# Research on Spectrum Allocation Strategy Based on Stackelberg Game in Ultra Dense Network

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**Abstract.** As one of the key technologies of 5G, ultra dense network (UDN), densely distributed small base stations has brought about an increase in system capacity and transmission rate, and has become a research hotspot in recent years. In order to compensate for the severe co-layer and cross-layer interference caused by UDN, clustering small cells first and Stackelberg game is applied to spectrum allocation, and the Nash equilibrium is solved to obtain a spectrum allocation strategy with less interference. The performance of spectrum allocation algorithm based on Stackelberg game (SASG) is simulated and the simulation results verify the performance of SASG, showing that SASG can effectively improve the system throughput under limited spectrum resources.

**Keywords:** Ultra dense network · Game theory · Spectrum allocation · Nash equilibrium · Clustering

## 1 Introduction

In recent years, wireless communication network technology has been rapidly updated. User requirements of communication services and the system and architecture of communication networks have undergone tremendous changes. On the one hand, the services supported by the mobile communication network are more complex, from traditional voice and short message services to multimedia services such as mobile data Internet access and video. On the other hand, various intelligent end users pursue higher rates and higher quality wireless communication service. Therefore, increasing the system capacity of mobile communication networks, supporting more communication users, and providing more stable, faster, and more efficient data transmission has become an urgent requirement for the future development of mobile communication.

The IMT-2020 (5G) Promotion Group of China promulgated the “5G Vision and Demand White Paper” in 2014, which vividly explained the key capabilities of the 5G mobile communication system [1]. And the related technologies of the 5G mobile communication system have become research hotspots. Within the coverage of the

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This work is supported in part by National Natural Science Foundation of China (No. 61671184, No. 61901137).

M. Guan and Z. Na (Eds.): MLICOM 2020, LNICST 342, pp. 36–46, 2021.
https://doi.org/10.1007/978-3-030-66785-6_4

macro base station, various types of small base stations are densely deployed, the communication distance between the small base stations and users is greatly shortened, and the transmission rate is significantly improved. However, a large number of densely deployed small base stations of different types and different service scales will cause serious cross-layer and co-layer interference, and the wireless network communication environment becomes more and more complicated. Therefore, a reasonable spectrum allocation strategy can make the most efficient use of limited spectrum resources, coordinate interference between base stations, and improve the spectrum utilization rate of the network.

A large number of scholars have conducted in-depth research on spectrum allocation strategies in ultra dense networks, and various new ideas are emerging. Combined with the idea of clustering, small cells are divided into different clusters for calculation according to different algorithms [2–5]. Combined with the idea of graph theory, cells with severe interference are assigned different colors, and each color represents a kind of spectrum resource. In this way, the interference problem between adjacent cells can be solved by allocating orthogonal spectrum resources. Paper [6] proposed a QoS graph coloring (QGC) spectrum allocation scheme. The QGC algorithm attempts to color the minimum number of colors for all vertices in each cluster, and matches the QoS requirements of the vertices by coloring each vertex once or twice. Paper [7] proposed a dynamic spectrum allocation algorithm based on interference graph (CBRA), which effectively suppressed the co-layer interference and improved the spectrum efficiency.

With the continuous improvement and development of game theory, it is increasingly used in the field of mobile communications, providing a good idea for solving resource allocation and interference coordination problems. Paper [8] proposed a macro base station power control and time-domain interference coordination algorithm based on game theory, using an adaptive configuration scheme for ABS subframes. Paper [9] allocates the spectrum resources of macro cell and small cell based on game theory, and obtains better results than the average allocation.

In this paper, Stackelberg game is applied to spectrum allocation, combined with the concept of Nash equilibrium, a spectrum allocation scheme that is satisfactory to every participant is obtained.

## 2 System Model of Ultra Dense Network

The issue of interference management between small base stations is an important challenge in the environment of large-scale deployment of small base stations. The system model and interference scenario of the ultra dense network are shown in Fig. 1. In this model, macro base station and small base stations co-exist, and small base stations serve their users. Within the coverage area of the macro base station, there are $N_r$ small base stations randomly distributed, and the coverage radius of the small base stations is $R_s$.

