Using Clustering Techniques to Plan Indoor Femtocells Layout

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Summary
with the rapid growth of mobile data, more than 70 percent of this data traffic expected to generate from indoor environments as statistics show. Almost all our houses and offices have poor coverage. Operators of mobile networks need cost-effective solutions to innovate an accurate indoor coverage with high capacity. Data explosion caused by smartphones and tablets solved by introducing the heterogeneous network (HetNet). One of the HetNet is composed of small Femtocell with lower transmit power within a conventional macro-cellular network. To avoid randomly deployment of Femtocells, our paper presents a solution to plan the Femtocell base stations layout using Cluster techniques. This work takes into account the path loss influenced by different types of obstructing, such as different types of walls, windows, and doors. In this paper, DBSCAN and hierarchical agglomerative original algorithms were modified to solve the problem of coverage indoor area. The results of this algorithm indicate that the proposed algorithm conducts to decrease the number of Femtocells so minimize the cost and maximize SINR with a grantee pass loss.

Key words:
network planning, cell planning, mobile network, Heterogeneous Mobile Networks, Cluster Technique, PAM, Constraints Cluster

1. Introduction

With rapid grown of the mobile network, operators are willing to solve the problem of coverage in the indoor area, where more than 70 percent of this data traffic predicted to generate in indoor environments. Indoor subscribers with outdoor macro base transceiver stations (BTS) is very hard to at higher carrier frequencies. Again, higher-frequency waves have a harder time penetrating buildings, making life a lot tougher for service providers deploying LTE-Advanced, at 2.6 GHz rather than 700 MHz. A heterogeneous network is a good solution of a coverage problem. To handle indoor cellular data demands without significantly increasing operators' expenditure, use of femtocells has been suggested [1]. Femtocell or Femto Access Point (FAP) is a small, low cost, low power cellular base station deployed in users' homes, public areas, or office buildings. Indoor femtocell technology gained attention because it is extend the capacity and coverage at low cost [2]. The femtocell network enhances the cellular coverage and capacity in the indoor area by use the advantage of an Internet backbone [3]. Base stations of Femtocell inside homes permit users of mobile phone using their Internet broadband connection to do their calls. Femtocells are consumer useable base stations that use the broadband connection of consumer as backhaul. The inherent low transmission power capabilities of femtocells allow efficient reuse of available spectrum without significantly increasing interference to nearby users. Additionally, indoor users benefited by stronger signal quality, higher bandwidth, and better battery life because of the reduced uplink transmission power [4], which may be between 10 mW to 200 mW. Since placement locations of femtocells are random, traditional network planning techniques fail to circumvent the interference introduced by them to primary Macrocell and neighboring femtocell users.

The end-users deployed the Femtocell Access Points (FAPs) which are tiny base stations on their home or office site [5]. The mobile operators initially designed the FAPs to expand indoor coverage, targeting to enhance the capacity of the network and offload data traffic coming from the Macrocell Base Station (MBS), solve the problem of coverage holes, allowing the operators of the mobile network to concentrate on outdoor and mobile users. More advantages of femtocells are signal quality enhancement and infrastructure cost reduction.

The Femtocell called home base are low-power, low-cost, short-range BSs composite by the customer for maximal indoor data and voice reception. The customer composite device communicates with the mobile network over a broadband connection like a dedicated radio frequency (RF) backhaul channel or a digital subscriber line (DSL) or modem [6].

The advantages of using femtocells are that there is a little direct cost to the service provider and better capacity and coverage [7, 8].

The femtocell deployment and placement planning strategies are still in question. The impact of the building dimensions, plan structure, and floor or wall partition play significant roles in the placement and planning of

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femtocell base station [9]. The femtocells have gain or decay depending on user type and the access mode. Besides the distances to the macro site, transmit power and FAP density have an impact on coverage quality and interference.
The remainder of this paper organized as follows. Section II describes interference scenario. Section III describes path loss model. Proposed cluster algorithm presented in Section III. Performance evaluation and concluding remarks are given in Section V and VI, respectively.

2. Interference Scenario

The buildings react as "natural shields" which reduce the signal power from outside macrocells into the buildings. This effect called Building-Penetration Loss (BPL). Interference from the indoor system to outdoor networks attenuated also by the BPL.

