This is a repository copy of *Small-cell deployment over existing heterogeneous networks*.

White Rose Research Online URL for this paper:
http://eprints.whiterose.ac.uk/92003/

Version: Accepted Version

Article:

E, N., Chu, X. and Zhang, J. (2016) Small-cell deployment over existing heterogeneous networks. Electronics Letters, 52 (3). pp. 241-243. ISSN 0013-5194

https://doi.org/10.1049/el.2015.2405

This paper is a postprint of a paper submitted to and accepted for publication in Electronics Letters and is subject to Institution of Engineering and Technology Copyright. The copy of record is available at IET Digital Library

Reuse
Unless indicated otherwise, fulltext items are protected by copyright with all rights reserved. The copyright exception in section 29 of the Copyright, Designs and Patents Act 1988 allows the making of a single copy solely for the purpose of non-commercial research or private study within the limits of fair dealing. The publisher or other rights-holder may allow further reproduction and re-use of this version - refer to the White Rose Research Online record for this item. Where records identify the publisher as the copyright holder, users can verify any specific terms of use on the publisher’s website.

Takedown
If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

eprints@whiterose.ac.uk
https://eprints.whiterose.ac.uk/

Small-cell Deployment over Existing Heterogeneous Networks

N. E, X. Chu, and J. Zhang

In order to meet the extra traffic demand of hot-spot users not expected in the original network planning, it is desirable to deploy new small cells on top of the existing heterogeneous network (HetNet) without replanning the overall network. In this paper, we propose to maximize the minimum user throughput in a HetNet with unexpected recurring hot-spots by jointly optimizing the number and locations of new small cells and user associations of all cells. A reduced-complexity iterative algorithm is devised to solve the joint optimization problem. The simulation results show that the proposed iterative algorithm significantly outperforms the random deployment of new small cells and achieves performance very close to numerically solving the joint optimization in terms of minimum user throughput and required number of new small cells, especially for a large number of unexpected hot-spot users.

Introduction: The appropriate deployment of small cells is crucial to the success of heterogeneous networks (HetNets). Existing deployment strategies mainly focus on designing the whole HetNet to offer good service quality at low cost [1], [2]. After a HetNet has been established, it is desirable to meet the extra traffic demands from recurring hot spots (HSs) of user equipments (UEs), which were not expected in the original network planning, by deploying new small cells on top of the existing HetNet without replanning the whole network. Mobile small cells mounted on vehicles can be used in this situation, however, the operators need to know the optimal number and locations of new small cells to be deployed. In this paper, we propose to maximize the minimum UE throughput in a HetNet with unexpected recurring HSs by jointly optimizing the number and locations of new small cells and user associations of all cells. Due to the high computational complexity of the joint optimization problem, we propose a reduced-complexity iterative algorithm to solve this optimization. Performance of the iterative new small-cell deployment algorithm in terms of minimum UE throughput and required number of new small cells is evaluated through simulations, in comparison with numerically solving the joint optimization and the random deployment of new small cells.

System Model: We consider the downlink (DL) of a two-tier HetNet consisting of one central macrocell and N_S small cells randomly distributed in the macrocell coverage area. The number of existing base stations (BSs) is $N_{eBS} = 1 + N_S$. Each cell has access to the total of N_{RB} resource blocks (RBs). Denoting the number of new small cells to be deployed as N_{nBS}, the total number of BSs is given by $N_{BS} = N_{eBS} + N_{nBS}$. Let N_{nhs} denote the number of non-HS UEs and N_{hs} denote the number of HS UEs. The set of all UEs is denoted as $\mathcal{N}_U = \{1, 2, ..., N_U\}$, where $N_U = N_{nhs} + N_{hs}$.

Assuming that the channel on each RB sees independent and identical Rayleigh fading, the channel power gain of the link between the ith UE and the jth BS in a RB is expressed as:

$$g_{i,j} = g_{f,ij} \cdot g_{pl,ij} \tag{1}$$

where $g_{f,ij}$ is the exponentially distributed fading gain with unit mean, and $g_{pl,ij}$ is the pathloss given by [4]:

$$g_{pl,ij} = -15.3 - \alpha \cdot 10log_{10}(\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2})\ \text{dB} \tag{2}$$

where (x_i, y_i) and (x_j, y_j) are the location coordinates of the ith UE and the jth BS, respectively, and α is the path loss distance exponent.

