Pilot Coverage Optimization for Cellular Network by Joint Beamforming of Multiple Sectors

Zhuyun Wu*, Aiping Huang†, Dongdong Fan*, Tony Q. S. Quek‡

* Institute of Information and Communication Engineering, Zhejiang University Hangzhou 310027, China
† Zhejiang Provincial Key Laboratory of Information Network Technology, Hangzhou 310027, China
‡ Singapore University of Technology and Design, 20 Dover Drive, Singapore
E-mail: {wuzhouyun, aiping.huang, dongdongfan}@zju.edu.cn and tonyquek@sutd.edu.sg

Abstract—Pilot coverage optimization is an important issue in daily operation of cellular networks. It is difficult to meet the various coverage requirements in practice using existing framework such as adjusting antenna downtils or transmit powers of sectors. In this paper, a novel coverage optimization method based on multi-sector joint beamforming is proposed to eliminate poor coverage and to minimize interference to the surrounding sectors. A heuristic algorithm is developed based on the iteration of sector coverage updating and antenna array excitation weights optimization. Numerical results show that the performance of our algorithm is superior to that of power exhaustion algorithm.

Index Terms—pilot coverage optimization, joint beamforming, sector coverage updating, semidefinite relaxation.

I. INTRODUCTION

Coverage optimization of broadcast pilot signals is one of key issues of the network optimization in cellular communication networks since high-quality pilot coverage is a prerequisite for seamless connectivity in cellular networks [1]. With rapid urban constructions and the anisotropy nature of radio propagation, poor pilot coverage appears from time to time and in turn, seriously affects the performance of cellular networks.

High-quality pilot coverage means no "weak coverage", i.e., the pilot signal power received at any location is sufficiently strong so that pilot coverage is seamless. It also requires no "over coverage", i.e., the signal to interference and noise ratio (SINR) at any location is high enough for signal demodulation. The existing methods to overcome poor pilot coverage are mainly based on adjusting base station (BS) transmit power and/or antenna downtilt [2-4]. However, they increase or reduce coverage distances in all directions simultaneously, thus have limited flexibility and may cause new coverage problem. Therefore, new methods to achieve accurately the pilot coverage requirement under anisotropic radio propagation conditions/distances are needed.

Antenna arrays which facilitate beamforming are typically equipped in the BSs of 3G cellular networks. Its radiation pattern can be adjusted flexibly by changing its excitation weights. As a result, beamforming is an effective way to achieve radiation intensity differentiation at different angles. For instance, this technique has been widely used in enhancing unicast/multicast service [5-7], and in real-time inter-cell load balancing [8].

In this paper, we investigate pilot coverage optimization based on antenna array beamforming. In this way, poor pilot coverage area is eliminated through joint beamforming of several neighboring sectors, while the interference from these sectors to the surrounding sectors is minimized. To solve this problem, a model for joint optimization of multi-sector coverage is established and a heuristic algorithm based on the iteration of sector coverage updating and joint beamforming is proposed. Unlike work related to existing beamforming for data transmission and interference avoidance [5-8], our work utilizes beamforming to realize seamless coverage of the pilot signals broadcasted on the common control channels. For convenience, pilot coverage will be referred to as coverage hereafter.

The rest of the paper is organized as follows. The system model of pilot coverage is given in Section II, where the received pilot power and SINR are formulated using antenna array. The problem of joint optimization of multi-sector coverage is established and a heuristic algorithm is proposed in Section III. Numerical results are shown and analyzed in Section IV. Conclusions are drawn in Section V.