- At the other hand with BPL=0, in this situation, the two systems indoor and outdoor robustly coupled and the inter-layer interference is the highest, i.e. between the indoor and outdoor systems there is no isolation. This may occur when the buildings are existing nearby the center of a Macrocell. In this situation, to add to the building of small cells (with the same frequency) is like to add cells to another center of the cell. This is the worst situation.
- If we consider BPL=∞, then both of two systems (the indoor and outdoor systems) are separated from each other. The indoor capacity is the highest; there is no inter-layer interference between indoor and outdoor systems, which is the better situation. Examples of infinite BPL are basements, subway stations, and terminals of an underground train.

In most real-life status, the situation lies between the two extremes; the BPL is zero or infinity. The lower the BPL, the highest interference of the inter-layer will be, and vice versa.
The values of BPL differ at various positions inside the same building. For example, a position beyond the second wall expected to be much more penetration loss compared to a position behind a first wall.
Another factor is the frequency. In general, signal attenuation from penetration increases with increasing frequency.
Note that, even for construction with few interior walls, we note that the deeper places inside the construction have the highest penetration loss. An example of this situation is the large shopping mall, where there exist dead zones approximately at the center of the mall where there are no many interior walls, especially on the first floor.
Another example is of the high buildings, where the BPL will be lower and the received power levels from outdoor macrocells are high at upper floors than at the lower floors, because of the shadowing effects of the surrounding buildings and other "clutter", so, the BPL effect will increase on lower floors.
These observations are significant for RF engineers when deploying indoor regardless of whether it is 2G or 3G, 4G or 5G because they can exploit the feature of unequal interference levels at various places inside the building. The allocation of RF resource for 5G indoor systems can consider the following: No or few constraints needed on femtocell-allocated RF resources (time and bandwidth), for locations with high BPL, which means higher indoor capacity.
For locations with low BPL for example near the windows, Interference mitigation methods, usually need some types of constraints on RF resources so the result is slightly lower capacity.
We can install Femtocells in public areas, homes or office buildings. Fig. 1 illustrates the different potential interference scenarios among the different types of deployment. In heterogeneous multi-cell networks, the interference is the major reason that damages the potential gain of small cells and makes its shape highly diverse, e.g., interferences in Femto-to-Femto, macro-to-macro, and macro-to-Femto. When increasing the number of small cells, severe interference grows put also the number of users at cell edges suffering from low through.
In dense metropolitan residential when femtocell deployments, there exist two possible interference outlines:

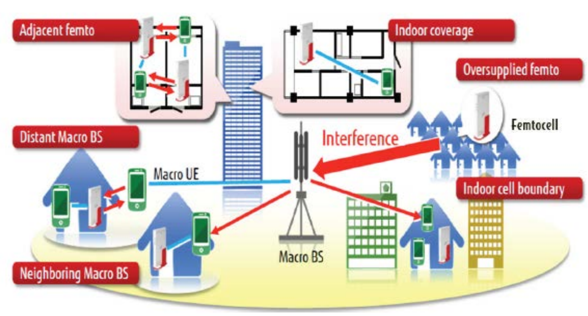

Fig. 1 Different interference concerns result from different types of femtocell deployment scenarios

(1) Inter-layer interference: The interference here will be between outdoor macrocell/microcell layer and indoor femtocell-layer. The essential interference of interest lying if BPL is too small, it is less of a concern if BPL is very large then it is less of a concern.
(2) Interference within the femtocell layer: It is also an essential interference which lying between neighboring femtocells inside the building. Femtocell position

accurately planned instead of randomly design is an enterprise deployment.

3. Pathloss Model

Li is the path loss under indoor environments. LI according to ITU-R model [10, 11], represented as:

$$L_i = L_{fs} + L_c + \sum K_{wj} L_{wi} + n^{\left(\frac{n+2}{n+1} - b\right)} L_{fi} \quad (1)$$

Where Lfs is a free space loss between transmitter and, it represented as

$$L_{fs} = - 10 \log_{10}\left(\frac{\lambda}{4\pi R}\right) \quad (2)$$

Where λ is a wavelength and R is a distance between transmitter and receiver.
Lc is a constant loss, and it is normally set to be 37Db.
Kwi and Lwi are the numbers of the penetrated walls of type I and the loss of wall type I respectively.
N is the number of the penetrated floors, and Lfi is the loss between adjacent floor.
Typical values of Lwi and Lfi described in Table 1.
B means an empirical parameter, typically set to 0.46.
If the frequency is 2.6 GHz then the building penetration losses described in Table 1.
The femtocell must carefully place to avoid interference.

