A Cooperative Downlink Power Setting Scheme for CA-based Femtocells

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Abstract—**Carrier Aggregation (CA) adds a new scheduling domain which makes the radio resource management more flexible for future LTE-Advanced system, and also provides a new path to solve the intra-tier interference among femtocells. This paper proposes a Cooperative Power Setting Scheme to mitigate the intra-tier interference among CA-based femtocells. In the proposed scheme the impact of transmission power is considered, and femtocells cooperatively adjust their transmission power to optimize the total throughput on each Component Carrier. Simulation proves that the proposed scheme is effective and compensates for the deficiency of existing researches. The advantage of the proposed scheme is obvious especially when the deployment of femtocells is dense.**

Keywords-Carrier Aggregation; Femtocell; Intra-tier Interference; Power Setting

I. INTRODUCTION

Traditional mobile communications system pays more attention to the outdoor coverage and mobile handover, while the indoor coverage and fixed access in hot spot are always de-emphasized [1]. With the development of mobile communications, the mobile terminals become more and more intelligent and personalized which brings about the growing demand for broadband services in hot spot and indoor scenario. Thus, the network optimization for hot spots and indoor scenario will be one of the focus areas of LTE-Advance standardization in the future.

Heterogeneous network is one of the effective approaches to coverage and capacity problems in the network deployment of hot spot and indoor scenario, which has been applied in 2G and 3G networks. The coverage and network capacity of hot spot and indoor scenario can be significantly improved by the introduction of low power access point. As one kind of low power access point, femtocells are considered as an feasible solution to the problem of indoor and hot spots coverage, and also as an complement to the network deployment, due to the advantages such as low expense, low power, flexible to access, plug and play, saving backhaul.

However, femtocells are user-deployed cells without the prior location planning and artificial setting of mobile network operators. So the femto-femto interference, which is also called intra-tier interference, becomes an unavoidable issue for system performance, especially when femtocells are densely deployed. Intra-tier interference mitigation cannot be achieved through traditional network planning and optimization conducted by mobile operators, but only can be achieved by femtocell itself through self-management of radio resource. Femtocell should automatically manage and configure the radio resources in accordance with the surrounding radio environment.

On the other hand, in order to meet the peak data rate requirements of IMT-Advanced, 1 Gb/s and 500 Mb/s for the downlink and uplink respectively [1], Carrier Aggregation (CA) is introduced as a new feature of LTE-Advanced which aggregates two or more Component Carriers (CCs) belonging to contiguous or non-contiguous frequency bands to support wider transmission bandwidth [3]. In addition CA also brings higher spectrum flexibility and keeps backwards compatibility so that LTE-Advanced can coexist with the earlier LTE Release. Agreement has been reached within 3GPP working group that Link Adaption, Packet data Scheduling and Hybrid ARQ are performed independently in each CC in coherence with LTE Rel'8 assumptions [3]. Considering that one user may be scheduled on multiple CCs, joint scheduling on multiple CCs should be supported.

As is shown in Fig.1, such a structure for CA adds a new scheduling domain which makes the radio resource management more flexible for future LTE-Advanced system, and also provides a new path to solve the intra-tier interference among femtocells. This paper focuses on the mitigation of intra-tier interference and proposes a cooperative power setting scheme based on CA for LTE-Advanced.

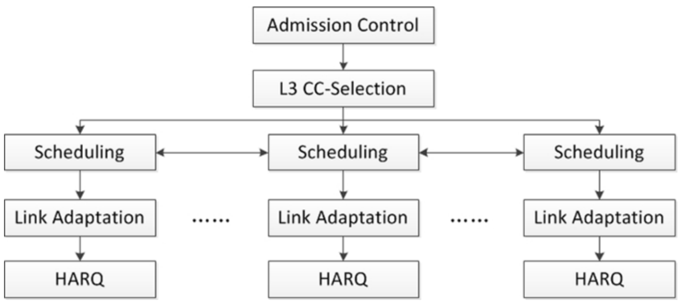

Figure 1. RRM framework of a multi-component carrier LTE-Advanced system

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The remaining sections of this paper are organized as follows. Section II introduces the related work in current research on CA-based femtocells. The proposed system model and theoretical analysis is introduced in Section III. Section IV details the proposed technical scheme. Section V evaluates the performance of the proposed scheme via system level simulation. Section VI summarizes the whole papers.

