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NEURAL NETWORKS BASED ADAPTIVE SMALL CELL BASE STATION TRANSMIT POWER CONTROL FOR INTERFERENCE MITIGATION IN HETEROGENEOUS NETWORKS

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Abstract

Heterogeneous networking of small cells such as pico/femtocells over the existing macrocell network is believed to augment the data rate requirement in forthcoming years. Closed access operation of femtocell base station (FBS) and shared spectrum assignment in the two-tier macro-femtocell network leads to unacceptable deterioration in achieved data rate of femtocell users. In this work, application of computationally efficient neural network to perform adaptive FBS transmit power control is proposed for mitigation of interference in two-tier heterogeneous network formed by macro-femtocells and to improve the Quality of Service perceived by femtocell users. A Neuro-controller is designed to regulate the FBS transmission power based on the channel quality indicator measurement report sent by user equipment. Since the proposed power control strategy employs the channel side information already available in the existing network, there would not be any signaling overhead to mitigate the co-tier interference. Simulation results validate the effectiveness of the proposed power control strategy which provides significant improvement in achieved data rate of femtocell users and prevents them from outage.

Keywords:

Heterogeneous Networks, Small Cells, LTE, Neural Networks, Interference Management, Power Control

1. INTRODUCTION

Heterogeneous network (HetNet), in which installation of miniaturized low power short range, plug and play type small cell base stations such as pico/femtocell is a promising and economical solution to cater for augmenting the data rate requirements particularly at indoors. Femtocell Base Stations (FBSs) denoted as Home eNode Base station (HeNB) in the Third Generation Partnership project (3GPP) terminology, are overlaid on the existing macrocells and connected to the mobile operator's core network via a wired / wireless Internet Protocol backhaul [1].

There exist many challenges for successful implementation of FBSs massively in urban and suburban areas, and interference management in two-tier macrocell femtocell network is a prime issue that needs addressing to reap the benefits of femtocell technology. There is a lack of sufficient coordination between macrocell base station (MBS) and FBSs mainly due to issues related scalability, security and limited availability of backhaul bandwidth. Additionally, due to the mode of operation and ad hoc deployment nature of FBSs, interference management in such networks faces many practical challenges. In this work we have considered the co-tier interference, where the provoker (e.g. an FBS) and the victim (e.g. a nearby FBS's user) belong to the same tier [2]. Unlike macrocell networks, where the careful placement of base stations alleviates inter-cell interference, the impact of the said interference is severe in terms of degradation of achieved user data rate.

In much of the previous works, many power control algorithms were proposed such as distance based power control [3], utility based power control [4], smart power control [5], max-min fairness based power control [6], adaptive sensing based power control [7] and range based transmission power control [8]. Zhang et al. has proposed joint subchannel and power allocation scheme for OFDMA femtocells [9]. Self-organization and power control using Q-learning-based distributed power allocation algorithm [10] have been proposed to maintain the QoS of macrocell users. In these two studies, the intra-tier inter-femtocell interference is ignored, whereas the cross-tier interference is fixed. Though such assumptions help to remarkably simplify the analysis, they are often not the case in practice. Leanh et al. attempted game theory based distributed power and channel allocation for cognitive femtocell network [11].

Rangan and Madan [12] have proposed Belief propagation (BP) framework for interference coordination and resource allocation (scheduling) optimization problem with femtocell networks. But implementation of BP for distributed optimization problems entails high computational complexity and communication overhead. In [13], a multichannel and multi antenna based cross-tier interference coordination using beamforming codebook restriction strategy along with an opportunistic channel selection has been proposed to improve the aggregate throughput of two-tier femtocell network. Similarly, orthogonal random beamforming with a beam subset selection that can provide spatial opportunity to the femtocells and distributed power control strategies are treated in [14]. However, beamforming techniques incur additional hardware complexity and extra cost.

As LTE wireless networks are being designed to improve spectral efficiency and high date rate, LTE based femtocells are expected to gain more market in near future, and the same has been considered in this work. The main contribution of this work is an adaptive transmit power control strategy, which is not related directly or indirectly to the existing methods discussed above. Initially, Signal-to-Interference-plus-Noise Ratio (SINR) of femtocell users in the heterogeneous network environment is modeled, and Channel Quality Indicator (CQI) based adaptive transmit power control is implemented using neural networks.

