An Algorithm for Finding Energy Efficient Relay Positions in Cellular Network

Ming Zhao, Saifeng Ni, Sihai Zhang, and Wuyang Zhou

PCN&SS Lab, University of Science and Technology of China
Hefei, Anhui, China
{zhaoming,shzhang,wyzhou}@ustc.edu.cn,
saifeng@mail.ustc.edu.cn

Abstract. In this paper, we propose an iterative algorithm for finding near-optimal Energy Efficient Relay Positions(EERP) in Amplify-and-Forward (AF) and Decode-and-Forward (DF) relay-assisted cellular networks. Each iteration of EERP algorithm contains two steps, i.e. energy efficient cell division and energy efficient center searching. Close-form expressions of energy efficient cell division boundaries are provided. And two-dimensional Fast Fourier Transform (FFT) is adopted to reduce the complexity of energy efficient center searching. Simulation results show near-optimal relay positions of different pathloss factors, relay scenarios and relay numbers, and demonstrates the effectiveness of EERP.

Keywords: relay position, energy efficiency, green communication.

1 Introduction

Statistics about energy consumption of cellular system show that a lot of energy is wasted owing to low utilization of cellular systems, especially base station (BS), resulting from low traffic. In order to save energy consumption of cellular networks, traffic-aware energy efficient network planning becomes essential and attracts a lot of attention recently[1][2][3]. Based on traffic fluctuation, many switching on/off schemes are proposed in both academia and industry to avoid wasting BS operation energy. Cell zooming, which adaptively adjusts cell size according to traffic load, has the potential to balance traffic load and reduce energy consumption [3]. However, it may easily cause coverage hole, and additional modules are needed to support cell zooming. Moreover, more powerful hardware is needed to get more information such as real-time traffic load and neighbor cell information for cell zooming.

Relaying is one of the features proposed for the 4G LTE-Advanced system. Therefore relay position in cellular network is a hot topic. Relay can enlarge coverage and increase network capacity, and it can also improve energy efficiency. Traffic-aware relay placement can effectively improve energy efficiency. Currently, most research on relay placement in wireless network focuses on improving relay-assisted network radius [4] and throughput [5][6], or minimize outage probability [7]. On the other hand, energy-efficient design of sensor and ad

H. Qian and K. Kang (Eds.): WICON 2013, LNICST 121, pp. 123–136, 2013.

hoc networks has received significant attention for decades with emphasis on prolonging battery life-time for sensor nodes and mobile terminals [8], but the networking planning problem in cellular network is different with those in sensor or ad hoc networks. As energy efficiency becomes one of the major goals in designing cellular system, the work [9] is among very few that optimizes relay station (RS) positions to reduce energy consumption, but it focuses on one-dimensional cellular network scenario.

Real-time traffic distribution in a cellular cell changes randomly. However, from a macro point of view, traffic distribution in a cell has statistical pattern, e.g. some subareas in the cell is hot-spot while some are sparsely populated. on the other hand, some mobile stations can be dynamically assigned as relay nodes according to the optimal relay position searching in future cellular networks. In this paper, we focus on traffic-aware energy-efficient relay position searching problem in a hexagon cell. By optimizing RS locations base on statistical traffic distribution, energy consumption will decline. To find the optimal RS locations, a near-optimal heuristic iterative algorithm named Energy Efficient Relay Position (EERP) is proposed in both AF and DF relay scenarios, which is based on the idea of *Lloyd algorithm*. Each iteration of EERP executes two steps: First, the cell is divided into small regions covered by RSs and BS. The division is based on the result of the most energy efficient power allocation. Close-form expressions of cell separation boundary and shapes of cell separation boundary in some specific pathloss factors are provided. Based on cell separation diagram, energy efficient RS locations are calculated according to traffic distributions. After several iterations, we can get the near-optimal positions for N RSs. Two-dimensional FFT is used to largely reduce the complexity.

2 System Model and Problem Description

2.1 System Model

Consider a hexagon cell with radius R_{cell} and N RSs in it. BS is located in cell center as shown in Fig. 1 and transmits signal to mobile station(MS) directly or through a RS for downlink. h_{BR}, h_{RM}, h_{BM} denote BS-RS channel, RS-MS channel and BS-MS channel respectively. Channel gain between position i and j is formulated as $h_{ij} = ad_{ij}^{-b}$, where d_{ij} is the distance between i and j; a,b are constants, where b denotes pathloss factor. Here, the channel model we adopted is Urban Macro Model in ITU-R M.2135, and the details can be found in Section 4. With orthogonal resource allocation technology, intra-cell interference can be avoided.

