HetNet Characteristics and Models in 5G Networks

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Summary
The fifth generation (5G) mobile communication technology is designed to meet all communication needs. Heterogeneous networks (HetNets) are a new emerging network structure. HetNets have greater potential for radio resource reuse and better service quality than homogeneous networks since they can evolve small cells into macrocells. Effective resource allocation techniques reduce inter-user interference while optimizing the utilization of limited spectrum resources in HetNets. This article discusses resource allocation in 5G HetNets. This paper explains HetNets and how they work. Typical cell types in HetNets are summarized. Also, HetNets models are explained in the third section. The fourth component addresses radio resource control and mobility management. Moreover, future study in this subject may benefit from this article's significant insights on how HetNets function.
Keywords:
HetNets, Resource allocation, 5G, small cells, femtocells

1. Introduction

The fifth-generation (5G) mobile communication system is aimed to increase capacity by 1000 times compared to the fourth-generation (4G) mobile communication system. In addition, the spectrum efficiency (SE) of the 5G system increases by 5 -15 times [1]. 5G incorporates diverse technologies and techniques as follows [2] [3]:

- unmanned aerial vehicles (UAVs)
- cloud computing
- mobile edge computing (MEC)
- cloud radio access networks (CRANs)
- Internet-of-Things (IoT)
- communications
- communications
- vehicular networking

From the standpoint of network design, wireless networks progressed from homogeneous networks (HomNets) to heterogeneous networks (HetNets). The 3rd generation partnership project (3GPP) established the HetNet in Release 12 [4]. By sharing the same spectrum resources (SRs), HetNet enables various kinds of small cells to cooperate with macrocells, which may greatly enhance SE and minimize inaccessible zones . The following are the three spectral sharing mechanisms used by HetNets:

(i) Underlay Spectrum Sharing: small cell users and marcocell users are sharing the same SR. However, this type of SR sharing introduces the problem of interference between users of all adjacent cells. Therefore, a solid technique is needed in order to control the interference and overcome the side effects of the interference on the network capacity.
(ii) Overlay Spectrum: sharing in this mechanism small cell users cannot use the same SR, which is used by the microcell users. Instead, small cell users use only the free SR, which is not used by the microcell users.
(iii) Hybrid Spectrum: in this mechanism the whole SR is divided into two parts. The first part of RS can be only used by small cell users or microcell users. On another hand, the second part can be shared amomg small cell users and microcell users.

It is also necessary to take into account the methods through which people are logging on to and connecting to the network. There are two access mechanisms in HetNets: closed access and open access [5]:

(i) Open Access: Under this mode, users are permitted to link with a small-cell base station or a macro-cell base station according to the covered zones. For instance, if a user is inside the coverage of a small cell, user can access this cell. On the contrast, if the user is out of the small cell range, but it is inside the macrocell range, it is permitted to link with the macrocell base station.
(ii) Closed Access: Under this access mode, the subscribed small cell users only can connect to the small cell. Likewise, the non-subscribed macrocell users would access only the macrocell even if they are inside the range of small cells.

The advantages of the HetNets are highlighted as follows [6]:

- Improving SE: While spectrum resources are few in traditional HomNets, it is preferable to develop a technique of improving SE. HetNet can coexist with other cells to increase SE and enable seamless connection at any time or place, as demonstrated in Fig. 1. The figure depicts how various networks with different capacities are divided into several

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tiers, ranging from communications in space to communications on the ground. Heterogeneous macro-micro networks, such as those found on the ground, are illustrated by the classic HetNet. To create a multi-tiered HetNet, licensed spectrum should be shared between macrocell users and innovative networks (such as D2D and V2V) as well as classic macro networks. However, in the future, HetNets will move away from ground-based communications and toward space-based communications, such as low- and deep-orbital communications. For instance, when the UAV as an air BS feeds various ground terminals, D2D users may share the spectrum of ground terminals, which establishes a low- altitude heterogeneous fusion network. Furthermore, deep-space satellites, near-orbit satellites, and airships may build a global HetNets.