The performance of the proposed method is validated by estimating the achieved data rate of femtocell users with respect to the distance between them and their serving base station. The proposed neural network based adaptive FBS transmit power control method can be implemented with available local information only, and hence there would not be any signaling overhead.

The rest of the paper is organized as follows. System model along with interference scenarios in two-tier macro-femtocell network is detailed in section 2. In section 3, the proposed Neural networks based adaptive transmit Power control is described. In section 4, simulation results and validation of the proposed method are presented and section 5 provides conclusion.

2. SYSTEM MODEL

In this work, downlink communication in the two-tier LTE-based femtocell network that consists of FBSs overlaid on a single macrocell with MBS located at the center of the coverage region, providing a cellular coverage radius R_m is considered. Each FBS has coverage radius R_f, serves a maximum of N_f femtocell users, and there are N_m active macrocell users. Therefore, totally $N_u = N_m + N_f$ users exist in the two-tier network considered here.

Let $M = \{m_1,m_2,\ldots,m_i,...,m_{N_m}\}$ represents the set of macrocell user equipment (MUE), $F = \{F_1,F_2,\ldots.,F_i,\ldots,F_{NF}\}$ represents the set of FBSs overlaid on the macrocell considered and $F_u = \{f_1,f_2,\ldots f_i,\ldots f_{NF}\}$ represents the set of femtocell user equipment (FUE), each one of them served by their corresponding FBSs. Hence, the whole UE set considered here is $U = M \cup F_u$. FBSs are preferably located at the cell edge of MBS to provide better indoor signal to the users, and it is assumed that all FBSs, whose coverage overlap and are operating in closed access mode, restricting unauthorized users to get connected with any particular FBS.

Since LTE based femtocell network is considered, the total system bandwidth B is divided into number of subcarriers N_{sc}, which are grouped into N subchannels (SCs) for multi-carrier transmission of information. Each SC has Δf sub carrier spacing frequency. The set of orthogonal SCs assigned by base stations to their associated users depends on availability of spectrum. The greater number of SCs assigned to any user, the higher the modulation and coding scheme used in the subcarriers, and the higher the achieved data rate. Any particular SC and number of the same the users assigned at a given point of time depend on the scheduling mechanism used.

Here, it is assumed that each user is assigned with at least one SC and a proportional fair scheduler is used to assign SCs to users depending upon their minimum data rate requirement R_{min}. Due to sharing SCs between the macrocell and femtocell tier, there is a greater chance for assignment of same SC to multiple UEs in nearby femtocells, at any particular instant of time. By this, co-tier interference may arise, and the Quality of Service (QoS) perceived by the femtocell users, particularly at cell edge may be deteriorated. With an assignment of a same SC n by MBS and FBSs to MUE and FUE respectively, the transmission from MBS causes cross-tier interference on FUE (marked as B in The Fig.1).

Apart from this, under the massive deployment of FBSs in sub-urban environment, there is overlap in coverage of nearby FBSs. On assignment of same radio resources by FBSs to their corresponding FUE, the transmission from the nearby FBS may instigate co-tier interference, when a non-registered FUE appears within its service range. Illustration of downlink co-tier interference scenario C in femtocell networks is shown in Fig.2.