For DF relays, downlink data rate R_{DF} is formulated as [10]

$$R_{DF} = \min\left(\frac{1}{2}\log_2\left(1 + P_s|h_{BR}|^2\right), \frac{1}{2}\log_2\left(1 + P_r|h_{RM}|^2\right)\right) \tag{1}$$

where P_s, P_r is transmission power of BS and RS, and Gaussian noise power N_0 is normalized. Channel gains are modeled as $|h_{RM}|^2 = a_1 d_{RM}^{-b_1}$, $|h_{BR}|^2 = a_2 d_{BR}^{-b_2}$,

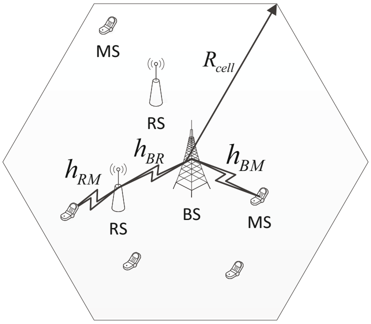

Fig. 1. System Model

$b_2 \leq b_1$.For AF relays, downlink data rate R_{AF} is

$$R_{AF} = \frac{1}{2}\log_2\left(1 + \frac{P_s\left|h_{BR}\right|^2 P_r\left|h_{RM}\right|^2}{1 + P_s\left|h_{BR}\right|^2 + P_r\left|h_{RM}\right|^2}\right) \tag{2}$$

If BS directly communicates with MS, downlink data rate will be expressed as

$$R_{DT} = \log_2\left(1 + P_s\left|h_{BM}\right|^2\right) \tag{3}$$

2.2 Problem Description

The objective is to find optimal positions for N RSs based on statistical traffic distribution to maximize cell energy efficiency i.e. minimize cell power consumption $h(\mathbf{H})$. We suppose cell traffic distribution follows function $f(\mathbf{X})$, where $\mathbf{X}$ denotes user's position (x, y) and $f(\mathbf{X})$ is the corresponding traffic requirement in bits. The problem can be formulated as

$$\min_{\mathbf{H}} h(\mathbf{H}) = \iint_S \frac{P_s(\mathbf{X},\mathbf{H}) + P_r(\mathbf{X},\mathbf{H})}{R} f(\mathbf{X})d\mathbf{X} \tag{4}$$

where R is data rate, $\mathbf{H}$ denotes RS location $(\eta_i, \zeta_i), i = 1, \ldots, N$ and Sdenotes the cell area over wich the double integral is computed. BS is located at $(0, 0)$. Transmission power of BS and RS is expressed as $P_s(\mathbf{X},\mathbf{H})$ and $P_r(\mathbf{X},\mathbf{H})$. So our goal is to find $\mathbf{H}^*$ which can minimize $h(\mathbf{H})$. Energy efficiency is defined as $EE = (P_r + P_s)/R$ in Joule/bit. The minimum $h(\mathbf{H}^*)$ is obtained when RSs' position and power allocation among all downlinks are most energy efficient.

3 Algorithm for Finding Energy Efficient Relay Position

To get the optimal solution $\mathbf{H}_i^*$ for MS i, BS will choose the optimal RS to forward its data, and RSs must be at the optimal position. According to the two principles, we proposed a heuristic algorithm for finding Energy Efficient Relay Position, namely EERP, based on the idea of *Lloyd algorithm*[11]. EERP is executed in following steps.

- **Step 1:** Initiate the N RSs' locations H_{RS}^{k} randomly with BS in cell center, where $k = 1$ is a counter.
- **Step 2:** After power allocation for each link with minimum energy cost, cell is divided into $N + 1$ subregions $S_i^k, i = 1, 2, \ldots, N + 1$.
- **Step 3:** Based on cell division diagram, new RS locations $\mathbf{H}_{RS}^{k+1}$ are obtained according to traffic distribution $f(\mathbf{X})$.
- **Step 4:** If $\|\mathbf{H}_{RS}^{k+1} - \mathbf{H}_{RS}^{k}\| > \varepsilon$ and $k < max\_iter$, then set $k = k + 1$ and go back to Step 2; otherwise, continue to Step 5.
- **Step 5:** Return $\mathbf{H}_{RS}^{k+1}$ as the near-optimal locations for N RSs.

In the above algorithm, ε denotes a predefined threshold and max_iter is the maximal iteration times.

Suppose that RS locations are $\mathbf{H_{RS}}$. Cell separation generates two kinds of subregion boundaries. One is between subregions of two RSs; the other is between subregions of the BS and one RS, which is determined by whether directly communication between BS and MS is better than BS transmitting its message through any RS to MS. AF and DF RS are illustrated as follows respectively.

