Fuzzy Logic-Based Downlink Subchannel Allocation for Capacity Maximization in OFDMA Femtocells

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***Abstract*—In this paper, we propose a fuzzy logic-based dynamic subchannel allocation scheme for densely deployed femtocell networks affected by strong co-tier interference. The channel model includes Rayleigh fading with path loss and the femtocells use OFDMA-based channel access. The reported signal-to-interference plus noise ratio (SINR) values at femtocell base stations are used to form a fuzzy superset, which in turn is utilized to allocate subchannels in an optimal way. The results are compared with the traditional user-oriented and channel-oriented subchannel allocation schemes. The proposed scheme provides almost the same system capacity with better fairness as compared to traditional channel-oriented scheme, while it also improves the sum-rate capacity of the femtocell network as compared to the user-oriented scheme. Simulations have been performed to judge the quality of proposed algorithm for a variety of densely deployed femtocells.**

I. Introduction

The demand for high data rates is increasing rapidly for next generation wireless systems. Because of the emergence of ultra broadband applications and multimedia services, it has become inevitable for the mobile operators to provide good quality links having higher capacity in modern cellular systems. In an outdoor environment, the provisioning of wireless signals with good signal strength is not a big problem for mobile operators. However, it becomes a challenging task to provide reliable indoor coverage. Recently, femtocell technology has been proposed to overcome the indoor coverage problem where femtocells increase both the coverage and capacity of wireless networks [1].

Femtocells are low-cost and low-powered indoor base stations with the functionality of providing standard mobile devices with an access method to mobile operator's network using the internet. Because of their operation in licensed frequency bands, interference becomes a critical problem in femtocell-based networks. The interference issues caused by the deployment of femtocells on overlaid macro-cellular network are broadly classified into two categories, i.e., co-tier interference and cross-tier interference. Co-tier interference occurs when the transmission of femtocell user equipment (FUE), connected to a particular femtocell base station (FBS) is interfered by another FBS or FUE using the same channels. On the other hand, cross-tier interference occurs when the transmission of FUE connected to a particular FBS is interfered by macrocell base station (MBS) or macrocell user equipment (MUE) using the same set of channels and vice-versa. Because of the use of licensed spectrum and unplanned deployment of femtocells, careful resource allocation is required for interference management, kepping in view the spectral efficiency [2].

A considerable amount of literature is available for femtocell interference mitigation or avoidance techniques such as power control, fractional frequency reuse, and reverse frequency allocation, [3-5] and the references therein. However, as this study deals with a specific type of orthogonal frequency division multiple access (OFDMA)-based heterogeneous network, we briefly discuss the subchannel allocation schemes devised in literature for interference management. In [6], user-oriented and channel-oriented subchannel allocation schemes have been proposed that allocate channels with respect to their respective priorities, however, these schemes compromise on network capacity and capacity fairness, respectively. In [7], a decentralized spectrum allocation policy is proposed but capacity fairness is not considered. The authors developed the distributed channel-gain oriented subchannel selection scheme in [8] to maximize capacity but there is not much insight on the capacity fairness. In [9], a centralized subchannel allocation scheme for interference avoidance is proposed by using intercell coordination but there are signaling overheads and computational complexities associated with this scheme. A utility-based subchannel allocation scheme is proposed in [10] by using graph theory, however, it provides sub-optimal channel allocation. In [11], resource optimization has been done for downlink transmission of macro-femto network. In this scheme, per-user bandwidth is reduced in order to minimize the interference. A dynamic stochastic subchannel allocation scheme is proposed in [12]. This scheme is based on random selection of subchannels for FBS and the effect of co-channel interference (CCI) is dispersed on all subchannels.

In this paper, we utilize a decentralized mechanism to allocate subchannels to the users in an OFDMA-based heterogeneous network, where a dense femtocell deployment is assumed in which co-tier interference dominates. Specifically,

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we focus on the downlink of a femtocell network and use an elegant framework of fuzzy logic to allocate subchannels to the users. The proposed algorithm not only provides sum rate maximization but also compensates for fairness factor to a reasonable extent. It has been shown that the proposed scheme outperforms general user-oriented and channel-oriented schemes specially in medium to high interference scenarios.

