A Femtocell Self-Configuration Deployment Scheme in Hierarchical Networks

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Abstract More Femtocells will be deployed in existing cell networks, improving system capacity and enhancing indoor coverage. However new Femtocells will introduce a series of several interferences, whether which are well dealt with or not is the key to widely deploy for Femtocells. A Femtocell self-configuration deployment scheme is proposed, in which an optimal power issue is formulized and solved based on various interferences that Femtocell base station may receive from other base stations. And that is supposed to maximize the Femtocell system capacity under the condition guaranteeing the original users' usual communication. The analysis and simulation results show that the proposed scheme cuts down the transmit power of Femtocell, increases the throughput.

Keywords Femtocells · Transmit power · Self-configuration · Signal to interference plus noise ratio

1 Introduction

The rapid increase in mobile data activity has raised the stakes on developing innovative new technologies and cellular topologies in an energy efficient manner. One of most interesting trends to emerge from cellular evolution is femtocells.

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Femtocells are small, inexpensive, low-power base stations that are generally consumer-deployed and connected to their own wired backhaul connection [1]. The main benefit of these small base stations is the improved indoor coverage and offloading of traffic from macro base stations [2]. As a result, not only do users enjoy better coverage due to the close vicinity to BSs, the network operators also benefit from a reduced demand for constructing macrocell towers. Due to the "win–win" situation, several standard bodies, such as 3GPP, 3GPP2, and WiMAX Forum, currently have started to standardize WCDMA, LTE, and WiMAX femtocells [3].

Femtocell networks are largely installed by customers or private enterprises often in an ad hoc manner without traditional Radio Frequency planning, site selection, deployment, and maintenance by the operator. In addition, as the number of femtocells is expected to be orders of magnitude greater than macrocells, manual network deployment and maintenance is simply not scalable in a cost-effective manner for large femtocell deployments. Femtocells must therefore support an essentially plug-and-play operation with automatic configuration and network adaptation, as is referred to a self-organizing network (SON) [2]. A self-organizing network, defined as a network that requires a minimal human involvement due to the autonomous and/or automatic nature of its functioning, will integrate the processes of planning, configuration, and optimization in a set of autonomous/automatic functionalities. These functionalities will allow femtocells to scan the air interface, and tune their parameters according to the dynamic behavior of the network, traffic, and channel [4]. The need for self-organization in femtocell networks is driven by achieving a substantial reduction in the Capital Expenditures (CAPEX) and Operational Expenditure (OPEX) of the network by reducing the human involvement, optimizing the performance of the network in terms of coverage, capacity, or QoS, and allowing the deployment of a larger number of femtocells. One aspect of SON that has attracted considerable research attention is automatic channel selection, power adjustment, and frequency assignment for autonomous interference coordination and coverage optimization. Such problems are usually formulated as mathematical optimization problems.

Self-configuration of femtocells, as an important part of SON, is aiming to minimize the impact on existing base stations and user equipments. Likewise transmit power self-configuration of femtocell base stations is the key that whether the femtocells can be successfully deployed in macrocell networks. A reducing interference method for UMTS networks has been proposed in [5], which adopts power control on pilot and data channel guaranteeing coverage, also analyzes how to set downlink and uplink power. The information of terminal mobility used to adaptively adjust the coverage of femtocell is studied in [6]. In [7], the uplink interference is solved through adjusting noise threshold. In [8], downlink power control is used to make the users of macrocell and femtocells achieve predefined Signal to Interference plus Noise (SINR). However methods above do not consider the interference on existing users. The impact on power setting of femtocell base station, which includes downlink signal of macrocell base station and uplink signal of macrocell users, is analyzed in [9]. But the interference on macrocell from femtocell is neglectful. In [10], a new cross-tier interference avoid scheme is proposed, in which power and sub-channel among macrocell and femtocell are reassigned based on information of cross-tier interference. The co-channel femtocell deployment in two-tier networks is investigated in [11], while considering cellular geometry and cross-tier interference in downlink. The issue on uplink power control in LTE hierarchical networks is researched thoroughly in [12]. In [13], the joint power and sub-channel allocation scheme is analyzed when large dense femtocells are deployed, and a binary power allocation form of power allocation is proposed. On-demand resource sharing and femtocell access control in OFDMA femtocell networks are studies in [14], also a more comprehensive perspective on self-organizing femtocell networks where users optimize their performance in a distributed manner is provided. However all above references are still not comprehensive, such as choosing excessive femtocells for analyzing interference or ignoring the impact of new added femtocell.

