On the Frequency Allocation for Coordinated Multi-Point Joint Transmission

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***Abstract*—Main purpose of this paper is to investigate the frequency allocation schemes combined with a downlink Coordinated Multi-Point (CoMP) joint transmission system. We suggest 6-sector directional antenna and according sector based frequency reuse scheme for CoMP system, and compare the edge user performance of conventional Fractional Frequency Reuse (FFR) systems and suggested CoMP system. The numerical results show that the suggested scheme is better than the conventional FFR systems in the performance and the energy efficiency perspectives.**

I. Introduction

Orthogonal Frequency Division Multiple Access (OFDMA) has been adopted as the downlink access technology in the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) and LTE-Advanced [1], [2] and is being considered for the 4th Generation (4G) wireless networks. OFDMA can effectively mitigate intra-cell interference within a single cell by the orthogonality among sub-carriers. However, inter-cell interference that can cause poor cell edge performance is still a problem. Moreover, inter-cell interference will rapidly increase in near future due to the smaller cell size for sure.

We focus on the inter-cell interference (ICI) cooperation and Coordinated Multi-Point (CoMP) transmission among several remedies for this problem. The most common method in ICI cooperation is Fractional Frequency Reuse (FFR) which uses two reuse factors in a cell by diving the cell into inner- and outer region. A typical example is the case, where the reuse factor (RF) 1 is used in the inner region, and RF 3, outer region [3]. CoMP transmission or reception is proposed to improve cell edge performance in 3GPP LTE-Advanced [4]. CoMP usually denotes dynamic coordination among transmitters and receivers located at geographically separated points. We consider *joint transmission* in the CoMP category [5] where coordinated multi-points simultaneously transmit for a single user without any cooperative scheduling or beamforming.

CoMP is rather to increase the reception power at the receiver while FFR is on the side of reducing inter-cell interference. Using same frequency in CoMP joint transmission cannot be avoided since signal has to be added up while it is the issue of FFR to use different frequency as much as possible in different cells. Although there are little amount of former researches on this theme, we found a relevant ones [6] and [7]. [6] did not capture this problem appropriately by considering only 2 cell cooperation and their suggested frequency allocation scheme is a kind of RF 1 FFR. As one knows, RF 1 system is fragile to interference from all other cells. And paper [7] is similar to ours. However, the authors focused more on the MIMO channel related issues with relatively small network size (3 tier cells). Compared to this, we focus on the general geographical distribution of the interfering cells and the effect of this to the capacity of the system. Through this approach, we show the relation between signal-to-interference ratio (SIR) and ICI more comprehensively when ICI is varying according to the different combinations of sectoring and antenna.

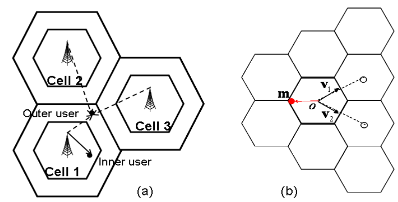

Fig. 1. (a) Downlink CoMP joint transmission system (b) Basis for hexagonal lattice with example mobile location $\mathbf{m}$.

The rest of the paper is organized as follows. In the next section, we describe the considered system model for analysis. In Section III and IV, we study a frequency allocation scheme for a downlink CoMP joint transmission system and analyze its cell edge spectral efficiency in omni- and directional antenna cases, respectively. Section V presents the numerical results and finally, Section VI concludes the paper with appendix addressing a general representation of a cell in hexagonal lattice.

II. System Model

Let us consider a downlink CoMP joint transmission system, where FFR is used with reuse factors 1 and 3. Each cell is divided into inner- and outer regions. We consider only the outer region to focus on the cell edge performance. In the outer region, three neighboring cells are coordinated for a single mobile, which is a typical CoMP scenario. In Figure 1(a), a mobile in the outer region 1 is simultaneously served by cell 1, 2 and 3 using the same frequency band. It is assumed that each

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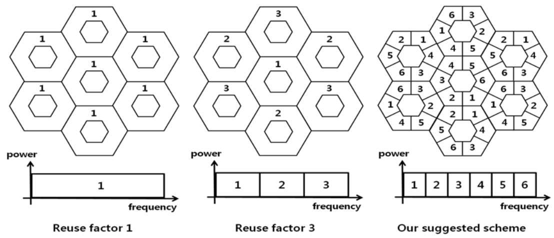

Fig. 2. Frequency allocation schemes in the omni-directional antenna case. The initial size of bandwidth is same for all as W.

cell has one transmitting antenna at the base station (BS) and each mobile has one receiving antenna, and the received signals from coordinated cells can be simply added up together. We assume that the radio signal attenuation is dependent only on pathloss, and the target system is interference-limited (i.e., we ignore the noise power).

