Adaptive Cell Zooming and Sleeping for Green Heterogeneous Ultradense Networks

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Abstract—With the increasingly dense-deployed small cells, the heterogeneous ultra-dense network (H-UDN) now faces new challenges. In order to fulfill user traffic demand and improve network energy efficiency in H-UDNs, this paper researches on the adaptive cell zooming scheme to achieve the optimized user association through adjusting cell coverages. Then, the cell sleeping scheme is further applied to turn off light traffic load cells for base station (BS) power saving. We define the cell zooming factor (CZF) to express cell coverage, which is derived as a closed-form expression with the relationship of small cell and macro cell densities. The user association probability with one typical cell is also derived, where the probability is related with both the transmission power and CZF. We apply the game theory to optimize the CZF based on reduction of area power consumption. Based on the fact that users are encouraged to associate with small cells to reduce transmission power consumptions, the small cell sleeping scheme is further applied to improve the network energy efficiency, while the sleeping small cell users could be offloaded to macro cells. The sleeping probability is defined and derived with influences of different sleeping thresholds. We optimize the threshold with maximized energy saving performance. Simulation results verify that the sleeping threshold has an optimized value.

Index Terms—cell sleeping, cell zooming, energy efficiency, game theory, heterogeneous ultra-dense networks.

I. INTRODUCTION

With rapid growth of mobile users, traditional cellular network infrastructure cannot meet the demand of increasing traffic. Heterogeneous ultra-dense network (H-UDN) has been studied as an appealing solution [1]. Under H-UDN architecture, a large number of small cells are deployed underneath macro cells’ coverages. Mobile users are encouraged by the network to associate with small cells due to the high-speed data service and less transmission power compared to with macro cells. The traffic offloading issue from macro cell to small cell also becomes the research focus, which verifies the gain for capacity increments and energy efficiency improvements [2].

However, with the increasingly dense deployed of small cells, the H-UDN now faces with new challenges. On one hand, although small cells could save the transmission power, Base Station (BS) circuit and hardware power consumptions also increase due to increasingly deployed small cells [3]. On the other hand, user associations will be more complicated in overlaid H-UDN, which constructs dynamic relationship between users and multi-tier cells. Furthermore, the cell sleeping and coverage zooming scheme for H-UDN also exacerbate the above trend [4]. Usually, users with high data rate requirements intend to associate with small cells in H-UDNs. But given the time variation and traffic fluctuation, some small cells may only serve few users, which results in severe energy underutilization. Therefore, the user association scheme design in H-UDN need to balance the hot-spot traffic providence and energy saving from light traffic cell sleeping mechanism.

In order to fulfill user traffic demand and improve network energy efficiency in H-UDNs, this paper researches on the adaptive cell zooming scheme for optimized user association through adjusting cell coverages. Then, the cell sleeping scheme is further applied to turn off light traffic load cells for BS power saving. Different from current works, the contributions of this paper are listed as below:

1) We define the Cell Zooming Factor (CZF) to express cell coverage. The small cells are deployed according to Poisson Point Process (PPP) model. Moreover, the user association probability with one typical cell is derived, where the probability is related with both the transmission power and cell coverage.

2) The CZF is derived as a closed-form expression with the relationship of small cell and macro cell densities. We apply the game theory to optimize the CZF based on reduction of area power consumption. Users are encouraged to associate with small cells to reduce transmission power consumptions.

3) The small cell sleeping scheme is further applied to improve the network energy efficiency, while the sleeping small cell users will be offloaded to macro cells. The sleeping probability is defined and derived with influences of different sleeping thresholds. We optimize the threshold with maximized energy saving.
A. Related Works

In recent works, based on stochastic geometry theory, the BS locations in densely deployed H-UDNs could be modeled by a homogeneous PPP model [5]–[7]. The network model is verified accurately as the real network in terms of the performance analyses of outage probability and coverage probability [8]–[10]. It is a tractable analytical model that could be extended to obtain the network coverage performance with user association criteria that a typical user connects to its nearest BS [11].

