Femtocell Cluster-based Resource Allocation Scheme for OFDMA Networks

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Abstract *– This is our term project for the course COE-540 namely computer networks. We chose "Femtocell Cluster-based Resource Allocation Scheme for OFDMA Networks" [17] to reproduce result and learn how to use experimental tools and write-up a research paper. We learn a lot about how to solve optimization problem, problem formulation, result and analysis etc from this experiment. However, recently -operators have resorted to femtocell networks in order to enhance indoor coverage and quality of service since macro-antennas fail to reach these objectives. Nevertheless, they are confronted to many challenges to make a success of femtocells deployment. In this paper, we address the issue of resources allocation in femtocell networks using OFDMA technology. Specifically, author proposes resource allocation strategy namely Femtocell Cluster-based Resource Allocation (FCRA). In this paper we do two experiment such as cluster formation and resource allocation for each cluster and finally we do analysis our result sets.*

Key words *– OFDMA, femtocell, cluster, mobile network, throughput, resource allocation.*

1. Introduction

In telecommunications, a **femtocell** is a small, low-power cellular base station, typically designed for use in a home or small business. It connects to the service provider's network via broadband (such as DSL or cable); current designs typically support two to four active mobile phones in a residential setting, and eight to 16 active mobile phones in enterprise settings. It improved coverage and potentially better voice quality and battery life. When femtocells are used in areas of poor or no coverage, macro/femto interference is unlikely to be a problem. If the femto network is sharing the channel (co-channel) with the macro network, interference can occur. However, if the interference management techniques advocated by the Femto Forum are adopted, the resulting interference can be mitigated in most cases. A femtocell network deployed on an adjacent dedicated channel is unlikely to create interference to a macro network. Additionally, the impact of a macro network on the performance of a femtocell on an adjacent channel is limited to isolated cases. If the interference mitigation techniques advocated by the Femto Forum are used, the impact is further marginalized. Closed access represents the worst-case scenario for creation of interference. Open access reduces the chances of User Equipment (mobile phone handsets, 3G data dongles, etc.) on the macro network interfering with a proximate femtocell. The same conclusions were reached for both the 850 MHz (3GPP Band 17) and 2100 MHz (3GPP Band 1) deployments that were studied.

Since the introduction of 3G services, customers demand more and more data while exacting high quality of service (QoS). In fact, mobile phone data traffic is forecast to increase 10 to 30 times between 2010 and 2013 [1]. On the other hand, most of the traffic takes place inside buildings where the macro antennas' coverage is quite poor [2]. To fend off this weakness, operators make use of femtocells (a.k.a. home base stations) to enhance indoor coverage and network capacity [3]. Femtocells are small wireless access points deployed inside buildings and connected to an operator's network commonly through a digital subscriber line (DSL) connection or fiber. Femtocells Access Points (FAP) are administered by operators and make use of licensed spectrum technology (e.g. UMTS, LTE, WiMAX). Thanks to FAPs, indoor coverage and quality of service in terms of bandwidth are significantly improved. Nonetheless, due to the high density of FAPs, many new chal- lenges have not been sufficiently addressed such as resources allocation and interference management. Finding the optimal resource allocation between FAPs in such highly dynamic and dense environment is, in general, a non-linear non-convex NP-hard optimization problem [4]. Hence, an optimal solution can- not be generated in large-sized networks and even in small-sized network with large set of constraints. Consequently, several heuristics have been proposed in the literature, which can be classified as either centralized or distributed.

The main problem of distributed method is allocating resource for each femtocell with in a short period of time. In this paper, we propose a new scalable resource allocation algorithm called *Femtocell Cluster-based Resource Allocation* (FCRA) for OFDMA based femtocells. Our proposal is satisfy maximum cluster's resource demand in a given time rather than tried to fulfill demand of all femto's. Our ob- jective is to associate the best spectrum set of frequency/time resources with each FAP in order to deliver the users data, while minimizing the gap between the required and allocated tiles and at the same time minimizing interference between FAPs. To achieve this, we formulate the resource allocation as a Min-Max optimization problem involving two main phases:
(i) Cluster formation
(ii) Cluster-head resource allocation

