}$, and $\nu_{su,k}$

Initialization: Set of all SBS in the system N; set of available macro channels in the system K; $\nu_{mu,k}$ is an identity matrix.
find the maximum of Q_n in all SBS and the number of needed channels (Φ)
while $\Phi \neq 0$
  for $Q_{max} \in Q_n$ **do**
    if $Q_n \neq 0$
      sort the utility function $\psi_{k,n}^{joint}$ (20) in descending order of each SBS
      find price object $P_o = \psi_n^{joint}(1) - \psi_n^{joint}(2)$
      price list = $P_o + \varepsilon$
      find the index of the maximum $\psi_n^{joint}(bidder_{max})$ in each SBS
      keep the number of K with the highest utility
      if price list < price list (update) & $bidder_{max} \neq$ SBS then
        update $(bidder_{max})$
        price list (update) = price list + ε
      else
        keep the assignment unchanged
      end if
      update $\nu_{su,k}$ selects the optimal channel in each SBS.
    end if
  end for
end while

The preceding three phases are repeated until each SBS satisfies its Q. The allocation of channels was updated accordingly. Consequently, it can be ensured that the channels will be fully occupied and the satisfaction of the SBSs will be fully met. The auction process is iterated with a constant incremental factor ε, and the channel prices are reset to a negligible random value. This process continues until either all the SBSs are connect with their allocation, or all the channels have been assigned. Figure 2 illustrates the flow chart of the proposed scheme.

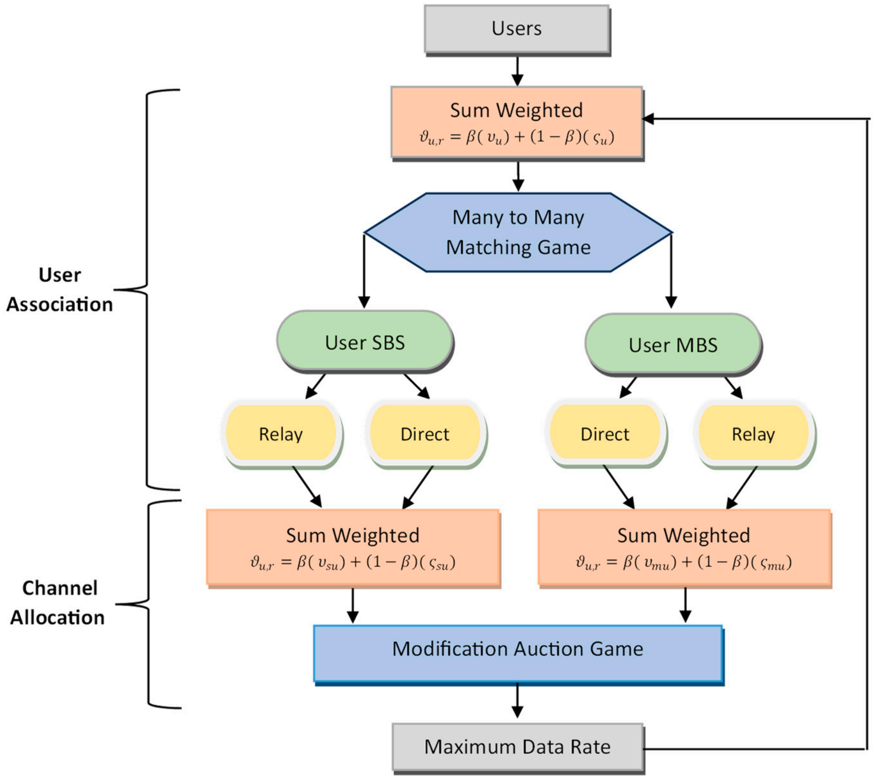

Figure 2. Flow chart.

6. Simulation Results and Discussion

6.1. Simulation Parameters

We simulate a 6G HetNet with a geographical area of 600 m × 600 m. The proposed topology considers a single MBS and 8 SBSs. A total of 60 users are distributed randomly in the coverage area. We assume that the neighboring SBSs are uniformly distributed in the coverage of the MBS. The maximum power of the MBS, SBSs, and relays is 30 dBm, 20 dBm, and 20 dBm, respectively. Each SBS could assign a random number of users, with a limit of $Q_{max} = 8$. We assume that the pathloss model as given in [44] is different from that of LTE BSs. The mmWave BSs and LTE BSs operate on a 94 GHz carrier frequency and have different antenna heights. Shadow fading is commonly modeled as a log-normal random variable with a zero mean and 1.5 standard deviations in dB. The bandwidth is set to 5 MHz and divided into 20 channels. One user may communicate with gNB by selecting relay or without relay. We consider that each user can associate with both the MBS and the SBS in a direct (without relay) or indirect (relay-assisted) communication link in a HetNet environment. A two-hop decode-and-forward relaying mechanism is considered [45]. We also assume that there is always one R nearby the user to establish a relay link. Table 1 enumerates the parameters used in the simulation.