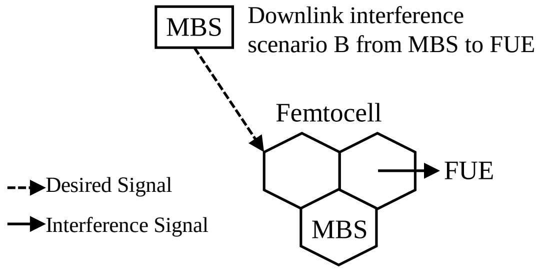

Fig.1. Downlink Cross-tier interference scenario B in femtocell networks

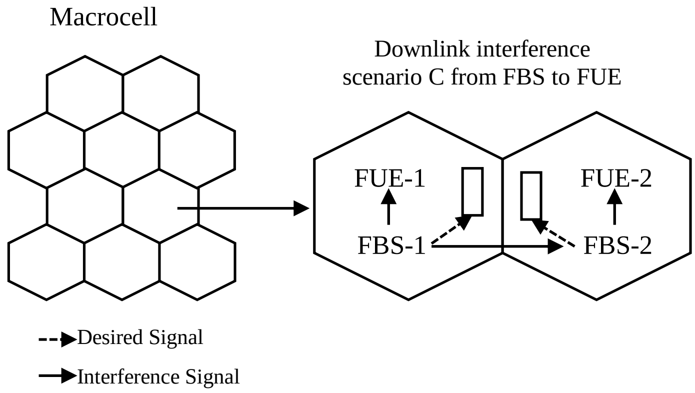

Fig.2. Downlink co-tier interference scenario C in femtocell networks

This kind of co-tier interference greatly influence the performance observed by users in terms of poor data rate [15]. The received signal y_{fi}^n at the FUE f_i from serving FBS on SC n is given by

$$y_{fl}^n = S_{fi}^n + I_M^n + I_{Fj}^n + N_o \tag{1}$$

where $S_{fi}^n = P_{tf} H_{Fi}^n$ is the desired signal received by the user from its serving FBS F_i, $I_M^n = P_{tm} H_{iM}^n$ denote the interference signal from the MBS M, I_{Fj}^n is the interference signal from nearby co-channel FBSs and it is given by

$$I_{Fj}^n = \sum_{\substack{j=1 \\ j \neq i}}^{N_{f_1}} P_{tf} H_{Fj}^n \tag{2}$$

Here, N_o is the additive white Gaussian noise (AWGN) power spectral density. Here, H_{Fi}^n implies link gain between the FBS F_i and the FUE f_i on SC n. Similarly, H_{iM}^n and H_{Fi}^n represents the link gain of interference respectively from MBS and nearby co-channel FBSs $F_j \in F$ imposed on the femtouser f_i. Hence, the signal-to-interference-plus-noise ratio (SINR) of femtouser f_i on SC n is given by

$$\Gamma_{fi}^n = \frac{S_{fi}^n}{I_M^n + I_{Fj}^n + N_o} \tag{3}$$

Now, the data rate R_{fi} achieved by the femtocell user f_i with N_1 SCs assigned to carry information is given by

$$R_{fi} = B\Delta f \sum_{N_1} \log_2 \left(1+\alpha F_{fi}^{n}\right) \tag{4}$$

where Δf is sub-carrier spacing frequency and α = -1.5/ln(5BER) a constant for a target bit error rate (BER). Here, bandwidth $B = N_{nf} \cdot b_s$, where N_{nf} is number of subcarriers per user, b_s is number of bits per symbol. Then Number of subcarriers per user $N_{nf} = N_{RB}.R/N_f$, where N_{RB} is number of subcarriers per resource block and R is number of resource blocks. Now, the overall data rate of serving FBS F_i is given as

$$R_{Fi} = \sum_{f_i}\sum_{n} R_{fi} X_{fi}^{n} \tag{5}$$

where $X^n f_i$ is the binary variable that indicates SC assignment to a particular femtouser. In case, $X^n f_i = 1$ means that the SC n is assigned to FUE f_i, otherwise $X^n f_i = 0$.

3. ADAPTIVE FBS TRANSMIT POWER CONTROL STRATEGY

In LTE networks, based on the downlink reference signal measurement, UE estimates the CQI and sends it as a feedback to the MBS as an indication of data rate which can be supported by the downlink channel. Depends upon the CQI, the MBS may select modulation and coding scheme and transport block size for the next sub-frame transmission. CQI is computed such that the transport block error rate will not exceed 10% [16]. Moreover, CQI is not just corresponds to the SINR the UE experiencing, it is the function of the ratio of the interference of the own base station compared with others. When the UE is close to the base station, a high CQI value is reported, and respectively, it is understood that low CQI reporting by the UE indicates that it is close to the cell edge as most of the interference comes from the nearby cells.

In this work, to perform adaptive FBS transmit power control, which can be considered as a downlink power control problem, a Neuro-controller is designed. In LTE, measurement of Reference Signal Received Power (RSRP), Received Signal Strength Indicator (RSSI) and Reference Signal Received Quality (RSRQ) that provides the signal strength metric, the cell-specific signal quality metric and total received wideband power respectively are available. They are utilized in addition to the CQI measurement report, which is fed as input to the Neuro-controller. The Neuro controller adjusts the FBS transmit power based on the CQI report received from UEs and performs subchannel power allocation accordingly to reduce the co-channel interference affected by the user f_i, during the previous sub-frame transmission.

