A Downlink Interference Suppression Scheme for Ultra Dense Networks

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In scenarios of the downlink of the ultra-dense network (UDN), in order to effectively overcome the influence of the interference sources of multiple similar-intensity on the user performance, resulting from the decrease of the distance between nodes and the similarity of the transmission loss of the neighboring nodes, a user-centric interference coordination scheme based on priority (PUCIC) was proposed in this paper.In order to facilitate quantifying the bandwidth performance gains achieved through base stations collaboration, a performance metric was proposed to calculate the bandwidth loss-gain-rate.Through the quantitative value of bandwidth loss-gain-rate, it's easy to know whether the user performance gain obtained in the scheme is less than the bandwidth loss to determine whether the scheme is profitable in specific UDN scenarios.Thus, parameter settings were optimized by the maximum loss ratio that the system can accept.


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1.Introduction

Ultra-dense network (UDN) [1] is one of the key technologies of 5G mobile communication. It increases network density by increasing the deployment density of the low-power site. Making the node closer to the end user greatly improves the system capacity.， The spectrum efficiency and power efficiency are improved as well. However, due to the reduction of node spacing, the transmission loss of adjacent nodes is not much different. When the multiple interference sources are closer to the user, it makes the user more seriously interfered than the traditional cellular network. Therefore, how to solve the problem of performance loss caused by multiple interference sources and how to improve user performance with network cooperation and interference management become the key problems in 5G UDN interference suppression.

Traditionally, there are many ways to deal with inter-cell interference issues. Inter-cell interference suppression is divided into three types: inter-cell interference randomization [2], inter-cell interference cancellation [3] and inter-cell interference coordination/avoidance [4]. In the interference management, the traditional frequency reuse scheme is based on user classification which divides the users into central users and edge users, and the performance will be limited to the edge users. There is also an existing interference management method which divides the whole network into disjoint clusters, and the performance will be limited to cluster edge users [5-6] as well. However, in the 5G UDN network, the low-power nodes are densely distributed and have a small coverage area. Therefore, the traditional user-based and cluster-based interference managements are no longer applicable to 5G UDN.

This paper proposes a priority-based user-centric interference coordination (PUCIC) scheme which can improve the users' performance with the lowest possible complexity. The main bottleneck of the interference network, namely, the cell edge users, will be solved.

2.System Model

A super-dense network with inter-cell interference is taken as an exemple. As shown in Figure 1, the base station has M antennas while the user has a single antenna.
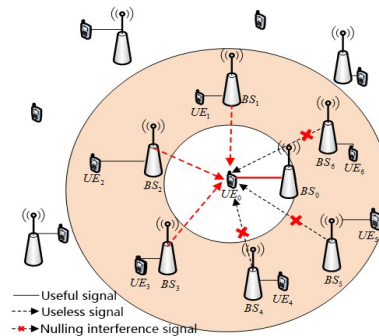
Figure 1: Super dense interference network diagram

The base station and the users in the cell are randomly distributed in a certain area. The number of the base stations is denoted as L_{BS}, where $L_{BS} = L+1$ and the 0th base station is the target base station .The other L base stations are the interfering base stations. The number of users is denoted as K. The nearest base station is the user's local base station, while the other nearby base stations are regarded as interfering base stations.Let's set user K as the central user for analysis. In the downlink of the cellular communication network, the user is subjected to the interference signals from neighboring base stations. Thus, the signal received by the user K

under the base station i, $y_{k,i}$, contains the useful signal of the local base station i, $s_{k,i}$, and the interference signals of adjacent base stations j ($j=1,\cdots,L_{BS}$ and $j\neq i$) , $I_{k,j}$. The received signal of the user K is expressed as:

$$y_{k,i}=s_{k,i}+\sum_{j=1,j\neq i}^{L_{BS}} I_{k,j}+n$$

(2.1)

Where $s_{k,i}=g_{k,i}h_{k,i}x_{k,i}$ is the desired signal of the user K at the base station i, $I_{k,j}=g_{k,j}h_{k,j}x_{k,j}$ represents interference signal from the base station j received by the user K, and n is a white Gaussian noise. Here, $g_{k,i}=p_i d_{k,i}^{-\alpha}\sqrt{2}$ represents the large-scale fading of the base station i to the user K, P_i is the transmission power of the base station i, $d_{k,i}$ is the distance between the base station i and the user K, α is the attenuation factor. $h_{k,i}$ represents the small-scale fading of the base station i to the user K and $x_{k,i}$ represents the transmission signal of the base station i.