II. RELATED WORKS

There have been previous works aiming at mitigate intra-tier interference among CA-based femtocells. Currently existing researches tend to design autonomous CC selection scheme for femtocells to avoid intra-tier interference on the same CC without artificial management, so that ‘zero touch’ can be achieved when femtocell is installed by users.

A typical scheme is Autonomous Component Carrier Selection (ACCS) proposed in [4], a fully distributed and scalable solution to the interference management problem in local areas. A CC reselection scheme is proposed in [5] based on ACCS to reduce the waste of radio resources in a typical home Internet access scenario caused by poorly ordered execution of the carrier selection. [6] proposes a two-step interference coordination scheme to deal with the interference between femtocells in LTE-Advanced networks with CA. The scheme is similar with ACCS, and two different objective functions are studied in the paper. [7] mentions ACCS as a dynamic interference management method for heterogeneous networks. [8] proposes A related autonomous carrier selection concept, but does not mention details of implementation.

It can be concluded that previews works on CA-based femtocells have not considered the impact of transmission power and simply assume that femtocell transmits on a fixed power. Femtocell determines whether a CC can be selected according to a predefined threshold, such as SINR and RSRP. So there are only two alternatives for femtocells when making CC selection, that is, any CC is either available with full transmission power or not for a femtocell.

In addition, there are also researches which focus on CA but not against femtocells specifically. The range of these researches [9~11] covers the areas related to CA such as scheduling, handover, interference management and so on. But these research achievements are not fully applicable to femtocells, since femtocells are user deployed low power access point and without backhaul coordination (X2, S1) [12].

In this paper, the impact of transmission power on interference management is considered in CC selection, and femtocells cooperatively adjust their transmission power aiming at optimizing the total throughput on each CC. In the process of CC selection, a femtocell will not determine whether to use a CC, but set a suitable transmission power for the CC instead. The transmission power of each femtocell will be adjust repeatedly and autonomously afterwards to optimize the throughput on the CC. Such a scheme makes the CC selection become a power setting process rather than a binary decision making process and compensates for the deficiency of existing researches.

III. SYSTEM MODEL AND ANALYSIS

A. PCC Selection and SCC Power Setting

In the system model, femtocells that are likely to have an interfering relationship are classified into the same ‘cluster’, and only femtocells in the same cluster can exchange their local information with each other.

Femtocell autonomously picks out a CC as Primary Component Carrier (PCC) which is used by the User Equipment (UE) to camp, providing basic service when the femtocell is powered on. The PCCs are non-overlapping with each other in the same cluster and transmit on their maximum power. If all CCs have already been selected as PCC, the femtocell shall select the carrier with the least interference, e.g. the CC on which the sum of RSRP from the surrounding femtocells is the smallest. The above method of PCC selection in the system model is the similar to that in [3] and [5]. PCC reselection should be avoided and the PCC has absolute priority of primary over other CC of the femtocell.

All the rest CCs except for PCC will be treated as Secondary Component Carrier (SCC) by femtocells. Each femtocell adjusts the transmission power of SCC to optimize the throughput in each CC in accordance with the local information gathered from its served UE and information from other femtocells in the same cluster. Such a power setting process is different from the scheme in currently existing researches and is carried out circularly by femtocells..

B. Analysis on Power Setting Process

It is assumed that there are N femtocells in one cluster. To simplify the analysis, each UE can only be scheduled on one CC, and all the bandwidth of the CC will be allocated to the UE scheduled on that CC. The downlink channel capacity on each CC is given by

$$C_1(P_1,P_2,\cdots P_i,\cdots P_N)=B\sum_{i\in F}log_{10}(1+\frac{P_i/L_{ii}}{\sum_{j\in F,j\neq i}P_j/L_{ji}+N_0B}) \quad (1)$$

Where

B is the bandwidth of the CC,

P_i is the transmission power of the femtocell i,

L_{ij} is the coupling loss which includes propagation loss and antenna gain from femtocell i to the served UE of femtocell j on the CC,

N_0 is the thermal noise spectral density.

