An Interference Coordination Scheme for Hyper-Dense Heterogeneous Networks

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Abstract. Network densification is needed to meet the throughput demands likely to arise in 2020 and beyond, and small cells are expected to carry a majority of traffic. Since the number of small cells is huge, and they are always randomly deployed, the interference scenarios become much more complicated than in conventional cellular systems. In this paper, an interference coordination scheme based on graph method and clustering strategy for hyper-dense heterogeneous networks (HetNets) is presented. It is shown that the proposed scheme improves the network throughput and user satisfaction by dynamically allocating frequency sub-bands in K-tier networks.

Keywords: Inter-cell interference coordination, Heterogeneous Cellular Networks, Small cell

1 Introduction

In the view of [1], the wireless industry is preparing for a challenge, an astounding 1000-fold increase in data traffic expected in this decade. As the demand for higher data rates increases, one of the solutions available to operators is to reduce the size of the cell. By reducing the size of the cell, area spectral efficiency is increased through higher frequency reuse, while transmit power can be reduced such that the power lost through propagation will be lower. Additionally, coverage can be improved by bringing the access point closer to the users. By definition, small cells are low-power wireless access points that operate in licensed spectrum, are operator-managed and feature edge-based intelligence [2]. Types of small cells include femtocell, picocell, metrocell and microcell. The concurrent operation of different classes of base stations is known as heterogeneous networks (HetNets).

One of the biggest problems for HetNets is inter-cell interference. Within operator-deployed cells like macrocells and relays, interference may be mitigated via frequency reuse planning. It is especially problematic with unplanned deployment of small cells, where the operators have little or no control of the location of the small cell. Furthermore, [3] summarizes the interference problem in HetNets is challenging also due to Closed Subscriber Group (CSG) access and power difference between nodes.

Inter-cell interference coordination (ICIC) techniques that reuse radio frequencies to minimize interference experienced in the network and maximize spectral efficiency was introduced in 3GPP Release 8 as an optimal method to solve inter-cell frequency interference. However, it is designed for macrocell only scenario, and may not be effective in the case of HetNets. With the implementation of HetNets, more cells with intra-frequency interference are introduced into the existing network and not only that but also their coverage areas are overlapped. To deliver high spectral efficiency per unit area, enhanced inter-cell interference coordination (eICIC) are needed to manage and control interference when small cells are added to macro cells in the same channel.

There are several time domain and frequency domain eICIC methods investigated in literature. The basic ideawith time domain eICIC is that an aggressor layer creates protected sub-frames for a victim layer by reducing its transmission activity in certain sub-frames, which is called Almost Blank Sub-frame (ABS) [4] [5]. [6]provides a dynamic time domain eICIC method, and further improves performance by adapting the ABS in response to dynamic variations in network load. Some approaches are proposed to enhance ABS to completely eliminating interference from the sub-frame [7] [8]. In frequency-domain eICIC solutions, users of neighbor

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cells are scheduled in pre-configured frequency sub-bands in order to have totally orthogonal transmission signals at different cells. Distributed utility-based algorithms for downlink frequency resource allocation is proposed in [9] [10].The proposed algorithms aim to maximize the sum utility of the whole system. [11] considers decentralized self-optimization network (SON) architecture of small cell cluster and proposes distributed coverage optimization algorithm using game theory. A Q-learning-based algorithm is presented in [12], and the proposed algorithm can select the appropriate network for access according to different traffic types, terminal mobility and network load status. However, the scenarios discussed in these papers are based on sparse model [13], and the fundamental limits of interference problem of the hyper-densification in HetNets are not yet fully considered.

In this paper, we provide a flexible and simplified model to estimate the minimum separation distance which controls the frequency reuse distance in a k-tier hyper-dense HetNet, and a dynamic interference coordination scheme based on graph method and clustering strategy is presented. It is shown that the proposed scheme achieves higher network throughput and user satisfaction by dynamically allocating sub-channels in K-tier networks according to the minimum cell separation constraint. The remainder of this paper is organized as follows: Section II provides the system model. In Section III, the minimum cell separation estimation model is presented. In Section IV, we propose a dynamic interference coordination scheme. Section V shows the performance evaluation. Conclusion is given in Section VI.

