

A Novel ICIC Scheme Combining 3D ML-SFR and CoMP

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Abstract. *With the development of the fifth generation (5G) wireless networks, the dense, heterogeneous and irregular network architecture puts forward higher requirements for inter-cell interference coordination (ICIC) technology. How to combine the existing technology to suppress inter-cell interference has become a focus worthy of research. This paper proposes a novel ICIC scheme that combines three-dimensional (3D) multi-level soft frequency reuse (ML-SFR) and coordinated multi-point (CoMP) transmission technology. Based on the scheme, a model of ML-SFR and CoMP is built for different scenarios. Finally, the information rates of users at the cell edge and the entire cell are analyzed through simulation, respectively. The results show that the proposed scheme is superior to the traditional anti-interference technology in suppressing inter-cell interference. The proposed scheme can effectively improve the transmission performance of the 5G wireless networks.*

Keywords

Inter-cell interference, inter-cell interference coordination (ICIC), multi-level soft frequency multiplexing (ML-SFR), coordinated multipoint (CoMP)

1. Introduction

The ultra-dense deployment of base stations, the rapid increase in the number of communication terminals and the diversification of various services have led to a sharp increase in the demand for data transmission rates and spectrum resources with the development of the fifth generation (5G) wireless networks. High-density spectrum spatial multiplexing is the main method to improve spectrum utilization. However, communication networks become inter-cell interference-limited due to the frequency reuse. Severe inter-cell interference inevitably deteriorates network performance and user service quality. How to more effectively suppress inter-cell interference has become an urgent and

long-term problem. Furthermore, the mobile communication environment is mainly concentrated in scenes such as urban areas and indoors. In these scenes, communication service requirements are unevenly distributed in the time and space, which also puts forward new challenges for anti-interference among cells.

In order to solve the problem of serious inter-cell interference, the 3rd Generation Partnership Project (3GPP) [1] proposed three inter-cell interference suppression technologies, namely: inter-cell interference randomization technology [2], inter-cell interference cancellation technology [3] and interference coordination technology. Interference randomization is designed to random interfere signal and make the mobile terminal to achieve interference suppression after channel coding/interleaving or frequency hopping of different types. For instance, if there are two adjacent cells, after channel coding and interleaving, their signals are scrambled respectively, then user equipment decoders judge whether the receive signal is belonging to themselves. We can also interleave transmission signal in different ways after channel coding [2]. However, due to the limited gain of interference randomization technology for inter-cell interference suppression, interference randomization is far from sufficient in the face of the complex and dense scenarios of existing wireless communications. Inter-cell interference cancellation makes use of multiple antennas at the mobile terminal to achieve the space-separated interference suppression, or can use pseudo-random interleave assign different interleaving patterns to different cells, the receiver in term of the corresponding pattern to de-interleave [2]. For inter-cell interference cancellation, a novel transmission technique was proposed in cellular networks in [3]. A multiple decision successive interference cancellation (MD-SIC) scheme was proposed to solve the error propagation problem, thus achieved a compromise between performance and complexity in [4]. The aforementioned method is improvement in the framework of successive interference cancellation, which cannot solve the problems of high latency and error propagation well. To solve the high latency and error propagation problems in the SIC algorithm, [5] combined the advantages of SIC and parallel interference cancellation (PIC) and proposed a joint inter-

ference cancellation (JIC) method, and compares the performance of the three algorithms. Simulation results in the literature showed that JIC could effectively reduce the time delay and improve the error propagation problem at low complexity. Additionally, some work combined SIC with other technologies in order to improve the network performance. For example, in [6], an analysis model was established to study the interaction between SIC and fraction frequency reuse (FFR) and the impact on network performance. In [7], SIC technology was applied to coordinated multiple points transmission (CoMP) technology to improve the spectral effect of CoMP by designing an efficient inter-cell interference cancellation scheme. Although the above solutions can effectively suppress inter-cell interference, the overhead and implementation complexity are relatively high. Therefore, 3GPP has proposed inter-cell interference coordination (ICIC), which is considered to be the most important and effective means to suppress the inter-cell interference problem. ICIC suppresses inter-cell interference mainly by dividing frequency domain resources or time domain resources, supplemented by base station transmit power control [8]. A lot of research has also been done on ICIC techniques by domestic and international scholars. In [2], an in-depth study on the ICIC technology between cells pointed out that the combination of ICIC technology, diversity gain technology and multi-antenna technology could improve the performance of edge users. In [9], the ICIC based on soft frequency reuse (SFR) and FFR relay was studied, and the impact of the macro-ICIC scheme on the interference management of heterogeneous systems was evaluated. ICIC technology was used in millimeter-wave cellular networks, and two ICIC schemes were proposed in mm-wave bands: one was merely based on the path loss incorporating the blockage effect (PL-ICIC) to improve network quality in [10]. The SFR is considered as an effective ICIC scheme for coordinating inter-cell interference and improving spectrum utilization [11].

