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Small Cells Placement for Crowd Networks

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Abstract—The deployment of small cells is one of the technical solutions to meet the challenge of data traffic rise. It reduces the cost of radio access networks. The efficiency of this solution depends on the success of cell planning to mitigate the interference. This work aims to optimize the incremental cell planning scheme that considers a preliminary macro-cell network infrastructure and expands it with new small cells to enhance the coverage and the capacity. In order to reduce the cost of installing new small cells, we consider a crowd networking business model where the Mobile Network Operator retrieves sites to deploy small cells above. We formulate the small cells placement problem as an Integer Linear Programming. It aims to maximize the coverage, ensure the required capacity and mitigate the cross-tier interference. Since the problem is NP-hard with large number of sites, we propose an heuristic to select the optimal sites locations around each macro cell. We tested the proposed heuristic with different simulation scenarios. The proposed Sequential Deployment scenario is better in coverage uniformity among dense and non dense zones whilst the Dense Zones First ensures more optimized selected sites number with better capacity in the dense zones in terms of users. The last scenario proves that higher candidate sites optimize the number of small cells in the non dense areas without compromising the coverage.

I. INTRODUCTION

Massive small cells deployment trend is planned to manage high data-traffic growth rates and increased demand for broadband in the industrialized countries. But it is also considered as a solution to cover white zones in emerging countries with a reasonable cost. The scarcity of radio resources, the high cost of network expansion and the problem of interference that it creates are the main issues of this approach. This approach can be applied with crowd networking business model that pools the usage of the street furniture such as billboards, bus shelters or street lights to reduce the purchase cost of new sites to deploy small cells. This work aims to study an incremental cell planning starting from a traditional network and a set of sites that can host small cells to overlaid it. The set of sites are characterized with their locations, their heights and some other features which give them different weights. We consider an optimization problem that selects the best sites in terms of coverage, interference mitigation and capacity enhancement. We formulate the problem as an Integer Linear Program (ILP). This problem is NP-Hard, hence we propose an heuristic based on tabu search algorithm principle [1] to solve it. This heuristic optimizes the sites selection locally in the coverage range of

each macro cell. Three scenarios are proposed, the first one is a sequential placement of small cells, the second starts with dense zones first while varying the candidate sites number. The third scenario considers different proportions of sites heights in the candidate sites. The conducted study showed that the first scenario covers uniformly the tested area, the second scenario focuses on getting a better capacity in the dense zones. The last scenario shows that higher candidate sites are more likely to be selected which validates our proposed algorithm.

The rest of this paper is outlined as follows: Section II summarizes the state of the art. The description of the system model is in Section III. Section IV is devoted to simulation results and the evaluation of the proposed solution. Finally, Section V concludes the article and gives some perspectives to this work.

II. RELATED WORK

The densification is defined as the key mechanism to satisfy the continuous growth of mobile data amounts. It includes -according to authors in [2]- both densification over space by massive deployment of small cells and densification over frequency by using larger radio spectrum.

Densification over space evokes the cell planning problem. Many cell planning schemes were studied in the literature. Some of them consider coverage and capacity as main objectives: In [3], authors propose a cell planning model for the downlink in HetNets with cell range expansion and macro-pico cell interference coordination. The objective that they consider is to find the minimum number of installed pico cells while covering all users. They used greedy algorithm to solve the problem. However, the pico-cells are deployed to cover white zones only without enhancing the capacity. Furthermore, they consider a joint spectrum between pico and macro cells and their study is limited to the LTE-advanced context. [4] proposes an optimized cell planning to reduce the pathloss using tabu search as optimization algorithm. His results showed a remarkable improvement in the data traffic coverage. But this work investigates the classical cell planning problem to optimally cover a white zone with macro base stations (BSs). Authors in [5] propose a cell planning approach using a meta-heuristic. They aimed to satisfy both cell coverage and capacity in areas with different user densities and inter-cell interference. Their work is oriented to 4G

networks, they do not consider a macro-small cell network in their dimensioning. They applied their proposed approach for two-tier HetNet networks to test its performance. They apply the algorithm in three steps: first they select macro BSs' locations to satisfy global coverage and capacity, second they apply it to select small BSs' locations to satisfy capacity in each subarea without considering coverage and finally they apply the elimination algorithm to remove redundant BSs. The small cells in their study are marginally considered to expand capacity in some areas where macro-cells can not satisfy users data traffic in some interval of time in the day. [6] gives an interesting comparative study between random and grid deployment of small cells in terms of spatial outage and throughput. The results proved that the performance of the two topologies converges to close values when the network density increases. But they do not propose alternative solutions to mitigate interference that densification creates considering the scarcity of radio resources.

