

Dynamic Fractional Frequency Reuse Method for Self-Organizing Smallcell Network

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Abstract—Smallcell is emerging as a cost-effective solution for satisfying the huge demands of mobile data. It can be deployed at any place where mobile traffic is required without the need for cell planning. However, coexistence of many uncontrolled smallcells using the same licensed frequency band can result in serious interference problems. In order to utilize smallcell efficiently, it is highly desirable that the smallcell can self-organize the network and mitigate interference automatically. In this paper, we propose a dynamic fractional frequency reuse (FFR) method for reducing the intercell interference automatically and improving the spectral efficiency. Key features of the proposed method are sub-band optimization with a central manner and sub-band size adjustment with a distributed manner. The proposed method has a low complexity and can be implemented as a feature of a self-organizing network (SON) in smallcell. Simulation results verify the effectiveness of the proposed method.

Index Terms—Smallcell, interference mitigation, self organizing network, fractional frequency reuse.

I. INTRODUCTION

The high cost of deploying macro base stations (BSs) means that, in recent years, smallcell has emerged as an attractive solution to meet the growing demand for mobile data [1], [2]. Though distributed antenna system (DAS) is much convenient in extending a coverage in a big building, smallcell has been proposed to provide a coverage and to increase the capacity more in hotspot such as shopping mall, coffee shop, etc. Also, outdoor smallcell has been proposed to extend the outdoor coverage in a cost effective manner [3], [4]. However, since smallcell can be installed without cell planning, significant interference problems may arise [5]–[7] which need to be addressed from a practical deployment point of view. In general, tremendous effort is required in optimizing to reduce the intercell interference since uncontrolled interference will cause poor signal quality even though the signal level is high.

The conventional methods to mitigate the interference of orthogonal frequency division multiple access (OFDMA) system by avoiding frequency collision can be divided into two main categories: (a) frequency segmentation (FS) and (b) fractional frequency reuse (FFR) [8], [9]. The FS method minimizes the interference by dividing the whole frequency band into smaller sub-bands and allocating a sub-band to each smallcell. However, this is spectrally inefficient because a smallcell cannot use the whole band. The FFR method minimizes the cell edge interference by dedicating a sub-band partially, and reuses common band for the cell center.

This makes FFR method more spectrally efficient than FS. In addition, it has been shown that cell coordination in resource block allocation can reduce the intercell interference as well as increase capacity [10].

The FFR method, in case of smallcell, has difficulties in manual optimizing of sub-band allocation and in cell coordination since the smallcells can be randomly located and their number may be large. In addition, the conventional FFR method will be inefficient in spectral usage when mobile-stations (MSs) are congested in the cell center because the reserved sub-band for the cell edge MS is not allocated to the cell center MS. Hence it is desirable to design the smallcell network as a self-organizing network (SON) [11], [12] that optimizes the sub-band allocation automatically for interference reduction and improves the spectral efficiency. SON provides efficiency in operating the network.

In this paper, we propose a dynamic FFR method associated with SON to mitigate interference automatically and to increase spectral efficiency in smallcell networks. The proposed method can be applied to BS enabled with a function of wireless network monitoring. Wireless network monitoring function is widely considered for SON and can be easily implemented with software MODEM. The key ideas in our proposed method are the followings:

- the sub-band optimization for FFR is performed automatically in a central manner by reducing sub-band collision to reduce the interference,
- the size of FFR sub-band is adjusted automatically in a distributed manner according to the real-time traffic conditions to increase the spectral efficiency,
- a low complexity is achieved to implement a real-time dynamic FFR which has a low computation power in a perspective of SON.

The rest of the paper is organized as follows. Section II presents the system model for FFR, along with the basic description of SON operation. Section III presents our proposed method which enables BS to choose the sub-band for interference reduction and to adjust the sub-band size adaptively according to the traffic conditions. Section IV presents the simulation results. Finally conclusions are presented in Section V.

II. SYSTEM MODEL

We consider a wireless smallcell network that is located randomly according to the demands of the mobile traffic. We assume the network has a self-organizing capability [11], [12] that is widely considered from macrocell to smallcell to operate the network effectively. Automatic cell optimization is the purpose of self organizing network (SON) to reduce the cost of deploying and operating the network, and it is critically needed for smallcell since the number of smallcells may be massive without cell planning.

