Interference in B5G Network Design

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Beyond Fifth Generation (B5G) networks are expected to be the most efficient cellular wireless networks with greater capacity, lower latency, and higher speed than the current networks. Key enabling technologies, such as millimeter-wave (mm-wave), beamforming, Massive Multiple-Input Multiple-Output (M-MIMO), Device-to-Device (D2D), Relay Node (RN), and Heterogeneous Networks (HetNets) are essential to enable the new network to keep growing. In the forthcoming wireless networks with massive random deployment, frequency re-use strategies and multiple low power nodes, severe interference issues will impact the system. Consequently, interference management represents the main challenge for future wireless networks, commonly referred to as B5G.

B5G interference HetNet D2D

1. Introduction

The rapid growth and sustained advancement in future wireless technologies of different new applications in Beyond Fifth Generation (B5G) communication networks have led to a massive growth increase in demand for user data. The volume of mobile data traffic was 7.462 EB/month in 2010 and it is expected that this traffic will be 5016 EB/month in 2030 [1]. A massive number of surveys were conducted and are continuously being performed in different areas of wireless communication such as interference management, mobility management, spectrum management, and energy management [2][3][4][5]. Researchers from various portions of networking and communication institutions, from academics to marketers and providers to operators, have collaborated and introduced an effective way to make this subject possible [6]. This development resulted in an increased growth rate in the user data rate of around 10 Gb/s with a minimum latency of around <1 ms, mobility of >1000 km/h, reliability of 99.999%, and better battery lifetime [7][8]. Furthermore, this trend is expected to increase dramatically during the next few years. The collection of advancements in previous technologies and innovative wireless transmission technology demonstrates a tendency to meet cellular users' requirements and the objectives of the next generation such as B5G, also known as the sixth generation (6G) networks [9][10]. Usually, the substantial rise in traffic is a direct result of an increase in request for certain services, such as super-intelligent society (SIS) [11], extended reality (ER) [12], connected robotics integrated systems [13], wireless interactions between computer and brain (WICB) [14][15], haptic communication (HC) [16], smart healthcare and biomedical communication [11], automation and manufacturing, information transfer through the five senses, internet of everything (IoE) [17][18][19], etc. Researchers also anticipate the better Quality of Service (QoS) needs for massive data and real-time applications while maintaining secure communications [20].

The combination between millimeter-wave (mm-wave) and THz bands was inserted in existing B5G networks due to the restrictions of the previous mobile generation and the requirement for wide bandwidth [21]. This provides a large amount of unused frequency bands that can be used to enhance the system spectral efficiency (SE) approximately by seven times compared with traditional homogeneous networks [22]. The combined frequency range depends on a direct transmission in order to mitigate the path loss for the cellular users (CUs) in both Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) transmission [23]. However, because of the short wavelength as well as several intra-cell interferences by neighboring devices, the frequency bands of B5G suffer from attenuation, fading, reflection, refraction, scattering, shadowing, and absorption by brick walls and concrete buildings, preventing them from penetrating long distances [24][25]. Meanwhile, in ultra-dense network urban areas, users face penetration, scattering, and interference problems. Therefore, it is very important to model the channel of each spectrum before the actual implementation [26]. Because of this, the weak signals received by edge cell user equipments (UEs) are compared with the minimum required communication signal. Small base station (SBS) deployment within the cell to improve the strength of the signal is not regarded as an applicable solution because it boosts inter-cell interference (ICI). This requires a highly complex coordination scheduling (CS) algorithm which can be costly to create [27][28][29].

2. Network Architecture of B5G for Reducing the Interference

The new network architecture is a combination of several technologies, including HetNet, D2D, UDNs, UAVs, beamforming, Massive Multiple-Input Multiple-Output (M-MIMO), mm-wave, etc. Architectural improvements are necessary to ensure that the new radio is compatible with a conventional network. However, diverse technology models' design and contemporary practice result in massive interference in each other's signals. These susceptible interferences affect the performance of the entire network [30][31].

From a technological perspective, B5G will merge terrestrial wireless communication, satellite communication, and direct communication over short distances. Concurrently, B5G will incorporate communication, perception, computing, navigation, and other emerging technologies. By leveraging the management of intelligent mobility and the methods of control, B5G will create a new architecture of the 3D core network that can combine those systems and assist universal ubiquitous coverage of very high-speed communications, comprising communications on the earth, in space, in air, and over the sea [7][32].

Although this 3D core network design has the potential to overcome conventional coverage restrictions and eventually establish an unparalleled universal coverage, some challenges should be solved to improve the performance of the B5G networks [21]. Interference is the most significant factor that influences the capacity and QoS provided to end-users. Therefore, in the B5G network, it is essential to explore how interference can be canceled using traditional interference cancellation techniques, such as successive interference cancellation (SIC) and parallel interference cancellation (PIC), or key enabling technologies such as M-MIMO, intelligent beamforming (IB), resource allocation (RA), etc. [1][33].

3. Interference in B5G Networks

3.1. Heterogeneous Networks

The future of B5G wireless networks is forecasted to manage applications demanding massive data rates. One of the proposed solutions given by the third generation partnership project (3GPP), Release 12, is to meet data rates demand to allow network densification through the deployment of SCs [34]. Such densification provides increased spectrum efficiency, increased network capacity and overall performance, cost-effective coverage expansion, and can even lower the mobile's power consumption because of communication with surrounding pico-cells [35]. This solution increases the coverage of the network dramatically. However, it necessitates invention in hardware miniaturizing and cost reduction in the construction of a small-cell base station (BS). These SC-BSs can be installed as low-power femto-cells for enterprise or residential installations or as higher-power pico-cells to improve a macro-cell's outdoor coverage. The synchronous operation of macro-, micro-, pico-, and femto-cells is referred to as HetNets [36]. Particularly, HetNet enables different types of SCs to cohabit with macro-cells by participating in the same resources of the spectrum, which can significantly enhance SE and decrease uncovered regions [37].