First, FCRA makes use of a distributed algorithm to build disjoint femtocell clusters. Then within each cluster, a Cluster-Head (CH) is elected, which assigns resources to all FAPs in its cluster taking into account their required bandwidth. Accordingly, each CH resolves the Min-Max optimization problem and converges to the optimal solution in a timely manner, as shown in this paper. To evaluate the efficiency of our proposal, we show a comparison between demand vs allocation of resources and also shown that throughput satisfaction rate for FAPs cluster.The obtained results show that FCRA converges to the optimal solution in small-sized networks. The rest of this paper is organized as follows. Next section discusses the previous works. Section 3 presents the network model and then section 4 describes cluster formation algorithm. Section 5 formulates the OFDMA resource allocation problem mathematically. Section 6 introduces experimental setup and result and analysis section is given in section 8. Finally conclusion and future work is shown in section 9.

2. Previous work

Resource management in OFDMA-based femtocell networks is a new concept and novice research area. Very few researches are done so far. In the following, we describe some of the main related works.

In [5], the authors proposed three resource allocation algorithms in OFDMA femtocells. The objective was to avoid interference between femtocells and macrocells in order to maximize the global network throughput. It divides the spectrum into two independent sets used by the macrocells and femtocells, respectively. However, no details are given to find its optimal value.

The authors in [6] proposed a distributed resource allocation algorithm namely Distributed Random Access (DRA), which is more suitable for medium-wide networks. The resources, represented as time-frequency slots (tiles) are orthogonalized between macrocells and femtocells based on the gradient ascent/descent heuristic. Moreover and

as opposed to our work; the throughput satisfaction rate of femtocells has not been considered in the analysis.
In [7], the authors propose a decentralized F-ALOHA spectrum allocation strategy for two-tier cellular networks. The proposal is based on a partition of the spectrum between the macrocell and femtocells. Once computed, each femtocell accesses a random subset of the candidate frequency subchannels. In addition,this scheme does not consider time-frequency slots as resources. Instead, it focuses on sub-carriers allocation.

3. Network Model

We consider a macro based hybrid network including a set *F* femtocells. That belongs to an enterprise or residential networks as shown in fig (1).

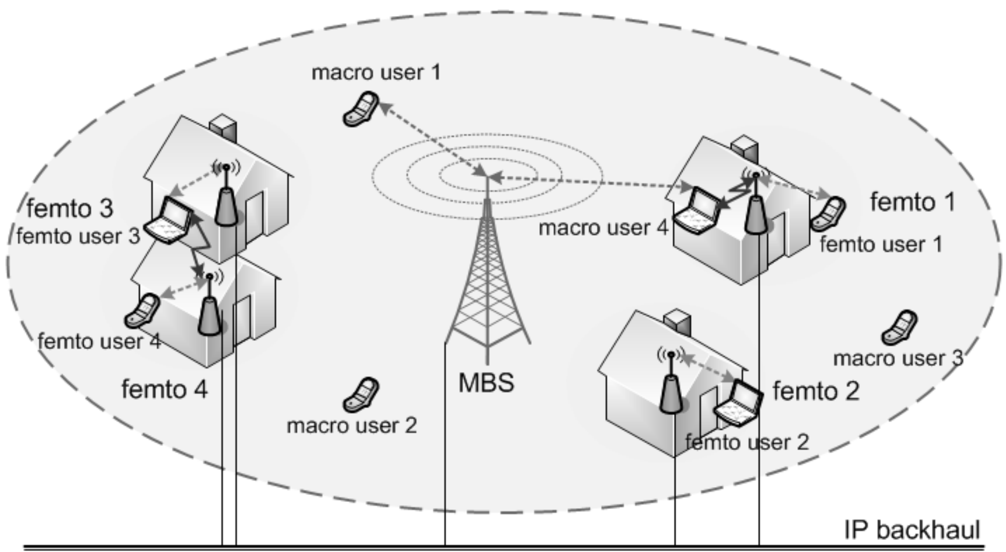

Fig 1: Macro/Femto Network Model.

To eliminate cross-layer interference is to divide the licensed spectrum into two parts (*orthogonal channel assignment*). This way, a fraction of the subchannels would be used by the macrocell layer while another fraction would be used by the femtocells. This approach is supported by companies such as Comcast, which have acquired spectrum to be used exclusively by their WiMAX femtocells. Although optimal from a cross-layer interference standpoint, this approach is inefficient in terms of spectrum reuse. Therefore, *co-channel assignment* of the macrocell and femtocell layers seems more efficient and profitable for operators, although far more intricate from the technical point of view.
OFDMA technology is used for both macrocells and femtocells and used time slots called tiles here. We consider downlink communication in our network model. Our objective is then to find the optimal allocation of resources dedicated for femtocells to deliver the users data, while minimizing the interference between femto/femto and at the same time ensuring the required QoS.