Wireless network monitoring is one of key functions for the SON. The BS recognizes its neighboring environment by listening and measuring the signals from other BSs. It can estimate the amount of interference and get its neighbor's broadcasting messages. BS uses this information for self optimization, or sends it to the SON server for central optimization. The former is known as distributed SON and the latter is centralized SON [12]. Hybrid SON is also available which combines both methods.

We are focusing, in this paper, only on the mutual interference between smallcells, assuming the interference between macrocell and smallcell is mitigated with a time technique such as almost blank subframe (ABS) technique [13]. With ABS, macro BS sends only small fraction of broadcast signals on specific subframes to minimize the interference against the smallcell, then the BS for smallcell sends the signal to its edge MS during the specific subframes without significant interference from macro BS.

A. Resource block allocation for minimum interference

Assuming that there are N_{BS} BSs and whole frequency band is divided into N_{RB} resource blocks, we want to guarantee a down-link throughput of T^{edge} by intercell interference control. In general, interference minimization is formulated as an optimization of resource block allocations given by

$$\mathbf{A} = \arg \max_{a_{ij} \in \{0,1\}} \sum_{i=1}^{N_{RB}} \sum_{j=1}^{N_{BS}} W \log_2 \left(1 + \frac{a_{ij} \cdot P_{ij} \cdot \text{PL}_{ij}}{I_{ij} + \sigma_{ij}^2} \right) \quad (1)$$

s.t. $\min(T_1^{\text{edge}}, T_2^{\text{edge}}, \dots, T_{N_{BS}}^{\text{edge}}) \geq T^{\text{edge}},$

where $\mathbf{A}$ is an allocation matrix size of $N_{RB} \times N_{BS}$ whose element a_{ij} located on the i -th row and j -th column of $\mathbf{A}$ is an indicator which is one if the i -th resource block of j -th BS is allocated, or zero if not. W is bandwidth of the resource block, P_{ij} is transmitted power on i -th resource block from j -th BS, PL_{ij} is pathloss from j -th BS to its serving MS on i -th resource block, σ_{ij}^2 is thermal noise on i -th resource block of j -th BS, T_j^{edge} is the edge throughput of j -th BS, and I_{ij} is interference on i -th resource block from other BSs to MS served by of j -th BS calculated as

$$I_{ij} = \sum_{k=1, k \neq j}^{N_{BS}} P_{ik} \cdot \text{PL}_{ik}^j, \quad (2)$$

where PL_{ik}^j is pathloss from k -th BS to MS which is served by j -th BS on i -th resource block. To increase the system

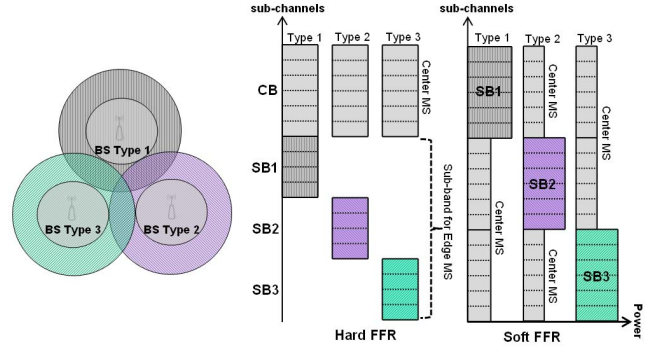


Fig. 1: Resource block allocation for fractional frequency reuse (FFR).

capacity, the allocation of resource block of all BSs should be optimized with a real-time manner according to the traffic condition. However, the real-time optimization is quite complex and not practical when there are many BSs and rapid changes of traffic.

B. Fractional frequency reuse

To alleviate the burden of optimizing in the allocation of resource block for interference mitigation, fractional frequency reuse (FFR) can be applied with a predefined pattern of resource block allocation. FFR is one of the resource block allocation methods which allocates common resource blocks to cell center MS and dedicates designated resource blocks to cell edge MS. Hard or soft schemes can be used for FFR [14] as shown in Fig. 1. Common-band (CB) and sub-band (SB) are the clusters of resource blocks for the cell center MS and the cell edge MS, respectively. The notable things in the case of soft FFR (SFFR) are that all resource blocks are fully used to increase the system capacity and SB is power-boosted while some resource blocks are not used in case of hard FFR (HFFR). However, since FFR is a technique for the SNR improvement of the cell edge MS by dedicating resource blocks, capacity loss of the cell center MS is inevitable. Also, the allocation of sub-band should be optimized for the less mutual interference between BSs.