3.1.1. Unique Features of HetNets

- Increase the capacity of the system: By allowing many mobile terminals with varying access technologies to cohabit in the same physical location, the total system capacity can be considerably increased.

- Massive density: To provide ultra-connectivity, multiple users with varying levels of power are distributed by deploying many SCs. The structure of the network gets significantly denser.

- Reduction of uncovered regions: With the deployment of diverse SCs (e.g., micro-cells, femto-cells), it is possible to decrease uncovered regions and extend the range of communication by improving access points in the environment of the poor channel.

- Decrease path losses and delay: In a wide-region communication environment without SCs, the channel path loss between mobile terminals and macro base station (vs) is severely deteriorated due to the vast distance between various devices. While slight path losses can be faced to the backhaul signals from mobile terminals to MBSs when SBSs are located between MBSs and mobile terminals [38].

- Increase SE: Given the scarcity of available spectral frequencies in traditional homogeneous networks, it is preferable to discover an efficient way to increase the SE of the system [39]. The radio frequency (RF) unit must be redesigned when the radius of transmission is small in the high band of frequency. However, HetNet can increase the SE and enable smooth connection at any time and everywhere by cohabiting with diverse cells. The figure depicts how various networks with various functions are divided into different tiers that span from space to ground communications. Particularly, the conventional HetNet is a depiction of terrestrial communications, such as macro–micro HetNets. By participating in the authorized spectrum with MC users, various emerging networks (e.g., D2D, vehicle-to-vehicle (V2V)) and conventional macro networks are combined into a multi-tier HetNet. However, the future directions indicate that HetNets via terrestrial communications will be developed toward space communications, such as communications at low altitudes and communications in deep space. For example, the spectrum of ground stations can be shared by D2D users when the UAV acts as an air BS serving different ground stations, forming a heterogeneous coalition network with low altitudes. Additionally, a spatial HetNet can be formed by balloons, satellites in deep space, and satellites in near orbit.

3.1.2. Types of Cell and Scenarios of the Communication of HetNets

- Macro-cell Networks: A macro-cell network can supply extensive coverage by utilizing a high-power BS, which is usually utilized in cellular networks. The macro-cell network characteristics include: (i) being permanently located in a high area, such as skyscrapers or summits of mountains which can provide a line of sight over the neighboring buildings and obstructions; (ii) having a high transmission space and a massive coverage region, where the radius of the cell ranges from 1 to 25 km. Moreover, the space between adjacent MBSs is large; (iii) shadowing, fading, and interference of multipath have a significant impact on the cell-edge user QoS; and (iv) due to the existence of uncovered or hot areas because of unevenly distributed serving demands, the indoor users' QoS is much lower when serviced by the MBS [40].

- Microcell Networks: A low-power BS is used to serve the micro-cell network that is always established in highly populated metropolitan areas, such as shopping malls [41]. This network's coverage radius ranges from 200 m to 1 km, which is significantly less than that of the macro-cell network. Meanwhile, with low-power BSs, the frequency reuse distance decreases, while the number of channels and the density of traffic both increase substantially [42].

- Pico-cell Networks: A pico-cell network spans a significantly lower area (between 100 m and 200 m) when compared to a micro-cell network, such as training buildings. Typically, pico-cells are utilized to increase the coverage of indoor regions. As a result, they have the potential to minimize the uncovered areas of indoor communications [43].

- Femto-cell Networks: A femto-cell network (also known as a Home e-Node B) is a network with a small and low-power BS that is formed to increase the quality of communication in a home or small company. Using the home BS improves the QoS for indoor users [44]. Furthermore, femto-cells are significantly easier and more cost-effective to deploy than other types of cells. Besides that, femto-cells can be used to fill in the gaps between pico-cells and prevent the loss of signal via buildings. The fundamental distinction between femto-cells and pico-cells is that the users' number in femto-cells is less than in pico-cells [45].

3.1.3. Interference in HetNet

The combination of such SCs grants offloading traffic from macro-cell and improves the experience of the network by associating UEs in SCs with minimum power transmission. However, this combination leads to significant ICI in networks, particularly for SC users at the cell edge. In general, macro-cells are often deployed in a cellular network by a reasonable network plan, whereas low-power small-cells are typically placed by the identification of coverage problems and traffic intensities (e.g., hotspots) in the network [46]. Various types of distribution scenarios are already available for HetNets. In a multi-carrier distribution, SCs use more various carrier frequencies than macro-cells. This method efficiently minimizes ICI but does not guarantee optimum spectrum utilization [47]. On the other hand, the co-channel distribution is used by utilizing the same carrier for macro-cell and SC, in which the spectrum efficiency is optimized through spatial reuse and a prominent distribution technique in HetNets. Even though the co-channel technique enables excellent spectral utilization, it results in great ICI among macro- and small-cells [48].

Because of the synchronous operating of many SCs within these cells, different types of smart devices or small equipment are connected in an MBS in the environment of HetNet, resulting in co-tier interference, which is the interference between entities belonging to the same network or tier. In the case of a femto-cell network, the co-tier interference happens between nearby femto-cells. While the interference between entities belonging to diverse networks or tiers is referred to as cross-tier interference.These interferences are especially common at big gatherings when numerous users demand high throughputs, such as heavy data applications, internet browsing, and downloading/uploading images and videos. Accordingly, the ICI management and minimization approach would be created for next-generation cellular communication. Furthermore, all other interferences must be canceled to provide user fairness and QoS in wireless cellular networks [49][50].

c. Hybrid Interference Solutions

In [51], the researchers proposed a novel interference mitigation and power allocation technique for downlinking with the MIMO technique in HetNet. The proposed technique, called Power Allocation-Based Interference Alignment and Coordinating Beamforming (PA-IA-CB), consists of two phases. The first phase consists of two steps of IA-CB, the first step constructs the transmit and receive beamforming vectors of Sus and SBSs to cancel inter-cluster and co-tier interference among SCs. The second step involves constructing transmit and receive beamforming vectors at macro users (Mus) and MBS, to eliminate inter-cluster interference within the MC. On the other hand, the cross-tier interference between the MC and the SCs is handled by the second phase. In this phase, that cross-tier interference can be eliminated by adjusting the amount of power allocated to the MBS and SBSs and selecting SBS frequency resources that are different from those allotted to MBS. Simulation results stated that the proposed technique can be superior to the traditional MIMO-orthogonal multiple access (OMA) and MIMO-non-orthogonal multiple access (NOMA)-based HetNet in terms of overall system sum rate and outage probability at various SNRs levels and the ranges of coverage distance. Additionally, the results indicated that the proposed technique has the advantage of decreasing the signaling overhead because of the channel state information (CSI) sharing among SCs and MC. However, when the SNR value was extremely high, the system sum rate of the suggested technique decreased. This is because the impact of residue cross-tier interference becomes prominent in comparison with the noise level, which minimizes the sum rate of the proposed technique.