3.1 Cell Division for DF Relays Assisted Networks

First, power allocation of P_s and P_r is to maximize energy efficiency of every downlink under the premise of guaranteeing data rate requirements R_{th}. The power allocation problem can be formulated as

$$\begin{aligned} \min_{P_s, P_r} \ & \frac{P_s + P_r}{R_{DF}} \\ s.t. \ & 0 < P_s, P_r < P_{max} \\ & R_{DF} > R_{th} \end{aligned} \tag{5}$$

where R_{DF} is defined as (1). Under the condition $P_{max} > (2^{2R_{th}} - 1)/|h_{SR}|^2$,$P_{max} > (2^{2R_{th}} - 1)/|h_{RD}|^2$[8], the optimal solution of (5) is

$$\begin{aligned} P_s^* &= (2^{2R_{th}} - 1)/|h_{SR}|^2 \\ P_r^* &= (2^{2R_{th}} - 1)/|h_{RD}|^2 \end{aligned} \tag{6}$$

3.1.1 Boundary Between Subregions of Two RSs

According to (6), energy cost of choosing RS_i is defined as

$$EE_{RS_i}(\mathbf{X}, \mathbf{H_i}) = \frac{(2^{2R_{th}} - 1)(a_2^{-1} d_{BR_i}^{b_2} + a_1^{-1} d_{R_iM}^{b_1})}{R_{th}} \tag{7}$$

The optimal subregion boundary between two RSs satisfies $EE_{RS_i}(\mathbf{X}, \mathbf{H_i}) = EE_{RS_j}(\mathbf{X}, \mathbf{H_j})$. By substituting (7), we can get

$$\begin{aligned} d_{R_iM}^{b_1} - d_{R_jM}^{b_1} &= a_1 a_2^{-1}(d_{BR_j}^{b_2} - d_{BR_i}^{b_2}) \\ \|\mathbf{X} - \mathbf{H_i}\|^{b_1} - \|\mathbf{X} - \mathbf{H_j}\|^{b_1} &= a_1 a_2^{-1}(d_{BR_j}^{b_2} - d_{BR_i}^{b_2}) \end{aligned} \tag{8}$$

where $\|\mathbf{X} - \mathbf{H_i}\|$ is the distance between MS and RS_i; the right parts of the two equalities in (8) are a constant since the distance between RS and BS is already known.

Theorem 1: Cell division among DF RSs satisfies (8).

Corollary 1: When $b_1 = 1$, the cell separation boundary is a hyperbola; when b1=2, cell separation boundary is a straight line. And when LOS exists between BS and RS, cell separation boundary tends to be a straight line.

Proof: When $b_1 = 1$, (8) turns to be $d_{R_iM} - d_{R_jM}$=const, which is a hyperbola; when $b_1 = 2$, (8) will be transformed to $\|X - \eta_i\|^2 - \|X - \eta_j\|^2$ =const, which is a straight line; when LOS exists between BS and RS, which means $b_2 < b_1$, then $d_{BR_i}^{b_2}$ is smaller than $d_{R_iM}^{b_1}$, and can be ignored, so (8) turns into $\|X - \mathbf{H_i}\| = \|X - \mathbf{H_j}\|$, which is a straight line.

3.1.2 Boundary Between Subregions of BS and RSs

When BS directly communicate with MS, P_s satisfy $P_s = (2^{R_{th}} - 1)a_1^{-1}d_{BM}^{b_1}$, so $EE_{BS}(\mathbf{X})$ can be expressed as

$$EE_{BS}(\mathbf{X}) = P_s/R = \frac{(2^{R_{th}} - 1)a_1^{-1}d_{BM}^{b_1}}{R_{th}} \tag{9}$$

Boundary between subregions of the BS and a RS satisfies,

$$\begin{aligned} d_{BM}^{b_1} - (2^{R_{th}} + 1)d_{RM}^{b_1} &= a_1 a_2^{-1}(2^{R_{th}} + 1)d_{BR}^{b_2} \\ \|\mathbf{X}\|^{b_1} - (2^{R_{th}} + 1)\|\mathbf{X} - \mathbf{H}_j\|^{b_1} &= a_1 a_2^{-1}(2^{R_{th}} + 1)d_{BR}^{b_2} \end{aligned} \tag{10}$$

Theorem 2: When RS adopts DF strategy, cell separation between BS and RS satisfies(10).

Corollary 2: When $b_1 = b_2 = 2$, cell separation boundary must be behind the line which passes RS point and is vertical to the connection of BS and RS. When LOS exists between BS and RS, cell separation boundary is a parabola.

Proof: When $b_1 = b_2 = 2$, from (7) and (9), we can get

$$EE_{RS}(\mathbf{X}, \mathbf{H})/EE_{bs}(\mathbf{X}) > (2^{R_{th}} + 1)((d_{RM}^2 + d_{BR}^2)/d_{BM}^2)^2 \tag{11}$$

Law of cosines tells us that cell separation boundary between BS and RS must be behind the line which is vertical to the connection between BS and RS and passes RS. When LOS exists between BS and RS, cell separation boundary can be approximated to $(2^{R_{th}} + 1)^{1/b_1}d_{RM} = d_{BM}$, which is a parabola.

