ETRI Journal, Volume 40, Number 3, June 2018
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# Application of Adaptive Neuro-Fuzzy Inference System for Interference Management in Heterogeneous Network

Padmaloshani Palanisamy and Nirmala Sivaraj

**Femtocell (FC) technology envisaged as a cost-effective approach to attain better indoor coverage of mobile voice and data service. Deployment of FCs over macrocell forms a heterogeneous network. In urban areas, the key factor limits the successful deployment of FCs is inter-cell interference (ICI), which severely affects the performance of victim users. Autonomous FC transmission power setting is one straightforward way for coordinating ICI in the downlink. Application of intelligent control using soft computing techniques has not yet explored well for wireless networks. In this work, autonomous FC transmission power setting strategy using Adaptive Neuro Fuzzy Inference System is proposed. The main advantage of the proposed method is zero signaling overhead, reduced computational complexity and bare minimum delay in performing power setting of FC base station because only the periodic channel measurement reports fed back by the user equipment are needed. System level simulation results validate the effectiveness of the proposed method by providing much better throughput, even under high interference activation scenario and cell edge users can be prevented from going outage.**

**Keywords: Adaptive neuro fuzzy inference system, Femtocells, Interference management, LTE, Transmission power setting, Power control.**

## I. Introduction

Application of intelligent control using soft-computing methodologies is already proved in industrial process control and robotics. But, the same has not yet explored well for wireless network application domain. This work attempts the application of Adaptive neuro fuzzy inference system (ANFIS) for interference management in femtocell networks. Mobile operators believe femtocell (FC) technology can handle ‘mobile data *Tsunami*’ in a cost-effective manner by offloading the voice and data traffic from the macrocell (MC) network on to the low-cost fixed broadband network in a transparent fashion and provide ubiquitous coverage to indoor users. Deployment of user installable femtocells over MC network in an ad hoc manner forms a two-tier heterogeneous network (HetNet). Femtocell Base Station (FBS) is a low power, short-range, plug-and-play type home base station (HBS). It gets connected to the core network via wired/wireless IP backhaul. Thanks to the proximity of the transmitter and mobile receiver that can provide high-quality voice and data service in the home or office environment [1]. Third Generation Partnership Project (3GPP) denotes femtocell as Home eNodeB (HeNB).

With the aim of achieving high spectral efficiency, sharing of radio resources between macrocell and femtocells is always preferred. However, such a kind of sharing of frequency bands in HetNet along with closed access mode functioning FBSs create strong cross-tier and/or co-tier interference (inter-cell interference (ICI)), which might cause a significant reduction in achieved throughput and outage of service in worse condition [2]. As there is uncertainty on the number of active FBSs and their place in user premises, the traditional centralized radio resource management (RRM) approaches were not applicable to handle interference problem in the FC networks.

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Manuscript received Sept. 16, 2017; revised Dec. 19, 2017; accepted Mar. 5, 2018.

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https://doi.org/10.4218/etrij.2017-0195

pISSN: 1225-6463, eISSN: 2233-7326

Most of the earlier work studied the problem using distributed power control methods [3]–[5], various complicated radio resource allocation schemes [6], [7] several energy efficient resource allocation schemes [8]–[10], cognitive RRM strategies using game theory [11], [12] and Fuzzy Q learning approach [13]. Nevertheless, existing methods incur huge computational complexity, signaling overhead and favoring only MC users. In the densely deployed FCs scenario, sharing of frequency bands among FCs independently may generate high ICI, which adversely affects the throughput of FC users. Hence, there is a need for decentralized dynamic ICI mitigation schemes that work independently on each cell, making use of only locally available information.

As a low power base station, FBS transmission power is an adjustable one. 3GPP release 10 [14]–[16] agrees that autonomous HeNB power setting is one straightforward way for coordinating ICI from HeNB to victim users. It is efficient in providing a good trade-off between mitigation of interference and the performance loss of FC user equipment (FUE). Additionally, this baseline solution has less impact on the network side specification. In [14] smart power control (SPC) for HeNB based on interference measurements proposed. Nevertheless, it yields poor performance under high interference activation scenario.

In this work, we propose a novel ANFIS controller based autonomous FBS power setting strategy for mitigation of interference from FBS to victim users. The main advantage of the proposed method is zero signaling overhead, reduced computational complexity and bare minimum delay in performing power setting of FBS, as it needs only the periodic channel measurement reports fed back by the user equipment. The system level simulation results show significant improvement in throughput attainment of cell edge users even under high interference scenario.

The rest of this paper organized with the following aspects: Section II describes the system model of Long Term Evolution (LTE) FC network. Section III explains the proposed autonomous power-setting algorithm and Section IV details optimization of FC transmission power setting using ANFIS controller. Section V presents the system level simulation description and the results obtained. Section VI briefs the concluding remarks.

## II. System Model

In this section, the system model of the LTE FC network considered is described. A dense-urban FC modeling considered in this work is detailed in Section V. Let $F = \{F_1, F_2, \ldots, F_i, \ldots, F_f\}$ denotes the set of $f$ closed access mode FBSs deployed in an FC block (dual strip apartments). For any FBS $F_i$, there is a set of $U_i = \{u_1, u_2, \ldots, u_i, \ldots, u_{Ji}\}$ FUE, where $|U_i| = J_i$ is the total number of users served by FBS $F_i$. The probability of active FBS in a given apartment is denoted as $P_{\text{act}}$.