In the PUCIC scheme, the user firstly ranks the received signal power P_i ($i=1,\cdots,L$)from the L interference base stations in descending order to obtain the priority of the interference coordination $I_1, I_2 \cdots, I_L$ .Through a series of processes upon the user judgments , the minimum L_1 and L_2 can be determined by the conditions which meet $SINR \geq \gamma$. The number of base stations that cooperate with the local base stations BS_0 for the user will be set to zero with beamforming.

Here, it is assumed that $\Theta_1=\{BS_1,BS_2,BS_3\}$ is the set of base stations cooperate with the local base station and $\Theta_2=\{BS_4,BS_5,BS_6\}$ is the set to be nulled . The user's received signal is expressed as:

$$y_0=s_0+\sum_{i\in\Theta_1} I_{0,i}+\sum_{j\in\Theta_2} I_{0,j}+\sum_{j\in\Psi_{ICBS}-\Theta_1-\Theta_2} I_{0,j}+n$$

(2.2)

Among which, $\sum_{j\in\Theta_2} I_{0,j}+\sum_{j\in\Psi_{ICBS}-\Theta_1-\Theta_2} I_{0,j}$ is the interference , $s_0+\sum_{i\in\Theta_1} I_{0,i}$ is the useful signal received by the user. $\sum_{j\in\Theta_2} I_{0,j}$ is set to zero after the local base station beamforms. Thus the user's received signal is expressed as:

$$y_0=s_0+\sum_{i\in\Theta_1} I_{0,i}+\sum_{j\in\Psi_{ICBS}-\Theta_1-\Theta_2} I_{0,j}+n$$

(2.3)

At this time, the strong interference around the user UE_0 is converted into a useful signal, and the second strong interference is suppressed.

2.PUCIC Mechanism
2.1PUCIC Process

Based on the user-centered idea, the PUCIC determines the number of base stations L_1 to be cooperated with the local base station and the number of base stations L_2 that are interference nulled by the local base station. PUCIC suppresses inter-cell interference and improves user performance and system with the base station collaboration and beamforming.

The PUCIC program consists of three execution modules and details are as follows:

2.1.1 Generate Coordination Priorities

The user first obtains the priority order of the interference coordination according to the received signal power P from the surrounding L interfering base stations $\Phi = \{I_1, I_2, ..., I_L\}$.

2.1.2 User Judgment Process

The corresponding SINRs are sequentially traversed and estimated according to the coordination priority and the minimum L_1 and L_2 should satisify the conditions of $SINR \leqslant \gamma$ (γ is the threshold required for the minimum SINR of the user service). L_1 is the number of elements Θ_1 of the base stations set together with the local base station BS_0 for the user's cooperation. is the number of elements Θ_2 of the base stations set to null at the local base station BS_0 .

2.1.3 Collaborative Transmission And Interference Nulling Process

The L_1 cooperative base stations and the L_2 interference nulling base stations carry out the corresponding cooperative transmission and interference nulling for local users respectively . CoMP is used by PUCIC for joint transmission (JT) and cooperative scheduling / beamforming CS / CB.

2.2 User Decision Algorithm

SINR estimation formula for the user is $SINR = \dfrac{P_0 + \sum_{i=1}^{L_1} P_i}{\sum_{j=L_1+L_2+1}^{L} P_j + \sigma^2}$, and the specific steps of the user's decision are as follows:

User decision calculation L_1 、 L_2 algorithm is based on the UDN scene. In the UDN, there are more intensive base stations. The implementation of a case of L_1 and L_2 decision algorithm is on the condition of $M \leqslant L$. With regards tosetting $M \leqslant L$, the specific descriptions are as follows:

1. Let $L_1 = 0$, the user UE_0 estimates SINR at $L_2 = 1$ and verifies whether the judgment condition $SINR \leqslant \gamma$ is satisfied. If it is satisfied, $L_2 = 1$ is the request; if it is not satisfied, follow Step 1-1 method (below) : traverse L_2 and estimate $SINR_1$ until you find the first L_2 that satisfies $SINR_1^{(n)} \geqslant \gamma$ (where $n \leqslant M-1$). According to the minimum requirements to meet user business on the basis of the principles of complexity, L_1 、 L_2 are for the request;

1-1 Method:1-1a. Fix L_1 constant to determine whether it will meet $L_1 + L_2 + 1 \leqslant L$. If it's not satisfied, then jump to Step 2. If satisfied, then make $L_2 = 1$, predict $SINR_1$ and mark $SINR_1^{(1)}$. If it satisfies $SINR_1^{(1)} \geqslant \gamma$, then $L_2 = 1$ is the request, otherwise continue to the next step;

1-1b. Repeat this step until you find the first one L_2 satisfies $SINR_1^{(n)} \geqslant \gamma$ (where $n \leqslant M - 1$). Then this L_2 is the optimal one for L_1.