We use *throughput of outer region* as a performance metric. According to Shannon theorem, the throughput of outer region S is defined as the sum of the amount of bits transmitted to the all users in outer region in a unit time and bandwidth (bps/Hertz) and is expressed as follows:

$$S = \sum_{i}^{W} \log_2 \left(1 + \gamma_i\right), \tag{1}$$

where W and γ_i are the total number of bandwidth parts to be allocated to the nodes in an outer region and SIR at the target receiver when the bandwidth part of index i is used, respectively. To focus on outer region performance, we assume a simplified resource allocation method as following. The same transmission power is allocated to all bandwidth parts. And the bandwidth part is evenly divided amount of frequency which is allocated to each mobile in the outer region. So, the total consumed power for users in the outer region is the same for all cells. Although there might be multiple solutions for power and bandwidth allocation method by the target metric of the system, we basically adopt this constant type allocation method for comparing the performances on different cell-wise frequency planning. And we consider geometrically evenly distributed users. In other words, we put six users at each corner of a hexagon. So, the outer region throughput of a cell is the sum of all throughput of these six users.

III. Omni-Directional Antenna Case

In this section, we derive the throughput of outer region of our suggested CoMP scheme in the omni-directional antenna case. For the terms $\mathbf{c}(i,j)$, *tier*, coordinate (i,j), *base cell*, and $r(i,j)$, refer the appendix.

A. Frequency Allocation Scheme

Let us consider the reuse factors 1 and 3. Fig. 2 compares frequency allocation schemes of RF 1, 3 and CoMP scheme in the omni-directional antenna case. In our suggested CoMP, the system bandwidth is divided into six sub-bands having same number of bandwidth parts of $W/6$ and all outer regions are divided into six sectors. Each sub-band is given to each sector. By the triangular lattice property, neighboring three cells coordinates for a single mobile using the same sub-band at a time.

B. Throughput of Outer Region

We investigate the throughput of outer region. For the conventional reuse partitioning system with reuse factors 1 and 3, the received signals from all other cells using the same frequency band are the interference. Therefore, for RF 1 system, interfering cells are all other cells such as:

$$\begin{aligned} A_1 &= \{(i,j) | (i,j) \in \mathbb{Z}^2 - (0,0)\} \\ &= \bigcup_{(i,j)\in\{(i,j)|i>0, j\geq 0 \ i,j\in\mathbb{Z}\}} r(i,j), \end{aligned} \tag{2}$$

and for RF 3 system, the interfering cells are represented by the union of indices as following:

$$A_3 = \bigcup_{(i,j)\in\{(i,j)|(i,j)=(3,0)m+(-2,1)n,\ m,n\in\mathbb{N}, i>0, j\geq 0\}} r(i,j). \tag{3}$$

On the other hand, in suggested CoMP scheme, the received signals from two coordinated cells are desired signals. Therefore, interfering cells are subtracted ones from A_1 as follows:

$$A_c = A_1 - \{(0,-1), (-1,0)\}. \tag{4}$$

Therefore, $A_1 \supset A_c \supset A_3$. The interference is summed over these cells

$$I_k = \sum_{(i,j)\in A_k} |\mathbf{c}(i,j) - \mathbf{m}|^{-\alpha} P. \tag{5}$$

where P is transmission power of BS, $\mathbf{m}$ is an edge mobile position and $k = 1, 3, c$ stands for the interference for RF 1, 3 and CoMP systems respectively. Under the same number of tier in the consideration, $|A_1| > |A_c| > |A_3|$ where $|\cdot|$ is the cardinality of set $\cdot$ and $I_1 > I_c > I_3$.