4. Cluster Formation

First, each FAP creates it one hop neighboring interference femtocell list then send to share with corresponding one hop neighbors so, every hop FAP can count the number of interfering femtocells that mention in this paper is interfering degree. According to this information a cluster head needs to be a cluster head and acknowledge to other cluster members. If more than one unique CH is chosen by the neighborhood's femtocells, the one with the highest interference degree is considered as CH in order to minimize the tiles' collision between femtocells (if equal degrees, a random tie-break is used). However, if no CH is chosen by the neighborhood's femtocells (i.e., all neighbors act as CMs and are associated to other clusters), the FAP is attached to the cluster of the neighbor with the highest interference degree. More formally, the cluster formation stage is described by the pseudocode in Algorithm 1.

Algorithm 1 **Cluster Formation Algorithm**

1: F_a creates the 1-hop neighbouring interfering femtocells list

2: F_a sends the associated interfering list to its 1

3: if F_a has the highest degree of interfering neighbours then

4: F_a elects itself as a cluster-head

5: else

6: if F_a is interfering with cluster-heads then

7: Fa attaches itself to the cluster administered by its highest interfered neighbour cluster- head

8: else

9: F_a selects the highest interfering neighbor femtocell F_b

10: F_a attaches itself to the F_b's cluster

11: end if

---

5. Resource Allocation

Problem 1 Min-Max femtocells resource allocation problem

$$\forall \; F_a \in \text{F: min } [\; max_a(\frac{R_a - \sum_{i,j} \Delta_a\,(i,j)}{|F| \times \; R_a})\;]$$

Subject to :

$(a) \qquad \forall F_a \; \epsilon F: \qquad \sum_{i,j} \Delta_a \;(i, \boldsymbol{j}) \;\le\; R_a$

$(b) \; \forall \boldsymbol{i}, \boldsymbol{j}, \; \forall F_a \; \epsilon F, \forall F_b \;\; \epsilon \boldsymbol{I}_a \; : \; \Delta_a \;(i, \boldsymbol{j}) + \Delta_b \;(i, \boldsymbol{j}) \le 1$

$(c) \; \forall \boldsymbol{i}, \boldsymbol{j}, \qquad\qquad \forall F_a \; \epsilon F : \qquad \Delta_a \;(i, \boldsymbol{j}) \; \epsilon \{0, 1\}$

Fa is a femtocell and *F* is set of femtocell. *Ra* is the required number of resource per femtocell where Δa denotes allocated number of resources per femtocell. Our objectives are minimizing the gap between the number of demand and allotted resources as well as maximize the number of femtocell get resources is shown in Problem (1). To do so, subjective condition describes here that number of allotted resource should be less than requirement and no tiles can be used by two interfering femtocells at the same time. Inteference of each femtocell is measured by using A1-type generalized path loss models for the frequency range 5 GHz developed in WINNER [14]. In addition, we define for each femtocell *Fa* the binary resource allocation matrix denoted by Δa, with 1 or 0 in position (i,j) according to whether the tile (i,j) is used or not. To represent the users' demands, we introduce a vector *Va* whose elements correspond to the bandwidth required by users associated with the femtocell *Fa*. We denote by *Ra* the total number of tiles required by the femtocell *Fa* to fulfill the attached users' demands (i.e., $Ra = \sum_{i=0}^{na} Va\,(i)$ where n_a is the total number of users belonging to femtocell *Fa*. The number of end users that can be associated with each femtocell follows a random uniform distribution with a maximum value of 4 per femto.

6. Experimental setup

As stated earlier, we have done two experiments are following – FAPs distribution then cluster formation and min max optimization for resource allocation. Table 1 shows used tools and software.