A femtocell self-configuration deployment scheme is proposed, which not only reduces the number of referred femtocells but also restricts the interference on original users. The rest is organized as follows: The interference model is given in Sect. 2; The proposed scheme is given in Sect. 3; The numerical results and conclusions are given in Sect. 4 and in Sect. 5, separately.

2 Interference Model

Generally hierarchical networks can be described as Fig. 1. When a new femtocell is deployed by a user, how to configure transmit power of the femtocell becomes a pressing issue. With 3GPP standard, power self-configuration means measuring around radio environment at the first stage, including various received signal and interference, then optimizing the transmit power at the self optimization stage [4].

The various received signal and interference can be represented with Fig. 2. It mainly contains signal from every macrocell base station (m-BS) and adjacent femtocell base station(f-BS). In addition because the huge difference (13dBm $\sim$ 33dBm) in the transmit power between m-BSs and f-BSs [15], the impacts of both m-BSs and adjacent f-BSs are considered when setting transmit power of f-BS. Assuming transmit power and radius of f-BS located in the center of room is 15 dBm and 10 m, separately.

The signals crossing one wall and two walls can be obtained as Fig. 3 [16]. From Fig. 3, the conclusion that adjacent femtocells in which only the number of walls is less than two need to be considered, can be obtained.

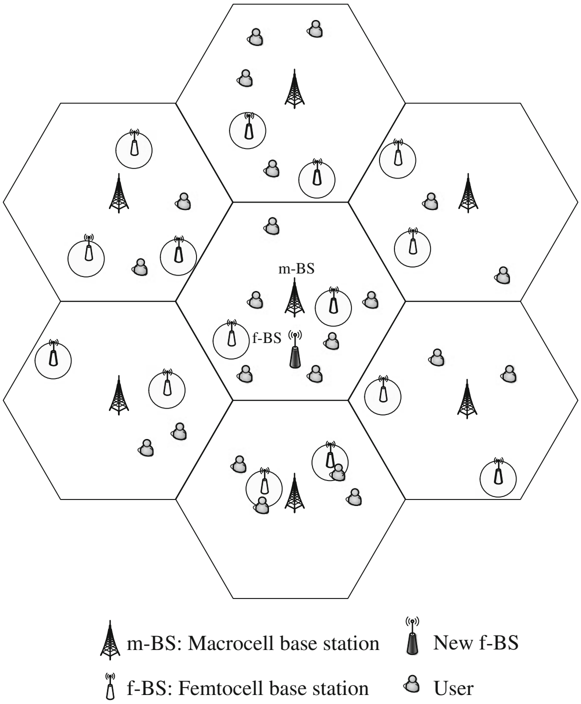


Fig. 1 Hierarchical networks

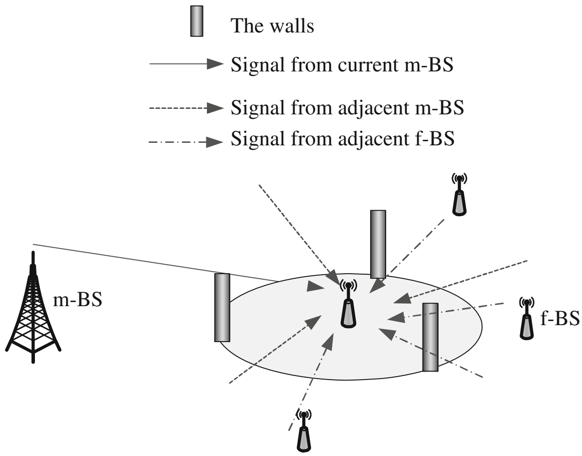


Fig. 2 Received signal and interference of new femtocell

3 Proposed scheme

Assuming the new f-BS can work as the user terminal [17], which can detect around radio environment and obtain network parameters through wired backhaul. Then the problem can be described as:

