# Backhaul Constraint-based Cooperative Interference Management for In-building Dense Femtocell Networks

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*Abstract*—**Dense femtocell networks have emerged as a key technology in residential, office building or hotspot deployments that can significantly improve the coverage and capacity of next-generation wireless networks. But, in the co-channel deployment scenarios, dense inter-femto interference might significantly deteriorate the overall system performance. In this paper, a new cooperative strategy in the dense femtocell networks with backhaul capacity constraints is proposed where multiple dominant interference from dense femtocells is classified into a number of groups, and different cooperative algorithms for these groups are used to mitigate the mutual interference and then obtain better trade-off between performance gains and needed cost. Simulation results show the proposed scheme yields great gains in terms of the average cell throughput, reaching up to 30% relative to the classical of non-cooperative transmissions.**

***Keywords-In-building femtocell networks, backhaul constraint, cooperative interference management***

## I. INTRODUCTION

Recently, it has been reported that about 80% of wireless communication traffic comes from indoors [1]. However, penetration loss and complex indoor environment make that it is difficult for existing cellular network to sufficiently follow the demand of indoor mobile traffic. The deployment of femtocells is envisioned to be a key solution for providing high wireless data-rates, offloading the macrocell traffic and enhancing the coverage of existing networking [2]. Femtocell is a low-power consuming base station connected to the service provider's network via broadband such as DSL or cable. It can improve the indoor coverage and data performance by means of spatial reuse of spectrum.

Femtocells can be densely deployed in a small area such as an office building, hotspot area, or residential area. Nevertheless, an unplanned user-installed deployment faces several challenges in terms of interference management and backhaul constraints [3]. In co-channel deployments, all femtocells reuse the spectrum resources, and interference from other femtocells might significantly deteriorate the overall system performance by multiple dominant interferences, which is from femtocells not only on the same floor, but also on the other floors. Hence, interference modeling used in traditional cellular scenario is not proper in a building environment.

Currently, mitigation of inter-cell interference in macro cellular networks has been widely studied mainly by means of frequency resource allocation [4] and cooperative transmission [5]. Unlike the macro base station, femto base stations can be installed by users in a random manner, making it difficult to handle the interference problem. The traditional methods can be applied to the mitigation of inter-femtocell interference when femtocells are deployed in a systematic way with low density [6]. However, when multiple femtocells are densely deployed in a building environment, the interference source will greatly increase, and the interference scenario will vary due to a large number of dominant interfering nodes.

In order to mitigate the inter-femtocell interference in the dense environment, several methods have been proposed, e.g. fractional frequency reuse (FFR) [7], which adjusts the frequency reuse factor with the aid of femtocell location information, and cooperative interference alignment [8], which applies the interference alignment algorithm in femtocell networks. But in these literatures, dense inter-femtocell interference and backhaul capacity constraints is not specially considered.

In this paper, a new cooperative strategy is proposed for interference management based on the backhaul capacity constraints in dense femtocell networks. Based on the received signal strength indication (RSSI) from the serving users, the multiple interference femtocells can determine to form several groups, and then decide the cooperative algorithms for these groups in term of the interference strength and the cost for information exchange. By maximizing a utility function, which captures both the benefits from grouping cooperation, in terms of achievable rate, and the costs, in terms of backhaul capacity for information exchange, the dense femtocells can perform interference mitigation, and consequently improve their overall performance and obtain the better trade-off between performance gains and needed cost. Simulation results show the significant performance gains.

The remainder of this paper is organized as follows. Section II describes the system model. Section III proposes a new cooperative strategy based on the backhaul capacity constraints of information exchange in a multi-femtocell deployment environment. In Section IV, the simulation results of the proposed scheme based on the iBuildNet® software tool [9] are presented, and finally, Section V summarizes the conclusions and further works.

The notation used in this paper follows usual convention methods: vectors are denoted by symbols in boldface, $(\cdot)^T$ and $(\cdot)^H$ are transpose and conjugate transpose of matrix or vector $(\cdot)$, respectively.

