A Distributed Power Control Scheme for the Mitigation of Co-Tier Downlink Interference for Femtocell in the Future 5G Networks

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Abstract. LTE Femtocell network categorized as small cell technology will play an important role in the future 5G networks owing to the fact that it cannot only expand the coverage of wireless communication systems but it can also increase frequency reuse. As the times of Internet of thing" (IOT) is coming, the data volume will be explosive tremendously in the future. Hence the need to deploy femtocell is stringent. However, the growing deployments of femtocell base stations (FBSs) have brought a serious issue of inter-FBS interferences (also referred to as co-tier interference) due to their easy and convenient installation. In this article, we propose a systematic approach to reduce FBS co-tier downlink interference under the scenario that FBSs are densely deployed in an environment. Power control for FBS is performed when the number of warning messages issued from Femtocell User Equipment (FUE) is greater than a threshold for a typical distributed power control scheme. However, it will reduce the *SINR* of its served FUEs; therefore reducing the total capacity. In our proposed LAGPC scheme, A FBS performs power control only when the number of FUEs connected to other FBSs interfered by itself is greater than that of its served FUEs. Our proposed scheme has been validated through simulations that it could effectively reduce co-tier downlink interference in shared-spectrum femtocell environments, thereby boosting system performance by 40% on average.

Keywords: Femtocell · Co-tier downlink interference · Alarm signal
FBS-excessive interference source · Power control · IOT

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1 Introduction

On the roadmap to the fifth generation (5G) wireless network, the goals are set to attain 1000 times higher mobile data volume per unit area, 10–100 times higher number of connecting devices and user data rate, 10 times longer battery life and 5 times reduced latency [1–3]. In order to attain the goals set above, femtocells play an important role in the next generation of 5G wireless network and IOT times. This is due to the fact that femtocell cannot only increase the frequency reuse but also that it can save power and increase SINR because of the short distance connection characteristic. Furthermore, femtocell network can expand the coverage, off-load the burden of the Macrocell Base Station (MBS), and enhance the total capacity by means of the back-haul connection with ultra-wide bandwidth. Furthermore, the sensor in IOT system generally is low power so the transmit distance in the last mile of network layer is very short as usual. As a result, the small cell technology such as femtocell will become significantly important and popular in the future. However, the growing deployment of FBSs is destined to bring a serious issue of inter-FBS interference (also referred to as co-tier interference) due to their easy and convenient installation. This problem is especially serious when the FBSs are densely deployed in an urban area. Every household deploys its own femtocell to increase the transmission rate but it might also incur serious co-tier interference at the same time due to residence proximity. In fact, cross-tier interference arising from the FBSs and MBSs also becomes a critical issue due to the deployment of femtocells. To cope with the co-tier or cross-tier interference, various power control schemes to migrate the penalty have been proposed [4, 6, 7]. Game theory such as Stackelberg game [8, 9] has been applied in power control and resource allocation negotiation between the FBS and MBS through the pricing mechanism so that leader and followers can achieve balance in terms of throughput, outage probability, spectrum efficiency and so on. The Fractional Frequency Reuse (FFR) scheme proposed in [10] is used to tackle the co-channel interference problem in OFDMA network. Simulation result shows that FFR method can increase SINR value in all scenarios considered. In scenario 1 with random distance, where the distances between MBS and FBS, between FBS and FUE, and between MBS and FUE are 572.503, 33.8378, and 541.288 meters, respectively. The SINR value increases from 57.8716 dB to 182.291 dB by 124.4194 dB. In scenario 2, where the distances between MBS and FBS, between FBS and FUE, and between MBS and MUE are 604, 37.5366, and 641.291 meters, respectively. The SINR value can increase from 78.5277 dB to 183.222 dB by 104.6943 dB in this scenario. Results in [5] also show that the quality can be improved and the interference can be mitigated for both Macrocell and FUE by applying the FFR scheme. However, this scheme suffers from the uneven distribution of FBSs and the frequency reuse is also restricted. In order to solve the former problem for the densely deployed femtocell networks, the enhanced Inter-Cell Interference Coordination (eICIC) has been extensively studied and adopted as a standard for LTE-A and surely will also be a standard for the future 5G networks. The Small Cell Group Muting (SCGM) scheme proposed in [13] is based on the eICIC technology and is used to mitigate the interference among neighboring small cells. The key motivation of this scheme is that one subframe of LTE-A is composed of 14 OFDM symbols for each resource block (RB) [14]. Some OFDM symbols are muted for some FBSs and others are not so that the interference can be mitigated or even be avoided. Simulation results show that the scheme can boost the average throughput by 7–15%. In this article, we propose a systematic approach to reduce co-tier downlink interference for FBSs under the scenario that FBSs are densely deployed. Our proposed Loading Aware Green Power Control (LAGPC) scheme is used to suppress the co-tier interference among FBSs. The key idea of this scheme is that if once a FUE is within the coverage of other FBSs, it will send a waning message to these FBSs. If the number of warning messages received by any FBS is greater than the number of its served FUEs, this FBS will decrease its power level by one dB gradually until the number of warning messages is no longer than the number of its served FUEs. If the number of its served FUE is very small for a FBS, even to zero, this FBS surely should reduce to its power level until no warning messages issued from the FUEs connected to other FBSs appear. The scheme is distributed and very easy to implement. The algorithm code developed for this scheme can be integrated into the control firmware of FBSs.