In LTE, orthogonal frequency division multiplexed access (OFDMA) used as the air interface for downlink transmission. The total system bandwidth $B$ divided into orthogonal subcarriers, which in turn combined into $S$ sub-channels (SCs) or Resource Blocks (RBs), each having a bandwidth $B_{\text{RB}} = B/S$. Each SC has $\Delta f$ sub-carrier spacing frequency. Without loss of generality, we assume full buffer traffic. Therefore, the BSs always have data to send to its users. Let $\Psi = \{s_1, s_2, \ldots\}$ be the set of SCs, where $|\Psi| = S$, and its subsets $\Psi_{\text{m}}$ and $\Psi_{\text{f}}$ are the set of SCs allotted respectively to macrocell and FC tier (that is, $\Psi = \Psi_{\text{m}} \cup \Psi_{\text{f}}$). $|\Psi_{\text{m}}| = S_{\text{m}}$ SCs would be allotted to macrocell users by macrocell base station (MBS). Likewise, $|\Psi_{\text{f}}| = S_{\text{f}}$ SCs are assigned independently by the active FBSs to their registered users with equal probability. Due to a separate set of SCs dedicated to macrocell assumed, there is no possibility of cross-tier interference. On the other hand, assignment of SCs independently by active FBSs gives rise to ICI problem due to the usage of the same frequency resources during the same time interval in adjacent cells. ICI reduces the signal-to-interference-plus-noise-ratio (SINR) of the users and thereby degrades the overall system performance. Specifically, ICI affects the cell-edge users' performance due to propagation loss and UE proximity to the interfering cells. This work analyzes the system performance in terms of the SINR and achieved throughput.

### 1. Signal Quality and Throughput Modeling

On the allotment of same SC by more than one FBS to their users, the transmission of the nearby FBSs gives rise to co-tier (inter-FC) interference, when any non-registered FUE appears within their service range. To perform resource allocation, BSs need their users to periodically report the downlink channel quality measure based on SINR. Channel Quality Indicator (CQI) is one such measure used to obtain the SINR. Under the influence of interference from $f_1$ ($< f$) FBSs, the SINR of femtocell user $u_i$ on SC $s$ is given by

$$\Gamma_{ui}^{s} = \frac{p_{tFiui}^{s} H_{Fiui}^{s}}{\sum_{\substack{j=1 \\ j \neq i}}^{f_1} p_{tFj}^{s} H_{Fjui}^{s} + B_{\text{RB}} N_o}, \tag{1}$$

where $p_{tFiui}^{s}$ and $p_{tFj}^{s}$ represent the transmission power allocated by the serving BS $F_i$ and interfering BS $F_j$, respectively on SC $s$. In (1), the numerator term indicates the desired signal received by the user from its serving FBS $F_i$, whereas the denominator denotes the sum of the interference signal from nearby co-channel FBSs and $N_o$ Additive White Gaussian Noise (AWGN) power spectral density. Here, $H^s_{Fiui}$ implies link power gain between the FBS $F_i$ and the FUE $u_i$ on SC $s$, whereas $H^s_{Fjui}$ representing the link power gain of interference from nearby co-channel FBSs $F_j$ imposed on the FC user $u_i$. In order to estimate the link gain parameter, the channel model accounts for small scale Rayleigh fading, large scale path loss and log normal shadowing is considered. We assume that the path loss $PL(d)$ is identical on all SCs assigned to any particular UE and use the path loss models for urban deployments in [17] to estimate the same. Let $\Psi_{F1}$ ($\subset \Psi_{\mathrm{f}}$) be the set of $S_1$ SCs freely available for being allocation by the active FBSs to their users; $\Psi_{Fi}$ ($\subset \Psi_{F1}$) represents the set of $S_{Fi}$ SCs used by FBS $F_i$ and $\Psi_{Fiui}$ ($\subset \Psi_{Fi}$) be the set of $S_{Fiui}$ SCs allocated to the user $u_i$. Here, $S_1 \le S_{\mathrm{f}}$, $S_{Fi} \le S_1$, and $S_{Fiui} \le S_{Fi}$. Now, the throughput $R_{ui}$ achieved by the user $u_i$ with $S_{Fiui}$ SCs assigned by its serving FBS $F_i$ to carry information is as given by

$$R_{ui} = B_{\mathrm{RB}} \sum_{s=1}^{S_{Fiui}} \log_2(1 + \alpha \Gamma^s_{ui})\chi_{ui,s}, \tag{2}$$

where $\chi_{ui,s}$ is the binary indicator of SC assignment to a particular user, and $\alpha = -1.5/\ln(5BER)$ is a constant to target bit error rate (BER). Now, the overall throughput of serving base station $R_{Fi}$ is given by

$$R_{Fi} = \sum_{ui\in U_i} R_{ui} = B_{\mathrm{RB}} \sum_{ui\in U_i} \sum_{s} \log_2(1 + \alpha \Gamma^s_{ui})\chi_{ui,s}. \tag{3}$$

The achieved throughput per unit of transmitting power of user $u_i$ is measured in terms of power efficiency. In other words, the data sent per Joule can be measured in terms of energy efficiency. Without loss of generality, equal power allocation on SCs assumed. Hence, with $P_{tFiui} = S_{Fiui} \times p^s_{tFiui}$ transmission power allocated to the user $u_i$, the power efficiency $\gamma_{ui}$ [18] is given by

$$\gamma_{ui} = \frac{R_{ui}}{P_{tFiui}}\,\mathrm{b/s/W\,or\,b/J}. \tag{4}$$

### 2. FBS Power Setting Problem

Since the active FBSs allocate radio resources to their users independently with full frequency reuse, the downlink transmission signal from closed access type FBSs will generate a strong interference to nearby co-channel assigned femto users, causing a large degradation of their downlink SINR. Specifically, FBSs with large transmission power may cause significant interference to nearby co-channel operating users, leading to dropped calls for the connected users on same and adjacent channels. Therefore, the FBSs should have the ability to adjust its power autonomously and/or based on the measurement report from UE about interference and signal quality detected by them. The aim of the considered FBS power setting strategy is to maximize the throughput of FCs while satisfying the cell edge femto users' minimum throughput requirement simultaneously. Without loss of generality, it is presumed that all SCs are fully loaded that is, they are all assigned to FUE beforehand. Now, the considered FC users' throughput optimization problem can be formulated as

$$\text{maximize} \sum_{ui\in Ui} R_{ui}(p^1_{tFiui},\ldots p^{S_{Fiui}}_{tFiui},\chi_{ui,1},\ldots\chi_{ui,S_{Fiui}}), \tag{5}$$

$$\text{s.t.} \quad \Gamma^s_{ui} \ge \Gamma_{\mathrm{tar}};\forall u_i \in U_i, s \in \Psi_{Fiui}, \tag{5a}$$

$$\sum_{u_i\in U_i} \sum_{s\in\Psi_{Fi}} p^s_{tFiui} \le P_{tFi\max};\forall u_i \in U_i, \forall F_i \in F. \tag{5b}$$