Some other tracks focus on the energy efficiency in the planning of small cells networks. [7] proposes small cell deployment as a solution to increase the capacity of cellular networks in an economical and ecological way. It suggests a large system analysis based on Random Matrix Theory (RMT) to provide tractable approximations of key performance measures of small-cell networks. [8] also presents an energy-efficient scheme to plan and deploy small cells according to various traffic patterns using stochastic geometry approach. [9] gives insights into optimal deployment strategies for planning cost-effective and energy-efficient small-cell and fiber backhaul networks. All these works do not consider coverage, capacity and interference as important factors in small cell networks planning.

To sum up, the factors to take into account to design a small cell network are numerous such as coverage, capacity, cost and energy and they vary with the context of study (suburban, urban, industrial, indoor, outdoor, etc.) The problem of placement is always NP-hard and it can be addressed from several viewpoints. The cell planning in the crowd networks context where macro cells are overlaid with small cells is rarely investigated. We consider in this paper a crowd network with a classical macro cell network and a set of industrial partner sites to deploy small cells above. We investigate small cells' placement with coverage improvement, interference mitigation and capacity enhancement which are the most important factors in small-cell network.

III. SYSTEM MODEL

This Section describes the network architecture and the deployment objective and constraints then it presents the proposed heuristic that we apply to get the cell planning.

A. Network Architecture

We consider a 2D area covered with macro cells. This area is classified according to the density of user equipments (UE) and the estimated traffic demand per zone into i non dense zones and ii dense zones. We consider CS the set of candidate

sites where we can deploy new small cells. Each candidate site CS_j is characterized with its coordinates (x_j, y_j) , its height h_j and its zone's density factor D_j . The zone's density factor D_j defines the needed capacity according to the maximum number of users in this zone. We consider also a set of test points TP . A test point TP_i corresponds to a UE in this paper. The coverage is tested in each TP_i to ensure that there are no white zones. The area to cover is modeled as shown in Figure 1.

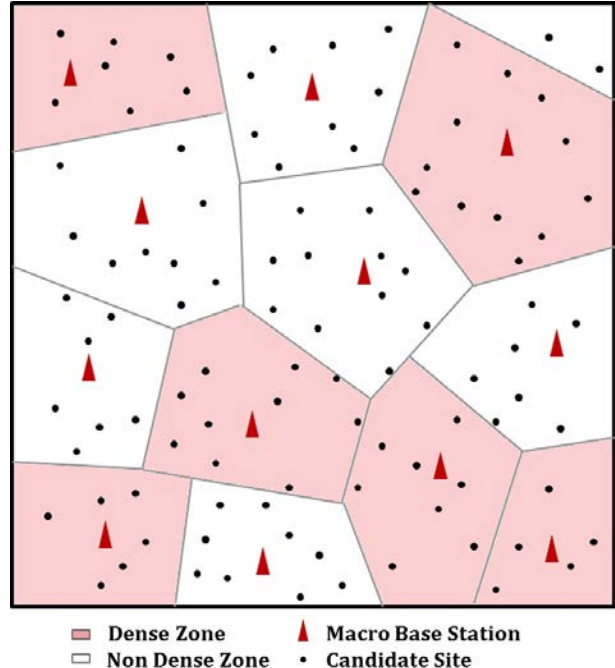


Fig. 1. Network Model

B. Deployment Objectives and Constraints

This subsection presents the objectives and constraints that we consider in the cell planning.

- **Coverage:** One of the small cells deployment objectives is to ensure a sufficiently high signal to each user and to cover white zones in the targeted area. From the transmitter to the receiver, the signal is exposed to many factors. Thus, in the cell planning, some parameters should be considered like transmission power, antenna height and Propagation Loss. A zone is considered covered when there is a Signal to Interference plus Noise Ratio ($SINR$) higher than a predefined threshold that can ensure a required Quality of Service (QoS) in all TPs in this zone.
- **Capacity:** The network capacity can be defined as the users number that it can serve simultaneously in case of mono-service or also the global traffic that can be conveyed in case of different services. We consider in our work the first definition. Hence, the required capacity corresponding to the zone's density in terms of UEs is translated to a number of BSs with a defined width of frequency sub-bands.