II. SYSTEM MODEL

A typical cellular network consists of many 120° sectors, as shown in Fig.1. The antennas are co-located for every three sectors. The whole network is divided into three regions according to the relationship with poor coverage area. The first region is known as "region to be optimized" (RTBO). It consists of several three-sector clusters, and the poor coverage area is located in some of these clusters. A three-sector cluster is composed of three adjacent sectors, whose main beams point at the same area from different base stations, such as Sectors 1, 2 and 3 in Fig.1. The sectors in RTBO are indexed by m, such that m = 1, 2, · · ·, M, and the set of these indexes is denoted by M. The second region is the region of first ring (ROFR) of RTBO. ROFR comprises of N sectors indexed by n = 1, 2, · · ·, N, and the set of these indexes is denoted by N. The third region is the rest region (RR) of the network. RR is
composed of \( L \) sectors indexed by \( l = 1, 2, \cdots, L \), and the set of these indexes is denoted by \( \mathcal{L} \). For example, a poor coverage appears in sector 1 due to the block effect of an obstacle (black rectangle in Fig.1), such as a group of buildings, thus RTBO consists of sectors 1, 2 and 3 and ROFR consists of sectors 3-15. RTBO would be composed of sectors 1, 2, 3, 14, 15 and 16, if a poor coverage is located at the junction of sectors 1 and 14.

The received pilot powers are acquired at \( Q \) sampling locations in the network. A sampling location is indexed by \( q \), and the set of all indexes is denoted by \( \mathcal{Q} \) with \(|\mathcal{Q}| = Q\). There are \( I \) sampling locations that fall into RTBO, and their corresponding index are denoted by \( i = 1, 2, \cdots, I \). The set of \( i \) is denoted by \( I \) with \(|I| = I\). The index of the serving sector of the sampling location \( i \) is referred to as \( m_i \).

Similarly, \( J \) sampling locations located in ROFR are indexed by \( j = 1, 2, \cdots, J \), and the set of \( j \) is denoted by \( \mathcal{J} \) with \(|\mathcal{J}| = J\). \( K \) sampling locations located in RR are indexed by \( k = 1, 2, \cdots, K \), and the set of \( k \) is denoted \( \mathcal{K} \) with \(|\mathcal{K}| = K\). The indexes of the serving sectors of sampling locations \( j \) or \( k \) are referred to as \( n_j \) or \( l_k \), respectively. Apparently, there stands \( Q = \mathcal{I} \cup \mathcal{J} \cup \mathcal{K} \). The set of sampling locations whose serving sector indexes are \( m_i \), \( n_j \) or \( l_k \) gives approximate area of RTBO, ROFR or RR, respectively.

Assume that all the sectors in the network are equipped with antenna arrays. Let \((\varphi_{m,i}, \theta_{m,i}, r_{m,i})\) denote the coordinates of the sampling location \( i \) in the spherical coordinate system, whose origin is the location of the antenna array of sector \( m \). For simplicity, the antenna array of sector \( m \) is referred to as antenna \( m \) in the following. Then the received pilot power from antenna \( m \) at the sampling location \( i \) is given by [5]

\[
P_{m,i}^r = e_m \frac{2\pi f_m^2 w_m^H \mathbf{V}_{m,i}^* \mathbf{w}_m}{\eta \cdot L_{m,i}} = w_m^H \mathbf{V}_{m,i} \mathbf{w}_m
\] (1)

where \( e_m \) is the efficiency factor of antenna \( m \), \( 0 < e_m \leq 1 \); \( \eta \) is the intrinsic impedance of medium (377 for air or vacuum); \( f_m \) is the element pattern of antenna \( m \), and a function of \( \varphi_{m,i} \) and \( \theta_{m,i} \); \( L_{m,i} \) is the pathloss from antenna \( m \) to sampling location \( i \), and a function of \((\varphi_{m,i}, \theta_{m,i}, r_{m,i})\); \( \mathbf{V}_m \) is the manifold vector of antenna \( m \); \( \mathbf{V}_{m,i} \) is a constant matrix for a given sampling location; \( \mathbf{w}_m \) is the excitation weight vector (referred to as weight vector hereafter for short) of antenna \( m \),

\[
\mathbf{w}_m = (e_{m,1} e^{-\sqrt{-1} \mu_{m,1}}, e_{m,2} e^{-\sqrt{-1} \mu_{m,2}} \cdots e_{m,M} e^{-\sqrt{-1} \mu_{m,M}})^T
\] (2)

where \( \sqrt{-1} \) stands for the imaginary unit, \( e_{m,a} \) and \( \mu_{m,a} \) are the amplitude and phase of the excitation current of the \( a \)-th element of antenna \( m \), respectively. Similarly, the received pilot power \( P_{n_j}^r \) and \( P_{l_k}^r \), which are from sector \( n \) in ROFR and sector \( l \) in RR respectively and measured at sampling location \( i \), can be derived.

