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Soft Computing Based Power Control for Interference Mitigation in LTE Femtocell Networks

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Abstract

In heterogeneous networks (HetNet), transmit power control at Femtocell Access Point (FAP) is a major problem in reducing cross-tier interference, where providing better Quality of Service to femtocell users should be taken into account. Two novel transmit power control methods using soft computing techniques are introduced to tune the transmission power of femtocell access point with respect to the instantaneous Channel Quality Indicator measurement report received from the user equipment. Data rate of femtocell user is analyzed with fixed transmission power and the same with neuro-controller tuned and fuzzy logic controller tuned transmission power of serving femtocell access point. Simulation result verifies the effectiveness of the proposed power control methods by showing a significant improvement in data rate of user even at femtocell edge. Hence the femtocell users’ QoS is improved, even the femtocell access points are deployed at middle coverage area of macrocell and the same may lead to improvement in overall network capacity.

Keywords: Femtocells, power control, heterogeneous networks, cross-tier interference, LTE, interference mitigation

1. Introduction

Multi-fold growth in global mobile traffic is anticipated in coming years and research study from various mobile experts verifies the same. To meet this rapid growth of mobile data demand, cellular network topology is shifting

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from homogeneous to heterogeneous. In heterogeneous networks (HetNets) femtocells complementing macro cells to improve throughput, coverage and user experience explicitly at indoors\(^1\). Femtocell Access Points (FAPs),foreseen as a cost efficient indoor coverage solution, serve as low-power, short range base station that are overlaid on the macrocell networks. Since it connects users to the core service network by making use of high speed broadband connections such as DSL, cable modem, it can provide improved coverage and increased throughput for home users, while off-loading traffic from expensive macrocell radio access networks onto the low-cost public internet. Overlaying femtocells on macrocells will improve spatial reuse and spectral efficiency. Moreover, they will provide power and battery savings due to the short range of transmission.

In spite of these benefits, fruitful launch of femtocell technology is not yet achieved in a full-fledged manner. The key technical challenge is interference management in the two-tier femtocell networks\(^2\). Compared to the orthogonal deployment, co-channel deployment is more attractive in these heterogeneous network settings as it can offer a much higher spectral efficiency. Here, the critical issue of signal interference arises as femtocell user equipments (FUEs) utilize the spectrum already allocated to the macrocell user equipments (MUEs)\(^3\). It is therefore imperative to mitigate the interference imposed on the users. Furthermore, the access mode in which femtocells operate is also a main cause of interference. Operators cannot manage femtocell interference using the classic centralized frequency planning/optimization, because they do not know the exact number and position of femtocells and may not own the femtocell backhaul. Hence, the development of distributed radio resource management techniques is necessary to handle femtocell interference.

Third Generation Partnership Project (3GPP) has recommended smart power control\(^4\) settings to mitigate the interference to the macro user from the FAP based on measurements such as the strongest receiving power of FAP from interfering Macrocell Base Station (MBS) and the reference signal received power (RSRP) information received from the nearest MUE. Chandrasekhar et al proposed a non-cooperative game-theoretic uplink utility based power control\(^5\). H.B.Jung and D.K. Kim addressed the power control of femtocells based on min-max fairness\(^6\) and a simple bisection method to reduce the complexity of Channel Side Information (CSI) exchange is also treated. Dong-Chan Oh et al had advocated power control with transmit beamforming\(^7\) to address the said problem. Beamforming code book restriction strategy\(^8\) and beam subset set selection strategy\(^9\) along with opportunistic channel selection are proposed for interference management in the femtocell networks. Joint allocation of resource blocks and transmit powers\(^10\) is also investigated for the downlink transmission of Orthogonal Frequency Division Multiple Access (OFDMA) based femtocells. Apart from this game theory based Cognitive Radio Resource Management (CRRM) schemes\(^11\) were also under investigation to handle the interference in an effective manner. Most of the existing solutions have inherent complexity and signaling overhead problem.

Nonetheless, application of soft computing techniques to perform power control of FAP transmission power is not discussed in previous works. This work proposes two novel power control methods to tune the FAP transmission power using soft computing techniques. Neuro-controller (NC) and fuzzy logic controller (FLC) are suggested to tune the FAP transmission power. Expecting enormous promotion of LTE femtocell in near future, this work considers interference management in the said network and simulation parameters specific to LTE are exercised. Achieved data rate of femtocell user under cross-tier interference signal from MBS 200m away is obtained, provided his serving FAP transmits at fixed, NC tuned and FLC tuned transmit power. Simulation results verify the effectiveness of the proposed methods by showing significant improvement in the data rate of the femtocell edge users.