Constraint (5a) represents that if the SC $s$ allocated to FUE $u_i$ in FBS $F_i$ for downlink transmission, the SINR of FUE $u_i$ should be higher than the target SINR $\Gamma_{\mathrm{tar}}$. Constraint (5b) means the total transmission power of FBS $F_i$ on its FUE should not exceed the maximum transmission power $P_{tFi\max}$. The optimization problem is non-convex with respect to the maximum transmission power of all FBSs, making it difficult to find the global optimum value for each FBS at a particular time instant. In fact, jointly optimizing all transmission powers is a challenging one and if we try to solve the problem using any direct search method, the convergence of optimal solution may require many iterations and the same incurs time complexity. Instead of solving the formulated optimization problem using traditional methods, we propose the application of soft computing techniques to calibrate optimal transmission power of FBS. Note that SC assignment is also a non-convex optimization problem, which needs to be handled exclusively. In order to minimize ICI and maximize user throughput, this work focus on optimizing FBS downlink power-setting rather than optimization of SC allocation, as the SC allocation schemes invite huge computational complexity and signaling overhead.

## III. Autonomous FBS Power Setting Algorithm

Indeed, application of intelligent control using soft-computing methodologies already proved in industrial process control applications and robotics. But, the same has not yet explored well for wireless network application domain. In HetNet, to maximize the network performance, each FBS transmits at the maximum power level. But, higher downlink transmission power of FBS will give rise to ICI, which affects the Quality of Service (QoS) of co-channel users. On the other hand, reducing transmission power would reduce coverage, and that would severely decline the desired signal level. Autonomous HeNB power setting solutions are effective in providing a good trade-off between mitigation of interference and the performance loss of FUE [14]. As the FBSs deployed randomly by users, their position and number of active FBSs at any instance of time are unknown. Hence, each FBS might selfishly fix the transmission power, which makes the power setting problem a non-convex one. Nonetheless, Optimal FC transmission power at each transmission time interval (TTI) is necessary to maintain QoS to all users in the network, and this necessitates a heuristic optimal power setting strategy. A traditional gradient based optimal power control method requires the computation of derivatives of the objective function and constraints. Though the derivatives can be easily obtained, the gradient based algorithm requires central processing unit, which needs channel side information from all FBSs.

We propose a distributed optimal FC power setting strategy using ANFIS controller to achieve a good balance between the FC coverage and nearby FC users' performance. Initially, we develop a fuzzy inference system (FIS) [18] through which expert knowledge integrated into the FBS power setting process. Since the fuzzy rules would produce only the approximate decision, ANFIS is developed for optimization and fine-tuning of FIS variables' membership functions (MFs). Moreover, the proposed algorithm is fully distributed, and it eliminates the computation of the derivatives. Altogether, this work proposes the application of ANFIS to perform distributed and autonomous power control in heterogeneous networks.

Indeed, HeNB typically set its transmission power by measuring surrounding RF conditions. Hence, with the intention of maximizing its performance, each FBS embedded with the proposed ANFIS controller in its power control section would self-optimize its transmission power and after that performs proportional fair scheduling and equal power allocation to augment the desired signal strength. Besides, the FBS must allocate adequate resources so as fulfilling the minimum rate requirement $R_{\text{req}}$ of its users.

Initially, this work decides the essential and locally available information as inputs to perform autonomous power control at FC. The first input is the periodic CQI sent by the UE to the BS [19], which is a parameter used to estimate the SINR of users. The second input is the Reference Signal Received Power (RSRP) per resource block – a cell-specific signal strength metric [20]. These two variables are locally available at the FBS in the uplink, and at the UE in the downlink, requiring no extra information exchange between FBSs. The reporting range of RSRP is delimited from $-140$ dBm to $-44$ dBm with 1 dB resolution. If RSRP is greater than $-75$ dBm, excellent QoS can be expected. In the range between $-75$ dBm and $-95$ dBm, a slight degradation of the QoS can be expected. Below $-95$ dBm the QoS becomes unacceptable, and throughput tends to decline down to zero at approximately $-108$ dBm to $-100$ dBm. Hence, the proposed algorithm chooses $-95$ dBm as the minimum value for initiation of power control action.

In LTE, one can use both RSRP and Reference Signal Received Quality (RSRQ) as a downlink ICI coordination (ICIC) measurement trigger quantity, which indicates the source from which the UE obtains the received signal power of a neighbor cell and the serving cell. Preferably, RSRP selected as downlink ICIC measurement trigger quantity, since obtained signal power does not dramatically fluctuate with the cell load. In broad terms, the autonomous power setting decision system evaluates the SINR and RSRP in a particular time slot (subframe $k$ transmission time) and determines FBS transmission power to satisfy the minimum rate requirement of users. Table 1 presents the proposed autonomous FBS power setting algorithm.

Initially, minimum transmission power $P_{tFi(\min)}$ is set as the FBS transmission power. During $k$-th subframe TTI, the FBS $F_i$ assigns $S_{Fi}$ freely available RBs to the UE based on their minimum throughput requirement $R_{\text{req}}$. Then power allocation on each SC performed such that $p^{s}_{tFiui} = P_{tFi(\min)}/S_{Fi}$ and data transmission for $k$-th TTI initiated. Based on the periodic CQI information and RSRP per RB, the proposed method makes the decision on initiation of power control process. If CQI of the time slot $k$ $CQI(k)$ is less than CQI threshold value $CQI_{\text{thres}}$ and RSRP less than $-95$ dBm, the BS understands the occurrence of high interference condition and prefers rescheduling of RBs. Here, there is a chance for an argument that why power control is not performed in this condition. Since the algorithm starts with minimum power transmission at all FBSs, it is natural to boost the transmission power to satisfy the required CQI and check whether the boosted power harms nearby users. Let us justify the frequency domain rescheduling instead of power control. As the proposed algorithm checks both CQI and RSRP for assurance of minimum QoS of any user, who is currently assigned with a particular SC,