- **Interference:** Fractional frequency reuse is a fundamental principle of small cells dense deployment to enhance the overall network capacity. Nevertheless, the main issue of this technique is the inter-cell interference. Small cells, densely deployed sharing the same spectrum, create strong interference in case the frequencies are not well assigned. We consider that the deployed small BSs use a disjoint spectrum from the macro BSs. Thus, there is only intra-tier interference. We use a Fractional Frequency Reuse (FFR=3), the interfering small BSs with a small cell are those situated at most 3 times its range (R) and using the same carrier.

1) *Problem Formulation:* The previous section briefly presented the parameters that we take into account in our cell planning model. Hence we propose an optimization objective function maximizing the coverage and minimizing the interference under the constraint to ensure the required capacity in each zone. The coverage is measured with ($SINR$) in all TPs in the range of a small cell, so the objective function depends on the site coordinates (x_i, y_i) , its height h_i , the transmission power P_i , the distance d_i to the test point TP_i and the set S'_i of interfering small cells using the same carrier. We consider a binary variable X_i denoting the state of the TP_i such as:

$$X_i \in \{0, 1\} = \begin{cases} 1, & \text{if } SINR \geq SINR_{th} \text{ in } TP_i \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

Where:

$$SINR = \frac{P_{r,i}}{I + N} \quad (2)$$

where $P_{r,i}$ is the received power, I the interference in this TP and N the Channel Noise.

$$P_{r,i_{dB}} = P_{i,dB} - L_{dB}$$

Where P_{i} is the transmission power and L is the transmission loss. We consider the model designed for Line of Sight (LoS) short range outdoor communication in the frequency range 300 MHz to 100 GHz. The upper and lower bounds $L_{LoS,u}$ and $L_{LoS,l}$ are as follows:

$$L_{LoS,u} = L_{bp} + 20 + \begin{cases} 25 \log\left(\frac{d}{R_{bp}}\right) \text{ if } d \leq R_{bp} \\ 40 \log\left(\frac{d}{R_{bp}}\right) \text{ if } d > R_{bp} \end{cases} \quad (3)$$

$$L_{LoS,l} = L_{bp} + \begin{cases} 20 \log\left(\frac{d}{R_{bp}}\right) \text{ if } d_i \leq R_{bp} \\ 40 \log\left(\frac{d}{R_{bp}}\right) \text{ if } d_i > R_{bp} \end{cases} \quad (4)$$

Where the breakpoint distance is given by:

$$R_{bp} \approx \frac{4h_s h_m}{\lambda}$$

and the above parameters are:

λ : wavelength, h_s : site's height above the ground, h_m : mobile UE height above the ground, d_i : distance and L_{bp} is the value for the basic transmission loss at the breakpoint, defined as:

$$L_{bp} = \left| 20 \log \frac{\lambda^2}{8\pi h_s h_m} \right|$$

We consider the average value between the upper and the lower bound. The interfering signal power is given as follows:

$$I = \sum_{k=1}^K P_{r,k}$$

where k is the index of the interfering small cell in the site CS_k in the set S'_i .

The optimization of the sites number should not compromise the capacity of the network. We consider that each small cell in the site CS_i is able to serve a number n_i of users in case of single service. If we suppose that M is the set of deployed small cells in the zone Z_j and N_j is the total capacity associated to the density D_j then the required capacity in this zone is:

$$N_{D_j} - \sum_{m=1}^M n_m \quad (5)$$

Thus, we get the following optimization problem:

$$\begin{aligned} & \max(\sum X_i) \\ & X_i \in \{0, 1\} \\ & \text{subject to} \\ & \sum_{m=1}^M n_m \geq N_{D_j} \end{aligned} \quad (6)$$