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## II. SYSTEM MODEL

Considering the downlink transmission of a femtocell network in a multi-floor office building, as shown in Fig. 1, $M$ femtocells and $N$ user equipments (UE) are deployed with $N_{\mathrm{T}}$ transmit and $N_{\mathrm{R}}$ receive antennas at each femtocell and UE, respectively. Here, we assume that the building is located in the macrocell coverage area, and femtocells use separated frequency band so that interference from macrocell can be neglected. For any transmission between a femtocell $m$ and one of its UE $k$, the received signal at UE $k$ over the subcarrier of OFDM systems can be denotes as

$$\boldsymbol{y}_k = \boldsymbol{h}_{k,m} \sum_{j=1}^{N} \boldsymbol{\omega}_{j,m} \boldsymbol{x}_j + \sum_{i=1, i \neq m}^{M} \boldsymbol{h}_{k,i} \sum_{j=1}^{N} \boldsymbol{\omega}_{j,i} \boldsymbol{x}_j + \boldsymbol{n}_k \quad (1)$$

where $\mathbf{y}_k \in \mathcal{C}^{N_R \times 1}$ denotes the received signal vector by the UE $k$, $\boldsymbol{h}_{k,i} \in \mathcal{C}^{N_R \times N_T}$ are complex matrices representing the multi-input multi-output (MIMO) channel matrix from femtocell $i$ to UE $k$, $\boldsymbol{\omega}_{j,i} \in \mathcal{C}^{N_T \times d_j}$ is the associated precoding vector by femtocell $i$ to UE $j$, $\boldsymbol{x}_j \in \mathcal{C}^{d_j \times 1}$ is the $d_j$-dimensional data stream vector for UE $j$, here, we can assume that $d_j$=1, and $\boldsymbol{n}_k$ represents the additive white Gaussian noise vector (AWGN) wth variance $\sigma^2$. In this section, we will focus on the deduction of the precoding vectors based on several cooperative algorithms.

### A. Coherent Joint-Transmission (JT) [5]

In the coherent joint-transmission, all the involved UEs feedback the MIMO channel information between each serving femtocell and UE pair, and then grouped femtocells exchange the feedbacked channel information to a central processing unit that should be responsible for computing the multi-cell multiuser precoding weighting vectors. Denote the composite channel matrix of UE $k$ with the feedbacked channel information as

$$\boldsymbol{H}_k = \left[\widehat{\boldsymbol{h}}_{k,1}, \widehat{\boldsymbol{h}}_{k,2}, \cdots, \widehat{\boldsymbol{h}}_{k,M}\right] \quad (2)$$

where the component channel $\widehat{\boldsymbol{h}}_{k,i}, i = 1,2,\cdots,M$ denotes the channel matrix between femtocell $i$ and UE $k$, so the $\boldsymbol{H}_k$ are $N_R \times MN_T$. This channel can be decomposed using the singular value decomposition (SVD) as $\boldsymbol{H}_k = \boldsymbol{U}_k \sum_k \boldsymbol{V}_k^H$, where the singular values in $\Sigma_k$ are arranged in a non-increasing order. Assuming that the linear detector at the UE $k$ is the Hermitian transpose of the left-most 1 columns of $\boldsymbol{U}_k$, denoted as $\boldsymbol{U}_k^{(1)^H}$, the equivalent channels of UE $k$ can be given as the Hermitian transpose of the left-most 1 columns of $\boldsymbol{V}_k$, denoted as $\boldsymbol{V}_k^{(1)^H} = \left(\boldsymbol{V}_{MN_T \times MN_T}^k(:,1)\right)^H$.