In the next parts of this article, system model of our proposed scheme will be presented and addressed in Sect. 2. Simulation results and discussions will be addressed in Sect. 3. Conclusions and the future works are given in Sect. 4.

2 System Model

The access methods of FBSs can be divided into three types, Open Subscriber Group (OSG), Closed Subscriber Group (CSG), and Hybrid Subscriber Group (HSG). In OSG, all FUEs can connect to all FBSs so that the MBSs can release the service loading from the requests of UEs. On the other hand, the FUEs must login in the FBS by their registration accounts in CSG. HSG is with the mixture characteristics of OSG and CSG. In this article, we assume the access method is OSG. About the spectrum allocations can be divided into two types split spectrum reuse and shared spectrum reuse. In the split spectrum reuse, the spectrum is portioned into two parts. One part is used by MBSs and the other part is used by FBSs. On the contrary, all spectrum or bandwidth is shared by FBSs and MBSs in shared spectrum reuse. In this article, we assume the partition scheme is shared spectrum reuse. We also assume that there are totally M FBSs and N FUEs located in the considered environment. We focus on the co-tier interference and the interference among the FBSs and MBSs is assumed to be very small so that it can be ignored. Our scheme assumes that once a FUE senses interference, it will broadcast a warning message to all FBSs within its range. If the number of warning messages received by a FBS is greater than a given threshold, it should be aware of the fact that it is causing interference to an excessive number of FUEs and will identify itself as an FBS-Excessive Interference (FBS-EI) source. Under the circumstance, it should reduce its power level to mitigate the interference toward other FUEs through a distributed FBS-EI detection algorithm. This scheme is distributed and easy to implement. On the contrary, Femtocell Management System (FMS)-based schemes such as those in [11] and [12] use a centralized control by a managing server. This server must collect a large amount of data in order to determine the source of interference through a special algorithm. Hence, these centralized approaches might be rather complicated and impractical to implement. In order to simplify the process of looking for the interference sources, our scheme is based on the observation that if the coverage of an FBS overlaps with that of neighboring FBSs, the FBS will likely interfere with the FUEs served by the neighboring FBSs. The interfered FUEs will send out warning messages. The message issued from the same FUE within a short period will be treated as the same so the number of warning message will not change in this scenario. The number of warning messages received by an FBS can be used as an indicator of the severity of interference. The procedures of finding a FBS-EI source mentioned above is illustrated in Fig. 1.