The rest of the paper is organized as follows. Section II describes the network architecture. In Section III, the proposed fuzzy logic-based subchannel allocation scheme is described. Simulation results are shown in Section IV. Finally, concluding remarks are given in Section V.

II. Network Architecture

We consider a single cell heterogeneous network in which an arbitrary number of femtocell base stations (FBSs) are randomly deployed within a macrocell. The coverage radius of a femtocell is denoted by R_f. It is assumed that the macro base station (MBS) has either $120°$ or $60°$ sectors and that double frequency reuse scheme is used in all sectors [13]. This implies that the subchannels allocated to FBSs in one sector of the macrocell are different from the subchannels allocated to the MBS in that sector. This will enable zero cross-tier interference and the system only has to deal with co-tier interference among FBSs in one sector of the macrocell. Let ξ represent the set of FBSs, which are deployed in one sector of the MBS. The index for FBS in a specific sector of MBS is denoted as f, such that $f = \{1, \cdots, \mid \xi \mid\}$ where $\mid \xi \mid$ represents the cardinality of set ξ. Minimum distance between two FBSs is denoted by d_{fmin}.

In this paper, we consider the scenario where all FBSs operate only in the closed-access mode, i.e., only legitimate users, which are part of the closed subscriber group (CSG) are allowed to use the services of a specific FBS. Any other user, which is not the part of CSG is denied service for that corresponding FBS. In this case, the effect of interference from neighboring FBSs is enhanced and the need for efficient interference management scheme becomes inevitable.

Without loss of generality, we assume that a maximum of K legitimate FUEs can be connected to each FBS. Let k be the index to represent an FUE such that $k = \{1, \cdots, K\}$. Each FBS has N data subchannels available and each subchannel consists of N_d OFDMA subcarriers. A graphical illustration of 6 OFDMA subchannels with 2 subcarriers per subchannel is shown in Fig. 1. To provide a fair comparison, we also assume that the maximum subchannels allocated to any user k of a femtocell f are limited to M_f. For example, K = 3 implies 2 subchannels per user in Fig. 1, i.e., M_f = 2.

Let a binary indicator function, $\mathbb{I}_{(f,k)}^{(n)}$, is used to denote the n^{th} subchannel allocated to user k of femtocell f such that

$$\mathbb{I}_{(f,k)}^{(n)} = \begin{cases} 1 & if\ n^{th}\ subchannel\ is\ allocated\ to\ user\ k \\ 0 & if\ n^{th}\ subchannel\ is\ not\, allocated\ to\ user\ k \end{cases} . \quad (1)$$

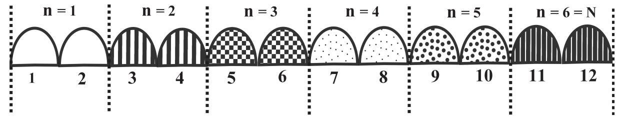

Fig. 1: OFDMA Subchannels; N = 6, N_d = 2.

Based on the above equation, we have

$$\sum_{k=1}^{K} \mathbb{I}_{(f,k)}^{(n)} = 1 \quad \forall n \ . \quad (2)$$

The equation above guarantees that a subchannel cannot be shared by more than one user in the same FBS. Keeping in view the requirements of proposed subchannel allocation scheme, the maximum number of subchannels allocated to user k in femtocell f are limited to M_f such that

$$\sum_{n=1}^{N} \mathbb{I}_{(f,k)}^{(n)} \leq M_f \leq N \ . \quad (3)$$

We consider equal transmit power for all the users in a femtocell and all FBSs also transmit with the same power. The transmit power for all subchannels of the FBS f is denoted as P_t. The recieved power at FUE k, for subchannel n, in the downlink of FBS f is given as

$$P_{r(f,k)}^{(n)} = \frac{P_t \mu_{(f,k)}^{(n)}}{d_{(f,k)}^{\beta}} \ , \quad (4)$$

where $\mu_{(f,k)}^{(n)}$ represents the channel gain for the subchannel n from FBS f to the user k. All channel gains are independent and exponentially distributed with unit mean, corresponding to Rayleigh flat fading. The distance between the FBS f and the user k is denoted by $d_{(f,k)}$ and β is the path loss exponent.