2 System Model

We consider a HetNet comprising of K -tier network where each tier models the BSs of a particular class, such as those of femtocells or picocells. We assume that the of BSs in the i -th tier are spatially distributed as a homogeneous Poisson point process (PPP) Φ_i of density λ_i, transmit at power p_i, and have a SINR target of β_i. Thus, each tier can be uniquely defined by the tuple $\{\lambda_i, p_i, \beta_i\}$, and the average number of BSs per unit area is λ_i. The users in the network are randomly scattered according to a stationary PPP with density λ_u (users/m^2). λ_u is independent of λ_i. Each user is associated with the BS based on SINR. The transmission power from serving BS m in the i -th tier to user n on sub-channel j is given by $p_{i,m,n,j}$, and the channel gain between BS m and user n on sub-channel j is denoted by $g_{i,m,n,j}$. The SINR of user n on sub-channel j is given by

$$\gamma_{i,m,n,j} = \frac{p_{i,m,n,j} \cdot g_{i,m,n,j}}{I_{n,j} + n_0} = \frac{p_{i,m,n,j} \cdot g_{i,m,n,j}}{\sum_{i=1}^{k} \sum_{x=1}^{x_{i,j}} p_{i,x,n,j} \cdot g_{i,x,n,j} + n_0} \geq \beta_i. \tag{1}$$

Where $x_{i,j}$ is number of BSs used sub channel j in i -th tier, so $I_{n,j}$ is the interference from other BSs to user n on subchannel j, and n_0 is the noise power. The channel propagation model represent as a combination of path-loss and log-normal shadowing, considers both the indoor and outdoor links [9][14].

3 Minimum Cell Separation

Consider a single tier case $\{\lambda, p, \beta\}$, a femtocell UE n connects to a femtocell m, the resulting SINR expression is

$$\gamma_{i,m,n,j} = \frac{p_{m,n,j} \cdot K_f \cdot |d_{mn}|^{-l_i} \cdot \chi_{mn}}{n_0 + \sum_{x=1}^{x_{i,j}} |d_{xn}|^{-l_i} \cdot p_{x,n,j} \cdot \chi_{xn} \cdot K_f \cdot L^{-2}} = \frac{p \cdot K_f \cdot |d_{mn}|^{-l} \cdot \chi_{mn}}{n_0 + \sum_{x=1}^{x_j} |d_{xn}|^{-l} \cdot p \cdot \chi_{xn} \cdot K_f \cdot L^{-2}} \geq \beta. \tag{2}$$

It's shown in [9][14], l_i is the outdoor (usually [3.5, 4.5]) and the indoor (usually [2.5, 3.5]) path-loss exponent respectively; $|d_{mn}|$ is the distance between femtocell m and UE n ; L is the wall loss;

$K_f \triangleq {d_{of}}^{\beta-2} \cdot [c/(4\pi f_c)]^2$ is an unitless constant depending on the wavelength of RF carrier c/f_c and indoor reference distance d_{of} ; χ_{mn} is the log-normal shadowing between BS m and UE n , and $10\lg \chi_{mn} \sim \left(N_0, \sigma_B^2\right)$.

As the simulation result shown in[9][15], we can ignore the effect of noise and shadowing. Set the transmit power on each sub-channel of all BSs in the same tier equal to p . The simplified SIR expression leads to the minimum distance constraint which ensures and controls a minimum separation distance between any BSs that use the same sub-channels in a single tier case of indoor scenario.

$$\left|d_{mn}\right|^{-l} \geq \beta \cdot L^{-2} \cdot \sum_{x=1}^{x_j} \left|d_{xn}\right|^{-l}. \tag{3}$$

Similarly, the minimum distance constraint in k -tier case of both outdoor and indoor scenarios is

$$\frac{p \cdot K_f \cdot \left|d_{mn}\right|^{-l}}{\sum_{i=1}^{k} \sum_{x=1}^{a_i x_j} \left|d_{xn}\right|^{-l_i} \cdot b_i p \cdot c_i K_f} \geq \beta_i. \tag{4}$$

$$\left|d_{mn}\right|^{-l} \geq \beta_i \cdot \sum_{i=1}^{k} \sum_{x=1}^{a_i x_j} \left|d_{xn}\right|^{-l_i} \cdot b_i \cdot c_i. \tag{5}$$

