Small cell deployment algorithm for cell edge throughput maximization in Heterogeneous Cellular Networks

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***Abstract*—The network operators are facing a big challenge to meet the gigantically growing demands of mobile broadband traffic. One potential cost-effective solution in parallel to the developing radio access technologies is the efficient deployment of small cells (also known as micro- or pico cells). With reduced transmission powers, the small cells allow spatial reuse of bandwidth leading to improved user data rates. In this work, we focus on designing a method to find the locations of a fixed number of small cells to be deployed in a heterogeneous cellular network (HetNet) in order to maximize the cell edge user throughput distribution of the cells. The location of the macro cells and spatial traffic distribution are assumed to be known. We describe a weighted harmonic mean of cell specific measure based optimization function that accounts for the interactions among the coverage areas of different cells and improves the performance of cell edge users while keeping fair user experience among the cells. We compare the performance of this optimization function with two baseline models, a Network coverage (NW) function that aggressively tries to maximize the network coverage and a Proportional Fair (PF) function that maximizes the proportional fairness measure of the network. The behavior of the optimization functions is analyzed on a coarse-grained small network before performing simulations on a large-scale network using a sub-optimal approach. Both the small-scale and large-scale network simulations reveal that WHM based optimization yields a better cell edge throughput distribution compared to the baseline models while providing almost the same network coverage and improved fairness over the NW based optimization.**

I. Introduction

The demand for wireless data is growing at a remarkable rate fuelled by the proliferation of data hungry devices such as smartphones, mobile PCs and tablets with cellular connectivity [1] [2].Traditional macro base stations, once the mainstay of carriers network are falling short on many levels.Introducing more macro base stations into the deployments even through techniques like cell splitting is difficult to realize in an economically sustainable manner due to the high cost overheads in site acquistion, network re-planning and establishment of integrated, in-band backhaul. Service providers have been forced to investigate various ways to meet this demand. The purchase of additional spectrum provides a straightforward approach for increasing the network capacity with the existing technologies but spectrum is a scarce commodity,hard to invest in most market situations.The improvements incorporated in the physical and medium access control layers by emerging wireless standards such as 3GPP Long Term Evolution have neared Shannon bound radio link performance and may not be sufficient to meet the projected demand [3].

One strong candidate solution is the deployment of multi-layered heterogeneous cellular networks (HetNets) consisting of small micro/pico cells overlaid by the traditional macro cellular network. In the HetNets scenario, macro cells are deployed in a planned way providing blanket coverage and seamless mobility while the small cells provide an extended network coverage and infuse additional capacity at traffic hotzones.Due to their lower transmission powers, reduced coverage area, and presumably smaller form factor, small cells have the potential to overcome the challenges of cost and ease of deployment. Small cells are installed and maintained directly by the network operator. There are many ways to build such a network and a few important choices must be made.

- What should be the density of the small cells to be deployed?
- Where should the small cells be placed?
- Compatibility of the small cell deployment with the supported traffic.
- Spectrum allocation : Shared or Dedicated?

In this work, we focus on the second question and our goal is to design a method to deploy a fixed number of small cells in the network that maximizes the cell edge throughput among the cells in the region of operation while maintaining a fair user experience among the cells. Cell edge throughput of a cell is defined to be the 5%-tile level of the user throughput distribution in a cell. Proportional fairness measure is the metric chosen to evaluate the fairness of a chosen deployment. Small cells are primarily used to offer a better signal quality and offload users from macro cells. For example, we would like to place the small cells in regions where users suffer low data rates but if the small cells are placed close to each other, it leads to severe interference causing reduction not only in the fraction of users offloaded to small cells but also leads to lower data rates to small cell connected users. Therefore, to optimally place the small cells we need to jointly consider both the non-uniformity in user traffic distribution as well as the interference, rendering a non-trivial problem.

The major contributions of this work are:

- We describe and compare different optimization metrics for deploying a fixed number of small cells in a heterogeneous cellular network to maximize the cell edge throughput distribution of the network
- By performing simulations on a small network, we show that the WHM model can provide almost the same network coverage and proportional fairness measure as NW model.
- Simulations on a large-scale network using a sub-optimal approach reveal that WHM model can provide better cell edge throughput distribution compared to other models while providing similar performance in other metrics as the optimal soutions.