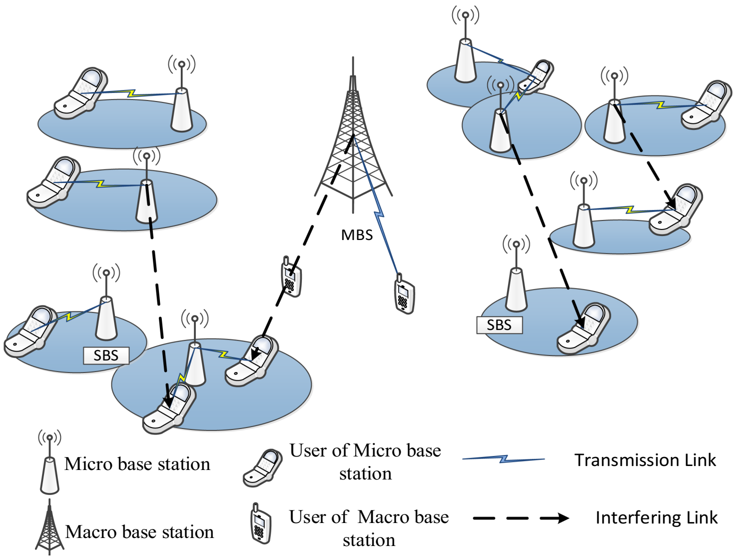

**Fig. 1.** System model of ultra dense network

The ultra dense network reduces the transmission delay by densely deploying small base stations to bring the transmission nodes closer to the terminal. The adding in the number of small base stations can increase system capacity, support massive user connections, and provide users with global coverage. Compared with traditional macro base station deployments, ultra dense networks have the advantages of strong blind spot coverage, low deployment costs, and flexible configuration. In response to different usage environments, different types and sizes of small base stations have been developed and put on the market, greatly accelerating the development of ultra dense networks.

## 3 Small Cell Clustering

Clustering is to divide the complex network topology into several small network clusters according to certain criteria (such as the location of the base station, the degree of interference in the network, etc.), and then perform intra-cluster or inter-cluster resources allocation in cluster units.

At present, domestic and international cluster-based spectrum allocation management schemes can be divided into two categories according to different optimization objectives of interference: one is to maximize intra-cluster interference; the other is contrary to the former. By dividing into the same cluster, there are base stations with very little intra-cluster interference, so that when the same frequency resources are reused in the cluster, no serious interference will occur, which greatly improves the utilization rate of resources. Therefore, adjacent base stations with severe interference to each other are divided into different clusters, and orthogonal frequency resources are allocated in the different clusters, thereby suppressing interference.

In the research of this paper, the latter optimization goal is selected, and annealing evolution algorithm (AEA) is used to cluster small base stations.

The algorithm flow can be implemented according to Algorithm 1.

**Table 1.** Algorithm flow

```
Algorithm 1: annealing evolution clustering algorithm
Input   $MAXGEN, T_{end}, k, p_c, p_m, gen = 0, T_i = T_0$
1.   Initial clustering $S$, interference sum $C(S)$
2.   for $r = 1, 2, \ldots N_b$ do
3.     for $gen = 1, 2, \ldots MAXGEN$ do
4.       Perform genetic operations such as selection, crossover,
         and mutation to obtain new clustering results $S'$ for
         small cells
5.       Get new interference sum $C(S')$
6.       $\Delta C = C(S') - C(S)$
7.       if $\Delta C < 0$ then
8.         Use new clustering results
9.       else
10.        Accept new clustering results with a probability of $\exp(-\Delta C / T)$
11.      end if
12.      $gen = gen + 1$
13.    end for
14.    if $T_i > T_{end}$ then
15.      $T_{i+1} = kT_i$, back to 3
16.    else
17.      break
18.    end if
19.  end for
Output  Clustering results
```

## 4 Spectrum Allocation Strategy Based on Stackelberg Game

The Stackelberg game is a hierarchical non-cooperative game, that is, some participants declare their own strategies before others choose strategies. When formulating a tiered strategy plan, the players who execute their strategies before other participants and dominate the game are called “leaders”, who can impose their strategies on other players. And those who respond to the leaders declare strategies of gamers are called “followers”.

The Stackelberg game can also be applied to a scenario containing one leader and multiple followers. At this time, for a given leader Stackelberg strategy, a set of follower joint strategy sets can be obtained by maximizing the utility. Each follower utility is a function of the leader strategy and other followers strategies. Therefore, the single-leader multi-follower non-cooperative game equilibrium solution corresponds to a situation in which the leader maximizes his utility according to the follower response set, and the followers play each other according to the leader's statement strategy until the Nash equilibrium is reached.