Where a_i , b_i , c_i are the ratio of $x_{i,j}$ to x_j , p_i to p , K_i to K_f . As mentioned before, K_i is affected by outdoor (d_{op}) or indoor reference distance [9][14], and in order to simplify the expression, the wall loss L is included here.

$$K_i = \begin{cases} {d_{op}}^{l_i-2} \cdot [c/(4\pi f_c)]^2 \cdot L^{-1} & \text{the i-th tier small cells are deployed outdoor.} \\ {d_{of}}^{l_i-2} \cdot [c/(4\pi f_c)]^2 \cdot L^{-2} & \text{the i-th tier small cells are deployed indoor.} \end{cases} \tag{6}$$

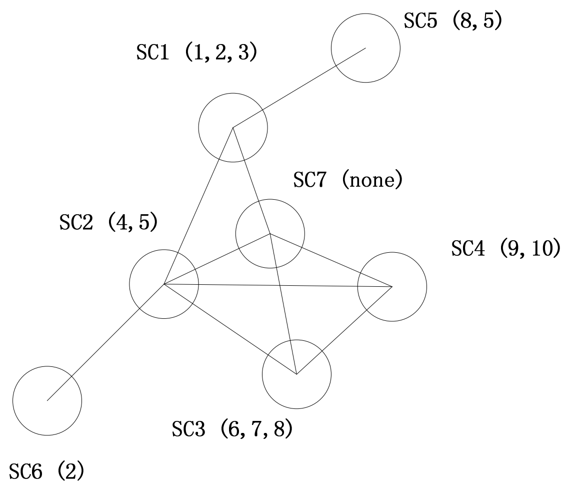
From (4), we note that in an interference-limited HetNet , for a given SINR target, the distance relation between UE and BSs nearby is determined, and is not directly related to the values of transmit power or link loss but relevant to the proportion of the parameters. The network system should check whether any other BSs have taken a certain sub-channel within the minimum distance before reusing the sub-channel. In turn, the system can control interference level on different sub-channel by controlling the corresponding frequency reuse distance. To improve the fairness of networks, system should maintain a similar minimum separation constraint of different sub-channels and the interference experienced in different region of networks will be similarly. On the contrary, if we want to improve the network throughput and capacity, system should assign some sub-channels with larger minimum reuse distance, and reserve them to the high priority users.

4 Dynamic Interference Coordination Scheme

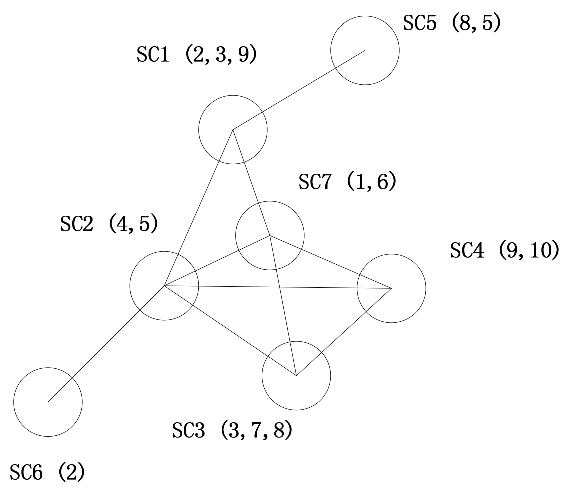
As a way to mitigate network interference and improve the user data rate, we propose a dynamic interference coordination scheme based on graph method and clustering strategy.

To simplify the discussion about signaling supporting for cross-tier communication, we assume the system has a global controller to manage all the network elements of the HetNet. At first, each BS starts by creating its scanning report which is collected from its served UE. UE scans the surrounding area and then selects a BS as serving BS based on SINR. The global controller could learn the interference knowledge of BSs from the scanning reports. And then the global controller generate a graph $G = \left(V, E\right)$. The vertex V of the interference graph stands for the small cells, and the edge E stands for interference collision relationship based on the minimum separation. Any two vertices that have an edge cannot be pre-configured to the same frequency sub-bands, and they are allocated into the same cluster. Each small cell may have interference relationship with many other small cells, so one small cell may joint many different clusters. Because of the high density of BSs, the BSs deployed to similar locations and interference conditions may have high probability of selecting to use the same sub-channel. If allow users to select sub-channels freely, there will be serious frequency collisions. Hence those

BSs form a cluster. They can transfer frequency sub-bands to each other when system is lack of resources available for distribution.