III. PROPOSED METHOD OF DYNAMIC FFR WITH SON

We introduce a practical FFR method associated with SON for the BS of smallcell which can be randomly located. This method reduce the interference automatically and increase the spectral efficiency dynamically. The method we suggest consists of two algorithms: (a) automatic sub-band allocation for interference reduction and (b) real-time adjustment of sub-band size for spectral efficiency.

A. Automatic sub-band allocation algorithm

To have a stable connection between BS and MS, the interference should be minimized automatically when the smallcell BS is turned on. The most simple method for the

Algorithm 1 Algorithm for automatic sub-band allocation

(STEP 1: Self-Optimizing at BS)

1) BS decides the most silent sub-band when it is turned on.

(STEP 2: BS Clustering at SON server)

2) Building an interference link with a graph-based approach:

- Wireless network monitoring result
- (if available) Neighbor list report from MS

3) Clustering and calculating the number of clusters N_{cluster} .

(STEP 3: Central Optimizing at SON server)

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for  $m = 1 : N_{\text{cluster}}$ 
  4)  $N_m^{\text{link}} \leftarrow$  maximum number of interference links of BS in  $m$ -th cluster.
  5) Initializing BS ID vector  $\mathbf{B}_m$ .
  for  $n = N_m^{\text{link}} : 1$ 
    6)  $\mathbf{B}_m^n \leftarrow$  all BS IDs that have  $n$  interference links.
    7) Sorting  $\mathbf{B}_m^n$  by the highest order of interference amount.
    8) Appending  $\mathbf{B}_m^n$  to  $\mathbf{B}_m$ .
  end
  9) Deciding the number of sub-bands  $N_m^{\text{sb}}$  based on  $n = N_m^{\text{link}}$ .
  10) All sub-bands set  $\mathbb{F}_m \leftarrow \{1, \dots, N_m^{\text{sb}}\}$ 
  for  $n = 1 : \text{length}(\mathbf{B}_m)$ 
    11)  $\mathbb{H}_m^n \leftarrow$  Already used sub-bands in BSs linked to BS of  $\mathbf{B}_m(n)$ .
    12) Available sub-band set  $\mathbb{G}_m^n = \mathbb{F}_m \setminus \mathbb{H}_m^n$ 
    if  $|\mathbb{G}_m^n| > 0$ 
      13)  $\mathbf{C}_m(n) \leftarrow$  any  $g \in \mathbb{G}_m^n$ 
    else
      14)  $\mathbf{C}_m(n) \leftarrow$  sub-band of the linked BS whose received power is the weakest to BS of  $\mathbf{B}_m(n)$ 
    end
  end
end

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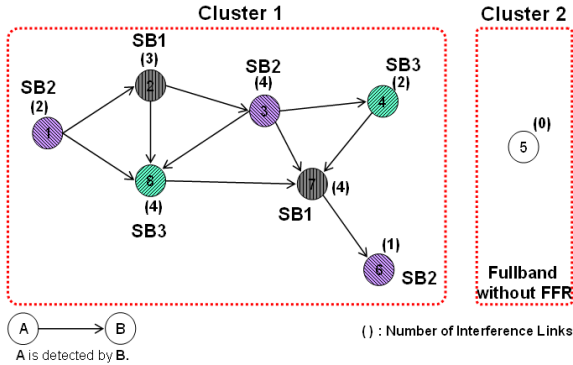


Fig. 2: The sub-bands are allocated by the SON server. If there is no neighbor interference, FFR is not triggered to minimize throughput loss due to FFR.

BS is a self-optimizing manner which chooses a silent sub-band when the BS is turned on. Though this method is simple, it has a drawback of sub-band collision when there is no silent sub-band.