II. Related Work

The problem of optimizing the joint deployment of multiple small cells under the macro cell layer has not been extensively studied in literature. The small cell deployment design falls into the broad class of multiple facility locations problem. Traditional multiple facility location algorithm focus on optimizing an objective function defined by the weighted distance measures. [4] modeled and analysed the problem of optimal locations of transmitters given a fixed distribution of receivers such that a simple objective function based on the pathloss and received signal strengths was minimized. Later, a few works focussed on cost-efficient deployment of base stations such that minimum quality of service is established in the network [5] [6].

Recently, using the approach of stochastic geometry [7], spatial models have been proposed where location of the base stations is drawn from stochastic point processes. Based on the intuition that human activities tend to be clustered, a few spatial clustering models have been explored such as Poisson Cluster Process and Thomas Cluster Process. Dhillon et.al designed a tractable model HetNets [8] consisting of independent layers of Poisson point process (PPP) distributed base stations. Such models can be used for femtocells [9], set up by the end users directly at unknown and unplanned locations, but are impractical for the higher layers which are deployed by the network operators after extensive traffic measurements.

Landstrom et.al [10] showed that the gains of deploying small cells can be significantly improved with good deployment principles. However, their analysis has a simple setting of one macro cell and one small cell in a traffic hotspot. Micallef et.al. [11] have addressed energy-efficient joint small cell deployment scheme using a deployment formula metric (DFM) but the approach is sub-optimal in terms of placing new sites as no iterative optimization of the joint deployment was included. Hu et.al [12] proposed a class of metaheuristic algorithms that iteratively optimize the small cell deployment with outage probability as the key performance indicator (KPI). In their approach, the KPI was coupled with the optimization and reduced the network outage compared to the DFM based scheme. The problem with coupling the KPI to the iterative optimization is that the improvements may occur at the cost of reduced throughput of a large fraction of users, leading to a highly unfair user experience among the cells. In their work, a greedy initial solution is found upon which the iterative optimization is performed. The reduction in outage probability can occur at the cost of reduced throughputs for a large number of users resulting in a decrease in the fairness in the network. The authors did not analyse the fairness of the deployment solution and it's proximity to the optimal solution.

Awada et.al. [13] proposed an encouraging approach to optimize cell specific measures in a macro cellular network with the tuning of the antenna azimuth orientation and downtilt. In their work, the weighted harmonic mean of a fixed percentile level of the per cell user throughput distribution was maximized by tuning the antenna parameters. The choice of the percentile level plays a big role in driving the optimization towards capacity or coverage maximization. The weight assignment is done such that cells with higher number of connected users have more impact on the optimization and this is essential to have a fair overall performance. We build upon this weighted harmonic mean approach (WHM) to find the locations where the small cells are deployed to maximize the cell edge user throughput distribution while ensuring a good fairness among the cells.

We use the proportional fairness measure, the sum of logarithms of the received rates of all the users in the network, as one of the measures to evaluate the fairness of a particular deployment. Proportional fairness maintains a good tradeoff between spectral efficiency and fairness. A proportional fair allocation is such that any positive change of a user in rate allocation must result in a negative overall change in the system [14].

For comparison, we define two optimization functions of small cell deployment. Firstly, the PF function finds the locations of small cells such that mthe sum of the logarithm of the user rates is maximized. Secondly, NW function deploys the small cells in locations such that the network coverage is maximized where network coverage is defined as the combined throughput of the worst 5% users in the network. A deployment formula metric model which places the users directly in the worst affected regions and a random model are also considered for comparison.

III. System Model

The region of operation R_{op} is a rectangle of dimensions $L \times W$ (kilometres). We divide the area into rectangular pixels of dimension $N_a \times N_b$ (metres). We focus on the downlink transmission in R_{op}. Suppose there are N_M macro cells already deployed in and around R_{op} providing blanket coverage and our goal is to place N_S small cells in the pixels. For any pixel, the small cell will be placed in the center of the pixel.

A. Cell Association and Resource Allocation

Allowing each layer of HetNet to transmit on dedicated frequency resources provides wide gains in coverage and capacity compared to the co-located scenario [15] [16]. In our model, the newly deployed small cells operate on the same carrier as that of Macro layer and total bandwidth is partitioned such that each layer has access to only half the total available system bandwidth and the offered peak rates will be reduced accordingly. The advantage of such a spectrum allocation becomes significant at high small cell densities as the fraction of users offloaded to small cell increases. However, for some of the simulations we allowed the macro cells and small cells to operate on the same bandwidth and such conditions have been explicitly stated at the start of the experiment.