C. Small Cells Placement Heuristic (SCPH)

In the previous section we formulated the objective function. Since the CS number is high, this problem is NP-hard. Furthermore, the studied area has different density zones. Overall optimization may not give optimal results locally which can penalize some users in certain zones. Thus, we propose hereafter an heuristic based on tabu search algorithm principle. Tabu search is a meta-heuristic that guides a local heuristic search procedure to explore the solution space beyond local optimality. It memorizes the visited solutions or user-provided sets of rules. If a potential solution has been previously visited within or if it has violated a rule, it is marked as "tabu" (forbidden) so that the algorithm does not consider that possibility repeatedly. The idea of the heuristic that we propose is to split the area to cover into Z hexagonal zones within a macro cell range. In each zone z_i , there is a macro BS and a set of CS . We apply the heuristic in order to find the best locations of small cells within this zone. z_i has a required capacity N_i according to the density in terms of UEs and the capacity covered by its Macro BS. For each CS , we calculate the $SINR$ in all the TPs , we find the list of TPs where the $SINR$ respects the threshold constraint. Then we sort the sites according to the size of their covered TPs lists, we select the site that covers the maximum TPs . We repeat this procedure until all TPs in z_i are covered and the required capacity is guaranteed. The proposed heuristic is presented in Algorithm 1: Small Cells Placement Heuristic (SCPH) that calls Algorithm 2: find_best_CS_coverage which finds the site covering the maximum number of TPs .

Algorithm 1 SCPH: Small Cells Placement Heuristic

Input: Z : Macro cells coverage zones, CS : Candidate Sites, TP : Test Points N : Required Network Capacity F_A, F_B, F_C : Frequency sub-bands

Output: SS : List of selected sites

```
1:  $SS \leftarrow \text{null}$ 
2: for all  $z_i \in Z$  do
3:    $List_i \leftarrow \text{null}$ 
4:    $TP_{covered} \leftarrow \text{null}$ 
5:    $Cap \leftarrow 0$ 
6:   while  $TP_{covered} < TP_i$  or  $Cap < N_i$  do
7:      $(CS_{first}, TP_{j,List}) \leftarrow \text{find\_best\_CS\_coverage}(z_i, CS_i,$ 
8:        $TP_i, TP_{covered}, F_A, F_B, F_C)$ 
9:     Add  $CS_{first}$  to  $List_i$ 
10:    Add  $TP_{j,List}$  to  $TP_{covered}$ 
11:     $Cap \leftarrow Cap + n_j$ 
12:   end while
13:   Add  $List_i$  to  $SS$ 
14: The solution is the elements of the list  $SS$ 
```

Algorithm 2 find_best_CS_coverage: find the CS with the maximum number of covered test points

Input: z_i : Macro cell i coverage zone, CS_i : Candidate Sites in z_i , TP_i : Test Points in z_i , $TP_{covered}$: Covered TP List F_A, F_B, F_C : Frequency sub-bands

Output: $CS_{i,first}$: CS with maximum covered TP

$TP_{first,List}$: List of TP covered by $CS_{i,first}$

```
1:  $TP_{j,List} \leftarrow \text{null}$ 
2:  $TP_{covered} \leftarrow \text{null}$ 
3: for all  $CS_j \in z_i$  do
4:    $TP_{j,List} \leftarrow \text{null}$ 
5:    $F_j \leftarrow$  Frequency of the lowest received power ( $F_A, F_B,$ 
6:      $F_C$ )
7:   for all  $TP_j \in TP_i$  and  $TP_j \notin TP_{covered}$  do
8:     if  $SINR_{TP_j} > SINR_{th}$  then
9:       Add  $TP_j$  to  $TP_{j,List}$ 
10:    end if
11:   end for
12:  $CS_{i,first} \leftarrow CS_j$  with the largest size of  $TP_{j,List}$ 
13:  $TP_{first,List} \leftarrow TP_{j,List}$  of  $CS_{i,first}$ 
```

IV. PERFORMANCE EVALUATION

We consider 3 test scenarios:

- *Sequential Deployment Scenario*: The Heuristic is applied in the order of macro cells locations. Candidate sites number is varied starting with 20 CS , then it is increased until reaching 150 CS .
- *Dense Zones First Deployment Scenario*: As in the previous scenario, CS number is increased progressively but in this case, the heuristic is applied first to dense zones then to non dense zones.

