Self-Adjustment Downlink Transmission Power for Femtocells in Co-Channel Deployment in Heterogeneous Networks

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Abstract—The employment of femtocells has been considered as a promising approach for increasing network capacity and enhancing end users’ QoS and throughput as well as low cost and simple deployment. Deploying femtocells is common in indoor environment such as residential buildings comprising adjacent apartments. However, dense deployment of femtocells introduces interference among femtocells and the undesirable influence of interference is incremented among adjacent femtocells. As a result, the performance of the network is diminished. One of the techniques, which is considered to mitigate the impact of the interference, is adjusting transmission power of the femtocells. In this work, a dynamic downlink transmission power of femtocells is proposed. Each femtocell adjusts its transmission power autonomously based on measured cost function unit. The transmission power level of femtocell is constrained by the rate of interference that femtocell produces to adjacent femtocells. A simulation experiment is conducted to validate the efficiency of the proposed scheme compared to other two different approaches. The numerical results show that the proposed scheme can achieve better capacity and also can preferably mitigate the impact of the interference among co-channel deployed femtocells compared to other schemes, which are considered in this work.

Index Terms—LTE, Femtocells, Power Control, Interference.

I. INTRODUCTION

The high demand toward providing high level of QoS and throughput, which is raised by users using Long Term Evolution (LTE) networks, has been increased so that the mobile operators have been forced to produce novel techniques in order to widen coverage, increase data rates and reduce the expenses while operating their mobile networks. In LTE, a macrocell, also called eNodeB, can expand and widen the coverage ranges especially for outdoor areas, but it is inefficient in an indoor environment and cell edge areas. The indoor UE experiences low level of Signal to Interference plus Noise Ratio (SINR) due to high penetration loss, and that leads to less capacity as well as unsatisfied QoS. Moreover, it has been found that most of the demand on high throughput is requested by indoor User Equipment (UE) [1]. This imposes great challenges on networks operators to enhance UEs QoS and throughput at indoor zones. Accordingly, both industry and academia have tried to improve QoS for indoor environment regions where UE receives poor condition of connection to the macrocells [2]. As a result, the concept of Small Cell Network (SCN) has been considered as a promising solution that can increase cell throughput as well as provide good QoS. Also, small cells are capable of enhancing cell coverage and network efficiency.

Femtocells, also called femto base station or Home eNodeB (HeNodeB), are using the users Internet connection in order to connect to operators core networks as backhaul. Basically, femtocells are installed by users with low power and short distance between receiver and transmitter. The spectrum band can be shared by both femtocells and serving macrocell or femtocell can use a dedicated frequency band. Unplanned deployment of massive femtocells raises a significant challenge. Sharing the same frequency band between femtocells and a macrocell leads to cross-tier interference between macrocell and femtocells. Also, sharing frequency band between adjacent femtocells leads to co-tier interference between femtocells. Due to the impact that occurs on the network performance, the necessity of interference alleviation needs to be addressed and resolved. Interference alleviation can be managed in different ways such as radio resource partitioning or handover events management. Also, adjusting the transmission power of HeNodeB is a significant key aspect for reducing the impact of inter-cell and intra-cell interference. The main point behind adjusting the downlink transmission power is to decrease the power so that unnecessary excessive level of transmission power can be avoided to mitigate impact of interferences.