The coherent JT precoding matrix for UE $k$

$$\boldsymbol{W}_k = \left[\boldsymbol{\omega}_{k,1}^H, \boldsymbol{\omega}_{k,2}^H, \cdots, \boldsymbol{\omega}_{k,M}^H\right]^H \quad (3)$$

can be designed to null all the multiuser interference after linear detection at the UE, namely,

$$\boldsymbol{U}_k^{(1)^H} \boldsymbol{H}_k \boldsymbol{W}_j = 0, \text{ for all } k \neq j \text{ and } 1 \leq k, j \leq N; \quad (4)$$

To compute the precoding matrix $\boldsymbol{W}_k$, we define

$$\overline{\boldsymbol{H}}_k = \left[\boldsymbol{V}_1^{(1)^H}, \cdots, \boldsymbol{V}_{k-1}^{(1)^H}, \boldsymbol{V}_{k+1}^{(1)^H}, \cdots, \boldsymbol{V}_N^{(1)^H}\right]^T; \quad (5)$$

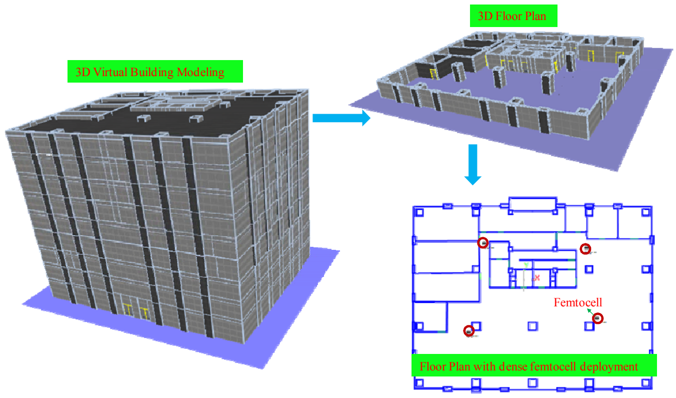


Fig.1 Office building model

Equation (4) imposes a constraint $\boldsymbol{W}_k$ should be in the null space of $\overline{\boldsymbol{H}}_k$ [10]. Let the SVD of $\overline{\boldsymbol{H}}_k$ be

$$\overline{\boldsymbol{H}}_k = \overline{\boldsymbol{U}}_k \overline{\Sigma}_k \left[\overline{\boldsymbol{V}}_k^{(1)}, \overline{\boldsymbol{V}}_k^{(0)}\right]^H \quad (6)$$

where $\overline{\boldsymbol{V}}_k^{(1)}$ contains the first 1 columns of singular vectors, while $\overline{\boldsymbol{V}}_k^{(0)}$ contains the rest singular vectors. Hence the columns in $\overline{\boldsymbol{V}}_k^{(0)}$ form a orthnominal basis of the null space of $\overline{\boldsymbol{H}}_k$.

Given the first sub-precoder $\boldsymbol{W}_{k,1} = \overline{\boldsymbol{V}}_k^{(0)}$, the data stream of UE $k$ can be transmitted on the dominant eigenmodes of the further equivalent channel $\boldsymbol{V}_k^{(1)^H} \boldsymbol{W}_{k,1}$ to maximize the channel gains.

$$\boldsymbol{V}_k^{(1)^H} \boldsymbol{W}_{k,1} = \widetilde{\boldsymbol{U}}_k \begin{pmatrix} \widetilde{\Sigma}_k & 0 \\ 0 & 0 \end{pmatrix} \left[\widetilde{\boldsymbol{V}}_k^{(1)}, \widetilde{\boldsymbol{V}}_k^{(0)}\right]^H; \quad (7)$$

Then, the second sub-precoder can be $\boldsymbol{W}_{k,2} = \widetilde{\boldsymbol{V}}_k^{(1)}$ and the total coherent JT precoder for UE $k$ is

$$\boldsymbol{W}_k = \boldsymbol{W}_{k,1} \boldsymbol{W}_{k,2} = \overline{\boldsymbol{V}}_k^{(0)} \widetilde{\boldsymbol{V}}_k^{(1)}; \quad (8)$$

### B. Non-Coherent Joint-Transmission [10]

The computing method for the non-coherent JT precoders is similar to that for the coherent JT case, except that the component physical channel matrix $\widehat{\boldsymbol{h}}_{k,i}$ shall replace the composite channel matrix $\boldsymbol{H}_k$ defined in (2), e.g.

$$\widehat{\boldsymbol{h}}_{k,i} = \boldsymbol{U}_k \sum_k \boldsymbol{V}_k^H; \quad (9)$$

which means that this algorithm only uses the channel information itself and independently calculates the precoders. Therefore, there don't need the exchange of channel information between cooperative femtocells.

