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Cluster based OFDMA Resource Allocation in Femtocell Networks

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Abstract:*Orthogonal frequency division multiple access (OFDMA) is one of the key technologies for broadband cellular wireless systems. It is a multiple-access technique which is better when compared to other techniques such as code division multiple access (CDMA). It works by allocating different subchannels to multiple users simultaneously. Recently, femtocells (also called small cells or Home eNode) are used by network operators to enhance indoor coverage and to meet the traffic demand. Femtocells are low powered small base stations which can be deployed in home/office enterprises. OFDMA femtocell networks can overcome indoor coverage problems and mitigate interference issues. To fully realize the potential of these networks, it is necessary to allocate resources optimally. Clustering can be used as a technique to reduce co-tier interference by coordinating the transmissions of FAPs in a dense deployment scenario and to reduce the complexity of resource allocation problem . The proposed algorithm uses a clustering scheme for downlink resource allocation in OFDMA femtocells network to provide throughput satisfaction among its users.*

IndexTerms:*Femtocell, OFDMA, interference mitigation, Femto-User satisfaction, Resource allocation*

I. Introduction

The demand for high quality wireless communication for mobile applications is continuously increasing since past years. The cellular networks find it difficult to handle this high increase in users demand as its coverage area and capacity is not sufficient. According to [2], more than 50% of voice calls and over 70% of data traffic occur from indoor users. Instead of deployimg large number of macrocells, a key piece of solution to provide high quality indoor coverage is to use femtocell or Small cells. Femtocells or Femto-Access Points (FAPs) are short ranged,low-powered base station which can be deployed inside a home or office building to provide cost effective and high bandwidth services to the end users.

Apart from these advantages, one of the major challenges faced by the femtocells are the interference issues. There are mainly two types of interference. They are cross-tier interference and co-tier interference. Cross-tier interference occurs among network elements that belong to the different tiers of the network, i.e., interference between femtocells and macrocellswhereas Co-tier interference occurs among network elements that belong to the same tier in the network. In case of a femtocell network, co-tier interference occurs between neighboring femtocells.

One practical solution for reducing interferenceissues in femtocells is by adopting Orthogonal Frequency Division Multiple Access (OFDMA) technology. OFDMA is a multiple access technique which works by allocating different subchannels to multiple userssimultaneously.Thus, OFDMA-femtocell networks can overcome indoor coverage problems and utilizes spectrum efficiently. The OFDMA exploits multi-user diversity by assigning resources according to channel qualities of Femto-user equipments(FUEs).

OFDMA is used by Long Term Evolution (LTE) for downlink communication purposes. LTE provides high data rates, flexible bandwidth capabilities, lower latency and high capacity for the systems. In OFDMA-LTE systems, the base station is called the evolved Node B or eNodeB (eNB) and the mobile terminal is called as the user equipment (UE).OFDMA frame structure can be viewed as time-frequency resource blocks (RBs) or tiles. A resource block (RB) is the fundamental unit of resources which can be used for allocating a user. Each user is allocated a number of RBs in time-frequency domain.A RB consists of 12 subcarriers along frequency domain and 7 OFDM symbols along the time domain as shown in Figure 1 [10]. The subcarrier spacing is 15kHz and is independent of the channel bandwidth. A time slot is of duration 0.5 millisecond and is formed by 7 OFDM symbols. A resource block pair comprises of 14 OFDM symbols and 12 subcarriers. It has (12 x 15 kHz) 180 kHz bandwidth and 1ms duration which forms a subframe(2 slots).