To reduce the occasion of sub-band collision, well known central optimization of sub-band allocation can be modified for the smallcell BS as shown in Algorithm 1 summarized as follows:

- (STEP1) is the self optimization of choosing silent sub-band performed by each BS when it is turned on.
- (STEP2) and (STEP3) are additional procedures for the

central optimization. In (STEP2), the SON server clusters all small BSs into groups with a graph approach of interference link [14]. The result of monitoring wireless network performed in BS or the report of neighbor scan sent by MS can be used in building an interference link.

- The sub-band is allocated with a priority to the most interference-linked BS that receives highest amount of interference in (STEP3). Also, FFR is not triggered if there is no interference around BS's neighbor. $\mathbf{B}_m$ is the BS ID vector of the m -th cluster, and $\mathbf{C}_m$ is the vector of the allocated subband.

Fig. 2 shows how the BSs are grouped into clusters and the sub-bands are allocated. There is no sub-band collision in this example, and the cluster 2 is not triggered into FFR mode since BS#5 does not have an interference link.

B. Real-time sub-band adjusting algorithm

It will not be efficient to dedicate a sub-band for the cell edge MS when MSs are congested in the cell center. The conventional FFR method which predefines the resource block usage pattern will waste the spectral resources by not allocating the center MS with the resource blocks dedicated for the cell edge MS. In addition, manual adjustment of sub-band size according to the distribution of MSs is a big burden.

Hence, we suggest a sub-band adjusting algorithm which enables BS to adjust the size of the sub-band dedicated for the cell edge MS. BS can reallocate the resources reserved for the cell edge MS to the cell center MS if there is no MS in the cell edge. BS can adjust the sub-band size automatically with a real-time manner according to the traffic condition as described in Algorithm 2 summarized as follows:

- (STEP1) is the building of initial FFR pattern with the result of the automatic sub-band allocation algorithm. $\mathbb{S}_j^{\text{center}}$ and $\mathbb{S}_j^{\text{edge}}$ are the initial sets of resource block indices reserved for the cell center MS and the cell edge MS, respectively, decided after automatic sub-band allocation.
- (STEP2) is the process of sub-band adjusting based on the actual traffic condition. With information of channel quality indicator (CQI) reported from MS, the j -th BS can count the number of MSs whose CQIs are above threshold as M_j^{center} , and the number of MSs below threshold as M_j^{edge} . Then, the resource block sets of $\mathbb{S}_j^{\text{center}}$ and $\mathbb{S}_j^{\text{edge}}$ will be adjusted to $\mathbb{U}_j^{\text{center}}$ and $\mathbb{U}_j^{\text{edge}}$, respectively, at every allocation with sizes of

$$|\mathbb{U}_j^{\text{center}}| = \begin{cases} \lfloor \alpha_j \cdot (|\mathbb{S}_j^{\text{center}} + \mathbb{S}_j^{\text{edge}}|) \rfloor, & \text{if } \alpha_j > \beta_j \\ |\mathbb{S}_j^{\text{center}}|, & \text{if } \alpha_j \leq \beta_j \end{cases} \quad (3)$$

and

$$|\mathbb{U}_j^{\text{edge}}| = \begin{cases} \lfloor (1 - \alpha_j) \cdot (|\mathbb{S}_j^{\text{center}} + \mathbb{S}_j^{\text{edge}}|) \rfloor, & \text{if } \alpha_j > \beta_j \\ |\mathbb{S}_j^{\text{edge}}|, & \text{if } \alpha_j \leq \beta_j \end{cases} \quad (4)$$

Algorithm 2 Algorithm for sub-band adjusting

(STEP 1: Initial FFR Pattern)

Deciding FFR pattern using the result of sub-band allocation:

1) $SB_j \leftarrow$ allocated sub-band of j -th BS

2) $S_j^{\text{edge}} \leftarrow$ all resource blocks $c \in SB_j$

if SFFR

3) $S_j^{\text{center}} \leftarrow$ all resource blocks $c \notin SB_j$

elseif HFFR

4) $S_j^{\text{center}} \leftarrow$ dedicated resource blocks for center MS

end

(STEP 2: Adjusting FFR Pattern for scheduling)

if Allocation scheduling required

5) $U_j^{\text{center}} \leftarrow S_j^{\text{center}}, U_j^{\text{edge}} \leftarrow S_j^{\text{edge}}, Z_j \leftarrow \emptyset$

6) $\alpha_j = M_j^{\text{center}} / (M_j^{\text{center}} + M_j^{\text{edge}})$

7) $\beta_j = |U_j^{\text{center}}| / |U_j^{\text{center}} \cup U_j^{\text{edge}}|$

if $\alpha_j > \beta_j$

repeat

8) Choose resource block $c \in U_j^{\text{edge}}$ which is the nearest to any subchannels of U_j^{center} .