Sl no	Tools Name and version	Purpose	Configuration
1	WIINER II A1-type [14]	To find SINR and compare with threshold	Frequency = 5 GHz
2	MatLab R2013b	Distribute FAPs, Cluster formation based on Algorithm 1and Result analysis.	Area = 400mX400m Single FAP area = 10mX10m, max. end users = 4 per FAP. Number of FAPs = 25 and 50
3	IBM ILOG Cplex 12.6 [16]	To solve Problem 1. Resource allocation and optimization.	Number of FAPs = 25* $0 \leq$ demand per FAP ≤ 25 Number of resource = 6X6 = 36*

Table 1: Used Tools and software.

First of all we distribute 25 FAPs in 400mX400m based on Bernoulli distribution. Then computed list of one hop interfering femtocell for each femtocell based on equitation 3 that is shown graphically in fig 2.

$$xLower = \{floor(x/10) \times 10\} - 10 \quad (1)$$

$$xUpper = \{Ceil(x/10) \times 10\} + 10 \quad (2)$$

yLower and yUpper is calculated similarly.

$$x >= xLower \text{ and } x <= xUpper \text{ and } y >= yLower \text{ and } y <= yUpper \quad (3)$$

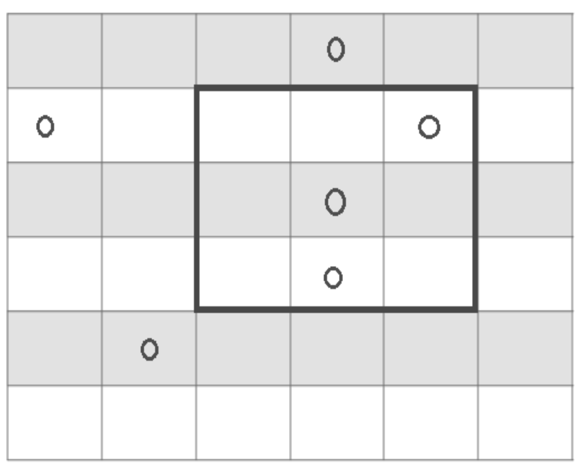

Fig 2: One hop boundary for FAPs.

By using this condition we computed number of interfering femtocell I_a for each femtocell that is shown in table 2 and then computed distance from one to another for all. After that calculated path loss from macro base station to a FAP according to the equation 4 where d denotes distance between two femtocells *fc* is signal frequency. In this case we consider $SINR_{threshold}$ = 10dB.

FAPSs Id	Number of Interfering Femtocell	Distance
8	1	10
14	1	10
17	1	10
38	1	10
42	1	10
45	1	10

Table 2: Interfering femtocell and distance

$$Path\ loss = 20 \log_{10} (d) + 46.4 + 20 \log_{10} (f_c/5.0) \qquad (4)$$

Based on SINR value and interfering degree we made cluster. Once cluster formation is finished we did second experiment that is resource optimization for each cluster. We used optimization tool IBM ILOG Cplex to allocate limited resources among femtocells. All intellectual property is shown in appendix section.

7. Result and Analysis

In this section, we evaluated performance of our proposal and reproduction of standard paper [17]. We run both experiment 30 times and choose best result. The distribution and cluster is shown in fig 3.