For ICIC technology, frequency domain interference coordination is the most common, such as FFR and SFR [12–14]. A comparison of SFR and FFR was done in [13] where analytical evaluation of both was presented. On this basis, a new soft-partial frequency reuse (SPFR) was proposed in [15]. Moreover, with the gradual maturity of this technology, a technology that can improve the sensitivity of cell edge users to the co-frequency interference of neighboring cells caused by SFR technology, namely multi-level SFR (ML-SFR) technology, which was expected to become one of the key technologies of 5G wireless network was proposed in [16]. ML-SFR technology was also used in [17]. CoMP technology is a space-dimensional inter-cell anti-interference technology, which was introduced by 3GPP in Release 11 [20]. Since then, CoMP technology has aroused the research of scholars for suppressing inter-cell interference. CoMP relies on network coordination between multiple base stations or transmission points and TPS to improve network efficiency and throughput. It

could be used with different configurations like joint transmission (JT), co-ordinate beamforming/scheduling (CB/CS) and dynamic point selection (DPS) [21]. Among these CoMP techniques, the coordinated multi-point joint transmission (CoMP-JT) technique offers the highest performance gains by fully sharing both data and control information among the coordinated BSs [23]. This paper mainly studies the application of CoMP-JT model in inter-cell. In the CoMP-JT, multiple coordinated cells can simultaneously transmit different data to a single user through different frequencies to increase the user's data rate, or transmit the same data to a single user through the same frequency to enhance signal strength [24]. CoMP-JT is implemented with location optimization algorithm and number optimization algorithm and enhanced the spectral efficiency of cell edge users by reducing inter cell interference in [25]. In [26], a CoMP-JT scheme in an orthogonal frequency division multiplexing (OFDM) based Light-Fidelity downlink network has been proposed to alleviate co-channel interference and blocking issues.

The mentioned single anti-interference technology is far from solving the problem of inter-cell interference of 5G wireless networks. Therefore, how to effectively combine the existing technology to suppress the problem of inter-cell interference has become the next research and development focus. The combination of SFR and CoMP technology is a method worth considering. However, the existing SFR scheme is not suitable for CoMP transmission, because it does not consider multiple cell joint transmission schemes in the frequency reuse rules. Some works have effectively combined the two technologies through new spectrum divisions. A cooperative frequency reuse (CFR) scheme was proposed in [27], which divided the cell-edge area of each cell into two types of zones, and defined a frequency reuse rule to support CoMP transmission for users in these zones. A hybrid dynamic frequency reuse and CoMP technique, DMFR, was proposed in [28], which was applicable to LTE macro-cell/femtocell networks and was able to enhance both the cell edge and adjacent sector transmission performance through adaptive spectrum allocation, interference management and CoMP techniques. Although the above schemes can combine SFR and CoMP, the process is very complicated. Therefore, this paper proposes a simple and easy-to-implement scheme, which combines three-dimensional (3D) ML-SFR and CoMP technology. The solution compares the signal-to-interference-to-noise (SINR) of users in different regions to decide whether to use CoMP technology or ML-SFR.

The remainder of the paper is organized as follows. Section 2 proposes the working models of CoMP and ML-SFR under different SINR conditions, effectively combining the two anti-jamming technologies. Section 3 gives the work flow of the novel ICIC scheme combining 3D ML-SFR and CoMP and the calculation method of user interference in different radius. Discussions on the obtained simulation results of CoMP and SFR in different situations are in Sec. 4. Finally, conclusions are mentioned in Sec. 5.

2. System Model and Spectrum Allocation

As shown in Fig. 1, the system model combining ML-SFR and CoMP divides each cell into N regions, and the radius of each region is r . Because ML-SFR is equivalent to multiple use of soft frequency multiplexing, the value of N is 2^n , $n = 1, 2, 3, \dots$. This paper takes $N = 4$ as an example to realize the scenario where ML-SFR and CoMP work together. Firstly, the interference threshold I_t and the size of a certain area are judged. When $N = 4$, the model is divided into 4 regions, and the radius of each region from the inside to the outside is $r_1 \sim r_4$. Then, determine whether the interference I_4 of the area 4 is greater than the threshold. If $I_4 > I_t$, continue to determine whether the interference I_3 of the area 3 is greater than the threshold, and so on, until the interference of a certain area is less than the threshold, and the areas whose interferences are greater than the threshold are regarded as one area. Finally, when the interference of the area is smaller than interference threshold, ML-SFR is used to resist interference, otherwise CoMP is used.