- Reducing delay and Loss: The network loss and channel gains between mobile terminal and macro base stations are severely impaired if the small cells are not considered in the wide-area communication scenarios. For example, when small cell base stations are located intermediate macro base stations and mobile terminals, the backhauling signals from mobile terminals to macro base station can be accomplished with a minimal path loss.
- Reaching uncovered zones: The deployment of access points (APs) at the poor channel environments holds a promise technique for reducing the range of uncovered zones and expanding the channel capacity by spreading different small cells such as picocells and femtocells.
- Improving network capacity: Many mobile terminals with various access strategies are permitted to coexist in the same physical place so that the total capacity can be enhanced significantly.

All kinds of communication situations are intended to be met by the fifth generation (5G) mobile communication system. Heterogeneous networks (HetNets) have been investigated in recent years as a novel evolving network structure. Because of HetNets' ability to expand small cells to encompass macrocells, they provide more potential for radio resource reuse and higher service quality for users than homogeneous networks. Effective resource allocation (RA) algorithms are critical to reducing inter-user interference in HetNets while also maximizing the use of the restricted spectrum resources. Resource allocation in HetNets for 5G communication is the subject of this article. This paper goes over what HetNets are and how they could be used. In the next section, a brief of cell types is given. Third section contains explanations about HetNets models. Fourth section explains the mobility management mechanisms. Also, research in this field might benefit from this article's valuable insights on how HetNets work, which can be utilized to drive future developments.

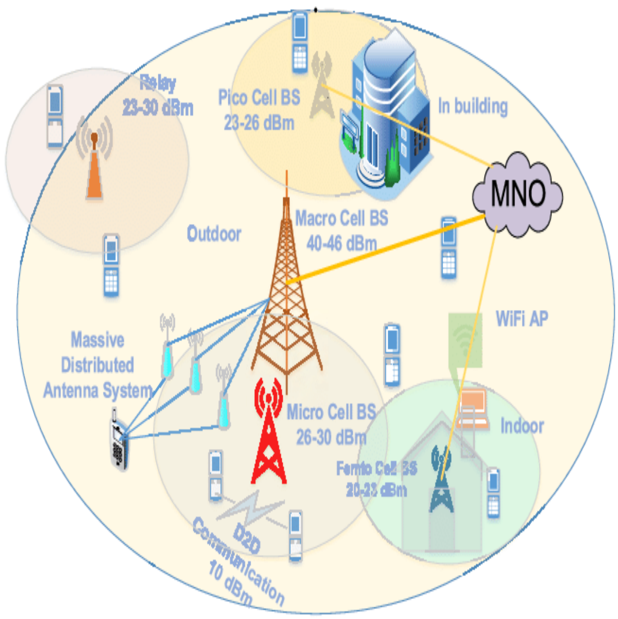

Fig. 1 HeNet Infrastructure [7].

2. Cell Coverage Categories in HetNet

Typical HetNet made up of a large number of different cells. Network types could be categorized into four groups based on the various coverage regions and application situations [8].

(i) Macrocell Networks: In a macrocell network, a high-power BS is utilized to cover a large region, as is the case in most cellular networks. The macrocell network has the following characteristics: It has a long transmission distance and a broad coverage area, with a cell radius ranging from 1 km to 25 km, since the MBS is always situated in a high spot, such as atop a mountain or a skyscraper, from where it can provide a clear view of the surrounding structures and barriers. The cell-edge user's QoS is severely impacted by shadow fading and multipath interference; (iii) There are uncovered spots or hot spots due to unevenly distributed service requests; (iv) The QoS of attached indoor UE is degraded when it is served by the MBS because of the uneven distribution of service requests.

(ii) Microcell Networks: In heavily populated metropolitan areas, such as retail malls, a low-power BS serves a microcell network. This network has a significantly lower coverage area (200 m to 1 km) than the macrocell network. As the low-power BS's frequency reuse distance shrinks, so does the number of channels and the density of traffic.
(iii) Picocell Networks: In comparison to the microcell network, a picocell network (e.g., 100 m-200 m) covers a smaller region (e.g., compared to the microcell network). Indoor regions are often covered by picocells. As a consequence, there will be fewer places where people are unable to communicate.
(iv) Femtocell Networks: In the case of a femtocell network (also known as a House eNode B), a compact and low-power BS is meant to enhance communication quality in a home or small business location. Using the home BS improves the quality of service (QoS) for indoor users. Femtocells, on the other hand, are significantly simpler and more lucrative to install than other cell types. In addition, femtocells may fill in the gaps of picocells and prevent signal loss via the buildings, making them ideal for cellular coverage. Femtocells have a far smaller user base than picocells, which is the primary distinction between the two technologies.