It's imagined that the non-coherent joint transmission has some performance loss compared with coherent mode. However, the significant advantage is that channel state information (CSI) exchange overhead among the femtoclls is reduced greatly.

### C. Interference Nulling

In this mode, each femtocell transmits the data stream to its target user; meanwhile, the femtocell nulls the interference to some other users in the adjacent femtocells. This is accomplished through appropriately designing weighting vectors for the transmitted data stream, which can name as coordinated beamforming/scheduling [5].

The procedure of calculating weighting vectors in this mode is similar to that in non-coherent joint transmission mode. The difference is that the user data is only transmitted from its serving cell. Thus, the interference nulling transmission can be regarded as a special case of non-coherent joint transmission, where the data stream for other-cell UEs is set to zero. Eq. (1) can be expressed as

$$\boldsymbol{y}_k = \boldsymbol{h}_{k,m}\boldsymbol{v}_{m,m}\boldsymbol{x}_m + \sum_{i=1,i\neq m}^{M}\boldsymbol{h}_{k,i}\boldsymbol{v}_{i,i}\boldsymbol{x}_i + \boldsymbol{n}_i \qquad (10)$$

where $\boldsymbol{v}_{m,m} \in \mathcal{C}^{N_T\times d_j}$. To eliminate interference completely, the precoding vector should satisfy $\boldsymbol{h}_{k,i}\boldsymbol{v}_{i,i} = 0, \forall i \neq m$.

It is noticeable that the nulling operation at each femtocell is at the cost of reducing to some extent the useful signal power. Thus, in this mode, there is a tradeoff between the interference nulling gain and useful signal power loss. The advantage of the interference nulling mode over the other two cooperative algorithms is that in interference nulling transmission, the user data is only transmitted from its serving cell. Thus, there is no need for data sharing, which further reduces the backhaul capacity demand.

### D. Remarks

Theoretically, coherent JT offers better performance than other modes, but at the cost of a large amount of exchange demand of user data and channel state information (CSI) among femtocells via backhaul network. Non-coherent and interference nulling is inferior to the other modes in terms of performance. However, it avoids to the large extent high backhaul capacity demand.

In particular, the backhaul is required to have high capacity and low latency. For example, assuming that a LTE-A system bandwidth is 10MHz, and 3 cells with 4 antennas each are cooperated, where each cell has 20 UEs, and 30% of UEs are in cooperative mode, Tab. I give the backhaul requirements for a LTE-A system [11].

But, the capacity of backhaul links in existing systems is limited, which imposes strict constraints on the data and CSI sharing for cooperative transmission. The choice of a suitable backhaul constitutes one of the main performance bottlenecks in the emerging cooperative femtocell networks. This heterogeneous nature of the backhaul may limit the benefits of cooperative transmission due to the costs during information exchange [12].

Tab. I Backhaul requirements

| | Capacity | Latency |
|---|---|---|
| Coherent JT | 8 - 14 Gbps (input), 6 - 11 Gbps (output) | < 1 ms |
| Non-coherent JT | 30 Mbps (input), 45 Mbps (output) | < 3 ms |
| Interference nulling | 5 Mbps (input & output) | < 10 ms |

## III. PROPOSED COOPERATIVE STRAGEGY

In dense femtocell network, due to the large number of interference nodes, selecting few nodes to cooperate like traditional cellular system will greatly impact the system performance; conversely, the backhaul will limit the benefits of cooperation. In this paper, we propose a new cooperative strategy for dense femtocell networks.