A significant segment of the present literature has been studied the impact of interference and power control issues of femtocells deployment. In [3], various power control algorithms have been studied to analyze the throughput performance for LTE femtocells networks deployed in a single macrocell. Network performance and co-channel interference influence on uplink and downlink capacity are discussed in [4] and [5]. A power control algorithm that verifies constant femtocells radius has been proposed to autonomously adjust the femtocell downlink transmission power based on received downlink power from serving macrocell in order to overcome macrocell-
femtocell co-channel deployment and diminish the subsequent interference according to [5]. In [6], the number of indoor UEs and handover occurrences are considered and investigated in order to be used for determining and adjusting the HeNodeB transmission power. Based on soft value of the SINR, an utility-based algorithm is proposed in [7] where femtocell transmission power is auto-configured based on analyzing interference measurements attained by UE. The femtocell accumulates interference measurements report in order to estimate an appropriate transmission power. A concept of priority grouping is introduced in [9] where demanded traffic load and power requirements are both considered and used to categorize UE in order to be assigned for a suitable cell. Energy-efficient Game-based Power Control (EGPC) algorithm is proposed in [2] based on game theory where power transmission is adjusted independently without inter-cell communication between BSs when each BS tries to maximize its utility function based on updating the power selection strategy. Based on Channel Quality Indicator (CQI) parameter, an autonomous power control scheme is introduced in [10]. A CQI-based scheme differs from conventional schemes because it takes users’ various services types into consideration with distributed power assigning, and there is no need for coordination between femtocells. Dynamic Power Control Algorithm (DPCA) was introduced by authors in [11] with objective of maximizing the system throughput of enterprise femtocell networks. DPCA adjusts transmission power for femtocells dynamically based on collected reports containing measurements about UEs and locations information. Estimating pathloss based on provided information from associated UEs and the femtocells network is employed by proposed cost index function, which is utilized in order to achieve optimal transmission power for femtocells according to [12]. The authors in [13] proposed Adaptive Smart Power Control Algorithm (ASPCA) and combined it with frequency reuse schemes to alleviate interference with disabling signaling overhead among cells.

In this work, Dynamic Transmission Power Adjustment (DTPA) scheme is proposed. DTPA adjusts deployed adjacent femtocells downlink transmission power level to enhance capacity as well as mitigate interference raised due to co-channel deployment. Each deployed femtocell has a degree of impact that causes interference to adjacent femtocells. Consequently, this proportion of impact rate is used to generate a cost function. Cost function is the basic reduction amount of downlink transmission power level that should be considered by each femtocell. Each femtocell generates its own cost function autonomously. Based on that femtocell decides an appropriate downlink transmission power level so that better capacity can be achieved. Also, interference to adjacent femtocells could be mitigated.

The rest of this paper is organized as follows. In section II, the system model is represented including prerequisites measurements. Section III includes clarification regarding DTPA algorithm. The experiment results of DTPA effectiveness is compared with other schemes and demonstrated in section IV. A conclusion of this work is given in the last section.

II. MODELING AND ANALYSIS

A dense co-channel deployment of femtocell system located in macrocell is considered in this work. The co-interference between femtocells is shown in figure 1. LTE Heterogeneous network comprising of macrocell and demtocells in indoor environment is considered in this work. Femtocells are connected with each other through Femto-gateway (FGW) entity and communicate with FGW over S1 Interface. Dense deployment of femtocells is considered in order to improve network performance and increase capacity.

Calculating path loss between a macrocell and its associated MUEs as well as calculating the path loss between femtocell and its associated FUEs are used in order to estimate the SINR for both MUEs and FUEs, respectively. The path loss model for outdoor MUE is given by [15]:

\[
\text{PathLoss}_{dB} = 15.3 + 37.6 \log_{10}(R) \quad (1)
\]

whereas, the path loss model for indoor MUE is determined as follows:

\[
\text{PathLoss}_{dB} = 15.3 + 37.6 \log_{10}(R) + L_{ow} \quad (2)
\]

where \((R)\) is the distance in meters between receiver and transmitter and \(L_{ow}\) is the penetration loss caused by outdoor wall. The path loss between femtocell and its associated FUE is given according to the following equation[15]:

\[
\text{PathLoss}_{dB} = 38.46 + 20\log_{10}(R) + 0.7d_{2D, \text{ indoor}} + 18.3n^{(n+2)/(n+1)-0.46} + W * L_{iw} \quad (3)
\]
where $W$ is the number of separating walls between FUE and femtocell base station and $n$ is the number of penetrated floors. $L_{iw}$ is the penetration loss caused by walls separating apartments, and $0.7d_{2d,\text{indoor}}$ is considered in meters and it is penetration loss caused by walls inside the apartments.