In [52], the model based on game theory which includes dynamic channel allocation, and a self-power optimization control method was proposed to address access exposure depending on priority by utilizing the idea of primary and secondary users. According to the simulation results, the suggested scheme was able to maximize the SINR level, channel usage, and system throughput capacity, as well as minimize outage probability, loopholes, and interference. Additionally, the proposed scheme assures high income for the operators while guaranteeing fair service costs for consumers. Nonetheless, the mobility of indoor and outdoor Ues that affect the system's power consumption was not considered in this model.

3.2. Device-to-Device (D2D)

The persistent demand for a maximum data rate with reduced end-to-end delay is one of the most significant defiance facing telecommunication providers. One method to accomplish it is via D2D communication. D2D communication allows nearby devices to communicate between them directly without passing into the BS. Due to the very low latency associated with D2D communication, it has garnered considerable attention from researchers operating on promising B5G cellular communication networks [53][54]. D2D communication can use both licensed and unlicensed cellular spectrum which is referred to as in-band and out-band communication, respectively. In the first situation, both D2D and cellular communication can coexist on the same licensed cellular spectral; this is referred to as the underlay mode of D2D communication. However, it causes increased interference between cellular and D2D users. To address this issue, a novel communication mode called overlay D2D communication was suggested, which allows D2D users to utilize a portion of cellular resources that are not allotted to typical cellular users. To avoid spectrum waste, the effectiveness of recourse allocation must be considered in the overlay mode. Concerning D2D communication performance, it provides more advantages in comparison with traditional cellular communication, when it is viable technically. The D2D communication technique is characterized by transparency besides being extremely effective in terms of massive spectrum efficiency, low energy consumption, and low latency. Thus, local traffic management becomes easier for user Ues that communicate directly in a certain vicinity. Another advantage of D2D communication is that it allows for computational offloading. D2D users under the environment of a static network can utilize D2D links for offloading computationally intensive activities to adjacent D2D users [55]. The mechanism of mode selection in D2D communication enables devices to simply move from the infrastructure communication path to the direct communication path. This helps to decrease network congestion. Economically, D2D communication has a significant role to play in commercial, e-commercial, and social apps, among others, where users can immediately share important information locally [56][57].

3.2.1. Unique Features of D2D

- Single-hop communication: A single hop is required for communication between the devices. Communication in D2Drequires fewer resources, resulting in the effective use of the spectral. Because proximity users connect directly with one another in D2D communication, latency is significantly decreased. These D2D communication features also assist the operators of mobile networks [58].

- Reusability of the frequency: When D2D communication is used in cellular networks, the same frequency is shared by both D2D and cellular users. This enhances frequency reuse, hence optimizing the frequency reuse ratio [59].

- Power levels optimization: The existence of D2D links between close-by devices results in minimum transmission power over a short distance. This extends the device's battery life. As a result, D2D communication in cellular networks can achieve improved energy efficiency (EE) [60][61].

- Increased area of coverage: Since D2D communication is feasible via relays, this allows for communication over larger distances, thus expanding the entire coverage area.

3.2.2. Communication Scenarios of D2D

There are new features defined in 3GPP Release 12 which enable the use of eNBs and core networks to facilitate D2D communication.

- In coverage mode: In this communication mode, all Ues are within the eNB's coverage.

- Out of coverage mode: In this communication mode, none of the Ues are under the eNB's coverage.

- Partial coverage mode: In this communication mode, certain Ues are covered by the eNB while others are not. Ues under the eNB's coverage communicate with Ues that are not within the eNB's coverage [62].

3.2.3. Interference in D2D

Interference management represents one of the major significant defiances for D2D communication. As explained earlier, the participating mode is the preferred mode for operators to maximize spectrum efficiency. However, this results in an interference problem. Because many cellular and D2D users utilize the same spectrum portion, they might cause interferences with each other.

To accommodate D2D communication, the cellular network's design was modified to contain two tiers instead of one [63][64]. The first tier is the traditional macro-cell tier, in which the BS and device communicate with each other. The new tier, known as the device tier, encompasses D2D communication. As a result, this type of system is referred to as the construction of a two-tier or cellular system. The device tier is an unregulated and arbitrary distribution of D2D user equipment (DUE). The new construction can significantly enhance data rate, probability of coverage, and end-to-end delay if constructed accurately [65]. However, it offers many technical defiances and problems for both device and cellular user equipment. Due to these defiances, one of the most crucial concerns for D2D communication in participating mode is interference management between cellular and D2D user equipments, in which the same frequency resources are utilized for both D2D and cellular communication. To maximize spectrum efficiency, it is preferable to use D2D communication in a participating mode. However, this creates significant interference management defiances since, in comparison to the scenarios of cellular communication, the system must manage new interference conditions. The total capacity and spectrum efficiency of the cellular system deteriorate if the produced interference is not adequately controlled, which would reduce the possible advantages of D2D communication. The most prominent interferences seen in D2D communication are classified into two categories: network domain (co-tier) and frequency domain (cross-tier) [66].