In the ultra dense network model, each small base station competes for available spectrum to maximize their own utility. First, the small base stations are clustered, and then the macro base station is the leader, and the small base station clusters are the followers to establish the Stackelberg game model.

Suppose a macro base station and $N_r$ small base stations are considered in the model, and the small base stations are numbered by $1, 2, \ldots, N_r$. The available spectrum bandwidth is $B$, the number of sub-carriers is $C$, adjacent sub-carriers have similar fading characteristics, set $S$ adjacent sub-carriers to form a channel, so the number of available spectrum resource blocks (number of frequency channels) is $M = C/S$ and the users of small base stations are random distributed in their respective coverage areas. According to Algorithm 1, the small base stations are divided into $N_g (N_g > M)$ clusters, and there are $N_r/N_g$ small base stations in each cluster. Matrix $\mathbf{G_r} \in R^{N_g \times \frac{N_r}{N_g}}$ is used to represent the distribution of each cluster. The row vector $G_m$ represents the number of all small base stations in the $m$th cluster.

$$\mathbf{G_r} = \begin{bmatrix} G_{1,1} & \cdots & G_{1,\frac{N_r}{N_g}} \\ \vdots & \ddots & \vdots \\ G_{N_g,\frac{N_r}{N_g}} & \cdots & G_{N_g,\frac{N_r}{N_g}} \end{bmatrix} \tag{1}$$

Firstly, according to the principle of not reusing the spectrum as much as possible, each small base station cluster is randomly assigned a spectrum resource block to obtain an initial spectrum distribution $\mathbf{S_r} \in R^{M \times N_g}$, in which time $S_{m,n} \in \{0, 1\}$. $S_{m,n} = 1$ indicates that the small base station $n$ is allocated the spectrum resource block $m$, and $S_{m,n} = 0$ indicates that the spectrum resource block $m$ is not allocated to small base station $n$. $Count(m)$ represents the number of small base station clusters to which spectrum blocks are allocated.

$$\mathbf{S_r} = \begin{bmatrix} S_{1,1} & \cdots & S_{1,N_g} \\ \vdots & \ddots & \vdots \\ S_{M,1} & \cdots & S_{M,N_g} \end{bmatrix} \tag{2}$$

$$\sum_{m=1}^{M} S_{m,n} = 1 \tag{3}$$

$$\sum_{n=1}^{N_g} S_{m,n} = Count(m) \times \frac{N_r}{N_g} \tag{4}$$

The small base station clusters at this time are classified: the first type cluster is a cluster whose allocated spectrum is not used by other clusters; the second type cluster is the allocated spectrum and other small base station clusters are used at the same time. For the first type cluster, the interference between them is small; for the second type cluster, because there is another cluster member using the same frequency spectrum at the same time, if the distance between some small base stations is close, it will cause a large co-layer interference.

The mathematical expression of Stackelberg game is:

$$G = \left\{N, \{S^c\}, \left\{u_j^c\right\}\right\} \tag{5}$$

Where $N$ represents the set of small base station clusters and $\{S^c\}$ represents the set of spectrum allocation strategies of the cluster. Where $S^c$ represents the spectrum allocated by the small base station cluster $c$, and $u_j^c$ represents the utility function of the small base station $j$ in the cluster $c$.

Consider that when a small cell $r$ transmits information to user $i$ within its coverage area, the user's signal-to-noise ratio can be defined as:

$$SINR_i^r = \frac{P_i^r (d_i^r)^{-\gamma} h_i^r}{\sum\limits_{m \in C_r, m \neq r} P_i^m (d_i^m)^{-\gamma} h_i^m + N_0} \tag{6}$$

Among them, $P_i^r$ represents the transmission power when the small base station $r$ transmits information to the user $i$. $d_i^r$ represents the distance between the small base station $r$ and the user $i$, and $(d_i^r)^{-\gamma}$ represents the path loss. $C_r$ represents the set of all small base stations that are allocated the same spectrum resource block as the small base station $r$. The noise consists of two parts, the additive white Gaussian noise and co-channel interference. $N_0$ represents the additive white Gaussian noise and co-frequency interference is represented by $\sum\limits_{m \in C_r, m \neq r} P_i^m (d_i^m)^{-\gamma} h_i^m$, which represents the total interference caused to user $i$ by other users using the same spectrum resource block.