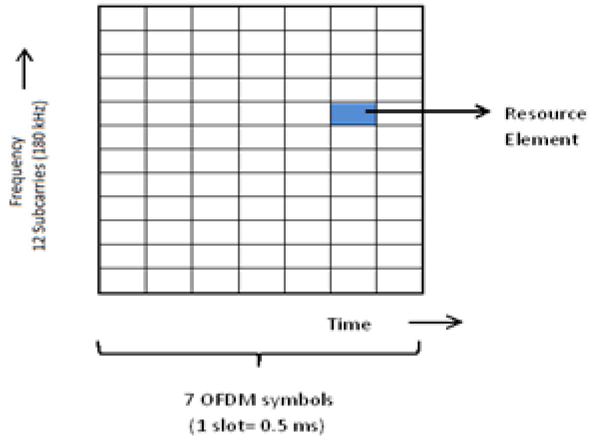

Figure 1: Resource Block

A resource element is the smallest unit which consists of one OFDM symbol along time domain and one subcarrier along frequency domain. Several resource elements form a resource block.Thereare two types of resource allocation schemes: shared-spectrum and split-spectrum schemes. In the first case, femtocells use the same frequency band as macrocells. On the other hand, in the case of split-spectrum schemes, FAPs use different frequency bands than those employed by macrocells, which can drastically simplify the interference management and resource allocation complexity.

II. System Model

Consider an OFDMA- femtocell's network consisting of several FAPs representing a residential or office networks. Closed access mode is assumed for the femtocells.. The number of UEs attached to each FAP is taken as four. The location of FAPs and FUEs are randomly selected.

A. Pathloss Model

The pathloss model is evaluated for estimating the signal to interefernce plus noise ratio(SINR). It is modeled based on [9].

Pathloss for outdoor UE with Macro BS (MBS) is given by:

$PL(dB) = 15.3 + 37.6\, log\, R$ (1)

For the case ofindoor UE with Macro BS (MBS)thepathloss is determined by:

$PL(dB) = 15.3 + 37.6\, log\, R + L_{ow}$ (2)

where R: distance between transmitter and receiver (in meters)

L_{ow}: outdoor wall penetration loss

The path loss between a femto base station and a UE is calculated by the following equation:

$$PL = 38.46 + 20\log_{10} R + 0.7 d_{2D,indoor} + 18.3 n^{(n+2)/(n+1)^{-0.46}} + q * L_{iw} \quad (3)$$

where $0.7 d_{2D,indoor}$: shows penetration loss due to walls inside the apartment(in meters)

n: number of penetrated walls

q: number of walls separating apartments between the femto BS and the UE

L_{iw} :indoor wall penetration loss

B. Sinr Estimation And Throughput Calculation

The channel gain G is affected by different pathloss scenarios and is determined by:

$G = 10^{-PL/10}$ (4)

The received SINR for a FUE j on a subcarrier k is given by:

$$SINR_{j,k} = \frac{P_{F,k} G_{j,F,k}}{N_o \Delta f + \sum_M P_{M,k} G_{j,M,k} + \sum_F P_{F,k} G_{j,F,k}} \quad (5)$$

where $P_{F,k}$: transmit power of femtocells on subcarrier k

$G_{j,F,k}$: channel gain of FUE j on kth subcarrier ofFAP F

$P_{M,k}$: transmit power of macrocell on subcarrier k

$G_{j,M,k}$:channel gain between FUE j and macrocell M on kth subcarrier

N_o:white noise power spectral density

C. Throughput Calculation

Based on the SINR estimation, throughput of the femtousers are calculated. It is given by:

$TP^{req} = \Delta f \log_2\left(1 + \propto SINR_{j,k}\right)$ (6)

where$\propto$ is a constant for target Bit Error Rate(BER) and is determined by:

$$\propto = \frac{-1.5}{\ln(5BER)}$$

D. Demand Calculation

The users attached to each FAP demands for their required bandwidth in terms of number of tiles needed by them for an efficient transmission. The users demand (D_j, expressed in number of tiles) is related to the throughput requirement of each users estimated using (6). The required tiles of user j is given by:

$$D_j = \left\lceil \frac{TP_j^{req}}{\varphi . eff_j} \right\rceil \quad (7)$$

where$\psi = (SC_{ofdm} \cdot SY_{ofdm})/T_{subframe}$ is a fixed parameter that depends on network configuration.

