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Terminal density dependent resource management in cognitive heterogeneous networks

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Abstract In cognitive heterogeneous network, when multitudes of femtocells coexist, effective resource management become important to enhance network performance. Based on the base station location and terminal distribution density, we propose spectrum management and power configuration scheme for femtocells deployment network. In the beginning, we consider two femtocells adjacent network and propose the resource management scheme. The scheme allocates time frequency resource by adopting complete reusing and private usage in non-overlapping and overlapping areas respectively. Subsequently the scheme optimizes base station power under the constraints of cross-tier interference and maximal transmission power to maximize network capacity. According to the analysis of the power variation effect to femtocell coverage, a near-optimal solution of the transmission power is derived, and the corresponding power configuration scheme is proposed. After then we extend the spectrum and power management to multiple femtocells coexisting networks, and propose the management scheme applied for multiple femtocells deployment networks. The simulation results indicate that in capacity performance, the proposed power solution is close to the optimal solution, and the proposed resource management outperforms the existing schemes.

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1 Introduction

Recently with the development of radio access technologies and mobile internet application, the demand of high-speed data services increases rapidly. Current surveys show that more than 80 % of mobile traffic is originated at home or work. Therefore the traditional network is confronted with the challenge of enhancing indoor traffic capacity. Femtocell deployment is considered a promising technology to offload the traffic from primary macrocells and improve the Quality of Service (QoS) of indoor users.

Cognitive radio is a technology that permits users to sense wireless environment and look for spare spectrum to access. In heterogeneous networks, femtocells can use the spectrum of primary network by cognitive radio to improve spectrum usage efficiency [1]. In a densely deployed femtocells network, if the management scheme of time frequency resource is not effective or the transmission power is too large, there will be severe interference between different cells. Therefore the effective management of frequency resource and transmission power becomes important to improve the user QoS and network capacity.

1.1 Related work

Recently, resource allocation is widely studied in heterogeneous networks. The research include frequency reusing between small cells or heterogeneous networks, power control of small cell and interference elimination between heterogeneous networks, etc. [2, 3] adopt the private frequency management that femtocells and macro cells use different frequency band respectively. The method is simple but reduces the available frequency of macro cells, and as a result decreases the usage efficiency of the whole frequency resource. Song et al. [4], Chen et al. [5] and Cheng et al. [6] build heterogeneous network model with one macro cell and multiple small cells coexisting. The small cells access system through cognitive radio and share the frequency resource with macro cells by overlay style so as to improve the frequency usage. Also [2, 9] adopt multiple small cells coexisting model, in which the small cells use the same frequency simultaneously. Hence there will be severe interference between adjacent small cells, which can result in user communication rate decreased. In [7], a hierarchical auction mode is introduced, in which the femtocell base stations buy frequency resource from cognitive network base station and each femtocell uses different frequency band. Thus the interference between femtocells is eliminated but the efficiency of frequency usage is degraded. Jagadish and Catherine [8] and Adian and Aghaeinia [10] build interference model for hierarchical heterogeneous network and optimize the configuration of time frequency resource. The interference model considers the interference of the licensed network to the second and third level network as well as the interference between the second and third level networks.

Currently the research of small cell power control is mainly based on the corresponding interference model and transmission power constraint. Wang et al. [9] and Adian and Aghaeinia [10] aim to maximize the capacity of cognitive network, considering the interference constraint of licensed network and transmission power constraint of cognitive network. The power control is formulated to an optimization problem under complex interference model and as a result need higher computational complexity. Zhang et al. [11] proposes a resource allocation scheme for cognitive femtocells with the consideration of sub-channel occupation fairness, co-tier and cross-tier interference mitigation and spectrum sensing errors. The subchannel and power allocation problem is modeled as a mixed integer programming problem, and is transformed into a convex optimization problem, which is finally solved using dual decomposition method.

In addition, in current research [8–10], the channel interference gain between networks is fixed commonly. But in fact the interference gain changes with the distance from transmitter to receiver, therefore building interference model based on distance dependent interference gain has more rationality.

1.2 Motivation and contribution

To enhance the frequency usage efficiency for heterogeneous networks while reducing the interference between femtocells, we propose an effective resource configuration scheme for femtocells deployment network. Firstly we take into account two femtocells adjacent network and propose the resource management scheme. The scheme adopts complete reusing and private usage of time frequency resource in non-overlapping and overlapping area respectively. Subsequently based on the user distribution density, the scheme adjusts the transmission power to change the cell coverage so as to maximize the femtocell network capacity. We analyze the effect of power variation to cell coverage, and as a result derive the close-form solution of the near-optimal transmission power. After then we extend the spectrum and power management to multiple femtocells coexisting networks and propose the management scheme applied for multiple femtocells deployment networks. The simulation results indicate that in the total capacity performance, the proposed power solution is close to the optimal solution, and the proposed resource management outperforms the existing schemes.

The main contributions of the paper can be summarized as following:

1. We propose spectrum management scheme for adjacent femtocells, in which complete reusing and private usage is adopted for non-overlapping and overlapping areas respectively.
2. We study transmission power configuration of base stations in adjacent femtocells with the consideration of terminal density and distance-dependent variation of channel gain;
3. We analyze the impact of transmission power variation to femtocell coverage area and derive the close-form expression of approximate optimal power configuration.
4. We extend the resource management scheme of two adjacent femtocells to multiple femtocells existing network, and propose practical scheme for densely deployed femtocells network.

1.3 Organization

The rest of this paper is organized as following: Sect. 2 constructs the system model, describes the spectrum deployment scheme and formulates power optimization problem to maximize the total network capacity under constraints of transmission power. Sect. 3 analyzes the influence of cell coverage radius to network capacity and proposes the optimal power and radius configuration scheme. Section 4 proposes the resource management scheme for densely deployed femtocells. Section 5 provides simulation results for performance analysis and validation. Section 6 concludes the whole paper.

2 Resource management scheme

2.1 System model

Based on [6, 12–14] we design two-level heterogeneous cognitive network, as Fig. 1. The macro cell with licensed spectrum is the first level, which uses the licensed frequency. The multiple femtocells compose the second level network, which adopt cognitive radio to sense the licensed frequency and find spare frequency to access.

Femtocell is constructed to enhance the communication QoS of indoor area [15, 16]. When the base station positions of two adjacent femtocells are fixed, the transmission power setting and frequency resource allocation become important in network configuration. Therefore, we construct the network model with two femtocells adjacent and coexisting as shown in Fig. 2. Here we omit the Macrocell part in order to simplify the figure and make femtocell structure more clarified. The distance between Femtocell 1 and Femtocell 2 base stations is denoted by D. The coverage radius of Femtocell 1 and Femtocell 2 is denoted by R_1 and R_2 respectively. The half of the intersection line of Femtocell 1 and Femtocell 2 coverage area edge is denoted by L_1. The distance D between the two base stations is divided into L_2 and L_2' by the intersection line. In the following we discuss the frequency sharing scheme and power configuration strategy between the two femtocells based on the model in Fig. 2.

2.2 Spectrum deployment scheme

In heterogeneous network, if adjacent femtocell uses different spectrum, the spectrum resource efficiency will be reduced. However if the adjacent femtocells use the same spectrum simultaneously, severe interference will be brought in the overlapping area of the two adjacent femtocells. Consequently, for analyzing the interference in overlapping area, we need to build a very complex interference model, which results in hard solved optimization problem. Therefore we design a spectrum management scheme with low complexity, which realizes spectrum reusing to the maximal extent in the premise of reducing the interference to adjacent femtocells.