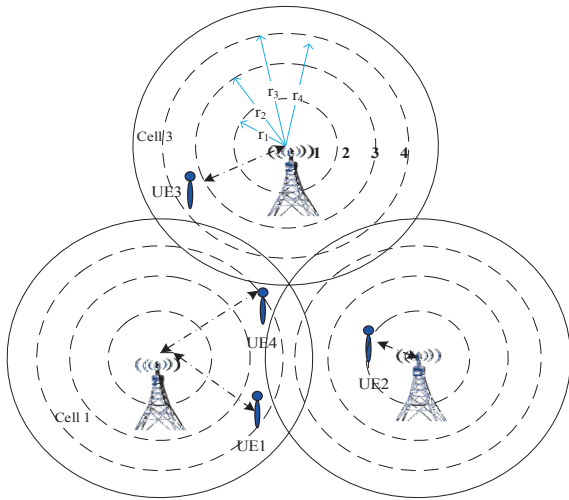


Fig.a. ML-SFR mode

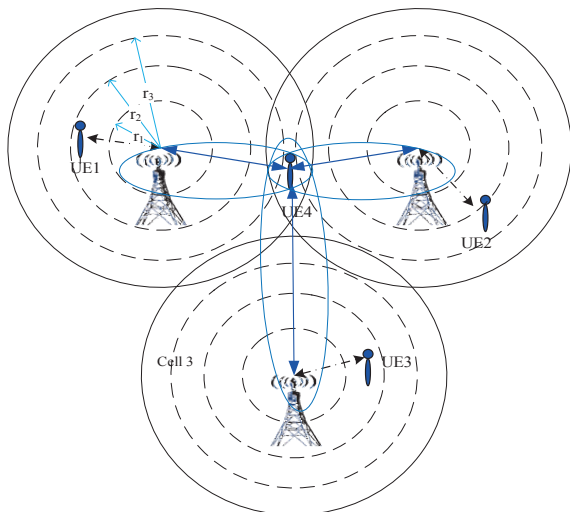


Fig.b. CoMP mode

Fig. 1. System model.

The division of ML-SFR spectrum resources is based on the standard SFR. Except for the outermost frequency bands of the cell, the spectrum resource allocation of the rest of the cell will vary according to the cell radius. The changes of users' number and position make it more fully and rationally use spectrum resources.

2.1 ML-SFR Spectrum Resource Allocation

SFR defines a power density threshold for each cell, and the actual signal power in the cell must be lower than this power density threshold (PDL). At the same time, the SFR scheme divides resources into 3 groups of sub-bands equally: two groups are used for cell center users, that is, secondary subcarriers in the SFR scheme; the other group is primary subcarriers for cell edge users. The power density limit of the main carrier is higher than the power density limit of the subcarrier, and the coverage range of the main carrier and subcarrier is controlled by controlling the transmission power of the main carrier and the subcarrier. In the SFR scheme, the primary subcarrier can be used by the entire cell user. In order to simplify the interference calculation, the primary subcarrier is allocated to the cell edge users.

In the ML-SFR scheme, the entire frequency band is divided into N parts, and each part adopts an independent 2-SFR scheme. [29] defines γ to evaluate the performance of soft frequency cells, which is expressed as (1), where PDL_s is secondary band of PDL, PDL_p is primary band of PDL. In the ML-SFR scheme, there is a specific γ and there are $2N$ PDL:

$$\gamma = \frac{PDL_s}{PDL_p} \quad (1)$$

In ML-SFR, the power density thresholds of the main carrier and sub-carriers of the N -part spectrum of the cell h_n^i and l_n^i need to satisfy the relationship:

$$l_1^{(i)} \leq l_2^{(i)} \dots \leq l_N^{(i)} \leq h_N^{(i)} \leq \dots \leq h_2^{(i)} \leq h_1^{(i)}.$$

Taking $N = 4$ as an example, that is, 4-SFR as shown in Fig. 3. The entire cell needs to be divided into 4 areas. At this time, the spectrum resource is divided into 6 parts, that is, 2-SFR is used twice. Assuming there are users in each area, use it once in the outermost and innermost layers of the cell, and use it again for the rest. For the first time, the primary subcarriers of the spectrum resources of this

	Cell 1	Cell 2	Cell 3
B_1	$h_1^{(1)}$	$l_1^{(2)}$	$l_1^{(3)}$
B_2	$l_1^{(1)}$	$h_1^{(2)}$	$l_1^{(3)}$
B_3	$l_1^{(1)}$	$l_1^{(2)}$	$h_1^{(3)}$
B_4	$h_2^{(1)}$	$h_2^{(2)}$	$l_2^{(3)}$
B_5	$l_2^{(1)}$	$l_2^{(2)}$	$l_2^{(3)}$
B_6	$l_2^{(1)}$	$l_2^{(2)}$	$h_2^{(3)}$

Fig. 2. Power thresholds for a ML-SFR cell.