According to the RSSI received by UEs, utilizing the network planning tool [9], the serving femtocell can classify the interference femtocells into a number of groups according to the interference strength threshold. For the strongest interference group 1, coherent JT algorithm will be used so as to completely mitigate the strongest interference. Here, a large amount of exchange of user data and CSI among femtocells in this group via backhaul network will be required. For the second strong interference group 2, non-coherent JT algorithm will be used. Here, only data and partial CSI exchange among these femtocells via backhaul will be required. For the third strong interference group 3, interference nulling algorithm will be used, and only partial CSI exchange among these femtocells via backhaul will required. For the smallest interference group 4, non-cooperative transmission will be used.

Assuming the RSSI of serving femtocell is $Q_s$, the RSSI of interference femtocells is $Q_i$, $i$=1,2,...,$M$-1, and $\Gamma_{JT}$, $\Gamma_{NJT}$, and $\Gamma_{IN}$ are the grouping threshold for using coherent JT, non-coherent JT, and interference nulling, respectively. So define

$$\begin{aligned}
&S1(\text{Group 1}): Q_s - Q_i \leq \Gamma_{JT}, \text{for all } i = 1,2,\cdots,M-1\\
&S2(\text{Group 2}): \Gamma_{JT} < Q_s - Q_i \leq \Gamma_{NJT}, \text{for all } i = 1,2,\cdots,M-1\\
&S3(\text{Group 3}): \Gamma_{NJT} < Q_s - Q_i \leq \Gamma_{IN}, \text{for all } i = 1,\cdots,M-1\\
&S4(\text{Group 4}): \Gamma_{IN} < Q_s - Q_i, \text{for all } i = 1,2,\cdots,M-1
\end{aligned} \qquad (11)$$

In the cooperative mode, the information exchange includes data and CSI, but compared with data sharing, the impact of CSI sharing on backhaul links is negligible [13]. Therefore, once giving the grouping threshold, the number of grouping femtocells will be determined. Assuming the Group 1 has $\alpha$ femtocells, Group 2 has $\beta$ femtocells, Group 3 has $\gamma$ femtocells, and then Group 4 has $M$-$\alpha$-$\beta$-$\gamma$ femtocells. At the same time, assuming the capacity of data exchange each femtocell is $R_d$, and the capacity of CSI exchange each femtocell is $R_c$, the capacity requirement of backhaul of the proposed scheme is

$$C_{backhaul} = \underbrace{\alpha(R_d + R_c) + \beta R_d}_{Input} + \underbrace{(\alpha + \beta + \gamma)R_c}_{Output} \leq C_{max} \qquad (12)$$

where $C_{max}$ is the backhaul capacity constraint. So equation (1) can be rewritten as

$$\boldsymbol{y}_k = \boldsymbol{h}_{k,m}\sum_{j=1}^{N}\boldsymbol{\omega}_{j,m}\boldsymbol{x}_j + \sum_{i\in S1}\boldsymbol{h}_{k,i}\sum_{j=1}^{N}\boldsymbol{\omega}_{j,i}\boldsymbol{x}_j + \sum_{i\in S2}\boldsymbol{h}_{k,i}\sum_{j=1}^{N}\boldsymbol{w}_{j,i}\boldsymbol{x}_j + \sum_{i\in S3}\boldsymbol{h}_{k,i}\boldsymbol{v}_{i,i}\boldsymbol{x}_i + \sum_{i\in S4}\boldsymbol{h}_{k,i}\boldsymbol{x}_i + \boldsymbol{n}_k \qquad (13)$$