SC_{ofdm} : number of subcarriers per tile

SY_{ofdm} :number of OFDM symbols per tile

$T_{subframe}$: frame duration in time units

eff: efficiency of the used modulation and coding scheme in bits/symbol

Proposed Algorithm

A cluster based Resource Allocation in OFDMA femtocell network is a framework in which tiles are allocated to users in each FAP in a fair manner. This system consists of two phases:

1. Cluster formation phase
2. Allocation phase

A. Cluster Formation Phase

In this phase, clusters containing certain FAPs are formed using the algorithm in [5]. When powered on, a FAP will listen to the surrounding transmissions and gather information from users attached to it. Based on this information, the FAP can compute the interfering femtocells and transmit it to the neighbouring femtocells. Therefore, each FAP will have a list containing the interference values of neighboring femtocells and will decide whether it is a cluster head (CH) or is attached to a neighboring cluster. According to this interference value, the femtocells are divided into clusters. Those femtocellswiththeirinterference value above a minimum threshold is grouped to a cluster and the remaining FAPs are grouped to another cluster. The CH election algorithm can be described as follows:

- Each femtocell elects the CH as the one with the highest interference value among its one-hop neighbors.
- If it is not a CH itself, the femtocell acts as a cluster member (CM) of a CH chosen by its immediate neighbors.
- If more than one unique CH is chosen by the neighboring femtocells, the one with the highest interference value is elected as the CH to minimize the collision of tiles between femtocells.
- Inorder to avoid large cluster size due to the attachment of femtocells to the clusters, a threshold is set on its size denoted by CS_{th}. When the threshold is reached, the corresponding femtocell will act as an isolated CH.

B. Allocation Stage

Once the femtocell network is partitioned into clusters, the second step is to jointly allocate resources to all FAPs within each cluster, taking into account their tile requirements of the attached users. To achieve this, each CM reports to its corresponding CH the required resources to satisfy its user's demands. The goal of the allocation stage is to assign resource blocks (RBs) or tiles to femtocells such that the same tile is not assigned to two interfering femtocells. After forming clusters, it executes the allocation algorithm. If an algorithm only tries to maximize the throughput expectations, it might just assign the tiles to the users randomly. But in this approach the goal is to maximize throughput while considering the interference issues. One way to do this is to use a fair allocation of resources among users.

In this allocation phase, after partitioning the femtocells into clusters, the whole available bandwidth is divided according to the number of clusters. Therefore a fixed amount of resources is made available for each cluster. The users are then allocated with the tiles available for each cluster till the remaining tiles in each cluster vanishes. At each allocation step *i*, that is, when tile *i* is being allocated, this algorithm looks at the FAP with the minimum assigned number of tiles and then allocates tile *i* to this FAP if needed by the user according to their demand. The advantage of this algorithm is that no two interfering femtocells uses the same tile/ Resource block thus avoiding collision on the tiles and mitigates the interference issue.

Simulation Results

An OFDMA- femtocell network was modelled first using MATLAB as the simulation platform. The parameters for the simulation are listed in Table I. The locations of FAP and FUEs are taken randomly. Figure 2 shows the environment scenario with 8 FAPs and 4 FUEs associated with each FAP. In this figure, the green mark shows the position of FAPs and red shows the FUEs attached to each FAP.

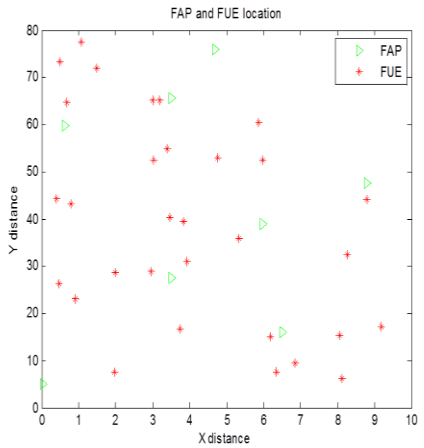

Figure2: MATLAB environment scenario with 8 FAPs and 4 femtousers in each FAP

Figure 3 showsthe throughput requirement evaluated using equation (6), for each user in each FAP ,whereasFigure 4 shows the total throughput requirement of all the users in each FAP which isexpressed in bits per second (bps).