For subchannel n, the downlink signal-to-interference plus noise ratio (SINR) at user k is given by

$$SINR_{(f,k)}^{(n)} = \frac{P_{r(f,k)}^{(n)} \mathbb{I}_{(f,k)}^{(n)}}{I_{(f,k)}^{(n)} + N_o} \ , \quad (5)$$

where $I_{(f,k)}^{(n)}$ is the co-channel interference (CCI), introduced by the nearby FBSs communicating at the same subchannel, while the power spectral density of white Gaussian noise is given by N_o. As we have already considered that the subchannels used by the FBS situated in a specific macrocell sector are different from the subchannels used by the MBS in that sector, therefore there will be no downlink interference from MBS to femtocell users. Similarly, there will be no downlink interference from FBS to macrocell users. Hence, the CCI on subchannel n of user k, connected to FBS f is given as

$$I_{(f,k)}^{(n)} = \sum_{\acute{f} \in \xi / f} \frac{P_t \mu_{(\acute{f},k)}^{(n)}}{d_{(\acute{f},k)}^{\beta}} \ , \quad (6)$$

where $\acute{f}$ represents the interfering FBSs, $\mu^{(n)}_{(\acute{f},k)}$ is the channel gain for the subchannel n from FBS $\acute{f}$ to user k and $d_{(\acute{f},k)}$ is the distance between interfering FBS $\acute{f}$ and user k.

The total throughput of an OFDMA-based femtocell is defined by the achieved capacity. The achieved capacity of user k in a femtocell f is denoted by $C_{(f,k)}$. If there are K users and N data subchannels available in a femtocell f, then the achieved capacity of an OFDMA-based femtocell can be calculated by

$$C = \sum_{k=1}^{K} C_{(f,k)} \ , \tag{7}$$

$$C = \sum_{k=1}^{K} \sum_{n=1}^{N} \mathbb{I}^{(n)}_{(f,k)} \frac{B}{M} \frac{N_d}{G+1} \eta^{(n)}_{(f,k)} \ , \tag{8}$$

where B is the system bandwidth, G is the guard fraction, M is the Fast Fourier Transform (FFT) size and $\eta^{(n)}_{(f,k)}$ is the theoretical spectral efficiency of subchannel n allocated to user k, which is connected to FBS f. The value of $\eta^{(n)}_{(f,k)}$ is obtained from [9, Table I].

Capacity fairness is also considered along with the femtocell capacity in designing subchannel allocation method. The fairness factor is defined as

$$\alpha = \frac{C^2}{K \sum_{k=1}^{K} C^2_{(f,k)}} \ . \tag{9}$$

The value of α ranges between 0 and 1, i.e., $0 \leq \alpha \leq 1$. If all users in a femtocell achieve the same throughput then $\alpha = 1$.

III. Fuzzy Logic-Based Subchannel Allocation

In this section, we propose a dynamic subchannel allocation scheme based on fuzzy logic. To make the subchannel allocation scheme practically implementable, a distributed network approach is applied instead of a centralized one. The former approach does not require a central control entity for subchannel allocations and hence the computational overhead on the central base station is minimized. In our scheme, the FUEs provide the information of received SINR on each subchannel to their respective FBS. The list of SINR values of each subchannel for every legitimate FUE is maintained by the FBS. Hence the problem in hand is to allocate the subchannels to the FUEs based on the reported SINR values. This is done optimally so that the effect of interference should be minimized and the overall capacity can be maximized keeping the fairness factor in consideration.

Traditional SINR-based subchannel allocation schemes are either user-oriented or channel-oriented. In the user-oriented approach, the users select the subchannels with the best SINR. In this way, the overall capacity of the femtocell network is compromised because the assigned subchannel cannot be allocated to another user, which may have better SINR on that specific subchannel and could achieve better capacity. Another widely used SINR-based subchannel allocation scheme is the channel-oriented scheme. This scheme improves the overall capacity of the network by assigning specific subchannel to the user that has maximum SINR for that subchannel but it compromises on fairness. The users who face more interference and have less SINR values for the available subchannels are badly affected by this scheme and may result in outage due to improper allocation of subchannels.

In our proposed subchannel allocation scheme, instead of considering only user-wise priority or channel-wise priority, we consider a mix of them and develop an algorithm that provides a better tradeoff between achievable capacity and fairness factor. The following subsections provide a step-by-step process of our proposed scheme.