The optimization problem can be stated as

$$\underset{0\leq P_i\leq P_{max}}{arg\,max}(C_1(P_1,P_2,\cdots,P_i,\cdots P_N)) \quad (2)$$

Where, P_{max} is the maximum downlink transmission power on a CC.

Equation (1) forms a multi-dimension surface that is complicated to solve the maximum value point. But if a individual femtocell only focuses on adjusting its own transmission power, the optimization problem of (2) will be simplified.

Assuming the goal of downlink transmission power setting is to achieve the maximum channel capacity of this CC, when femtocell i^* is setting its transmission power, the objective function can be formulated as

$$C_2(P_{i^*}) = B[log_{10}(1+\frac{P_{i^*}/L_{i^*i^*}}{\sum_{i\in F,i\neq i^*} P_j/L_{ii^*}+N_0B})+ \sum_{i\in F,i\neq i^*} log_{10}(1+\frac{P_i/L_{ii}}{\sum_{j\in F,j\neq i,j\neq i^*}P_j/L_{ji}+N_0B+P_{i^*}/L_{i^*i}})] \quad (3)$$

Equation (3) is the objective function of variable P_{i^*}, and solving the maximum value of (3) is simpler than (1) since other parameters are fixed when femtocell i^* is setting its transmission power P_{i^*}. The optimization problem can be expressed as

$$\underset{0\leq P_{i^*}\leq P_{max}}{arg\,max}(C_2(P_{i^*})) \quad (4)$$

If such a power setting process is carried out by different femtocells independently and circularly, the set of transmission power of different femtocells will gradually converge to one of the local maximum values on the multi-dimension surface for (1).

To illustrate the above convergence process, a two-cell scenario is taken as an example since the multi-dimension surface is visible when there are only two femtocells in a cluster. The scenario is shown in Fig.2 (a) and the normalized total channel capacity surface is shown in Fig.2 (b). The surface has two local maximum points, C and C', and C' is the global maximum point of the surface.

a) Convergence path: A→B→C

If the initial transmission power of femtocell 1 and 2 is on Point A of the surface, the transmission power will be transferred to Point B after the power adjusting of femtocell 1 in order to pursue higher total channel capacity. Then the transmission power will be transferred to Point C after the power adjusting of femtocell 2. The transmission power will keep stable at Point C if the coupling loss does not vary, since there will be no motivation for femtocells to pursue a higher channel capacity.

b) Convergence path: A'→B'→C'

Similarly, if the initial transmission power of femtocell 1 and 2 is on Point A', the transmission power will be transferred to Point C' after the power adjusting of femtocell 1 and 2 and keep stable if the coupling loss does not vary.

In this example, the above two paths make the transmission power converge to two different local max points on the surface. The initial location on the surface determines the final convergence point. It can be seen that the power setting process of (4) simplifies the optimization problem of (1), but the cost of simplification is that convergence point is not global maximum but one of local maximum points. Nevertheless such a simplification is still better than currently existing scheme since it explores the potential channel capacity