In [4], the user association schemes are researched. The BS cooperation is achieved by adjusting the corresponding cell coverages. Moreover, certain BSs could be turned into sleep due to their light traffic loads. The optimal deployment of base station density is deduced based on the random geometry theory in [12] and the traffic will be offloaded from small cells to macro cells. Small cells in light load conditions are supposed to be turned off for energy saving. Authors of [13] analyze the tradeoff between energy efficiency and traffic delay. Compared with uniform traffic distributions, the burst traffic could provide more sleeping opportunities, which will also help to reduce the BS energy consumption. Authors in [14] propose one algorithm that one BS could be turned off at a time to minimize the impact on network. Three heuristic sleeping schemes are proposed and the network impact value serves as the evaluation metrics. The quality-of-service (QoS) aware BS switching and cell zooming design for green cellular networks is proposed in [15]. By dividing each cell into partitions, user QoS requirements are satisfied with efficient switching mechanisms.

The aforementioned research work study the network performances through the cell zooming or cell sleeping mechanisms. However, the optimization analyses are not based on area power consumption, which is more important in densely deployed H-UDNs. Take a step forward, this paper proposes adaptive cell zooming optimization analysis considering the area power consumption and analyzes the optimal cell coverage with the defined CZF. Based on cell zooming results, the cell sleeping probability is analyzed considering both the transmission power and the statistical circuit power of BSs.

The remaining of this paper is arranged as follows. In Section II, the system model is presented for the H-UDN deployment scenario and user associations. The user association probability with typical cell is also derived in Section II. In order to reduce power consumption and improve the network energy efficiency, we propose the adaptive cell zooming scheme in Section III. The cell sleeping scheme design is analyzed in Section IV. Then the performance evaluation and simulation results are provided in Section V. Finally, there are concluding remarks.

II. SYSTEM MODEL

A. Network Model

For the network model of H-UDNs, the BSs are classified into macro cells and small cells. Under H-UDN deployment, the cellular network protocol structure is separated into control plane and traffic plane [16], where the control plane is mainly taken over by macro cells, while the small cells will be responsible for traffic plane. For the control plane, the macro cell will act as the control cell to manage multiple small cells and mobile users within its coverage. The macro cell can also perform as the traffic cell due to its serving ability for user traffics. However, its traffic cell coverage should be constrained by its control coverage. The coverage of control plane is made of all the coverage area of multiple macro cells, which will not change in short period. But the coverage of traffic cells can zoom in or zoom out adaptively with different user traffic requirements.

In this paper, it is assumed that traffic cells include both macro cells and small cells that are deployed according to PPP model. Traffic cells coverage is supposed to zoom in accordance with data traffic. But in this paper, only small cells can switch to sleep mode. The area power consumption is the main concern to improve energy efficiency [17]. In the process of traffic cell zooming, the transmission power should be saved as much as possible. For small cells sleeping, the BS static circuit power are also taken into consideration. When the small cell is in sleeping mode, it only consumes lower power and users will be offloaded to overlaid macro cells.

As shown in Fig. 1, the macro cell BS (denoted by blue square point in Fig. 1) is responsible for the Control Plane, which can provide a wide range of control plane coverage (denoted by purple dot line in Fig. 1). The blue circle describes the traffic coverage which is provided by the small cell BS (denoted by red triangle point in Fig. 1) with zooming capabilities. The blue dot circle denotes the coverage of BS after zooming. It shows that macro cell BS M1 and small cell BS S1 are shrunk after zooming, and the coverages of small cell BS S2, S3, S4 and S5 are increased, as examples. The traffic cell will form the service coverage which covers users inside its area. The traffic cell coverage can zoom in or zoom out adaptively with the traffic requirements fluctuations.

B. User Association Strategy

The user association strategy applied in this paper is that the users will be served by the BS which provides the strongest...
reference signal receive power (RSRP). \( P_{0,j} \) is the access threshold of BS \( j \).

\[
P_{i,j}^* + \text{bias} > P_{0,j} \quad (1)
\]

where \( P_{i,j}^* \) denotes the receiving power from BS \( j \) to user \( i \). The \( \text{bias} \) denotes deviation value. According to the stochastic geometry theory, the BS and user deployments can be reasonably modeled by a homogeneous PPP model. The intensity of BS deployment is \( \lambda \), and the intensity of user deployment is \( \lambda_u \).

