Autonomous Transmission Power Adjustment Strategy for Femtocell Base Station

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Summary

Femtocells have recently been recognized for their potential to boost network capacity, improve end-user QoS and throughput, and do so at a cheap cost and with ease of implementation. The use of femtocells in indoor environments, such as residential buildings with neighboring homes, is becoming more popular. Femtocells are subject to interference from other femtocells, and the unwanted effects of interference are amplified when femtocells are deployed in close proximity to one another. As a consequence, the network's overall performance is degraded to a significant degree. One of the strategies that is thought to be effective in reducing the impact of interference is altering the transmission power of the femtocells. In this paper, a dynamic downlink transmission power of femtocells is suggested. In accordance with the observed cost function unit, each femtocell automatically changes its transmission power. If a femtocell causes too much interference for its neighbors, its transmission power level will be limited by that interference's rate. A simulation experiment is conducted to validate the effectiveness of the suggested system when compared with other schemes. When compared to previous schemes, which are addressed in this study, the numerical results show that the proposed strategy could provide more capacity while also ideally mitigating the influence of interference among co-channel deployed femtocells.

Keywords:
Femtocells, Interference, LTE, Power Control.

1. Introduction

The high demand for high levels of quality of service (QoS) and throughput, which has been raised by users of Long Term Evolution (LTE) and other wireless networks, has increased to the point that mobile operators have been obliged to develop unique ways in order to expand coverage, boost data rates, and lower operational costs while running their mobile networks. In LTE, a macrocell, also known as an eNodeB, may be used to increase and extend coverage ranges, particularly in outdoor regions. However, it is ineffective in an indoor setting and at cell edge locations. Low Signal to Interference plus Noise Ratio (SINR) is experienced by the indoor UE due to high penetration loss, resulting in reduced capacity and unsatisfactory Quality of Service (QoS) performance. Furthermore, it has been shown that the majority of the demand for high throughput is coming from indoor User Equipment (UE) [1]. This presents significant issues for network operators in terms of improving the quality of service (QoS) and throughput of UEs in indoor zones. Therefore, both business and research have attempted to enhance quality of service (QoS) in interior environments when UE suffers poor connection conditions to macrocells [2]. Small Cell Network (SCN) technology has emerged as a viable alternative that can both enhance cell throughput while also providing high quality of service (QoS), as a consequence of this. Additionally, small cells have the potential to improve cell coverage and network efficiency.

Femtocells, also known as femto base stations or Home eNodeB (HeNodeB), are small wireless devices that leverage a user's Internet connection to connect to the operators' core networks as backhaul for data transmission. In general, femtocells are deployed by users with minimal power transmission and a short distance between the receiver and the transmitter to improve their communications. The spectrum band may be used by both femtocells and serving macrocell, or a separate frequency band can be used by either macrocell or femtocell. The unplanned deployment of large numbers of femtocells is a serious challenge. When femtocells and macrocells use the same frequency band, cross-tier interference occurs between the macrocell and the femtocells. Co-tier interference between neighboring femtocells occurs as a result of the sharing of a frequency band between adjacent femtocells. Because of the negative effect that interference has on network performance, it is necessary to address and handle the problem of interference reduction. Various methods of interference mitigation, such as radio resource partitioning and handover event management, are available for managing interference. Additionally, controlling the transmission power of HeNodeB is a critical key aspect of limiting the effect of inter-cell and intra-cell interference. The primary goal of controlling the downlink transmission power is to reduce the power so that unnecessarily high levels of transmission power may be avoided, hence reducing the effect of interferences.

Interference and power control challenges of femtocell deployment have been extensively explored in the current literature. The performance of LTE femtocell networks

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installed in a single macrocell has been investigated in [3] using a variety of power management methods. The effects of network performance and co-channel interference on uplink and downlink capacity are explored in [4] and [5], respectively. According to [5], a power control algorithm that validates constant femtocell radius has been proposed to autonomously control the HeNodeB downlink transmission power based on received downlink power from the macrocell in order to overcome macrocell-femtocell co-channel deployment and reduce the associated interference. Furthermore, in [6], the number of indoor UEs and the number of handover events are taken into consideration and analyzed in order to be utilized for calculating and changing the HeNodeB transmission power.