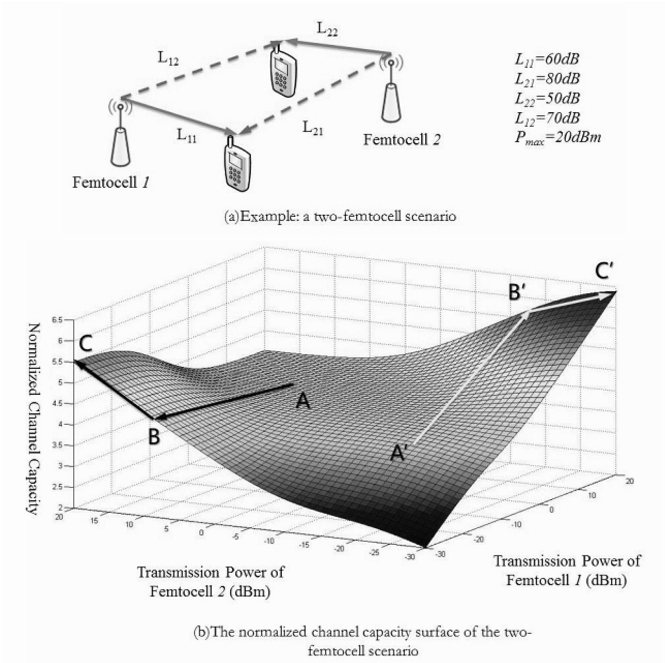
IV. COOPERATIVE POWER SETTING SCHEME

This Section details the proposed Cooperative Power Setting Scheme. The exchange of local information is introduced first in this section, since the proposed scheme relies on local information gathered by the UEs of different femtocells. Then the proposed method for Power Setting is subsequently explained.

A. Receiving Power Matrix

Local information is gathered by served UE of each femtocells and is exchanged by femtocells in the same cluster. The information exchange can be achieved through the backhaul to Femto Gateway (FG) which provides femtocell security, control, aggregation and standard interfacing with core network elements of mobile network operator.

In the system model, local information from different femtocells in the same cluster composes a Receiving Power Matrix (RPM) which is the receiving power coupling on a CC between femtocells in the same cluster. Fig.3 shows an example of RPM in a cluster with five femtocells.



(a)Example: a two-femtocell scenario

(b)The normalized channel capacity surface of the two-femtocell scenario

Figure 2. An Example for the Convergence Process

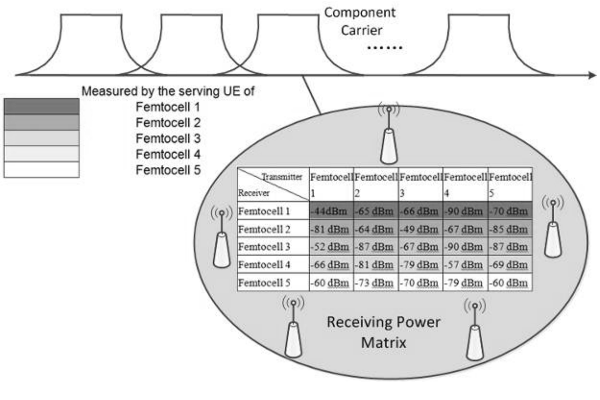


Figure 3. An Example for Receiving Power Matrix （RPM）

Each active UE served by femtocells performs downlink measurements of reference signal receiving power (RSRP) which are reported to its serving femtocell. These measurements are similar to that for handover purposes and conducted towards both the serving cell and the surrounding cells. Considering different serving UE may be scheduled on the same CC, the receiving power in RPM is non-realtime and is an estimation of the potential signal strength drawn from the measurement report. Each measurement report is a receiving power sample, and a statistic drawn from the samples, e.g. the mean value or the value corresponding to certain outage probability of the samples, will determine the receiving power value in RPM. According to the RPM, femtocells can estimate the downlink signal quality and the propagation loss to femtocell UEs.

Each femtocell can only maintain its own receiving power value in RPM. The maintenance of the total RPM relies on the information exchange in the same cluster. When a femtocell updates its own receiving power value in RPM, all the other femtocells in the cluster should be informed.

B. Proposed Power Setting Scheme

In the system model analyzed above, the P_{i*} corresponding to the maximum value of objective function (4) can be found based on optimization theory. But considering the adoption of Adaptive Modulation and Coding (AMC) in the radio interface of mobile communications, such an optimization problem can be simplified since the numbers of Modulation and Coding Standards (MCS) is finite and all possible P_{i*} can be traversed so that the P_{i*} corresponding to the maximum throughput can be worked out.