Since the deployment of new small cells and UE-BS association can be updated at much lower frequencies than radio resource allocation, we assume that RBs are allocated in each cell following the round robin algorithm with full bandwidth allocation [3]. That is, all the RBs are allocated to UEs in each cell following the round robin algorithm at all times. This can be considered as the worst-case interference scenario, as there will be inter-cell interference in each RB. The throughput of the ith UE is given by:

$$\gamma_i = \sum_{j=1}^{N_{BS}} N_j^{RB} \cdot W \cdot \log_2(1 + \frac{P_j \cdot g_{i,j} \cdot b_{i,j}}{I_{i,j} + N_0}) \tag{3}$$

where $b_{i,j} = 1$ if the ith UE is served by the jth BS, $b_{i,j} = 0$ otherwise; W is the bandwidth of a RB, P_j is the DL transmit power of the jth BS in a RB, and $N_{RB} \cdot P_j = P_{M}(_S)$ if it is a macro (small-cell) BS; N_j^{RB} is the number of RBs per UE in cell j and is given by:

$$N_j^{RB} = \left\lfloor \frac{N_{RB}}{\sum_{i=1}^{N_U} b_{i,j}} \right\rfloor,\ \forall j \tag{4}$$

where $\lfloor \cdot \rfloor$ denotes the floor function; N_0 is the additive white Gaussian noise (AWGN) power; and $I_{i,j}$ is the interference power received by UE i from BSs other than BS j, i.e.,

$$I_{i,j} = \sum_{j'=1, j' \neq j}^{N_{BS}} P_{j'} \cdot g_{i,j'} \tag{5}$$

Problem Formulation: For a given HetNet and extra traffic demand from HS UEs not expected in the original network planning, we propose to maximize the minimum UE throughput among all UEs by jointly optimizing the number and locations of new small cells and user associations of all cells. That is,

$$\underset{\mathbf{B},\ (\mathbf{x},\mathbf{y})}{\arg\max}\ \min_i\{\gamma_i\},\ i \in \mathcal{N}_U. \tag{6}$$

$$\text{s.t.} \quad (\mathbf{x}, \mathbf{y}) \in |\mathcal{H}| \tag{7}$$

$$\gamma_i \geq \gamma_{th}, \forall i \tag{8}$$

$$\sum_{j=1}^{N_{BS}} b_{i,j} = 1, \forall i \tag{9}$$

$$N_{RB} \geq N_j^{RB} > 0, \forall j \tag{10}$$

$$b_{i,j} \in \{0, 1\}, \forall i, j \tag{11}$$

where $\mathbf{B}$ is the $N_U \times N_{BS}$ UE-BS association matrix that contains all $b_{i,j}$ as elements; $(\mathbf{x}, \mathbf{y})$ are the $N_{nBS} \times 1$ location vectors of new small cells, (7) limits the deployment area of new small cells to the feasible deployment area $|\mathcal{H}|$ as presented in [5] while avoiding coverage overlap between any two small cells; (8) guarantees that the throughput of each UE is above the threshold γ_{th}; (9) ensures that each UE is associated with one BS; (10) guarantees that the number of RBs each UE can be allocated is not beyond the total number of available RBs; and (11) is the binary constraint on the user association indicators.