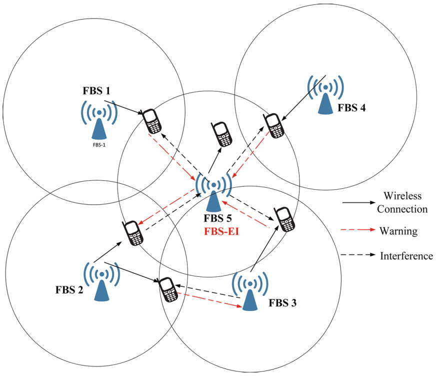

Fig. 1. Illustration of the procedures for identifying an FBS-EI source.

Figure 1 shows that the service area of FBS-5 overlaps with those of FBS-1, FBS-2, FBS-3, and FBS-4. Therefore, FBS-5 will receive a lot of warning messages from the FUEs served by neighboring FBSs and FBS-5 will be aware that it is an FBS-EI source if the number of the warning messages received from other FUEs is greater than the threshold. As a result, FBS-5 will reduce its power level to mitigate the interference toward the FUEs served by other FBSs. It is noted that the coverage area of an FBS depends on the radio sensitivity of FUEs; the radio sensitivity is assumed to −56 dBm in this article. Without loss of generality, the radio sensitivity is assumed to the signal strength corresponding to the 20-meter radius coverage with the transmit power of 23 dBm for each FBS. Of course, the radius can be extended to 25 m or farther. In fact, it can be treated as an environment parameter. The coverage of each FBS is based on receiver sensitivity,−56 dBm in this article, so due to some blockages, whether the shape of the coverage area in Fig. 1 is a circle or not might not be a problem. It is noted that the number of FUEs served by FBS 5 is only 1 as in Fig. 1, but the number of warning messages from other FUEs of other FBSs such as FBS 1, 2, 3, 4 is as high as 4. Hence FBS 5 will be aware that it is a FBS-EI, then the power control is performed by FBS 5 and the coverage of Fig. 1 will be reshaped into Fig. 2. On the contrary, the FBS 3 in Fig. 1 does not hold this condition, so it will not regard itself as a FBS-EI, so no power control is needed as in Fig. 2.

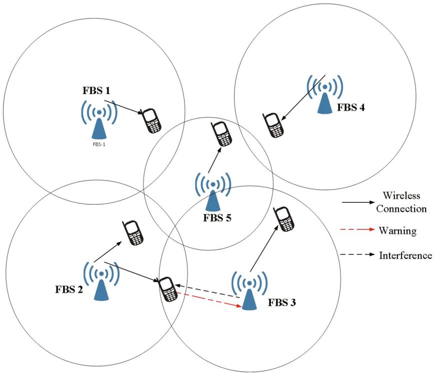

Fig. 2. Illustration of FBS interference on FUEs after the power reduction of FBS 5.

In order to attain the goals set above, we propose a Loading Aware Green Power Control (LAGPC) algorithm for this scheme to proceed with this mechanism. In this scheme, three assumptions are made:

(1) Every FUE is assumed to connect to the nearest FBS.
(2) Every FUE in the coverage of other FBSs can detect the interference from these FBSs.
(3) Every FBS will receive the FUEs' waring messages if they are in the coverage of these FUEs.

If we denote the power of all FBSs as matrix $\mathbf{P} = [p_1, p_2, \ldots, p_M]$ and the channel states among all FBSs and FUEs as $\mathbf{H} = [h_{ij}]$, a $M \times N$ matrix, the interference power state $\mathbf{I} = \mathbf{P} \otimes \mathbf{H} = [I_k]$. Note that the element (I_k) operated with $\otimes$ can be defined by

$$I_k = \sum_{i=1, j=FBS(k), i \neq j}^{M} P_i h_{ik}. \tag{1}$$

It is noted that h_{ik} denotes the channel state for FBS i to FUE k, it can be given by