Table 1: Pathloss Parameters and Values Regarding Wall Structures

Parameters	Description	value
L_{w1}	Concrete	15-30
L_{w2}	Brick	10
L_{w3}	Wooden floor	5
L_{w4}	Thick Glass	3-5
L_{w5}	Thin Glass	1-3
L_{w6}	Lift Door	20-30
L_{fi}	Reinforced concrete	41.3

For convenient analysis, some assumptions made and listed below.
Assumption 1: "For FBSs, the open access mode adopted, i.e. FBSs behave as regular BSs and are accessible by any user. This access mode considered to use widely for enterprise deployments, in shopping malls, cafes, and other public areas" [12, 13, 14].
Assumption 2: Each user can serve by at most one BS. Cell selection is based on minimum path loss between femtocell and user.
Specific macro–femtocell interference mitigation approaches (e.g. [15-18]) can additionally be applied without deteriorating the performance of our power control scheme. For this reason, we focus only on the problem of interference in the femtocell tier.

4. The Proposed Algorithm

In this Section, discussion of the formula, the constraints, and building dimensions are done in system model and the proposed OptCPLSINR algorithm which guarantees minimum threshold Pathloss value to all users inside the building and maximizes the signal to interference plus noise ratio SINR.
System Model
This work considers an LTE-A HetNet system comprising Macro Base Stations "MBSs" deployed in the outdoor environment and FBSs deployed inside the building. We also assume that the location of the user equipment's "UEs" is known inside the building and the layout of the building is available to the telecom operator. The FBS and MBS are assumed to operate in the same frequency band (i.e., reuse one) in LTE-A HetNet.
For convenient analysis, some assumptions are made and listed below.
Assumption 1: "For FBSs, the open access mode is adopted, i.e. FBSs behave as regular BSs and are accessible by any user. This access mode is considered to use widely for enterprise deployments, in shopping malls, cafes, airports, and other public areas" [19] [20] [21].
Assumption 2: Each user can be served by at most one FBS. Cell selection is based on minimum path loss between femtocell and user.
Assumption 3: in order to provide good signal strength and maximize the SINR to indoor users, all femtocells FBSs must operate at maximum transmit power.
Assumption 4: Specific macro–femtocell interference mitigation approaches (e.g. [22] [23] [24] [25]) can additionally be applied without deteriorating the performance of our scheme. For this reason, we focus only on the problem of interference in the femtocell tier.
The operator stores the building information (rooms number and coordinates), users locations and initial femtocells location into the database. Initially, femtocells are located at the center of each room in the ceiling. The program will extract data to calculate optimal locations for the femtocells using OptCPLSINR clustering algorithm. Finally, we get the location of femto base station FBS and all related information will be displayed.
The main goal is to distribute femtocells in a building considering the following constraints:

1. The path loss of the line between the femtocell and the user must be less than or equal to 88 dB, taking into consideration diverse types of obstacles and different penetration parameters.
   In Equation (3) [26], [27] if there is no obstruct between user and femtocell (free space) then femtocell can serve up to 50 meters.
   Li= 37 + 30 log10 d= 37+ 30*log10 50= 88 dB (3)
   Where Li is the path loss for user i.

Therefore, femtocell can serve user when path loss is less than or equal 88 dB.

2. Maximize Signal to Interference Plus Noise Ratio SINR: The SINR for the user is computed by Equation (4) [28] [29]:

$$\text{SINR i} = \frac{P_{rx}(a)}{\Sigma{\sim}aP_{rx} + N_0} \quad (4)$$

Table 2 shown the simulation parameters.

Table 2: Simulation Parameters

Transmission Power of FBS	10mWatt
Received Power Threshold	47.5dBm
Operating Frequency	2.6 GHz
SINR Threshold	2.2dB

The OptCPLSINR algorithm consists of two consecutive phases. The first phase builds one cluster for each FBS and identifies the users served by this FBS. The nodes, in this cluster, are divided into two types. The first type is the Femtocell base station “FBS” and the second type of nodes are the users. To construct this cluster, we proposed a modification method for clustering of heterogeneous networks. The proposed method is called semi-supervised clustering algorithm (Constraint clustering Technique) [30]. This type of algorithms allows the user to steer the clustering algorithm by providing information to the algorithm [31]. This information called a constraint, which provides the relation between two data instances as a pair.

In data mining, domain information usually represents the specific constraints in their systems. Examples of domain information such as temperature or time could have a huge impact on the experiments as constraints [32].