Article [7] introduces a utility-based method based on the soft value of the SINR, in which femtocell transmission power is modified in a distribution way and calculated based on the SINR measurement received. In [8], the authors proposed an algorithm in which the femtocell transmission power is automatically set based on the interference measurements obtained by the user equipment (UE). The femtocell collects interference measurements and reports them in order to determine a suitable transmission power. It is stated in [9] that a concept of priority grouping is utilized to classify UEs in order to allocate them to an appropriate cell, taking into account both the expected traffic load and the power requirements. In [2], authors introduce a method based on game theory. It is energy-efficient Game-based Power Control (EGPC). In this scheme, power transmission is independently adjusted between BSs without inter-cell communication in order to optimize the utility function of each BS by changing the power selection strategy. An independent power control strategy is introduced in [10]. It is based on the Channel Quality Indicator (CQI) parameter value. .A CQI-based strategy differs from conventional strategies because it considers UEs' services types into consideration and adjusting transmission power according to them. In this there is no need for collaboration among distributed femtocells.

In [11], the Dynamic Power Control Algorithm (DPCA) was developed with the goal of increasing the system throughput of corporate femtocell networks. DPCA dynamically adjusts transmission power for femtocells based on collected reports, which comprise measurements about user equipment (UEs) and geographic position information. According to [12], the suggested cost index function uses information from related UEs and the femtocells network to estimate pathloss. This information is then used to achieve optimum transmission power for femtocells by using the information from the femtocells network. Adaptive Smart Power Control Algorithm (ASPCA) was introduced by the authors in [13]. It was paired with frequency reuse techniques in order to decrease interference caused by removing signaling overhead among cells.

In this paper, a dynamic transmission tower adjustment mechanism is introduced to aid femtocell base station determining proper transmission power level dynamically. The downlink transmission power level of installed neighboring femtocells is adjusted by the proposed mechanism in order to increase capacity while also mitigating interference caused by co-channel deployment. Each installed femtocell has a certain level of effect that creates interference to neighboring femtocells. As a result, the cost function is generated using the proportion of the effect rate that has been determined. Each femtocell should take into account the cost function, which is the basic degree of decreasing the downlink transmission power level. Autonomously generated cost functions are generated by each individual femtocell. The femtocell determines a suitable downlink transmission power level on the basis of this information, allowing for increasing the network capacity. It is also possible to reduce interference with neighboring femtocells.

The remainder of this paper is arranged in the following manner. Section two depicts the system model, which includes the measurements that are required as a precondition. The DTPA algorithm is explained in further detail in Section three. In section four, the efficiency of DTPA is verified and it is compared with other schemes.

The last section of this paper provides the conclusion of this work.

2. System Model

In this paper, a dense co-channel deployment of a femtocell system within a single macrocell coverage is taken into consideration. As seen in figure 1, the co-interference between femtocells is presented. In this paper, a LTE-Advanced heterogeneous network, which composes a macrocell and femtocells that are operating in an indoor environment. Femtocells are linked to one another by the Femto-gateway (FGW) entity, which communicates with the femtocells over the S1 Interface protocol. Dense deployment of femtocells is being studied in order to enhance network performance and capacity. Calculating the path loss between a macrocell and its associated MUEs, as well as calculating the path loss between a femtocell and its associated FUEs, are both utilized to estimate the SINR for MUEs and FUEs, respectively, when estimating the SINR for MUEs. The path loss for outdoor microcell UE is calculated as follows [15]:

$$PathLoss_{dB} = 15.3 + 37.6\, log_{10}\,(R) \qquad (1)$$

While the path loss model for indoor UEs is given as follows:

$$PathLoss_{dB} = 15.3 + 37.6\, log_{10}\,(R) + L \qquad (2)$$

(R) represents the distance between the transmitter and the receiver in meter. L represents the penetration loss caused by the wall.

The received SINR is modeled as follows [14]:

$$SINR_{i,s} = \frac{\gamma_{m\ ,s}\ G_{i,m,s}}{\sum_{m'} \gamma_{m',s}\ \ G_{i,m',s} + \sum_{F} \gamma_{F,s}\ \ G_{i\ ,F,s} + N_0\,\Delta f} \quad (3)$$

the transmitting power for serving macrocell m on subcarrier s and the transmitting power for adjacent macrocells m$'$ on subcarrier s are represented by $\gamma_{m\ ,s}$ and $\gamma_{m',s}$, respectively. The channel gain is indicated by $G_{i,m,s}$, where m represents serving macrocell, i represents macrocell's UE, and s represents received subcarrier. The channel gain $G_{i,m',s}$ indicates interfering signal received from adjacent macrocell, where m$'$ represent adjacent macrocell, i represent UE, and s represents the subcarrier. Also, in case of receiving interference from femtocells, which are adjacent to macrocell's UE i, $\gamma_{F,s}$ indicates femtocell's F transmission power on subcarrier s, and $G_{i\ ,F,s}$ indicates gain of received subcarrier s. Spacing of subcarrier is indicated by $\Delta\, f$ and white noise power spectral density is indicated by N_0 .