2. Let $L_1 = 1$, the user UE_0 estimates $SINR_2$ of $L_2 = M - 1$, verifies whether it will meet the decision condition $SINR_2 \geqslant \gamma$. If it's not satisfied, then jump to step 3; if satisfied, according to the method of step 1-1, traverse L_2 andestimate $SINR_2$ until it meets $SINR_2^{(n)} \geqslant \gamma$ (where $n \leqslant M - 1$) the first L_2 so far. Then the L_1 and L_2 are the best. In addition, in the process of traversing L_2 adering to the method of step 1-1, $L_2 + 1$ should be satisfied under the condition that it satisfies $L_1 + L_2 + 1 \leqslant L$. Skip to Step 3 if the condition is not satisfied;

3. Under the condition that it satisfies $L_1 + 1 \leqslant L$, let $L_1 + 1$ repeat this step until the first L_1 in $L_2 = M - 1$ and $SINR_c \geqslant \gamma$ are satisfied.Traverse L_2 following the method of step 1-1 to find the first L_2 that satisfies $SINR_c^{(n)} \geqslant \gamma$ (where $c \leqslant L, n \leqslant M - 1, c + n \leqslant L$). Then L_1 and L_2 are for the request. Furthermore, if the process of $L_1 + 1$ does not meet $L_1 + 1 \leqslant L$, then the L_1 and $L_2 = M - 1$ are optimal. In the process of traversing L_2 in step 1-1, $L_2 + 1$ shouldbe satisfied under the condition of satisfying $L_1 + L_2 + 1 \leqslant L$, and if the condition is not satisfied, L_1 、 L_2 are for the request;

4.On the basis of L_1 in Step 3, if the algorithm does not satisfy $L_1 + 1 \leqslant L$, the algorithm ends and the L_1 and L_2 obtained in Step 3 are optimal. If $L_1 + 1 \leqslant L$ is satisfied, then $L_1 + 1$, traverse L_2 in the way of Step 1-1, and estimate $SINR_{c+1}$ until first L_2 satisfying $SINR_{c+1}^{(n)} \geqslant \gamma$ (where $c \leqslant L, n \leqslant M - 1, c + n \leqslant L$) is found. Besides, in the process of traversing L_2 according to the method of step 1-1, $L_2 + 1$ should be satisfied under the condition that it satisfies $L_1 + L_2 + 1 \leqslant L$.The algorithm ends if the condition is not satisfied.

5. Compare $SINR_c^{(n)}$ and $SINR_{c+1}^{(n)}$. If it satisfies $|SINR_{c+1}^{(n)} - SINR_c^{(n)}| \leqslant \zeta$, then select the L_1 and L_2. Corresponding $SINR_c^{(n)}$ is the optimal; otherwise select the L_1 and L_2 and corresponding $SINR_{c+1}^{(n)}$ is the optimal.

3.PUCIC PerformanceSimulation Analysis

In order to simulate the impact of PUCIC mechanism on user SINR under different parameter changing environment, this paper builds the corresponding UDN scene based on MATLAB platform.The performance indicators used to evaluate the PUCIC mechanism are user average signal-to-noise ratio (SINR), an average bandwidth loss rate.

3.1Comparison of Performance under Different Base Stations

In order to analyze the user SINR gain obtained by coordinating the priority of the scheme and the base station, this paper compares the selection scheme UCIIC.,It is comparable because UCIIC does not use the base station cooperative transmission. The number of base stations BS_NUM of 10 and 30 is set. The number of antennas M is 4.
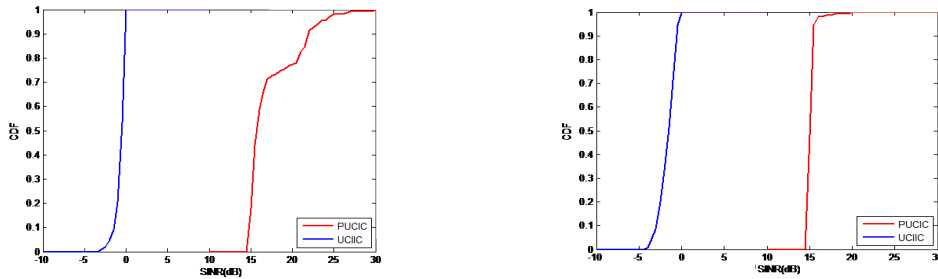