The co-tier interference between D2D users happens when one D2D user communicates with another D2D user in the same tier. To establish a direct connection between D2D users, the SINR value should be greater than a preset threshold value. Otherwise, a direct connection link cannot be created if the SINR of DUE falls below the set threshold value due to co-tier interference. Co-tier interference occurs in OFDMA systems when the same resource block set is assigned to several DUEs. The D2D pairs which are allocated the same cellular frequencies are always subject to interference from the D2D transmitter to the D2D receiver, irrespective of the frequency reuse direction (Uplink (UL)/Downlink (DL)).

On the other hand, cross-tier interference occurs when network elements are from different tiers. Cross-tier interference can occur between (i) a cellular user equipment (CUE) and a DUE, or (ii) a CUE and many DUEs. This type of interference happens when a cellular user's assigned resource blocks are reutilized by one or more D2D users. In this form of interference, the aggressor (interference source) and the interference victim vary based on the direction of resource reuse (UL/DL) [67].

Scenario 1: D2D-cellular network interference: When the same frequencies of the uplink CUEs are reused by D2D users, the D2D transmitter interferes with the BS and the uplink cellular user interferes with the D2D receiver.

Scenario 2: Cellular network-D2D user interference: When downlink frequencies from the licensed spectrum are reused by D2D communications, the BS interferes with D2D receivers, while the D2D transmitter interferes with the downlink cellular user.

Finally, both co- and cross-tier interference from the D2D transmitter can be reduced at a D2D receiver using a suitable power allocation strategy, spectrum allocation strategy, or both.

3.2.4. Interference Control Level

Generally, the strategies of interference management can be categorized as centralized, semi-distributed, and distributed according to the scenario operation.

- Centralized

In the centralized method, the interference between D2D and cellular users is completely managed by BS. This central entity combines information about each user in the network, such as the quality of the channel, CSI, and interference level. Moreover, it selects the channels that must be allocated to each user in the network with the appropriate format and power level. The central entity assigns the resources to each CUE or DUE depending on the collected information. The major issue of centralized methods is the massive amount of signaling necessary to exchange CSI and feedback. Furthermore, because the process is conducted by a single entity, which must handle massive amounts of data, the complexity of interference management increases significantly with the users' number in the network. Therefore, centralized methods are appropriate only for limited-scale D2D networks.

2. Distributed

In a distributed method, the interference management process does not need a central entity and is conducted independently by DUEs. Due to finite CSI and feedback, the distributed method minimizes control and computational cost. Thus, due to the difficulty of interference coordination, this method is better suited for large-scale D2D networks.

3. Semi-distributed

Although both centralized and distributed methods have benefits and drawbacks, trade-offs can be made between them. Interference management strategies of this type are referred to as semi-distributed or hybrid. Various levels of participation can be established in the strategies of semi-distributed interference management. Such strategies can be appropriate for relatively massive networks [59][68].

3.3.1. Unique Features of UDNs

- A massive number of SCs and AP (more than or equal to the Ues number). The massive number of SCs can enhance frequency reuse in the same manner that adjacent distance and frequency reuse operate in macro-cells. The dense SCs increase the capacity of the network by offloading the traffic of macro-cell, balancing loads of the network, and minimizing congestion [69][70].

- Dense and extensively interconnected cross-tier distribution. This comprises macro-cell, SCs (femto-cell, pico-cell), relay nodes, D2D connections, etc., which boost the network environment's complexity. Due to the multi-tier distribution, the signals of various frequencies are sent throughout the overlapping region (e.g., macro-cell and SC). Furthermore, the proximity of SCs results in a great frequency reuse factor. Thus, the coordination of sophisticated interference is critical to reducing intra-tier interference and inter-tier interference, as well as assisting with resource management [71][72].

- Quick access and flexibility of switching (e.g., handovers). In the dense distribution scenario, the mobile UE may often swap the connection among access nodes, to get, the best service, optimal communications, and so on. The performance of high-quality handover (HQHO) is required to hand over smooth and seamless communications [73][74].

3.3.2. Interference in UDNs

Interference is a tricky problem in UDNs because dominating interferers occur near the intended receivers. The coordination of interference is a sophisticated issue in UDNs because of the various BS density, which causes some BSs to interfere more than others. Fortunately, because of the relative number of Aps and Ues, several Aps may not have any linked Ues. Thus, shutting off such Aps, or minimizing their transmission power is a preferable strategy to minimize the impact of interference and total power consumption. For example, discussed three sleeping modes: cell-driven, core network-driven, and UE-driven [75][76]. The SC is triggered in the first mode if a planned active user is present. In the second mode, the network's central core has the authority to send a wake-up message to a specific BS. The last mode indicates that UE can wake up a neighboring cell by transmitting a wake-up message. The most popular types of interference in UDNs can be described as follows:

- Inter-Cell Interference: ICI occurs because of spectrum scarcity when the available spectrum is unable to meet the rising demand. To accommodate a rising number of Ues, frequency reuse mechanisms across various cells are developed. However, the ICI will be strict in UDN, as frequency reuse will be possibly increased by a factor of more than one, and will be more complex because of intensive deployment, near distance, irregular distribution, etc. Therefore, ICIC techniques should be improved to minimize ICI. The ICI can be minimized by the use of sophisticated receivers on the UE side, scheduling of joint cells on the network side, or joint collaboration between UE and the components of the network side [77].

- Multi-tier Interference: In UDN, both macro-cells and SCs are distributed through the network. Different emission powers, topologies of cells, radio access points [78][79], and other factors all contribute to the interference created by multi-tiers. For instance, SCs utilize the macro cell's frequency range, causing interference with the macro cell's UE (MUE), particularly the MUEs located at the cell edge (CE). At the CE, MUEs received a signal with significant fading and path loss [80]. When several SCs communicate over the same sub-channel, the interference with MUE will be more severe. Furthermore, because of the regulation of power, the MUE near the CE boosts its power emission, causing interference to the SC Ues [81].

- Small-to-small Interference (S2SI): Due to the high density of SCs and the topology of irregular distribution, the distributed method located on the SUE side, or the SC BS side is the preferable method to alleviate S2SI. The primary approaches for mitigating S2SI in SC BSs and SUEs are interference avoidance and interference elimination [82].