Also, the channel gain of an UE is expressed by [14]:

$$Gain = \ 10^{-\,PathLoss/10} \qquad (4)$$

The estimated capacity of any UE u on any subcarrier s is given as follows [14]:

$$C_{u,s} = \ \Delta f\ log_2\left(1 + \ \alpha\, SINR_{u,s}\right) \qquad (5)$$

here α indicates BER. In this work, its target is considered to be $10^{-\,6}$. The cell overall throughput model is expressed as follows [14]:

$$Throughput = \sum_{u} \ \sum_{s} \ \ \beta_{u,s}\ \ C_{u,s} \qquad (6)$$

where $\beta_{u,s} = 1$ if particular subcarrier s is allocated to UE u; otherwise it is set to be $\beta_{u,s} = 0$.

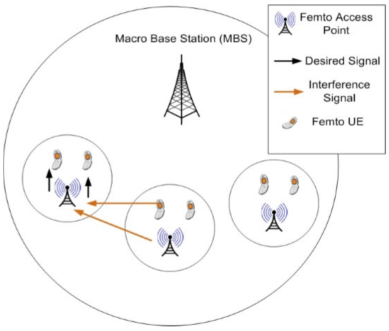

Fig. 1 Co- channel interference between femtocells [14].

3. The Proposed Solution

In this work, Dynamic Transmission Power Adjustment mechanism is introduced to aid femtocell base station determining proper transmission power level dynamically. The introduced transmission power control scheme is compared with two different mechanisms.

One of them has been introduced in [5], and it is based on constant extend of the femtocell base staion according to femtocell radius r. Additionally, downlink transmission power, which is received from a macrocell base station, is considered, so femtocell downlink transmission power can be properly adjusted. The femtocell transmission power is specified according to the following expression:

$$P_F = min(P_M + G_\theta - PL_M(D) + PL_F(r), P_{max}) \qquad (7)$$

where P_M is macrocell transmit power and G_θ 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 mechanism is the Utility-Based Power Control (UBPC). It has been introduced in [7]. In this mechanism femtocell base station cyclically readjusts its downlink transmission power to reach required SINR rate. In that femtocell can adapt its downlink transmission power based on the converging power control algorithm. It is expressed as follows:

$$P_{k+1} = \frac{SINR_t}{SINR_c} \quad p(k) \qquad (8)$$

$SINR_t$ is the target SINR level and $SINR_c$ is the current SINR level. P_k is the downlink transmission power degree in the kth iteration time. If the resulting transmission power level exceeds the maximum transmission power level the mechanism would not converge in the case.

In the proposed power control technique, femtocells autonomously control their downlink transmission power to increase throughput by reducing co-interference among femtocells. The unplanned dense deployment of femtocells causes interference, which has a negative impact on network capacity and performance. Femtocells must deal with the problem of co-interference and maximizing throughput at the same time when they attempt to adjust their downlink transmission power. The problem is addressed by enabling each femtocell to take into account the interference percentage caused to neighboring femtocells and to utilize this rate as a cost function.

Let $N_1{}^n = [f1, f2, f3, \ldots fn]$ be a set, which includes all femtocells operated in the network. Accordingly, F_{total} would be the total number of femtocells and F_{total} = n. For each $fi \in N_1{}^n$ there would be a Ii. Now, a set Ii includes all femtocells that generate interference to femtocell fi. A group of all Ii , which were computed would form a new set $\Theta^n{}_1$. This would be like $\Theta^n{}_1 = [I1, I2, I3, \ldots In]$. From the previous generated set $\Theta^n{}_1$, we would derive another set, which is θi . Each θi set includes the number of frequent occurrences for each fi in $\Theta^n{}_1$. Specifically, θi includes frequencies amount for each femtocell $fi \in N_1{}^n$ occurs in $\Theta^n{}_1$. Therefore, θi denotes the total number of femtocells interfered and impacted by fi in extend of λi which is determined as follows:

$$\lambda_i \geq \pi((\alpha * r_i)^2) \qquad (9)$$

where r_i denotes the radius of femtocell fi and α is a constant value, which is assumed as follows:

$$\alpha \geq 2.5 \qquad (10)$$

Each femtocell fi in the system can operate with a preset maximum level of downlink transmission power ($P_{[max]}$). Femtocell base station should not exceed this preset maximum downlink transmission power. The downlink transmission power level for each femtocell base station is varied among femtocells $[f1 \ldots fn]$ operated in the system. The cost function Ω rate is used to adjust downlink transmission power for each femtocell base station. As a result, the downlink transmission power Pi for a femtocell fi is reduced when computed cost function Ωi is increased. The computation of cost function Ωi would be impacted by the total number of femtocells interfered by fi . They form θi set according to λi domain. The rate of cost function is computed according to the following formula:

$$\Omega_i = \frac{\theta i}{F_{total}} \qquad (11)$$

Finally, each femtocell $fi \in N_1{}^n$ is empowered to adopt its suitable downlink transmission power level based on the interference measure that it introduces to other neighboring femtocell base stations within predefined λi region. Accordingly, the downlink transmission power level for each femtocell $fi \in N_1{}^n$ is computed as follows:

$$P_i = P_{[max]} - [P_{[max]} * \Omega_i] \qquad (12)$$

The pseudo code of the proposed algorithm is given as follows:

Algorithm 1 Proposed Mechanism

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$N_1{}^n = [f_1, f_2, f_3, \dots f_n]$
$F_t = n$
$\Theta^n{}_1 = [I_1, I_2, I_3, \dots I_n]$
While $i \leq n$ do
  While $j \leq n$ do
    If $D_i \leq \lambda_i$ && $i$ =! $j$ then
        $I_i \leftarrow f_j$
    End If
  End While
End While
While $x \leq n$ do
   For $y \leq n$ do
      If $\Theta(x, y) == x$ && $x$ =! $y$ then
            $\theta_x \leftarrow \theta_x + 1;$
      End If
   End For
    $\Omega x = \frac{\theta x}{F_t}$
    $Px = P_{\lceil max \rceil} - [P_{\lceil max \rceil} * \Omega x]$
  End While
END
```

4. Simulation and Numerical Results

The system model, which is introduced in this work, is simulated using MATLAB tool. Table 1 depicts the simulation parameters, which are considered in the conducted simulation experiment.

Table 1: Simulation Parameters

Parameter	***Value***
Macrocell radius	500 m
Femtocell radius	5 m
Frequency	2 GHz
Macrocell power P_m	46 dBm
Maximum Femtocell power $P_{f,max}$	21 dBm
Wall Loss	15 dBm, 7 dBm
Bandwidth	20 MHz
Subcarrier spacing	15 KHz
White Noise Power Density	-174 dBm/Hz

The femtocell base stations are deployed according to (5 × 5 grid model) [16]. In this scenario a building includes about 25 adjacent apartments with size of 100 m^2 for each apartment. The considered grid is depicted in figure 2.

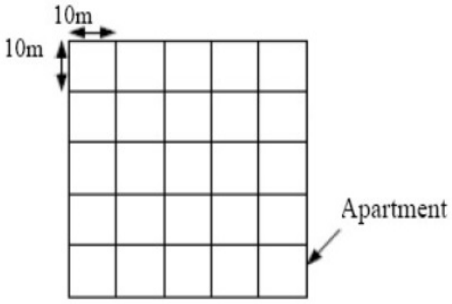

Fig. 2 (5 by 5) grid model [16].

In each apartment, a femtocell HeNodeB is installed in the middle of the building, and each femtocell is linked to at least one indoor FUE. The macrocell is offloading indoor UEs to femtocells. The system assesses the capacity of the system once more femtocells is inserted to the system. Throughput is the comparison measure that is used to compare the proposed method with two other schemes. The proposed mechanism is identified as DPTA. We compare DTPA with two other approaches: one using a constant range, the other SINR-based.

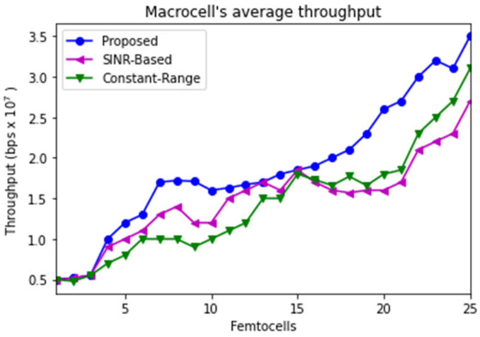

Fig. 3 Cell average throughput.

In figure 3, the average throughput of each cell is displayed and provided. It clearly demonstrates that increasing the number of femtocells in the system results in higher over all cell average throughput. The reason for the presented improvement in the macrocell's throughput is that the macrocell offloads its related indoor users to the femtocells. DTPA and SINR-based mechanisms show similar throughput. However, DTPA provides better throughput when the number of inserted femtocells is increased. When compared to the other techniques, the Constant-Range strategy is the least effective. In addition, DTPA outperforms other techniques in terms of mitigating the impact of interference, which reduces the system's performance.