9) $Z_j \leftarrow c$

10) $U_j^{\text{center}} \leftarrow (U_j^{\text{center}} \cup Z_j)$

11) $U_j^{\text{edge}} \leftarrow (U_j^{\text{edge}} \setminus Z_j)$

12) Update β_j

until $\alpha_j \leq \beta_j$

end

13) Scheduling center MSs on U_j^{center}

14) Scheduling edge MSs on U_j^{edge}

end

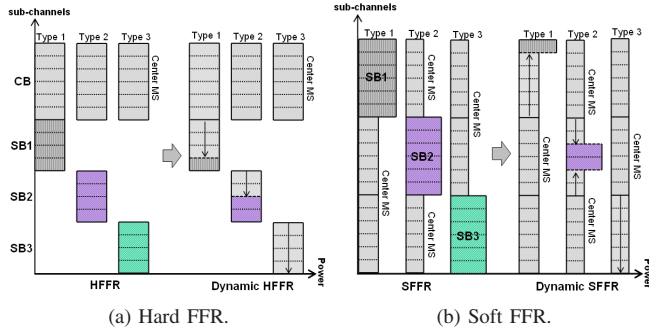


Fig. 3: Dynamic resource block allocation for both schemes of HFFR and SFFR.

where α_j is the center MS ratio calculated as

$$\alpha_j = \frac{M_j^{\text{center}}}{M_j^{\text{center}} + M_j^{\text{edge}}}, \quad (5)$$

and β_j is the center resource ratio given by

$$\beta_j = \frac{|U_j^{\text{center}}|}{|U_j^{\text{center}} \cup U_j^{\text{edge}}|}, \quad (6)$$

and $\lfloor \cdot \rfloor$ is the floor function.

For example, if α_j is close to one, i.e., most of MSs are located at the cell center of the j -th BS, BS can reallocate the parts of cell edge resource blocks reserved for the cell edge MS to the cell center MS. Fig.3 presents how the BS

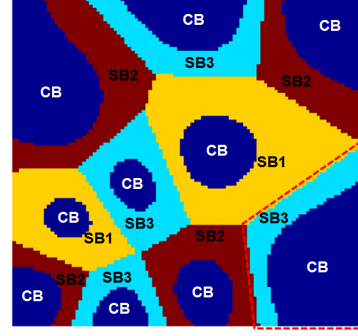


Fig. 4: Example of automatic sub-band allocation for FFR. The whole band is segmented 4 bands of CB (blue), SB1 (yellow), SB2 (brown) and SB3 (cyan). Dotted area can be switched to full-band due to less interference link.

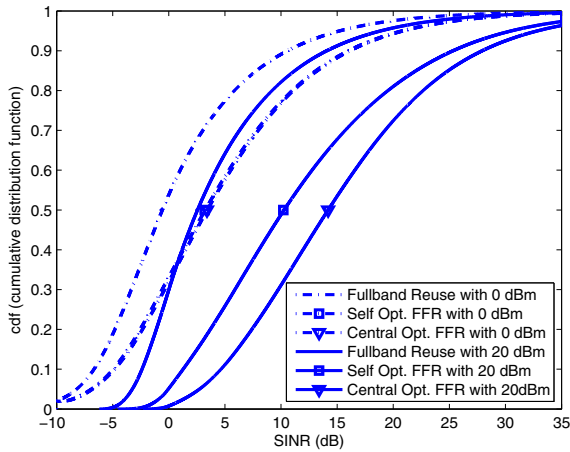
adjusts its FFR pattern with a given initial FFR pattern in both cases of HFFR and SFFR when MSs are congested in the cell center. Also, in case that the MSs are congested at the cell edge which is extremely rare but can happen, the initial FFR pattern will be used.