LTE femtocell network system model considered in this work is detailed in section 2. In section 3, the proposed soft computing based power control for enhancing the achieved data rate of femtocell user is described. Simulation results and concluding remarks are presented in section 4 and 5 respectively.

2. System Model

Consider the downlink of a two-tier wireless network, in which \(N_f\) newly deployed femtocells share the available radio spectrum with one existing macrocell which have coverage region \(\mathbb{M}\). It assumed that each femtocell is serviced by one FAP and denote the set of all FAPs as \(F=\{F_1,F_2,\ldots,F_{\#},\ldots,F_N\}\). Since femtocell APs are deployed randomly in densely populated areas, the distribution of FAPs is assumed to be a homogeneous Spatial Poisson Point Process (SPPP) \(\Phi\). Let FAPs are distributed in each macrocell with intensity \(\varphi\) and it is considered to be the
spatial density. It is expressed as the average number of FAPs per unit. The average number of FAPs in a macrocell coverage region is equal to $\phi$. The FAPs are assumed to provide closed access service to registered indoor users who fall within the range of each femtocell coverage area. The total system bandwidth $B$ is divided into orthogonal sub-carriers, which in turn are combined into $N_p$ sub-channels (SCs) or Resource Blocks (RBs). A RB is the coarse unit of radio resource that can be assigned to a user; in other words, it is the basic time-frequency unit corresponding to 0.5 ms and 180 KHz frequency band. Each SC has a sub-carrier spacing frequency. A proportional fair scheduler is employed to assign the available SCs among $N_m$ macro users and $N_f$ FAPs. Each user (macrocell / femtocell) is allocated with only one sub-channel $p$, containing OFDM symbols, in each frame. A perfectly synchronized OFDMA network is assumed. FAPs may be deployed in middle service area of macrocells primarily for offloading the congested mobile traffic. Since the MBS operates at a much higher transmit power compared to the FAP, the MBS transmission causes interference to the downlink reception at the FUE, especially if the FAP is not very far from the MBS. Hence, under shared SC assignment, the transmission from the FAP to the FUE is inflicted by downlink signal transmission from MBS. In other words, with an assignment of a same SC $p$ by MBS and FAP to MUE and FUE respectively, the transmission from MBS creates cross-tier interference on FUE.

Let $P_{tm}$ and $P_{tf}$ represent the transmit power of MBS and FAPs respectively. Then, the received signal at the FUE $f_i$ from the serving FAP on SC $p$ is given by

$$y_{fi}^p = S_{fi}^p + I_{M}^p + I_{Fj}^p + N_o$$  \hspace{1cm} (1)

Where $S_{fi}^p = P_{fi} H_{fi}^p$ is the desired signal received by the user from its serving FAP $F_i$. $I_{M}^p = P_{m} H_{im}^p$ denote the interference signal from the MBS $M$. $I_{Fj}^p = \sum_{j=1}^{N_f} P_{j} H_{ij}^p$ is the interference signal from $N_f$ nearby co-channel FAPs and $N_o$ is the AWGN power spectral density. Here $H_{fi}^p$ implies link gain between the FAP $F_i$ and the FUE $f_i$ on SC $p$. Similarly $H_{im}^p$ and $H_{Fj}^p$ represent the link gain of interference respectively from MBS and nearby co-channel FAPs $F_j \in \mathcal{F}$ impose on the femtouser $f_i$. Hence, the signal-to-interference-plus-noise ratio (SINR) of femtouser $f_i$ on SC $p$ is given by

$$\Gamma_{fi}^p = \frac{S_{fi}^p}{I_{M}^p + I_{Fj}^p + N_o}$$  \hspace{1cm} (2)

Now, the data rate $R_{fi}$ achieved by the femto user $f_i$ with $N_f$ SCs assigned to carry information is given by

$$R_{fi} = B \Delta f \sum_{N_f} \log_2 (1 + \alpha \Gamma_{fi}^p)$$  \hspace{1cm} (3)

where $\alpha = -1.5 \ln(5BER)$ is a constant for a target bit error rate (BER). Let $SRB$ is the number of subcarriers per resource block, $R_b$ is the number of resource blocks, $b_s$ is the number of bits per symbol. Here, bandwidth $B = N_{sf} b_s$, where $N_{sf} = \frac{SRB R_b}{N_f}$ the number of subcarriers per femtocell users.