Generally, to alleviate interference, current coordination systems are established concerning partitioning the resources depending on frequency-domain, time-domain, power domain, and spatial domain either on the UE side or network side, or a control combination between them [83]. On the other hand, overhead signaling is required for cell coordination. ICI can be alleviated by the cooperative macro-cell BSs and the assistance of UE. Specifically, the coordinating scheduling of the time domain, the signal orthogonalization of the frequency domain, and the coordination of spatial cells using advanced antennas can all be employed cooperatively to alleviate the ICI. The coordination of frequency cooperation and the sensing of the UE spectrum can be able to address the multi-tier interference. In the spatial domain, the interference can be mitigated by cell clustering cooperative combinations on the network side and advanced antenna of UE with interference cancelation. Due to the massive frequency reuse and near distance, S2SI is strikingly similar to ICI. Collaborative spectrum management, adaptive carrier selection, and adaptive power management are all possible strategies for mitigating S2SI. Interference can be controlled by the coordination of the network or through advanced receiver design [84].

3.3.3. Related Work in UDNs

Based on the above methods for reducing interference, in this subsection, researchers present the most recent studies conducted on the time-domain approaches ([85][86]), frequency-domain approaches ([87][88][89][90][91][92][93]), power-domain approaches ([94][95]), and spatial-domain approaches ([96][97][98]) in UAVs, as follows:

- Time-Domain approaches

In [85], the researchers considered two-tier heterogeneous UDN (HUDN) with hexagonal macro-cells and PPP small-cell deployment. An interference-aware non-coherent coordinated multipoint transmission (IA-COMP) scenario was utilized to minimize both co-tier and cross-tier ICI for HUDN. As well, range expansion (RE) was used to optimize the load balance between macro-cells (MSs) and SCs in HUDN. The simulation results stated that the suggested technique can supply a more precise upper bound than the Monte Carlo simulation. Moreover, the system coverage increases with the larger one of the main ICI judging coefficients and the RE bias. However, the suggested technique resulted in difficult performance analysis because of the complexity of hexagonal networks.

In [86], the researchers investigated the interference management problem for UDN in the TDD downlink scenario. A location-aware self-optimization (LASO) scheme was proposed for managing the downlink ICI in UDN as well as to improve the per-user throughput by adjusting downlink transmission power offset based on the effective provision of positioning. The simulation results confirmed that the proposed scheme achieves significant SINR gain and enhanced per-user-throughput, compared with the SC on/off-discovery signal (DS). Since the LASO scheme does not require DSs, it is not affected by the UE category and does not degrade network quality as a periodic interferer due to the DS transmission. Thus, the LASO scheme is a good solution for DL interference management in UDNs. Nonetheless, increasing the number of UEs increases the interference level, and this reduces the capacity of the system.

b. Frequency-Domain approaches

In [87], the researchers investigated the interference management in UDNs based on OFDMA in a two-tier downlink scenario. A centralized user-centric merge-and-split coalition formation game in which the users engage as players in the game was proposed to predict inter-user interference and leverage users' information (e.g., distance) to aid in the distribution and utilization of subchannels. The simulation results demonstrated that the proposed techniques eliminate intra-tier interference effectively and increase total throughput significantly through the TDMA in the coalition MIMO scenario. Nevertheless, allocating orthogonal sub-channels for all users cannot be realized because of the imperfection of the available sub-channels. One common sub-channel can be associated with several users, which causes a massive CCI and minimizes the total throughput for the proposed system.

In [88], the researchers investigated the resource management in downlink multi-user-centric UDN with a massive number of lightweight access points (Aps) managed by a cloud-based intelligent transport system (ITS) for mitigating both frequency handover and ICI. The simulation results stated that the proposed scenario provides better performance in terms of RA fairness compared with the Nesterov successive convex approximation (Nesterov SCA) algorithm, multiplicative update (MU) algorithm, and centralized algorithm under the same conditions. Moreover, the proposed scenario was found to have a significant impact on theoretical and practical aspects of future V2X communication in UDN. Yet, in this scenario, the SINR decreased significantly with the increment of the vehicle hotspot size. This is due to the difficult management between VCs when increasing the multicast group size, which causes a decrease in the system data rate. The effect of intra-cell interference was not taken into consideration.

In [89], the researchers investigated resource management in UDNs based on single-carrier OFDMA in an uplink scenario. A conflict-graph strategy based on machine learning that uses the uplink SINR and RB allocation data was proposed. Simulation results showed that the proposed strategy is both practical and precise. Therefore, this strategy was able to be implemented with network auto-adjustment and optimizing intelligent RA. Yet, the effect of CCI in this strategy was found to be severe due to the reuse of the RBs, resulting in throughput degradation.

In [90], the researchers investigated a joint RA and SIC in UDNs based on NOMA in a two-tier downlink scenario. An interference management strategy was proposed that involves joint optimization of clustering, sub-channel allocation, and SIC. The simulation results indicated that the average capacity and spectrum efficiency for the proposed strategy increased significantly as compared with optimal Femto base station sub-channel allocation (OFBSSA) and cluster-based Femto base station sub-channel allocation (CFBSSA) strategies. However, the average capacity of the proposed system decreased significantly due to many reasons such as an increase the co-tier interference, the number of FBS users in overlapping areas, and interference among users.

In [91], the K-mean clustering algorithm was applied for determining the optimum number of clusters to increase network capacity while considering frequency reuse usage and inter-cluster interference. The BSs and UEs were distributed randomly throughout the cluster using the PPP scenario. The simulation results indicated that the best number of clusters is around 13, and it was discovered that the operating frequency band has the greatest influence on the optimum number of clusters. However, when a certain threshold was crossed, the inter-cluster interference increased with the increment of the number of clusters. Nonetheless, when the number of clusters increases, the interference also increased, and this led to a decrease in the channel capacity of the proposed system.

