Research on interference suppression methods in Ultra-Dense Heterogeneous Networks

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Abstract: With the continuous development of 5G technology and the continuous growth of user needs, traditional computing methods can no longer meet the needs of the times. Ultra-Dense Heterogeneous Networks (UDHNs) can meet the requirements of 5G networks for high data rates and large system capacity, improve network coverage and flexibility, and reduce network deployment and maintenance costs. Therefore, UDHNs have become a key technology in 5G, but their application development has also brought thorny interference problems. In this paper, the interference problem in Ultra-Dense Heterogeneous Networks is discussed, the downlink interference scenarios are analyzed, and an optimization method based on interference randomization and inter-cell interference coordination is proposed, effectively improving the network performance.

Keywords: UDHNs, Cell interference, Interference optimization

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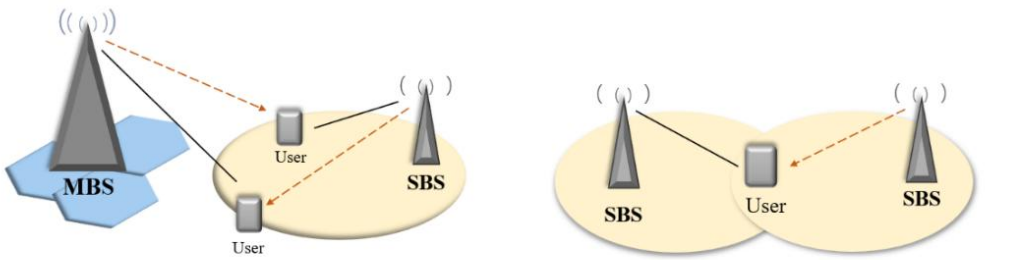
1 Introduction and challenges of UDHNs

Ultra-Dense Heterogeneous Networks is a communication technology that improves spectrum efficiency and system capacity by deploying a large number of small cells with low power consumption and small coverage[1]. This technology increases the system's capacity but also brings certain problems and challenges. In ultra-dense networks, the extremely high deployment density of small base stations leads to serious network overlap coverage, which brings serious interference problems, especially between different Base Stations(BS). Small Base Stations (SBS) are deployed randomly, making it difficult to plan[1], resulting in more severe interference. This interference not only affects the network's performance but can also seriously impact the quality of communication for users. However, traditional interference mitigation techniques have limited effectiveness in such dynamic and dense network environments. Therefore, it is necessary to study better interference mitigation techniques to optimize system performance.

2 Downlink interference scenarios in UDHNs

In the ultra-dense network environment, users suffer from two types of downlink interference, as shown in the figure:



(1) Interference between Macro Base Station(MBS) and SBS

(2) Interference between SBS in adjacent areas

Fig1. Downlink interference scenarios in UDHNs

2.1 Co-channel interference

In UDHNs, the use of the same frequency resources by adjacent cells may lead to co-channel interference. Due to the increase in network density in UDHNs, the shortening of the distance between users and base stations, and the irregular deployment of base stations, co-channel interference will be severe[1]. At the same time, to suppress the co-channel interference, the network has to reduce the signal transmission power or allocate more frequency band resources for isolating the interference.

2.2 Shared spectrum resource interference

In UDHNs, users will reuse the same spectrum to improve spectral efficiency when the available spectrum resources are difficult to meet the growing demand for data traffic[2]. In this case, when multiple network standards share the same spectrum resource, the interference of shared spectrum resources will occur. This interference may be caused by signals interfering with each other between different network standards, affecting the stability and reliability of the system.

2.3 Interference from neighboring terminals

In UDHNs, it is difficult to achieve clear cell coverage boundaries in actual network deployment, and the coverage areas of adjacent cells will overlap, and end users may receive signals from multiple base stations at the same time. When these signals interfere with each other, neighbor terminal interference occurs. Interference not only affects the quality of users' communications, but also consumes network resources, reduces network capacity, and worsens the user experience.

3 Interference suppression methods

3.1 Interference randomization techniques

Interference randomization technology is a key means used in wireless communication systems to deal with interference problems, the core of this technology is to break the original law of interference signals and reduce the negative impact of interference on communication quality by making the characteristics of interference signals random and unpredictable[2]. Common techniques for interference randomization include interleaving and scrambling algorithms, which are as follows:

(1) Interleaving Algorithm: After the channel is coded, the transmitted signal is intertwined with different interleaved patterns. Interleaved patterns can be generated by a pseudo-random number method, with different interleaved lengths corresponding to different interleaved pattern numbers. The user device decides which interleaving mode to use by checking the number of the interleaving mode. Through interweaving, the interference signal is more evenly distributed in the dimensions of time and frequency, which is close to the characteristics of white noise.

(2) Scrambling Algorithm: Scrambling Algorithm is a technology that improves the anti-interference ability and security of communication systems by performing specific randomization processing on the original signal[4]. Scrambling is to compute the original signal with a pseudo-random sequence, thereby changing the statistical characteristics of the original signal.