Table 1. Autonomous FBS power-setting algorithm.

```
Initialize $\Psi$, $\Psi_{\mathrm{m}}$ and $\Psi_{\mathrm{f}}$; Set initial transmission power of all active FBSs, $P_{tFi} = P_{tFi(\mathrm{min})}$.
for each subframe TTI $k$ do
    for each FBS $F_i$ do
        for each user $u_i$ do
            Perform proportional fair scheduling of $S_{Fi}$ SCs based on user minimum throughput requirement $R_{\mathrm{req}}$.
            Perform power allocation to each SC, such that $p^s_{tFiui}(k) = \frac{P_{tFi(\mathrm{min})}}{S_{Fi}}$. Data transmission for $k$- th time slot initiated.
            Analyze the channel measurement reports sent by users to the BS.
            If $CQI(k) < CQI_{\mathrm{thres}}$ and $RSRP < -95$ dBm then perform SC rescheduling.
            elseif $R_{ui} < R_{\mathrm{req}}$.
                Initiate FBS power-setting action using ANFIS controller, which determines the optimal transmission power $p^*_{tFi}(k)$ by fine tuning the premise and consequent parameters of fuzzy rule base.
                Perform power allocation to each SC such that $p^s_{tFiui}(k) = \frac{p^*_{tFi}(k)}{S_{Fi}}$; Continue data transmission for next TTI.
            elseif $R_{ui} > R_{\mathrm{req}}$ then $p^s_{tFiui}(k) = p^s_{tFiui}(k-1)$; Continue data transmission for the next TTI.
            end if
        end for
    end for
end for
```

$CQI < CQI_{\mathrm{thres}}$ and $RSRP < -95$ dBm obviously indicates the high interference scenario. Boosting of power may increase the interference to nearby victim users, as this algorithm functions in a distributed manner. Hence, to create a win-and-win situation, FBS $F_i$ prefers rescheduling of SC as an indication of its cooperation to mitigate interference at the network level. Now, if $CQI(k) > CQI_{\mathrm{thres}}$, $R_{ui} < R_{\mathrm{req}}$ and $RSRP > -95$ dBm, initiation of the transmission power setting of the FBS for $k$-th time slot performed using an ANFIS controller, which determines the optimal FBS transmission power $p^*_{tFi}(k)$. This updated value of transmission power on SC $s$ $p^s_{tFiui}(k) = p^*_{tFi}(k)/S_{Fi}$ is used in the next time slot, and again data transmission carried out. On the other hand, if $CQI(k) > CQI_{\mathrm{thres}}$, $R_{ui} > R_{\mathrm{req}}$ and $RSRP > -95$ dBm, then transmission power of $k$-th time slot is equal to that of $(k-1)$-th time slot that is, $p^s_{tFiui}(k) = p^s_{tFiui}(k-1)$. The same procedure repeated in all active FBSs in the scenario and transmission power of FCs optimized continuously. Additionally, it is imperative that the UE would modify its modulation and coding scheme (MCS) depending on the CQI.

As the proposed algorithm uses local measurements alone, the ICIC is possible with zero signaling between FBSs. Moreover, the computational complexity of the proposed method with $S_{Fi}$ number of SCs assigned to $J_i$ number of users is $O(2 \times (S_{Fi} \times J_i)^2)$, as the ANFIS controller has two inputs only. Furthermore, the proposed FBS power setting has a bare minimum delay, as it uses only the periodic CQI report received from UE. Altogether, the major advantages of the proposed ANFIS based FBS power setting strategy are zero signaling, reduced computational complexity and minimized delay. Note that all FBSs can implement the proposed algorithm in a distributed fashion without any performance degradation and the algorithm may require several data transmissions at the initial power setting stage to reach the optimal point. Anyway, as the ANFIS controller is offline trained, it works well in the dynamic condition. FBS has a transmission power control section because it is a low power BS, and to accurately calibrate the optimal transmission power the proposed ANFIS controller can be implemented in that power control section.

## IV. Autonomous FBS Transmission Power Setting Using ANFIS

An adaptive neuro fuzzy inference system (ANFIS) is a type of FIS, finely-tuned using Artificial Neural Networks training algorithms to improve the accuracy of results obtained using FIS alone [21]. With training data obtained from an exceptionally limited mathematical representation of the system, the ANFIS trained and made to recognize the near-optimal membership functions of Fuzzy Logic Control (FLC) system to realize desired input-output mappings. The fundamental learning rule of ANFIS is based on the gradient method. As it is slow and has an affinity to become trapped in local minima, a hybrid learning algorithm, which quickens the learning process substantially was first proposed by Jang [22], [23]. It employs a combination of the least square method and back propagation gradient descent method for fine-tuning of FIS membership function parameters to follow a given training data set. ANFIS can refine the fuzzy if-then rules obtained from experts to describe the input-output performance of a complex system. However, if such expertise is not available, it is possible to generate a set of fuzzy rules to approximate the desired data set. The system converges, when the error is within an acceptable bound. In ANFIS, the adaptive network is a multilayer feed-forward network.

Fig. 1 shows the architecture of proposed ANFIS controller. The ANFIS controller designed to perform FBS transmission power setting composed of five layers. Each layer has nodes of type either fixed or adaptive [22]. Each node performs node function on its input as well as a set of parameters connected to it [24]. The rule for node function designed based on the overall input-output function that needs to do by the adaptive network. In broad terms, ANFIS is a type of Sugeno FIS, and its structure can update its parameters according to the gradient descent procedure.