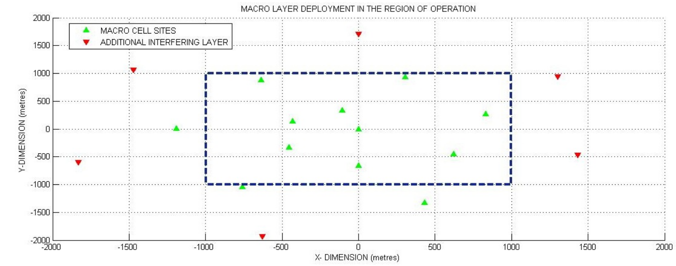

Fig. 1: Layout for Wide-scale performance analysis

In a traditional macro cellular network, users connect to the strongest base station, which offers the best SINR. Many small cells will have just a few users and the load may vary with time form no load to very high load. The deployed small cells should be able to satisfy the peak load conditions in their coverage area. An intelligent cell association policy should assign users to base stations that offer them the highest user-perceived rate [17]. Such a policy requires an exhaustive search over all possible pairings of users and base stations. Recently, a suboptimal approach known as *range biasing* has been proposed where the small cells are preferred over macro cells by a certain bias value [18].The bias value is chosen by brute force but an interesting result is that the optimum bias value does not strongly depend on the network topology or density of small cells. The users connect with the base station that offers them the highest SINR with a certain bias for the small cells as used in [18]. This approach would allow more users to be assigned to the small cells taking advantage of the interference mitigation provided by resource partitioning. The propagation path loss is modeled after the Cost-Hata Model with variations for macro and small cell layer as used in [16]. The indoor users suffer an additional 20 dB wall penetration loss. In equation form, the SINR received by the k^{th} user connected to l^{th} base station is given by

$$SINR_k = \frac{P_l}{\sigma^2 + \sum_{n \neq l} I_n} \tag{1}$$

where P_l refers to the received power from l^{th} cell, σ^2 is the thermal noise. A cell c distributes the resources equally amongst it's assigned users computed as

$$N_{PRB,c} = \frac{N_{total}}{N_c}, \text{if} N_c > 0 \tag{2}$$

where N_{total} denotes the total number of PRBs for each cell and N_c denotes the number of users connected to cell c.

The downlink data rate for a user i can be estimated by Shannon's capacity equation as

$$R_i = N_{PRB,c} \bullet BW_{eff} \bullet BW_{PRB} \bullet \log_2 \left(1 + \frac{SINR_i}{SINR_{eff}}\right) \text{[kbps]} \tag{3}$$

where BW_{eff},BW_{PRB} and $SINR_{eff}$ are the bandwidth efficiency factor, bandwidth occupied by a single PRB in kHz and SINR efficiency factors respectively [3].

IV. Small Cell Deployment Algorithms

Our focus is to develop algorithm to deploy a fixed number of small cells N_S. The small cells can be placed in any of the $N_a \times N_b$ pixels subject to the constraints of minimum inter-site distance (ISD) between any two small cells and minimum ISD from each Macro site. Clearly, finding the optimal locations for the small cells is a non-trivial problem as the complexity in computing the optimal locations grows exponentially $O((N_a N_b)^{N_s})$ with the increase in number of small cells to be deployed.

The location coordinates of these N_S new sites are represented by the matrix: $L_S = [l_{i,j}], 1 \leq i \leq N_a, 1 \leq j \leq N_b$

$$l_{i,j} = \begin{cases} 1, \text{if small cell is located in coordinate (i,j)} \\ 0, \text{otherwise} \end{cases} \tag{4}$$

Each of the deployment algorithm is divided into a fast non-iterative algorithm and a meta-heuristic algorithm similar to the one defined in [12]. The non-iterative algorithm is to help the meta-heuristic algorithm converge faster to an optimal set of small cell locations. The solution for the non-iterative algorithm is obtained from the macro layer performance analysis of the region of operation R_{op}.

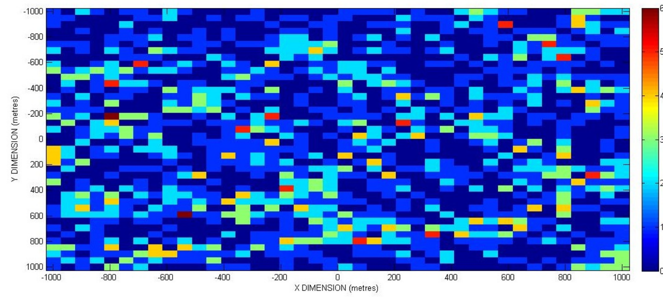

Fig. 2: A snapshot of User Traffic Profile with peak traffic load of 1500 users in the network.The colorbar indicates the number of users in each pixel of dimension 50m x 50m