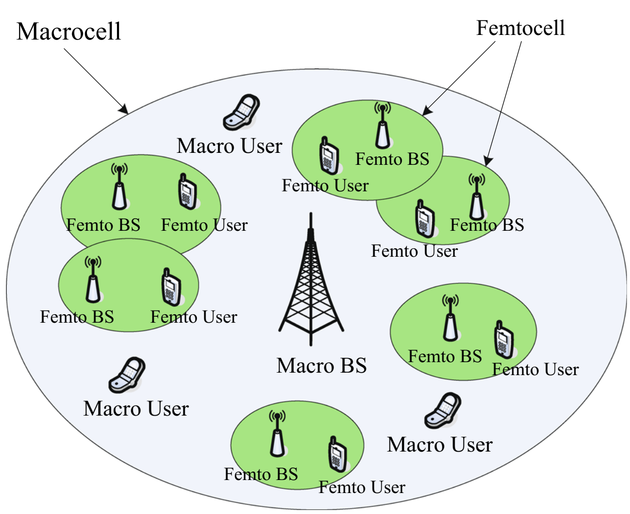


Fig. 1 Two leveled heterogeneous cognitive network model

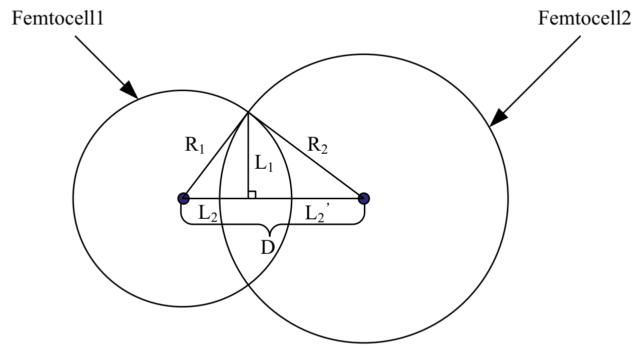


Fig. 2 Adjacent femtocell coexisting model

Femtocells employ cognitive radio technology to sense the licensed spectrum and choose the spare spectrum to access. In other words, licensed network share the spectrum resource by Overlay style with cognitive network. Assume that during a period the number of spare subcarriers remains N, we design the following frequency deployment scheme as Fig. 3:

1. in the non-overlapping area of Femtocell 1 and Femtocell 2: Femtocell 1 and Femtocell 2 use the N subcarriers at the same time;
2. in the overlapping area of Femtocell 1 and Femtocell 2: Femtocell 1 and Femtocell 2 use the N subcarriers by TDMA(Time Division Multiple Access) style.

Figure 3 shows the spectrum usage scheme for overlapping and non-overlapping area. In Fig. 3a Femtocell 1 and Femtocell 2 sharing all the RBs (Resource Block) for all time, while in Fig. 3b Femtocell 1 and Femtocell 2 use

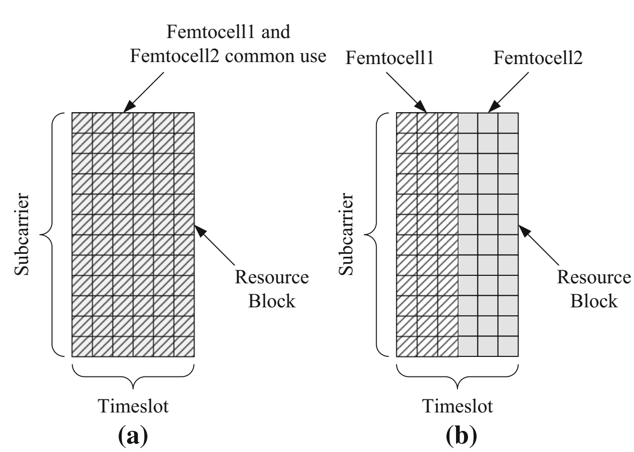


Fig. 3 Femtocell 1 and Femtocell 2 RB deployment scheme

different RBs by the time division style. The spectrum deployment scheme reduces the interference between adjacent femtocells and realizes the time frequency resource reusing to the maximal extent.

2.3 Power control strategy

For wireless communication, the coverage area of a cell is decided by base station power and channel condition. The larger the base station power and the better the channel condition, the coverage area is larger and the network capacity is higher. However in femtocells network, the larger the base station power is, the interference to adjacent femtocell is larger and the capacity loss of adjacent femtocell is higher. Therefore, we need to research the power configuration of femtocells and obtain the tradeoff between the femtocell capacity and the interference to its adjacent femtocell to maximize the whole network capacity.

In femtocell network, the channel gain between user and base station changes with the distance between user and base station, and the larger the distance is, the channel gain is smaller. Here we define the base station coverage radius as the distance between user and base station in which the users' receiving Signal Noise Rate (SNR) equals to the minimal SNR requirement. Assume that in Fig. 2 the transmission power of Femtocell 1 and Femtocell 2 is denoted by P_1 and P_2 respectively, the minimal SNR requirement is SRE_1 and SRE_2 respectively. The channel Gauss white noise power is σ^2 and the channel gain in the edge of Femtocell 1 and Femtocell 2 is H_{1,R_1} and H_{2,R_2}. Then according to literature [17] we obtain (1) and (2) as following

$$P_1 = \frac{\sigma^2 SRE_1}{E[H_{1,R_1}]C_1 {R_1}^{-\alpha_1}} \tag{1}$$

$$P_2 = \frac{\sigma^2 SRE_2}{E[H_{2,R_2}]C_2 {R_2}^{-\alpha_2}} \tag{2}$$

In (1) and (2), $E[H_{1,R_1}]$ and $E[H_{2,R_2}]$ indicate the mean value of H_{1,R_1} and H_{2,R_2}, C_1 and C_2 indicate path loss constant of Femtocell 1 and Femtocell 2 and α_1 and α_2 indicate distance related path loss exponent of Femtocell 1 and Femtocell 2 respectively.

Deduce (3) and (4) from (1) and (2)

$$R_1 = \left(\frac{\sigma^2 SRE_1}{P_1 E[H_{1,R_1}]C_1}\right)^{-\frac{1}{\alpha_1}} \tag{3}$$

$$R_2 = \left(\frac{\sigma^2 SRE_2}{P_2 E[H_{2,R_2}]C_2}\right)^{-\frac{1}{\alpha_2}} \tag{4}$$

(1)–(4) indicate the relation between transmission power P_1, P_2 and the coverage area of Femtocell 1 and Femtocell 2.

In heterogeneous network, femtocells capacity can be effected by the user distribution density. Therefore the user density is worthy of consideration in the process of power configuration for enhancing the network capacity. Lin et al. [17] constructs a heterogeneous network model with one Macro cell and multiple femtocells around the Macro cell. For femtocells network, Lin et al. [17] provides the probability density function (PDF) of the distribution of mobile user which is located at a distance relative to the reference base station. Assume that users of each femtocell are mutually independent and uniformly distributed, we can obtain the user density from the calculation of the integral of the PDF of femtocell users and the femtocell coverage area.