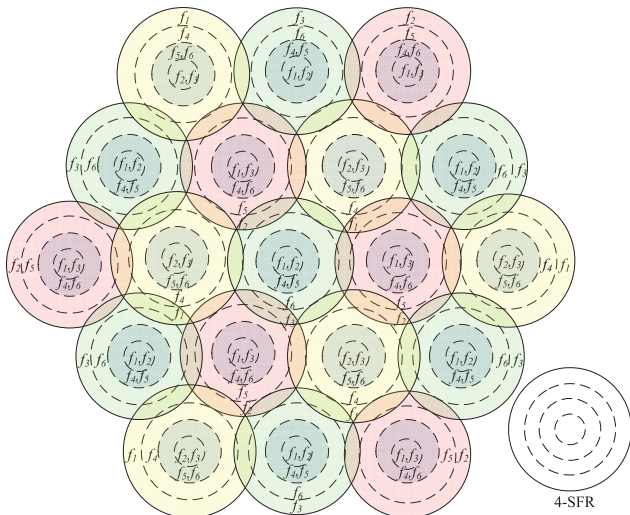


Fig. 3. 4-SFR spectrum resource division.

frequency band are used for the outermost layer of the cell to ensure that the spectrum at the edge of each cell is orthogonal to the spectrum used by the neighboring cells, and the rest is used for the cell center. For the second time, follow the above method and so on. This method of frequency division ensures that edge users of adjacent cells use different frequency bands to transmit data, which greatly reduces inter-cell interference. Because cell edge users use pre-allocated frequency bands for data transmission, fixed base stations are sending data to the cell. Edge users can use full power transmission when transmitting signals. The transmit power of the frequency band used by the central user will be limited to a certain extent to control the extent to which the frequency is used in order to adjust the frequency reuse factor, thereby achieving soft frequency reuse. If there are no users in a certain area, the area is taken on the inner side in order to improve the utilization of the spectrum. If there are no users in area 4, the area 4 is scattered and merged in the area, and the area is taken to the inner side 2, and so on.

2.2 CoMP-JT Mode

In order to improve the average SINR \overline{SINR}_u of users at the edge of the cell, CoMP technology comes into being. The CoMP transmission scheme can improve the performance of the terminal through multi-point coordination among base stations, and it has a significant effect in improving the performance of cell edge users. The CoMP-JT is considered to be an effective way to eliminate the impact of inter-cell interference [30]. When using CoMP technology, users are necessary to divide into cell center users M_{CCU} and cell edge users M_{CEU} . This paper is based on users' \overline{SINR}_u to determine the communication performance of central users and edge users. First, divide the entire cell into N areas on average. Then, set a threshold $SINR_{th}$, and compare \overline{SINR}_u and $SINR_{th}$ from the outermost area. Finally, the user classification is based on the following relationships:

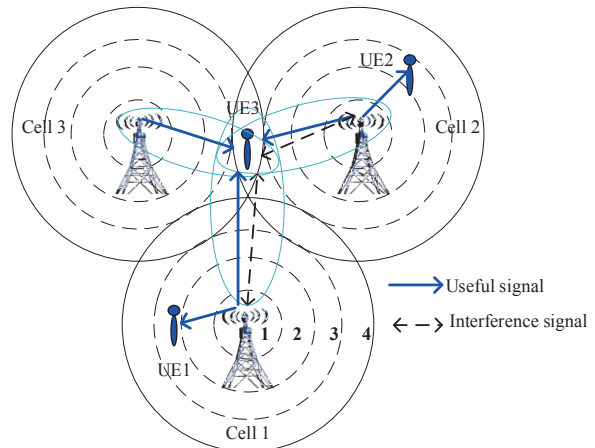


Fig. 4. CoMP-JT model.

$$M_{CCU} = \left\{ m : \overline{SINR} \geq SINR_{th} \right\},$$

$$M_{CEU} = \left\{ m : \overline{SINR} < SINR_{th} \right\}.$$

Taking $N=4$ as an example, if \overline{SINR}_u of area 4 is less than $SINR_{th}$, continue to determine whether \overline{SINR}_u of area 3 is less than $SINR_{th}$, until \overline{SINR}_u of a certain area is not less than the threshold and treat these areas whose $\overline{SINR}_u < SINR_{th}$ as one area of the cell edge. In area 4, if $\overline{SINR}_u \geq SINR_{th}$, the area 4 is directly used as the cell edge, and the model is shown as Fig. 4.