The deployment area of cells and users is \( A \). The receiving power \( P_{i,j} \) after zooming is formulated as follow:

\[
P_{i,j} = P_j \left( \frac{x_{i,j}}{r_j} \right)^{-\alpha_j} \quad (2)
\]

where \( P_j \) denotes the transmission power of cell \( j \), \( x_{i,j} \) denotes the distance between user \( i \) and cell \( j \), \( r_j \) is the CZF of cell \( j \), \( \alpha_j \) is the path-loss factor of cell \( j \).

\[
P_{i,j} = P_{i,j}^* + \text{bias}
\]

\[
\text{bias} = P_j \left( \frac{x_{i,j}}{r_j} \right)^{-\alpha_j} - P_j x_{i,j}^{-\alpha_j}
\]

\[
= P_j x_{i,j}^{-\alpha_j} (r_j^{\alpha_j} - 1) \quad (4)
\]

If \( r_j = 1 \), the value of \( \text{bias} \) is 0. There are no zooming effect and all users will be associated with the BS when the receiving power is \( P_{i,j} \). If \( r_j > 1 \), the value of bias is greater than 0. The area of cell expands and more users could associate with it. If \( r_j < 1 \), the value of bias is less than 0. The area of cell shrinks, and when it zooms in a much smaller range, the cell may have the chance to turn into the sleeping state.

C. User Association Probability With Adaptive Cell Zooming

Without loss of generality, it is assumed that one typical user is served by traffic cell \( k \), and the probability of association is derived as follows. It means that the typical user receives more power from cell \( k \) than any other cells. \( P_{i,k} \) and \( P_{i,j} \) denote receiving power which user \( i \) receives the power from traffic cell \( k \) and \( j \) after zooming. And user \( i \) is associated with traffic cell \( k \). So we can get the following conclusion:

\[
P_{i,k} > P_{i,j} \quad (5)
\]

We consider that user association is based on the Downlink Received Signal Strength (DL-RSS) [18]. The distance based path-loss is considered in DL-RSS modeling. According to power law, the receiving power after zooming can be expressed as follow:

\[
P_k \left( \frac{x_{i,k}}{r_k} \right)^{-\alpha_k} > P_j \left( \frac{x_{i,j}}{r_j} \right)^{-\alpha_j} \quad (6)
\]

The relation to the different distance is expressed in formula (7).

\[
x_{i,j} > \left( \frac{P_j}{P_k} \right)^{\frac{1}{\alpha_j}} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k} \quad (7)
\]

\( P_{ro}(n = k) \) denotes the probability which user associated with traffic cell \( k \). The \( x_k \) is a mathematical mark. The probability can be derived as

\[
P_{ro}(n = k) = E_{x_k} \left[ P[P_{i,k} > \max_{j,j \neq k} P_{i,j}] \right]
\]

\[
= E_{x_k} \left[ \prod_{j,j \neq k} [P[P_{i,k} > P_{i,j}]] \right]
\]

\[
= E_{x_k} \left[ \prod_{j,j \neq k} \left[ x_{i,j} \left( \frac{P_j}{P_k} \right)^{\frac{1}{\alpha_j}} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k} \right] \right]
\]

\[
= \int_0^\infty \prod_{j,j \neq k} \left[ x_{i,j} \left( \frac{P_j}{P_k} \right)^{\frac{1}{\alpha_j}} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k} \right] f_{x_k}(l) dl \quad (8)
\]

In the 2-D poisson process, there is conclusion in [19]:

\[
P[\text{NO Cell Close than } l] = e^{-\pi l^2} \quad (9)
\]

The transition length is Rayleigh distributed.

\[
f_{x_k}(l) = \frac{1 - P[\text{NO Cell Close than } l]}{dl} = 2\pi \lambda le^{-\pi l^2} \quad (10)
\]

At first, we derive part of formula (8), where (9) and (10) are substituted into below formula.

\[
\prod_{j,j \neq k} \left[ x_{i,j} \left( \frac{P_j}{P_k} \right)^{\frac{1}{\alpha_j}} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k} \right] = \prod_{j,j \neq k} P[\text{NO Cell Close than Cell } k]
\]

\[
= \prod_{j,j \neq k} e^{-\pi \lambda \sum_{j,j \neq k} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k}^2}
\]

\[
= e^{-\pi \lambda \sum_{j,j \neq k} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k}^2} \quad (11)
\]