For simple quantitative example, we use unit transmission power for each frequency at each BS and assume that the pathloss coefficient (α) is 4. The network of consideration is 7 tiers of cells thus total number of cells is 43. There are 7 base cells such as $\{(1,0), (1,1), (2,0), (2,1), (1,2), (3,0), (2,2)\}$. And we are considering the edge mobile indicated by vector $\mathbf{m}$ as shown in Fig. 1 (b) where $\mathbf{m} = -\frac{R}{\sqrt{3}}(\mathbf{v_1} + \mathbf{v_2})$. Then the other 5 edge mobiles are located at the other 5 vertices of a hexagon and the relative distances from the interfering cells to them are the same as $\mathbf{m}$ pointed mobile case. Therefore, the outer region throughput is calculated by summing the n users throughputs which are the same irrespective of index n. For the resource, let us assume that system bandwidth for outer region has $W = 6$ number of bandwidth parts. Then, the throughputs of outer region of RF 1 (S_1), 3 (S_3) and our

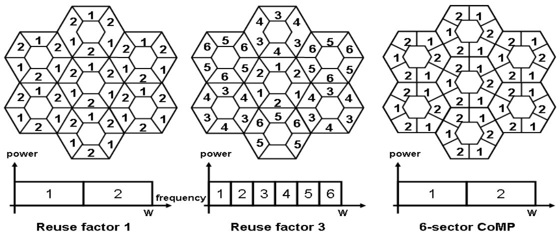

Fig. 3. Frequency allocation schemes in the 6-sector directional antenna case.

CoMP scheme (S_c) are given by:

$$S_1 = \sum_{n=1}^{6} \frac{W}{6} \cdot \log_2\left(1+\frac{\left(\frac{1}{R}\right)^{\alpha}}{I_1}\right) \approx 3.0246,$$
$$S_3 = \sum_{n=1}^{6} \frac{W/3}{6} \cdot \log_2\left(1+\frac{\left(\frac{1}{R}\right)^{\alpha}}{I_3}\right) \approx 6.1662,$$
$$S_c = \sum_{n=1}^{6} \frac{W}{6}\frac{1}{3} \cdot \log_2\left(1+\frac{3\left(\frac{1}{R}\right)^{\alpha}}{I_c}\right) \approx 6.234.$$

In the above equations, n is the mobile index. For S_1, one mobile is served by one sixth of system bandwidth at all the time since system bandwidth are evenly distributed to each mobile. For S_3, one mobile is served by one sixth of the number of allocated frequency band to a cell, which is $W/3$. For S_c, each mobile is served by one sixth of W, but at every three times since our CoMP is done among neighbor three cells and they also have a mobile in their sectors[1]. The results show that the suggested CoMP scheme has very marginal performance improvement over the RF 3. The reason is that there is a mismatch between sectorized frequency allocation and omni directional signal radiation pattern for reducing interference. In other words, geographically evenly allocated frequency in our CoMP is enabling three neighbor cells to cooperate, on the other hand, the interference per mobile is increasing since the radiation pattern of BS antenna is not affected by sector-based frequency allocation. This is a system cost for facilitating cell-wise cooperation.

IV. 6-Sector Directional Antenna Case

In this section, we consider the 6-sector directional antenna as one of the possible ways to decrease the interfering cells while obtaining CoMP effect. For the comparison purpose, we also assume that the conventional systems also use these directional antennas under the RF 1 and 3.

A. Frequency Allocation Scheme

In 6-sector directional antenna case, all outer regions are divided into six sectors, where two neighboring sectors within a cell use different frequency sub-bands to remove inter-sector interference caused by side and back lobe of directional antenna. Fig. 3 shows frequency allocation schemes of RF 1, 3 and our CoMP scheme for the 6-sector directional antenna case. As same as omni-directional antenna case, neighboring three cells coordinate for a single mobile using the same frequency sub-band in CoMP.

[1]Each receiver is located at equidistance away from 3 servers, therefore the S_c is an lower-bound in practice, and the performance improvement of this CoMP configuration would be greater.

B. Throughput of Outer Region

Similarly to the former section, we consider the cell edge performance of the system including 7 tiers of cells. In our CoMP scheme, the received signals from other cells except two coordinated cells are interference. The set of interfering cells can be represented by 3 lines intersecting at the center cell of which intervening angles are the same as $\pi/3$ as shown in Fig. 4. Since in this directional antenna case, the interfering cells have one third portion of each tier, we directly represent the set of interfering cells by using $(i,j) \in \mathbb{Z}^2$ instead of using $r(i,j)$, the rotated versions. Let $\mathbf{m}$ be the vector pointing a mobile at the cell edge. As shown in Fig. 4, the interfering cells for RF 1, 3 and CoMP are respectively:

$$\begin{aligned} B_1 &= \{(i,j) | \text{intersect of any two conditions among} \\ &\quad (i \le j), (2i > -j), (2j \ge i)\} \\ B_3 &= B_1 \cap \{(i,j) | (1,1)m + (-1,2)k,\ m,k \in \mathbb{Z}\} \\ B_c &= \{(i,j) | \text{intersect of any two conditions among} \\ &\quad (j \ge 0), (i \le -j), (i > 0)\} - \{(1,0),(1,-1)\}. \end{aligned} \tag{6}$$

According interference is:

$$I'_k = \sum_{(i,j)\in B_k} |\mathbf{c}(i,j) - \mathbf{m}|^{-\alpha} P. \tag{7}$$

for $k = 1, 3, c$.