A. Macro Layer Analysis

In general, a small cell deployment algorithm should automatically locate areas where users of only macro cellular network experience low data rates. The non-uniform spatial traffic distribution has been modeled by dividing the study area into bins classified as a traffic cluster or an outdoor bin similar to [19] such that 70% of the downlink traffic is directed towards the traffic clusters. Figure 2 shows an example of the user traffic profile in the region of operation R_{op}. Let there be only macro cells in the network. Monte-Carlo simulations are performed for a number of snapshots to obtain the average rate of a user in every pixel of R_{op}. We define the following terms that are used in the algorithms:

- **Normalized Average Rate Matrix**
  $A = [a_{i,j}]$ where $a_{i,j}$ counts for the average data rate being received by the users located in the pixel (i,j)
- **Candidate Matrix:**
  $C = [c_{i,j}]$
  where

$$c_{i,j} = \begin{cases} 1, \text{if pixel (i,j) is included in the candidate list} \\ 0, \text{otherwise} \end{cases} \tag{5}$$

To avoid an exhaustive search process, the top $a\%$ pixels in the $[A_{i,j}]$ with lowest average data rates are included in the candidate list. We assume that pixels with low values of average data rate are likely to be in poor service area or high traffic zones and need small cell deployment. Only the pixels consisting of users and satisfying macro-pico ISD constraint are considered for the candidate list.

- **Initial Location Matrix** $D^{initial} = [d_{i,j}^{initial}]$ The Initial Location matrix represents the initial location of the small cells. The better the initial set of locations for the small cells can be selected, the faster the iterative algorithm converges to theoretical optimal small cell deployment. Top N_S pixels with the lowest average rates are selected as the initial locations for N_S small cells subject to the inter-site distance constraints.

B. Optimization Objective

The optimal small cell deployment can be formulated as the following maximization problem.

Maximize:

$$OptimizationMetric(OM)|L_S$$

subject to:

$$\sum l_{i,j} = N_S, 1 \leq i \leq N_a, 1 \leq j \leq N_b \tag{6}$$

where the optimization metric is calculated by performing Monte-Carlo simulations of the network, given the location of small cells L_S. Next, we describe each model and it's optimization metric.

C. Optimization Metric based on WHM of Cell-Specific Measure (WHM)

This model is based on the calculation of a percentile level of the user throughput distribution in a cell [13]. The x percentile (x%-tile) level of the user throughput distribution in a cell c, denoted by $\alpha_{c,x}$ is computed. Whether the optimization steers towards coverage or capacity maximization largely depends on the value chosen for x. For a low value of x for e.g 5-10%, the metric increases the network coverage as the cell edge users have a stronger impact. For a high value of x, the optimization maximizes the network capacity and there is a lesser impact of the cell edge users. In our network, deployment of a small cell effects the $\alpha_{c,x}$ of all its neighbors. To account for the interactions existing among the coverage areas of different cells at both macro layer and small cell layer, the performance measures of all cells are bundled into one optimization function.

The aim of the optimization metric is to improve the performance measure $\alpha_{c,x}$ for each cell c simultaneously keeping a fair user experience in the network. For low values of x, the goal is to avoid maximizing the throughput of cell edge users at the cost of highly reduced rates for other users. For a high value of x,it is desired to avoid the scenario where a few users receive extremely high rates while a large fraction of users in the network suffer. To achieve this, applying different weights for the cells becomes essential as the cells having higher number of users than others should have more impact on the overall optimization metric. This weighting is essential to have a fair overall performance evaluation. For these reasons, the first optimization function is defined to be the weighted harmonic mean (WHM) of $\alpha_{c,x}$, i.e,

$$WHM(\alpha_{c,x}) = \frac{N_{users}}{\sum_{c=1}^{C} \frac{N_c}{\alpha_{c,x}}} \tag{7}$$

With multiple layers in the network, there are more chances of having users with high rates due to non-uniformity in the spatial traffic distribution. In such situations, harmonic mean function is preferred to an arithmetic mean as harmonic mean gives less significance to high-value outliers - providing a truer picture of the average $\alpha_{c,x}$ across the cells. Thus, WHM provides a more homogeneous experience in the network compared to weighted arithmetic mean. We choose the value of 5% for x as we are trying to maximize the network coverage.