Then, we put above formula into (8),

\[
P_{ro}(n = k) = \int_0^\infty e^{-\pi \lambda \sum_{j,j \neq k} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k}^2} \times 2\pi \lambda le^{-\pi l^2} dl
\]

\[
= 2\pi \lambda \int_0^\infty le^{-\pi \lambda \sum_{j,j \neq k} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k}^2} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k}^2 + l \right) dl
\]

\[
= \pi \lambda \int_0^\infty e^{-\pi \lambda \sum_{j,j \neq k} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k}^2} \left( \frac{r_j}{r_k^{\alpha_j/\alpha_j}} \right)^{\frac{\alpha_k}{\alpha_j}} x_{i,k}^2 - L + L \right) dl \quad (12)
\]

In order to simplify the above probability formula, we consider that cells have same configurations, which are all users have the same bandwidth allocation. For the path-loss, according to the 3rd Generation Partnership Project (3GPP) Long Term Evolution-Advanced (LTE-Advanced) simulation methodology,
the path-loss exponents are 3.76 for macro cell and 3.67 for small cell in the outdoor scenario [20]. Therefore, we conduct the following analyses based on the approximation that the path-loss exponents of small cell and macro cell are almost equal to each other, which means $\alpha_k = \alpha_j = \alpha$. This approximation has been verified as very limited impacts for the performances [21]. So, the main differences will be the deployment location and CZF. $R_k$ denotes standard cover radius of cell $k$.

$$P_{r0}(n = k) = \pi \lambda \int_{0}^{\infty} \frac{1}{L+1} \left[ \sum_{j \neq k} \left( \frac{P_j}{\pi R_j^2} \right)^{\frac{1}{\alpha}} \right] dL$$

$$= \int_{0}^{\infty} \frac{1}{L+1} \left[ \sum_{j \neq k} \left( \frac{P_j}{\pi R_j^2} \right)^{\frac{1}{\alpha}} \right] d\lambda L$$

$$= \frac{(P_k \frac{\pi}{r_k})^2}{\sum_{j \neq k} (P_j \frac{\pi}{r_j})^2} = \frac{1}{\sum_{j \neq k} (\frac{P_j}{\pi R_j^2} - \frac{P_k}{\pi R_k^2})^2} \ (13)$$

The derived closed-form expression reveals the relationship between the probability which user associated with traffic cell $k$ and CZFs. The association probability is not only related with CZF of traffic cell $k$, but also with all other cells CZFs. In fact, CZF of traffic cell has relationship with cell coverage, so the association probability reflects both the transmission power and cell coverage.

### III. ADAPTIVE CELL ZOOMING BASED ON AREA POWER CONSUMPTION

#### A. Area Power Consumption

The area power consumption and area energy efficiency are new metrics of network performance measures. On the basis of fulfilling user requirements, maximizing area energy efficiency is equivalent to minimizing area power consumption. The area power consumption optimization can also help to rationally adjust the user association relationship.

The number of deployed small cell BS is $M$ and the number of mobile user is $N = \Lambda n$. The number of users served by traffic cell $k$ is $N_k$:

$$N_k = \sum_{n=1}^{N} P_{r0}(n = k) = N P_{r0}(n = k) \ (14)$$

The coverage area of cell $k$ is $A_k$:

$$A_k = \pi (R_k r_k)^2 \ (15)$$

The power consumption of cell $k$ is expressed as follow, where $C_k$ denotes total capacity of cell $k$.

$$P_k^c = \sum_{N_k} P_{k,i} = N_k P_k = \Lambda n \frac{(P_k \frac{\pi}{r_k})^2}{\sum_{j} (P_j \frac{\pi}{r_j})^2} \ (16)$$

Area power consumption $P_k^c$ is defined as the transmission rate of per unit area power in cell $k$.

$$P_k^c = \frac{P_k^c}{\Lambda n} = \frac{\sum_{j} (P_j \frac{\pi}{r_j})^2}{\pi (R_k r_k)^2} = \frac{A \lambda_n P_k^{\frac{1}{\alpha}}}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (17)$$

The objective is to minimize $P_k^c$, therefore maximize $-P_k^c$.