Using the throughput of each cluster as the utility function, the utility function of the small base station $r$ in the cluster $c$ is:

$$U_r^c = \sum_{i \in \{r\}} \log_2(1 + SINR_i^r) \tag{7}$$

The utility of each small cell cluster is:

$$U^c = \sum_{r \in C_r} U_r^c \tag{8}$$

Since the spectrum allocation of each cluster is controlled by the cluster head, and each cluster is independent and selfish. When the game reaches the equilibrium point, each cluster has no incentive to change its strategy, and the game reaches an equilibrium.

If formula (9) holds for any $S^c$, then point $(S^{1*}, S^{2*}, \ldots, S^{c*})$ is the equilibrium point of the Stackelberg game.

$$U^c(S^{c*}, S^{-c*}) \geq U^c(S^c, S^{-c*}) \tag{9}$$

The total utility function of the system can be expressed as:

$$U = \sum U^c \tag{10}$$

The flow of spectrum allocation strategy algorithm based on Stackelberg game is shown in Algorithm 2 (Table 2).

**Table 2.** Algorithm flow

```
Algorithm 2: Spectrum allocation strategy based on Stackelberg game
Input  Small cell cluster obtained from Algorithm 1
for $T = 1,2,3,\ldots$ do
    for $r = 1,2,\ldots,N_g + 1$ do
        Change strategy of cluster $r$
        Calculate the utility of cluster $r$ according to formula (7)(8)
        if satisfy (9) then
            Cluster $r$ chooses the corresponding strategy
        end if
        $r = r + 1$
    end for
end for
```

## 5 Simulation Analysis

Based on the ultra dense network model, considering Rayleigh fading and path loss, this paper simulate the throughput of macro base stations and small base station clusters. The system simulation parameters are shown in Table 1 (Table 3):

**Table 3.** Simulation parameters

| Parameters | Value |
|---|---|
| System bandwidth | 6 MHz |
| Carrier frequency band | 2.6 GHZ |
| Number of subcarriers | 360 |
| Number of resource blocks | 4 |
| Transmit power of MBS | 45 dBm |
| Transmit power of SBS | 20 dBm |
| Coverage radius of MBS | 500 m |
| Coverage radius of SBS | 50 m |
| Path loss index | 3.7 |
| White Gaussian Noise | −174 dBm/Hz |

The interference change when using AEA for clustering is shown in Fig. 2. It can be seen from the figure that with each change, the interference and the cluster gradually become smaller until the minimum value is reached or the termination condition is satisfied.

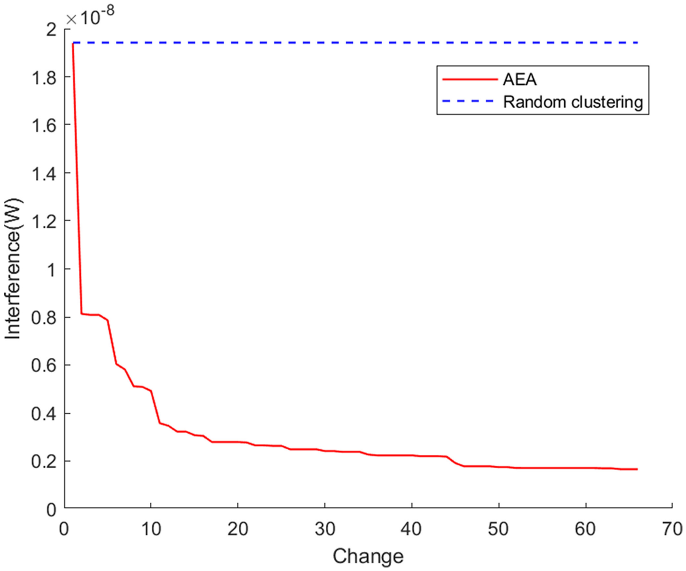

**Fig. 2.** Interference change when clustering

When the Stackelberg game reaches Nash equilibrium, the performance simulation of the macro base station and small base station clusters is shown in Figs. 3, 4 and 5.

As can be seen from Fig. 3, in the initial game stage, in order to optimize their utility, the small base station clusters and macro base stations continuously change their own strategies until all participants reach a stable state.