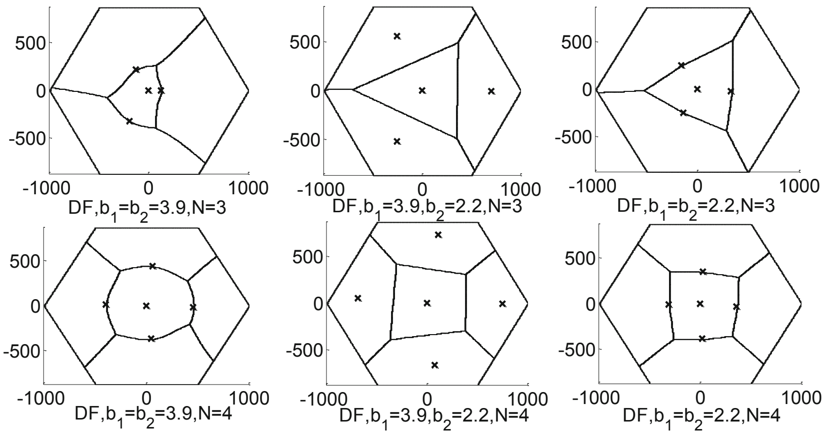

Fig. 2. Cell separation diagram (DF)

When DF strategy is adopted, cell separation boundary is shown in Fig. 2. The 'x' mark denotes RS locations. Based on RS locations, cell separation is done. Cell separation boundary is changing with fading factor b. As the growing of b_1,b_2, the curvature of cell separation boundary becomes larger, which matches with the theoretic results.

3.2 Cell Division for AF Relays Assisted Networks

With data rate expression (2) energy efficient power allocation problem can be modeled as

$$\begin{aligned} \min_{P_s,P_r} \ & \frac{P_s + P_r}{R_{AF}} \\ s.t. \ & 0 < P_s, P_r < P_{max} \\ & R_{AF} \geq R_{th} \end{aligned} \tag{12}$$

With high SNR assumption, data rate expression (2) is approximated to

$$R_{AF} = \frac{1}{2} \log_2 \left(\frac{P_s |h_{SR}|^2 P_r |h_{RD}|^2}{1 + P_s |h_{SR}|^2 + P_r |h_{RD}|^2} \right) \tag{13}$$

Then the optimal result of (11) is

$$\begin{aligned} P_s &= \frac{\left(2^{2R_{th}} - 1\right) |h_{RD}|^2 + \sqrt{2^{2R_{th}} \left(2^{2R_{th}} - 1\right) |h_{SR}|^2 |h_{RD}|^2}}{|h_{SR}|^2 |h_{RD}|^2} \\ P_r &= \frac{\left(2^{2R_{th}} - 1\right) |h_{SD}|^2 + \sqrt{2^{2R_{th}} \left(2^{2R_{th}} - 1\right) |h_{SR}|^2 |h_{RD}|^2}}{|h_{SR}|^2 |h_{RD}|^2} \end{aligned} \tag{14}$$

We omit the proof of the result due to space limitation.

3.2.1 Boundary between Subregions of Two RSs

The energy cost of RS_i is expressed as

$$EE_{RS_i}(\mathbf{X},\mathbf{H_i}) = \frac{1}{R_{th}}\left((2^{2R_{th}}-1)\left(a_1^{-1}d_{R_iM}^{b_1}+a_2^{-1}d_{BR_i}^{b_2}\right)\right.$$
$$\left.+2\sqrt{2^{2R_{th}}(2^{2R_{th}}-1)a_1^{-1}a_2^{-1}d_{R_iM}^{b_1}d_{BR_i}^{b_2}}\right) \quad (15)$$

When $EE_{RS_i}(\mathbf{X},\mathbf{H_i}) \approx (2^{2R_{th}}-1)/R_{th}\left(\sqrt{a_1^{-1}d_{R_iM}^{b_1}}+\sqrt{a_2^{-1}d_{BR_i}^{b_2}}\right)^2$, cell separation boundary can be expressed as

$$\sqrt{a_1^{-1}d_{R_iM}^{b_1}}-\sqrt{a_1^{-1}d_{R_jM}^{b_1}} = \sqrt{a_2^{-1}d_{BR_j}^{b_2}}-\sqrt{a_2^{-1}d_{BR_i}^{b_2}}$$
$$\|\mathbf{X}-\mathbf{H_i}\|^{b_1/2}-\|\mathbf{X}-\mathbf{H_j}\|^{b_1/2} = \sqrt{a_1a_2^{-1}d_{BR_j}^{b_2}}-\sqrt{a_1a_2^{-1}d_{BR_i}^{b_2}} \quad (16)$$

Theorem 3: When RS adopts AF strategy, cell separation boundary between RSs similarly satisfies(14).