The model of path loss when outdoor FUE is associated with indoor femtocell base station is given according to the following equation [15]:

$$
PathLoss_{dB} = \max(15.3 + 37.6 \log_{10}(R), 38.46 + 20\log_{10}(R)) + 0.7d_{2d,\text{indoor}} + 18.3(n/(n+2)/(n+1) - 0.46) + W * L_{iw} + L_{ow}
$$

(4)

Now received value of SINR form macrocell UE MUE $i$ on subcarrier $s$ is considered in order to evaluate the throughput of the system while neighboring macrocells and closed femtocells are interfering MUE $i$ on subcarrier $s$. In this case, estimating SINR is given as [14]:

$$
SINR_{i,s} = \frac{P_{m,s} G_{i,m,s}}{\sum_{m'} P_{m',s} G_{i,m',s} + \sum_{F} P_{F,s} G_{i,F,s} + N_0 \Delta f}
$$

(5)

where $P_{m,s}$ and $G_{i,m,s}$ are the transmitting power for serving macrocell $m$ on subcarrier $s$ and the channel gain between serving macrocell $m$ and MUE $i$ on subcarrier $s$. $P_{m',s}$ and $G_{i,m',s}$ are the transmitting power for neighboring macrocells $m'$ on subcarrier $s$ and the channel gain between neighboring macrocells $m'$ and MUE $i$ on subcarrier $s$. $P_{F,s}$ and $G_{i,F,s}$ are the transmitting power for neighboring femtocell $F$ on subcarrier $s$ and the channel gain between neighboring femtocell $F$ and MUE $i$ on subcarrier $s$. $\Delta f$ is subcarrier spacing and $N_0$ is white noise power spectral density. The received SINR form femtocell UE FUE $j$ on subcarrier $s$ is estimated with consideration of interference caused by serving macrocell and all other adjacent femtocells and given by [14]:

$$
SINR_{j,s} = \frac{P_{F,s} G_{j,F,s}}{\sum_m P_{m,s} G_{j,m,s} + \sum_F P_{F',s} G_{j,F',s} + N_0 \Delta f}
$$

(6)

where $P_{F,s}$ and $G_{j,F,s}$ are the transmitting power for serving femtocell $F$ on subcarrier $s$ and the channel gain between serving femtocell $F$ and FUE $j$ on subcarrier $s$. $P_{m,s}$ and $G_{i,m,s}$ are the transmitting power for serving macrocell $m$ on subcarrier $s$ and the channel gain between serving macrocell $m$ and FUE $j$ on subcarrier $s$. $P_{F',s}$ and $G_{j,F',s}$ are the transmitting power for neighboring femtocell $F'$ on subcarrier $s$ and the channel gain between neighboring femtocell $F'$ and FUE $j$ on subcarrier $s$.

The channel gain is by the UE position whether it is indoor or outdoor and it is given as [14]:

$$
G = 10^{-PathLoss/10}
$$

(7)

The practical capacity of UE $u$ on subcarrier $s$ can be expressed as [14]:

$$
C_{u,s} = DF \log_2(1 + \alpha SINR_{u,s})
$$

(8)

where $\alpha$ is target BER and in this work BER is set to $10^{-6}$. The total throughput is calculated and given by [14]:

$$
Throughput = \sum_u \sum_s \beta_{u,s} C_{u,s}
$$

(9)

where $\beta_{u,s}$ reports whether UE $u$ is assigned subcarrier $s$ or not. $\beta_{u,s} = 1$ when subcarrier $s$ is assigned for UE $u$, otherwise $\beta_{u,s} = 0$.

III. DYNAMIC TRANSMISSION POWER ADJUSTMENT ALGORITHM

In this work, Dynamic Transmission Power Adjustment (DTPA) scheme is proposed to enable femtocell deciding appropriate transmission power level autonomously. The proposed transmission power control scheme DTPA is compared with two different present schemes.