A. Formation of the SINR Matrix

From the reporting of FUEs, the FBS maintains the SINR values of every subchannel n for each user k. Let $\mathbf{S}$ be the SINR matrix such that $s_{(n,k)} \in \mathbf{S}$, where $n = \{1, \cdots, N\}$ and $k = \{1, \cdots, K\}$. In other words, the SINR values of all the subchannels for the k^{th} user are located in the k^{th} column of $\mathbf{S}$. Similarly, the SINR values for all the users on the n^{th} subchannel are recorded in the n^{th} row of $\mathbf{S}$.

B. User-wise Priority Matrix

Let $\mathbf{P}_u$ denotes the user-wise priority matrix such that $p_{u(n,k)} \in \mathbf{P}_u$. The matrix indicates the priority of users regarding the selection of available subchannels based on the SINR values. The priority value of any user k for subchannel n is calculated from a proportionate SINR value, which depends on the SINR of that specific subchannel and maximum SINR value achieved by that user on any subchannel from 1 to N. If the maximum SINR value achieved by user k is represented by $\Gamma^{(k)}_{max}$, then the priority value of user k for subchannel n will be $p_{u(n,k)}$= $\frac{s_{(n,k)}}{\Gamma^{(k)}_{max}}$. Priority values in user-wise priority matrix can range from 0 to 1. If a user k has the best SINR for subchannel n among all other subchannels, then $p_{u(n,k)}$ = 1. To better understand the calculation of priority values $p_{u(n,k)}$, for user-wise priority matrix $\mathbf{P}_u$, we consider the example of Fig. 1 for K = 3. In Fig. 2(a), the SINR values for the first user $(k = 1)$ are shown for all 6 subchannels. To calculate the user-wise priority values, we normalize the SINR values of user 1 for all 6 subchannels with the maximum SINR, i.e., $\Gamma^{(1)}_{max}$ = 10.5 as shown in Fig. 2(b). Hence user 1 has the highest priority for subchannel 5, i.e., $p_{u(5,1)}$ = 1 and the rest of the entries are calculated in the same manner. In our subchannel allocation scheme, $\mathbf{P}_u$ contributes in the capacity fairness.

C. Channel-wise Priority Matrix

Let $\mathbf{P}_c$ denotes the channel-wise priority matrix such that $p_{c(n,k)} \in \mathbf{P}_c$. It indicates the priority of subchannels regarding the selection of users based on the SINR values. The same procedure is repeated as described in the previous subsection and normalized values of $\mathbf{P}_c$ are calculated by dividing $s_{(n,k)}$ with the maximum SINR value for a particular subchannel n. If the maximum SINR value achieved by any subchannel n is represented by $\Gamma^{(n)}_{max}$, then the priority value of subchannel n for user k will be $p_{c(n,k)}$= $\frac{s_{(n,k)}}{\Gamma^{(n)}_{max}}$. The phenomenon is

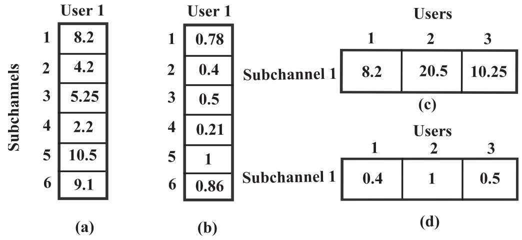

Fig. 2: Calculation of priority values

described in Fig. 2(c), where the SINR values for the first subchannel $(n = 1)$ are shown for all 3 FUEs. After normalizing, the first subchannel $(n = 1)$ has highest priority for user 2, i.e., $p_{c(1,2)}$=1, which is shown in Fig. 2(d). In our proposed scheme, channel-wise priority will contribute in capacity maximization.

D. Formation of Fuzzy Subsets

The consideration of user-wise and channel-wise priority separately may result in suboptimal allocation. For instance, the subchannel, which is on the first priority for a particular user may have the least priority for that specific user. Therefore, instead of using binary decisions to allocate subchannels, we use the concept of fuzzy logic where probabilistic weights are assigned for the selection of subchannels according to user-wise or channel-wise priority.