Figure 4 depicts the adverse impact and effect of co-interference with dense deployment of femtocells in an indoor scenario. This figure illustrates the average throughput of only a femtocell network without taking into account the throughput of macrocells. It displays the unfavorable impact of the interference on the femtocell network's performance and reliability. When additional femtocells are added to the network, the overall throughput of the network decreases. In this scenario, interference cannot be prevented, but it may be mitigated. To preserve average throughput, DTPA is the best mechanism compared to other mechanisms. The Constant-Range mechanism operates better with more inserted femtocells and can maintain similar average throughput level compared to SINR-based mechanism. However, when the number of femtocells is low, SINR-based operates better than Constant-Range. However, when the number of femtocells is low, SINR-based operates better than Constant-Range.

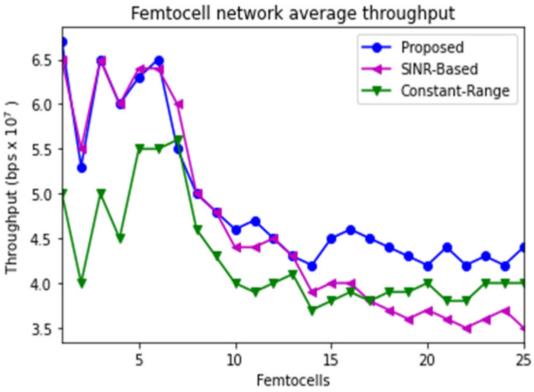

Fig. 4 Femotcell network average throughput.

As illustrated in Fig. 5, the expected increase in throughput when a macrocell offloads users to femtocells is presented. The projected amount of throughput that may be obtained by the system when the macrocell offloads indoor users to the femtocells is shown in this figure. When more femtocells are taken into consideration, the gain is increased. The gain varies depending on which technique is used to adjust femtocell downlink transmission power. DTPA functions better when there are more femtocells inserted. For low inserted femtocells, DTPA gains are comparable to that obtained with SINR-based technique. Additionally, DTPA outperforms both SINR-based and Constant-Range techniques in terms of gain throughput while delivering higher gain. When a large number of femtocells are taken into consideration, constant-range may provide a superior gain than SINR-based. However, SINR-based approach performs better when a smaller number of femtocells is considered, and they may yield higher gains when compared to the Constant-range technique.

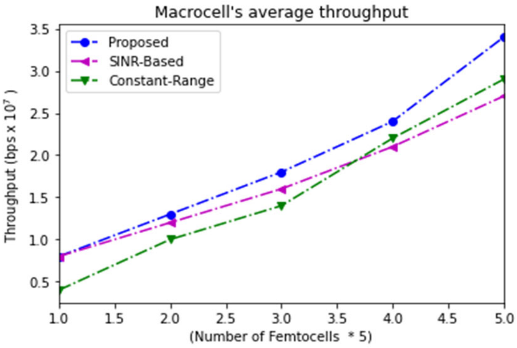

Fig. 5 Estimated additional average throughput.

3. Conclusion

Interference mitigation is a crucial problem that should be taken into consideration while deploying a femtocell network. In this paper, a femtocell with a dynamic transmission power strategy is given, which takes into account the deployment of co-channel femtocells. According to the DTPA scheme, femtocells may dynamically and independently adjust their downlink transmission power in accordance with a previously computed cost function value. Additionally, it supports the femtocell network in minimizing the effect of the interference on the femtocells network. Additionally, the DTPA imposes an assessment rate on each femtocell based on the interference impact that it produces to adjacent femtocells. As a result, each femtocell adjusts its downlink transmission power with consideration of mitigating interference impact on adjacent femtocells. This would reduce the overall interference impact on the network. Furthermore, DTPA makes every effort to maintain an adequate level of network capacity.

The suggested method is compared to two different approaches. Based on the results of the simulations, it is clear that the suggested method outperforms the other mechanisms. The goal of the future study is to link the power control management mechanism with the frequency partitioning mechanism to achieve a better femtocell network environment in the future.

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