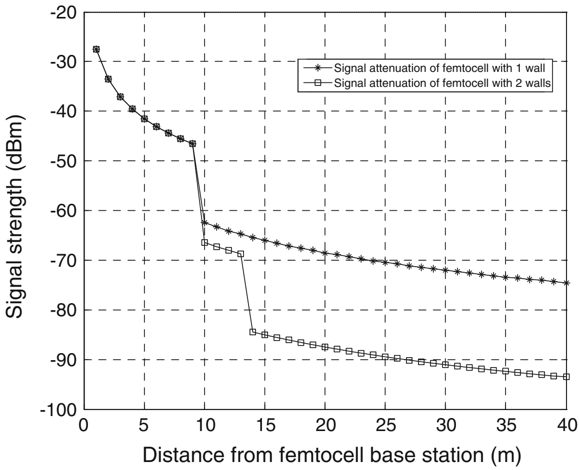


Fig. 3 Signal attenuation of femtocell

$$\begin{aligned} & Max \sum_{i=1}^{l} C_{f\_new,i} && i = \{1,2,\ldots,l\} \\ & s.t.\ SINR_{m,j} \geq SINR_{m,thr} && j = \{1,2,\ldots,n\} \\ & SINR^{s}_{f,k} \geq SINR_{f,thr} && k = \{1,2,\ldots,r\}, \\ & && s = \{1,2,\ldots,t\} \end{aligned} \tag{1}$$

where $C_{f\_new,i}$ denotes the throughput of user i, and $i = \{1,2,\ldots,l\}$ denotes the users in the new femtocell. $SINR_{m,j}$ denote the Signal to Interference plus Noise(SINR) of user j in adjacent m-BS, and $SINR^{s}_{f,k}$ denotes SINR of user k in s femtocell. $SINR_{m,thr}$, $SINR_{f,thr}$ denotes the related SINR threshold.

The throughput can be computed[18] as:

$$\begin{aligned} C_{f\_new,i} &= W * \log_2\left(1 + \frac{p_{f,new} * g_{new,i}}{I_{new,i}}\right) \\ I_{new,i} &= \sum_{a=1}^{q} p_{m,a} * h_{a,i} + \sum_{s=1}^{t} p_{f,s} * g_{s,i} \end{aligned} \tag{2}$$

$$\begin{aligned} C_{m,j} &= W * \log_2\left(1 + \frac{p_m * h_{m,j}}{I_j + p_{f,new} * g_{new,j}}\right) \\ I_j &= \sum_{a=1}^{q-1} p_{m,a} * h_{a,j} + \sum_{s=1}^{t} p_{f,s} * g_{s,j} \end{aligned} \tag{3}$$

$$\begin{aligned} C^{s}_{f,k} &= W * \log_2\left(1 + \frac{p_{f,s} * g_{s,k}}{I_k + p_{f,new} * g_{new,k}}\right) \\ I_k &= \sum_{a=1}^{q} p_{m,a} * h_{a,k} + \sum_{s=1}^{t-1} p_{f,s} * g_{s,k} \end{aligned} \tag{4}$$

where $s = \{1,2,\ldots,t\}$ denotes the femtocell impacting on power setting, $C_{m,j}$ represents the channel capacity of user j in m-BS near new femtocell, $j = \{1,2,\ldots,n\}$. $C^{s}_{f,k}$ denotes the capacity of user k in s femtocell near new femtocell, W represents the downlink bandwidth. $p_{f,new}$ denotes transmit power of new femtocell, $g_{new,i/j/k}$ denotes channel gain from new femtocell to user $i/j/k$. $p_{f,s}$ denotes transmit power of s femtocell, $g_{s,i/j/k}$ represents channel gain from femtocell s to user $i/j/k$. $\mathrm{p_m}$ denotes transmit power of current m-BS, $\mathrm{h_{m,j}}$ represents channel gain from current m-BS to user j. $p_{m,a}$ denotes transmit power of a m-BS, $h_{a,i/j/k}$ represents channel gain from a m-BS to $i/j/k$. $I_{new,i}$ denotes downlink interference which user i received. I_j and I_k represent downlink interference signal which user j and k received.