Table 1. System parameters.

Parameter	Value
System bandwidth	5 MHz
Number of sub-channels	20
Sub-channel	240×10^3 KHz
Number of macro base stations	1
Number of small base stations	8
Number of users	60
Radius of the MBS, SBS	600 m, 200 m

Table 1. *Cont.*

Parameter	Value
Maximum transmission power of the MBS	30 dBm
Transmission power of the SBS	0–20 dBm
Transmission power of the relay	20 dBm
Noise power (dBm)	−174
Rate requirement of a downlink user (Mbps)	1
Static power for a circuit (W)	0.1
Partition factor β	0.8
Maximum quota	8
The weight parameter ζ	0.5
ε	0.0001

6.2. Simulation Analysis and Results

We compare our proposed scheme's performance to that of the maximum rate scheme [24] and the repeated auction algorithm [31] to ensure its efficiency. Take the repeated auction algorithm as an example. We chose the result with the highest system QoS among the current schemes as our optimization solution.

As shown in Figure 3, we examine the variation in average data rate in situations of MBS power (20, 30, and 40 dBm) and show how the proposed scheme obtains this rate given a minimum QoS requirement of 1 Mbps for each user. The different powers of the MBS can have an effect on SBS users. Although the interference from the MBS increased as the power increased, the average data rate also increased accordingly. The figure illustrates that the proposed scheme can attain a lower average data rate in cases where the MBS power is low. The reason is that if a user has no connection with SBSs and has a low probability of connecting with the MBS in low-power transmission, then the average data rate will decrease. It is obvious that the average data rate in all cases is nearly stable for the symmetry SBS transmission power (0–6 dBm), while the average data rate in all cases rose gradually as the SBS transmission power increased (7–20 dBm). The reason is that the user receives an efficient value of transmission power.

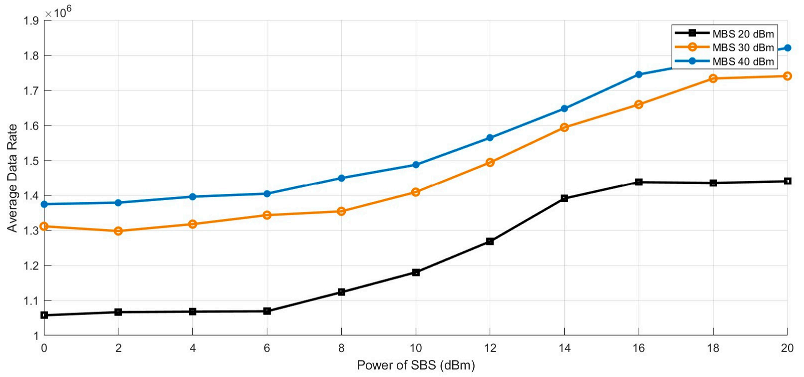

Figure 3. Average data rate with different power levels of the MBS.

In Figure 4, the outcome curve shows a higher probability of connection when setting different powers of the MBS. The probability of a connection increases with the increased power of SBSs. The users in the wireless environment will suffer high interference when the power of the MBS is 40 dBm. The probability of connection when the power of the MBS is 40 dBm, is almost the same as the probability of connection when the power of the MBS is 30 dBm. The reason is that the users of SBSs will suffer from MBS interference. For efficient power consumption, the performance of our scheme is better when the MBS power is 30 dBm. It is observed that the probability of connection for all cases ranges from 0.3 to 0.48 for SBS transmission power (0–10 dBm), while the probability of connection ranges from 0.5 to 0.79 as the SBS transmission power increases (11–20 dBm). The reason is that the SINR is directly proportional to the SBS transmission power. Hence, the probability of a connection increased.

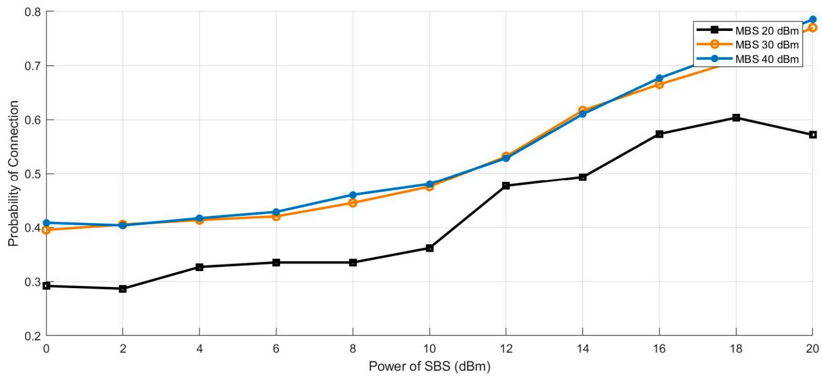

Figure 4. Probability of connection with different power levels of the MBS.