$$h_{ik} = 10^{-3.7} (D_{ik})^{-3} \tag{2}$$

based on 3GPP TR25.952 25. *FBS* (k) denotes the ID of FBS which FUE k connected to. The Received Signal Strength (RSS) sensed by all FUEs, $\mathbf{R} = \mathbf{P} \otimes \mathbf{H} = [R_k]$ and the element of R, $[R_k]$ can be given by

$$R_k = P_{FBS(k)} h_{FBS(k)k}. \tag{3}$$

The total capacity C can be given by

$$\mathrm{C} = \sum\nolimits_{\mathrm{i}=1}^{\mathrm{N}} B \times log_2(1 + \frac{R_k}{I_k + \eta}). \tag{4}$$

The maximal capacity C_{Max} can be achieved when all the powers of FBS are properly controlled. If we let power control of all FBSs be optimal, we can get C_{Max} by

$$C_{Max} = \underset{P}{arg} \max \sum\nolimits_{k=1}^{N} B \times log_2 \left[1 + \frac{P_{FBS(k)} h_{FBS(k)k}}{\sum\nolimits_{i=1, j=FBS(k), i \neq j}^{M} P_i h_{ik} + \eta} \right]. \tag{5}$$

Unfortunately, the optimal power control is impossible due to the reasons listed in the followings:

(1) The complexity of optimal power control for all FBSs is NP-hard if a brute-force calculation is applied because the possible number of power level to be taken is exponentially large with the order of the number of FBSs. If the number of FBSs is 100 assumed in this article, the possible combinations can be up to PL^{100} if PL is the possible number of power levels.

(2) An individual distributed FBS cannot know all channel states of all UEs to FBSs, that is, the matrix **H** listed before is NP-hard to be known.

In fact, all the FUEs are mostly interfered by their neighboring FBSs located in the close proximity. The interferences from other distant FBSs should not be taken into consideration because these interferences from distant FBSs might also be hard to be sensed. A FBS can tune its power level according to the number of FBS-EI waring messages it received. If this FBS reduces its power level, all the FUEs issuing FBS-EI messages can boost their data rate due to the interference reduction. In addition, if the number of FUEs served by this FBS-EI is very small even to zero; this power reduction for this FBS-EI has little or no impact on the total capacity of this FBS. On the contrary, if the number of FUEs served by this FBS-EI is very large, the power reduction could reduce the inferences toward other FUEs connected to other FBSs at cost of reducing the total capacity of the FBS-EI cell itself as well. In our proposed scheme, if the number of FUEs interfered by this FBS-EI is s, the ID of the FBS-EI is i, and the power of this FBS-EI, P reduces to P' ($P > P'$), the interferences revived from this FBS-EI for an individual FUE k will reduce from $P_i h_{ik}$ to $P'_i h_{ik}$. In the meanwhile, the total capacity of these m FUEs will increase from

$$\mathrm{C}_S = \sum\nolimits_{\mathrm{i}=1}^{\mathrm{s}} B \times log_2(1 + \frac{R_k}{P_i h_{ik} + \eta}) \tag{6}$$

to

$$\mathrm{C}'_S = \sum\nolimits_{\mathrm{i}=1}^{\mathrm{s}} B \times log_2(1 + \frac{R_k}{P'_i h_{ik} + \eta}) \tag{7}$$

if set S in (6) and (7) consists of the s FUEs. The total capacity of the FBS-EI will reduce from

$$C_T = \sum\nolimits_{\mathrm{k}=1}^{\mathrm{n}} log_2(1 + \frac{P_i h_{ik}}{I_k + \eta}) \tag{8}$$

to

$$C_T^{'} = \sum\nolimits_{\mathrm{k}=1}^{\mathrm{n}} log_2(1 + \frac{P_i^{'} h_{ik}}{I_k + \eta}) \tag{9}$$