3. ICIC Scheme

3.1 Work Flow of the ICIC Scheme

The main idea of the scheme in this paper is to combine CoMP and ML-SFR. The scheme flow is as follows:

- Definition the number of each area is $1 \sim N$, the radius of each area of the cell is $r_1 \sim r_N$, the number of users in each radius is m_i , the threshold is ∂ , the input power ratio is λ , and the total spectrum resource is f_i ;
- Count the number of users m_i , $i = 1, 2, \dots, N$ of each area and the average SINR \overline{SINR} ;
- Determine whether the \overline{SINR} of the outermost area N is greater than the threshold ∂ ;
- If the user's value in area N is $\overline{SINR} < \partial$, compare the value in area $N-1$ with the threshold value, and so on, until the value in a certain area is not less than the threshold value;
- The last area compared in area N to (4) is regarded as the cell edge, and the rest are the cell center;
- Use CoMP technology for cell edge users, and use ML-SFR technology for cell center;

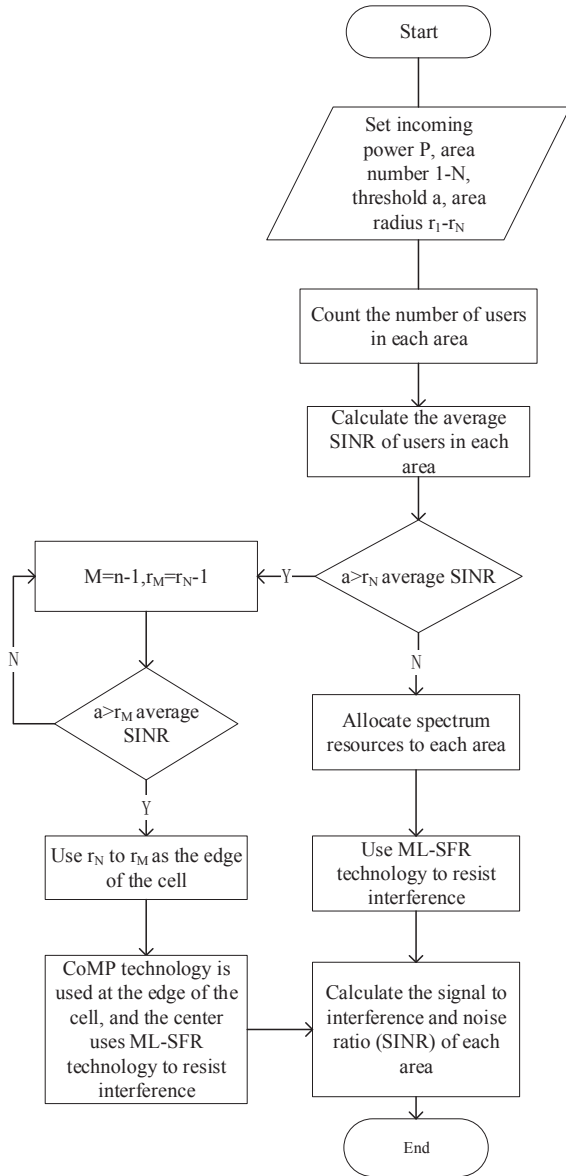


Fig. 5. Work flow of the ICIC scheme.

- Otherwise, the area N is directly regarded as the cell edge, and spectrum resources are allocated according to Fig. 1, and the whole cell uses ML-SFR technology;
- Cycle steps 2 to 7.

According to 3.1, the implementation steps of this scheme are shown in Fig. 5.

3.2 Interference Calculations

The wireless channel is a typical variable parameter channel, and this randomness seriously affects the performance of the mobile communication system. There will be a certain degree of loss in the process of signal propagation in the wireless channel, such as free space propagation loss, shadow fading, and multipath fading. This paper assumes that the shadow fading obeys a lognormal distribution, usually 5–12 dB, and 4 dB in the direct-view path scenario.

Parameters	Description
$L_{i,k}$	Path loss between base station and user
L_0	Path loss factor
S_e	Shadow fading
P_0	User received power
P_b	Base station transmit power
P_i	Cooperative base station transmit power
I	Cumulative interference
I_e	Cumulative interference of a middle-edge user
I_c	Cumulative interference of a middle-center user
N_b	Total number of base stations
N_u	Total users
$D_{i,k}$	The distance between the user and the base station
$b_{m,k}$	Base station marking in the same cooperative cluster
E	Cooperative base station serving the same user
M_i	Total number of users served by the base station

Tab. 1. Parameters of the ICIC scheme.

Path loss is one of the main factors of signal fading. This paper calculates the path loss L_0 of the signal propagating from the base station to the user according to (2)

$$L_0 = 32.5 + 20\log f + 20\log d \quad (\text{dB}) \quad (2)$$

where f is the carrier frequency, and d is the distance between the user and base station. Other parameters involved in this scheme are shown in Tab. 1.

For each user in the reference cell, the received useful signal power in dB can be expressed as:

$$P_0 = P_b - L_{i,k} - S_e^i \quad (\text{dB}). \quad (3)$$

If the user is a cell edge user, P_b is equal to the transmission power of the fixed base station. If the user is a cell center user, in the ML-SFR scheme, the transmission power of the fixed base station to the cell center user is multiplied by the "power ratio".