Table 1 summarizes the features of various networks based on the information presented previously. The BS's transmission radius is denoted by the radius. The BS's maximum transmit power is indicated by the term "power." Each cell's application environment is defined by the scenario.

Table 1: Network Types of HetNet

Type	Range in km	Transmission Power (W)
Macro	1 - 20	20 - 160
Micro	0.3 - 1	2 - 20
Pico	0.1 – 0.25	0.25 - 2
Femto	0.01 – 0.05	0.01 – 0.2

3. The Model of HetNets Networks

In this section, we will cover a variety of communication scenarios for HetNets, including single-antenna transmission, multiple orthogonal subchannels, orthogonal multiple access (OMA), non-orthogonal multiple access (NOMA), and multi-antenna transmission, all of which are based on the aforementioned cell types and communication types [9].

(i) Traditional HetNets: in the network model of classic HetNet each BS and each user equipped with a single antenna connects with a femto BS (FBS) or an MBS without relay nodes. In this network topology, there are at least two kinds of networks, such as macrocells and femtocells. The macrocell network as a major network is the owner of SRs and femtocells utilize the same SRs held by macrocells. Femtocell users modify their transmit power for minimizing the cross-tier interference to macrocell users as well as assuring the QoS of FUs. The MBS serves multiple macrocell users using an uplink/downlink transmission. Besides, femtocells are created to deliver high throughput and fulfill the QoS needs of femtocell users.
(ii) NOMA-Based HetNets: To increase performance, NOMA has been suggested to enable additional users to utilize the same sub- channel with the use of successive interference cancellation (SIC). NOMA's primary premise is to achieve non-orthogonal RA across various users while increasing the complexity of the receiver hardware. Also, in a power-domain NOMA system, various NOMA users are assigned varying power levels by the BS depending to the channel quality. The same time/frequency/code resources may be shared across numerous users. Furthermore, on the receiver side, the signals of distinct users are deciphered by employing SIC. Due to the benefits of NOMA, the combination of NOMA with HetNets generates a new NOMA HetNet which can improve overall throughput and enormous connection.
(iii) OFDMA HetNets: To lower the mutual interference among various subcarriers and enable more users to access into HetNets, orthogonal frequency division multiplexing (OFDM) was designed and incorporated into HetNets by splitting the SRs into numerous orthogonalized subcarriers (also called subchannels) [10]. The subcarriers may fulfill the communication needs of users through a dynamic subcarrier allocation. Hence, orthogonal frequency division multiple access (OFDMA)-based HetNets are vital for boosting network throughput and supporting more users.
(iv) Multi Antenna NetNets: Multi-antenna Using a large number of antennas at the base stations, HetNet is yet another sophisticated wireless network architecture based on spatial multiplexing. By using transmit beamforming, MIMO channels may provide many users with spatial division

multiple access (SDMA) [11]. Unlike the single-antenna channel, the direct/interfering connections in multi-antenna HetNets have different properties. A numerous antennae are deployed in the MBS. It may give effective communication for macrocell users and also deliver higher interference power to picocell users (PUs). Moreover, in the multi-antenna networks, there are three main types, which are single-input multiple-output (SIMO), multiple- input single-output (MISO), and MIMO massive MIMO is a particular instance of (MIMO) [12]. The idea of massive MIMO has been introduced by T. L. Marzetta [13]. The amount of antennas in massive MIMO systems can be more than 100 antennas. The benefit of installing several antennas is to decrease the influence of noise, inter-cell interference, and large-scale fading. Moreover, the beamformer technique is simpler than standard MIMO systems. For instance, in massive MIMO systems, it is important to develop the hybrid analog/digital beamforming. Traditional MIMO systems, on the other hand, simply examine the digital beamforming architecture. Nonlinear precoding strategies (such filthy paper coding) can be utilized in typical MIMO systems. It is possible to employ a simple linear precoding scheme for a large-scale MIMO system.