In Figure 5, the average data rate is demonstrated for various minimum QoS requirements of R_{min} = 100 Kbps, 500 Kbps, and 1 Mbps. The gNB′s behavior at each level of SBS transmission power can be determined by the minimum QoS requirements of the UE. The figure illustrates that the proposed scheme can attain a superior average data rate under the condition that each user has a minimum QoS requirement of 1 Mbps. This is due to the fact that if a user has a high need for QoS, the demand may be efficiently met, which results in a large number of connected users. On the other hand, the average data rate drops when users demand a minimum QoS of 100 Kbps. The reason is that the number of connected users is high with a low data rate. Obviously, when the minimum QoS requirement is between 100 Kbps and 500 Kbps, the average data rate is nearly the same for a SBS with a 20 dBm transmission power. The reason is that the users suffer from severe interference due to the high number of connected users.

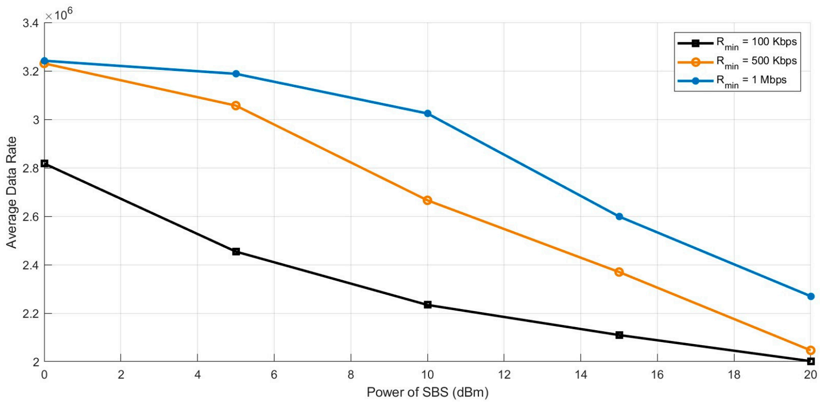

Figure 5. Average data rate with different QoS requirements.

Figure 6 shows the probability of connection attained by the presented scheme with different minimum QoS requirements. As can be observed from the figure, the proposed scheme achieves full connection when each user has a minimum QoS need of 100 kbps and 20 dBm of SBS transmission power. On the other hand, if a gNB has a greater need for the QoS requirement, it would be difficult to meet the demand, which would result in a large number of users being in a non-connection status. It was noted that the probability of connection is very low when the SBS transmission power ranges from 0–10 dBm and the minimum QoS is 1 Mbps. The reason is that the user cannot satisfy the gNB requirements.

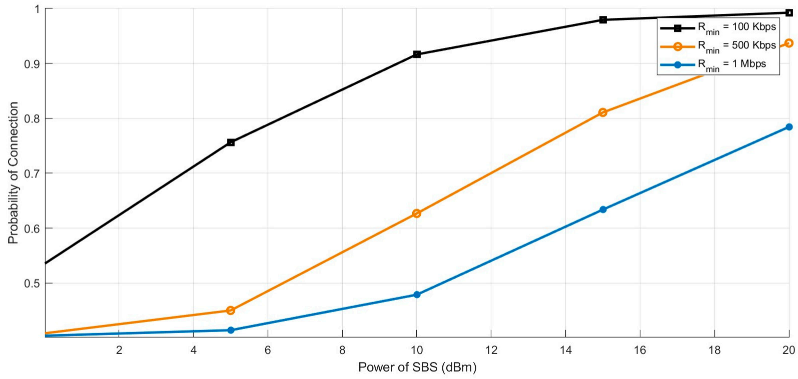

Figure 6. Probability of connection with different QoS requirements.

Figure 7 illustrates the probability of connection between the gNBs and the users in a relay-assisted scenario. At different values of transmitted power for SBSs, the probability of connection of the users for the proposed scheme is plotted in Figure 7 against the repeated auction and maximum rate schemes. It is clear that the probability of connection for the proposed scheme is better than the current schemes. One reason is that the limited transmit power of SBSs will be shared by more users in our proposed scheme, resulting in a high probability of connection. Additionally, the probability of connection can be improved as the power of the SBS increases by taking into consideration the maximum power of the SBS. It is observed that the repeated auction scheme achieves a higher probability of connection than the maximum rate scheme when the SBS transmission power ranges from 0–10 dBm. On the other hand, the maximum rate scheme achieves a higher probability of connection than the repeated auction scheme when the SBS transmission power ranges from 11–20 dBm. The reason is that the maximum rate scheme depends on the SINR values, while the repeated auction scheme has a different attribute. It is also seen that, compared with the repeated auction and maximum rate schemes, the proposed scheme has an 8.5% and 12.7% performance gain, respectively.