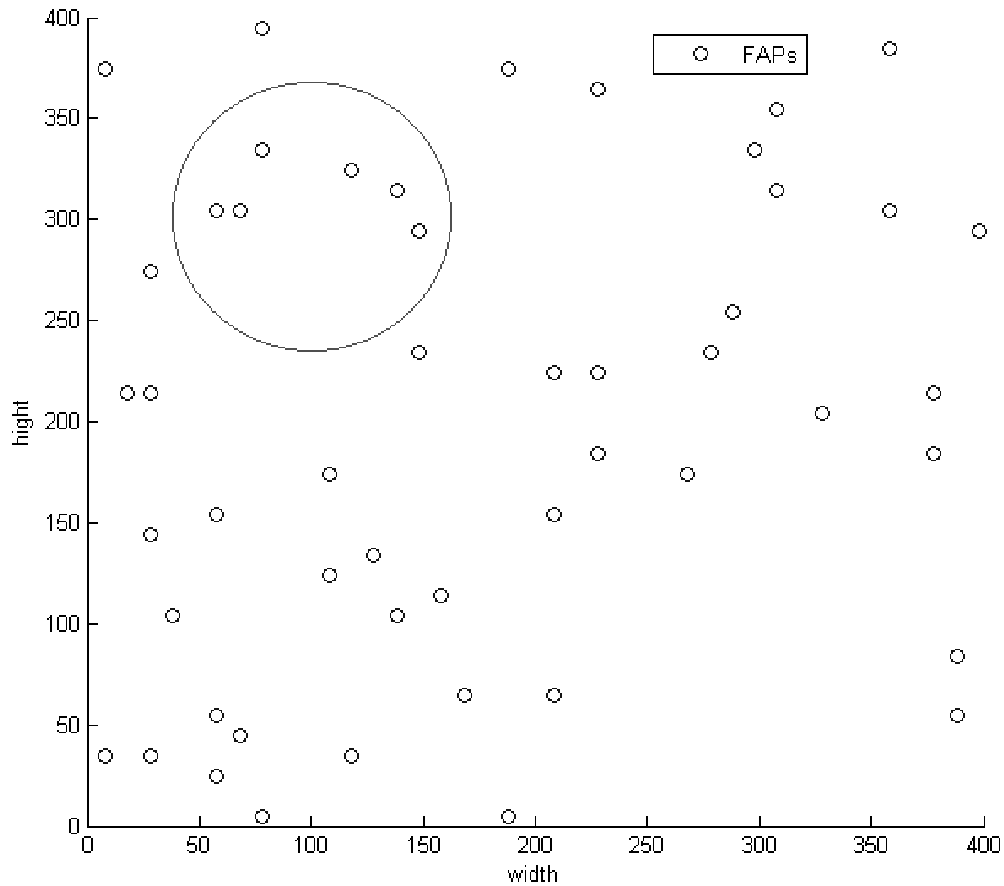

Fig 3: FAPs cluster

Min-Max Resource allocation problem is NP hard problem so, we subdivided whole problem in to sub problems and tried to satisfy clusters one after one. To do so, we distributed 6X6 tiles among 25 FAPs based on their demand. The demand versus allocation for each femtocell is shown in fig 5. We run optimization solver in a personal computer having following configuration core i3 2.4GHz, 4GB RAM, 64bit OS(Win7). Detailed optimization result is shown below where allocation is 2D matrix. It takes 280ms with bound 0.8623.

```
Allocation[femtocell][resource] =
        [[0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0]
          [1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0]
          [0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 0 0]
          [0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
          [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0]
];
```

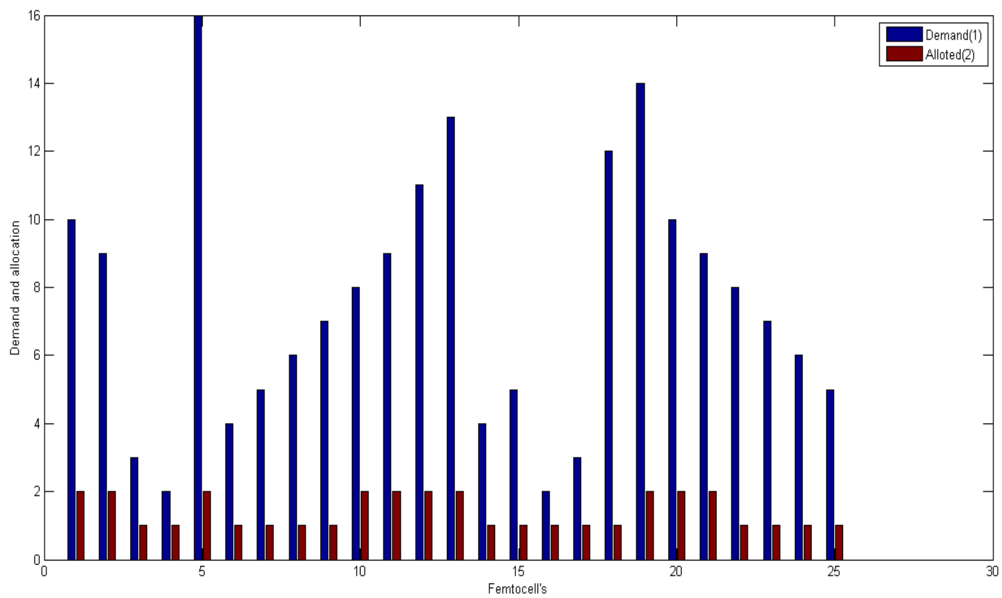

Fig 4: Demand Vs allotted resource.