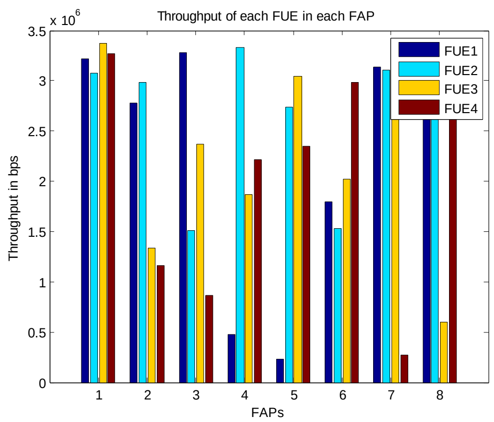

Figure 3: Throughput requirement of each FUE in each FAP

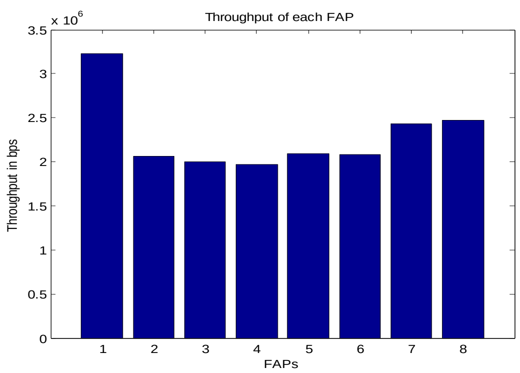

Figure4: Throughput of each FAP

According to the throughput requirement, the demand of each users are computed in terms of number of tiles. The demand required by the users in each FAP is depicted in Figure5. In the case of FAP1, the third user has a higher demand of 6 tiles while the other users of the same FAP requires 5 tiles each. This shows that the demand for tiles for the usesr may vary according to their throughput requirement.

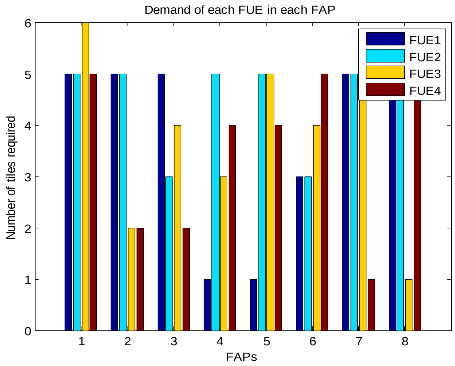

Figure 5: Number of tiles required for each users in each FAP

Fig 7.5 shows the FemtoUser Satisfaction Ratio which represents how close the femtouser throughput is to the maximum throughput of a user in the same Femto-access point(FAP). Ti is calculated using:

$$FUS = \frac{\sum_{j=1}^{U} TP_j^{req}}{\max(user\_throughput) \times U}$$

Where U is the total number of users in each FAP

TP_j^{req} : throughput required for each user j in

$\max(user\_throughput)$: maximum throughput value achieved by the user in that particular FAP

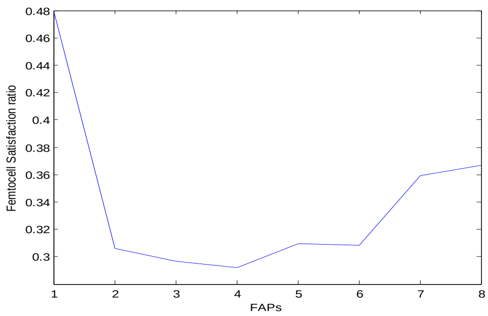

Figure 6: FemtoUser Satisfaction Ratio

Figure 7 and Figure8 show the tile allocated for users in Cluster 1 and Cluster 2 respectively. According to the setup used for simulation FAPs 2,3,4,5 and 6 were grouped to Cluster 1and the remaining FAPs 1, 7, 8 formed Cluster 2. The tiles are allocated to each user according to their demand.