IV. SIMULATION RESULT

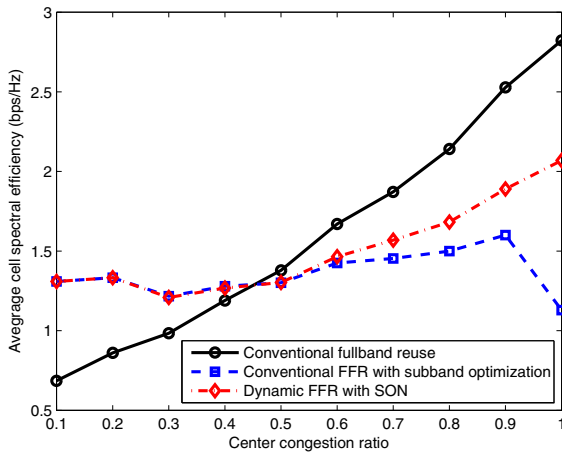
The performance improvement of dynamic FFR with SON is verified with simulations considering a big building such as a business park, office complex, or shopping mall where smallcell BSs can be deployed randomly. DAS can be used for the indoor coverage of big building, but smallcell is considered for the capacity purpose. The building is assumed to be single story of size of $(100 \times 100) m^2$, and the office pathloss model of ITU-R P.1238 [15] at 1.8 GHz (LTE Band 3) is used. Insertion loss of wall is ignored for simple simulation, and the signal of smallcell BS is transmitted with omni-antenna at the fixed power of 0 dBm and 20 dBm. Bandwidth is assumed as 10 MHz for LTE service, and Rx sensitivity level of wireless network monitoring is -95 dBm considering a real product. $N_{BS} = 10$ small BSs are randomly distributed for each simulation, and 10 MSs are distributed randomly within the service area of each BS. Sub-band for FFR is allocated automatically with a suggested method of automatic sub-band allocation. 1000 trials of simulation are performed to get the statistical result. HFFR is applied in this simulation, and the whole band is initially divided into common band (CB) and 3 sub-bands (SBs) with the ratio of 2:1:1:1. For simplicity, MS whose downlink SINR over -1 dB is allocated to CB and MS below -1 dB is allocated to the designated SB. Also sub-band adjusting algorithm is applied to improve the spectral efficiency.

A. Result of automatic sub-band allocation

An example of automatic sub-band allocation is shown in Fig.4 when 10 BSs are deployed randomly with full-band allocation. Sub-band for FFR is optimized with Algorithm 1 and the BS (dotted area) which has a low interference link



(a) Cdf of down-link SINR distribution with automatic sub-band optimization.



(b) Average down-link spectral efficiency versus center congestion ratio.

Fig. 5: Numerical Results

with other BSs will be switched to full-band mode to improve the spectral efficiency. Fig. 5(a) shows the SINR distribution with different Tx powers of BS. There is about 5 dB SNR gain with central sub-band optimization method compared to that with self optimization method in case of 20 dBm Tx power. However, there is no difference in SINR when the Tx power is decreased from 20 dBm to 0 dBm. This means that central optimization is better than self optimization in heavy interference environment, and self optimization is sufficient when interference is light.

B. Result of sub-band adjustment

Fig. 5(b) compares down-link spectral efficiencies versus center congestion ratio of MSs with 3 allocation methods of the conventional full-band reuse, the convention HFFR with sub-band optimization, and the suggested dynamic HFFR with SON. Tx power is assumed to be 20 dBm, and central optimization method is used in sub-band allocation.

The conventional method of full-band reuse is better than other methods in case that MSs are located in cell center, while HFFR method is better than full-band method when MSs are congested in the cell edge. In case of HFFR, the loss in maximum capacity is inevitable due to the resource dedication for the cell edge. However, dynamic HFFR with SON is better than the conventional HFFR when MSs are congested in the cell center. Dynamic HFFR with SON can provide more spectral efficiency when MSs are congested at the cell center.

V. CONCLUSION

In this paper, we suggested a practical simple method of dynamic FFR with SON for smallcells. It consists of two algorithms of automatic sub-band allocation and sub-band size adjusting. This method can mitigate the interference automatically between smallcells, also can improve the spectral efficiency by triggering FFR adaptively. Sub-band size adjustment can be performed in a distributed manner for improving the real-time spectral efficiency. This method can be implemented as a feature of self organizing network (SON) for the automatic interference reduction and for the improvement of spectral efficiency of smallcell.

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