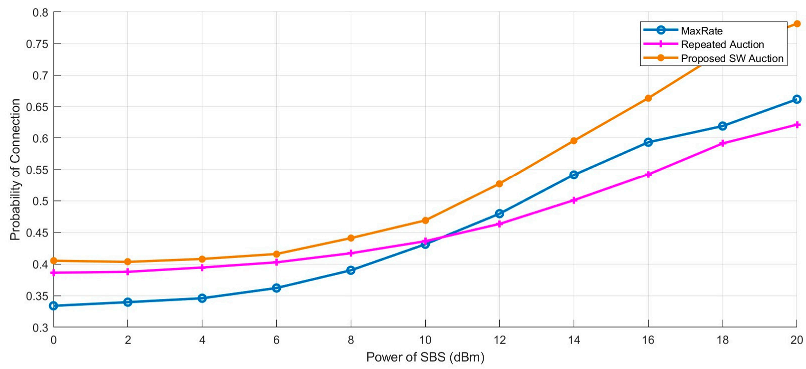

Figure 7. Probability of connection.

Figure 8 presents the average data rate of all users against the transmission power of the SBS in a relay-assisted scenario. The proposed scheme yields improved downlink network throughput outcomes through the increase in the transmission power of the SBSs. As a consequence, it provides optimal system performance in the context of repeated auctions and maximum rate solutions, which experience reduced performance as a result of network congestion and interference effects. The reason for this is attributed to the downlink utility functions, which mainly consider user rates. While our proposed scheme takes into account the sum-weighted strategies of the EE and SE and the severe interference resulting from channel reuse, it outperforms the current scheme in terms of average data rate. Compared with the maximum rate scheme, the proposed scheme has a 30.23%

performance gain when the power of the SBS = 10 dBm and a 42.76% performance gain when the power of the SBS = 20 dBm.

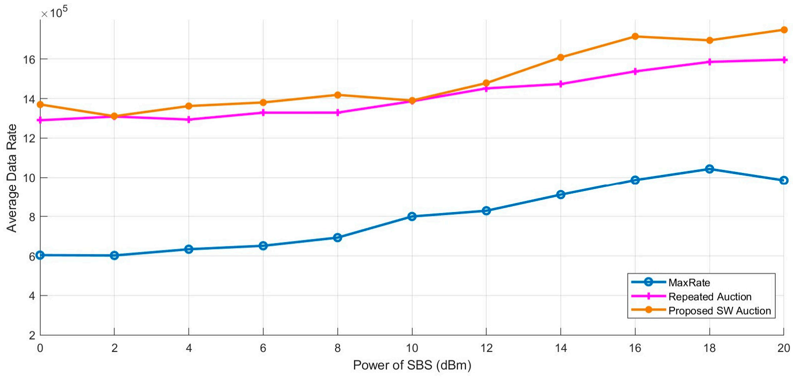

Figure 8. Average data rate.

Figure 9 illustrates the energy efficiency of our proposed scheme at various levels of transmitted power for the SBSs with respect to the repeated auction and maximum rate schemes. It is clear that the energy efficiency of the proposed scheme is better than that of the repeated auction and maximum rate schemes. The figure shows that energy efficiency increases with the increase in power of the SBSs. One reason is that the transmission power of the SBSs will be shared by more users in our proposed scheme. Consequently, the ratio of the average data rate to the consumed power increased. It is also seen that, compared with the current scheme, the proposed scheme has a 40.51% performance gain when the power of the SBS = 1 dBm and a 33.93% performance gain when the power of the SBS = 20 dBm.

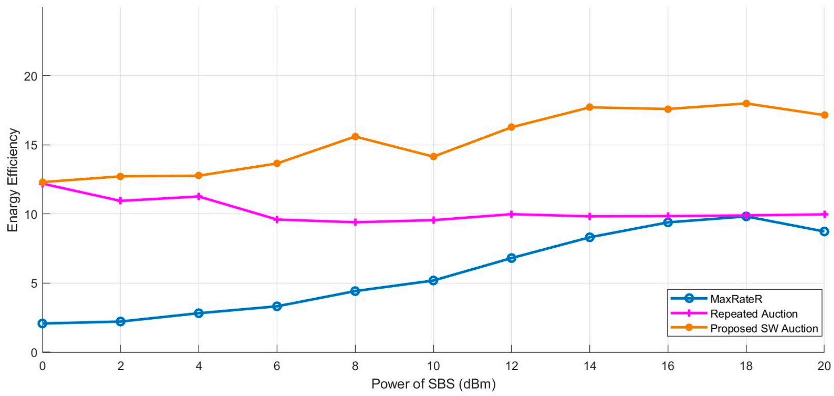

Figure 9. Energy efficiency.