Assume that the user distribution density of Femtocell 1 and Femtocell 2 is denoted by ρ_1 and ρ_2 respectively. The network capacity can be denoted by the product of user average traffic rate and user number. From the afore description, it can be seen that in the edge of each femtocell the user SNR is always equal to the minimal rate requirement. Therefore the average user traffic rate of the whole femtocell can be treated as a constant. Also as the average rate value has no influence to power configuration, we can ignore it in capacity calculation temporally during the stage of power configuration design. For simplicity and ignoring the variable of average user rate, we substitute the variable with constant 1. Therefore the network capacity calculation can be transformed to the calculation of the user number, which can be obtained by the product of the user density and coverage area.

According to the spectrum allocation scheme in Sect. 2.2, since each femtocell can only use a half of RBs in the overlapping area, the network capacity of this area is reduced by half compared with the complete RBs sharing. As we have set the average rate variable as constant 1, the value of the network capacity become equal to the total user number of the network. As a result, based on Fig. 2 the expression of the total capacity of Femtocell 1 and Femtocell 2 can be obtained as (5)

$$C_{tot} = \left(\rho_1 \pi {R_1}^2 + \rho_2 \pi {R_2}^2\right) - \frac{1}{2}(\rho_1 + \rho_2)S_{ovlap} \tag{5}$$

in which, C_{tot} denotes the total capacity of the network and S_{ovlap} denotes the coverage overlapping area of Femtocell 1 and Femtocell 2.

According to Fig. 2, we deduce (6)–(8)

$$L_1^2 + L_2^2 = {R_1}^2 \tag{6}$$

$$L_1^2 + {L_2'}^2 = {R_1}^2 \tag{7}$$

$$L_2 + L_2' = D \tag{8}$$

From (6)–(8) L_1 can be computed as (9)

$$L_1 = \frac{\sqrt{-R_1^4 + 2R_1^2R_2^2 + 2R_1^2D^2 - R_2^4 + 2R_2^2D^2 - D^4}}{2D} \tag{9}$$

According to Fig. 2 S_{ovlap} is computed as (10)

$$\begin{aligned} & S_{ovlap} \\ & = 2\left(\frac{1}{2}R_1^2\arcsin\frac{L_1}{R_1} - \frac{1}{2}L_1L_2\right) + 2\left(\frac{1}{2}R_2^2\arcsin\frac{L_1}{R_2} - \frac{1}{2}L_1L_2'\right) \\ & = R_1^2\arcsin\frac{L_1}{R_1} + R_2^2\arcsin\frac{L_1}{R_2} - L_1D \end{aligned} \tag{10}$$

$$\begin{aligned} & \max_{R_1,R_2}\left(\rho_1\pi{R_1}^2 + \rho_2\pi{R_2}^2\right) - \frac{1}{2}(\rho_1 + \rho_2)S_{ovlap} \\ & = \max_{R_1,R_2}\left(\rho_1\pi{R_1}^2 + \rho_2\pi{R_2}^2\right. \\ & + {R_1}^2\arcsin\frac{\sqrt{-R_1^4 + 2R_1^2R_2^2 + 2R_1^2D^2 - R_2^4 + 2R_2^2D^2 - D^4}}{2DR_1} \\ & + {R_2}^2\arcsin\frac{\sqrt{-R_1^4 + 2R_1^2R_2^2 + 2R_1^2D^2 - R_2^4 + 2R_2^2D^2 - D^4}}{2DR_2} \\ & \left. - \frac{\sqrt{-R_1^4 + 2R_1^2R_2^2 + 2R_1^2D^2 - R_2^4 + 2R_2^2D^2 - D^4}}{2}\right) \end{aligned} \tag{11}$$

We aim to maximize the total capacity of Femtocell 1 and Femtocell 2 by the restraint of transmission power and interference to licensed network. Therefore the optimization problem can be expressed as (11) with constraints (12)–(14), s.t.

$$\frac{\sigma^2 SRE_1}{E[H_{1,R_1}]C_1{R_1}^{-\alpha_1}}h_{1p} + \frac{\sigma^2 SRE_2}{E[H_{2,R_2}]C_2{R_2}^{-\alpha_2}}h_{2p} \le I_p \tag{12}$$

$$\frac{\sigma^2 SRE_1}{E[H_{1,R_1}]C_1{R_1}^{-\alpha_1}} \le P_{LT1} \tag{13}$$

$$\frac{\sigma^2 SRE_2}{E[H_{2,R_2}]C_2{R_2}^{-\alpha_2}} \le P_{LT2} \tag{14}$$

For convenience to solve the optimization problem, the optimized variables in (11) are set to R_1 and R_2. After the optimal value of R_1 and R_2 is obtained we can compute P_1 and P_2 according to (1) and (2). In (12) h_{1p} and h_{2p} denote the interference gain to licensed network from Femtocell 1 and Femtocell 2, I_p denotes the interference power constraint to licensed network. In (13) and (14), P_{LT1} and P_{LT2} are transmission power constraints of Femtocell 1 and Femtocell 2.

Since optimization problem (11) is non-convex, it is hard to achieve the closed form of the optimal solution, thus we attempt other methods to solve it.

3 Solution for optimization problem

3.1 Capacity variation analysis

To solve optimization problem (11), we analyze the influence of R_1 and R_2 variation to network capacity to find the approximate optimal value of R_1 and R_2. As shown in Fig. 4, Femtocell 1 and Femtocell 2 neighbors with each other with covering radius R_1 and R_2 respectively. Define θ denoting the corresponding radian to the half overlapping area of Femtocell 1 and Femtocell 2 in Femtocell 1, alike define θ' denoting the corresponding radian in Femtocell 2. We will find the optimal value of θ and θ' by Theorem 1 so as to decide the optimal configuration of R_1 and R_2.

Theorem 1 *Without considering deep overlapping of Femtocell 1 and Femtocell 2, which indicates* $\theta < \frac{\pi}{2}$ *and* $\theta' < \frac{\pi}{2}$ *are satisfied, if* $\forall R_1 \in (0, D)$, $\forall R_2 \in (0, D)$, *the total capacity of Femtocell 1 and Femtocell 2 attains the maximal value when (15) and (16) are satisfied:*

$$\theta = \frac{2\rho_1\pi}{\rho_1 + \rho_2} \tag{15}$$

$$\theta' = \frac{2\rho_2\pi}{\rho_1 + \rho_2} \tag{16}$$

Proof In Fig. 4, we assume that Femtocell 1 covering radius is fixed, and Femtocell 2 covering radius R_2 is increased to R_2'. Thus the added covering area of Femtocell 2 can be divided into two parts: one is the overlapping area with Femtocell 1, denoted by S_1, and the other is the non-overlapping area, denoted by S_2. Also we define variable L_1', denoting the half of the connection line between the two intercrossing points of the new edge of Femtocell 2 and Femtocell 1 edge. Next we analyze the influence of Femtocell 2 covering radius addition to network capacity.