Corollary 3: When $b_1 = 2$, cell separation boundary between RSs is a hyperbola; when $b_1 = 4$, cell separation boundary is a straight line. When LOS exists between BS and RS, cell separation boundary becomes a straight line.

Proof: When $b_1 = 2$, cell separation boundary (14) can be translated into $d_{R_iM} - d_{R_jM}$ =const, which is a hyperbola. When $b_1 = 4$, cell separation boundary (14) turns to be$\|\mathbf{X}-\mathbf{H_i}\|^2 - \|\mathbf{X}-\mathbf{H_j}\|^2$, which is a straight line. When LOS exists between BS and RS, cell separation boundary (14) is approximated to $\|\mathbf{X}-\mathbf{H_i}\| - \|\mathbf{X}-\mathbf{H_j}\|$, which is a straight line.

3.2.2 Boundary between Subregions of BS and RSs

Cell separation boundary satisfies $EE_{RS_i}(\mathbf{X},\mathbf{H_i}) = EE_{BS}(\mathbf{X})$,then from (9) and (15), we can get

$$\sqrt{d_{BM}^{b_1}/(2^R+1)}-\sqrt{d_{RM}^{b_1}} = \sqrt{a_1a_2^{-1}d_{BR}^{b_2}}$$
$$(2^{R_{th}}+1)^{-1/2}\|\mathbf{X}\|^{b_1/2}-\|\mathbf{X}-\mathbf{H_j}\|^{b_1/2} = \sqrt{a_1a_2^{-1}d_{BR}^{b_2}} \quad (17)$$

Theorem 4: When RS adopts AF strategy, cell separation between RS and BS approximately satisfies(17).

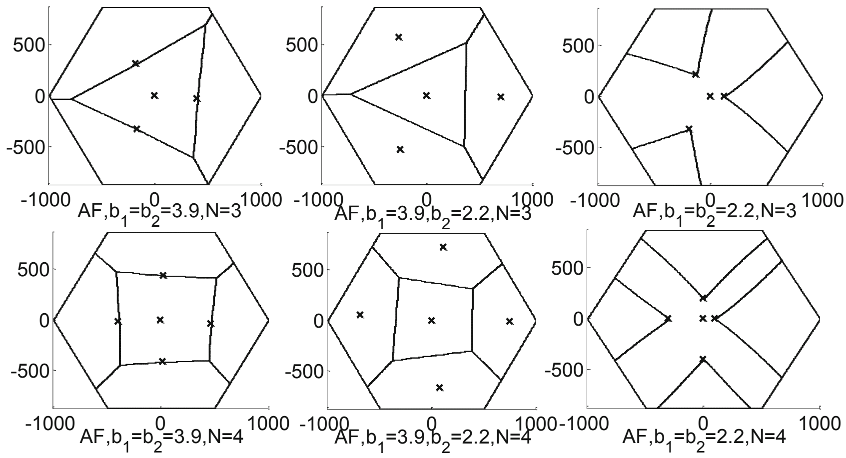

Fig. 3. Cell separation diagram (AF)

Corollary 4: When $b_1 = b_2 = 2$, no RS is needed. When $b_1 = b_2 = 4$, cell separation boundary between BS and RS is behind the line which is perpendicular to the connection of BS and RS and pass RS. When LOS exists BS and RS, cell separation boundary is a parabola.

Proof: If $b_1 = b_2 = 2$,then

$$EE_{RS}(\mathbf{X}, \mathbf{H}) > \frac{2^{2R_{th}} - 1}{R_{th}} \left(\sqrt{a_1^{-1} d_R^{b_1} M} + \sqrt{a_2^{-1} d_{BR}^{b_2} / d_{BR}} \right)^2 \tag{18}$$

So,

$$EE_{RS}(\mathbf{X}, \mathbf{H_i}) / EE_{BS}(\mathbf{X}) > (2^{2R_{th}} + 1) \left(\frac{d_{RM} + d_{BR}}{d_{BM}} \right)^2 \tag{19}$$

Triangle inequality tells us that $d_{RM} + d_{BR} > d_{BM}$, so $EE_{RS}(\mathbf{X}, \mathbf{H}) > EE_{BS}(\mathbf{X})$, which means BS should transmit data to MS directly. When $b_1 = b_2 = 4$,$EE_{RS}(\mathbf{X}, \mathbf{H}) / EE_{BS}(\mathbf{X}) > (2^{2R_{th}} + 1) \left(\frac{d_{RM}^2 + d_{BR}^2}{d_{BM}^2} \right)^2$. Law of cosines tells us that cell separation boundary between BS and RS must be behind the line which vertical to the connection of BS and RS and pass RS. When LOS exists between BS and RS, then $d_{BM} - (2_{th}^{R} + 1)^{1/b_1} d_{RM} = 0$,which is a parabola.