Let $F_{(n,k)}$ represents a fuzzy subset that contains the membership values of the subchannel n for user k and vice-versa. There are a total of NK fuzzy subsets that form the fuzzy superset **F**, i.e., $F_{(n,k)} \subset \mathbf{F}$. The membership of any user k to acquire subchannel n is denoted by the membership function ϕ_u and its value is acquired from the user-wise priority matrix such that $\phi_{u(n,k)} = p_{u(n,k)}$. Hence ϕ_u denotes the membership function such that $\phi_{u(n,k)} : s_{(n,k)} \rightarrow [0\ 1]$. Similarly, the membership of any subchannel n to acquire user k is denoted by the membership function ϕ_c and its value is attained from channel-wise priority matrix such that $\phi_{c(n,k)} = p_{c(n,k)}$. Thus we can write the fuzzy subset as a 2-tuple mathematical object such that $F_{(n,k)} = \left(\phi_{u(n,k)}, \phi_{c(n,k)}\right)$.

E. Cardinality of Fuzzy Subsets

Although $\phi_{u(n,k)}$ and $\phi_{c(n,k)}$ represent the membership degree of user k to subchannel n and vice versa, it is required to find a *measure* of suitability for this user-subchannel pair. In fuzzy mathematics, this measure is defined by the cardinality of fuzzy sets. In general, the cardinality can be calculated by using the l_1 norm of the fuzzy set, i.e.,

$$\mid F_{(n,k)} \mid = \sum_i \phi_{i(n,k)};\ i\ \in \{u, c\}\,. \tag{10}$$

We have considered the l_1 norm because we are adding the weights of the membership values for fuzzy subset to select the favorable subchannel n for user k. In general, l_2 norm also provides the same result for the subchannel selection in this case.

Algorithm 1 Fuzzy Logic-Based Dynamic Subchannel Allocation Scheme

Initialization

1. A set of K users, where $k = \{1, \cdots, K\}$.
2. A set of N subchannels, where $n = \{1, \cdots, N\}$.
3. Maximum M_f subchannels allocated to user.
4. Subchannel Allocation Matrix, $\mathbf{X} = 0_{(N\times K)}$.

Subchannel Allocation

1. Create **S** from reported SINR values.
2. Compute matrices $\mathbf{P}_u$ and $\mathbf{P}_c$.
3. Form fuzzy subsets, $F_{(n,k)}$ and fuzzy superset **F**.
4. Compute the cardinality matrix, **C**.

while $C \neq$ *Null Matrix* **do**
  5. Assign subchannel n to user k corresponding to the highest value in **C**.
  6. Set $\mathbf{X}_{(n,k)} = 1$.
  7. Set $\mathbf{C}_{(n,\ 1:K)} = 0$.
  if $\sum_{i=1}^{N} X_{(i,k)} = M_f$ **then**
    8. Set $\mathbf{C}_{(1:N,\ k)} = 0$.
  else
    go back to step 5
  end
end

Output: The subchannels n for which $\mathbf{X}_{(n,k)} = 1$ will be allocated to user k.

On the same lines, we compute the cardinality matrix, **C** that contains the cardinalities of all fuzzy subsets $F_{(n,k)}$ of **F** for $n = \{1, \cdots, N\}$ and $k = \{1, \cdots, K\}$.

F. Allocation of Subchannels

Subchannels are allocated to the users on the basis of cardinality values. It can be noticed that the highest cardinality value for a user-subchannel pair represents the optimal combination. Thus the highest value of cardinality in matrix **C** is calculated and the corresponding subchannel is allocated to the corresponding user. As one subchannel can only be allocated to a single user, therefore, after this allocation of subchannel $(say\ n)$ to the user, the cardinality values of subchannel n in **C** are set to zero for all K users, i.e., $\mathbf{C}_{(n,1:K)} = 0$. The maximum number of subchannels allocated to user k are bounded by M_f. If this condition is satisfied, then the cardinality values of the user k for all the subchannels from 1 to N become zero and the user cannot take part in further allocation of subchannels. Same process is repeated until all N subchannels are allocated among all K users and **C** becomes a null matrix. Subchannels are allocated dynamically to the users and the entire subchannel allocation process is repeated after specific interval of time for reallocation of subchannels. The entire process of fuzzy-based subchannel allocations is summarized in Algorithm 1.