(v) H - CRAN HetNets: to accomplish centralized processing and multiple networking functionalities, cloud computing has been added into HetNets, such as H-CRANs. As a novel network architecture, H-CRAN combining the benefits of cloud computing and HetNets can offer strong processing capabilities and high throughput. Moreover, the network can effectively deal with the large-scale data processing and management. The remote radio heads (RRHs) are considered as an essential component in the architecture of H-CRAN and they are deployed in hot zones and offer high and speed data services. Also, the coordination of network resources is handled via the cloud's baseband unit pool (BBU). Using fronthaul connections, the low-cost RRHs are linked to the BBU pool for centralized management. Furthermore, in order to optimize Spectral Efficiency, it is necessary to coordinate and minimize the excessive inter-tier interference between the Macrocell base station and RRH.

(vi) Relay HetNets: Relay communication (sometimes termed cooperative communication) would efficiently increase the coverage of the network. Consequently, more and more researchers integrate HetNets with relays to construct a heterogeneous relay network for achieving a large coverage area. The signal transmission of relay-based HetNets is accomplished with the aid of relays (e.g., Femtocell base station or Femtocell Users). The transmission route is substantially more complicated and the transmission method is more adaptable.

4. Mobility Management

Handoff systems for HetNets are also critical to ensure great quality of service (QoS) and perfect mobility across networks. Handoffs in multi-tier networks need the use of mobility management. HetNet handoffs allow mobile nodes to effortlessly switch between wireless networks without affecting their performance. Handoff methods may be divided into two broad categories: vertical and horizontal [14].

(i) Vertical handoff: as the mobile terminal moves across an area covered by many wireless networks, it is referred to as a vertical handoff. Inter-system handoff is another name for it. Different access technologies were used to link the various systems. The vertical handoff in HetNets also consists of the uplink and the downlink handoffs. With the first setting, the mobile terminal roams to a large-coverage network with a limited bandwidth. Mobile terminal roams to the small-coverage network with a higher bandwidth in the later case.

(ii) Horizontal handoff: as opposed to vertical handoff, which deals with the mobility of the user, horizontal handoff deals with access/network technologies. The internal system is where the handoff takes place.

5. Resource Allocation

There are three different mechanisms to allocate radio resources in HetNets: centralized, decentralized, and distributed. All channel gains, interference power information, user's QoS requirements, and so on, can be acquired by small base stations and macro base stations as the central resource manager in a centralized mechanism. The ability to collect data from all around environments is an advantage of the central approach. Therefore, the significant computational complexity and energy overhead of cross-tier/inter-tier information exchanges and channel delays may substantially decrease the effectiveness of radio resource mechanism. As a result, an ultra-large-scale network might be unable to support this phenomenon.

It is possible to allocate resources in a distributed mechanism [15] without requiring central processing equipment to deal with coordination and interaction of information. The base stations may benefit from this approach since it reduces the computing burden.

Decentralized mechanism [16] is characterized by the absence of coordination between the transmitters as well as the absence of signaling overheads for the purpose of exchanging Channel State Information (CSI). Without a central resource manager, each base station may execute its own resource allocation. Accordingly, the CSI of a direct connection between the small base station and a small cell user's receiver is required. Different base stations, on the other hand, may coordinate all information to maximize the total network utility.

Designing an algorithm for resource management can be based on one of the following utility functions from the point of view of performance criteria: maximum energy efficiency, minimal mean square error, minimum total transmit power, maximum throughput, maximum weighted rate/secrecy rate, maximum number of accessing users, etc. The radio resource allocation optimization issues and the methods used to solve them are distinct for each objective function.

To tackle radio resource allocation problems in HetNets, it is vital to recognize the typical techniques. There are several techniques such as heuristic algorithms, learning-based algorithms, game theory, graph theory, match theory, convex optimization while allocating radio resources with perfect CSI. On another hand, there are robust and stochastic optimization methods for radio resource allocation in the presence of inaccurate CSI.