The SINR at sampling location \( i \) is given by

\[
\gamma_{m,i} = \frac{P_{m,i}^r}{\sum_{n=1}^M P_{n_i}^r + \sum_{l=1}^L P_{l,i}^r + \delta^2} = \frac{w_m^H \mathbf{V}_{m,i} \mathbf{w}_m}{\sum_{n=1}^M w_n^H \mathbf{V}_{n,i} \mathbf{w}_n + \sum_{l=1}^L w_l^H \mathbf{V}_{l,i} \mathbf{w}_l + \delta^2}
\] (3)

where in the denominator, the first item is the interference from sectors in RTBO, the second item is the interference from sectors in ROFR, the third item is the interference from sectors in RR and the fourth item \( \delta^2 \) is noise power. Similarly, the SINR acquired at sampling location \( j \) in ROFR \( \gamma_{n,j} \) and that at sampling location \( k \) in RR \( \gamma_{l,k} \) can be derived.

III. Joint optimization of multi-sector coverage

Our key idea is to jointly adjust the weight vectors of all antenna arrays in RTBO so that their beams complement each other to form reasonable sector coverage, and thus the poor coverage area in RTBO is eliminated. Meanwhile, the transmit powers of all the sectors in RTBO is minimized to mitigate interference to the surrounding sectors in ROFR and RR so that no new poor coverage is resulted.

A. Mathematical model

The problem for joint optimization of multi-sector coverage is formulated as

\[
\min_{\mathbf{w}_m, \mathbf{V}_{m,i}} \sum_{m=1}^M \sum_{i=1}^I P_{m,i}^r \quad \text{s.t.} \quad \gamma_{m,i} \geq \gamma_{m,i}^r, \quad i \in \mathcal{I} \quad \gamma_{n,j}^r \geq \gamma_{n,j}, \quad j \in \mathcal{J} \quad \gamma_{l,k} \geq \gamma_{l,k}^r, \quad j \in \mathcal{K} \quad P_{m,i}^r \leq P_{m,i}^r, \quad m \in \mathcal{M}
\] (4a)

(4b)

(4c)

(4d)

(4e)

(4f)

where \( P_{m,i}^r \) is the transmit power of the pilot signal (transmit pilot power) of sector \( m \) in RTBO, and a function of the input impedance \( R_m \) and weight vector \( \mathbf{w}_m \) of antenna \( m \), given by

\[
P_{m,i}^r = \mathbf{w}_m^H \mathbf{w}_m R_m
\] (5)
$P_{th}$ and $\gamma_{th}$ are the thresholds of received where pilot power and SINR respectively, $P_{max}$ is the maximum transmit power. Eq. (4a) gives the objective function which is the total transmit pilot power of all the sectors in RTBO. Eqs. (4b) and (4d) mean that no weak coverage is allowed in RTBO and ROFR. Eqs. (4c) and (4e) represent that there is no over coverage in RTBO and ROFR. Eq. (4f) is the constraint for the transmit pilot power of any sector in RTBO.

Problem (4) is a mixed discrete and continuous optimization problem because its optimization variables include the weight vectors of all the concerned antennas, and the indexes of the sampling locations’ serving sectors $m_i$, $n_j$, and $l_k$. The coverage of all sectors is not only the prerequisites to acquire the weight vectors of all antennas but also functions of the weight vectors.