Then Eq. (1) can be changed as:

$$\begin{aligned} & Max \sum_{i=1}^{l} W * \log_2(1 + \tfrac{p_{f,new} * g_{new,i}}{I_{new,i}}) && i \in \{1,2,\ldots,l\} \\ & s.t.\, p_{f,new} * g_{new,j} \le (\tfrac{p_m * h_{m,j}}{SINR_{m,thr}} - I_j) && j \in \{1,2,\ldots,n\} \\ & p_{f,new} * g_{new,k} \le (\tfrac{p_{f,s} * g_{s,k}}{SINR_{f,thr}} - I_k) && k \in \{1,2,\ldots,r\}, \\ & p_{f,new} > 0 && s \in \{1,2,\ldots,t\} \end{aligned} \tag{5}$$

For convenience some transforms are needed as:

$$\begin{aligned} & \alpha = \min(\frac{1}{g_{new,j}} * (\frac{p_m * h_{m,j}}{SINR_{m,thr}} - I_j))\, j \in \{1,2,\ldots,n\} \\ & \beta = \min(\frac{1}{g_{new,k}} * (\frac{p_{f,s} * g_{s,k}}{SINR_{f,thr}} - I_k))\, k, s \\ & \gamma = \min(\alpha, \beta) \end{aligned} \tag{6}$$

Lagrange multiplier method [19] can be used in Eq. (5),

$$\begin{aligned} L(p_{f,new}, \lambda, \mu) = & -(\sum_{i=1}^{l} \log_2(1 + \frac{p_{f,new} * g_{new,i}}{I_{new,i}})) \\ & + \lambda * (p_{f,new} * g_{new,x} - \gamma * g_{new,x}) \\ & + \mu * (-p_{f,new}) \end{aligned} \tag{7}$$

$$\begin{aligned} \frac{\partial(p_{f,new}, \lambda, \mu)}{\partial p_{f,new}} = & \frac{-1}{(1 + \frac{p_{f,new} * g_{new,i}}{I_{new,i}}) * \ln 2} * \frac{g_{new,i}}{I_{new,i}} \\ & + \lambda * g_{new,x} - \mu = 0 \end{aligned} \tag{8}$$

With Kuhn-Tucker condition, we have:

$$\begin{cases} \lambda * (p_{f,new} * g_{new,x} - \gamma * g_{new,x}) = 0 \\ \mu * p_{f,new} = 0 \end{cases} \tag{9}$$

$$\begin{cases} p_{f,new} = \gamma \\ \lambda = \dfrac{1}{\ln 2 * g_{new,x}} * (\dfrac{I_{new,i}}{g_{new,i}} + \gamma)^{-1} \\ \mu = 0 \end{cases} \tag{10}$$

Then optimal power $p^*_{f,new}$ can be obtained if we define x^+:max(x,0).

$$p^*_{f,new} = [\gamma]^+ \tag{11}$$

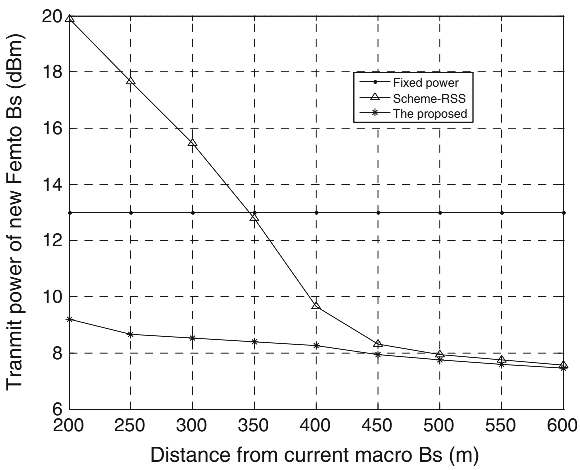
From Eq. (11), the optimal power is related with original user's location and radio environment.