Algorithm 1 Iterative Algorithm

```
Initialization: $\sigma = 1; b_{i,j}^r \leftarrow 0, \forall i, j; (\mathbf{x},\mathbf{y})_\sigma, \sigma^* \leftarrow \varnothing;$ MAXVAL$\leftarrow 0$
Main Algorithm:
function MAIN ALGORITHM(Loop until $\sigma^* \neq \varnothing$)
    $g_\sigma(\mathbf{B}^*, (\mathbf{x},\mathbf{y})^*) \leftarrow$ B&B_SEARCH($\mathbf{B}_r, (\mathbf{x},\mathbf{y})_\sigma$, MAXVAL)
    return $\mathbf{B}^*, (\mathbf{x},\mathbf{y})^*, \sigma^*$
end function
B&B Algorithm:
function B&B_SEARCH($\mathbf{B}_r$,$(\mathbf{x},\mathbf{y})_\sigma$, MAXVAL)
    $|\mathcal{H}| \leftarrow |\mathcal{H}|_{(\mathbf{x},\mathbf{y})_\sigma}$
    $(g_\sigma(\mathbf{B}_r, (\mathbf{x},\mathbf{y})_\sigma)) \leftarrow$ Solve (6) for $\mathbf{B}_r, (\mathbf{x},\mathbf{y})_\sigma$
    if (6) $> \gamma_{th}$, $\mathbf{B}_r \in \mathbb{Z}^+$ then
        if $g_\sigma(\mathbf{B}_r, (\mathbf{x},\mathbf{y})_\sigma) >$MAXVAL then
            MAXVAL$\leftarrow g_\sigma(\mathbf{B}_r, (\mathbf{x},\mathbf{y})_\sigma)$
            $\mathbf{B}^* \leftarrow \mathbf{B}_r$
            $(\mathbf{x},\mathbf{y})^* \leftarrow (\mathbf{x},\mathbf{y})_\sigma$
            $\sigma^* \leftarrow \sigma$
        else if $g_\sigma(\mathbf{B}_r, (\mathbf{x},\mathbf{y})_\sigma) \leq$MAXVAL then
            return $\sigma = \sigma + 1$
        end if
        return MAXVAL, $\mathbf{B}^*, (\mathbf{x},\mathbf{y})^*, \sigma^*$
    else if (6) $> \gamma_{th}$, $\mathbf{B}_r \notin \mathbb{Z}^+$ then
        for all $b_{i,j}^r \notin \mathbb{Z}^+$ do
            B&B_SEARCH($(b_{i,j}^r = 0) \rightarrow \mathbf{B}_r, (\mathbf{x},\mathbf{y})_\sigma$, MAXVAL)
            B&B_SEARCH($(b_{i,j}^r = 1) \rightarrow \mathbf{B}_r, (\mathbf{x},\mathbf{y})_\sigma$, MAXVAL)
        end for
    else if (6) $< \gamma_{th}$ then
        return $\sigma = \sigma + 1$
    end if
end function
```

Solving the Optimization Problem: Since the joint optimization of the number (N_{nBS}) and locations ($\mathbf{x}$, $\mathbf{y}$) of new small cells together with the user association ($\mathbf{B}$) in (6) is a mixed integer programming problem, which is NP-hard, the global optimal solution is difficult to obtain. Therefore, we devise a reduced-complexity iterative algorithm (in Algorithm 1) to solve the optimization problem in (6) based on the branch and bound (B&B) method, where the binary constraint in (10) is relaxed to $0 \leq b_{i,j} \leq 1, \forall i, j$, forming a relaxed matrix $\mathbf{B}_r$. The algorithm iteratively optimizes the number of new small cells, starting with the initial value $\sigma = 1$. In each iteration, the optimization problem in (6) is solved with the number of new small cells from the previous iteration (or the initial value); if no feasible solution is obtained, then the number of new small cells is increased by 1; otherwise, the iteration terminates and the optimal solution is returned, where $(\mathbf{x}, \mathbf{y})_\sigma$ denote the location vectors of new small cells with the size of $\sigma \times 1$.

Simulation Results: The performance of the proposed iterative algorithm of deploying new small cells on top of the existing HetNet is evaluated through simulations in comparison with the solution obtained by numerically solving (6) using the method of exhaustion for optimizing user associations and using the generalized reduced gradient (GRG) method [6] for optimizing new small cells' locations; as well as the random deployment of new small cells following a homogeneous spatial Poisson point process (SPPP). In the simulation, two existing small cells are distributed in the coverage area of the macrocell following a homogeneous SPPP. 40 non-HS UEs are uniformly distributed in the coverage area of the macrocell, and the N_{hs} HS UEs are uniformly distributed in a circular area with a radius of 40m centered at a randomly selected point in the coverage area of the macrocell. The transmit power of the macro BS and a small-cell BS is 46dBm and 23dBm, respectively. We set $W = 180$kHz, $N_{RB} = 50$, $N_0 = -174$dBm/Hz, $\gamma_{th} = 4$Mbps and $\alpha = 4$, the coverage radius of a macrocell is 300m and that of each small cell is 20m.

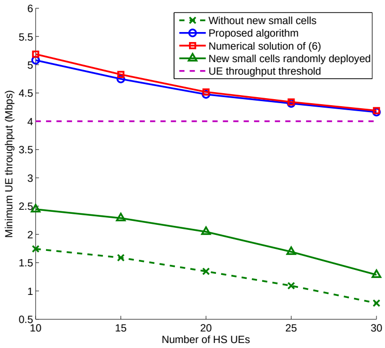

Fig. 1: The minimum UE throughput vs. the number of HS UEs.