IV. Simulation Results and Performance Analysis

In this section, we present the simulation results of our proposed scheme and compare them to the general user-oriented and channel-oriented schemes given in [6]. We consider a femtocell network with dense deployment where 50

TABLE I: Simulation Parameters

Downlink OFDMA Parameters	Values
FBS transmit power (P_t)	15 dBm
System bandwidth (B)	10 MHz
FFT Size (M)	1024
Subcarrier bandwidth	10.9375 kHz
Number of data subchannels (N)	36
Subcarriers for each data subchannel (N_d)	20
Guard Fraction (G)	1/8
Path loss exponent (β)	2.5

FBSs are randomly distributed in an area of $300\times300\ m^2$. The minimum distance between two nearest FBSs is kept at 20 m. In each FBS, there are 36 subchannels allocated to K authorized users. The maximum number of subchannels allocated to any user are $M_f = \frac{N}{K}$. We analyze a worst-case interference scenario such that all K FUEs of all 50 FBSs are active. The simulation parameters for the considered OFDMA-based femtocell network are listed in Table I.

Fig. 3 and Fig. 4 show the average femtocell capacity and fairness factor, respectively, for different number of femtocell users. We have compared the results of proposed fuzzy logic-based subchannel allocation scheme with the channel-oriented and user-oriented subchannel allocation schemes and find out that the proposed scheme provides better tradeoff between the achieved capacity and fairness.

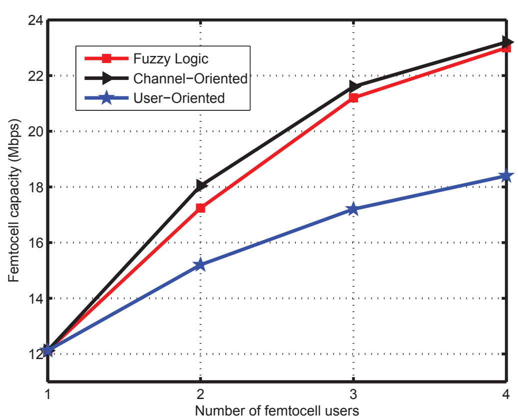

Fig. 3: Femtocell capacity for different number femtocell users

For $K = 2$, the proposed scheme provides a 17% increase in fairness factor as compared to channel-oriented scheme, however there is 4.4% decrease in the achieved capacity. For $K = 4$, there is a 22% increase in fairness factor with only 0.86% decrease in the achieved capacity. This shows that the performance of proposed subchannel allocation scheme improves with the increase in the number of femtocell users. In comparison with the user-oriented subchannel allocation scheme, we can see that the proposed scheme provides a 25% improvement in achieved capacity with only 4.6% decrease in fairness factor for $K = 4$. These results indicate that the proposed scheme outperforms the user-oriented and channel-orieneted schemes. In [14], it can be seen that the scheme

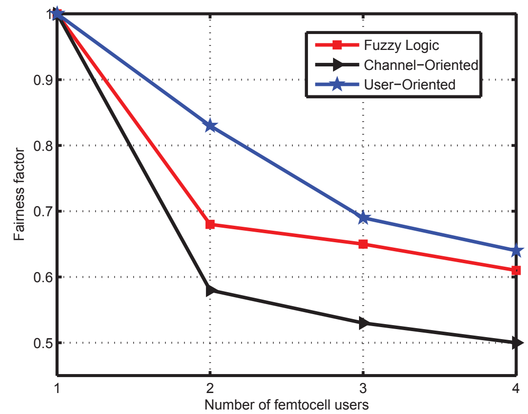

Fig. 4: Fairness factor for different number of femtocell users

proposed by authors provides better fairness at the expense of capacity. However, our scheme not only provides almost the same maximum achievable capacity as that of channel-oriented scheme but also provides a fairly better performance on fairness factor.

Fig. 5 shows the comparison of three schemes for two different values of FBSs in the same area, which shows the effects of dense femtocell deployment. It can be observed that the performance of the proposed subchannel allocation scheme improves in dense femtocell environment as compared to the other two schemes. For 30 FBSs, the improvement in achieved femtocell capacity is 21% as compared to user-oriented scheme for $K = 4$. However, the achieved capacity improves from 21% to 25% when the number of FBS is increased to 50 in the same area. Similarly, the difference between the achieved capacity for proposed scheme and the channel-oriented scheme is reduced from 2.14% to 0.86% when the FBSs are increased from 30 to 50.