Figure 10 shows the spectrum efficiency of our proposed scheme compared to the repeated auction and maximum rate schemes at various levels of transmitted power for the SBSs. As seen in Figure 10, the spectrum efficiency of the proposed scheme outperforms the current schemes. We can observe that the proposed scheme achieves SE closing compared to the repeated auction scheme with a small performance gain. The conventional maximum rate scheme is not ideal because of unreliable channel reuse. Furthermore, when the transmission power of the SBSs increases, the performance gap of the repeated auction scheme becomes larger. This superior performance further demonstrates the effectiveness of the proposed scheme. Compared with the repeated auction, the proposed scheme has a 24.89% performance gain when the power of the SBS = 10 dBm and a 37.51% performance gain when the power of the SBS = 20 dBm.

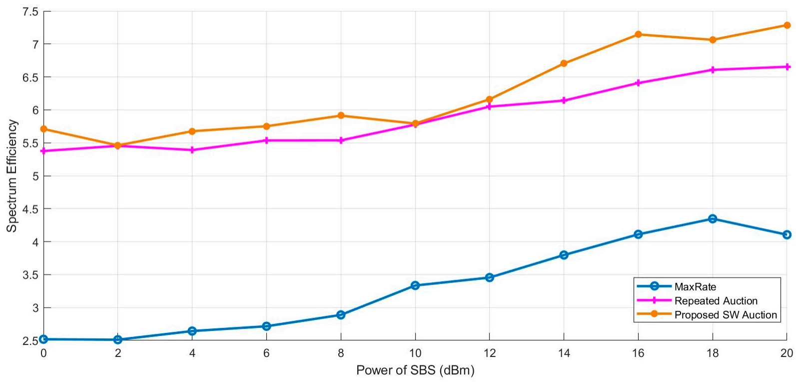

Figure 10. Spectrum efficiency.

Figures 11 and 12 show the comparison between the direct scenario and the relay-assisted scenario in terms of average data rate and probability of connection with different levels of SBS transmission power. It is obvious that the proposed scheme with a relay-assisted scenario outperforms the current schemes with any scenario. In Figure 11, the probability of connection is stable when the transmission power of the SBSs ranges from 0–8 dBm due to the inefficient power needed to satisfy the user requirements. In contrast, the probability of connection increases gradually when the transmission power of the SBSs ranges from 9–20 dBm due to the satisfaction of user requirements. In Figure 12, the average data rate of the proposed sum-weighted scheme with relay is almost the same as the average data rate of the repeated auction with relay when the transmission power of the SBS ranges from 0–12 dBm, while the former performs better than the latter when the transmission power of the SBS ranges from 13–20 dBm. This shows the effectiveness of the proposed scheme with high power transmission levels from a SBS. It is seen that the probability of connection in a relay-assisted scenario is always higher than 0.4, while the probability in a direct scenario is less than 0.4 when the SBS transmission power is less than 13 dBm. The reason is that the relay assists the user in forming a connection and acts as a repeater.

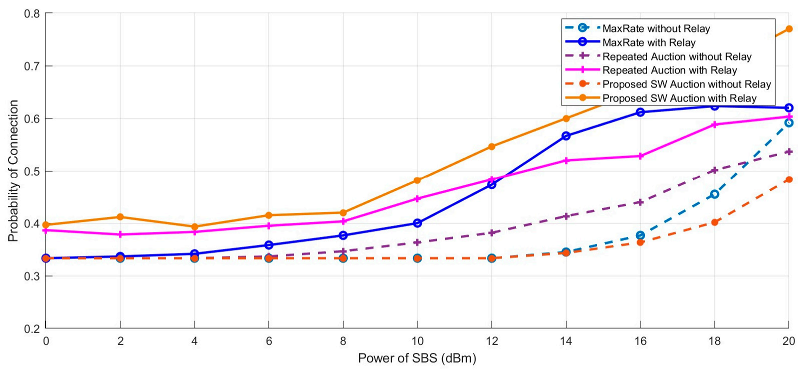

Figure 11. Probability of connection in different scenarios.

Hence, the proposed scheme balances the load between the SBS users and provides a greater opportunity for MBS channels to be assigned to SBSs. The observed behavior can be attributed to the restricted number of users assigned to each SBS in the matching algorithm, where the channels are assigned based on a modified auction algorithm that considers the quota of each SBS. Furthermore, the low transmission powers of SBSs may result in insufficient available channels to meet their requirements. The aforementioned deficiency is reflected in the comparatively diminished level of satisfaction and the limited reuse of MBS channels.