Cell separation boundary for AF strategy is shown in Fig. 3. Three different channel cases are provided, which conform to theoretic analysis.

3.3 Energy Efficient Center Searching

Energy efficient cell separation divides a cell into $N + 1$ regions. BS communicates with MS in S_i through RS_i, while BS transmits data to MS in region

S_{N+1} directly. In this section, we will optimize RS_i position to maximize energy efficiency in S_i, which can be formulated as

$$\min_{\mathbf{H_i}} \iint_{S_i} \frac{P_s(\mathbf{X}, \mathbf{H_i}) + P_r(\mathbf{X}, \mathbf{H_i})}{R} f(\mathbf{X}) d\mathbf{X}, i = 1, 2, \ldots, N \tag{20}$$

Owing to complex shape of S_i, and complex expression of traffic distribution, it is hard to get a theoretic solution of the optimal RS locations; however, numerical techniques can be used to find near-optimal relay positions. We quantize a cell region into grids. So (20) can be translated into

$$\min_{\mathbf{H_i}} \sum_{\mathbf{X_j} \in S_i} \frac{P_s(\mathbf{X_j}, \mathbf{H_i}) + P_r(\mathbf{X_j}, \mathbf{H_i})}{R} Prob(\mathbf{X_j}), i = 1, 2, \ldots, N \tag{21}$$

Where $Prob(\cdot)$ is the probability function. When grid is small enough we can get the near-optimal result. To make the calculation faster, two-dimensional FFT is utilized.

Expression (7) and(15) can both denote energy cost of RS and BS, because when $d_{BR_i}^{b_2} = 0$,(7)=(9),(15)=(9). And (7), (15) can be both expressed as $EE_{RS_i} = g(\mathbf{X} - \mathbf{H_i})$. So (17) can be transformed into

$$\min_{\mathbf{H_i}} \sum_{\mathbf{X_j} \in S_i} g(\mathbf{X_j} - \mathbf{H_i}) f(\mathbf{X_j}) \tag{22}$$

which is a convolution of $g(\mathbf{X})$ and $f(\mathbf{X})$. Using two-dimensional FFT can largely decrease the complexity of calculation.

After a few iterations of energy efficient cell separation and energy efficient center searching, the near-optimal locations for N RSs will be obtained.

4 Numerical Results for EERP Algorithm

The EERP algorithm was implemented for both AF and DF relays. Both uniform and random traffic distribution is examined. We suppose cell radius $R_{cell} = 1000m$. The channel model we adopted is Urban Macro Model in ITU-R M.2135 [12] with and without LOS as follows,

$$\begin{aligned} PL_{NLOS} &= 39 \log_{10} d + 20 log_{10} d + 20 log_{10} f_c + 13.5 \\ PL_{LOS} &= 22 \log_{10} d + 20 log_{10} d + 20 log_{10} f_c + 28.0 \end{aligned} \tag{23}$$

So we can get $a_1 = 10^{-2.1}$, $a_2 = 10^{-3.6}$,$b_1 = 3.9$,$b_2 = 2.2$.When traffic follows uniform distribution $f(\mathbf{X}) = c, c > 0$, the near-optimal RS locations are shown in Fig.4 and Fig.5, when $N = 3, 4, 6, 12$. The cross mark denotes the near-optimal RS locations. We find that channel fading factor b has a great effect on results. In uniform distribution, the near-optimal results show symmetric

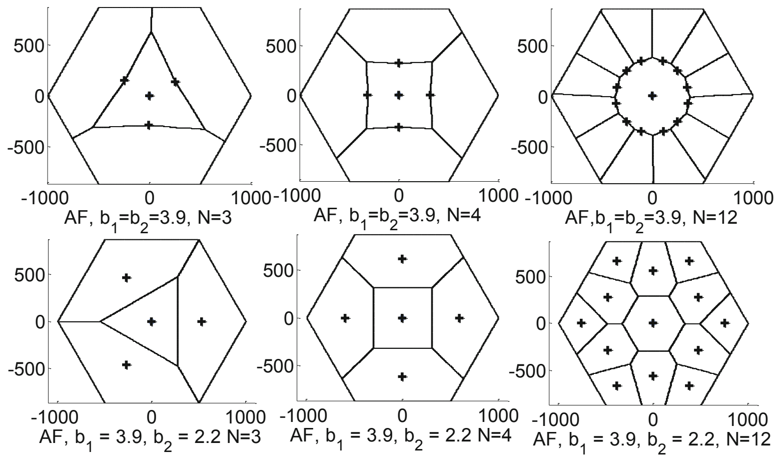

Fig. 4. Near-optimal RS locations for uniform traffic distribution(AF)