In [92], the researchers investigated the interference management problem for two-tier UDNs in the uplink scenario. A cross-tier cooperation load-adapting interference management (CCLA-IM) distributed strategy was suggested to minimize ICI by RA optimization between users in UDNs. The simulation results stated that the suggested strategy provides superior performance in terms of SE, SBSs throughput, EE, and ICI allocation whereas users' density and traffic loading were altered in UDNs. Nevertheless, the increased number of users who share the same bandwidth decreases the density of SBSs because of the increased uplink interference from the surrounding users. Furthermore, the increment number of users per SBS led to an increase in the mutual interference among various users served by various SBSs, which caused a decrease in the average EE of the proposed system.

In [93], the researchers investigated the coordinative interference management in UD-SCN based on OFDMA in a two-tier downlink scenario. A new and simple-to-implement interference reduction technique that depends on a hierarchical clustering algorithm (HCA) between SBSs to calculate the member pairs was proposed. The simulation results indicated that the proposed scenario could increase the data rate of the network by 422.13 % for a network of 100 cells as compared with the non-cooperative scenario in a UD-SCN. Furthermore, it was especially suitable for hyper-dense deploying networks of SBSs. Yet, the effect of CCI in this technique was found to be severe due to the sub-channel being allocated to more than one SUE, resulting in data rate degradation in the proposed system.

c. Power-Domain approaches

In [94], a new non-cooperative game theory-based interference mitigation strategy for uplink power allocation was proposed to mitigate the ICI and optimize energy efficiency in the uplink mm-wave UDN multicarrier system. The simulation results demonstrated that the suggested strategy considerably improves EE performance while maintaining an acceptable SE performance as compared to previous iterative water-filling strategies. Moreover, the suggested strategy offered a low computational complexity. However, each SUE selected its own PA strategy depending on the assumption of optimizing its EE without considering the influence of other SUEs, which caused an increase in power consumption.

In [95], the researchers investigated interference mitigation in downlink indoor coverage scenarios with autonomous UDN deployment. A completely distributed self-learning interference minimization (SLIM) scenario for independent networks under a model-free multi-agent reinforcement learning (MARL) structure was suggested for mitigating ICI, accommodating additional UEs, and decreasing the outage ratio of the system. The simulation results demonstrated that SLIM outperforms several existing known interference coordination schemes in mitigating interference and reducing power consumption while guaranteeing UEs' QoS for autonomous UDNs. Nonetheless, by increasing the number of users, the ICI increased as well, and the system became overloaded, leading to maximizing the outage ratio.

d. Spatial-Domain approaches

In [96], the researchers considered a HetNet where a macro-cell layer provides essential service and coverage was overlayed by an ultra-dense layer of SBSs. A novel metric technique was proposed to optimize a UDN's downlink throughput with an appropriate degree of special spectrum reuse (SSR). The simulation results demonstrated that a UDN must achieve an optimal trade-off between reuse of the spectrum and interference to provide high throughput and low outage performance. Nevertheless, when the number of SCs increased, the outage threshold also increased. This is mainly due to the increased users' number in the outage, specifically for the total reuse. This resulted in a decrease in the throughput.

In [97], the researchers adopted chance constraint programming (CCP), in which occasional violations of the load threshold at BSs were permitted, and they introduced a control parameter, called risk level, to address traffic uncertainty while also achieving the trade-off between load balancing and the probability of constraint violation. The numerical results stated that the suggested strategy is resistant to traffic uncertainty. Furthermore, it was able to suppress severe interference and use the density of BSs to achieve superior load balancing performance compared to existing benchmark systems. However, a significant time delay could be observed for the proposed system if there was a high traffic level, in which each BS was compelled to offload the traffic from other BSs. This caused an increase in the congestion risk due to the arrival of burst traffic.

In [98], the researchers investigated the small-cell clustering in UDN based on orthogonal frequency division multiplexing (OFDM) in a two-tier downlink scenario. A user-centric adaptive small-cell (SC) clustering strategy relying on an enhanced K-means algorithm was presented to decrease interference in UDN. The simulation results demonstrated that the proposed approach is capable of dynamically adjusting the number and size of SC clusters in response to the user's SINR and effectively reducing the complexity associated with the clustering process. It is important to mention that the radio RA strategy was not considered in this strategy, which has a significant effect on the optimal fairness among the users.

3.4. Unmanned Arial Vehicle (UAV)

A UAV, sometimes known as a drone, is a type of flying aircraft that can be controlled from the ground without the use of a human pilot. The primary application of UAVs is as temporary flying BS in B5G communication. UAVs often fly via low-reliability point-to-point connectivity, which leads to lost signal at any moment during the flight. High reliability and minimal latency are two advantages of using a B5G network for UAV operations. This implies that a UAV can quickly receive and respond to orders sent by the ground control system or pilot. B5G speeds up the process of transmitting, receiving, and responding to orders, thus lowering the error margin that may occur during the flight. This low latency is very important when UAVs are flying in areas where a global positioning system (GPS) is not available or when they are flying beyond line of sight (BLOS). UAVs cannot use GPS in this situation, so they have to use visual-inertial odometry (VIO) to navigate in places where the view of the pilot is occluded [99]. To provide the pilot with a precise view of where the UAV is, B5G will allow the UAV's camera feed to be updated in real-time on the ground control system (GCS) of the pilot [100]. Air inspection, delivery, film and entertainment, critical missions, surveillance, intelligence, and mapping are just a few of the applications that will benefit from UAVs running on a B5G network [101]. UAVs enabled-5G can safely carry medical supplies such as COVID-19 testing to impacted populations by restricting human-to-human interaction and therefore avoiding infection spread [102]. A UAV used for rescue and search can send data and images in real-time and with low latency, which increases the speed and efficiency of the search and rescue process. In general, the accuracy and low latency of B5G will enable these new use cases and boost the adoption of UAVs. This exponential growth of UAV-enabled applications in the high-speed wireless communication field B5G has resulted in a paradigm shift in the wireless communication field [103]. The main benefit of UAV-assisted wireless communication is that it is the most appropriate technique for providing wireless connection and coverage to end-users who lack infrastructure coverage. The main benefit of UAV-assisted wireless communication is that it is the most appropriate technique for providing wireless connection and coverage to end-users who lack infrastructure coverage because of mountainous terrain, densely populated areas, severe shadowing, and degradation of communication infrastructure due to natural disasters [104].