The first one is proposed in [5], and it is based on constant coverage of the femtocell according to femtocell radius $r$. In addition, transmission power received from a macrocell is considered in order to set femtocell transmission power. The following expression is used in order to specify femtocell transmission power:

$$
P_F = \min(P_M - PL_M(D) + PL_F(r), P_{max})
$$

(10)

where $P_M$ is macrocell transmit power and $G_\theta$ is antenna gain. $PL_M(D)$ and $PL_F(r)$ are macrocell path loss at distance $D$ and femtocells path loss at radius $r$, respectively.

The second scheme is called Utility-Based Power Control (UBPC) and proposed in [7]. In this scheme femtocell periodically resets its transmission power in order to reach demanded SINR value so that femtocell can adjust its transmission power according to the converging power control algorithm, which is expressed as:

$$
P_{(k+1)} = \frac{SINR_t}{SINR_c} P_k
$$

(11)

$SINR_t$ is the target SINR value and $SINR_c$ is the current SINR value. $P_k$ is the transmission power level in the $k$th iteration time. The algorithm would not converge in the case that the resulting transmission power level exceeds the maximum transmission power level.

In DTPA power control algorithm, femtocells autonomously adjust their downlink transmission power to enhance throughput by alleviating co-interference among femtocells. Unplanned dense deployment of femtocells increases interference.
affecting network performance and throughput. The challenge arises here when each femtocell aims to adjust its transmission power in a way that it mitigates co-interference and achieves as good throughput as possible. To adapt this issue, each femtocell is stimulated to consider the interference proportion, which is caused to adjacent femtocells and use this rate as cost function.

Let \( N_1^n \) be a set of all femtocells where \( F_{\text{total}} \) is the total number of femtocells and \( F_{\text{total}} = n \). For each \( f_i \in N_1^n \) there is an \( I_i \) set, which is a set of all femtocells that cause interference to femtocell \( f_i \). From \( \Theta_1^n = [I_1, I_2, I_3, ... I_n] \) we can derive \( \theta_i \) set that contains the number of frequent occurrences for each \( f_i \) in \( \Theta_1^n \). Specifically, \( \theta_i \) includes frequencies amount for each femtocell \( f_i \in N_1^n \) occurs in \( \Theta_1^n \). Now, \( \theta_i \) indicates the total number of femtocells interfered and affected by \( f_i \) in range of \( \lambda_i \) which is determined by:

\[
\lambda_i \geq \pi((\alpha \cdot r_i)^2)
\]

where \( r_i \) is the actual radius of femtocell \( f_i \) and \( \alpha \) is a constant assumed and given based on:

\[
\alpha \geq 2.5
\]

Each femtocell \( f_i \) has maximum level of downlink transmission power \( P_{i[\text{max}]} \) that should not be exceeded. The Transmission power level is varied among femtocells \( [f_1, ..., f_n] \) based on cost function \( \Omega \) rate. The downlink transmission power level \( P_i \) for each femtocell \( f_i \) is decreased when cost function \( \Omega_i \) is increased. The degree of cost function \( \Omega_i \) is affected by the number of femtocells interfered by \( f_i \) and they form \( \theta_i \) based on \( \lambda_i \) domain. The rate of cost function is given by:

\[
\Omega_i = \frac{\theta_i}{F_{\text{total}}}
\]

Finally, each femtocell \( f_i \in N_1^n \) is enabled to decide its appropriate downlink transmission power level based on the interference amount that it causes to other adjacent femtocells within \( \lambda_i \) region. Now, the downlink transmission power level for each femtocell \( f_i \in N_1^n \) is given by:

\[
P_i = P_{[\text{max}]} - (P_{[\text{max}]} \ast \Omega_i)
\]

The pseudo code of the DTPA algorithm is explained as the following procedure and steps.