For radio resource allocation in HetNets, optimizing various parameters for accomplishing particular goals (e.g., maximal energy efieciency) is very significant. Many HetNets optimization factors should be taken into account, including transmit power, cell selection, RB allocation, and so on. Also, the transmit power must be constantly adjusted to ensure the quality of service (QoS) of users and maximize the overall rate of HetNets.

Depending on the design of the network, radio resource allocation issues may arise, and the difficulties they provide are distinct. In terms of network designs, there are classic HetNets, of which NOMA-based HetNets and so on. Optimization variables, system models, and restrictions may all be affected by varied network circumstances. As a result, the HetNets network scenarios must be figured out.

6. HetNets Challenges and Future Research

6.1 Network Scenario

In recent times, various unique techniques have been introduced. For example, breakthrough technologies like carrier aggregation, intelligent reflecting surface (IRS), millimeter waves were suggested to enhance the capacity of the networks. The combination of these techniques with HetNets may yield some novel HetNets that could make the RA concerns more challenging. In the sixth generation (6G) mobile communication system, the ultra-dense network development will become an inescapable trend such that the combination of the forthcoming methodology and the HetNet may successfully handle this issue. For instance, an IRS-assisted HetNet may provide a greater capacity and reduced power consumption. However, the B issue is difficult to address because of the linked transmit power and the phase shift of IRS. Producing a solution for combining both low-complexity and high-flexibility network model for further increasing network performance is an important area of investigation.

6.2 Spectrum

Spectrum resource is a valuable and restricted resource, so that we need to develop effective strategies to increase Spectral Efficiency. For the next- generation HetNet, it goes towards an intelligent and adaptive management communication system. Cognitive radio may increase the Spectral Efficiency of the network in an adaptive approach, where the users with cognitive capabilities can dynamically identify unoccupied spectrum and utilize spectrum resources. Spectrum sensing-based HetNet is a crucial technology to increase Spectral Efficiency. In cognitive HetNets, finding a good balance between spectrum detection capabilities and dynamic resource allocation is a major challenge. The inaccurate probability of spectrum sensing might offer additional obstacles for successful resource allocation algorithms.

6.3 Security

The next generation of HetNets will face several risks from the radio frequency environment, such as eavesdroppers and fake base stations, that make it imperative that they find ways to increase communication security. The current resource allocation techniques may be ineffective if we include secure communication into the models of resource allocation issues in advance. As a result, more study and research for HetNet communication security is essential.

6.4 Power consumption

With the growth of 5G, energy and power consumption becomes a serious problem. Boosting the speed of data transmission while minimizing energy usage is complicated matter. The integration of the energy harvesting technology or green communication technique with HetNets is a meaningful of research and study. Energy efficiency-based resource allocation algorithms may become the effective ways to overcome the mentioned concerns.

6.5 HetNets structure

As depicted in Fig. 1, future HetNets expand from ground communication to space communication or underwater communication. The interference management and network handoff across various networks provide additional obstacles to radio resource management, despite the fact that multi-tier coexisting networks may offer large and expanded area coverage. HetNet resource allocation difficulties would be more complex in the future because of channel uncertainty and unreliable feedback channels.

7. Conclusion

In this paper, a review of radio resources management in current HetNets has been introduced. The types of cells are summarized, such as macrocells, microcells, picocells, femtocells. Also, network scenarios of HetNets have been described that include classic cellular HetNets, OFDMA HetNets, NOMA HetNets, relay HetNets, and multi-antenna HetNets. In addition, the major function of mobility management was explained. There were two major handoff mechanisms: vertical handoff and horizontal handoff. Also, management and control mechanisms of radio resource allocation in HetNet were discussed. Moreover, future research directions in this subject are introduced as well as relevant challenges and future research trends that demand extensive explorations.

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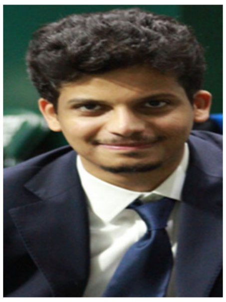

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