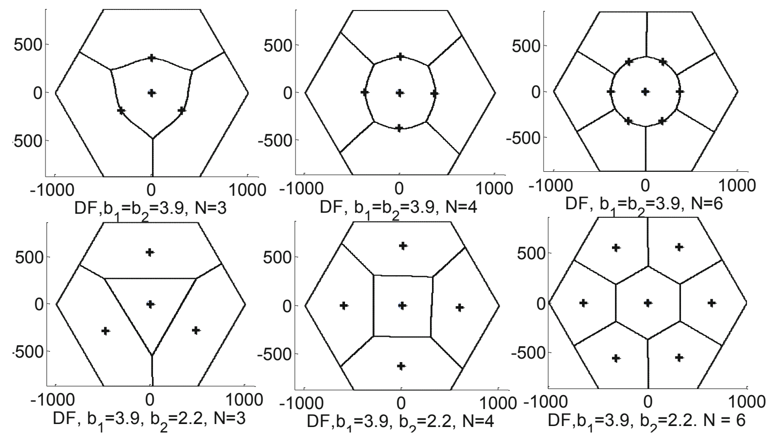

Fig. 5. Near-optimal RS locations for uniform traffic distribution(DF)

placement in a cell. And comparing DF and AF relay strategy, we find that RS locations are almost the same. However, the cell separation boundaries are different, especially when $b_1 \neq b_2$, which conform to the above theorems and corollaries. When traffic distribution $f(\mathbf{X})$ is not uniform, the nearoptimal RS locations are shown in Fig.6. The color shows the normalized traffic density. By comparing with uniform case Fig.5, we can see that energy efficient relay postion of each region tend to be near high traffic density areas. RS locations are not symmetric any more.

In a specific traffic distribution, as shown in Fig.7, nearoptimal RS locations are illustrated for different RS types,different channel conditions and different RS number. When LOS exists between BS and RS, AF and DF have almost the same near-optimal RS locations and similar cell separation diagram. Without LOS

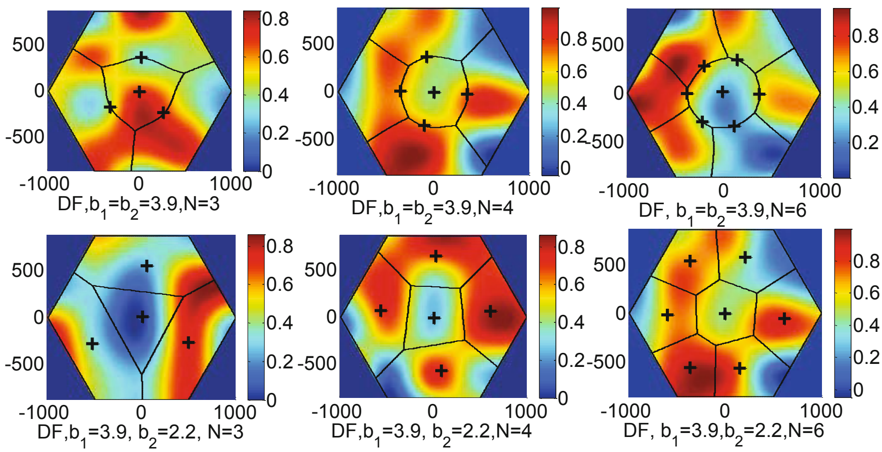

Fig. 6. Near-optimal RS locations under random traffic distribution in DF

between BS and RS, both cell separation boundary and RS locations are different for two kinds of relay strategies. Comparing with uniform traffic distribution, we find that both the RS locations and cell separation boundaries are affected by the distribution.

To evaluate the effectiveness of EERP algorithm, we repeat simulation for 1000 times with N=6 and the same traffic distribution as Fig.7. The red lines are CDF (cumulative distribution function) of cell energy consumption of EERP algorithm with random initial relay positions, while the blue lines are CDF of cell energy consumption when relays are randomly distributed in the cell. From Fig. 8, we can see that EERP algorithm can largely reduce cell energy consumption, and the red lines also prove stability of EERP algorithm.

5 Conclusion

In this work, we propose a traffic-aware energy-efficient relay position searching method for relay-assisted cellular network. We optimize multiple relay locations in a cell based on statistical traffic distribution to maximize energy efficiency. An algorithm named EERP is proposed to solve the problem, which contains an iteration of two steps, i.e. energy efficient cell division and energy efficient center searching. A cell is divided into small subregions covered by RSs and BS based on energy efficient power allocation. Close-form expressions of cell separation boundary are provided, and shapes of cell separation boundary are concluded under certain pathloss factors b. Energy efficient center searching is used to get the optimal RS positions according to cell division and traffic distribution. Two-dimensional FFT is used to reduce the complexity. Simulation results show near-optimal relay positions in different pathloss factors, relay scenarios and relay numbers.