TABLE I
SIMULATION PARAMETERS

Network size	2000m x 2000 m
Radius of a macro cell	700m
Radius of a small cell	150m
Small cell transmit power	2W
Number of macro UE devices in a cell	50
Number of small UE in a cell	5
Frequency band	3.5GHz
Sites heights	$h_{s,1}=14\text{m}$, $h_{s,2}=4\text{m}$
Test points number	210

- *Impact of candidate sites' height*: In this scenario, CS number is fixed to 150, but the proportions of the sites heights $h_{s,1}$ and $h_{s,2}$ are varied to investigate the behaviour of our heuristic towards this parameter.

Test parameters are summarized in Table I.

A. Simulation Results and Analysis

These scenarios are simulated using Matlab in order to investigate the impact of sites selection order in the resulted topology, the coverage, the expanded capacity in dense and non dense zones. The impact of sites heights proportions is also investigated.

1) *Impact of Candidate Sites Number on Coverage and Capacity*: Figure 2 shows that with a small number of CS , most of sites are selected and the results of Sequential scenario are close to those of Dense Zones First scenario. There is no interference issues in this case and the selected sites number is lower than the coverage and capacity requirement. With a higher number of CS , Results of Dense Zones First scenario are more optimized. This is due to the sites located in the border of dense zones. They ensure the coverage for non dense zones that don't need extra ones for capacity which reduces the overall number of selected sites. A very high number of CS raises the number of locations ensuring a $SINR$ higher than the required threshold and gives more sites eligible to cover more TPs , which explains the slight decrease of selected sites number with $CS = 150$. Nevertheless, the outage probability is higher for the second scenario as presented in Figure 3. Here the non dense zones' users are penalized especially those located in the borders. Sequential scenario ensures a uniform coverage. We should mention here that the outage probability is tested with a number of TP higher than that used in the sites' selection. The expanded capacity in Sequential scenario exceeds the required values with a high number of CS especially in non dense Zones as shown in Figure 4. It selects extra sites to ensure the coverage. Whilst Dense Zones First scenario selects more sites in dense zones to meet the required capacity. The coverage in non dense zones in this scenario is partially provided by small cells located in the borders of the dense zones and selected to enhance the capacity. With a sufficiently high number of CS , Dense Zones First scenario provided the required capacity for both kind of zones.

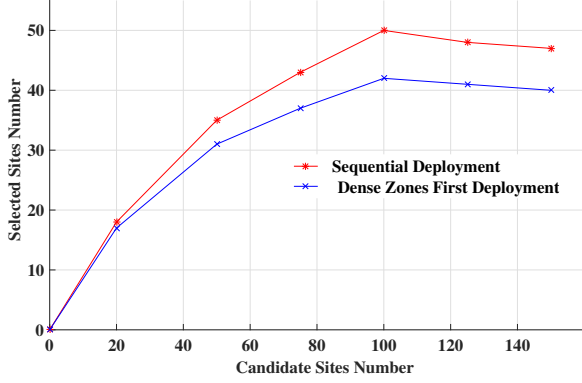


Fig. 2. Selected sites number in Sequential and Dense Zones First scenarios

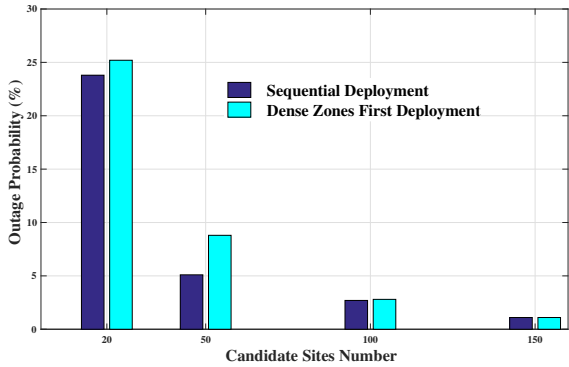


Fig. 3. Outage probability

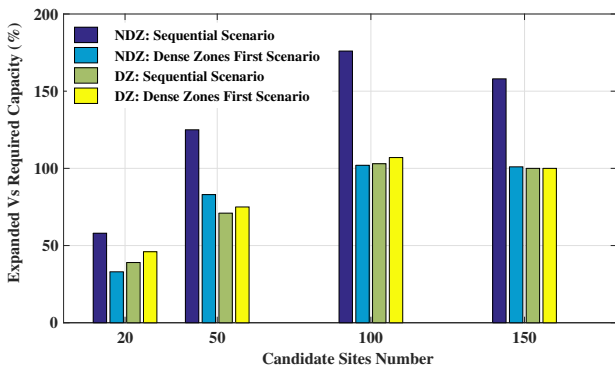


Fig. 4. Expanded vs required capacity in dense and non dense zones

B. Impact of Sites Heights on the Signal Loss

CS number in this scenario is fixed to 150, the proportion of sites with height $h_{s,1} > h_{s,2}$ in the CS is varied between