From Fig. 4 we get (17) and (18)

$$S_1 = \arcsin\frac{L_1'}{R_2'}\left({R_2'}^2 - R_2^2\right) \tag{17}$$

$$S_2 = \left(\pi - \arcsin\frac{L_1'}{R_2'}\right)\left({R_2'}^2 - R_2^2\right) \tag{18}$$

According to the spectrum allocation scheme in Sect. 2.2, the added network capacity C_{add} caused by Femtocell 2 area adding can be computed as (19)

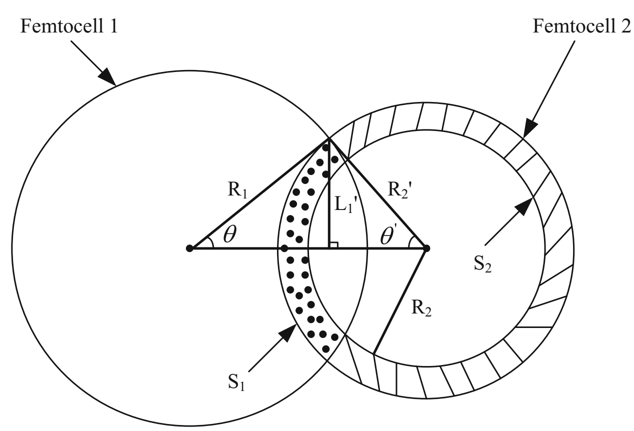


Fig. 4 Influence of Femtocell 2 covering radius variation to network capacity

$$C_{add} = \rho_2 S_2 + \frac{1}{2}\rho_2 S_1 \tag{19}$$

The reduced Femtocell 1 capacity because of the two cells overlapping can be computed as (20)

$$C_{del} = \frac{1}{2}\rho_1 S_1 \tag{20}$$

Then the total network capacity variation C_{var} can be expressed as (21)

$$\begin{aligned} C_{var} &= C_{add} - C_{del} \\ &= \rho_2\pi\left(R_2'^2 - R_2^2\right) - \frac{1}{2}(\rho_1+\rho_2)\arcsin\frac{L_1'}{R_2'}\left(R_2'^2 - R_2^2\right) \end{aligned} \tag{21}$$

From Fig. 4 θ' can be expressed as (22)

$$\theta' = \arcsin\frac{L_1'}{R_2'} \tag{22}$$

Then (21) can be arranged to (23)

$$C_{var} = \left(\rho_2\pi - \frac{1}{2}\rho_1\theta' - \frac{1}{2}\rho_2\theta'\right)\left(R_2'^2 - R_2{}^2\right) \tag{23}$$

From (23), if $\rho_2\pi - \frac{1}{2}\rho_1\theta' - \frac{1}{2}\rho_2\theta' > 0$ is satisfied, $C_{var} > 0$ is concluded, in other words when $\theta' < \frac{2\rho_2\pi}{\rho_1+\rho_2}$ is satisfied, $C_{var} > 0$ is concluded, which means the network capacity increases, otherwise the network capacity decreases. Without considering deep overlapping, if $\theta < \frac{\pi}{2}$ and $\theta' < \frac{\pi}{2}$ are satisfied, θ' increases with Femtocell 2 covering radius increasing. Thus when θ' arrives at θ'_{zr}, which is expressed as (24), the network capacity attain the maximal value.

$$\theta' = \theta'_{zr} = \frac{2\rho_2\pi}{\rho_1+\rho_2} \tag{24}$$

in which, θ'_{zr} denotes corresponding θ' when $C_{var} = 0$.

For the same analysis, when Femtocell 2 covering radius is fixed and Femtocell 1 covering radius varies, if (25) is satisfied the network capacity achieves the maximal value, with θ_{zr} denoting corresponding θ when $C_{var} = 0$.

$$\theta = \theta_{zr} = \frac{2\rho_1\pi}{\rho_1+\rho_2} \tag{25}$$

Summarized from (24) and (25), Theorem 1 is proved.

From Fig. 4 we can obtain the corresponding R_1 and R_2 value. When $\theta = \theta_{zr}$ is satisfied

$$R_2 = \sqrt{R_1^2 + D^2 - 2R_1 D\cos\theta_{zr}} \tag{26}$$

From (2) the corresponding value of P_2 can be obtained.

When $\theta' = \theta'_{zr}$ is satisfied

$$R_1 = \sqrt{R_2^2 + D^2 - 2R_2 D\cos\theta'_{zr}} \tag{27}$$

From (1) the corresponding P_1 value can be obtained.

3.2 Power configuration scheme

From capacity variation analysis, the optimal power and radius configuration can be summarized as Fig. 5. When D is fixed, we can configure R_1 and R_2 under the constraints (12)–(14) randomly. θ and θ' varies with the variation of R_1 and R_2. When $0 < \theta_{zr} < \frac{\pi}{2}$ and $0 < \theta'_{zr} < \frac{\pi}{2}$ are both satisfied, it can be concluded that the total capacity attains the maximal value when $\theta = \theta_{zr}$ and $\theta' = \theta'_{zr}$ are both satisfied. Then we can choose the adaptive R_1 and R_2 configuration to make $\theta = \theta_{zr}$ and $\theta' = \theta'_{zr}$ satisfied. In Fig. 5 the intercross dot A of R_1 and R_2 decides the chosen value of R_1 and R_2. When $\theta_{zr} > \frac{\pi}{2}$ or $\theta'_{zr} > \frac{\pi}{2}$ exists, R_1 or R_2 can be set to the largest permitted value to maximize the total capacity computed by (23).

From (24) and (26), the effect of ρ_1 and ρ_2 value to θ_{zr} and θ'_{zr} can be divided into three conditions:

1. if $\rho_1 \geq 3\rho_2$, $\theta'_{zr} < \frac{\pi}{2}$ and $\theta_{zr} > \frac{\pi}{2}$ are satisfied
2. if $\frac{\rho_2}{3} \leq \rho_1 \leq 3\rho_2$, $\theta'_{zr} > \frac{\pi}{2}$ and $\theta_{zr} > \frac{\pi}{2}$ are satisfied
3. if $\rho_1 \leq \frac{\rho_2}{3}$, $\theta'_{zr} > \frac{\pi}{2}$ and $\theta_{zr} < \frac{\pi}{2}$ are satisfied

We configure transmit power of Femtocell 1 and Femtocell 2 according to the up three conditions:

Condition 1 Since $\theta_{zr} > \frac{\pi}{2}$ is satisfied, according to (23), $C_{var} > 0$ is always satisfied when θ is chosen in $[0, \pi/2]$ randomly, therefore we configure Femtocell 1 covering radius to the maximal value according to restriction (13) and obtain the corresponding power according to (1), and then configure Femtocell 2 radius according to (24) and (26) under restriction (12) and (14) to make $\theta' = \theta'_{zr}$ satisfied, and obtain the corresponding power P_2 according to (2).

Condition 2 Since $\theta'_{zr} > \frac{\pi}{2}$ and $\theta_{zr} > \frac{\pi}{2}$ are satisfied, $C_{var} > 0$ is always satisfied when θ and θ'_{zr} are chosen in $[0, \pi/2]$ randomly, therefore we configure power according to (12)–(14) and the non-deep covering conditions $\theta < \frac{\pi}{2}$ and $\theta' < \frac{\pi}{2}$.