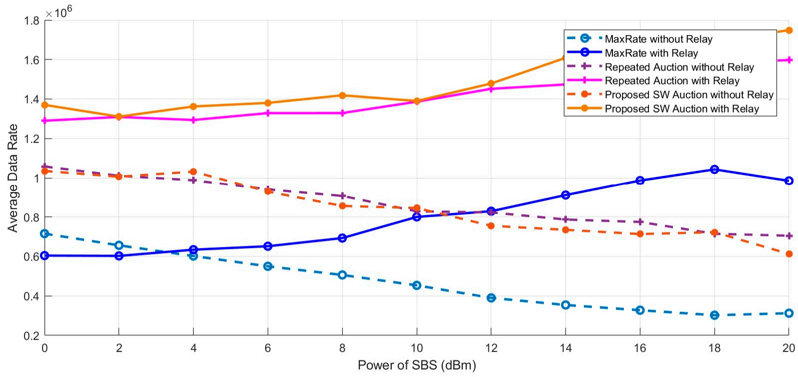

Figure 12. Average data rate in different scenarios.

7. Conclusions

This paper discusses the investigation of user association and channel allocation problems within 6G two-tier HetNets. A joint optimization scheme is proposed to improve QoS. A many-to-many matching game-based user association is employed to facilitate the matching process between users and multiple gNBs that are uniformly distributed. A sum-weighted strategy, which is dependent on the EE and SE, is used to calculate the matching game's utility function. A modified auction game is used to determine which channel should be allocated based on the sum-weighted strategies of the EE and SE that are achieved by the users while taking into consideration the users who are associated with those gNBs. In terms of connection probability, average data rate, EE, and SE, the simulation results show that the suggested scheme outperforms the state-of-the-art schemes. They also demonstrate the significance of evaluating the MBS power level, as shown in the probability of connection and average data rate. Moreover, auctions allow for load balancing between the macro channels allocated to SBSs. Furthermore, the effectiveness of the proposed scheme in a relay-assisted scenario is demonstrated.

Author Contributions: Conceptualization, H.F.A. and M.N.H.; Methodology, H.F.A. and M.N.H.; Software, H.F.A. and M.N.H.; Validation, H.F.A. and M.N.H.; Formal analysis, H.F.A. and M.N.H.; Investigation, H.F.A., M.N.H. and T.F.T.M.N.I.; Resources, H.F.A., M.N.H. and K.D.; Data curation, H.F.A., M.N.H., E.B.H. and T.F.T.M.N.I.; Writing—original draft, H.F.A.; Writing—review & editing, M.N.H. and T.F.T.M.N.I.; Visualization, M.N.H., K.D. and E.B.H.; Supervision, M.N.H. and K.D.; Project administration, M.N.H. and K.D.; Funding acquisition, E.B.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research work has been supported by Ministry of Higher Education under the Fundamental Research Grant Scheme (FRGS/1/2020/TK0/UM/02/30).

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Alhashimi, H.F.; Hindia, M.N.; Dimyati, K.; Hanafi, E.B.; Safie, N.; Qamar, F.; Azrin, K.; Nguyen, Q.N. A Survey on Resource Management for 6G Heterogeneous Networks: Current Research, Future Trends, and Challenges. *Electronics* **2023**, *12*, 647.
2. Han, S.; Chih-Lin, I.; Xie, T.; Wang, S.; Huang, Y.; Dai, L.; Sun, Q.; Cui, C. Achieving high spectrum efficiency on high speed train for 5G new radio and beyond. *IEEE Wirel. Commun.* **2019**, *26*, 62–69.
3. Hassan, R.; Qamar, F.; Hasan, M.K.; Aman, A.H.M.; Ahmed, A.S. Internet of Things and its applications: A comprehensive survey. *Symmetry* **2020**, *12*, 1674.
4. Qamar, F.; Siddiqui, M.H.S.; Hindia, M.N.; Dimyati, K.; Abd Rahman, T.; Talip, M.S.A. Propagation Channel Measurement at 38 GHz for 5G mm-wave communication Network. In Proceedings of the 2018 IEEE student conference on research and development (SCOReD), Selangor, Malaysia, 26–28 November 2018; IEEE: New York, NY, USA, 2018; pp. 1–6.
5. Manap, S.; Dimyati, K.; Hindia, M.N.; Talip, M.S.A.; Tafazolli, R. Survey of radio resource management in 5G heterogeneous networks. *IEEE Access* **2020**, *8*, 131202–131223.