if set T consists of the n FUEs connected to the FBS-EI where I_{k} denoted as unknown interferences received from other FBSs for any individual FUE in this set T. If we set the SINR increase benefit in percentage be C_{inc} and the SINR loss in percentage be C_{dec} from this power reduction as $(C_{\mathrm{S}}^{'} - C_S)$ and $(C_T - C_T^{'})$, respectively, the FBS-EI should perform power reductions is based on the criterion that C_{inc} is greater than C_{desc} in terms of total capacity. C_{inc} and C_{desc} can be estimated and reduced from (6), (7), (8), (9), (10) and (11) if the thermal noise is very small compared to the interferences. In fact, the number of FUEs not connected to the FBS-EI and surround about this FBS is not limited to m. Therefore, the number of FUEs beneficial from the power reduction is not limited to m; thus $C_{\mathrm{inc},}$ C_{desc} can be given by (10) and (11), respectively.

$$C_{inc} \approx \sum\nolimits_{\mathrm{k}=1}^{\mathrm{s}} log_2(\frac{P_i}{P_i^{'}}) = log_2(\frac{P_i}{P_i^{'}})^s \tag{10}$$

$$C_{desc} \approx \sum\nolimits_{\mathrm{k}=1}^{\mathrm{n}} log_2(\frac{P_i}{P_i^{'}}) = log_2(\frac{P_i}{P_i^{'}})^n \tag{11}$$

It is noted that set S can be given by

$$S = \{k | P_i h_{ik} > R_{min}\} \tag{12}$$

and

$$s = |S|. \tag{13}$$

It is noted that if n is zero, that is, there is no FUE connected to the FBS-EI, C_{desc} is destined to be 1, in other word, no SINR is lost no matter how low the $P_i^{'}$ is. If both s and n are greater than 0, the capacity gain denoted by $G = B \times (C_{inc} - C_{dest})$ can be given by (14) reduced from (10) and (11) where B is the bandwidth occupied by the system.

$$G = B \times (C_{inc} - C_{desc}) = B \times log_2(\frac{P_i}{P_i^{'}})^{\frac{n}{s}}. \tag{14}$$

Equation (14) shows that if n is greater than s, G is positive. On the contrary, if n is less than s, G is negative. The larger of n/s and power reduction ratio, the larger the gain is. If no power reduction is performed by the FBS-EI, that is the power reduction ratio is 1, G is zero based on (14). Therefore, the outcome is no gain and no loss in this scenario. In fact, s is determined by R_{min} and P_i. If P_i reduces, s decreases. Then, s is a function of the power P_i and $R_{\min}$.

This model motivates us to propose the LAGPC algorithm described in Fig. 3 and the variables shown in Fig. 3 are explained in Table 1.

3 Simulation Results and Discussion

The simulation parameters are listed in Table 2. In this study, suppose there are totally 100 FBSs and 300 as well as 400 FUEs randomly distributed over a 200 × 200 m^2 area. There are 3 and 4 FUEs served by one FBS on average for the 300 and 400 FUEs, respectively. Any FUE will connect to a FBS which is the closest to it and it can get the best channel gain from this FBS connection. A total of 10 runs of simulations are performed to investigate the behavior of IAPC and LAGPC.