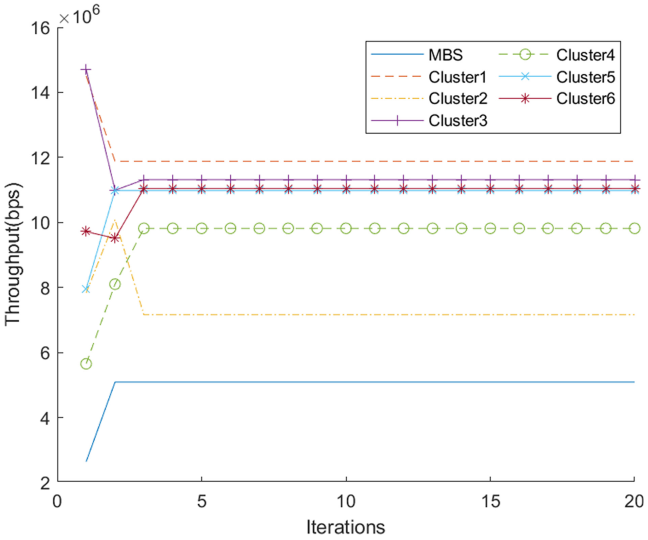

**Fig. 3.** Performance of small cell cluster

After reaching the equilibrium, the macro base station change the strategy independently, and the strategies of other participants remain unchanged. The throughput changes of all participants are shown in Fig. 4. It can be seen from the figure that the throughput of the macro base station decreases, which meets the definition of Nash equilibrium.

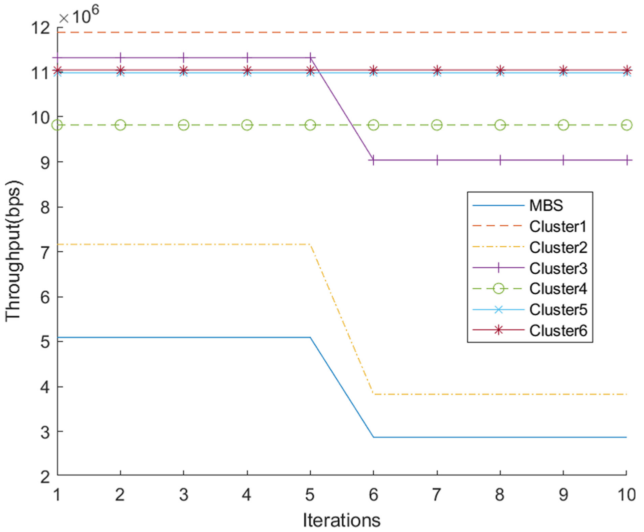

**Fig. 4.** Performance changes when the macro base station changes its strategy

The trend of the total throughput of the system during the game is shown in Fig. 5. It can be seen from the figure that in the initial stage, due to the players playing each other and changing their strategies, the system throughput fluctuates to a certain extent. After about 15 games, the system reaches the Nash equilibrium.

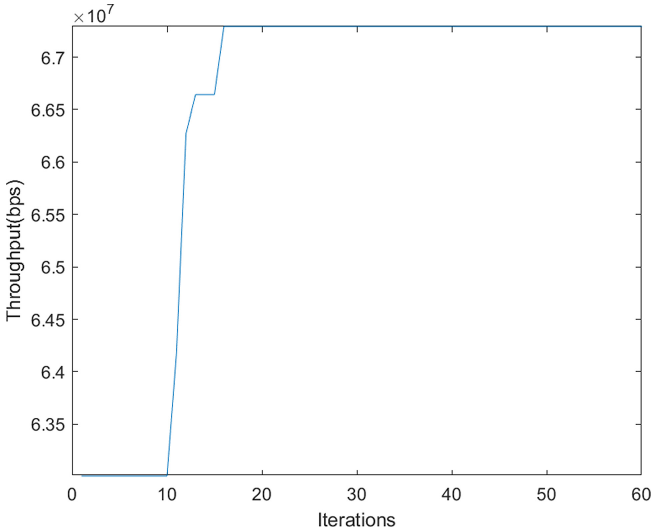

**Fig. 5.** Performance of system

## 6 Conclusion

This paper proposes a spectrum allocation strategy based on Stackelberg game. In the proposed strategy, the first goal is using AEA for clustering to minimize the intra-cluster interference. Then let the macro base station as the leader and the small base station cluster as the followers to construct the Stackelberg game model. Optimizing the spectrum allocation strategy of small base stations by solving Nash equilibrium of games. The simulation analysis of the performance is processed from the number of iterations, throughput and so on.

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