D. Optimization Metric based on Network-Wide Measure (NW)

The optimization function γ_x is the $x\%$-tile level of the network wide user throughput distribution and not specifically in a cell as in Section IV-C.γ_x is computed by plotting the CDF of the user throughputs and then taking the $x\%$-tile level.

E. Optimization based on Proportional Fairness Measure (PF)

The proportional fairness measure of a deployment is defined to be the sum of the logarithm of the data rates of all the users in the network. In mathematical form,

$$PF = \sum_{i=1}^{N_{users}} \log(R_i) \tag{8}$$

In this model, the initial location matrix obtained from macro cell coverage analysis is chosen as the final solution.

F. Random Model

In this model, N_S pixels satisfying the ISD constraints are randomly chosen without using the knowledge of user traffic information. Monte-Carlo simulations are performed to obtain the mean values for the performance metrics.

G. Iterative Optimization

Iterate i **(while** MAX **number iterations is not exceeded)**

- Select a small cell by uniformly sampling the set of N_S small cells in the current deployment solution, select one new position by uniformly sampling pixels in candidate matrix *C*, thus obtain a new candidate location matrix L^{tmp} for the set of N_S new sites.
- Obtain optimization metric OM^{tmp} by Monte-Carlo Simulation of the network $fn_{MC}(\bullet)$, assuming that N_S small cells are deployed at locations given by L_{tmp}:
  $OM^{tmp} = fn_{MC}(L^{tmp})$
- If $OM^{tmp} > OM^{i-1}$
  $L^i = L^{tmp}, OM^i = OM^{tmp}$
  Else
  $L^i = L^{i-1}, OM^i = OM^{i-1}$

Go to next iteration $i+1$

V. Performance Evaluation

In this section, we show the results of our experiments. All the simulations have been performed using the MATLAB simulation tool. A summary of the simulation parameters is given in Table I. We are interested to answer the following questions:

- How do the different optimization functions perform when allowed to perform an exhaustive search? This helps in understanding the characteristics of the different optimization metrics.
- How does the initial greedy non-iterative solution perform compared to the optimal solution? How better/worse is it from the baseline model of random selection?
- Performance comparison of sub-optimal WHM based deployment compared to the optimal solution?
- Performance evaluation of the discussed optimization functions in a large-scale network where exhaustive search is computationally difficult

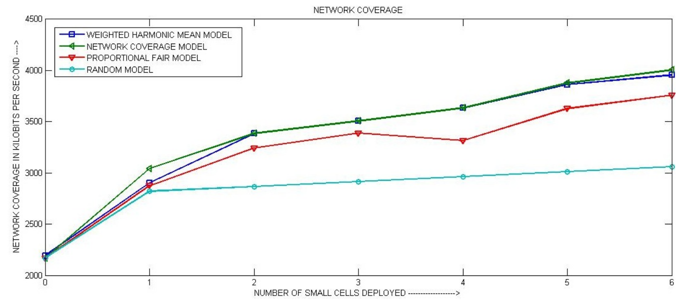

Fig. 3: Network coverage provided by the optimal deployment solution of the optimization metrics

A. Optimization Metrics Behaviour

In this experiment, we are primarily interested to know how each of the optimization metrics perform when allowed to compute an exhaustive search over the network. In this manner, we can observe the behaviour of the optimization metrics in isolation without getting affected by the limit on the maximum number of iterations. To perform this experiment, a target area of 600m x 600m is chosen covered by 4 macro sites (12 macro cells). The region is divided into pixels of 150m x 150m to reduce the computational complexity. All spatial calculations are performed at this granularity. The macro cells operate on a frequency reuse of 3 such each sector at a macro site operates on the total bandwidth. For this scenario, we have chosen the co-located spectrum scheme where both the macro cells and small cells operate on the same bandwidth interering with each other's transmissions. The number of small cells deployed range from 1 small cell to 6 small cells. The traffic load is distributed to the pixels using the model described in IV-A.