It is assumed there are M different MCSs which constitute a set $\{MCS_j\}$, where $1 \leqslant j \leqslant M$. A given MCS requires a certain SINR to operate with an acceptably low BER (Bit Error Rate) in the output data. The SINR corresponding to different MCSs composes the SINR set $\{SINR_j\}$. A given SINR also corresponds to a theoretical throughput which depends on the model of link adaption. The link adaption model can be expressed as a function $TP(SINR)$, and is out of the scope of this paper. The proposed power setting process of femtocell $i*$ on an SCC goes as follows:

Step 1: Calculate the required transmission power P_{i*j} of femtocell $i*$ if the $SINR_j$ in the set $\{SINR_j\}$ is satisfied. The P_{i*j} is given by：

$$P_{i*j} = SINR_j\big(\textstyle\sum_{i\in F, i\neq i*} P_i / PL_{ii*} + N_0 B\big) \tag{5}$$

All MCS should be traversed, and finally a required transmission power set $\{P_{i*j}\}$ is formed for femtocell $i*$, where the variable j corresponds to different MCSs.

Step 2: Calculate the total theoretical throughput T_j of all femtocells in the same cluster if the transmissions power of femtocell $i*$ on the SCC is set as P_{i*j}. The T_j is given by

$$T_j(P_{i*j}) = TP(SINR_j) + \sum_{i\in F, i\neq i*} TP\Big(\frac{P_i / PL_{ii}}{\sum_{j\in F, j\neq i, j\neq i*} P_j / PL_{ji} + N_0 B + P_{i*} / PL_{i*i}}\Big) \tag{6}$$

All the power value in $\{P_{i*j}\}$ should be traversed, and finally the throughput set $\{T_j\}$ can be obtained, where variable j corresponds to different MCSs.

Step 3: Set the transmission power of femtocell $i*$ on the SCC as

$$P_{i*} = \{P_{i*j} \mid \underset{1\leq j\leq M}{arg\,max}\{T_j(P_{i*j})\}\} \tag{7}$$

The above three steps are carried out by different femtocells in the same cluster independently and circularly. The set of transmission power will gradually converge to a stable value, which corresponding to one of the local maximum points on the multi-dimension surface in (1).

V. PERFORMANCE EVALUATION

A. Simulation Assumptions

The simulation adopts the 5x5 grid scenario in [13]. Femtocells are randomly distributed in 25 grids and there is no more than one femtocell in each grid. Macrocells are not considered in the simulation. UE selects the femtocell with the least propagation loss to access. Other parameters of the simulation are from [13] [14], which are shown in Table 1.

B. Results and Analysis

The rate of convergence for the proposed scheme is evaluated first since the process of power setting is also an iteration process and necessary number of iterations has the direct bearing on the feasibility proposed. Then a comparison is made between the proposed scheme and ACCS scheme proposed in [3].

TABLE 1 SIMULATION PARAMETERS

Parameter	Value
System bandwidth	10MHz*5CC
Carrier frequency	2000 MHz
Cell layout	5*5 grids，grid length is 8m
Antenna gain	5dBi for femtocell and 0 dBi for UE
Maximun/Minimun TX power of femtocell	20dBm/-30dBm
White noise power density	-174 dBm/Hz
Number of UEsx	5 per cell
Pathloss	127+30lgd，d in km
Lognormal Shadowing	10dB
Noise Figure	9dB
Numbers of femtocells	2~13
Traffic Model	Full buffer
Link adaption model	Figure A.4 [14]

Fig.4 is the results which illustrate the iteration error under different numbers of iterations, and different curves are obtained when there are different numbers of femtocell in a cluster. Assuming that 5% iteration error or lower is acceptable, ten iterations is enough for the proposed scheme even when there are thirteen femtocells in a cluster, which proves the feasibility of the proposed scheme. Therefore, the number of iterations is set to be ten in the following performance evaluation.

Fig.5, Fig.6 and Fig.7 are the normalized average throughput of PCC, SCC and femtocell downlink respectively.

There is a discontinuity point corresponding to five femtocells in a cluster on the curve of Fig.5, since PCC can be kept non-overlapping when the number of femtocells is equal to or less than five. When the number of femtocells is more than five, the PCC will overlap, and the throughput will decrease faster along with the femtocell number, which causes a discontinuity point on the curve.