4 Numerical Results

In this part, the proposed scheme is compared with scheme-RSS [17]. The parameters setting is listed in Table 1. Assuming some femtocells distributed uniformly in each macrocell, the number of femtocells affecting new femtocell is 1 ~ 4, and there are 2 users in each femtocells.

From Fig. 4, the power is reducing with apart from m-BS for scheme-RSS. When distance is more than 450 m, the change is small. That is because the signal from f-BS is larger than from m-BS. When distance is less than 450 m, f-BS has to increase the power to improve users' SINR. While the power is more large, it may affect both macro users and femto users. In addition, the power of proposed scheme is slowly changing, that is because of the constraint on users' SINR. That is to say, proposed scheme has minimal impact on original users.

Fig. 4 New femtocell power setting



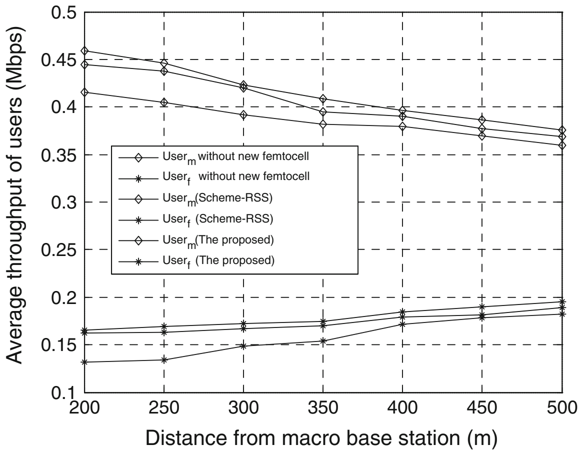


Fig. 5 Users' throughput

From Fig. 5, the scheme-RSS reduces original user's throughput because of setting high power when distance from m-BS is less than 400 m. While distance is more than 400 m, power setting accords with radio environment, which leads to slowdown throughput decrease. The proposed scheme has no difference in throughput, because of considering the impact on original users. That is the scheme make the interference introduced minimized (Table 1).

Table 1 Parameter setting

Parameters	Setting
Bandwidth	5 MHz
Carrier frequncey	2Ghz
m-BS radius	800 m
f-BS radius	10 m
The number of m-BS	One tier (7 macrocells)
Transmit power of m-BS	20 W (43 dBm)
Transmit power of f-BS deployed	20 mW (13 dBm)
Channel model (Path loss, PL)	$PL_{outdoor\text{-}indoor} = 15.3 + 37.6 \log_{10}(d) + PL_{out}[dB]$ $PL_{outdoor\text{-}} = 15.3 + 37.6 \log_{10}(d)$ d:[m], distance $PL_{indoor\text{-}indoor} = 38.5 + 20 \log_{10}(d) + 1.5{*}PL_{in}[dB]$ $PL_{indoor\text{-}outdoor} = 38.5 + 20 \log_{10}(d) + PL_{out}[dB]$ $PL_{indoor} = 38.5 + 20 \log_{10}(d)$
Loss crossing walls (PL_{in},PL_{out})	15 dB, 30 dB
Shadow standard deviation	8 dB (outdoor), 4 dB (indoor)
$SINR_{th}$	1 dB

5 Conclusion

According to above analysis, the proposed scheme can efficiently reduce the impact on original users, simultaneously guaranteeing avail communication between users. Although the analysis is only as to one femtocell, it is not limited and can be expanded to more femtocells. Based on the same mechanism, the proposed scheme will obviously perform as good as the state with one femtocell, and the similar results will be obtained in the same way.

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