First, a pseudo-random sequence is generated, and the scrambled sequence c(n) is commonly generated by the Linear Feedback Shift Register (LFSR). Taking m-order LFSR as an example, the state transition equation is as follows:

$$s(n+1)=\sum_{i=1}^{m} a_i s(n-i+1)(\mathrm{mod}2) \quad (1)$$

where$s(n)$ is the state of LFSR at time n, and a_i is the feedback coefficient. After the initial state$s(0), s(1), \ldots, s(m-1)$ is determined, the scrambling sequence $c(n)=s(n)$ is generated. Then, the original signal to be transmitted is scrambled with this pseudo-random sequence, and the sending signal $x(n)$ and the scrambling code sequence $c(n)$ are added by mode 2 to realize the scrambling, and the scrambled signal$x_s(n)=x(n)\oplus c(n)$, $\oplus$ represents the mode 2 plus. The receiver needs to know the pseudo-random sequence used by the sender and be in sync with the sender in time. The receiver receives the scrambling signal $y(n)$, and adds and descrambles with the same scrambling sequence $c(n)$ mode 2 to restore the original signal $x^\wedge(n)=y(n)\oplus c(n)$.

3.2 Inter-cell interference coordination(ICIC)

In cellular networks, due to frequency multiplexing, interference will occur when adjacent cells multiplex the same frequency band, especially users at the edge of the cell will be severely affected by interference. The core idea of inter-cell interference coordination technology is to coordinate and control the use of resources between cells, avoid or mitigate mutual interference, and enable users at the edge of the cell to obtain reliable services[5]. To reduce inter-cell interference and improve spectral efficiency in a system, Fractional Frequency Reuse (FFR) and Soft Frequency Reuse (SFR) can be used.

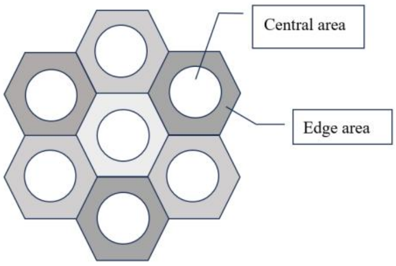


Fig 2. Soft Frequency Reuse model

3.2.1 Fractional Frequency Reuse analysis

FFR is an effective method in inter-cell interference coordination techniques. In FFR, as shown in Figure 2, each cell is divided into a central area and a marginal area. Users in the central area experience relatively less inter-cell interference, while users in the periphery area experience more inter-cell interference due to their proximity to adjacent cells. Frequency resources with a higher multiplexing factor are allocated to the central region, that is, the central region can use the frequency resources of the entire system. This is because users in the central area are less disturbed and the high multiplexing factor can improve the spectral efficiency[4]. For the edge area, a frequency resource allocation strategy with a lower multiplexing factor is adopted. Different frequency subsets are used in the edge areas of adjacent cells, which can effectively reduce interference between users in the edge areas. Through this differentiated frequency allocation, inter-cell interference is coordinated. This method effectively reduces interference, improves the spectrum utilization efficiency of the whole system, and is relatively simple to implement.

3.2.2 Soft Frequency Reuse analysis

SFR is an important method in inter-cell interference coordination techniques, which divides the entire available spectrum into multiple subbands. Users in the center of the cell can use the full frequency sub-bands with low transmit power. This is because the cell center users are closer to the base station and have relatively good signal strength, which ensures good communication quality even when using lower power[3], while low-power transmission also reduces interference to other cells. Users at the edge of the cell can only use certain frequency subbands and use higher transmit power. These specific frequency subbands are orthogonally allocated in adjacent cells, that is, edge users of adjacent cells use different frequency subbands, which can effectively reduce interference between users at the edge of the cell. Inter-cell interference coordination is realized through this joint control strategy of frequency and power.

As shown in Figure 2, the cell is divided into the central and edge areas, and the spectrum resources are also partitioned accordingly. Let the total available frequency band be B, and divide it into three frequency band sets: B_1、B_2、B_3, and the frequency band widths are: b_1、b_2、b_3, satisfying $\mathrm{B} = \mathrm{b}_1 + \mathrm{b}_2 + \mathrm{b}_3$. The cell center area has a high multiplexing factor, and all frequency bands can be used, and users at the edge of the cell allocate protected frequency bands to reduce interference. Let the spectral density of the transmitted power of the edge user of cell i be limited to a specific frequency band, within the $\mathrm{B}_{\mathrm{edge}}$, and the Signal to Interference plus Noise Ratio (SINR) of the received signal is

$$\mathrm{SINR}_\mathrm{i} = \frac{\mathrm{P}_\mathrm{i}\mathrm{G}_{\mathrm{i,i}}}{\sum_{\mathrm{j}\neq\mathrm{i}}\mathrm{P}_\mathrm{j}\mathrm{G}_{\mathrm{j,i}}+\mathrm{N}} \quad (2)$$

wherein, P_i is the transmit power allocated by cell i to the edge user in the frequency band, $\mathrm{G}_{\mathrm{i,i}}$ is the channel gain from cell i to its user, $\mathrm{G}_{\mathrm{j,i}}$ is the channel gain from adjacent cell j to cell i user, and N is the noise gain. By rationally allocating frequency bands, reducing $\sum_{\mathrm{j}\neq\mathrm{i}}\mathrm{P}_\mathrm{j}\mathrm{G}_{\mathrm{j,i}}$ this distractor.