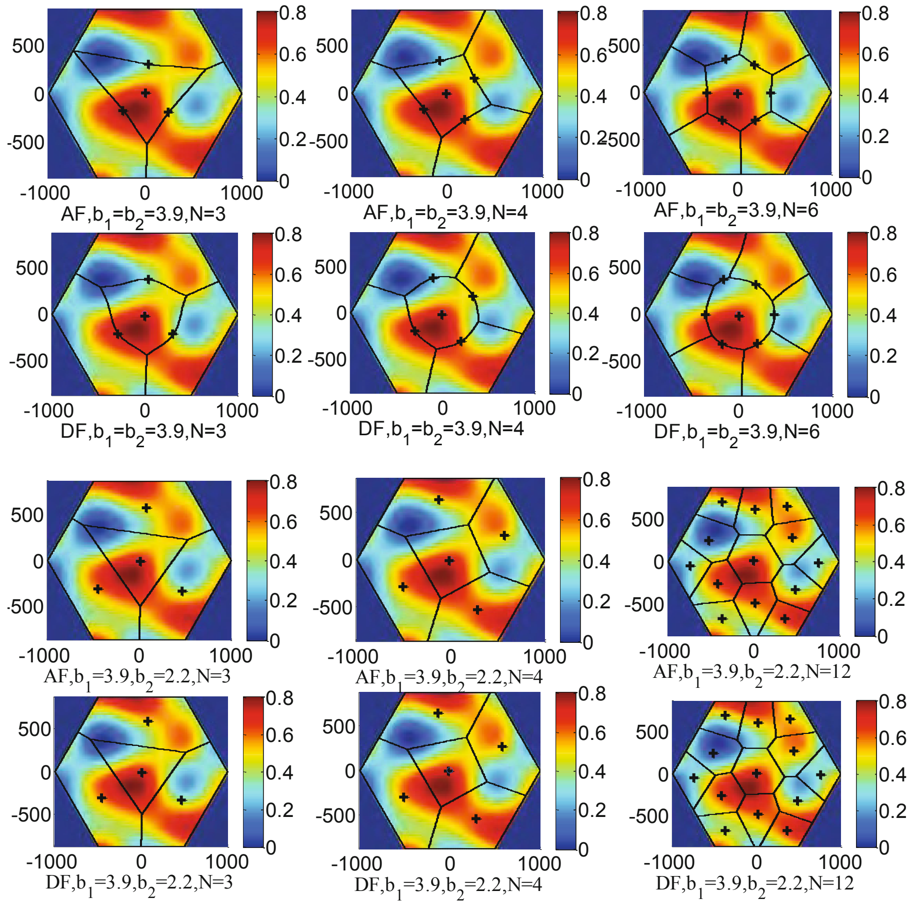

Fig. 7. Near-optimal RS location compare of AF and DF

The main contribution of this paper contains three aspects. First, an algorithm which can effectively obtain near-optimal positions for N RSs is provided. Second, close-form cell division boundary and its shape under some specific pathloss conditions are concluded, which can help placing or selecting relay nodes. Third, energy efficient center searching scheme is based on traffic distribution. Once network planning is proposed based on traffic distribution, less energy will be wasted because of low traffic. FFT is adopted to decrease the complexity from N2 to Nlog2N, which make EERP more practical.

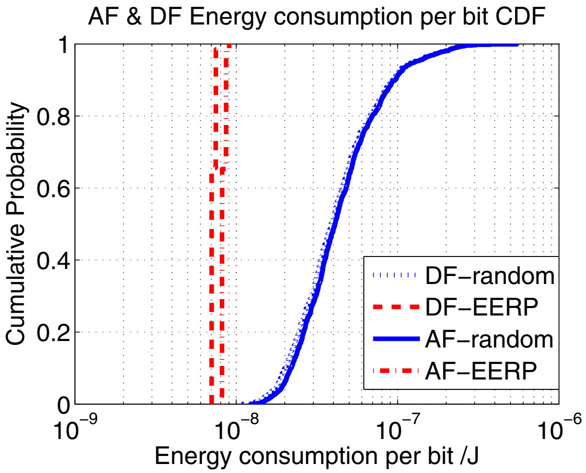

Fig. 8. Energy consumption CDF,when $N = 6$

Acknowledgment. This work is supported by National programs for High Technology Research and Development (SS2012AA011402) and NSFC(61172088).

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