Table 1. Notations used in LAGPC scheme

$\mathrm{P_j}$	The transmission power level of the FBS-j in dBm
P_{npc}	The transmission power level of FBS with no power control (NPC) in dBm
RS_{i,j_k}	The receiving signal strength of FUE k of FBS-i (or FUE$_{i\_k}$) from FBS-j in dBm
I_{j,i_k}	The interference received by the FUE$_{i\_k}$ from FBS-j in dBm
k	The ID of FUE served by FBS
η	Thermal noise
$R_{\min}$	The minimal Received Signal Strength (RSS) for each FBS to receive any message theoretically
ψ	The minimal strength of the received signal from FBS-EI for FUE to send warning messages
RSS_{j,j_k}	The RSS for FUE$_{j\_k}$ received from FBS-j
L_{i,i_k}	The path loss from FBS-i to FUE$_{i\_k}$ in dB
C_{i_k}	The capacity of the kth FUE of FBS-i
|FBS-i|	The number of FUEs served by FBS-i
$LMAX_i$	The largest path loss among all FUEs served by FBS-i
n_i	The number of warning messages received by FBS i from FUE$_{i,j\_k}$ and $j = FBS(k)$, $i \neq j$ so far for each run
m_i	The number of FUEs served by FBS-i
D_{i,i_k}	Distance of FBS i to the FUE k

```
Input: $M$ FBSs, $N$ FUEs, $\sum_{i}^{M} |\text{FBS-}i| = N$
Input: $i = 1$ to $M$, $k = 1$ to |FBS-$i$|.

Output: The new power distribution of femtocell.
Begin a Run
        For 1=0 to $M$ //initialize NWM to zero { $NWM_i = 0$}
For $i$=1 to $M$ {
  $k \leftarrow 1$
  $LMAX_i = L_{i,i\_k} = P_{npc} - RSS_{i,i\_k}$
    For $k$=2 to |FBS-$i$|
    $L_{i,i\_k} = P_{npc} - RSS_{i,i\_k}$
    If $L_{i,i\_k} > LMAX_i$ then{ $LMAX_i = L_{i,i\_k}$}
    If (FUE$_{i\_k}$ senses interference from FBS>=$j$) then
              Send a warning message to FBS-$j$ ($i \neq j$)
}
For $i$=1 to $M$ {
    //The following algorithm is implemented by individual FBS
    If FBS-$i$ receives interference from FUE then
      $n_i \leftarrow n_i + 1$
    If $n_i > m_i$ then {
       $P_{min} \leftarrow R_{min}+LMAX_i$
       If ($P_i > P_{min}$)
           $P_i \leftarrow P_i - 1$
     }
}
```

Fig. 3. Our proposed IAPC scheme

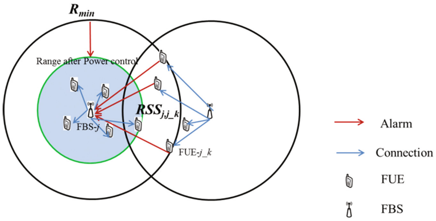

Fig. 4. Illustration of the power control of FBS-EI

Table 2. Simulation parameter values

Parameter	Value
Map range	200 m × 200 m
Number of FBSs (M)	100
Number of FUEs (N)	300, 400
FBS radius of coverage	20 m
FBS transmit power (max)	23 dBm
Bandwidth	10 MHz
Frequency	2 GHz
Minimal sensitivity to receive (R_{min})	−56 dBm
T value	1, 2, 3, 4

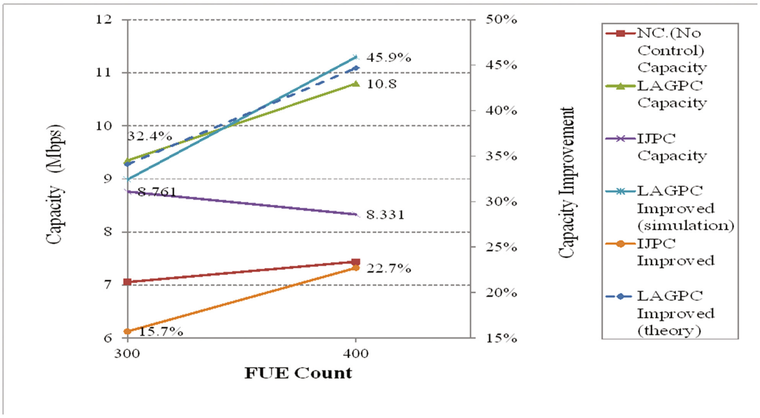

Fig. 5. Capacity and capacity improvement for IJPC and LAGPC.