Using the detection algorithm at the receiver, equation (13) can be rewritten as

$$\bar{\boldsymbol{y}}_k = \boldsymbol{W}_k^H\boldsymbol{y}_k = \boldsymbol{W}_k^H\boldsymbol{H}_{k,m}\sum_{j=1}^{N}\boldsymbol{\omega}_{j,m}\boldsymbol{x}_j + \sum_{i\in S1}\boldsymbol{W}_k^H\boldsymbol{h}_{k,i}\sum_{j=1}^{N}\boldsymbol{\omega}_{j,i}\boldsymbol{x}_j +$$

$$\sum_{i\in S2} \boldsymbol{W}_k^H \boldsymbol{h}_{k,i} \sum_{j=1}^{N} \boldsymbol{w}_{j,i}\boldsymbol{x}_j + \sum_{i\in S3} \boldsymbol{W}_k^H \boldsymbol{h}_{k,i}\boldsymbol{v}_{i,i}\boldsymbol{x}_i + \sum_{i\in S4} \boldsymbol{W}_k^H \boldsymbol{h}_{k,i}\boldsymbol{x}_i + \boldsymbol{W}_k^H \boldsymbol{n}_k \quad (14)$$

Considering the interference-limited scenario, the average achievable rate at receiver $k$ can be expressed as [8]

$$C_k = E_{\boldsymbol{h}}\left\{\left[\log\det\left(1 + \frac{\tilde{\boldsymbol{h}}_{m,k} Q_m \tilde{\boldsymbol{h}}_{m,k}^H}{\sigma^2 + \sum_{i\in S2} \hat{\boldsymbol{h}}_{i,k} Q_m \hat{\boldsymbol{h}}_{i,k}^H + \sum_{i\in S3} \bar{\boldsymbol{h}}_{i,k} Q_m \bar{\boldsymbol{h}}_{i,k}^H + \sum_{i\in S4} \breve{\boldsymbol{h}}_{i,k} Q_m \breve{\boldsymbol{h}}_{i,k}^H}\right)\right]\right\} \quad (15)$$

where $Q_m$ represents the covariance matrix of transmission signal $\boldsymbol{x}_j$ ,and $\tilde{\boldsymbol{h}}_{i,k} = \boldsymbol{W}_k^H \boldsymbol{h}_{k,i} \sum_{j=1}^{N} \boldsymbol{\omega}_{j,i}$ , $\hat{\boldsymbol{h}}_{i,k} = \boldsymbol{W}_k^H \boldsymbol{h}_{k,i} \sum_{j=1}^{N} \boldsymbol{w}_{j,i}$, $\bar{\boldsymbol{h}}_{i,k} = \boldsymbol{W}_k^H \boldsymbol{h}_{k,i}\boldsymbol{v}_{i,i}$, $\breve{\boldsymbol{h}}_{i,k} = \boldsymbol{W}_k^H \boldsymbol{h}_{k,i}$.

This information exchange constraint is equivalent to a portion $0 < \theta \le 1$ of the superframe. So the value function $U$ can be defined as the total achieved rate as follows:

$$U = \sum_{m=1}^{\alpha+\beta+\gamma} \sum_{k=1}^{\tau} \theta_{m,k} C_{m,k} \quad (16)$$

where $\tau$ is the number of cooperated UEs. By maximizing the value function under satisfying the constraints in (12), the threshold, and then the cooperative partners can be obtained.

## IV. Simulation Results

The modeling platform is based on the iBuildNet® [9], which is an in-building network planning & optimization software tool produced by Ranplan Wireless Network Design Ltd.. This tool is used to generate path loss (PL) data for a variety of building settings in which dense femtocells network may be deployed. The data encompasses path loss between femtocells and UEs. It incorporates all of the shadowing effects of the local environment. Architectural drawings of floor plans of the modeled building are imported into the iBuildNet® software and materials such as glass, concrete and metal are selected from the material database. Additionally outer walls of surrounding structures are modeled to capture shadowing. The path loss data generated via iBuildNet® is combined with fading model to provide detailed propagation environment. Based on the path loss, a LTE system simulation is launched to evaluate the performance of the proposed scheme.