Condition 3 Since $\theta'_{zr} > \frac{\pi}{2}$ is satisfied, $C_{var} > 0$ is always satisfied when θ' is chosen in $[0, \pi/2]$ randomly, therefore we configure Femtocell 2 power to the maximal

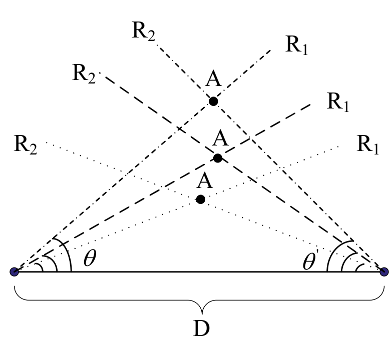


Fig. 5 Influence of R_1 and R_2 variation to θ and θ'

transmission value according to restriction (14), and then configure Femtocell 1 power according to (25) and (27) under restriction (12) and (13) to make $\theta = \theta_{zr}$ satisfied.

We define P_1' and P_2' denoting the middle variables, and the procedure of power configuration can be summarized as Algorithm 1.

Algorithm 1 Power Configuration Procedure

```
if ρ1 ≥ 3ρ2 then
    P1' ← P_LT1 / h_1p
    θ' ← θ'_zr
    set R2 according to (24) and (26)
    compute P2' according to (2)
    if P2' h_2p ≥ P_LT2 then
        P2' ← P_LT2 / h_2p
    end if
    if P1' h_1p + P2' h_2p > I_p then
        P1 ← I_p P1' / (P1' h_1p + P2' h_2p)
        P2 ← I_p P1' / (P1' h_1p + P2' h_2p)
    else
        P1 ← P1'
        P2 ← P2'
    end if
else if ρ2/3 ≤ ρ1 ≤ 3ρ2 then
    P1' ← P_LT1 / h_1p
    P2' ← P_LT2 / h_2p
    if P1' h_1p + P2' h_2p > I_p then
        P1 ← I_p P1' / (P1' h_1p + P2' h_2p)
        P2 ← I_p P1' / (P1' h_1p + P2' h_2p)
    else
        P1 ← P1'
        P2 ← P2'
    end if
else
    P2' ← P_LT2 / h_2p
    θ ← θ_zr
    set R1 according to (25) and (27)
    compute P1' according to (1)
    if P1' h_1p ≥ P_LT1 then
        P1' ← P_LT1 / h_1p
    end if
    if P1' h_1p + P2' h_2p > I_p then
        P1 ← I_p P1' / (P1' h_1p + P2' h_2p)
        P2 ← I_p P1' / (P1' h_1p + P2' h_2p)
    else
        P1 ← P1'
        P2 ← P2'
    end if
end if
```

4 Scheme extension to densely deployment femtocells

Dense femtocell deployment is one of the main features for the future 5G mobile network. The afore described management scheme is only adaptive to two adjacent femtocells network. To make it more practical for actual networks, we enhance the scheme to make it applicable for multiple adjacent femtocells network. We firstly consider the scenarios of one more femtocell joining two adjacent femtocells network. And then we extend the scenarios to more densely deployment femtocells and obtain the corresponding resource management scheme.

4.1 Scenario 1 of new femtocell joining to two adjacent femtocells

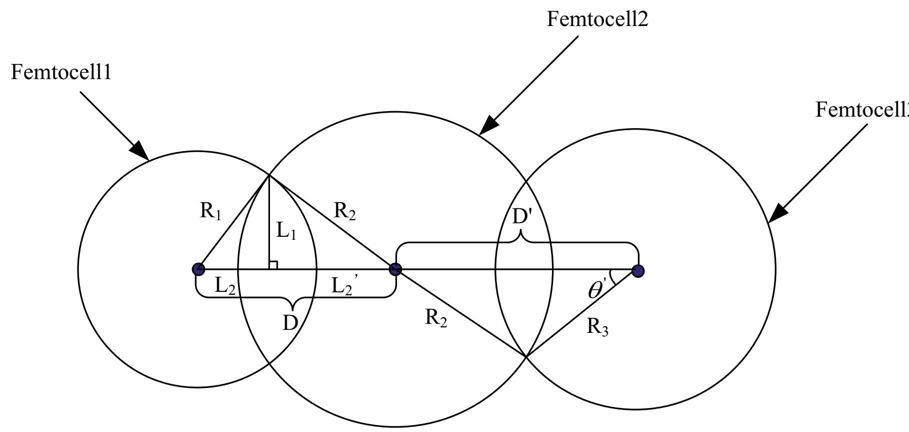
When a new femtocell is constructed adjacent to the existing two adjacent femtocells network, there are two joining scenarios we need to consider. One is that the newly joining femtocell is only adjacent to one existing femtocell, and the other is that it is adjacent to two existing femtocells simultaneously. In this subsection we analyze the first scenario, which is denoted in Fig. 6. Femtocell 3 is deployed adjacent to Femtocell 2 but not to Femtocell 1. The distance between Femtocell 2 and Femtocell 3 base stations is denoted by D'. The coverage radius of Femtocell 3 is denoted by R_3.

For this scenario we can adopt the afore described resource management scheme directly for Femtocell 2 and Femtocell 3. The scheme includes two steps, which are spectrum deployment and power control. The spectrum deployment is performed according to the described scheme in Sect. 2.2. As Fig. 3, the spectrum deployment scheme for Femtocell 2 and Femtocell 3 can be summarized as following:

1. in the non-overlapping area of Femtocell 2 and Femtocell 3: Femtocell 2 and Femtocell 3 uses all RBs at the same time;
2. in the overlapping area of Femtocell 2 and Femtocell 3: Femtocell 2 and Femtocell 3 uses a different half of all RBs individually.

The power control is carried out according to Theorem 1 in Sect. 3.1 and the scheme in Sect. 3.2. From Theorem 1 we know that if Femtocell 1 covering radius is fixed, when (16) is satisfied the total capacity of Femtocell 1 and Femtocell 2 attains the maximal value. We apply Theorem 1 to the scenario of this subsection. Since the covering radius of Femtocell 2 is obtained in the resource configuration of Femtocell 1 and Femtocell 2, we would not change the covering radius

Fig. 6 Scenario 1 of newly joining femtocell adjacent to only one existing femtocell



of Femtocell 2 in this stage and just adjust the covering radius of Femtocell 3 to make (16) is satisfied. From Theorem 1 if (16) is satisfied the total capacity of Femtocell 2 and Femtocell 3 attains the maximal value.

Assume P_3 indicating the transmit power of Femtocell 3. Also assume that P'_{LT} indicates the maximal power of Femtocell 3, which is obtained with the consideration of primary network interference constrict and maximal transmit power of base station. Define ρ_3 indicating the user distribution density of Femtocell 3. According to the scheme in Sect. 3.1, the power control strategy for Femtocell 3 can be considered from two conditions:

Condition 1 When $\rho_1 \geq 3\rho_3$, $\theta'_{zr} < \frac{\pi}{3}$ is satisfied. Therefore if we configure P_3 to make (16) satisfied, the maximal capacity can be attained. However P'_{LT} is not definitely large enough to make (16) satisfied, then if P'_{LT} is not large enough, we just configure P_3 to P'_{LT} to obtain the maximal capacity under the P'_{LT} constraint.

Condition 2 When $\rho_1 \leq 3\rho_3$, $C_{var} > 0$ is always satisfied when θ is chosen in $[0, \pi/2]$ randomly. Then we just configure P_3 to P'_{LT} to obtain the maximal capacity under the P'_{LT} constriction.

The detailed procedure of power configuration is summarized as Algorithm 2.