### IV. SIMULATION AND NUMERICAL RESULTS

The system model presented in the second section of this work is simulated using MATLAB. The simulation parameters, which are considered in the simulation experiment, are listed in Table I.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrocell Radius (( r_m ))</td>
<td>500 m</td>
</tr>
<tr>
<td>Femtocell Radius (( r_f ))</td>
<td>5 m</td>
</tr>
<tr>
<td>Frequency</td>
<td>2 GHz</td>
</tr>
<tr>
<td>Macrocell Transmission Power ( P_m )</td>
<td>46 dBm</td>
</tr>
<tr>
<td>Maximum Femtocell Transmission Power ( P_{f,max} )</td>
<td>21 dBm</td>
</tr>
<tr>
<td>Outdoor Walls Loss ( L_{ow} )</td>
<td>15 dB</td>
</tr>
<tr>
<td>Indoor Walls Loss ( L_{iw} )</td>
<td>7 dB</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Subcarrier Spacing</td>
<td>15 kHz</td>
</tr>
<tr>
<td>White Noise Power Density</td>
<td>-174 dBm/Hz</td>
</tr>
</tbody>
</table>

The deployment of the femtocells follows \( (5 \times 5 \) grid model)[16] where a building of single floor comprises of 25 adjacent apartments and the size of each apartment is 100 \( m^2 \). \( 5 \times 5 \) grid model is demonstrated in figure 2.

The femtocell HeNodeB is placed at the center of each apartment and each femtocell is associated with at least one indoor FUE. Macrocell is offloading indoor UEs to femtocells and the system examines the capacity each time the number of femtocells is increased. Throughput is the comparative
metric used to compare proposed scheme with two other schemes. It is a medium achievable data rate of UEs during simulation run. The proposed scheme is indicated as DPTA. DTPA is compared with two different schemes indicated as constant-range and SINR-based.

The cell average throughput is demonstrated and given in Fig. 3. It clearly shows that the throughput is increased when more femtocells are added to the system. The presented improvement of the macrocell is because the macrocell offloads its associated indoor users to the femtocells. DTPA and SINR-based show similar throughput, but as the number of femtocells increased in the system DTPA delivers better throughput. Constant-Range approach is the worst approach compared to the other approaches. Also, DTPA mitigates the influence of the interference, which causes degradation of the system performance, better than other compared approaches.

The unfavorable impact and affect of co-interference with dense deployment of femtocells at indoor environment is demonstrated in Fig. 4. This figure demonstrates the average throughput of femtocells network with no consideration of macrocell throughput. It depicts the undesirable influence of the interference on the femtocells network. The throughput of the network is decreased when more femtocells are inserted into the system. In this case, the interference can not be avoided but alleviated. DTPA is the best approach that can preserve its throughput when it is compared to other approaches. The Constant-Range approach performs better with more inserted femtocells and can preserve similar throughput level compared to SINR-based approach. However, SINR-based performs better than Constant-Range when the number of femtocells is not large.

The estimated additional throughput when macrocell offloads users to femtocells is demonstrated in Fig. 5. This figure shows the expected amount of throughput that can be gained by the system when macrocell offloads indoor users to the femtocells. The gain is improved when more femtocells are considered. The gain varies among the approaches of femtocell power adjustment. DTPA performs better with more inserted femtocells. Also, DTPA delivers gain close to SINR-based when the number of inserted femtocells is not large. Also, DTPA overcomes both SINR-based and Constant-Range approaches and delivers better gain throughput. Constant-Range can deliver better gain with considering large number of femtocells compared to SINR-based. In another hand, SINR-based performs better when less number of femtocells is considered and can deliver better gain compared to Constant-
Mitigating interference is a significant issue that should be considered with femtocell network employment. In this work, femtocell with dynamic transmission power scheme is presented based on a consideration of co-channel femtocells deployment. DTPA scheme allows femtocells adjust their downlink transmission power autonomously and dynamically based on pre-calculated cost function unit. Also, it assists femtocell network to alleviate the impact of the interference on the femtocell network. In addition, DTPA imposes assessment rate on each femtocell based on its interference impact that it produces to adjacent femtocells, so each femtocell adjusts its downlink transmission power with consideration of mitigating interference impact on adjacent femtocells. Moreover, DTPA attempts to preserve acceptable level of network capacity as much as it possible.

The proposed algorithm is compared with two different schemes. The conducted simulation results demonstrate the preponderance of the proposed scheme over other schemes. The direction of the future work is to combine power control management mechanism and frequency partitioning mechanism to accomplish better femtocell network environment.

REFERENCES