6. Jiao, J.; Liao, S.; Sun, Y.; Wu, S.; Zhang, Q. Fairness-improved and QoS-guaranteed resource allocation for NOMA-based S-IoT network. *Sci. China Inf. Sci.* **2021**, *64*, 169306.
7. Fadlullah, Z.M.; Mao, B.; Kato, N. Balancing QoS and security in the edge: Existing practices, challenges, and 6G opportunities with machine learning. *IEEE Commun. Surv. Tutor.* **2022**, *24*, 2419–2448.
8. Alibraheemi, A.M.H.; Hindia, M.N.; Dimyati, K.; Izam, T.F.T.M.N.; Yahaya, J.; Qamar, F.; Abdullah, Z.H. A Survey of Resource Management in D2D Communication for B5G Networks. *IEEE Access* **2023**, *11*, 7892–7923.
9. Alzubaidi, O.T.H.; Hindia, M.N.; Dimyati, K.; Noordin, K.A.; Wahab, A.N.A.; Qamar, F.; Hassan, R. Interference Challenges and Management in B5G Network Design: A Comprehensive Review. *Electronics* **2022**, *11*, 2842.
10. Dang, S.; Amin, O.; Shihada, B.; Alouini, M.-S. What should 6G be? *Nat. Electron.* **2020**, *3*, 20–29.
11. Giordani, M.; Polese, M.; Mezzavilla, M.; Rangan, S.; Zorzi, M. Toward 6G networks: Use cases and technologies. *IEEE Commun. Mag.* **2020**, *58*, 55–61.
12. Ullah, Y.; Roslee, M.B.; Mitani, S.M.; Khan, S.A.; Jusoh, M.H. A Survey on Handover and Mobility Management in 5G HetNets: Current State, Challenges, and Future Directions. *Sensors* **2023**, *23*, 5081.
13. Poryazov, S.; Andonov, V.; Saranova, E. Methods for Modelling of Overall Telecommunication Systems. *Res. Comput. Sci. Bulg. Acad. Sci.* **2021**, *934*, 325–361.
14. Louvros, S.; Paraskevas, M.; Chrysikos, T. QoS-Aware Resource Management in 5G and 6G Cloud-Based Architectures with Priorities. *Information* **2023**, *14*, 175.
15. Zhang, Y.; Xiong, L.; Yu, J. Deep learning based user association in heterogeneous wireless networks. *IEEE Access* **2020**, *8*, 197439–197447.
16. Khawam, K.; Lahoud, S.; El Helou, M.; Martin, S.; Gang, F. Coordinated framework for spectrum allocation and user association in 5G HetNets with mmWave. *IEEE Trans. Mob. Comput.* **2020**, *21*, 1226–1243.
17. Khan, H.Z.; Ali, M.; Naeem, M.; Rashid, I.; Akhtar, A.N.; Akram, F. Joint dl/ul decouple user association in microwave and mmwave enabled beyond 5G heterogeneous networks. *IEEE Access* **2021**, *9*, 134703–134715. [CrossRef]
18. Sana, M.; De Domenico, A.; Yu, W.; Lostanlen, Y.; Strinati, E.C. Multi-agent reinforcement learning for adaptive user association in dynamic mmWave networks. *IEEE Trans. Wirel. Commun.* **2020**, *19*, 6520–6534. [CrossRef]
19. Hassan, N.; Fernando, X. An optimum user association algorithm in heterogeneous 5G networks using standard deviation of the load. *Electronics* **2020**, *9*, 1495.
20. Sanyal, J.; Samanta, T. Game Theoretic Approach to Enhancing D2D Communications in 5G Wireless Networks. *Int. J. Wirel. Inf. Netw.* **2021**, *28*, 421–436.
21. You, M.; Zheng, G.; Chen, T.; Sun, H.; Chen, K.-C. Delay guaranteed joint user association and channel allocation for fog radio access networks. *IEEE Trans. Wirel. Commun.* **2021**, *20*, 3723–3733. [CrossRef]
22. Zhu, L.; Yang, L.; Zhang, Q.; Zhou, T.; Hua, J. Cluster-based energy-efficient joint user association and resource allocation for B5G ultra-dense network. *Phys. Commun.* **2021**, *46*, 101311.
23. Khodmi, A.; Rejeb, S.B.; Agoulmine, N.; Choukair, Z. A joint power allocation and user association based on non-cooperative game theory in an heterogeneous ultra-dense network. *IEEE Access* **2019**, *7*, 111790–111800. [CrossRef]
24. Jain, A.; Lopez-Aguilera, E.; Demirkol, I. User association and resource allocation in 5G (AURA-5G): A joint optimization framework. *Comput. Netw.* **2021**, *192*, 108063.
25. Liu, R.; Lee, M.; Yu, G.; Li, G.Y. User association for millimeter-wave networks: A machine learning approach. *IEEE Trans. Commun.* **2020**, *68*, 4162–4174.
26. Hattab, G.; Cabric, D. Long-term rate-based user-centric association for downlink multi-antenna HetNets. In Proceedings of the 2018 IEEE International Conference on Communications Workshops (ICC Workshops), Kansas City, MO, USA, 20–24 May 2018; IEEE: New York, NY, USA, 2018; pp. 1–6.
27. Gatti, R.; GB, A.K.; KN, S.K.; Palle, S.; Gadekallu, T.R. Optimal resource scheduling algorithm for cell boundaries users in heterogenous 5G networks. *Phys. Commun.* **2022**, *55*, 101915.
28. Qi, X.; Khattak, S.; Zaib, A.; Khan, I. Energy efficient resource allocation for 5G heterogeneous networks using genetic algorithm. *IEEE Access* **2021**, *9*, 160510–160520.
29. Ji, P.; Jia, J.; Chen, J. Joint optimization on both routing and resource allocation for millimeter wave cellular networks. *IEEE Access* **2019**, *7*, 93631–93642.
30. Saha, R.K. Approaches to improve millimeter-wave spectrum utilization using indoor small cells in multi-operator environments toward 6G. *IEEE Access* **2020**, *8*, 207643–207658.
31. Rostom, M.A.; Abd El-Malek, A.H.; Abo-Zahhad, M.; Elsabrouty, M.M. A two-stage matching game and repeated auctions for users admission and channels allocation in 5G HetNets. *IEEE Access* **2022**, *11*, 17739–17754.
32. Alizadeh, A.; Vu, M. Early acceptance matching game for user association in 5G cellular HetNets. In Proceedings of the 2019 IEEE Global Communications Conference (GLOBECOM), Waikoloa, HI, USA, 9–13 December 2019; IEEE: New York, NY, USA, 2019; pp. 1–6.
33. Amine, M.; Kobbane, A.; Ben-Othman, J.; Walid, A. Two-sided matching framework for optimal user association in 5G multi-RAT UDNs. *Int. J. Commun. Syst.* **2020**, *33*, e4346.
34. Pratap, A.; Das, S.K. Stable matching based resource allocation for service provider's revenue maximization in 5G networks. *IEEE Trans. Mob. Comput.* **2021**, *21*, 4094–4110. [CrossRef]