The proposed Neuro-controller is a feed-forward neural network (Multilayer Perceptron) that is trained using the Quasi-Newton Backpropagation algorithm, which is an alternative of conjugate gradient method for fast optimization. Even though it requires more computation in each iteration and more storage, it generally converges in little iteration [17].

Another very important parameter of neural network is the selection of the activation function. Since the input neurons do not process any information, identity function is chosen as the activation function. For function approximation, hyperbolic tangent is used as activation function of hidden neurons, while a linear activation function is used in the output. It should be remembered that any function may be approximated to an arbitrary degree using one hidden layer itself, but over fitting can occur if there are too many hidden units. The said neural network has an input layer, a single hidden layer, and an output layer. Block diagram of the Neuro-controller is shown in Fig.3. CQI, RSRP, RSRQ, RSSI and received interference power are fed as input to the Neuro-controller, whereas the adjusted FBS transmit power is the output of the same.

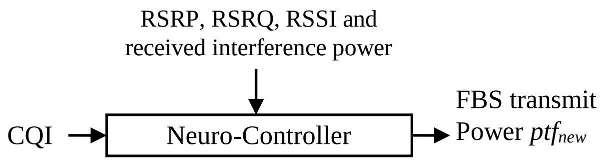

Fig.3. Block Diagram for Intelligent FBS Transmit Power Control

4. ADAPTIVE FBS TRANSMIT POWER CONTROL STRATEGY

A HetNet system level simulation is performed to analyze the performance of the proposed adaptive FBS transmit power control strategy. Since LTE based femtocell network is considered in this work, simulation parameters relevant to LTE network are utilized, and the same are listed in the Table.1.

Table.1. Simulation parameters

Parameter	Values
Carrier frequency	2 GHz
System bandwidth	20 MHz
Number of subcarriers per RB	12
Number of RBs	100
Modulation	64 QAM
Target BER	10^{-6}
FBS transmit power	100mW
MBS transmit power	20W
Penetration loss of outer wall	20 dB
Penetration loss of inner wall 5	5dB
Noise PSD	-174 dBm
Number of macrocell user	50

The HetNet scenario used in this work assumes the MBS deployed in the center of the macrocell along with FBSs, macrocell users and femtocell users are randomly distributed. Initially, the SINR of the users is simulated for various interference scenarios discussed in section 2, and the same is used for estimating their achieved data rate with fixed transmission power P_{tf} and compared the same with the proposed Neuro-controller adjusted FBS transmission. The achieved data rate of femtocell users with respect to the distance from their serving base station has been evaluated. Additionally, the plots pertaining to the Neuro-controller adjusted P_{tf} is also presented.

The Fig.4 illustrates an improvement in the data rate of the femtocell user with Neuro-controller adjusted P_{tf}, in the case of one and two interfering nearby FBSs, whereas The Fig.5 explains the same in the case of three and four interfering FBSs. It is observed that with a greater number of interfering FBSs transmitting at fixed P_{tf}, the cell edge user (at the distance above 20m) would accomplish very poor QoS due to data rate less than 0.5 Mbps. However, with Neuro-controller adjusted P_{tf}, the data rate achieved is significantly improved, and even the cell edge user can achieve 2.69Mbps.

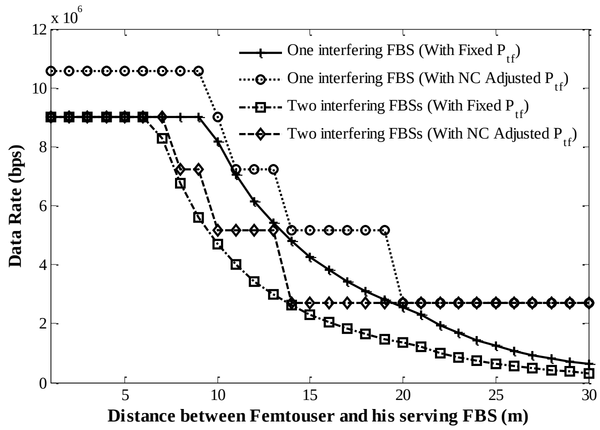

Fig.4. Achieved data rate of femtocell user with one and two numbers of interfering FBSs