As shown in Fig. 1, SINR and RSRP are the inputs of nodes in layer 1 and the nodes in this layer compute the MFs of the inputs $\mu_{Ai}(SINR)$ and $\mu_{Bi}(RSRP)$ as follows:

$$\begin{aligned} O^1_{SINRi} &= \mu_{Ai}(SINR) = \frac{1}{1+\left|\frac{SINR-c_i}{a_i}\right|^{b_i}}; i=1,2,\ldots \text{ and} \\ O^1_{RSRPi} &= \mu_{Bi}(RSPR) = \frac{1}{1+\left|\frac{RSPR-c_i}{a_i}\right|^{b_i}}; i=1,2,\ldots \end{aligned} \tag{6}$$

where $A_i$ and $B_i$ are the linguistic variables of inputs SINR and RSRP, respectively. In this work, bell-shaped MFs are selected, which takes the value between 0 and 1. $\{a_i, b_i, c_i\}$ is the premise parameter set, and the values of them are determined during the training phase of the hybrid learning. The values of $a_i$ and $c_i$ adjust the width and the center of bell-shaped MF, while the values of $a_i$ and $b_i$ control the slopes at the intersecting point. Nodes in layer 2 and 3 are of the fixed type. In layer 2, nodes multiply the incoming signal by a scaling factor. The output of layer 2 represents the firing strength of each rule and the nodes in layer 3 normalize the same. The output of nodes ($w_i$) in layer 2 and layer 3 given respectively in (7) and (8).

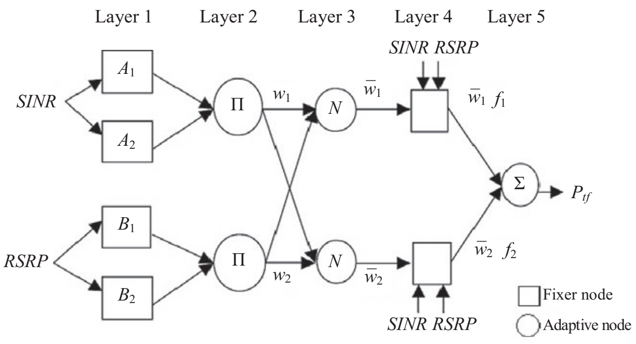


Fig. 1. ANFIS architecture for the proposed FBS transmission power setting.

$$O^2_i = w_i = \mu_{Ai}(SINR)\mu_{Bi}(RSRP), \tag{7}$$

$$O^3_i = \bar{w}_i = \frac{w_i}{\sum_i w_i}. \tag{8}$$

The fourth layer consists of adaptive nodes. At first, their node function computes the linear combination of inputs and the set of consequent parameters $\{p_i, q_i, r_i\}$, whose values are determined by the training. Then, it calculates the contribution of each rule towards the overall output. Layer 5 consists of single fixed type node, which sums up all incoming signals from layer 4. The output of layer 4 and layer 5 given respectively in (9) and (10).

$$O^4_i = \bar{w}_i f_i = \bar{w}_i(p_i SINR + q_i RSRP + r_i), \tag{9}$$

$$O^5_i = \sum_i \bar{w}_i f_i, \tag{10}$$

where $f_i$ denotes the output of the rules. The block diagrams of the proposed ANFIS controller in training phase and application phase are shown respectively in Figs. 2 and 3. Here, FAP denotes FC access point that is, FBS. Then, $e$ and $P_{tf(\text{Req})}$ represent the training error and the required transmission power to ensure minimum throughput requirement, respectively. Once the ANFIS controller is offline trained, it can provide optimal transmission power in the application phase. Due to the

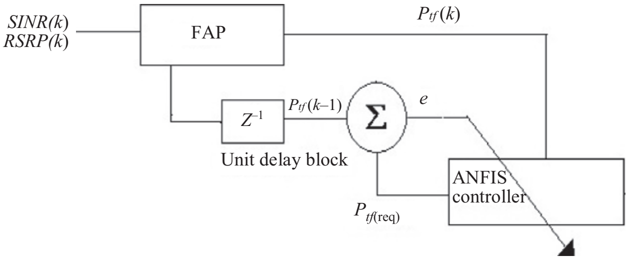


Fig. 2. Block diagram of autonomous power setting using ANFIS controller (Training phase).

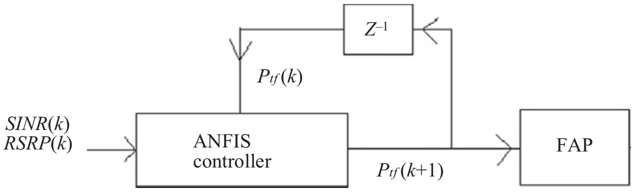


Fig. 3. Block diagram of autonomous power setting using ANFIS controller (Application phase).

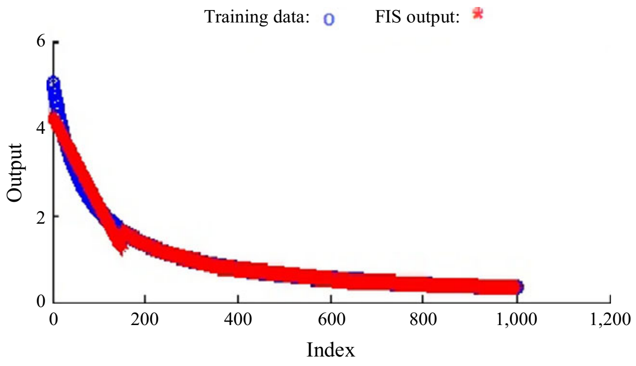
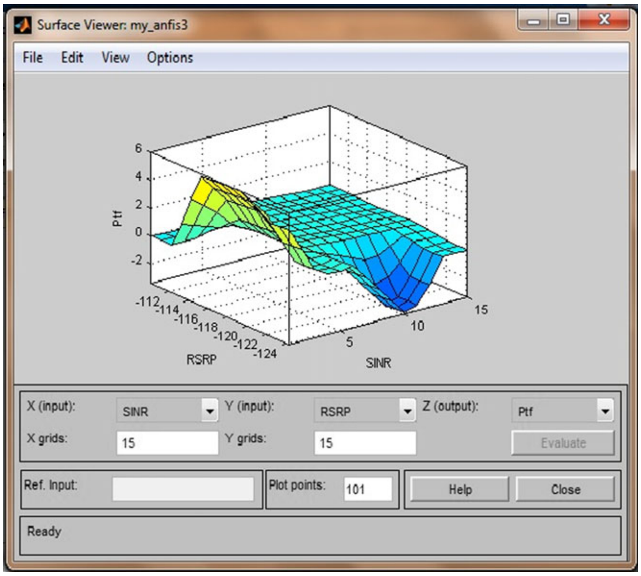


Fig. 4. Convergence of the ANFIS training.