Tab. II Simulation parameters

| Parameter | Value |
|---|---|
| Cell layout | 36 Femtocells/9600m$^2$ with 9 floors |
| Path loss model | iBuildNet RRPS propagation modeling |
| Shadowing | Lognormal shadowing with 3 dB std |
| Bandwidth | 2GHz, 10MHz |
| # of resource blocks (RB) | 50 |
| Femtocell Tx power | 8dBm |
| Femtocell antenna gain | 0 dBi |
| UE antenna gain | 0 dBi |
| UE noise figure | 5 dB |
| Downlink scheduler | Round Robin |
| UE number | 25 UEs per cell/5 RBs per UE |
| User traffic model | Full Buffer |

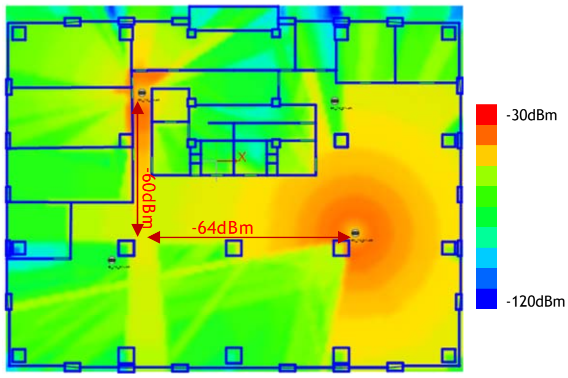


Fig 2 Best signal level

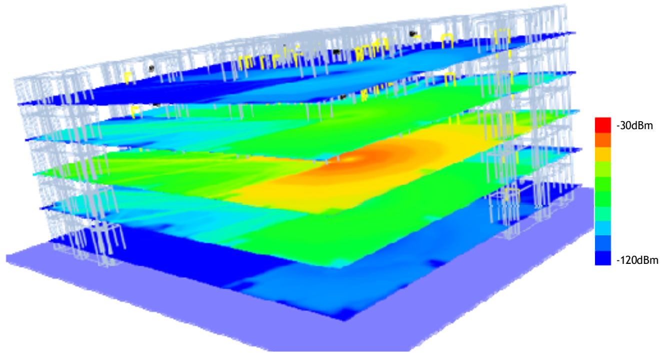


Fig 3 Cross-floor signal level

System simulation is based on 9-floor Office building with 4 femtocells deployment on each floor. The deployment of femtocell network is shown in Fig.1, and the simulation parameters are given in Tab. II.

Fig 2 shows the best signal level of one floor, where 2 femtocells is deployed. From this figure, we can see that the signal level to a location are up to -60dBm and -64dBm, respectively, which means there have severe interference at the femtocell edge.

Fig 3 shows the cross-floor transmission of femtocell signal, there is a femtocell on the 3rd floor. From this figure, comparing to the -41dBm signal level on this floor, we can see the signal strength on the 2nd and 4th floors are up to -77dBm and -66dBm, respectively. The signal strength are also up -100dBm on the 1st and 5th floors.

Form Fig. 2 and Fig. 3, which means a UE on the 4th floors will receive the interference from other femtocells not only on the 4th floor, but also on the 3rd and 5th floors. Therefore, this is a 3-dimensional interference environment with dense interference sources, up to 11 femtocells.

Fig. 4 presents the SINR and data rate map. From the figures, it can be observed that inbuilding environment is more complex, and encounter more penetration loss and shadowing fading. But due to the transmission loss of wall and pillar, the signals between the femtocells can be well isolated, so the interference can be reduced. Therefore, in the femtocell deployment, walls and pillars can be utilized to form directional transmission.