The average throughput decreases along with the increase in the number of femtocells in a cluster for the intra-tier interference. Fig.5 and Fig.6 show that the proposed scheme can improve the throughput of SCC significantly while the PCC throughput is nearly the same with ACCS scheme. The average throughput of femtocell is also improved, which is indicated in Fig.7.

The advantage of the proposed scheme is obvious especially when the deployment of femtocells is dense. So the proposed scheme is proven to be effective to deal with the intra-tier interference and improves the downlink throughput of femtocells.

VI. CONCLUSION

This paper proposes a Cooperative Power Setting Scheme to mitigate the intra-tier interference among CA-based femtocells. The impact of transmission power is considered, and femtocells cooperatively adjust their transmission power aiming at optimizing the total throughput on each CC. The transmission power of each femtocell will be adjusted repeatedly and autonomously to approach the maximum available throughput. The simulation results indicate that the proposed scheme is feasible and compensates for the deficiency of existing researches. The advantage of the proposed scheme is obvious especially when the deployment of femtocells is dense.

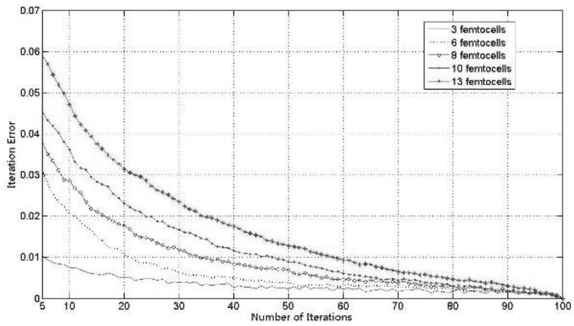


Figure 4. Convergence property of the proposed scheme

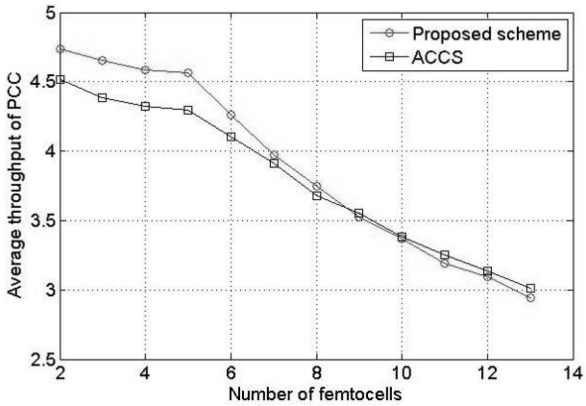


Figure 5 Average throughput of PCC

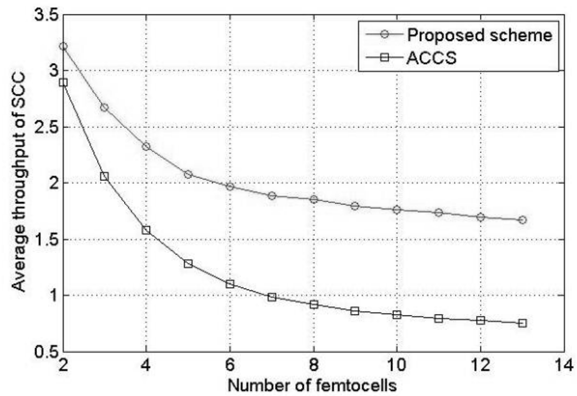


Figure 6 Average throughput of SCC

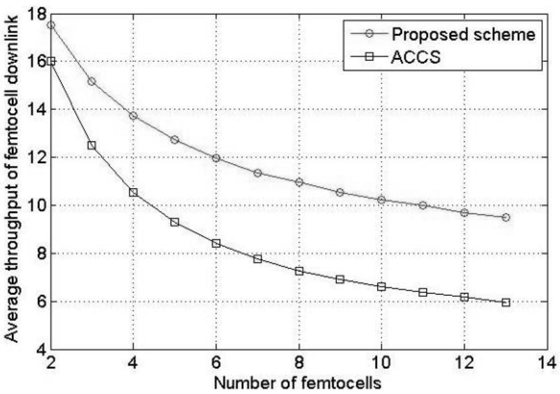


Figure 7 Average downlink throughput of femtocell downlink

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