Fig. 1 plots the minimum UE throughput versus the number of HS UEs. It shows that without deploying new small cells, the minimum UE throughput falls below the threshold, because the existing HetNet cannot fulfil the extra traffic demand from HS UEs. While with new small cells deployed following the proposed algorithm or by numerically solving the joint optimization in (6), the minimum UE throughput can be kept above the threshold even for a large number of HS UEs. If the same number of new small cells (same as our proposed algorithm) are deployed randomly over the macrocell coverage area, the minimum UE throughput is increased as compared to the case without new small cells, but still falls below the threshold. The solution obtained by numerically solving (6) offers a slightly higher minimum UE throughput than the proposed iterative algorithm, at the cost of a higher computational complexity. The proposed algorithm needs 2×10^4 to 5×10^4 loops to get the optimal solution, while numerically solving (6) needs 3.75×10^{11} to 8×10^{12} loops. The performance of the iterative algorithm gets closer to that of the joint optimization for more HS UEs.

Fig. 2 shows the average number of new small cells required for all UEs to meet the UE throughput threshold versus the number of HS UEs. We can see that the proposed iterative algorithm requires slightly more new small cells than the numerical optimization solution, with the gap between them reducing as the number of HS UEs increases. The random deployment requires a lot more new small cells than both the proposed algorithm and the numerical optimization solution.

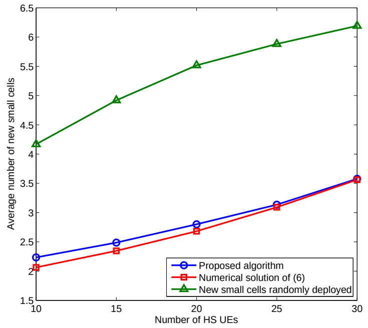

Fig. 2: The average number of new small cells vs. the number of HS UEs.

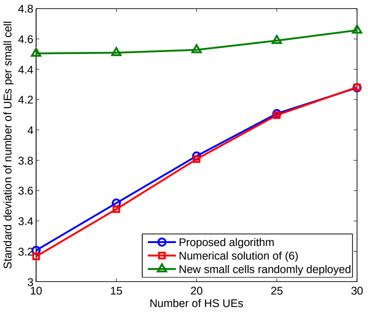

Fig. 3: The SD of number of small cell UEs vs. the number of HS UEs.

Fig.3 plots the standard deviation (SD) of the number of UEs per small cell under the same setting as Fig. 2. We can see that the proposed iterative algorithm achieves a SD of UEs per small cell very close to that of the numerical optimization solution, which is much lower than that of the random deployment of new small cells. This shows that the proposed algorithm achieves a more balanced load distribution using less new small cells than the random deployment, due to the optimized locations of new small cells.

Conclusion: We have proposed an iterative algorithm to optimize the number and locations of new small cells to be deployed on top of an existing HetNet and the user associations of all cells, in order to fulfil the extra traffic demands of HS UEs. The simulation results have shown that the iterative algorithm offers a much higher minimum UE throughput and requires less new small cells for all UEs to meet the UE throughput threshold than the random deployment of new small cells. Moreover, the iterative deployment algorithm achieves a more balanced load distribution using less new small cells than the random deployment.

N. E, X. Chu, and J. Zhang (*Department of Electronic and Electrical Engineering, University of Sheffield, UK*)

E-mail: nan.e@sheffield.ac.uk

References

1 Hsieh, H. Y., Wei, S. E., and Chien C. P.: 'Optimizing Small Cell Deployment in Arbitrary Wireless Networks with Minimum Service Rate Constraints', *IEEE Trans on Mobile Computing*, 2014, pp.1801-1815
2 Qutqut, M. H., Abou-zeid, H., Hassanein, H. S., Rashwan, A. M., and Al-Turjman F. M.: 'Dynamic small cell placement strategies for LTE Heterogeneous Networks', *ISCC*, 2014, pp. 1-6
3 3GPP TR 36.814 V9.0.0.: 'Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9)', 2010
4 3GPP TR 36.921 v11.0.0.: 'E-UTRA FDD Home eNode B Radio Frequency requirements analysis (Release 11)', 2012
5 Wu, J., Chu, X., Lĺópez-Pĺęrez, D., and Wang H.: 'Femtocell exclusion regions in hierarchical 3-sector macrocells for co-channel deployments', *ICCC*, 2012, pp. 541-545
6 Lasdon, L. S., Waren, A. D., Jain, A., and Ratner, M.: 'Design and testing of a generalized reduced gradient code for nonlinear programming', *ACM Transactions*, 1978, 34-50.