Algorithm 2 Power Configuration Procedure for Scenario 1 of New Femtocell Joining

```
if ρ1 ≥ 3ρ3 then
  if P'_LT is large enough then
    configure P3 to make (16) is satisfied
  else
    P3 ← P'_LT
  end if
else
  P3 ← P'_LT
end if
```

After the power control application, the total capacity of Femtocell 2 and Femtocell 3 achieves the maximal value and consequentially the total capacity of the whole network achieves the approximate maximal value.

4.2 Scenario 2 of new femtocell joining to two adjacent femtocells

We consider the other scenario that the newly joining femtocell is adjacent to the two existing femtocells simultaneously, which is denoted in Fig. 7. The coverage radius of Femtocell 3 is denoted by R_3. We also consider the resource management from two aspects of spectrum deployment and power control.

The spectrum deployment is considered from two divided conditions, as implied in Fig. 7. Area 1 indicates the overlapping area of two adjacent femtocells and Area 2 indicates the overlapping area of three adjacent femtocells. For Area 1 the spectrum deployment is performed according to the scheme in Sect. 2.2, also just described in the afore Sect. 2.1. For Area 2 the spectrum is shared dividually by the users of three different femtocells. The spectrum deployment scheme can be summarized as following, just indicated in Fig. 8:

1. in the non-overlapping area of three Femtocells: all femtocells use all RBs at the same time;
2. in the overlapping area of two Femtocells: each femtocell use a different half of all RBs individually;
3. in the overlapping area of three Femtocells: each femtocell use a different one third of all RBs individually.

The power control strategy for this scenario need to consider the affect of Femtocell 3 power to the capacity of Femtocell 1 and Femtocell 2 simultaneously. As the power control scheme we proposed in Sect. 3 is performed between two adjacent femtocells, in this scenario we decide the power configuration with the combination of two aspects: power control between Femtocell 1 and Femtocell 3 and power control between Femtocell 2 and Femtocell 3. We can adopt the scheme in Sect. 3.1 in this scenario for power control between Femtocell 1 and Femtocell 3 and between Femtocell 2 and Femtocell 3 respectively. From the two aspects of power configuration, we obtain two power values of Femtocell 3 and accordingly two covering radius values of Femtocell 3. Since we would not hope the femtocells overlap with each other complexly, we choose the minimal value of the two obtained power value to reduce the femtocell overlapping.

Assume P'_3 and P''_3 are the power value of Femtocell 3 configured between Femtocell 1 and Femtocell 3 and between Femtocell 2 and Femtocell 3 respectively. And P_3 indicates the final power configuration of Femtocell 3. Also assume that P'_{LT} indicates the maximal power of Femtocell 3, which is obtained with the consideration of primary network interference constrict and maximal transmit power of base station. Define ρ_3 indicating the user distribution density of Femtocell 3. The procedure of power control is summarized as Algorithm 3 in following.

Algorithm 3 Power Configuration Procedure for Scenario 2 of New Femtocell Joining

```
fix the radiuses of Femtocell 1 and Femtocell 2 unchanged
Step 1: power control with the consideration of Femtocell 1 and Femtocell 3 as a whole network
if ρ1 ≥ 3ρ3 then
  if P'_LT is large enough then
    configure P'_3 to make (16) is satisfied
  else
    P'_3 ← P'_LT
  end if
else
  P'_3 ← P'_LT
end if
Step 2: power control with the consideration of Femtocell 2 and Femtocell 3 as a whole network
if ρ2 ≥ 3ρ3 then
  if P'_LT is large enough then
    configure P''_3 to make (16) is satisfied
  else
    P''_3 ← P'_LT
  end if
else
  P''_3 ← P'_LT
end if
Step 3: decide the final value of Femtocell 3 power
P_3 ← MIN(P'_3, P''_3)
```

After the power control application, the whole network of three femtocells can achieve relative greater capacity and better overlapping structure.

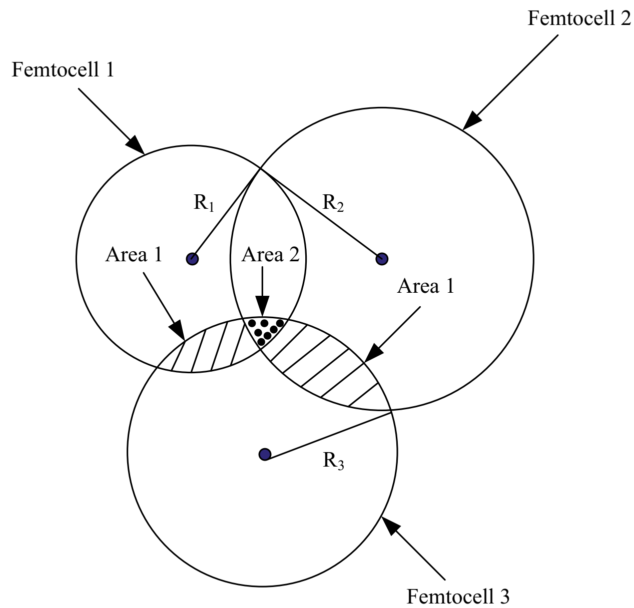


Fig. 7 Scenario 2: newly joining femtocell adjacent to two existing femtocells

4.3 Extension to more densely deployment femtocells network

We consider more densely deployment scenarios, in which more than three femtocells adjacent to construct a network. We analyze the network overlapping continually in succession of scenario 2. Assume one more femtocell joining the network of three femtocells, we consider the resource management from three conditions dividedly:

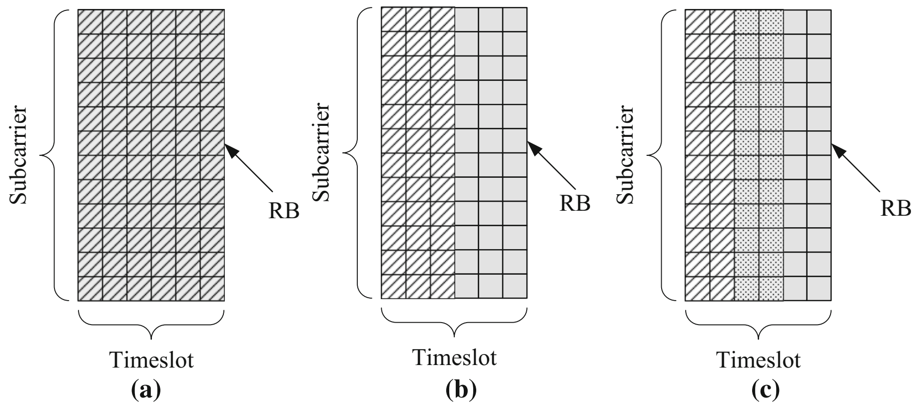
Condition 1 The newly joining femtocell is only adjacent to one existing femtocell, which is the same with scenario 1 analyzed in Sect. 4.1. Therefore we can just adopt the management scheme for scenario 1.

Condition 2 The newly joining femtocell is adjacent to two existing femtocells simultaneously, which is the same with scenario 2 analyzed in Sect. 4.1. Therefore we can just adopt the management scheme for scenario 2.

Condition 3 The newly joining femtocell is adjacent to three existing femtocells simultaneously, which is indicated in Fig. 9. For this condition we adopt the scheme for scenario 2. Firstly we perform spectrum deployment dividedly for non-overlapping and overlapping area, secondly perform power control between Femtocell 4 and the other three femtocells and obtain three power values, and lastly configure power to the minimal value.