Since the interference signal received by each user in the reference cell is related to the location of the user, the interference cannot be calculated uniformly. The specific calculation situation takes $N = 4$ as an example, that is, the spectrum resources are divided as shown in Fig. 3. Because the number of subcarriers used by users in different areas of the cell is different, the interference from the same frequency signal is also different. If the user U is in the central area of the reference cell, the fixed base station of the cell can use all the frequency band to provide services for the user (assuming the frequency band is selected). If the fixed base stations of surrounding cells also use the frequency band to transmit signals when providing services to users this will cause co-channel interference to user U . The analysis in Fig. 3 shows that the probability of using the frequency band in the central area of the surrounding 6 cells is 1/2, and the probability of using the edge area is also 1/2; for the 12 peripheral cells, the probability of using the central area of the cell is 3/4, and the probability of using the edge area is 1/4. Therefore, the cumulative calculation of interference for a central user in 4-SFR is as follows:

$$I_{r_i} = \sum_{i=1}^6 \left[\frac{1}{2} (P_{b-r_i}^i - L_{i,k}) + \frac{1}{2} (P_{b-r_i}^i - L_{i,k}) \right] + \sum_{j=1}^{12} \left[\frac{3}{4} (P_{b-r_i}^j - L_{j,k}) + \frac{1}{4} (P_{b-r_i}^j - L_{j,k}) \right] \quad (\text{dB}). \quad (4)$$

From this, the interference calculation method for ML-SFR can be derived. Taking 4-SFR as an example, if only the cumulative interference of a user under the condition that base stations in two circles outside the reference cell is considered, the cumulative interference received by a user can be calculated according to (5). However, due to the use of the ML-SFR scheme, the frequency bands used in the edge areas of adjacent cells are not the same, and co-frequency interference will not occur. Therefore, the interference from the surrounding 6 cells to the edge users in the reference cell only comes from the fixed base station pair:

$$I_{4\text{-SFR}} = \sum_{i=1}^6 \left[\frac{c}{6} (P_b^i - L_{i,k}) + \frac{c}{6} (P_{b_i}^i - L_{i,k}) - S_c^i \right] + \sum_{j=1}^{12} \left[\frac{c}{12} (P_b^j - L_{j,k}) + \frac{c}{12} (P_{b_j}^j - L_{j,k}) - S_c^j \right] \text{ (dB)}. \quad (5)$$

In the model, the calculation of interference requires the division of cell center users and cell edge users. When $\overline{SINR}_u < SINR_{th} \quad \forall u = 1, 2, \dots, N_u$, the users with $\overline{SINR}_u < SINR_{th}$ are regarded as cell edge users, and the remaining users are cell center users. \overline{SINR}_u represents the average SINR of users in each area and $SINR_{th}$ is the threshold.

If the user is located in the central area of the cell, the base station closest to the user serves it, and the serving base station is marked as b_k . The powers of useful signal and interference calculation of cell center users are as follows:

$$P_0 = P_{b_k} - L_{j,k} - S_c^j \text{ (dB)},$$

$$I_c = \sum_{i=1, i \neq b_k}^{N_b} (P_i - L_{j,k} - S_c^i) \text{ (dB)}, \quad (6)$$

$$k = \left\{ i \mid D_{b_k} = \min \{ D_{1,k}, D_{2,k}, \dots, D_{N_b,k} \} \right\}.$$

If the user is located at the edge of the cell, the E base stations closest to the user serve it, and the serving base stations in the cooperative cluster are marked as $b_{m,k}$. Then, the powers of useful signal and interference calculation of cell edge users are as follows:

$$P_0 = \sum_{m=1}^E (P_{b_{m,k}} - L_{i,k} - S_c^i) \text{ (dB)},$$

$$I_e = \sum_{i=1, i \neq b_{m,k}}^{N_b} (P_i - L_{i,k} - S_c^i) \text{ (dB)}, \quad (7)$$

$$k = \left\{ i \mid D_{b_k} \leq D_E = \min \{ D_{1,k}, D_{2,k}, \dots, D_{N_b,k} \} \right\},$$

$$P_i = \sum_{j=1}^{M_i} P_{i,j}.$$

4. Results and Discussions

4.1 Simulation Scenario

In order to verify the effectiveness of the novel ICIC scheme combining 3D ML-SFR and CoMP, this section

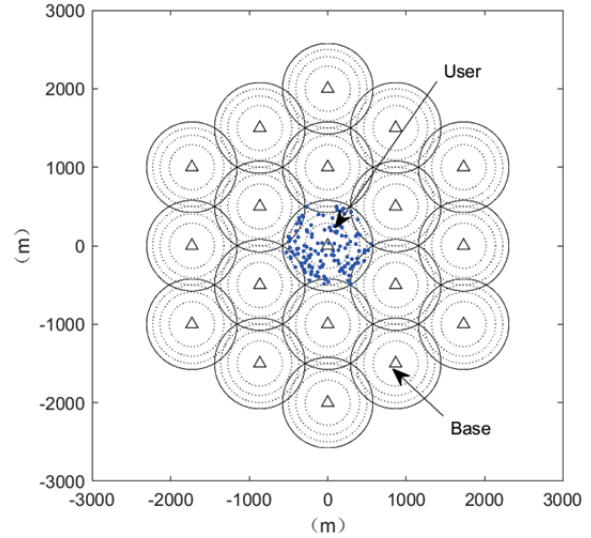


Fig. 6. Simulation scenario.