35. Simsek, M.; Hößler, T.; Jorswieck, E.; Klessig, H.; Fettweis, G. Multiconnectivity in multicellular, multiuser systems: A matching-based approach. *Proc. IEEE* **2019**, *107*, 394–413.
36. Devi, M.; Sarma, N.; Deka, S.K. Multi-winner heterogeneous spectrum auction mechanism for channel allocation in cognitive radio networks. In Proceedings of the Distributed Computing and Internet Technology: 16th International Conference, ICDCIT 2020, Proceedings 16, Bhubaneswar, India, 9–12 January 2020; Springer: Berlin/Heidelberg, Germany, 2020; pp. 251–265.
37. Devi, M.; Sarma, N.; Deka, S.K. DAMW: Double auction multi-winner framework for spectrum allocation in cognitive radio networks. In Proceedings of the Innovations for Community Services: 20th International Conference, I4CS 2020, Proceedings 20, Bhubaneswar, India, 12–14 January 2020; Springer: Berlin/Heidelberg, Germany, 2020; pp. 266–281.
38. Ghosh, S.; De, D.; Deb, P. Energy and spectrum optimization for 5G massive mimo cognitive femtocell based mobile network using auction game theory. *Wirel. Pers. Commun.* **2019**, *106*, 555–576.
39. Hasan, M.; Hossain, E. Distributed resource allocation in D2D-enabled multi-tier cellular networks: An auction approach. In Proceedings of the 2015 IEEE International Conference on Communications (ICC), London, UK, 8–12 June 2015; IEEE: New York, NY, USA, 2015; pp. 2949–2954.
40. Poryazov, S.A.; Saranova, E.T.; Andonov, V.S. Overall Model Normalization towards Adequate Prediction and Presentation of QoE in Overall Telecommunication Systems. In Proceedings of the 2019 14th International Conference on Advanced Technologies, Systems and Services in Telecommunications (TELSIKS), Niš, Serbia, 23–25 October 2019; IEEE: New York, NY, USA, 2019; pp. 360–363.
41. Chen, W.-K.; Liu, Y.-F.; Dai, Y.-H.; Luo, Z.-Q. Optimal Qos-Aware Network Slicing for Service-Oriented Networks with Flexible Routing. In Proceedings of the ICASSP 2022–2022 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Singapore, 22–27 May 2022; IEEE: New York, NY, USA, 2022; pp. 5288–5292.
42. Alizadeh, A.; Vu, M. Distributed user association in B5G networks using early acceptance matching game. *IEEE Trans. Wirel. Commun.* **2020**, *20*, 2428–2441. [CrossRef]
43. Si, Z.; Chuai, G.; Zhang, K.; Gao, W.; Chen, X.; Liu, X. Backhaul Capacity-Limited Joint User Association and Power Allocation Scheme in Ultra-Dense Millimeter-Wave Networks. *Entropy* **2023**, *25*, 409.
44. Ju, S.; Xing, Y.; Kanhere, O.; Rappaport, T.S. Sub-terahertz channel measurements and characterization in a factory building. In Proceedings of the ICC 2022-IEEE International Conference on Communications, Seoul, Republic of Korea, 16–20 May 2022; pp. 2882–2887.
45. Chen, C.-Y.; Sung, C.-A.; Chen, H.-H. Capacity maximization based on optimal mode selection in multi-mode and multi-pair D2D communications. *IEEE Trans. Veh. Technol.* **2019**, *68*, 6524–6534.