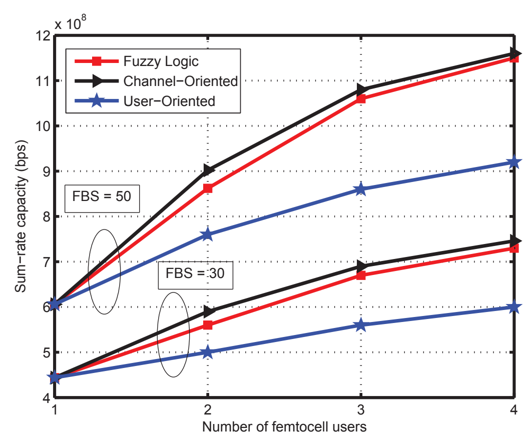

Fig. 5: Sum-rate capacity for different number of femtocell users

Fig. 6 shows the results of femtocell capacity when 20 FBSs are randomly deployed in areas of different sizes.

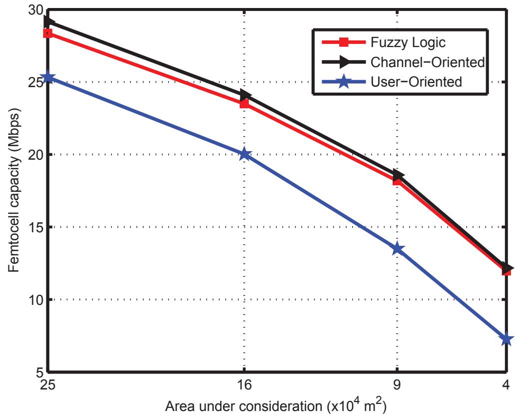

Fig. 6: Femtocell capacity for different areas with 20 FBSs; K = 4 in each FBS.

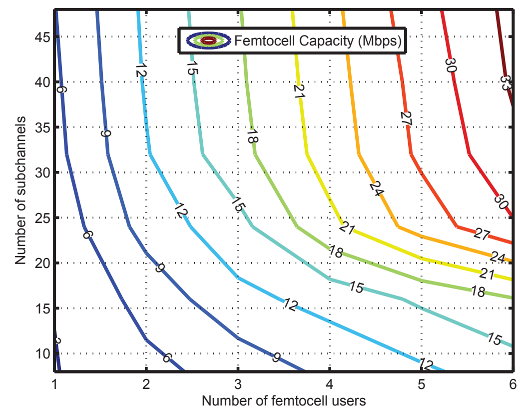

Fig. 7: Femtocell capacity for different number of FUEs and subchannels; number of FBSs = 60; area = 300×300 m^2.

The deployment of femtocells in small-sized area refers to a rather dense deployment. The results show that there is 64% increase in achieved capacity of proposed scheme as compared to user-oriented scheme when the area under consideration in 200×200 m^2. We also notice that the difference in achieved capacity between proposed scheme and channel-oriented scheme is reduced from 2.8% to 0.8% when the area is reduced from 500×500 m^2 to 200×200 m^2. It shows that the performance of our proposed scheme improves in dense deployment scenarios, however, the other two schemes show performance degradation.

Fig. 7 shows a contour plot of femtocell capacity for varying number of users and subchannels. The number of FBS is kept at 60 for an area of 300×300 m^2. This result can be used to allocate subchannels to femtocells based on the rate requirements. For instance, if each femtocell has 3 users and rate requirement in 9 Mbps, then 12 subchannels should be allocated to each femtocell. However, if the requirement exceeds to 15 Mbps, then 14 additional subchannels should be allocated to obtain the required quality of service.

V. Conclusion

A novel fuzzy logic-based subchannel allocation scheme is proposed in this paper and its performance has been evaluated after comparison with user-oriented and channel-oriented subchannel allocation schemes. Specifically, we introduced the concept of fuzzy memberships and applied it to the values obtained in the received SINR matrix at the FBS. The FBS then allocates channels based on the cardinality of fuzzy subsets. A significant improvement in network capacity as compared to user-oriented subchannel scheme has been quantified that also ensures capacity fairness as compared to the channel-oriented scheme. The performance of the scheme improves with larger number of users per femtocell. The proposed scheme is simple and can be implemented for decentralized femtocell networks. For future work, we can assign scaling weights to the membership functions. In this way, the FBS can choose between improved data rate or fairness depending on the magnitude of interference.

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