Parameters	Value
System bandwidth	100 MHz
Carrier frequency	3500 MHz
Number of cells	19
Total number of users	135
2- SFR center users	57
2-SFR edge users	78
4- SFR center users	38
4-SFR sub-center users	40
4- SFR sub-edge users	43
4- SFR edge users	14
Base station total transmit power	60 W
Fixed base station spacing	1000 m
Mean value of shadow fading	0
Standard deviation of shadow fading	6 dB

Tab. 2. Values of the simulation parameters.

takes $N = 4$ as an example, and uses MATLAB to simulate the user rate. As shown in Fig. 6, this simulation scenario sets up 19 cells, each cell is equipped with a fixed base station, and each cell is divided into four areas. Users are randomly distributed in all the cells, and the number of users in different layers (regions) is different (Only the users in current cell are shown in Fig. 6). In the simulation, the path loss is calculated according to (2), and the shadow fading obeys the lognormal distribution. According to the 5G wireless networks, parameters involved in this simulation are shown in Tab. 2.

4.2 Results

Figure 7 illustrates the relationship of user distance and user rate. In the figure, "None" means that no inter-cell interference suppression technology is used; "SFR" and "CoMP" mean traditional SFR technology (using a fixed power ratio) and CoMP technology (full-cell cooperation); "L2" represents the proposed scheme in the case of $N = 2$, "CoMP Pro" means the cell edge cooperation in the proposed scheme; "SFR Pro" means the SFR in a certain area of this program with the optimal power ratio, "L4" represents the case of the proposed scheme with $N = 4$, in which, CoMP and ML-SFR are both used in the cell at the same

time. It can be seen intuitively from Fig. 7 that as the distance between the user and the base station increases, the user's rate becomes lower and lower. In the case of using 4-SFR combined with CoMP technology, the rate is improved compared with not using or using only one technology, especially after 400 m from the base station, the user rate is very low, because the base station is far away. The use of 4-SFR combined with CoMP technology can effectively improve the rate of edge users.

Figure 8 illustrates the number of users and the cumulative rate of users. It can be seen from Fig. 8 that as the number of users increases, the cumulative rate of users also increases. After using anti-interference technology, the cumulative rate of cell users is significantly improved. Since the number of users in the figure is accumulated from the cell edge users, it can be seen that the 4-SFR combined with CoMP technology is used at the cell edge, the user accumulation rate is the highest, followed by the enhanced CoMP type.

Figure 9 illustrates the average rate of the edge users. The use of traditional SFR and CoMP technologies improves the edge user rate by 22.26% and 18.97%, respectively. The enhanced SFR and CoMP technologies under the optimal power ratio improve the edge user rate by 27.25% and 67.96%, respectively. The CoMP technology has better performance in improving the rate of cell edge users. L4 is the new scheme that combines ML-SFR and CoMP technology, which improves the rate of cell edge

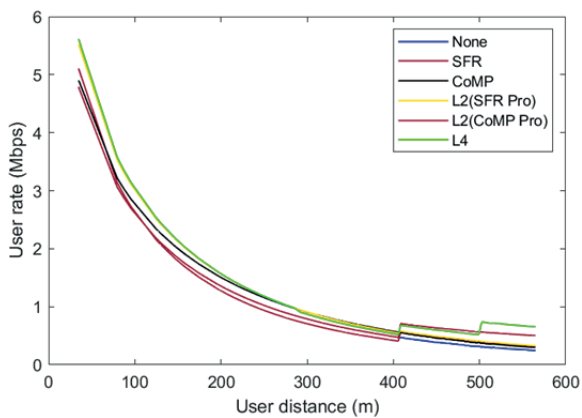


Fig. 7. Relationship of user distance and user rate.

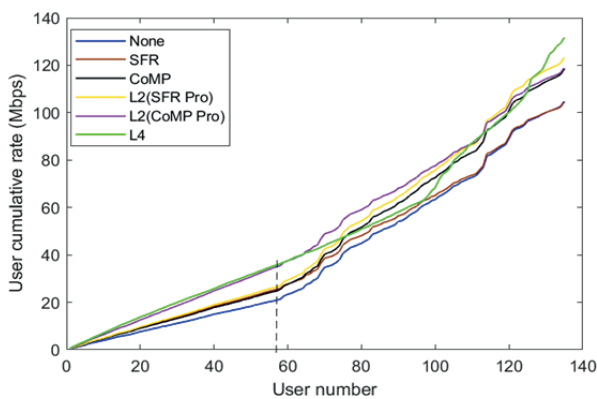


Fig. 8. Relationship between user number and user rate.