In this work, two main steps are done to reach the goal which is the optimal distribution of FBSs to serve all users with granted path loss threshold and maximized SINR.

The first step was, modifying the DBSCAN algorithm [33]. Two parameters must be determined in this algorithm Eps and MinPoint:

Eps is the radius of the circle, the center of the circle is a core. Core in DBSCAN algorithm is the point surrounded by the number of points equal or greater than Minpoint. All points in DBSCAN have a single type. Our problem in our case is different because we have two types of points; femtocell points and user points, so, we modify DBSCAN to be Constraint clustering Technique where Femtocell type serve users type.

Femtocell base station is fixed in celling in the center of the room, and Eps in DBSCAN algorithm is replaced by the pathloss from the femtocell to users. Pathloss between FBS and users is calculated taking into consideration that it may be free air or there exist obstacles like walls and floors with different types of materials which have different penetration values as illustrated in Table 1.

Initially, all femtocells are considered as core points, for each user we calculate pathloss using equation (1).

The algorithm distributes users to FBS’s as following:

Calculate for each user path loss from each FBS to that user, if pathloss is less than or equal to 88 dB, considering different types of walls, assign the user to the FBSi with lowest pathloss.

The number of users assigned to each FBSi must be <= 64 otherwise choose another FBS according to less value of pathloss. Minpoint is set to the Maximum number of users who can attach to one femtocell. Minpoint equal 64.

After the first phase, each user is assigned to one femtocell. The boundaries of the cell are not uniform, not circle, this is because pathloss value depends on the number and type of obstacles that intersect the path between users and FBSs.

In DBSCAN the boundary contour is the circle but in modified algorithm DBSCAN the boundary contour is defected according to the number of walls and their material type which affect the values of pathloss for each user. Figure 2 shows the modified DBSCAN algorithm.

The second phase of the algorithm is to obtain the minimum number of FBSs which satisfy constraints discussed in the previous section.

In this step, Hierarchical Agglomerative Clustering (HAC) algorithm [33] is applied with single linkage, after modifying the dissimilarity matrix and add constraints, for all FBSs to remove unnecessary FBSs and merge the most similar two clusters to form one big cluster. The algorithm iterates until no more merging clusters.

Figure 3 shows the modified agglomerative (single-linkage) algorithm which satisfies good merging of clusters according to the previous rules.

Applying OptCPLSINR clustering technique to the case study. The results are compared with previous work to present the advantages of our system.

The previous system model, [34] considers the following parameters:

- Co-channel interference between FBS and macro BSs, wall attenuation factor and user density in an enterprise building environment. In this work, they formulate two mixed integers linear programming (MILP) optimization models: optimal constant threshold signal to interference plus noise ratio (OptCTSINR) and optimal handover (OptHO). They solve these MILP models by utilizing branch and cut framework of CPLEX solver using General Algebraic Modeling System (GAMS) tool.
- OptCTSINR model guarantees a certain minimum SINR for each region inside the building and at the same time minimizes the number of FBS needed for the coverage of the entire enterprise building. In their system, they compared the results with K-means clustering based placement scheme, for a given number of Femtos. This system works on one floor only and they did not study the multiple floors.

5. Performance evaluation

Figure 4 shown the case study. A building of dimension 52 m* 52 m* 4m with 16 rooms of dimension 12 m* 12 m *4m each and two corridors of dimensions 4 m * 52 m * 4m and 52 m * 4m * 4m running through the center of the building. Femtocells are fixed at the ceilings of the rooms at a height of 4 m [87]. Figure 5 is a comparison between the number of Femtocells in K-Means [34], OptCTSINR [34] and OptCPLSINR algorithms.

From figure 3 the minimum number of femtocells is obtained from our system with an improvement of 20% than OptCTSINR and 43% than K-Means.

```
Pathlosstotal = 0
For (j=1 to number of users)
    Pathloss (j, 1) = 1000;
   For (i=1 to candidate No)
      Calculate the Pathloss (j, 2) from femtocell (i) to user (j);
     If (Pathloss (j, 2) <= 88 and Pathloss (j, 2) < Pathloss (j, 1) and femtocell (i) < 64)
       Then Pathloss (j, 1) = Pathloss (j, 2)
             Pathloss (j, 3) = i;
    End For
  If (Pathloss (j, 1) <= 88 and femtocell (Pathloss (j, 3)) < 64)
        Then    femtocell (Pathloss (j, 3)) = femtocell (Pathloss (j, 3)) + 1
          Pathlosstotal = Pathlosstotal+ pathloss (j, 1);
 End For
```