#### B. Optimal Traffic Cell Zooming With Game Theoretic Solution

Above formula shows the relation between the area power consumption and CZF. It is worth noting that our optimization goal is to minimize area power consumption. As a result, the utility function is constructed with game theory [22]. The game theory is applied to maximize the revenue function, which needs to use preserving convexity operation to change the formula. So minimizing $P_k^c$ is modified to maximizing $-P_k^c$ as the revenue function.

There are three basic elements in non-cooperative game model:

1. Domain: a set of cells for playing the game, $k \in \{1, 2, ..., M\}$.
2. Strategy: The CZF of traffic cell $k = \{r_k\} = \{r_k | r_k \in [0, r_{max}]\}$.
3. Utility: The utility function of cell is $u(r_k, r_{-k})$. Utility function of cell includes revenue function and penalty function, defined as:

$$u(r_k, r_{-k}) = -P_k^c - b \pi (R_k r_k)^2$$

$$= -\frac{A \lambda_n P_k^{\frac{1}{\alpha}}}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} - b \pi (R_k r_k)^2 \ (18)$$

where $b$ is a fixed parameter. The revenue function and penalty function will increase with $r$ value. The physical meaning of revenue function is to minimize the area power consumption. And the physical meaning of penalty function is that if the cell area is expanding, the punishment will be increased.

The objective of this game is to maximize the utility of players:

$$\max u(r_k, r_{-k}) \ (19)$$

1. Existence of the Equilibrium: The first-order partial derivative of $u(r_k, r_{-k})$ is:

$$\frac{du(r_k, r_{-k})}{dr_k} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$

And the second-order partial derivative of $u(r_k, r_{-k})$ is:

$$\frac{d^2 u(r_k, r_{-k})}{dr_k^2} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$

$$\frac{d^2 u(r_k, r_{-k})}{dr_k^2} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$

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$$\frac{d^2 u(r_k, r_{-k})}{dr_k^2} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$

$$\frac{d^2 u(r_k, r_{-k})}{dr_k^2} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$

$$\frac{d^2 u(r_k, r_{-k})}{dr_k^2} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$

$$\frac{d^2 u(r_k, r_{-k})}{dr_k^2} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$

$$\frac{d^2 u(r_k, r_{-k})}{dr_k^2} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$

$$\frac{d^2 u(r_k, r_{-k})}{dr_k^2} = \frac{2A \lambda_n P_k^{\frac{1}{\alpha}} - b \pi R_k^2 r_k}{\pi R_k^2 \sum_{j} (P_j \frac{\pi}{r_j})^2} \ (20)$$
Area power consumption with CZF $r_m$ and $r_s$. 

$$-2b\pi R_k^2 = \frac{2A\lambda_u P_k^{rt}}{\pi R_k^2} \cdot \frac{\pi R_k^2}{2} \frac{\sum_j (P_j \hat{r}_j)^2 - 4 P_k \hat{r}_k^2}{(\sum_j (P_j \hat{r}_j)^2)^2} - 2b\pi R_k^2$$

When $\sum_j (P_j \hat{r}_j)^2 - 4 P_k \hat{r}_k^2 \leq 0$, we have $r_k^2 \geq \frac{1}{4} P_k \hat{r}_k^2 \sum_{j,j \neq k} (P_j \hat{r}_j)^2$ and $\frac{\partial u(r_k, r_s)}{\partial r_k} \leq 0$, so $u(r_k, r_s)$ is a concave function. For proposed game, the Nash equilibrium exists.

2) Uniqueness of the Equilibrium: Making $\frac{\partial u(r_k, r_s)}{\partial r_k} = 0$, namely

$$\frac{2A\lambda_u P_k^{rt}}{\pi R_k^2} \cdot \frac{\pi R_k^2}{2} \frac{\sum_j (P_j \hat{r}_j)^2 - 2b\pi R_k^2 r_k - 2b\pi R_k^2}{\sum_j (P_j \hat{r}_j)^2} = 0$$

Assume the value of parameters is not zero, we can derive (22) as follow,

$$r_k = \sqrt[2]{\frac{\sqrt{2A\lambda_u P_k^{rt}} - P_k^{-\frac{1}{2}}} {b\pi R_k^2}} - \frac{1}{\sum_{j,j \neq k} (P_j \hat{r}_j)^2} \sum_{j,j \neq k} (P_j \hat{r}_j)^2$$

Then, the Nash equilibrium is unique.