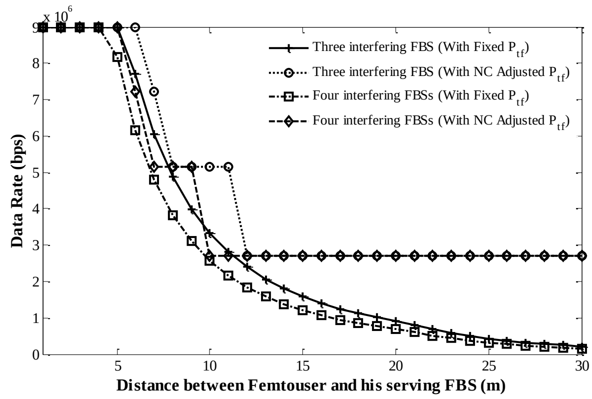

Fig.5. Achieved data rate of femtocell user with three and four numbers of interfering FBSs

The Fig.6 demonstrates the trade-off between the Neuro-controller adjusted P_{tf} and the number of interfering FBS.

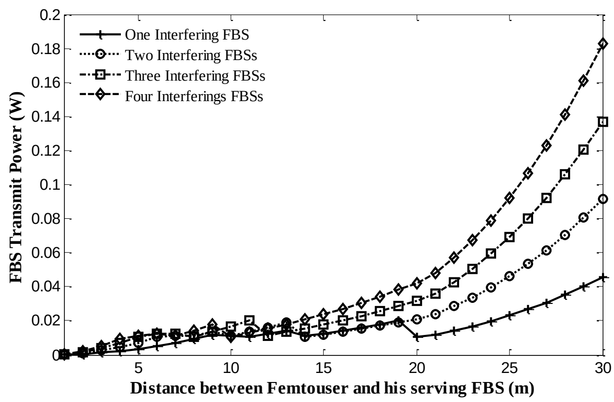

Fig.6. Neuro-controller adjusted FBS transmit power for the case of increasing quantity of interfering FBSs

It is apparent that FBS needs very low P_{tf} to serve users in close proximity (less than 10m). As the user moves far away from his serving FBS, the Pf_{tf} needs to be increased. Particularly, with a greater number of interfering FBSs alone high P_{tf} is required for serving femtocell edge users. However, employing a well distributed SC assignment strategy, the number of interfering FBSs can be controlled. With just one interfering FBS, which is the case that may happen frequently, the P_{tf} requirement is very low. Finally, it is noteworthy that femtocell users at a distance less than 12m can achieve a comparatively high data rate than that can be achieved from MBS. This fact confirms the benefit of using FBSs with low P_{tf} and makes the entire network energy efficient.

In fact, with already available periodic or aperiodic CQI measurement report, the Neuro-controller implemented in the FBSs needs to estimate P_{tf} and initiate the control signal associated with the same. Hence, no need of any additional message exchange between FBSs and MBS. Since the Neuro-controller is used computationally efficient and converging faster, there would not be any delay in computing the P_{tf}. Moreover, the Quasi-Newton Backpropagation training algorithm used for Neuro-controller converges in just 10 epochs with a mean square error of 10^{-1}. This verifies the accuracy and fastness in computing P_{tf}.

5. CONCLUSION

In this work, downlink communication in the two-tier LTE-femtocell network is considered, and a novel neural network based adaptive FBS transmission power control strategy is proposed. The performance of the proposed power control strategy is evaluated using system level simulation and compared with the fixed FBS transmission power. Under shared subchannel usage, the data rate achieved by the users with respect to the distance from their serving base station is simulated. The observation of deterioration in data rate with fixed FBS 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 FBS transmission power control method provides significant performance improvement in terms of achieved data rate at very low FBS transmission power. Additionally, the plot related to Neuro-controller adjusted FBS transmission power signifies the energy efficiency of the network considered. Since the proposed method uses only the local CSI available at the FBS, there might not be any signaling overhead problem. In fact, the Neuro-controller employed for adjusting the P_{tf} leads to the minimization of downlink transmission power independently at every FBS 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.

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