B. Heuristic algorithm based on sector coverage updating and joint beamforming

To solve Problem (4), a heuristic scheme is proposed where indexes of the sampling locations’ serving sectors and weight vectors are solved separately and iteratively. In each iteration, weight vectors are obtained under given indexes of the sampling locations’ serving sectors, and then the indexes of the sampling locations’ serving sectors are updated according to the newly obtained weight vectors. The procedure is described below.

1) Initialization of sector coverage: The initial coverage of RTBO is first determined so that at each of its sampling locations the received pilot power from any sector in ROFR or RR is lower than the threshold,

$$ I = \{ q| P_{n,q} < P_{th}, P_{l,q} < P_{th} \quad q \in Q, n \in N, l \in L \} \quad (6) $$

These sampling locations should be served by the sectors in RTBO to ensure seamless coverage. Then, the index of the serving sector of sampling location $i$ is determined as

$$ m_i = \arg \{ \min_m \{ L_{m,i} \} \}, \quad i \in I \quad (7) $$

where $m_i \in M$. The pathloss $L_{m,i}$ can be measured from the practical network or calculated using propagation models.

Secondly, the coverage of ROFR is initialized. The set of the sampling locations in ROFR is given by

$$ J = \{ q| P_{n,q} > P_{th}, P_{l,q} > P_{th} \quad q \in (Q-I), n \in N, l \in L \} \quad (8) $$

and the index of the serving sector of sampling location $j$ is determined as

$$ n_j = \arg \{ \max_n \{ P_{n,j} \} \}, \quad j \in J \quad (9) $$

At last, let the rest sectors of the network belong to RR, i.e.,

$$ \mathcal{K} = Q-I-J \quad (10) $$

and the index of the serving sector of sampling location $k$ is determined as

$$ l_k = \arg \{ \max_k \{ P_{l,k} \} \}, \quad k \in \mathcal{K} \quad (11) $$

2) Optimal weight vectors for given coverage requirement: Once the indexes of serving sectors of all sampling locations are given, Problem (4) becomes a separable quadratically constrained quadratic programming (QCQP) problem as follows [9]

$$ \min_{\{w_m\}_{m=1}^M} \sum_{m=1}^M w_m^H R_m w_m \quad (12a) $$

subject to

$$ w_m^H V_{m,i} w_m \geq P_{th,i}, \quad i \in I \quad (12b) $$

$$ w_m^H V_{m,i} w_m - \gamma_{th} \sum_{m=1, m \neq m}^M w_m^H V_{m,i} w_m \geq \gamma_{th} \left( \sum_{m=1}^N P_{n,j}^r + \sum_{l=1}^L P_{l,j}^r + \delta^2 \right), \quad i \in I \quad (12c) $$

$$ P_{n,j}^r \geq P_{th}, \quad j \in J \quad (12d) $$

$$ \gamma_{th} \sum_{m=1}^M w_m^H V_{m,j} w_m \leq \gamma_{th} \left( \sum_{m=1, m \neq m}^M w_m^H V_{m,j} w_m \right) \quad (12e) $$

$$ w_m^H w_m R_m \leq P_{max}, \quad m \in M \quad (12f) $$

where Eqs. (12c) and (12e) are derived by substituting Eq. (3) into Eqs. (4c) and (4e), respectively.

Problem (12) is an NP-hard problem which can be approximately solved using semidefinite relaxation (SDR) technique [10]. Observing that $w_m^H w_m = \text{Tr}(w_m w_m^H)$ and $w_m^H V_{m,j} w_m = \text{Tr}(w_m V_{m,j})$, where $\text{Tr}(\cdot)$ represents the trace of a matrix. Problem (12) can be rewritten as

$$ \min_{\{W_m\}_{m=1}^M} \sum_{m=1}^M \text{Tr}(W_m) R_m \quad (13a) $$

subject to

$$ \text{Tr}(W_m V_{m,i}) \geq P_{th,i}, \quad i \in I \quad (13b) $$

$$ \text{Tr}(W_m V_{m,i}) - \gamma_{th} \left( \sum_{m=1, m \neq m}^M \text{Tr}(W_m V_{m,i}) \right) \geq \gamma_{th} \left( \sum_{m=1}^N P_{n,j}^r + \sum_{l=1}^L P_{l,j}^r + \delta^2 \right), \quad i \in I \quad (13c) $$