With the same parameters of the omni-directional antenna case, the outer region throughput is as follows:

$$S_1^{'} = \sum_{n=1}^{6} \frac{W}{2} \cdot \log_2\left(1+\frac{\left(\frac{1}{R}\right)^{\alpha}}{I_1^{'}}\right) \approx 15.4164,$$
$$S_3^{'} = \sum_{n=1}^{6} \frac{W}{6} \cdot \log_2\left(1+\frac{\left(\frac{1}{R}\right)^{\alpha}}{I_3^{'}}\right) \approx 20.67,$$
$$S_c^{'} = \sum_{n=1}^{6} \frac{W}{2}\frac{1}{3} \cdot \log_2\left(1+\frac{3\left(\frac{1}{R}\right)^{\alpha}}{I_c^{'}}\right) \approx 25.9872.$$

In $S_1^{'}$, a mobile has $W/2$ of sub-band all the time, while $W/6$ in S'_3. Each edge mobile of CoMP system has $W/2$ of sub-band allocated but is served at every three times. As shown in Fig. 4, $|B_1| > |B_c| > |B_3|$ and $I'_1 > I'_c > I'_3$ since B_c is always the subset of B_1 and strongest 2 interfering cells indicated as $(1,0)$ and $(1,-1)$ are disappeared in B_c compared with B_1. However, $S'_c > S'_3 > S'_1$ since the signal power triples. Although the order of these quantities are the same as omni-directional antenna case, the difference between throughput of RF 3 and CoMP case gets larger. In detail, the outer region throughput of our CoMP increases by 68% and 25% comparing with reuse factors 1 and 3, respectively. This

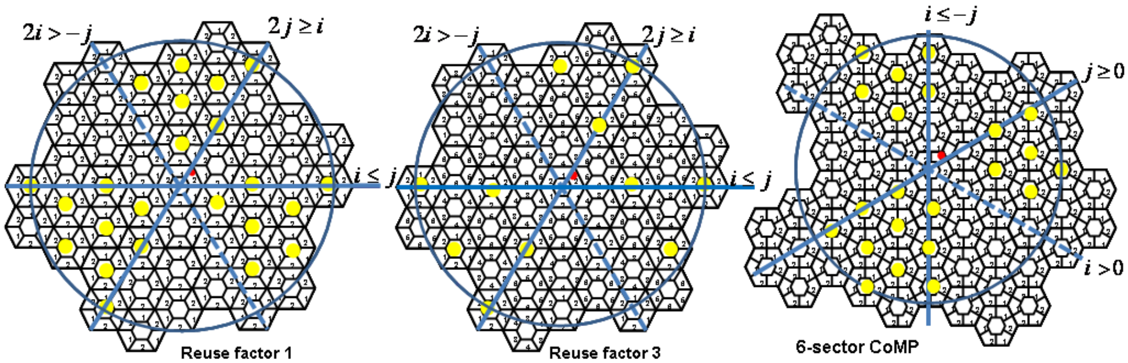

Fig. 4. Interfering cells in 6-sector directional antenna case when 7 tiers of cells are counted. A red dot in the center cell is an edge mobile who is using sub-band 2,2 and 1 in the RF 1, 3 and CoMP cases respectively.

is from the fact that the enhanced signal strength is maintained while interference level of all systems gets lower by the sector antenna and this reduced interference amplifies the increase of signal strength portion in SIR.