Figure shows the optimal network coverage performance of the different optimization metrics. We observe that optimal NW and optimal WHM provide almost the same network coverage with a slight decrease for optimal WHM when the density of small cells to be deployed is high. Both the models perform better than the optimal PF model whereas the random model of placing the small cells performs the worst. When only 1 small cell is deployed, only a small fraction of users connect to

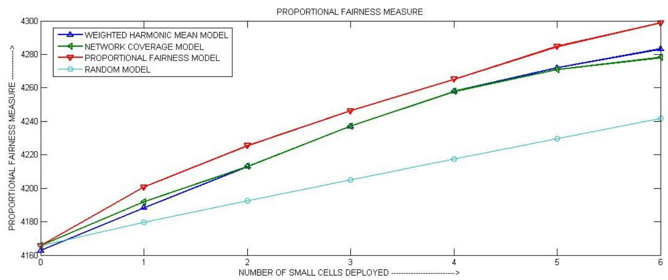

Fig. 4: Proportional Fairness measure of the optimal deployment solution of the optimization metrics

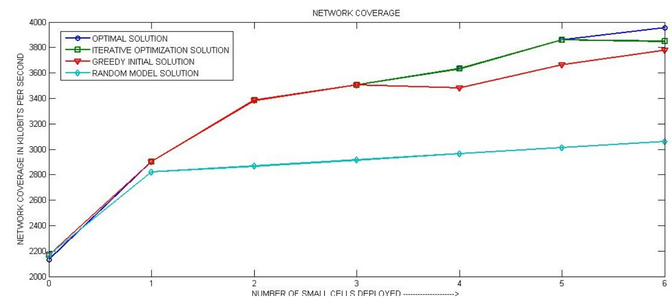

Fig. 5: Proximity of the sub-optimal approach and greedy initial solution to the optimal solution

the small cell and get good rates leading to high cell edge throughput for the small cell. Due to this, the cell edge throughput of the small cell has a very small impact on the WHM expression. Hence, the WHM model does not have much improvement in network coverage with a low density of small cells deployed like in this case only 1 small cell. As the density increases, the impact of deploying small cells rises as more users get offloaded to the small cells also leading to improvements in data rates of users still connected to macro cells.

In Figure , the PF model as expected performs the best. When only 1 small cell is to be deployed in the network, the NW algorithm has provided a better fairness than WHM model. Similar to the observation in Figure , this happens because of the low impact of the small cell edge throughput on the WHM expression. As the density increases, the users are distributed among more cells. The fraction of users with extremely high rates relative to others decreases and also the fraction of cells with a very high number of connected users compared to others decreases hence more number of cells are having an impact on the WHM expression leading to not only improvement in coverage but also improvement in fairness which is observed through the proportional fairness measure. The WHM model has a better proportional fairness measure compared to NW model when the number of small cells deployed is more than 4 small cells.

Figure shows the proximity of the fast non-iterative solution and the sub-optimal solution obtained after iterative optimization using the WHM function with the optimal solution obtained by performing an exhaustive search over the whole region. As there are only 16 pixels in the region, 50% of the pixels are chosen for the candidate list. We observe thatthe greedy initial solution performas equally good as the optimal solution when the number of small cells to de deployed is 3 or less. We find there is a decrease in network coverage of the greedy initial solution when 4 small cells are deployed compared to the 3 small cells case. This occurs because the greedy intial solution chooses the pixels usffering the worst average rates and does not specifiaclly try to maximize the coverage. The additional cell deployed interacts through interference with the existing cells and canges their coverage areas leading to slightly reduced rates for the cell-edge users observed as a decrease in the total network coverage. As the number of small cells goes above 4, the difference in performance between optimal solution and greedy initial solution is significant. However, the sub-optimal solution obtained by the iterative optimization over the greedy initial solution matches in performance with the optimal solution at all points on the plot except when the number of small cells to be deployed is 6. At all points, the greedy initial solution has performed better than the random model thereby showing that considering the user traffic profile is essential for deployment aimed at maximizing the throughputs of cell-edge users in the network.

B. Wide-Scale Experiment

The experiment is to deploy 60 small cells in a target area of 2km x 2km given the macro cell deployment and a number of snapshots of a peak traffic load of 1500 users in the region. The area is covered by 12 macro sites (36 macro sectors). The region of operation is divided into pixels of dimension 50m x 50m. All spatial calculations are performed at this granularity. One of the most commonly used layout for the Macro layer is the hexagonal clover-leaf layout, also used in the 3rd Generation Partnership project (3GPP).The problems with such a deployment range from geographically varying radio propagation conditions, restrictions in the site

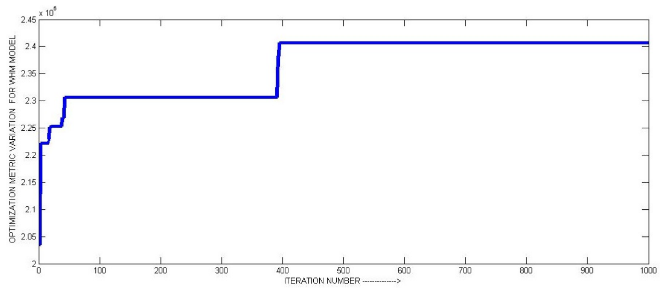

Fig. 6: Variation of the WHM algorithm optimization metric for the scenario of deploying 60 small cells in the network.