For a deployed network with more than four femtocells, when a new femtocell joins into the existing network, we can also find the corresponding scenario from the above

Fig. 8 Newly joining femtocell adjacent to three existing femtocells. **a** The non-overlapping area of three Femtocells, **b** the overlapping area of two Femtocells, **c** the overlapping area of three Femtocells



three conditions basically. Therefore by performing the above described scheme, we can obtain practical resource management for the deployed networks with possible multiple femtocells in actual environment.

4.4 Complexity analysis of proposed scheme

The complexity of proposed scheme exists mainly in power computation. For two femtocells adjacent network, we compute power by (1), (2) and (26), (27), in which only limited simple computation is needed. Therefore we define such computation, computing power of a femtocell, as one time of computation, and the complexity is indicated by $o(1)$. For two femtocells adjacent network, the complexity is $o(2)$. For three femtocells adjacent network, from Sects. 4.1 and 4.2 in this section, for scenario 1, only three times of power computation are needed, hence the complexity is $o(3)$. For scenario 2, since the third femtocell is adjacent to two femtocells simultaneously, four times of power computation are needed totally, hence the complexity is $o(4)$. Analogically, from Sect. 4.3 in this section, when multiple femtocells coexist, we consider the most complex condition as one femtocell adjacent to three femtocells simultaneously. Therefore the largest computation complexity for a network including N femtocells adjacent is $o(3N)$. Since even in densely deployment networks, the number of femtocells adjacent with each other is unlikely too large, the total computation complexity for the network is very low.

5 Simulation results

5.1 Performance in two femtocells adjacent network

We build simulation model based on Fig. 2. We adopt the distance dependent channel model in [17] and consider the 2.5 GHz band usage with the path loss exponent α_1 and α_2 equal to 4. The spectrum bandwidth of each femtocell is set to 10 MHz. The distance between Femtocell 1 and Femtocell 2 base stations is 800 m. Femtocell 1 covering radius is fixed to 600 m. We change Femtocell 2 covering radius to validate the network capacity variation according to Femtocell 2 covering radius variation and also compare the deduced value of (22) and (23) with the actual optimal value. Femtocell 2 user density ρ_2 is set to 100. The service rate of each user is set to 100 bits/s. Figures 10 and 11 show R_2 influence to network capacity when ρ_1 is 400 and 600 respectively. From the curve variation, we can conclude that when R_2 is small the network capacity increases with R_2. Because at this time θ' is small, Femtocell 2 network capacity addition can compensate Femtocell 1 capacity loss, therefore the total capacity increases. Also the curves show that when R_2 increases to the value which makes Femtocell 2 network capacity addition is smaller than Femtocell 1 capacity loss, the total network capacity decreases with R_2 increasing. In Figs. 10 and 11 the maximal value of network capacity and the corresponding network capacity value to R_2 obtained from (23) are labeled. It is shown that the network capacity value

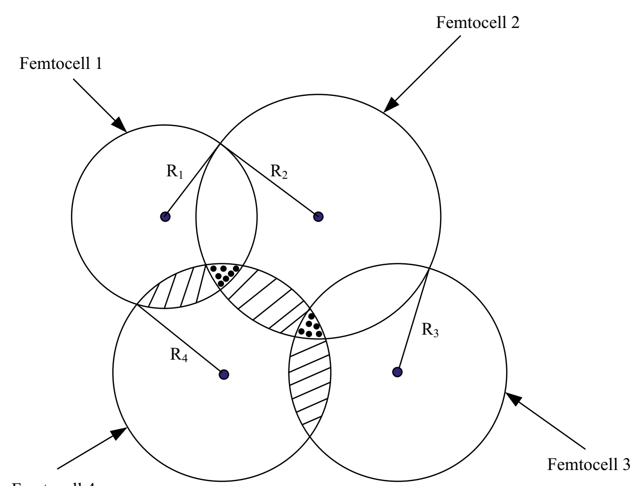


Fig. 9 Spectrum deployment for scenario 2

corresponding to (23) is close to the actual maximum value of network capacity. Therefore it can be concluded that (23) can give the approximate optimal solution of transmission power. Furthermore, the power configuration scheme in Sect. 3.2 can achieve the near-optimal network capacity performance.

We analyze the total network capacity variation versus P_{LT1} and P_{LT2}, as shown in Fig. 12. Assume that P_{LT1} is equal to P_{LT2} and both increase from 20 to 40 dBm. Also assume ρ_1 is 100 and ρ_2 is 400 respectively. To verify the performance of proposed algorithm, we design two schemes with existing methods in [18, 19]. In [18] two cognitive networks use different spectrums individually, and in [19] the femtocell base station power is always set to maximal transmit power. Therefore the compared Algorithm 1 is designed as that the spectrum allocation is deployed according to our proposed method in Sect. 2.2, and the power configuration is carried as [19]. And the compared Algorithm 2 is designed as that the spectrum allocation is deployed according to [18] and the power configuration is carried as [19]. In Fig. 12, it is shown that for proposed algorithm, when P_{LT1} and P_{LT2} are small, P_1 and P_2 are both set to maximal transmit power, therefore the capacity performance is the same with the compared Algorithm 1. With P_{LT1} and P_{LT2} increasing, the optimal configuration and proposed algorithm choose the adaptive power value so as to outperform the compared Algorithms 1 and 2. When P_{LT1} and P_{LT2} increase to some value, P_1 and P_2 in proposed algorithm attains the optimal values which are lower than P_{LT1} and P_{LT2}. Hence when P_{LT1} and P_{LT2} increase continuously, P_1 and P_2 don't change anymore and the capacity keeps stable. Whereas for compared Algorithm 1, since the power is always set to maximal value, when P_{LT1} and P_{LT2} increase to bigger value, the capacity decreases because of the increase of the overlapping area and the reduction of the spectrum sharing extent. For compared Algorithm 2, since each femtocell uses different spectrums, which results in low spectrum usage rate, the capacity is just one half of the other methods approximately.

5.2 Performance in three femtocells adjacent network

We build simulate model as Figs. 6 and 7 and analyze capacity performance for three femtocells adjacent network. Figure 13 shows total network capacity versus I_p, which increases from −15 to −5 dBm. Figure 13 compares the proposed algorithm with compared Algorithm 1 in Sect. 4.1, in which the spectrum allocation is deployed according to our proposed method, and the powers are configured to maximal value. For scenario 1, since the third femtocell is

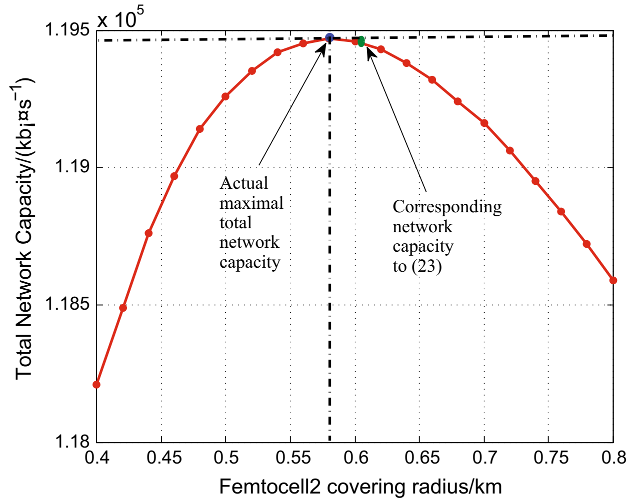


Fig. 10 Influence of R_2 variation to total network capacity ($\rho_1 = 400$)