(a). The original frequency sub-bands allocation result



(b). The result of frequency sub-bands transfer

Fig.1. An example of frequency sub-bands transfer

As shown in Fig.1 (a), considering a simple single tier case, there are 6 small cells in the area. Denote these small cells from SC1 to SC6. Each circle represents a small cell, and the line between two circles means these two circles have interference relationship. The whole frequency band is divided into 10 sub-bands, and assigned to each small cell. Those small cells have interference relationship are assigned to different frequency sub-bands. The numbers in parentheses indicate the serial numbers of frequency sub-bands assigned to the small cell.

Now, a user starts a new small cell and it is denoted by SC7. In the current allocation circumstance, the set of available frequency sub-bands for SC7 is empty. Hence, SC7 send an application for the transfer of frequency sub-bands to those small cells of interference relationship. Because of selfishness, other small cells prefer to transfer the frequency sub-bands of lower data rate. They calculate the data rate of each sub-band and sort the order. Then they send the results to SC7. SC7 chooses the frequency sub-bands according to the following 2 principles: (1) The transfer of sub-bands cannot cause serious loss of data rate to the original owners. Comparing to access-reject, dropping calls provide poorer user experience. (2) The reason that SINR of some sub-bands are lower is they are reused during short distances, as analyzing in Section III. Choosing this kind of sub-bands will cause more small cells to involve in the transfer, but it frees up resources and the reuse distance of sub-bands may be lengthened. So SC7 should choose the frequency sub-band of lower data rate and high reuse ratio, and it chooses sub-band 1 and 6. SC1 and SC3 each want one sub-band more, and they both find new frequency sub-band available. The transfer result is shown in Fig.1 (b).

The resources transfer can resolve the frequency conflict in a small cell cluster or a small scale of clusters, instead of recoloring the interference graph. Fig.2 shows the result of redistribution of the case discussed above by graph method. It needs 3 times more of changing of sub-bands than resource transfer. It shows that the transfer scheme based on clustering strategy is effective in mitigating interference at a lower cost. It reduces the overhead of information exchanging and signaling transmission.

Especially, in order to keep the resource transfer from an endless loop, a small cell is not allowed to send application of resource transfer more than once. When its request is satisfied, it exits to the recursive process.

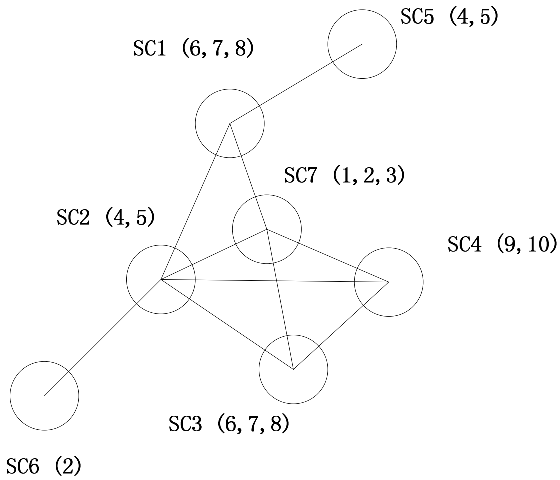


Fig.2. The result of redistribution by graph method

Furthermore, we should note that we classify the cells based on their location and interference environment, and other properties such as they belong to which tier, deployed indoor or outdoor, they are picocells or femtocells or other types of small cells are not considered. For a hyper-dense HetNet, improving per-user throughput by utilizing multiple cells resources such as CoMP (Coordination Multi-Point) becomes more feasible. Focus of resources management study will move from multiple cells competing to use a sub-channel to control the interference and fully share the resources by more users. Combining the scheme with CoMP is left for further study.

5 Performance Evaluation

In this section, we consider a 10MHz LTE system, and the simulation parameters are given in Table 1. Users are uniformly generated over the cells. The data rate requirement R_r of each user is randomly generated between 50-2000 kb/s.