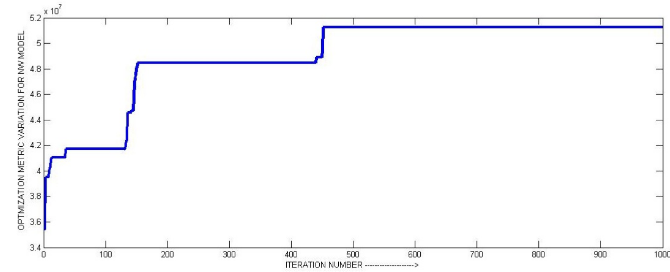

Fig. 7: Variation of the NW algorithm optimization metric for the scenario of deploying 60 small cells in the network.

acquisition and non-uniform user traffic distributions. In order to better reflect the live network deployments, the Springwald layout based on Archimedean spiral [20] is chosen for the Macro Layer deployment in the study area. An additional tier of interfering macro cells causing background interference to the outer tier cells is placed to minimize the border effects. Figure 1 shows the macro cell layout in the area with the rectangular box indicating the center target area over which the performance studies are carried out.

We choose the top 10% with the lowest average received rates from the macro cells as the candidate list of locations for deploying the small cells. The metaheuristic algorithm for each model can take multiple iterations to converge. As we are not performing an exhaustive search, it is important to select an appropriate value for the MAX iterations. The value should allow each algorithm to converge to a reasonable sub-optimal solution. Figures 6 and 7 show the variation of the optimization metrics for WHM algorithm and NW algorithm respectively. Similar results have been observed for simulations performed on varying traffic loads and varying number of small cells to be deployed for all the three algorithms. Hence, we choose 500 as the value for MAX iterations after which the iterative algorithm terminates for each model.

Figure 8 shows the box plot of the network coverage metric for the different models. We see that WHM algorithm and NW algorithm have almost the same performance while random model and DFM model give low peformance as they do not take part in iterative optimization. WHM algorithm and NW algorithm give a 9.5% median gain and 9.35% median gain over the PF algorithm respectively. There is a slightly lower performance of NW algorithm compared to WHM algorithm even though NW algorithm directly couples the network

TABLE I: SIMULATION PARAMETERS

Macro Antenna	Height:30m,3-sectored,Beamwidth:75 deg Downtilt:10 deg, Hor. Antenna Gain: 14 dBi Tx Power: 46 dBm
Macro ISD	350m
Pico Cell Antenna	Height:12m,Omnidirectional Tx Power: 36 dBm
Pico ISD Macro Pico ISD	40m 75m
Macro-UE min.distance Pico-UE min.distance	25m 10m
Bandwidth	Only Macro layer - 20 MHz Joint Deployment Dedicated bandwidth - Macro: 10 MHz Small cell: 10 MHz Co-located - Macro and Small cell: 20 MHz
Shannon Equation	$BW_{eff} = 0.88, BW_{PRB} = 180kHz$ $SINR_{eff} = 1.25$
Path Loss Model	Macro:$128.1 + 37.6 \bullet \log dist_{km}$ Pico: $140.7 + 36.7 \bullet \log dist_{km}$ Indoor Penetration Loss: 20 dB
Thermal Noise	-104 dBm on a single PRB
Small Cell Range bias	10 dB

coverage metric to the iterative optimization. This is because an exhaustive search is not performed. The random model gives the worst performance with WHM and NW algorithms both providing over 13% median gains over the random model. Thus, considering the user traffic profile is essential in coverage optimization to avoid deterioration in performance.

Even if there is an improvement in network coverage of the WHM and NW algorithms over the PF algorithm we must ensure that the fairness in the system is maintained. To measure fairness, first we consider the proportional fairness measure as a metric and the box

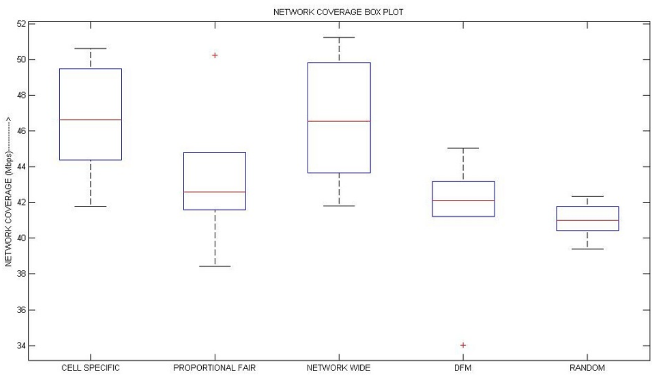

Fig. 8: Box plot of the network coverage for the case of deploying 60 small cells in the network