Throughput Satisfaction Rate (TSR): TSR denotes the average degree of satisfaction of a femtocell with respect to the requested resources. For each femtocell *Fa*, *T S R*(*Fa*) is defined as the ratio of the received number of allocated tiles to the total requested ones and can be expressed as follows:

$$\forall Fa \in F: \quad TSR\,(Fa) = \left(\sum_{i,j} \Delta a\,(i,j)\right) / Ra \tag{5}$$

The TSR metric can be thus given by:

$$TSR = \sum_{Fa \in F} (Fa) / |F| \tag{6}$$

Title	**Value**
Total Demand	188
Total Allocation (36)	35
TSR	22%
SSR	3.8%
Computational Time	280 ms
Best Bound	0.8623

Table 3: Optimization summary

Clearly observed that problem 1 is solved in a way that it tried to minimize the gap between demands and allotted resources as well as satisfy every FAP in the network that is shown in fig 4. Detailed optimization result is shown in table 3 and appendix. CDF vs TSR is shown in fig 5.

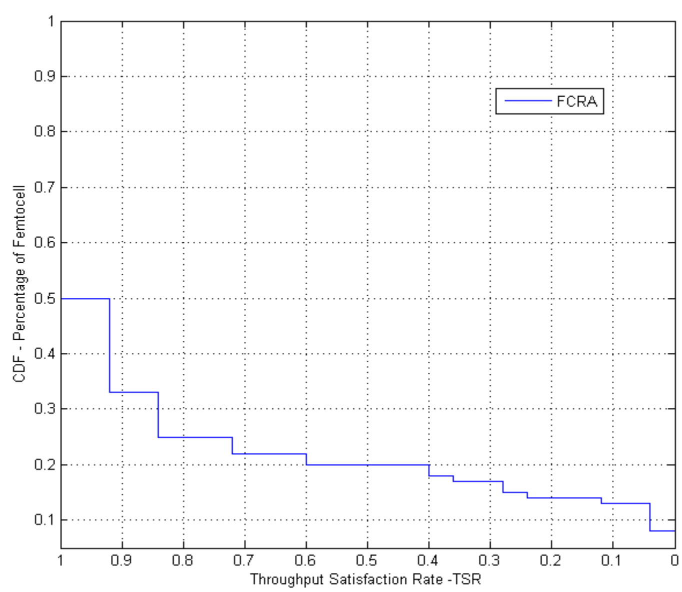

Fig 5: CDF Vs TSR

8. Conclusion And Future Work

In this paper, we studied the resource allocation problem in OFDMA-based femtocell networks and author's of this paper proposed a new allocation scheme called Femtocell Cluster-based Resource Allocation (FCRA). FCRA is based on a hybrid centralized/distributed approach and involves three main phases: (i) Construction of disjoint clusters; (ii) Optimal cluster-head resource allocation by resolving a Min-Max optimization problem; the results concern the throughput satisfaction rate, the spectrum spatial reuse. We tried to reproduce similar result by following same procedure of experiment but due to some limitation we did only in a small scale and tried to prove that FCRA is best approach to solve resource allocation problem for femtocell network. In the future, we plan to compare results with Centralized Optimal (C-DFA) and Distributed resource allocation (DRA) methods.

9. Acknowledgement

WINNER II is a trademark of **Information Society Technology**™

IBM ILOG Cplex optimization studio is a trademark of **IBM** with student license.

10. References

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11. Appendix

Code.m

```
%creating feps location
[x_loc,y_loc,I,col,row] = DistributeFCs(50, 400, 10);
scatter(x_loc,y_loc)
clc

%concatenating x_loc and y_loc of each fep
feps = [x_loc; y_loc];
distance = zeros(50,9);
for i=1:50
    u = [0;0];
    j=feps(:,i);

    xLower = (floor(j(1)/10)*10)-10;
    xUpper = (floor(j(1)/10)*10)+20;

    yLower = (floor(j(2)/10)*10)-10;
    yUpper = (floor(j(2)/10)*10)+20;

    for q = 1:50
        if q~=i
        hop = feps(:,q);
            if hop(1)>=xLower && hop(1)<=xUpper && hop(2)>=yLower && hop(2)<=
yUpper
                j
                hop
                distance(i,q) = pdist2(j',hop');
```

```
                distance
            end
        end
    end
%     u(:,1) = [];
%     singleDistance = pdist2(j',u');
%     singleDistance
%     l = length(singleDistance);
%     for p = 1:l
%         distance(i,p) = singleDistance(p);
%     end
end
%constant definition
A = 36.8;
B = 43.8;
C = 20;
frequency = 4;

loss = A*log10(distance) + B + C*log10(frequency/5);
```