Table 1. Simulation parameters

Parameters	Value
K (tiers of HCN)	3
λ_m (density of macrocells)	1
λ_p (density of picocells)	10
λ_f (density of femtocells)	100
p_m (transmit power of macrocells)	43dBm
p_p (transmit power of picocells)	25dBm
p_f (transmit power of femtocells)	10dBm

We compare the proposed scheme with a traditional clustering scheme (FCRA) [11] and a distributed algorithm based on game theory (DGT) [12]. Fig.3 shows the CDF of user data rate for 3 schemes. Because of minimum cell separation constraint and resource transfer, sub-channel is reused fully and in a distance acceptable. Hence the overall interference is controlled within the allowed range.

As shown in Fig.4, the proposed scheme improves small cell user satisfaction due to user classification. A user is assumed to be satisfied when its average throughput could meet its minimum requirement. User satisfaction is the percentage of satisfied users to total users. Since there are fewer macrocells in the network, the maximum number of macrocell users is less than 100, and the users satisfaction curves are not shown in Fig.2. In our simulation, 3 schemes have similar level of satisfaction of macrocell users and generally higher than small cell users, while picocell users have higher satisfaction than femtocell users. This is mainly because of the transmit power setting of different types of cells. To be more accurate, user satisfaction depends on its QoS requirement and is measured by throughput and delay. In further study, we will detail the user satisfaction criterias for specific service types.

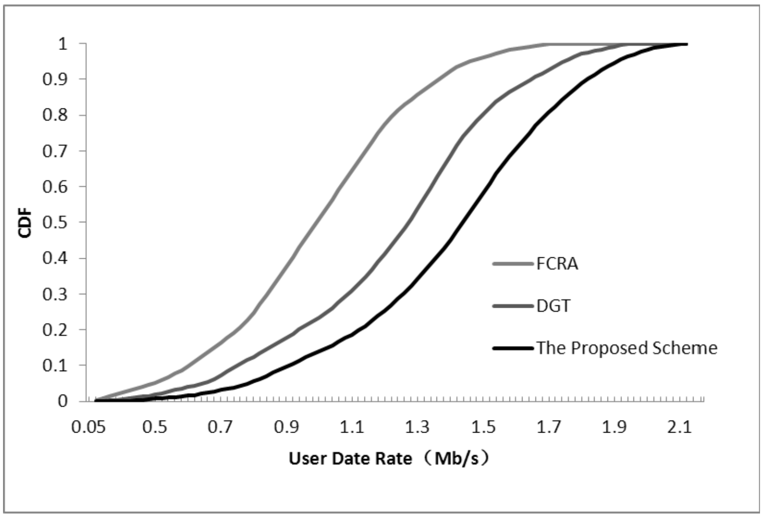


Fig.3. Comparison of CDF of user data rate

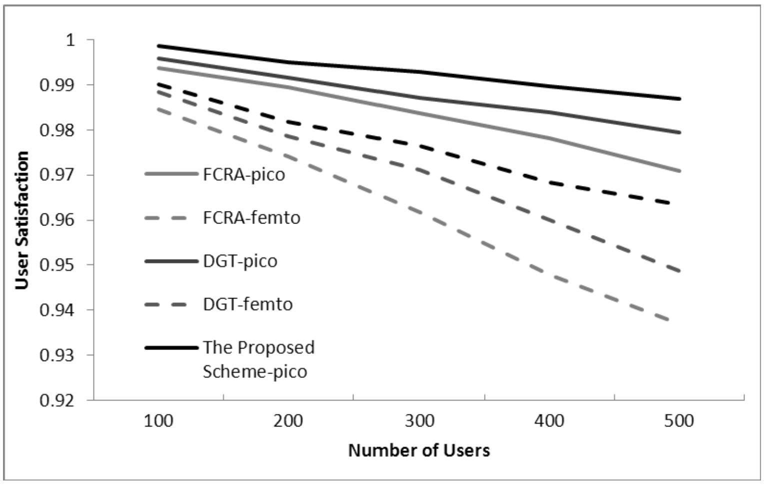


Fig.4. Comparison of small cell user satisfaction

6 Conclusion

The goal of this paper is to provide a flexible and simplified model to estimate minimum cell separation distance. We have provided a dynamic interference coordination scheme based on graph method and clustering strategy.

By employing the proposed scheme, both network throughput and the user satisfaction are improved. Implementing the scheme in a fully distributed way is left for further study.

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