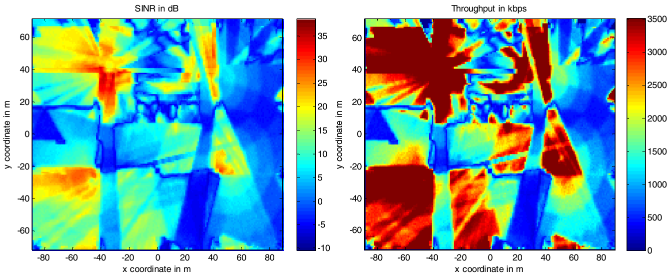


Fig 4 SINR and data rate map of non-cooperative mode

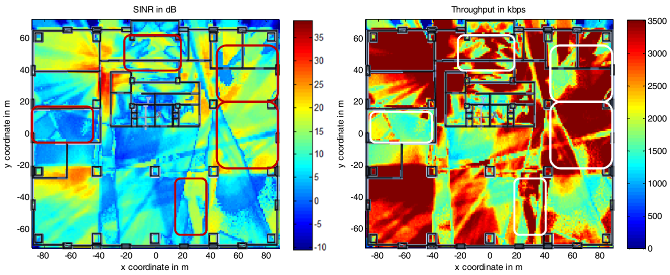


Fig 5 SINR and data rate map of proposed scheme

Fig. 5 presents the SINR and data rate map of proposed scheme. Comparing to fig. 4, it can be observed the proposed cooperative femtocells can greatly improve the cell-edge performance up to 10dB, as indicated by the red and white boxes in the figure, respectively.

Fig. 6 shows the CDF of the SINR and data rate in different cooperative modes. From this figure, it can be observed that the proposed scheme achieves better SINR by about 7dB than the non-cooperative mode. Especially in the low SINR region, the proposed scheme can be up to 10dB performance improvement. At the same time, the user throughput of the proposed scheme is greatly improved, especially in the femocell edge region, the smallest rate can up to 1Mbps. Therefore, the proposed scheme can meet the mobile traffic requirements of in-building users.

The averaged spectrum efficiencies of the three methods are summarized in Tab. III. From this table, it can be observed that about 30% throughput gains are achieved by the proposed scheme over non-cooperative mode, and only 7.7% degradation comparing to the coherent JT. When comparing the femtocell edge performance, there are up to 2.2 times over the non-cooperative mode, and only 13% performance degradation. Obviously, the proposed scheme obtains better trade-off between performance gains and needed cost.

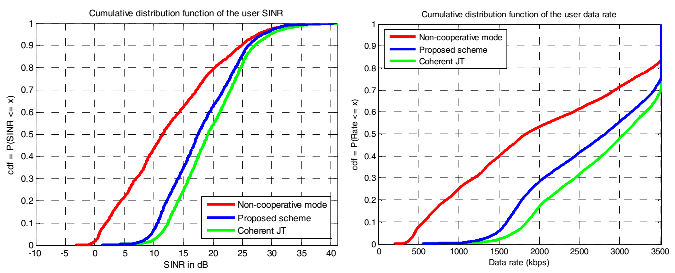


Fig. 6 CDF of SINR and data rate of different cooperative scheme

Tab. III Spectrum efficiency comparison

| | Femtocell average spectrum efficiency(bps/Hz/cell) | Femtocell edge spectrum efficiency(bps/Hz) |
|---|---|---|
| Non-cooperative mode | 1.9824 | 0.0465 |
| Proposed scheme | 2.59(30.65%) | 0.1475(220%) |
| Coherent JT | 2.8045(41.47%) | 0.1687(262%) |

## V. Conclusions and Future Works

In this paper, a new cooperative strategy under backhaul capacity constraints is proposed for interference management in dense femtocell networks. Based on the mutual interference information, it classifies dense inter-femtocell interference into a number of groups, and then adaptively selects the cooperative algorithm for different groups based on different information exchange requirements. Thus, the dense femtocells can cooperatively perform interference mitigation, and consequently improve their overall performance and obtain better trade-off between performance gains and incurred system cost. The simulation results show that the proposed cooperative strategy among dense interference femtocells can provide significant gains, reaching up to 30% relative to the non-cooperative case.

However, the grouping threshold of femtocell grouping is a key factor which impacts the cooperative performance, which will be investigated further in the next works.

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