In our previous proposed scheme, IAPC [15], the value *T* denotes the threshold number of warning messages received by one FBS to reduce its power level. If *T* is equal to 1, it implies that an FBS receiving any warning message will treat itself as a FBS-EI source and will reduce its transmission power immediately. In order to evaluate the performance of our proposed LAGPC and compare it with that of the previous proposed scheme, IJPC, the throughput improvement is shown in Fig. 5.

Figure 5 shows that the improvements of average capacity for IJPC are only 15.7% and 22.7% for the 100 FBSs with 300 FUEs and 400 FUEs to be served, respectively. On the contrary, the improvements for our proposed LAGPC scheme can be as high as 32.4% and 45.9% for the FBSs with 300 FUEs and 400 FUEs. The theoretical improvement based on (14) is shown in the Dotted line of Fig. 5. Figure 5 shows that the simulation and theoretical results are very close. It demonstrates the preciseness of our model. For the IJPC, if the T is set to be one only, all FBSs are inclined to reduce their power level so that the SINR of their served FUEs decreases on average. On the contrary, the SINR of FUEs does not reduce frequently if the value *T* is over 2 because the criterion to reduce power level is stricter compared to that of *T* being one. We show the effect of the value of *T* on the SINR of all FUEs for these ten run simulations in Fig. 6. Hence, our scheme could reduce the total power consumption by about 50%; it could also be a green communication scheme based on our LAGPC algorithm. The capacity comparison of IJPC with that of No Power Control (NPC) scheme is illustrated in Fig. 5. Figure 5 shows that the average capacity can increase from 4.8 Mbps to 5.8 Mbps for each FUE. Therefore, the total capacity can increase by 20.8% on the average. The impact of *T* value on the throughput improvement for IJPC can be shown in Fig. 7.

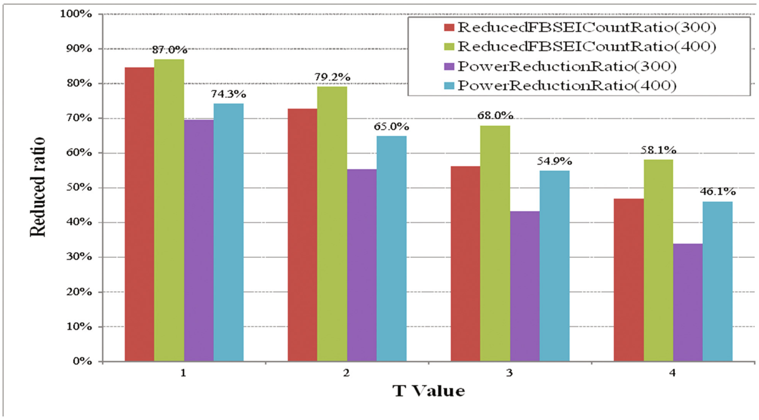

Fig. 6. The reduced FBS-EI count and reduced power reduction ratio with various T values for our previous proposed IJPC scheme.

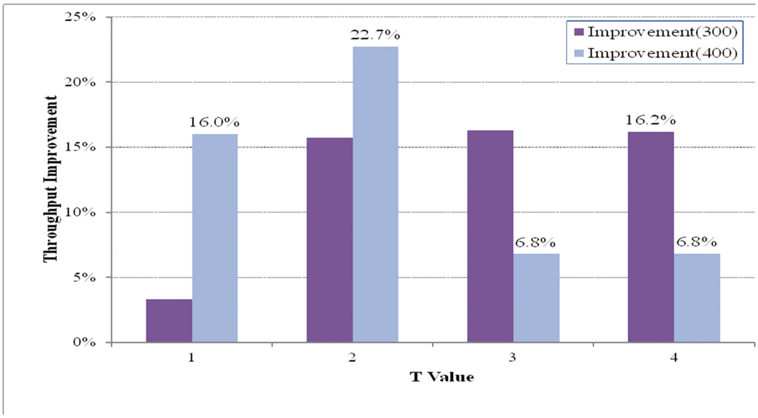

Fig. 7. The T value impact on the throughput improvement of IJPC.