C. Energy Efficiency and Decreased BS Density

It is natural that high throughput can lead to a high energy efficiency and the coverage enhancement while satisfying a given target performance level. Fig. 5 (c) shows transmission power saving of BS under the given target performance in the presence of a receiver noise. As this graph is per bandwidth performance, the saving of transmission power can be increased by the total bandwidth. Based on this edge performance, we can find the decreased BS density to cover same area (we, here, only consider the coverage perspective not an increased load per cell). Assuming that channel consists of only pathloss term, then the gain of SNR (signal-to-noise ratio) at the edge mobile can be represented by the cell radius R in dB unit.

$$\begin{aligned} G_{SNR} &= SNR(R_1) - SNR(R_2) \\ &= P_t - N - \alpha 10 \log R_1 - (P_t - N - \alpha 10 \log R_2) \\ &= -\alpha(R_1(dB) - R_2(dB)), \end{aligned} \tag{8}$$

where P_t and N are the transmission power of BS and noise power in dB, respectively. The ratio of the BS density for each case of R_1 and R_2 can be simply found out as:

$$\begin{aligned} G_{Dens} &= 10 \log\left(\frac{1}{\pi R_1^2} \frac{\pi R_2^2}{1}\right) \\ &= -2(R_1(dB) - R_2(dB)) = \frac{2}{\alpha} G_{SNR}. \end{aligned} \tag{9}$$

From Table I, $\alpha = 3.76$ hence, $G_{Dens} = 0.5319 G_{SNR}$ is depicted in Fig. 5 (c) in the numerical results.

V. Numerical Results

We made numerical simulations to evaluate the performance of all the systems aforementioned with the realistic channel parameters. Table I lists the simulation parameters based on [8].

TABLE I
SIMULATION PARAMETERS.

Parameters	Values
Number of cells	63
Cell radius	500 m
Carrier frequency	2 GHz
Total transmission power in BS	43 dBm
Antenna gain of BS	11 dB
Antenna gain of MS	0 dB
Minimum Coupling Loss (MCL)	53 dBm
Distance-dependent loss	L=128.1+37.6log(r)
Shadowing variance	8 dB
Inter-cell shadowing correlation	0.5
Noise density	-174 dBm/Hz
Noise figure	9 dB

Under the situation that 6 edge users are deployed at each edge side for all cells, the spectral efficiency of one bandwidth part is the typical performance metric and can be obtained simply by eliminating the sum operator and giving $W = 1$ in equations of outer region throughput. We investigate this by varying several parameters. Fig. 5 (a) shows the spectral efficiency on varying distance of a mobile from BS, for the omni- and the directional antenna cases, respectively. According to this graph, the gains from CoMP are shown in the $400m$ and $450m$ point in omni-directional and 6-sector antenna cases, respectively. Especially, the gain of CoMP scheme at the cell edge (500 m) in the directional antenna case is about 26% over that in the RF 3 system. This is almost same number as shown in Section IV.

To show both of SNR and spectral efficiency gains in 6-sector directional antenna case jointly, we plot the spectral efficiency in Fig. 5 (b) using SINR at edge mobile by varying the transmission power of BS given receiver noise value listed in Table I. The curves are mainly specified by the log functions where low SNR and high SNR region represent noise- and interference-limited situations, respectively. The differences between systems in x-axis denote SNR gains obtained by using better system at cell edge. On the other hand, the differences in y-axis denote spectral efficiency gains at cell edge. Our CoMP has not only SNR gain but high spectral efficiency which the counter systems cannot reach even with the infinite BS power.