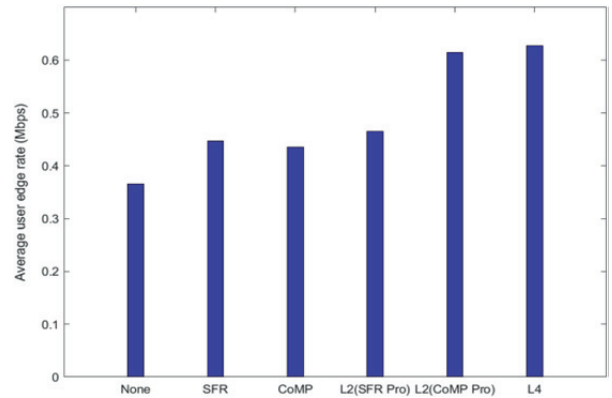


Fig. 9. Average rate of the edge users.

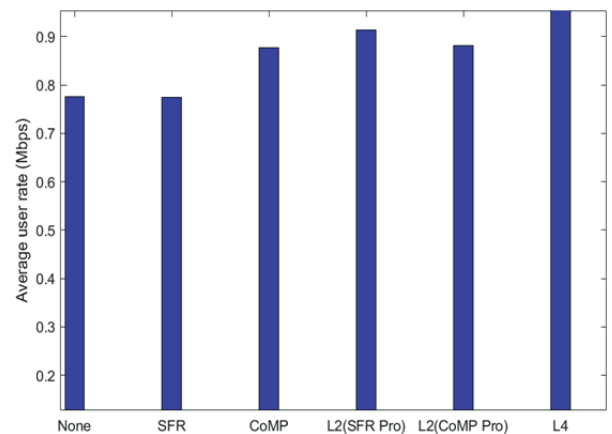


Fig. 10. Average rate of all the users.

users the best (71.47%). Therefore, the effectiveness of the novel ICIC scheme in this paper is verified. In addition, in the case of the single traditional technology and the single enhanced technology, the SFR and CoMP technologies are different in improving the average rate of the cell edge users. The traditional SFR technology orthogonalizes the adjacent cell edge frequencies, thus reducing the co-frequency interference at the cell edge. The CoMP technology puts edge users on the same frequency of several base stations, and several base stations serve the same edge users at the same time. At this time, the edge users are far away from the base station and the path loss is serious. CoMP pro with edge cooperation improves the average rate of cell edge users more significantly than SFR Pro under the optimal power ratio. The reason is that when CoMP pro is used, the average SINR of the edge users is greater than the threshold, and all the three nearest base stations serve the edge users, which can effectively increase the received power of edge users.

Figure 10 illustrates the average rate of all the users. As shown in Fig. 10, the average rate of all the users are improved by 12.99%, 17.74%, 13.51% and 25.68% by CoMP, SFR Pro, CoMP Pro and L4, respectively. The average rate of all the users is improved the most by the scheme proposed in this paper. Although the edge user rate increases, the traditional SFR does not improve the average rate of all the users. This is because the use of traditional SFR technology has a fixed division of the entire spectrum

resources, and one-third of the spectrum resources are used for edge users, but the edge users are not one-third of all the users. CoMP utilizes the coordinated transmission of neighboring cells, and the surrounding fixed base stations can convert interference signals into useful signals. In this way, the interference of the cell edge will be reduced. Therefore, the performance of CoMP is better than SFR. However, SFR pro can significantly improve the average rate of all the users better than CoMP Pro. This is because the frequencies of adjacent cells using SFR Pro are orthogonal to each other, and base stations have the optimal power ratio. For SFR Pro, low power can be allocated to the sub-bands, and high power can be allocated to the main frequency band. For CoMP Pro, the interference of the cell edge can be reduced through coordinated transmission among base stations, but interference of the central users cannot be reduced. As shown in Fig. 10, the novel ICIC scheme (L4) combining 3D ML-SFR and CoMP is best. On the one hand, it improves the edge user rate through cooperation among base stations. On the other hand, it uses ML-SFR to reasonably divide spectrum resources to improve the utilization of spectrum.

5. Conclusion

The 5G wireless networks are inter-cell interference-limited due to their dense, heterogeneous and irregular network architectures. A novel ICIC scheme combining 3D ML-SFR and CoMP is proposed. On the one hand, it improves the edge user rate through cooperation among base stations. On the other hand, it uses ML-SFR to reasonably divide spectrum resources to improve the utilization of spectrum. Based on the scheme, a model of ML-SFR and CoMP is built for different scenarios, and the interference calculations are given. Simulation results show that the proposed scheme is superior to the traditional anti-interference technology in suppressing inter-cell interference. The scheme can improve the average transmission rate of the edge users and all the users by 71.47% and 25.68%, respectively.

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