$$ P_{n,j}^r \geq P_{th}, \quad j \in J \quad (13d) $$

$$ \gamma_{th} \sum_{m=1}^M \text{Tr}(W_m V_{m,j}) \leq \gamma_{th} \left( \sum_{m=1, m \neq m}^M \text{Tr}(W_m V_{m,j}) \right) \quad (13e) $$

$$ \text{Tr}(W_m) R_m \leq P_{max}, \quad m \in M \quad (13f) $$

rank($W_m$) = 1, $W_m \succeq 0$, $m \in M \quad (13g)$

where $W_m = w_m w_m^H$, $W_m \succeq 0$ means that $W_m$ is a
semidefinite matrix. Eq. (13g) is added to make sure that $W_m$ can be decomposed into a multiplication of $w_m$ and $w_m^H$.

Problem (13) is a non-convex problem. A convex relaxation problem can be obtained by discarding constraint (13g) in (13). It can be solved efficiently using available software like CVX [11]. Its optimal solution is denoted as $\bar{W}_m, m \in M$.

The optimal weight vectors $\bar{w}_m$ cannot be derived directly by decomposing $\bar{W}_m$ in general, due to the ignorance of constraint (13g). However, they can be obtained using a so-called “randomization” technique [5]. Then the resulted transmit pilot power of antenna $m$ and total transmit pilot power of all sectors in RTBO can be calculated as

$$\bar{P}_m = \bar{w}_m^H \bar{w}_m R_m, m \in M$$

(14)

$$\bar{P} = \sum_{m=1}^{M} P_m$$

(15)

3) Sector coverage with given weight vectors: Applying the optimal weight vector $\bar{w}_m$ to excite antenna $m, m \in M$, the sets of the sampling locations of RTBO and ROFR can be determined as

$$I' = \{q | \min_{m} \{P'_{m,q}\} > \max_{n} \{P'_{n,q}\}, q \in I \cup J\}$$

(16)

$$J' = Q - K - I'$$

(17)

where $P'_{m,q}$ is the received pilot power from antenna $m$ at sampling location $i$, which is calculated using $\bar{w}_m$. The indexes of the serving sectors of the sampling locations in RTBO and ROFR can be determined correspondingly as

$$m'_i = \arg\{\max_{m} \{P'_{m,i}\}\}, i \in I'$$

(18)

$$n'_j = \arg\{\max_{n} \{P'_{n,j}\}\}, j \in J'$$

(19)

The coverage of the sectors in RR remain unchanged.

4) SCU-JBF algorithm: A new minimal objective value $\bar{P}'$ and corresponding optimal weight vectors $\bar{w}_m, m \in M$ can be obtained by substituting the updated indexes $m'_i, n'_j$ and $k'_l$ into Problem (4) and then solving. There must stand $\bar{P}' \leq \bar{P}$, because $\bar{W}'_m$ is the optimal solution while $\bar{W}_m$ obtained in Subsection 3.2.2 is a feasible solution of Problem (4) under the condition of $m'_i, n'_j$ and $k'_l$. Therefore, a better solution of Problem (4) can be approached gradually through an iterative scheme.