We plot Fig. 5 (c) using SNR gain of Fig. 5 (b) with

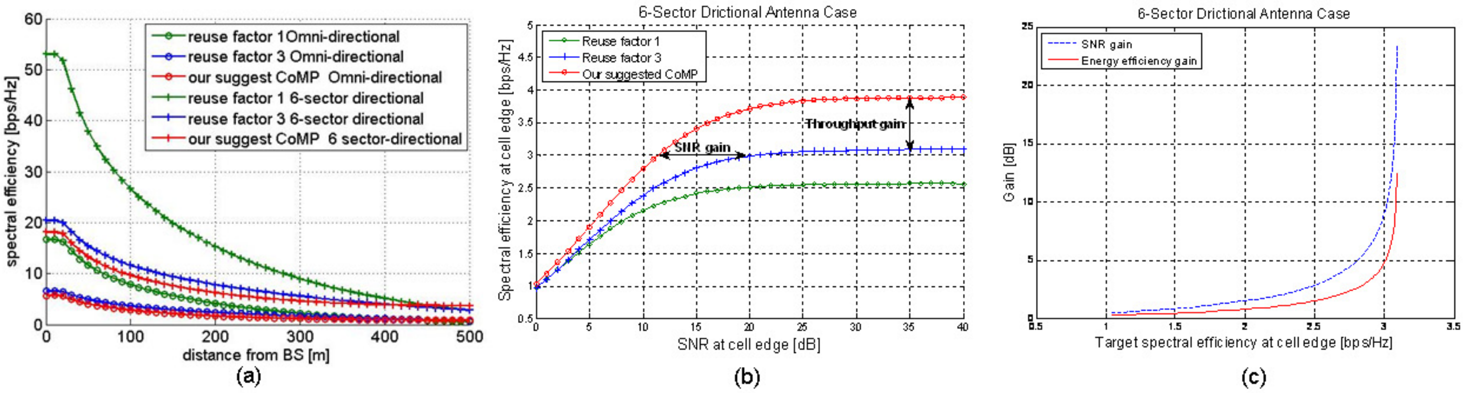

Fig. 5. (a) Spectral efficiencies as a function of the distance from the BS with given noise parameter (b) Cell edge spectral efficiencies as a function of SNR at cell edge (c) SNR (transmission power saving) gain of our suggested scheme over the RF 3 as a function of the cell edge spectral efficiency.

variation of the cell edge spectral efficiency. If the target spectral efficiency is 2.54 bps/Hz, then our suggested scheme has about 3 dB transmission power saving gain over the RF 3 system. The graph says the reduced BS density can be achieved by using CoMP over RF 3 system, and this also can be interpreted as reduced energy to serve the same area.

VI. Concluding Remarks

In this paper, we investigate the frequency allocation scheme for a downlink CoMP joint transmission system. The key factor for this is to allocate the sub band of frequencies to each sector so that 3 neighbor cells have one group of sectors using same sub band. However, only sectorized frequency allocation scheme cannot guarantee significant improvement of performance since omni-directional radiation pattern of BS antenna in each cell is not effective to reduce the interference in spite of increased signal power by cooperation among neighbor cells. To tackle this, directional radiation pattern matched with 6 sector frequency allocation is suggested and this guarantees better performance than those of RF of 1 and 3 system with the same directional antenna situation. And we show that according energy saving can reduce the BS density. Although the simplification of radiation pattern of 6 sector antenna and additional cost for establishing this might be an obstacle for adopting this scheme, low operational complexity can be a merit compared to the complex joint processing of other CoMP techniques such as MIMO.

Appendix

A. General Representation of A Cell in Hexagonal Lattice

To obtain the general form of the distance between cell edge point m and each center of interfering cells, we model the cellular system as the regular hexagonal lattice structure. Every cell centers can be represented by the basis $V = \{\mathbf{v_1}, \mathbf{v_2}\}$, where $\mathbf{v_1}$ and $\mathbf{v_2}$ are the unit vectors with angle of $\pi/3$ as shown in Figure 1(b).

For a vector pointing an arbitrary cell center $\mathbf{c}(i,j)$, $\mathbf{c}(i,j) = i \cdot 2R \cdot \mathbf{v_1} + j \cdot 2R \cdot \mathbf{v_2}$, where R is the cell radius and $i, j \in \mathbb{Z}$ are used for coordinates. From now on, we use a coordinate (i,j) for the cell having center $\mathbf{c}(i,j)$ for the simplicity. The distance from the origin o to the center of a cell (i,j) is $|\mathbf{c}(i,j)| = 2R\sqrt{i^2+j^2+|ij|}$ by law of cosines. Restricting $i > 0$ and $j \geq 0$, each tier can be represented by a cell (i,j) (we call this *base cell* in the following) and its 5 rotated versions. k times rotation with angle $\pi/3$ from the vector pointing (i,j) makes new coordinates for the rotated cells $\mathbf{c}(i',j')$ where i' and j' are the functions of i, j, k and have the values $i' = i(\cos\frac{k\pi}{3} + \frac{1}{\sqrt{3}}\sin\frac{k\pi}{3}) + j(\frac{\sqrt{3}}{2} + \frac{1}{2\sqrt{3}})\sin\frac{k\pi}{3}$, $j' = -i\frac{2}{\sqrt{3}}\sin\frac{k\pi}{3} + j(-\frac{1}{\sqrt{3}}\sin\frac{k\pi}{3} + \cos\frac{k\pi}{3})$. Finally, let $r(i,j) = \{(i',j') | k = 0,1,2,...,5\}$ denote the set of indices pointing cells of an arbitrary tier of which distance is $2R\sqrt{i^2+j^2+|ij|}$.

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