In LTE, the Channel Quality Indicator (CQI) is a measure of downlink radio channel quality that specifies the best modulation constellation and coding rate to match the link quality. The value of this one is computed such that the transport block error rate will not exceed 10%\textsuperscript{12}. The higher the value of the CQI measure, the higher the
modulation order and the higher the coding rate. In a typical link adaptation process at sub-frame \((n)\), the downlink BS forms the resource grid from the user data Physical Downlink Shared Channel, (PDSCH) and the Downlink Control Information, (DCI) in the Physical Downlink Control Channel (PDCCH). The DCI contains the scheduling assignments that help the UE correctly decode the sub-frame information. The information contained in the PDCCH includes the modulation and coding schemes (MCS), the precoder matrix, rank information, and the MIMO mode used. The UE can then perform the critical step of channel condition measurement as part of the process of decoding the received resource grid. In this process, it estimates channel quality measurements that include the CQI, the precoder matrix estimation (PMI), and the rank estimation (RI). In this work CQI alone is considered in data rate estimation. As part of uplink transmission, the UE may embed the channel quality measures within the PUCCH and transmit to the BS as a closed-loop feedback mechanism. The base station can then decode the PUCCH information to obtain channel measurements. In fact, this information available enables the system scheduler to decide whether or not to adapt various system parameters in the next frame as a result of feedback received from downlink channel quality. At the base station in the downlink transmitter operations for the next subframe \((n+1)\), the scheduling decisions and the new MCS allocated based on channel conditions are encoded into the PDCCH information and transmitted to the mobile terminal.\(^\text{12}\)

3. Neuro-controller and Fuzzy Logic Controller based FAP Transmit Power control

Soft computing, basically an optimization technique, is the fusion of methodologies that were designed to find solutions to nondeterministic polynomial time (NP) complete problems and has the capability to exploit the given tolerance if imprecision, partial truth and uncertainty in the given information. They derive their power of generalization from approximating or interpolating to produce output for unknown inputs from previously learned inputs. Among the various soft computing techniques, application of neural networks and fuzzy logic are considered in this work. Based on the periodic / aperiodic CQI report from UE, the proposed Neuro-controller (NC) and Fuzzy Logic Controller (FLC) tunes the transmit power of FAP to mitigate the cross-tier interference from high power MBS and thereby protects its users in terms of better data rate.

3.1. Neuro-controller for FAP Transmit Power Control Strategy

An artificial neural network, which is a parallel data processing system that has learning and self-organizing ability, can be used for tuning the \(P_{tf}\). The proposed Neuro-controller is a feed-forward neural network which is trained for SINR to CQI mapping using BFGS Quasi-Newton back propagation learning algorithm. The feed forward neural network developed consists of one neuron in the input layer, eight neurons in the hidden layer and one neuron in the output layer. RSRP and RSRQ are also used in addition to the CQI for tuning the \(P_{tf}\). The structure of the proposed Neuro-controller is shown in Fig.1.

![Fig. 1 Structure of Neuro-Controller to tune FAP transmit power](image)

3.2. Fuzzy Logic Controller for FAP Transmit Power Control

Fuzzy Logic controller (FLC) is an expert system using ‘If-then’ rules. It could simultaneously work with numerical data and can trigger several rules which lead to smooth control of the \(P_{tf}\). The block diagram of the FLC is shown in Fig.2.
Initially, the input CQI and the output $P_{if}$ are mapped to the appropriate membership function and truth values. Five different membership functions viz. very low, low, moderate, high and very high are assigned and fuzzy rules relevant to perform the FAP transmit power control are framed. In general, FLC includes three basic steps: (1) Fuzzification of input-output to the appropriate membership functions and truth values. (2) Fuzzy inference is performed by selecting appropriate rules, estimate the output of each and aggregate the outcome of the chosen rules. (3) Defuzzification is done to obtain to obtain a specific output value. In this work, a mamdani fuzzy inference system is used. The fuzzy rules which are framed to tune $P_{if}$ have been given in Table 1.

Table 1. Fuzzy Rules Framed to tune $P_{if}$.

<table>
<thead>
<tr>
<th>CQI</th>
<th>$P_{if}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>Very High</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Very High</td>
<td>Very low</td>
</tr>
</tbody>
</table>

4. Simulation Results

The HetNet considered in this work consist of a single macrocell with MBS located at its centre, FAPs are deployed at the middle coverage area of the macrocell and the femtocell users are at the indoor. The simulation parameters are listed in Table 2.