X (input): SINR

Y (input): RSRP

Z (output): Ptf

X grids: 15

Y grids: 15

Ref. Input:

Plot points: 101

Ready

Fig. 5. Surface viewer of ANFIS.

presence of unit delay element $z^{-1}$, there subsists one-time slot delay in providing optimal transmission power.

Each epoch of training consists of a forward pass and a backward pass [24]. In the forward pass, data inputs applied to each node in layer 1, which performs Fuzzification of inputs. The functional signals go forward up to layer 4, which generates de-fuzzified values for each rule fired. The hybrid learning adjusts the consequent parameter set using the least square method. This process reiterated for all the training input/output data pairs, and the training error measurement obtained. In the backward pass, the error values propagated backward from output to input, and the premise parameters set updated using the gradient descent method, which accelerates the convergence and speeds up the training process. Therefore, in training phase, the MFs and the weights would be adjusted to provide accurate FBS transmission power as output to ensure minimum rate requirement of the users. In the sequel, the offline trained ANFIS can provide fast and accurate FBS transmission power in the application phase. In FLC, a set of fuzzy rules is the backbone for the fuzzy control. Successful control application depends on linguistic information and trial and error tuning of the MFs. The ANFIS power setting process can take further advantage of the statistical information (input-output data pairs) and refine the MFs systematically. Hence, a set of training data set generated with SINR, RSRP as inputs and FBS transmission power (obtained using (1)) as output are used for training. Here, the ANFIS has 15 fuzzy rules. We have used one thousand input-output data pairs for training the ANFIS. Since the downlink transmission power setting of each FBS is performed in a distributed fashion by offline trained ANFIS controller, the number of training data sets is purely independent of the system size that is, the number of FBSs and FUE. Besides the proposed algorithm works well in dynamic condition due to the same reason. The convergence of the ANFIS training after 200 epochs is shown in Fig. 4. The mean square error of the ANFIS model achieved is 0.1019. Figure 5 shows surface viewer of the ANFIS, which depicts the mapping between inputs and output.

## V. Simulation Results

Monte Carlo simulation has been performed to validate the effectiveness of the proposed ANFIS based FBS power setting strategy to mitigate ICI effects on user throughput attainment. An FC-block, which represents two strips of apartments, each strip has two by ten single-floored apartments of size 10 m × 10 m [17] is considered for FC deployment scenario. One such FC block is dropped 400 m away from the MBS. In that FC block, one FBS and two users per apartment are dropped. In each snap shot of simulation, the FBS and users are uniform randomly distributed inside the apartment. Each FBS minimum and maximum transmission power is set as $-10$ dBm and 20 dBm, respectively. Besides, the probability of active FCs $P_{\text{act}}$ is set to 0.8. The system bandwidth is 20 MHz; therefore, 100 usable RBs are available per TTI. Each RB has a bandwidth of 180 kHz. It is assumed that 50 RBs are reserved for macrocell users, and the remaining 50 RBs are allocated independently by the active FBSs to their users. Hence, there is no cross-tier interference, but there is a possibility for allotment of same RB by the active FBSs to their users, which gives rise to ICI. Thus, 1,000 snapshots are simulated, and the results are averaged to obtain mean achieved throughput

Table 2. Simulation parameters.

| Parameters | Values |
|---|---|
| Carrier frequency | 2 GHz |
| Number of subcarriers per RB | 12 |
| Number of RBs | 100 |
| Number of RBs allotted to FCs | 50 |
| RB bandwidth $B_{\mathrm{RB}}$ | 180 KHz |
| Time slots | 20 ms |
| FBS transmission power | 100 mW |
| Penetration loss of inner wall | 5 dB |
| Penetration loss of outer wall | 20 dB |
| Spectral noise density $N_o$ | –174 dBm/Hz |
| Target BER | $10^{-6}$ |
| $CQI_{\mathrm{thres}}$ | 3 |

and power efficiency of the system. Each snapshot of Monte Carlo simulation is iterated over twenty subframe duration (20 milliseconds), such that average SINR and FC user desired signal received power statistics are gathered. The simulation parameters relevant to LTE specifications [17] used are listed in Table 2.

The path loss model for urban deployment in [17] is used. Rayleigh fading and lognormal shadowing effects are included. The minimum data rate requirement $R_{\mathrm{req}}$ of 2 Mbps is assumed. The periodic CQI feedback reporting to the FBSs has been done for every two milliseconds (two subframes TTI) [19], whereas the RSRP per RB is evaluated for every millisecond. At each FBS, a proportional fair scheduler allocates RBs based on full buffer traffic model. Usual link adaptation (LA) procedure is performed; in other words, based on CQI reporting, adaptive MCS selection is performed to ensure the QoS to users. We introduce the probability of interference ratio $P(int)$, which defines the probability of potentially interfering FCs within the coverage of a particular FBS. $P(int)$ takes the value of zero for no interferer occurrence and one for the maximum number of interferers occurrence within the coverage of the FBS for which performance measurements are collected. Without loss of generality, we assume that a maximum of ten interfering FCs might appear during any TTI.

### 1. Existing Works Used for Comparison

From the simulation, the statistics of FC user throughput (Mbps), desired signal power received (dB), and power efficiency (bps/W) are generated for the systems employing ANFIS controller and compared against the interference measurement based SPC [14] and FLC based power control [18]. Indeed, these methods adjust its RB transmission power based on the total interference signal received at the FBS.

### 2. Performance Evaluation of Proposed Method

User throughput, power efficiency and desired signal power data of the user at a distance 20 m from the serving FBS and potential interferers at a distance 15 m are collected for analysis. Figure 6 shows the throughput of FC user as a function of the probability of interference ratio $P(int)$.