20% and 80%. Figure 5 shows that the site height influences the selection decision. Sites with $h_{s,1}$ are more likely to be selected because that reduces the propagation loss and thus improves the SINR. We can also notice in Figure 6 that when the proportion of sites with height $= h_{s,1}$ is higher, the selected sites number decreases. This optimization in the number of sites to be deployed is due to the coverage of non dense zones. The required capacity in non dense zones is low and most of sites are selected to ensure coverage. When we use higher sites, each one will cover more TPs which reduces the total number of small cells. While in the dense zones, the need of a large number of sites is related to the data traffic amounts and higher sites guarantee a better quality of $SINR$ without reducing the number of small cells to be deployed. These results prove that the proposed heuristic optimizes the number and the quality of coverage.

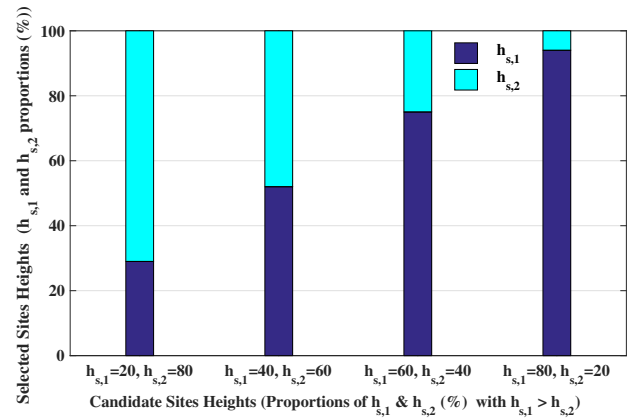


Fig. 5. Selected sites Vs candidate sites heights proportions

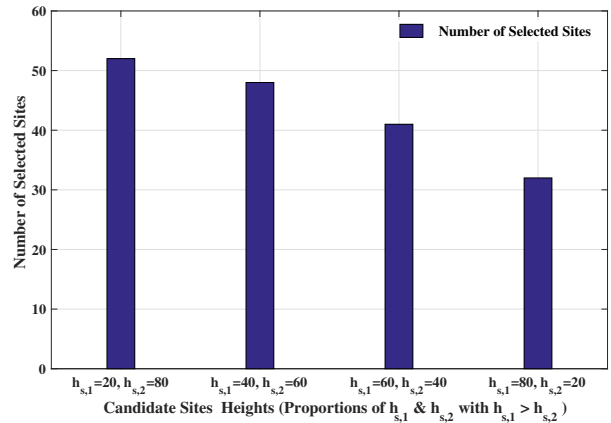


Fig. 6. Impact of candidate sites heights proportions on the number of selected sites

V. CONCLUSION

Small cells placement optimization is a NP-hard problem. We proposed in this paper an algorithm to tackle with this

issue. It aims to improve the coverage and the capacity and to mitigate the interference with the minimum number of sites. The algorithm optimizes the sites selection around each macro cell already deployed to meet the different traffic demand values among highly dense zones and zones with lower density. Three scenarios have been studied, the first one considers a sequential deployment and the second starts with the deployment in dense zones first while the third vary the proportions of heights $h_{s,1}$ and $h_{s,2}$ in the CS. Simulation results show that the sequential scenario ensures a uniform coverage through the investigated area, the second scenario gives more optimized sites number and provides better capacity to dense zones while the latter proves the importance of boosting the number of higher sites in CS to improve the signal quality and optimize the deployed small cells number especially in non dense zones without compromising the coverage. Further work will be carried out in the future. The suggested scheme will be completed by including installation cost and energy coefficients in the objective function in order to optimize the deployment of small cells considering more factors likely to improve cell planning.

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