Table 2. Simulation Parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Bandwidth</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Number of subcarriers per RB</td>
<td>12</td>
</tr>
<tr>
<td>Number of RBs</td>
<td>100</td>
</tr>
<tr>
<td>Modulation</td>
<td>64 QAM</td>
</tr>
<tr>
<td>Target BER</td>
<td>$10^6$</td>
</tr>
<tr>
<td>FAP Transmit Power</td>
<td>100mW</td>
</tr>
<tr>
<td>MBS Transmit Power</td>
<td>20W</td>
</tr>
<tr>
<td>Penetration loss of outer wall</td>
<td>20 dB</td>
</tr>
<tr>
<td>Penetration loss of inner wall</td>
<td>5dB</td>
</tr>
<tr>
<td>Noise PSD</td>
<td>-174 dBm</td>
</tr>
</tbody>
</table>
At least one wall penetration loss along with shadow fading loss may be included in any victim femtocell users’ link gain calculation. Since MBS transmit power $P_{tm}$ is high, QoS of the macrocell user won’t get affected at the middle coverage area of the macrocell and the same is not treated in this work. Sharing of SCs between the macrocell and the femtocell is presumed. In order to calculate the link gain path loss models recommended by 3GPP in\(^3\) is applied. It is assumed that there is no interference from nearby FAPs (i.e. $N_f = 0$). Initially, SINR of the femtocell user with respect to the distance from his serving FAP, which is deployed 200m away from the assailant MBS, is obtained. Then the achieved data rate of the user with fixed $P_{tf}$, NC tuned $P_{tf}$ and FLC tuned $P_{tf}$ are simulated. The simulation results verify the effectiveness of the proposed NC and FLC tuned $P_{tf}$ by showing significant improvement in achieved data rate of the femtocell user. Plot related to percentage of data rate of the user at every 5m from his serving FAP for the above said three cases is also verifies the same.

![Achieved Data Rate of Femtocell user with interfering MBS at 200m away](image1)

Fig. 3 Achieved Data rate of femtocell user with interfering MBS at 200m away

The achieved data rate of femtocell user with respect to the distance from their serving FAP is shown in Fig. 3. With fixed $P_{tf}$, only the femtocell user in close proximity to his serving FAP can achieve higher data rate ($\approx 3$ m). If he moves away the data rate reduced drastically due to the interference from the high power MBS and he may face call drop / termination of service from 10m onwards. But, if the $P_{tf}$ is tuned by the Neuro-Controller (NC) or Fuzzy Logic Controller (FLC) which is suggested to be included in FAPs, then the data rate improves significantly by both the controllers. Even though, with FLC tuned $P_{tf}$ it seems the femtocell user achieve better data rate, there might be a change in $P_{tf}$ continuously under high mobility condition of the user. But, with NC tuned $P_{tf}$ the femtocell users can achieve a reasonable and constant data rate, even at the cell edge. Hence it can be concluded that NC can perform better Transmit Power control more efficiently. The % of the data rate achieved by the femtocell user at 1m, 5m, 10m, 15m, 20m, 25m and 30m from his serving FAP, for the above said three cases also shown in Fig. 4 for illustrating the improved data rate of the user with the proposed controller tuned $P_{tf}$.

![Percentage of Data Rate of Femtocell user with interfering MBS 200m away](image2)

Fig. 4 Percentage of Data Rate of Femtocell user with interfering MBS 200m away
At the femtocell edge (from 20m to 30m), the user can achieve 30% data rate with NC tuned $P_f$, whereas it is only 18% with FLC tuned $P_f$. Hence Neuro-controller transmit power control is better than FLC to provide a stable data rate, even at the cell edge.

5. Conclusion

In this work, downlink communication in the two-tier LTE-femtocell network is considered and soft computing based FAP transmission power control strategy, which includes Neuro-controller tuned $P_f$ and FLC tuned $P_f$, is proposed. The performance of the proposed power control strategy is evaluated using system level simulation and compared with the fixed FAP transmission power. Under shared subchannel usage, the data rate achieved by the femtocell users with respect to the distance from their serving base station is simulated. The observation of deterioration in data rate with fixed FAP transmission power indicates the impact of interference and addresses the need for an efficient interference mitigation strategy for improving the QoS perceived by the users. The proposed NC tuned and FLC tuned transmission power control methods provide significant performance improvement in terms of achieved data rate at very low FAP transmission power. The percentage of the data rate of users verifies the efficiency of the proposed method. Additionally, comparing the performance of the above controllers in tuning the FAP transmission power, it can be concluded Neuro-controller performs constant and better QoS than the fuzzy logic controller. Since the proposed method uses only the local CSI available at the FAP, there might not be any signalling overhead problem. In fact, the Neuro-controller employed for adjusting the $P_f$ leads to the minimization of downlink transmission power independently at every FAP and the same can be considered as a remarkable self organizing network (SON) feature, which is a prime requisite widely accepted for the success of the femtocell technology.

References