With fixed FBS transmission power and SPC, the $R_{\mathrm{req}}$ cannot be achieved even under low interference activation scenario, and the user would go outage by the high value of $P(int)$. Even though the power control using FLC ensures $R_{\mathrm{req}}$, the same using ANFIS not at all degrades the throughput of users. The ANFIS controller-equipped FBSs choose their optimal transmission power according to the specific SINR and RSRP at any particular TTI and thus capable of reducing the interference to victim users without significantly compromising their users' achievable performance. Hence, comparing with FLC, the ANFIS controller provides throughput gain of 8% more with least $P(int)$ and 63.6% more with highest $P(int)$. Moreover, power setting using ANFIS controller, not only the $R_{\mathrm{req}}$ of users ensured, but also the maximum throughput can be achieved. Thus, ANFIS controller can provide better performance thanks to the ANFIS capability of optimizing the MF parameters of FIS.

Figure 7 shows the throughput with respect to the distance between the user and his serving FBS, with 50% probability of interference activation. Even the cell-center user (at a distance 5 m onward) experience poor QoS (due to declination in achieved throughput) with

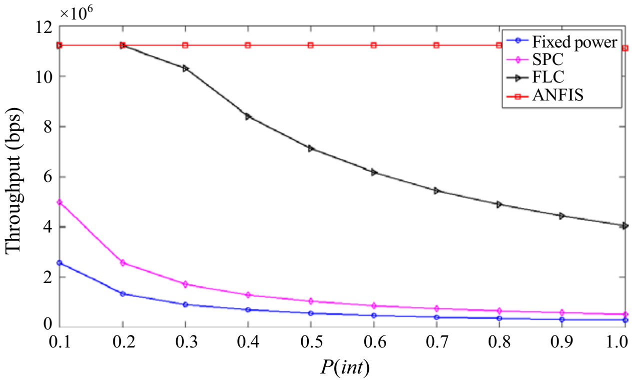


Fig. 6. Femtocell user throughput as a function of $P(int)$.

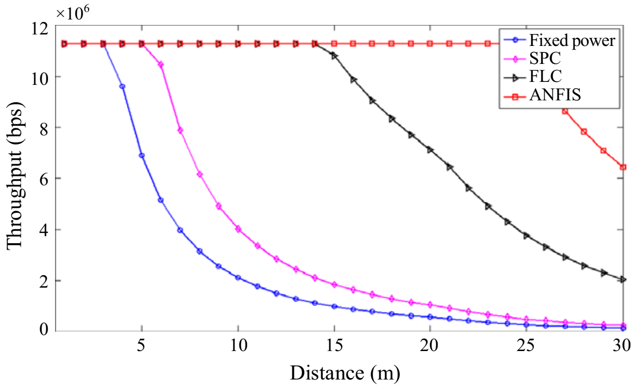


Fig. 7. Femtocell user throughput as a function of distance.

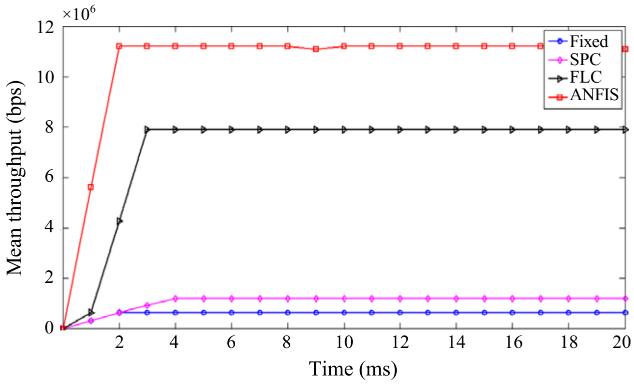


Fig. 8. Femtocell mean throughput with respect to time.

fixed FBS power and SPC, whereas FLC based FC power calibration shows improvement in performance. However, with ANFIS based power setting, even the cell-edge user can attain much higher throughput. Anyway, both FLC and ANFIS methods can provide $R_{\text{req}}$ of users. The proposed method provides 68.46% and 96.2% of throughput gain to the user at a distance of 30 m as compared against FLC and SPC methods, respectively. Hence, we can conclude that the FLC method provides only a sub-optimal solution, while the proposed method provides an optimal solution to the throughput maximization problem.

Figure 8 shows FC user mean throughput with 80% of $P(int)$ and user a distance of 15 cm analyzed for twenty subframes TTI. Since FC transmission power setting takes place only after reception of CQI, (received at every two (milliseconds) TTI) there subsists two milliseconds of delay in performing optimal power setting. In fact, both SPC and FLC methods also have a delay of one millisecond in performing power control action as they function based on the interference measurement per TTI.

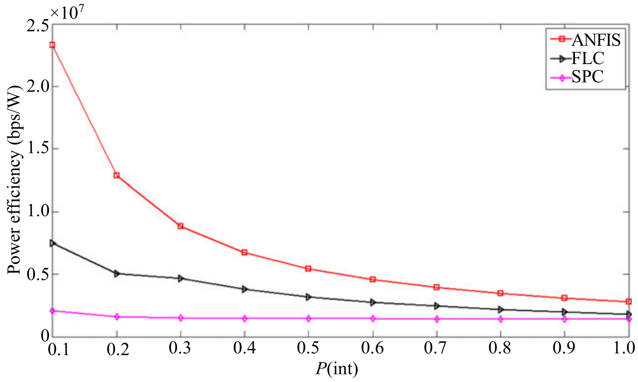


Fig. 9. Femtocell power efficiency as a function of $P(int)$.

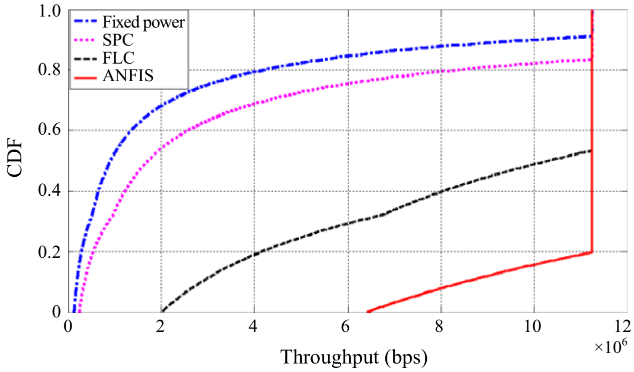


Fig. 10. CDF of user throughput.