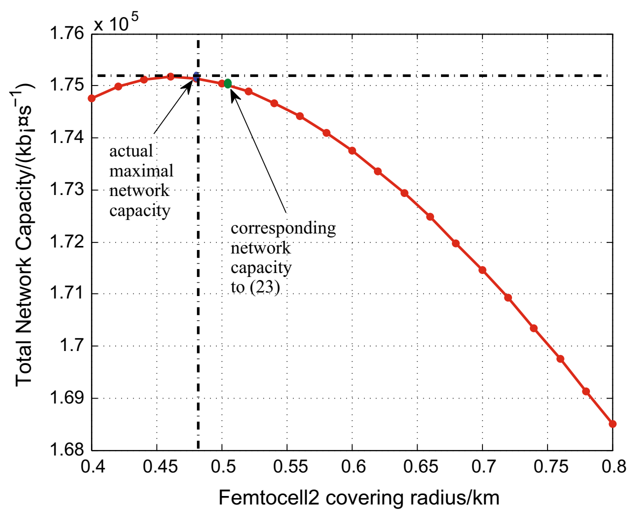


Fig. 11 Influence of R_2 variation to total network capacity ($\rho_1 = 600$)

only adjacent to one existing femtocell, the capacity performance is the same with the two femtocells network, just shown as Fig. 12. For scenario 2, since the third femtocell is adjacent to two existing femtocells simultaneously, the spectrum usage rate is decreased. And moreover we choose smaller value for the third femtocell power, which is described in Sect. 4.2, the capacity of scenario 2 is smaller than scenario 1 obviously.

5.3 Performance in multiple femtocells deployment network

We analyze the capacity performance of proposed algorithm in densely deployment network. Figure 14 shows the

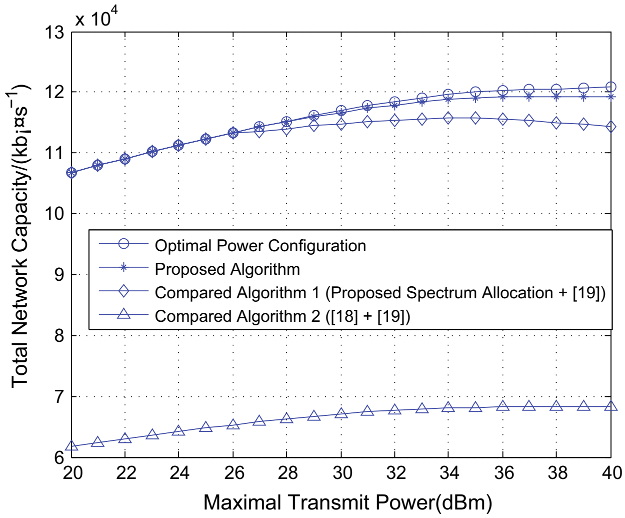


Fig. 12 Total network capacity versus P_{LT1} and P_{LT2} (two femtocells adjacent network)

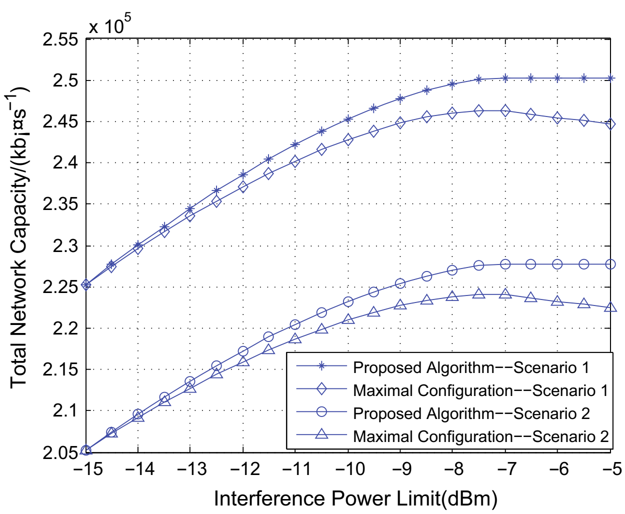


Fig. 13 Total network capacity versus I_p (three femtocells adjacent network)

total network capacity versus number of femtocells, which increases from 5 to 20. The femtocells distributes in a Macro cell with the covering radius as 2 km. The average value of maximal transmit power for each femtocell is set to 30 dBm. We consider two conditions of $I_p = -30\,\text{dBm}$ and $I_p = -20\,\text{dBm}$ in Fig. 14 respectively. We compare the proposed algorithm with the method of configuring the power of each femtocells to its maximal transmit power limitation. From Fig. 14 we can see that the total capacity increase with the number of femtocells, and moreover the bigger femtocells number is, the more slowly the network capacity increases. This is because with the femtocells number increases, the femtocells distribution become

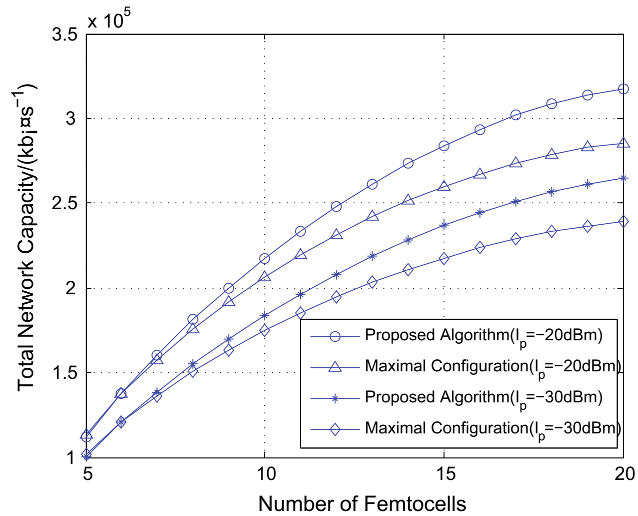


Fig. 14 Total network capacity versus femtocells number

complex and the extent of spectrum usage by different femtocells is decreased. From Fig. 14 it can also be seen that because the proposed algorithm adopts adaptive power configuration, it obtains obvious capacity gain compared with the method of maximal power configuration.

6 Conclusion

In this paper, we designed a spectrum management and power configuration scheme for femtocell based heterogeneous network. Neighboring femtocells adopt the complete sharing and private usage of time frequency resource in non-overlapping and overlapping area of adjacent femtocells respectively. The transmit power of femtocell base station were configured effectively under the licensed network interference and maximal transmit power constraint. To maximize the total capacity of femtocell networks, we analyzed the influence of transmit power to network capacity based on user distribution density. We derived the close-form solution of the approximate optimal power and designed the corresponding power configuration scheme. Furthermore, we analyzed femtocells distribution in densely deployment network and proposed adaptive spectrum and power management scheme. Simulation results verify that the derived optimal network capacity is close to the actual maximal value of network capacity. Moreover simulation indicated that the proposed scheme outperformed the existing schemes in network throughput. Therefore, the corresponding power configuration scheme have good application value in actual engineering area. In the future, we will study the resource management scheme with the consideration of complicated interference in dense femtocells deployment network.

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