3.4.1. Unique Features of UAV

UAV communications demonstrate the following significant characteristics as a prospective option to replace or supplement terrestrial cellular networks [105][106]:

- LoS connections: UAVs flying in space without human pilots have a greater chance of connecting to ground users via LoS connections, which enables very reliable communications over long distances. Furthermore, UAVs can change their hovering places to preserve communication quality.

- The capability of dynamic deployment: In comparison to the ground station's infrastructure, UAVs can be distributed dynamically based on real-time requirements, making them more resistant to changes in the environment. Furthermore, UAVs as aerial BSs do not need the expense of site rental, eliminating the necessity for cables and towers.

- Swarm networks based on UAVs: A swarm of UAVs can establish scalable multi-UAV networks and provide ubiquitous connections to ground users. A multi-UAV network is a good choice for quickly restoring and expanding connectivity because it has a high degree of flexibility and speed of service.

3.4.2. Types of UAV

There are several varieties of UAVs. To maximize the efficiency of UAV use, it is necessary to utilize an application-particular type. UAVs are categorized based on their altitude and the type of wings [107].

UAVs are classified as low-altitude or high-altitude UAVs as follows:

- Low-altitude platforms (LAPs) are easier to install and deploy than high-altitude platforms, but their coverage area is smaller, and their endurance time is shorter than high-altitude platforms.

- High altitude platforms (HAPs) can support the task for many months, but they are more expensive to deploy than low altitude platforms (LAPs).

Depending on the wing type, UAVs can be classified as fixed-wing or rotary-wing as follows:

- A fixed-wing creates lift utilizing forward-moving wings. It requires a runway for takeoff and landing, and it must be able to maintain a certain forward speed. Its features are simple construction, high speed, and large cargo.

- A rotary wing uses blades that revolve around a rotor shaft to generate lift. It is capable of hovering and moving in every direction. Its mechanism depends on vertical takeoff and landing. Its features are a lower payload, a shorter range, and a slower speed [108].

3.4.3. Interference in UAVs

Interference with a UAV in flight may prove damaging to the UAV's mission success. The most serious types of interference are those that affect global navigation satellite system (GNSS) transmissions. This may force the UAV to compromise on the quality and accuracy of the data it stores. Once the data is analyzed, this may lead to re-fly the task again. Interference could lead to a complete loss of signal and UAV because it will lose tracking and positioning [109]. There are two main types of interference in UAVs. The first type is internal interference which represents the interference from other electronic devices on the UAV. Due to the compact size of electronic devices, certain GNSS antennas are located next to other electronic and electrical equipment. The second type is external interference which refers to the other interference sources that can come from the UAV itself, whether deliberate or not.

Certain operations, such as inspecting bridges and other relevant structures, employ UAVs that are close to roads. In this situation, the probability of interference from in-car devices such as jammers increases. This type of device is illegal, inexpensive, and easily available [110].

A UAV designer should consider utilizing receivers and antennas that are very precise to achieve very high accuracy and to get rid of interfering signals from third parties, thereby providing data with high reliability [111].

3.4.4. Related Work in UAVs

In this subsection, researchers present the most recent studies conducted on drone interference schemes ([112][113][114]), inter-cell interference schemes ([115][116][117][118]), co-channel interference schemes ([119][120][121][122]), and mutual interference schemes ([123][124][125]) in UAVs, based on the interference management schemes used for mitigating these types of interference, as follows:

- Drone Interference Schemes

In [112], a reverse frequency allocation (RFA) scheme with decoupled association (DeCA) was proposed to minimize the effect of ICI, drone interference (DI) and enhance the uplink SIR of MBS coverage edge users. The DI is a result of excessive drone utilization (EDU) for 5G-enabled apps, whereas the ICI is a because of the deployment of multi-tier. Two-tier HetNet was considered. Simulation results stated that the proposed scheme produces an increase in the SE due to improved uplink coverage as opposed to the coupled association (CA) with RFA. Nonetheless, an increase in the density of drones caused significant DI and consequently reduced the UL coverage of the proposed model.

In [113], Drones were used as air routers to construct a LAN in complicated pipeline networks. An optimum 3D drone scheme based on two-phase evolution was presented for use in the deployment of drones, which allows pipeline inspectors to receive instructions and respond to accidents in real-time, thereby reducing the effect of accidents when they carry special communication equipment to inspect pipelines. The proposed scheme analyzed the quality of coverage issue and signal interference issue in two phases and minimized drone signal interference while preserving the feasible quality of coverage. The simulation results revealed that the proposed scheme can find out the optimum and maximum drone deployment in a few steps and was more feasible than the clustering and greedy schemes. However, when the number of drones and the distance between them increase, the effect of interference also increased. As a result, the spectrum efficiency of the proposed scheme decreased.

In [114], the potential benefits of joint detection (JD) in a hybrid-duplex (HD) UAV communication system were investigated as a step toward overcoming the scarcity of spectrum in UAV communications. A new method for obtaining closed-form explanations for the outage probability and limited SNR diversification gain of a joint detector operating across Rician fading channels was presented. The analysis of the multiplexing gain region (MGR) demonstrated that the HBD-UCS based on JD provides higher SNR diversification gain with better QoS requirements compared with the HBD-UCS based on interference ignorant and HBD-UCS based on the SIC detector. However, increasing the inter-UAV interference resulted in maximizing the probability of an outage. Thus, the optimal coverage probability of the proposed system decreased.

b. Inter-cell Interference Schemes

In [115], the interference management scheme based on UAVs was proposed for optimizing the performance of in-band UAV-aided integrated access and backhaul (IAB) networks. Two modes of spatial configuration for UAVs were presented, namely distributed UAVs and drone antenna array (DAA); according to the spatial distribution of the ground user. The simulation results indicated that the attainable performance benefits are directly proportional to the number of drone elements in DAA. Moreover, the complexity of the proposed scheme was unaffected by the number of UAVs when designed as DAA. Nevertheless, when the number of UAVs increased, the mutual interference levels between access and backhaul links also increase, and this led to a decrease in the performance of the proposed scheme.