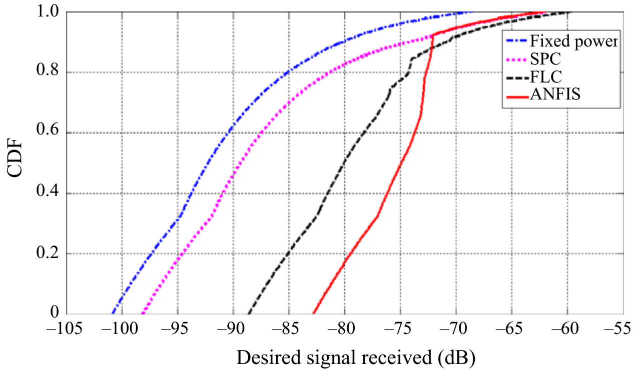


Fig. 11. CDF of desired signal received.

Figure 9 shows the superiority of the proposed power setting strategy by obtaining power efficiency (that is, achieved user throughput per unit transmission power) plot as a function of $P(int)$. The proposed method provides much better power efficiency under low interference activation scenario and comparably better for the high value of $P(int)$. Due to optimal transmission power setting using ANFIS, improved power efficiency achieved.

In order to analyze the benefits gained by users at cell-edge and mid-coverage region, cumulative distribution functions (CDFs) of throughput and the desired signal received are obtained. Figure 10 shows the CDF of throughput (with 50% of $P(int)$). The 5-th percentile throughput achieved indicates the cell-edge user performance. Since the ANFIS controller in each FBS provides the optimal transmission power for every TTI (in a distributed manner), the interference signal power reduced and the desired signal power boosted significantly. Hence, in the CDF plot, the 5-th percentile throughput is above $R_{\text{req}}$ for FLC and ANFIS methods, while fixed power and SPC methods cannot offer minimum throughput requirement to users both at mid-coverage region and cell-edge region. Specifically, the proposed method provides 67.8% and 96.1% of throughput gain in cell-edge user performance as compared against FLC and SPC methods, respectively.

Figure 11 shows CDF of the desired signal received to validate the effectiveness of the proposed method for gaining much better desired signal reception. The proposed ANFIS method provides higher desired signal power as compared with fixed power, SPC and FLC methods. Due to higher desired signal power reception, SINR of user boosted, which makes it possible for the user to achieve much higher throughput even at cell-edge.

Additionally, numerical results on the achieved throughput of the user at mid-coverage region and cell-edge are obtained with 30%, 50% and 80% interference activation ratio, and presented in Tables 3 and 4, respectively. Due to reduced SINR, user throughput attainment is lower than the $R_{\text{req}}$ for fixed power and SPC methods (both at mid-coverage region and cell-edge region). Even though FLC method can provide a marginally high value of throughput above the $R_{\text{req}}$, the proposed ANFIS method of power calibration can provide a much higher value of throughput attainment to all users irrespective of their proximity from the serving base station.

Ultimately, the power setting using ANFIS controller outperforms the FLC and SPC, because the FIS variables' membership functions are fine-tuned and FBS transmission power $P_{tF}$ is accurately determined. The autonomous FBS power setting carried out based on the CQI measurements made at every two-subframe TTI and RSRP measurement per TTI. Thus, there is two millisecond setback in performing the change of power level. Since all FBSs embedded with the ANFIS controller in their power control section cooperatively performs control on its transmission power with the locally available measurements, there is zero signaling overhead. Furthermore, the proposed ANFIS controller needs only two essential parameters, so the complexity is reduced (50%) as compared with the FLC method proposed in [18], where four inputs were used, and Table 5 illustrates the comparison of computational complexity.

Table 3. Throughput of user at mid-coverage region.

| $P(int)$ | Throughput of user at mid-coverage region (Mbps) | | | |
|---|---|---|---|---|
| | Fixed | SPC | FLC | ANFIS |
| 30% | 1.581 | 3.010 | 11.243 | 11.243 |
| 50% | 0.971 | 1.829 | 10.781 | 11.243 |
| 80% | 0.615 | 1.152 | 7.701 | 11.243 |

Table 4. Throughput of user at cell-edge.

| $P(int)$ | Throughput of user at cell-edge region (Mbps) | | | |
|---|---|---|---|---|
| | Fixed | SPC | FLC | ANFIS |
| 30% | 0.246 | 0.457 | 3.599 | 10.161 |
| 50% | 0.148 | 0.275 | 2.277 | 7.074 |
| 80% | 0.092 | 0.172 | 0.900 | 4.886 |

## VI. Conclusion

In this work, an autonomous FBS power setting strategy using the least input ANFIS controller is presented to tackle the femto-femto interference problem. The key parameters used to perform power setting are locally available at each base station. The proposed ANFIS evaluates the inputs at each subframe interval of data transmission, fuse them based on the rule base and determine the transmission power of FBS to protect the link quality of the users in nearby FCs while satisfying the minimum data rate requirement of its cell edge users. Performance comparison of our proposed method with fixed FBS transmission power, SPC and FLC methods in the aspect of throughput, and power efficiency confirm the ability of the ANFIS

Table 5. Comparison of computational complexity.

| Complexity with $n$ inputs, $S_{Fi}$ SCs and $J_i$ users | FLC proposed in [18] (inputs $n = 4$) | Proposed ANIFS controller (inputs $n = 2$) |
|---|---|---|
| $O(n \times (S_{Fi} \times J_i)^2)$ | $O(4 \times (S_{Fi} \times J_i)^2)$ | $O(2 \times (S_{Fi} \times J_i)^2)$ |

controller to provide enhanced throughput and power efficiency. The main advantage of our proposed FBS power setting strategy is zero signaling overhead, reduced computational complexity, and bare minimum delay because it needs only the periodic locally available essential signals. Specifically, the proposed ANFIS controller based FBS power setting outperforms the SPC and FLC methods by providing respectively 95.3% and 63.6% of mean throughput gain to FC users, even under high interference scenario.

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