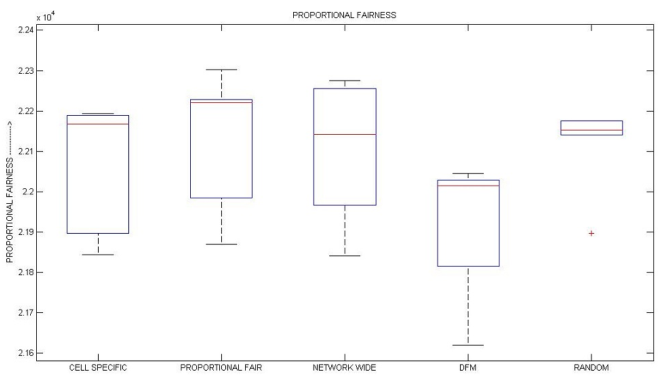

Fig. 9: Box plot of the proportional fairness measure for the case of deploying 60 small cells in the network

plot is shown in Figure 9. The greedy allocation of DFM model shows and it has performed the worst of all the models. The PF performs slightly better but the gains are less than 1% over the WHM and NW algorithms. The dampening in the fairness gains has occurred due to the logarithmic nature of the proportional fairness measure function.

Figure shows the box plot for the distribution of the cell edge throughput among the macro cells and small cells in the network for the case of deploying 60 small cells by the sub-optimal approach for each of the discussed optimization functions. We observe that the lowest cell edge throughput for both WHM and NW is almost the same and higher than PF model illustrating that WHM and NW aim to maximize the network coverage. WHM model clearly has a higher median gain, 75%-quantile and maximum value.

Figure 11 shows the final locations of the 60 small

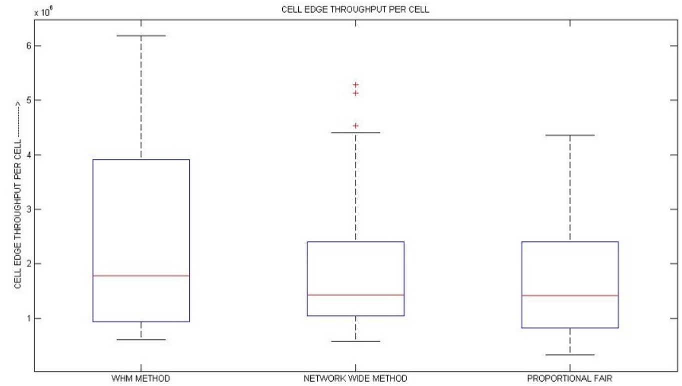

Fig. 10: Cell edge throughput distribution for the sub-optimal approaches of WHM, NW and PF models

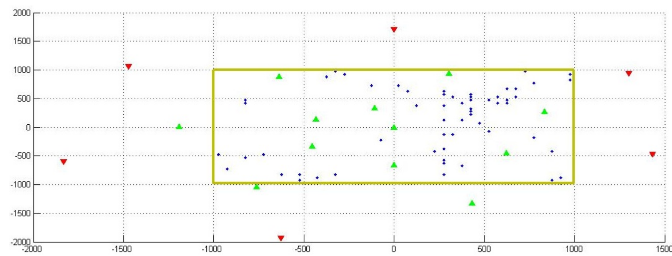

Fig. 11: Joint deployment of macro cells and 60 small cells whose locations are obtained by WHM algorithm

cells using the WHM algorithm.

VI. Conclusion

In this work, we have presented a conceptual analysis of a problem involving the location of small cells to maximize the cell edge user throughput in a region of exisitng macro cells and known user traffic distribution. An optimization function based on the weighted harmonic mean of cell edge user throughput was described and compared with baseline models. The behaviour of the optimization functions was understood by conducting simulations on a coarse-grained small network in which an exhaustive search leading to the global optimum was feasible. The proximity of the sub-optimal approach and the similiarity in performance patterns were observed by conducting simulations for small cell deployment in a large-scale network. Looking ahead, the immediate extensions include integrating the backhaul link quality into the optimization function for small cell deployment.

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