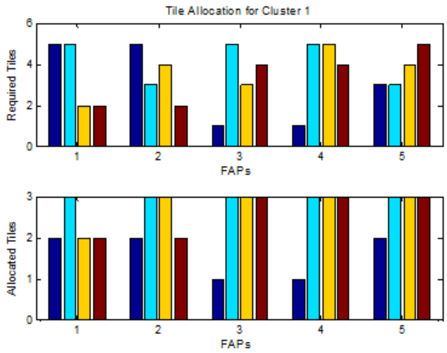

Figure 7: Tile allocation for Cluster 1

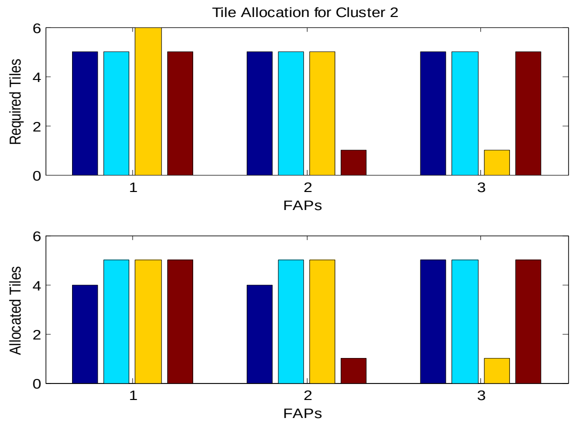

Figure 8: Tile allocation for Cluster 2

In Cluster 1, the required demand for all the users were not fully satisfied since the sum of users demand exceeds thenumber the tiles which was made available for the first cluster, whereas in the case of Cluster 2, most of the users demand werefullysatisfied.

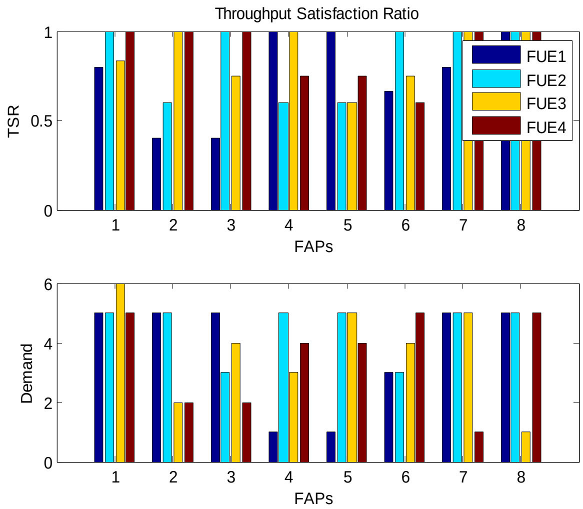

Figure 9: TSR vs Demand

The performance of the network is evaluated using throughput satisfaction ratio(TSR) associated with users in an FAP. Throughput satisfaction ratio of a FAP is the ratio of the allocated number of tiles to the tiles requested by the users in that FAP.

$$TSR(j) = \frac{\left(\sum_{i=1}^{N} \Delta_j(i)\right)}{D_j}$$

Where N is the total number of available tiles
$\Delta_j(i)$: binary allocation matrix with 1 or 0 in position i whether the tile i is used or not

Figure 9shows an analysis of TSR and the demand of all the users in each FAP associated within the clusters. It is shown thatallthe users having low demands are fully satisfied first and then a fair resource allocation is done for the remaining users. The fairness of the system can be evaluated in terms of Jain's Fairness index. It is expressed as [5]:

$$\beta = \left(\sum_{j=1}^{U} TSR(j)\right)^2 \Bigg/ \left(U.\left(\sum_{j=1}^{U} TSR(j)\right)^2\right)$$

III. Conclusion

A cluster based resource allocation in OFDMA-femtocell network is studied. It consistsof mainly two phases: Cluster formation and Allocation phase. The whole OFDMA frame is divided into frames known as Resource blocks/tiles and each user is allocated with different number of tiles according to their demand. Inorder to avoid interference issues, no two interfering users are allocated with the same tile. Clustering is done to mitigate interference issue and to reduce the complexity of the resource allocation problem. The proposed algorithm used a clustering scheme fora fair resource allocation in the downlink of an OFDMAfemtocell network to provide throughput satisfaction among its users.

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