distributeFCs.m

```
function [x_loc, y_loc, I, col, row] = DistributeFCs(N, L, L1)
%
% no of L1 by L1 tiles in one row/column of the overall L by L area
n = floor(L/L1);

number = n*n;
% get N uniform random indices from 1 to n*n
I = randperm(number,N);
row = floor((I-1)./n)+1; % compute the col/row in the grid from index
col = mod(I-1,n)+1;

% tiles are determined - now locate the FC inside the L1 by L1 tile
loc_tile = L1*rand(1,2); % uniform within the L1 by L1 tile
x_loc = (col-1)*L1 + loc_tile(1); % compute location relative to origin
y_loc = (row-1)*L1 + loc_tile(2
```

fcra.mod

```
/*********************************************
 * OPL 12.6.0.0 Model
 * Author: Cobra
 * Creation Date: Dec 1, 2014 at 2:50:44 AM
 *********************************************/
int f=...;
int t=...;

range femtocell = 1..f;
range tiles = 1..t;

dvar boolean allocation[femtocell][tiles];
int demand[femtocell]=...;
```

```
minimize max(i in femtocell) (((demand[i] - sum(k in tiles) allocation[i][k]))/
demand[i]);

subject to{
      forall(i in femtocell) demand[i] >= sum(k in tiles) allocation[i][k];
      forall (j in tiles) sum(i in femtocell) allocation[i][j] <= 1;
      }
```

```
Fcra.dat
```

```
/*********************************************
 * OPL 12.6.0.0 Data
 * Author: Cobra
 * Creation Date: Dec 1, 2014 at 2:50:44 AM
 *********************************************/
f = 25;
t = 36;

      demand = [10 9 3 2 16 4 5 6 7 8 9 11 13 4 5 2 3 12 14 10 9 8 7 6 5];
```

Detailed optimization output

```
No of femtocells, f = 25;
No of Resources, t = 36; (6*6)

Demand[femto] = [10 9 3 2 16 4 5 6 7 8 9 11 13 4 5 2 3 12 14 10 9 8 7 6 5];

Allocation[femto][tiles] =
          [[0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0]
            [1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0]
            [0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 0 0]
            [0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
            [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0]
];
```

Engine Log

```
        Nodes                                                     Cuts/
   Node  Left     Objective  IInf  Best Integer    Best Bound    ItCnt     Gap

*     0+    0                         0.8750        0.8623      808    1.45%
      0     0        0.8285    21        0.8750        0.8623      808    1.45%
      0     0        0.8537    13        0.8750      Cuts: 34      832    1.45%
      0     0        0.8580    16        0.8750      Cuts: 12      843    1.45%
      0     0        0.8597    15        0.8750      Cuts: 12      851    1.45%

Repeating presolve.
Tried aggregator 2 times.
MIP Presolve eliminated 48 rows and 178 columns.
MIP Presolve modified 18 coefficients.
Aggregator did 3 substitutions.
Reduced MIP has 11 rows, 13 columns, and 30 nonzeros.
Reduced MIP has 9 binaries, 0 generals, 0 SOSs, and 0 indicators.
Presolve time = 0.00 sec. (0.14 ticks)
Probing fixed 3 vars, tightened 1 bounds.
Probing time = 0.00 sec. (0.01 ticks)
Presolve time = 0.00 sec. (0.01 ticks)
Represolve time = 0.00 sec. (0.51 ticks)

Root node processing (before b&c):
  Real time             =    0.28 sec. (82.82 ticks)
Parallel b&c, 4 threads:
  Real time             =    0.00 sec. (0.00 ticks)
  Sync time (average)   =    0.00 sec.
  Wait time (average)   =    0.00 sec.
                          ------------
Total (root+branch&cut) =    0.28 sec. (82.82 ticks)
```

Zip Folder structure

Code – contains all code.

Report – contains all softcopy of given report and progresses.

Result – results and output graphs.