Figure 7 shows that if the number of FUEs is 300 served by 100 FBSs, the throughput improvement with T value 1 for IJPC is only 3%. It illustrates that if we set the definition of FBS-EI as only one warning message received, most of the FBSs are inclined to reduce their power level and their throughput also reduces as well; therefore the total throughput improvement is also limited. On the contrary, if we set T value over or equal to 2 as the criterion to be FBS-EI for any FBS, the throughput improvement can be about 16.0%. However, if the number of FUEs increases to 400 served by 100 FBSs, the scenario of T value set to 1 can have throughput improvement as high as 16%. It accounts for the fact that the interference for the scenario with 400 FUEs is much higher that of the scenario with 300 FUEs intuitively. Hence, power reduction is much critical to the interference reduction as well as total capacity. It is interesting that the maximal throughput improvement occurs when the T value is 2 for the scenario with 400 FUEs. It motivates us to propose the LAGPC scheme. The IJPC scheme does not consider the number of FUEs served by the FBS-EI itself, so if the threshold *T* value is set to be too high or too low, the FBSs cannot achieve the maximal throughput. On the contrary, in our LAGPC scheme, both the number of warning messages and the number of FUEs served by FBS are considered, so if we set the criterion of power reduction to be the number of warning messages greater than or equal to the number of FUEs served, the maximal throughput improvement, about 46% can be obtained. Note that the throughput is calculated on average; most throughput improvement can be over 50% even up to 70%, but sometimes it is worthless to apply this scheme to improve the throughput. We owe this bad throughput improvement to the border effects. If most FUEs are so unlucky distributed at the border of two FBSs, reducing the power is destined to reduce the interference at cost of reducing the throughput as well, so the overall throughput cannot be improved. This issue will be discussed in the future works. The FBSEI count reduction and power reduction ratio with 300 FUEs and 400 FUEs by applying IJPC scheme are shown in Fig. 6. Figure 6 illustrates the FBSEI count ratio and power reduction ratio can be as high as 87.0% and 74.3% with *T* value = 1. This large scale power reduction is at cost of lower higher throughput improvement. It is also certainly that as *T* value increases, the reduction ratio decreases, but the best throughput improvement is 22.7% when the optimal *T* value is 2 as shown in Fig. 7.

4 Conclusion and Future Works

In this article, we propose a distributed LAGPC algorithm to reduce the downlink interference under the co-channel shared spectrum environment for the femtocell and the future 5G networks so that the average SINR and capacity can increase by about 44% on average. On the contrary, our previous proposed algorithm, IJPC is only 22.7% with *T* value 2, the best case of IJPC. The power reduction ratio of LAGPC can be up to around 70% slightly lower than that of IJPC at benefit of double throughput improvement on average. This algorithm is distributed and easy to implement as stated before. The centralized control system such as Femtocell Management System (FMS) might have better performance. However, it is really very hard for FMS to control and collect the distributed data for each FBS. It seems not practical at all.

Despite that the average capacity improvement can be up to 44%, we find that the improvement is not so stable. In some scenario, the distribution of many FUEs lies on the boarder of two FBSs so that the FUEs cannot get good SINR connection from the FBSs' service under this co-channel environment. There are many schemes supposed to solve this problem. Enhanced Inter-Cell Interference Coordination (eICIC) is one of the schemes, proposed to suppress this interference by changing the shared-channel to partition-channel allocation through the communications between the two FBSs so that the FUEs on the border of the two FBSs would not interfere with each other. On the other hand, a FUE is not aware of the location of its FBS connected to. If a cross-layer scheme can be applied to our proposed LAGPC by guiding the FUE approaching toward its connected FBS, the connected SINR can be improved and the interference is expected to be mitigated tremendously. We list these as our future works.

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