A heuristic algorithm based on sector coverage updating and joint beamforming (SCU-JBF algorithm) is proposed based on the derivation above:

Step 1. Initialize the total transmit pilot power of all the sectors in RTBO as $\bar{P}^{(0)} = 0$ and the $A$-dimensional weight vectors as $\bar{w}_m^{(0)} = \frac{1}{\sqrt{P_{max}/R_m}}$ and $\bar{P}_m^{(0)} = \bar{w}_m^{(0)} R_m$, $\forall m \in M$; let the iteration number $\lambda = 1$, then the indexes of serving sectors of all the sampling locations $m'_i^{(1)}, n'_j^{(1)}$ and $k'_l^{(1)}$ are initialized according to Eqs. (6)-(11);

Step 2. Solve the SDR of Problem (13) to obtain $\bar{W}_m^{(\lambda)}, m \in M$;

Step 3. Calculate $\bar{w}_m^{(\lambda)}$ from $\bar{W}_m^{(\lambda)}$ using randomization technique and $\bar{P}'^{(\lambda)}$ using Eqs. (14) and (15);

Step 4. if $\bar{P}'^{(\lambda)} < \bar{P}^{(\lambda-1)}$, then iteration number $\lambda$ increases by 1, $m^{(\lambda)}$ and $n^{(\lambda)}$ is calculated using Eqs. (16)-(19), the algorithm goes back to Step 2; if $\bar{P}'^{(\lambda)} \geq \bar{P}^{(\lambda-1)}$, then $\bar{W}_m^{(\lambda-1)}, m \in M$ is considered as the optimal solution of Problem (4), algorithm ends.

C. Coverage optimization of whole network

SCU-JBF algorithm can be extended to realize coverage optimization of the whole network: divide all the sectors in the network into several non-overlapping multi-sector clusters, take one cluster as RTBO to perform SCU-JBF algorithm at one time till all clusters have been optimized.

In practical network, the pilot coverage optimization is usually implemented every several months. During the implementation, optimal weight vectors are calculated by specialized software based on the network configurations, data collected from the network, radio propagation model and electronic map. Then, original weight vectors of all sectors are replaced with the obtained weight vectors to achieve a new pilot coverage.

IV. NUMERICAL RESULTS

Numerical calculations were carried out to validate the proposed SCU-JBF algorithm. Power exhaustion (PE) algorithm is chosen as baseline for performance comparison since it gives the best achievable performance by jointly adjusting the transmit pilot powers of all sectors in RTBO. In PE algorithm, the optimal transmit pilot powers of all the sectors are obtained in an exhaustive way so that the total transmit pilot power is minimized while the received pilot power and SINR at any location in RTBO and ROFR are higher than their thresholds.

A. Parameter settings

The network scenario is shown in Fig.1. The BSs are located at the vicinities of the vertexes of hexagons of radius 1000 meters. Each BS has a random distance to the vertex, with a variance of 50 meters. Sampling locations distribute at the vertexes of uniform square grids with length 50 meters. An obstacle of width 400 meters locates in sector 1, 600 meters away from the BS. The penetration loss is set to be 20 dB and the wideband PCS propagation model [12] is given by

$$L(dB) = \begin{cases} 25.6 \lg r + 38 + 20, & \text{blocked by obstacle} \\ 25.6 \lg r + 38, & \text{otherwise} \end{cases}$$

(20)

The thresholds of received pilot power and SINR are -95dBm and -6dB, respectively. The heights of all antenna arrays are 32 meters. The antenna array is a uniformly spaced linear array with 8 identical elements, and the inter-element spacing is one-half wavelength. Its efficiency factor $\eta$ is 1 and input impedance $R$ is 73. Its element pattern follows the settings of 3GPP standards [13]. The intrinsic impedance of air is 377. The carrier frequency of the cellular system is 2GHz.

RTBO includes sectors 1, 2 and 3, and the maximum of transmit power of their antenna arrays $P_m^{(\lambda)} = 46$ dBm. ROFR consists of sectors 3-15 and transmit pilot powers of their antenna arrays are 36 dBm. The number of randomization
samples in SCU-JBF algorithm is 800. The adjustment step of transmit pilot power in PE algorithm is 0.1 dBm.

B. Sector coverage achieved

Fig. 2 shows the sector coverage obtained by SCU-JBF algorithm and PE algorithm. Sectors 1, 2 and 3 in RTBO are colored by green, blue and magenta, respectively. The sectors in ROFR are colored by red and black.