 (a) when BS_NUM=10，PUCIC VS. UCIIC   (b) when BS_NUM=30，PUCIC VS. UCIIC
Figure2:Comparison of User SINR CDF for Different Mechanisms when Base Station Number Changes

In Figure 2, the SINR of the two mechanisms decreases whenthe base station increases.The user SINR of the PUCIC is 15 dB higher than the UCIIC. When the number of base stations increases, PUCIC user SINR value is more concentrated. When the user SINR performance difference decreases, it, to a certain extent, enhances the user fairness.

3.2 Comparison of Performance under DifferentAntenna Numbers

When the number of base stations is constant, the more antennas there are the more interference each local base station can handle and the better performance the user can achieve. The number of antennas of 2 and 16 is set respectively. The number of base stations BS_NUM is 30.
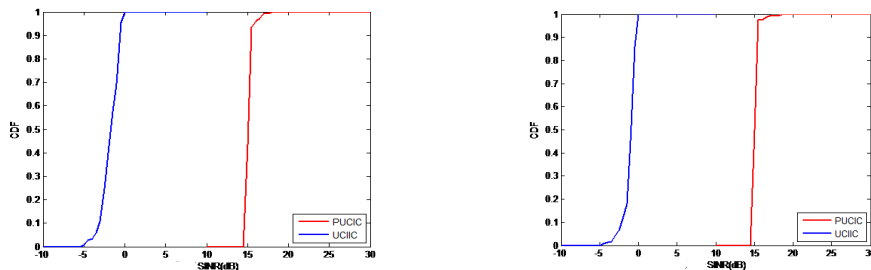
(a) when M=2，PUCIC VS. UCIIC   (b) when M=16，PUCIC VS. UCIIC
Figure 3: Number of Antennas vs. User SINR CDF

In Figure3, the SINR of the two mechanisms does not change greatly with the increase of the antennas, and the user SINR of the PUCIC is 15 dB higher than the UCIIC. This indicates that the user SINR performance of the PUCIC is not limited by the number of base station antennas. In general, the increase in the number of antennas hardly affects the user SINR.

3.3Effects of Different Base Stations on PUCIC Bandwidth Performance

In order to evaluate the performance improvement of the user performance obtained by the PUCIC and the bandwidth loss caused by the cooperation with the base station, the change of the average bandwidth loss-gain-rate of the PUCIC is observed when the number of base stations changes. BS_NUM, the number of base stations, is set as 10 and 30.

As shown in Figure 4, the PUCIC average bandwidth loss-gain-rate curves when the BS_NUM changesin the base stations . If the number of base stations is in the moderate, say 10 to 20, the loss ratio is acceptable, and PUCIC is effective and in the value of use., It will also be of a certain detection significance in the specific application.
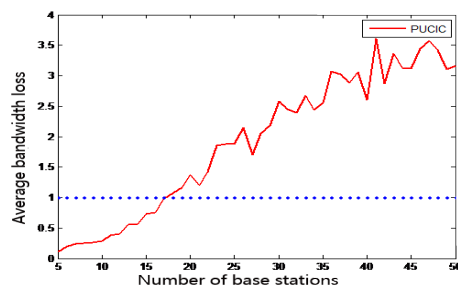
Figure 4: Effect of Base Station Number Change on PUCIC Average Bandwidth Deficit Rate

4. Conclusion

In this paper, a user-centric inter-cell interference suppression scheme, PUCIC, is proposed based on the base station collaboration for the inter-cell interference problem of UDN downlink. The scheme is proposed from the perspective of user performance experience. It is found that the PUCIC not only has a better user SINR performance than the UCIIC with achangable number of base stations it also effectively improves the user of the UCIIC SINR performance limited by the number of antennas and makes SINR about 15dB gain. Moreover, , PUCIC effectively maintains the user fairness, which solved the problem of low performance limited to the existed traditional interference suppression mechanism.Taking the bandwidth loss rate into consideration,   we can see that, on the whole, PUCIC improves the user performance and maintains the user fairness at the cost of the bandwidth loss.

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