Fig. 2 Modified DBSCAN algorithm

```
Calculate Pathloss Matrix
Calculate Distance Matrix
1 Min-pathloss= 99
For (i = 1 to candidate-number-of-femto)
    For (j = 1 to candidate-number-of-femto)
     If Pathloss (i, j) ≠ INF and Pathloss (i, j) < Min-pathloss
       Then Min-pathloss = Pathloss (i, j)
           And femto1 = i
           And femto2 = j; "femto2 must be remove"
End for;
End for;
 If Pathloss (femto1, femto2) = Pathloss (femto2, femto1)
   And Distance (femto1, Total) < Distance (femto2, Total)
Then non-Removed-femto= femto1 and femto1= femto2 and femto2= femto1;
For (i = 1 to candidate-number-of-femto)
If Pathloss (i, femto1) = INF or Pathloss (i, femto2)=INF
          Then Pathloss (i, Femto1) = INF
           Else Pathloss (i, Femto1) = Pathloss (i, Femto1) + Pathloss (i, Femto2);
Delete raw femto2;
Delete column femto2;
For (i = 1 to candidate-number-of-femto)
    For (j = 1 to candidate-number-of-femto)
     If Pathloss (i, j) ≠ INF then go to 1
End for;
End for;
End;
```

Fig. 3 The modified agglomerative (single- linkage) algorithm

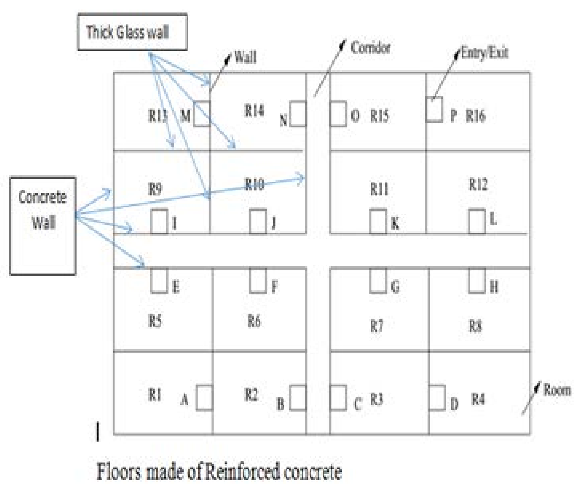

Fig. 4 Case study

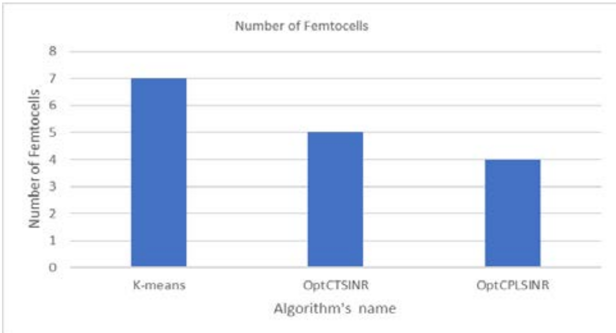

Fig. 5 Comparison between Number of Femtocells in traditional k-MEANS, OptCTSINR and OptCPLSINR algorithms

6. Conclusion

To avoid random deployment of Femtocells in indoor, our work presents a solution to the problem of topology plan of Femtocells base stations layout using Cluster techniques. This work takes into account the path loss influenced by different types of obstructing, such as different types of walls, windows, and doors. In this work, two clustering techniques are modified to planning heterogeneous mobile networks.

Firstly, DBSCAN original algorithm is modified and constraints are added to solve the problem of coverage indoor area, minimize the number of femtocells and guarantee path loss threshold. By using path loss in setting, instead of distance, we detect optimal locations for femtocell base stations.

Secondly, Hierarchical Agglomerative Clustering (HAC) is applied after using modified DBSCAN to optimize clusters, maximize the SINR and minimize cost.

In testing this work we use suitable penetrations of 4G and 5G and distinct types of obstacles taking into consideration its penetration values.

In our solution, we suppose that the femtocells are fixed at the middle of the ceiling to serve the maximum number of users.

The result indicates that this work conducts to decrease the number of Femtocells so minimize the cost with a guaranteed pathloss and maximized SINR.

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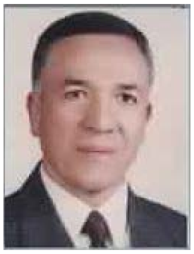

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