Fig. 2(a) is the optimal sector coverage of PE algorithm, the corresponding total transmit pilot power of 3 sectors in RTBO and the worst SINR are 39.78 dBm and -5.9 dB, respectively. It can be observed from Fig. 2(a) that the areas above and below the obstacle belong to sectors 3 and 1 respectively; there exists significant difference between coverage areas of the 3 sectors, this is because sector 3 increases transmit pilot power to cover the area above the building, resulting in a increment of its coverage radius in all directions; coverage area of the neighbor sectors of sector 3 are correspondingly reduced to avoid "over coverage". Fig. 2(b) is the initial sector coverage of SCU-JBF algorithm calculated using Eqs. (6) (11). Fig. 2(c) is the sector coverage after the first iteration of SCU-JBF algorithm calculated by Eqs. (16) (19). Fig. 2 (d) is the optimal sector coverage after the SCU-JBF algorithm ends with the termination condition satisfied, 3 iterations are enough in this case. The corresponding total transmit pilot power of sectors in RTBO is 37.25 dBm, i.e., 2.5 dB lower than that of PE algorithm. And the worst SINR is -3.07 dB which is 2.8dB higher than that of PE algorithm. As can be seen from Figs. 2(b), (c) and (d), and sector coverage varies as the algorithm iterates. The final optimal beams of sectors 1, 2 and 3 gear to each other and form a proper 3-sector coverage, thus the transmit pilot power is minimized. The coverage areas of three sectors in RTBO in Fig. 2(b) are similar to each other, which is more preferable than those in Fig. 2(a).

C. SINR distribution

Fig. 3 shows the optimal SINR distributions of these two algorithms, under the conditions of Figs. 2 (a) and (d) coverage. In Fig. 3, the deep blue region represents the region with SINR less than 0dB. The worst SINRs of SCU-JBF algorithm and PE algorithm are -3.068 dB and-5.9 dB respectively, indicating that SCU-JBF algorithm has a stronger ability to control the inter-sector interference. It can be found that the color of Fig. 3(a) is generally lighter than Fig. 3(b), and the dark blue region in Fig. 3(a) is far smaller than that in Fig. 3(b). It implies that the SINR obtained by the SCU-JBF algorithm is significantly higher and the inter-sector interference obtained by SCU-JBF algorithm is much smaller.

D. Received pilot power

Fig. 4 shows the contours of received signal power -85 dBm from the 3 sectors obtained by the two algorithms. The five-pointed stars in the figure mark the locations of sector base stations. For the convenience of observation, the regular hexagons are plotted in Fig. 4, although the actual sector coverage is generally not of regular hexagon.

It can be seen from Fig. 4(a) that the contour shape of sector 2 is the same as the element pattern, the contour shape of sector 1 is distorted due to the obstacle, and the contour of sector 3 is extended to the top of the obstacle so that the poor coverage has been avoided. However, the contour of sector 3 extends in the other directions as well, invades into the areas of the surrounding sectors obviously and will cause new over coverage. In contrast, the contours of the 3 sectors obtained by SCU-JBF algorithm gear to each other, as shown in Fig. 4(b). This is the reason why the poor coverage in RTBO can be eliminated, the total transmit power of RTBO can be minimized, and in turn the interference to the surrounding sectors can be minimized.

V. Conclusions

Achieving high-quality pilot coverage is an important issue for cellular network optimization. The existing methods including adjusting transmit power or antenna tilt are lack of flexibility, and may even results in new poor coverage. Coverage optimization based on antenna array beamforming is investigated. A heuristic algorithm based on the iteration of sector coverage updating and multi-sector joint beamforming is proposed. It can eliminate poor coverage while minimizing
the interference to the surrounding sectors. Numerical results showed that, compared with power exhaustion algorithm, our algorithm can reach a much higher SINR and a much lower transmit power, which means better quality of service and less interference. Lastly, our algorithm can be extended to the coverage optimization of the whole network.

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