In [116], a generalized side-lobe mitigation strategy applicable to collaboration beamforming (CBF) in 3D-UAVs wireless sensor networks utilizing the gravitational search scheme (GSS) was designed to minimize interference and improve coverage capacity. The simulation results stated that the proposed strategy outperforms the peak side-lobe mitigation strategy in terms of the total side-lobe level and the performance capacity. The proposed side-lobe mitigation strategy was an excellent candidate for implementation in CBF in feasible wireless sensor networks based on 3D-UAVs. However, the mobility of sensor nodes that affect the system power consumption was neglected in this strategy.

In [117], the researchers investigated a distribution algorithm for interference management in UAV HetNets two-tier downlink scenarios that influence the mobility of UAV, optimized ICIC and cell range expansion (CRE) methods. The simulation results demonstrated that a simple heuristic-based ICIC strategy beats the deep Q-learning-based ICIC strategy. Taking advantage of various optimization factors for interference coordination, the ICIC strategy based on heuristic can realize 5pSE values that are relatively close to those obtained with comprehensive brute force search strategies, with significantly less complexity. Yet, the impact of Rician or Rayleigh fading that causes a decrease in the SE of the proposed scenario was neglected.

In [118], the researchers investigated interference management based on an artificial intelligence (AI) solution and used a single AI agent to model all MBSs and UABSs in the UAV HetNet two-tier downlink scenario. A greedy algorithm and an algorithm based on double deep Q-learning (DDQN) were proposed to compute the optimal FeICIC and eICIC criteria independently for all MBSs and UABSs, and the positions of UABSs, to optimize the mean and median SE. In comparison to traditional optimization methods, for the suggested algorithms, the greedy algorithm was able to obtain better performance in terms of mean and median SE, while the AI approach achieved 95.83 % and 93.46 % of the optimum mean and median SE respectively. However, the effect of Rician or Rayleigh fading that minimizes the SE of the proposed model was not taken into consideration.

c. Co-channel Interference Schemes

In [119], the co-channel interference in the industrial, scientific, and medical (ISM) frequency band 2.4 GHz between UAV and connected WLAN vehicles system was investigated according to the disturbing system's received SNR. The simulation results stated that if the height separation between the UAV and the WLAN-connected vehicles system is more than 6.2 km, the UAV elevation angle can guarantee that there is no co-channel interference with the WLAN-connected vehicles system in all statuses. Moreover, it was found that increasing the UAV elevation angle can mitigate the UAV interference with the WLAN-connected vehicles system. Nonetheless, this neglected the variable altitude and elevation of the UAV that affect the received SNR of the proposed system.

In [120], the researchers investigated the joint unmanned aerial vehicles-ground user (UAV-GU) association, sub-channel allocation, and UAV track control issue for wireless networks based on UAVs with spectrum re-utilization and interference management to enhance the fairness of resource participation among ground users concerning the requests of their data transition and spectrum re-utilization. Furthermore, it was demonstrated that the deployed number of UAVs, the number of subchannels, and the maximum velocity of the UAV all have significant effects on the realized maximum–minimum average rate. Nevertheless, when the number of ground users and UAVs increased, the co-channel interference also increases, and this resulted in a decrease in the average data rate of the proposed method.

In [121], the researchers investigated the downlink interference problem of the UAV and internet of vehicles (IoVs) cooperative network that exists in the same region. In which the compatibility of frequency between UAVs and IoVs operating in the Ka-band is studied to quantify the separation distance necessary to avoid co-channel interference between UAVs and IoVs. The simulation results stated that the noise and interference ratio between UAV and IoV is calculated under various steering angles between interference and interfered antenna and various altitude angles from UAV to geosynchronous orbit (GSO) satellite. Yet, the interference probability and duration that have a massive effect on the system gain were not considered in the calculation process of the proposed algorithm.

In [122], the researchers investigated the interference management in uplink wireless UAV-enabled information collection from a dispersed set of sensors in the scenario of IoT by using the mobility of several UAVs operating in the same band of frequency for the supporting network. According to the simulation results, the proposed algorithm with RA, and track optimization took at least 25% less time than previous dynamic orthogonal benchmark algorithms when deployed with four UAVs. Finally, a perceptible metric and associated concept for assessing the appropriateness of the suggested algorithm were presented, which can aid in the creation of a strategy for calculating the maximum number of UAVs that can be used in practice. However, this did not take into consideration the altitude freedom of UAVs that can help to minimize interference and optimize the performance of the proposed system.

d. Mutual Interference Schemes

In [123], the idea of associating SCs with network flying platforms (NFPs) in HetNet, eliminating total interference and maintaining a minimum data rate requirement was formulated. The simulation results stated that the proposed algorithms return sub-optimal solutions with less complexity and minimum overall interference. However, the mobility and power consumption of NFPs, which affect the system's power consumption, were not considered.

In [124], the researchers investigated a transmission method based on TDMA in both up and downlinks scenarios to maximize the data rate between a BS and UE by using multiple relaying UAVs. A joint optimum strategy for 3D track design and power allocation was proposed to maximize the network's data rate while meeting the interference restriction. The simulation results demonstrated the effectiveness of the proposed strategy in optimizing the maximum flow and mitigating interference. Yet, in this strategy, the effect of the non-LoS path that has a massive effect on the system's data rate was neglected.

In [125], a power optimization based on CoMP and clustering strategy was designed in a UAV-assisted network. The strategies of power allocation were then updated frequently until convergence is achieved, and the ultimate optimum PA result is acquired. The results demonstrated that the cluster size regularity, cluster number, and the limitation of minimum distance have large effects on interference mitigation. Nonetheless, when the number of ground users increased, the inter-cluster interference also increased, and this caused system data rate degradation. Furthermore, the mobility of ground users and UAVs that affect the power allocation of the proposed system was not taken into consideration.

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