4 Uplink(UL) and downlink(DL) interlinear interference analysis

4.1 Interference models and types

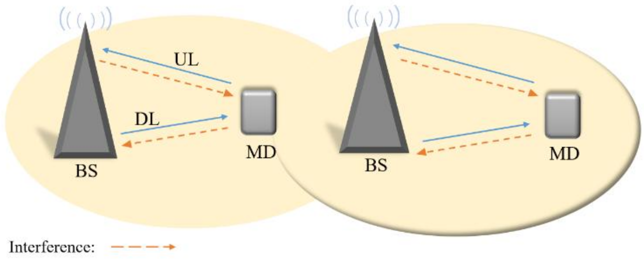


Fig 3. Uplink and downlink interference model

(1)Co-channel interference:The uplink and downlink signals use the same frequency, and the signals inside and outside the cell interfere with each other, such as in the LTE system, where adjacent cells are networked at the same frequency.

(2)Adjacent Frequency Interference: Mainly because the actual filter characteristics are not ideal. Although the communication system divides the upstream and downstream signals into adjacent bands, the energy of the upstream signal is diffused to the downlink band and vice versa because the filter cannot completely filter out the out-of-band signal. This interference can vary depending on how tight the frequency bands are and the performance of the device.

(3)Spurious interference:The nonlinear nature of the transmitter causes the uplink signal to produce spurious components and fall into the downlink band for interference.

4.2 Impact of Interference

(1)Degradation of signal quality: Interference causes a decrease in the signal-to-noise ratio of the received signal so that useful information in the signal is drowned out by noise. This can increase the bit error rate, leading to data transmission errors, murmur, stuttering on voice calls, and mosaic or even interruption in video playback.

(2)Reduced communication capacity: To overcome interference, communication systems often need to reduce transmission power or adopt more complex coding methods, which undoubtedly reduces spectral efficiency, reduces the number of users who can communicate at the same time, and limits the capacity of communication networks.

4.3 Resolution

(1)Optimize frequency planning: re-plan frequency bands, increase isolation, and avoid co-frequency and adjacent frequency interference; Dynamic frequency allocation technology is used to adjust the frequency in real-time.

(2)Improve equipment performance: select high-performance equipment, regular maintenance and upgrade: and install filters to reduce spurious and intermodulation interference.

(3)Optimize network layout: Reasonably adjust the location, height, antenna inclination and direction of the base station to reduce signal overlap and interference: Adopt technologies such as cell splitting and sector to reduce interference.

5 Summary and outlook

This paper puts forward the problems and challenges in ultra-dense networks, analyzes the interference problems in ultra-dense networks, and constructs a system model for the interference scenarios, which well explains the connections and problems between macro base stations, micro base stations and users, and then studies the interference suppression methods according to the interference problems, and finally makes a supplementary analysis of the interference between the uplink and downlink. Through the research, it has laid a relevant foundation for subsequent research on interference suppression.

However, the interference optimization scheme studied in this paper still needs to be improved, and as far as interference randomization is concerned, when the system is fully loaded, the interference randomization technology can improve the performance of the system to a limited extent. Interference randomization does not eliminate interference, but only converts the interference signal into white noise, so it may need to be used in combination with other interference management techniques in practical applications. In future research, these methods can be further optimized to find a better optimal suppression scheme.

References

[1]Guo F, Zhang H, Ji H, et al. An efficient computation offloading management scheme in the densely deployed small cell networks with mobile edge computing[J]. IEEE/ACM Transaction on Networking, 2018, Vol.26(6): 2651-2664.
[2]Zhou T, Fu Y, Qin D, et al. Secure and multi-step computation offloading and resource allocation in ultra dense multi task NOMA enabled IoT networks[J]. IEEE Internet of Things Journal, 2024, Vol.11 (3): 5347-5361.
[3]Spectrum Effect Inc.; Patent Issued for Downlink Interference Detection Using Transmission Matrices (USPTO 10,701,574)[J].Telecommunications Weekly,2020,
[4]Basu S ,Pradhan A ,Roy D S .Radial Sub-band Allocation with Downlink Interference Mitigation in Macro‐Femto Environment[J].Wireless Personal Communications,2019,106(2):955-969.
[5]Mei W ,0006 Z R .Cooperative Downlink Interference Transmission and Cancellation for Cellular-Connected UAV: A Divide-and-Conquer Approach.[J].CoRR,2019,abs/1906.00220.