There is one macro cell and $M$ small cells in one independent control area. Assuming macro cell and small cell CZFs are $r_m$ and $r_s$ respectively. So the CZFs of the small cells are derived as:

$$r_s = \sqrt[2]{\frac{1}{M} \left( \frac{\sqrt{2A\lambda_u P_m^{rt}} - P_m^{-\frac{1}{2}}} {b\pi R_m^2} \right)}$$

The area power consumption is changing with CZF $r_m$ and $r_s$ as Fig. 2.

It has a minimum point value which shows the minimum area power consumption in Fig. 2. The area power consumption is reduced when $r_m$ is decreased and $r_s$ is increased. As a result, area energy efficiency will be improved accordingly. The macro cell coverage has a trend to shrink. On the other hand, the small cell coverage has a trend to extend.

IV. SMALL CELL SLEEPING FOR ENERGY EFFICIENCY IMPROVEMENTS

Based on above analysis, the number of users served by a typical small cell has a probability to decrease after adjusting the CZF. The power consumption of small cell $k$ contains two parts, static circuit power and transmission power [23]. In order to save energy further, the small cell with light traffic load could switch to sleep and offload the users to macro cell.

$P_k^t$ denotes total power consumption of small cell $k$.

$$P_k^t = \begin{cases} P_k^0 + P_k^s, & N_i \geq N_t \\ P_k^s, & N_k < N_t \end{cases}$$

(25)

where $P_k^0$ denotes BS circuit power of small cell $k$ when it is active. $P_k^s$ denotes transmission power of small cell $k$ when it is working. $P_k^t$ denotes circuit power of small cell $k$ when it is sleeping. Lightly loaded small cells can offload users to macro cells. Namely, if the number of mobile users is less than a certain threshold, small cell will switch to sleep. $N_i$ is the threshold.

The sleeping probability of small cell $k$ is derived as follows:

$$p(N_k < N_i) = \sum_{i=1}^{N_k} p(N_k = i) = \sum_{i=1}^{N_k} \prod_{j \neq k} \Pr_0(n = k)$$

(26)

For the setting of same transmission power and different CZF, the sleeping probability of small cell is derived as follows:

$$p_s = p(N_k < N_i) = \frac{r_k^2 (\sum_{j,j \neq k} (P_j \hat{r}_j)^2)^2}{(\sum_{j,j \neq k} (P_j \hat{r}_j)^2)^2} (N_i + 1)$$

(27)

When small cell has a opportunity to sleep, the average total power consumption of cell $k$ will be:

$$P_k = P_k^s \cdot p_s + (P_k^0 + P_k^s) \cdot (1 - p_s)$$

(28)

$$P_k^0 + P_k^s - P_k = P_k^0 + P_k^s - P_k^s \cdot p_s - (P_k^0 + P_k^s) \cdot (1 - p_s)$$

(29)

Formula (29) proves that average reducing power consumption has linear relation with sleeping probability. In order to saving more power consumption, we want to maximize the sleeping probability.

$$\max p_s$$

(30)
\( p_s \) is not a convex function, therefore, it needs to relax \( p_s \) and get an approximate convex function. First, we define lower bound of \( p_s \) as follow:
\[
\begin{align*}
p_s &= r_k^2 \left( \sum_j r_{kj}^2 \right)^{N_t} - r_k^2 (N_t+1) \\
&> r_k^2 \sum_{j, j \neq k} r_{kj}^2 - r_k^2 (N_t+1) \\
&= \sum_{j, j \neq k} r_{kj}^2 \left[ 1 - \left( \frac{r_k^2}{\sum_{j, j \neq k} r_{kj}^2} \right)^{N_t} \right] \\
&= \tau (1 - \tau^{N_t}) \\
\end{align*}
\]

The above formula shows that \( p_s \) increases with \( N_t \). Maximizing \( N_t \) can get the maximum \( p_s \). When the small cell is sleeping, users are offloaded to macro cell. Macro cell may not have the ability to receive all users. Therefore, looking for the maximum \( N_t \) value has restricted condition.

\[
\begin{align*}
\max & \quad N_t \\
\text{s.t.} & \quad B_i < W_m
\end{align*}
\]

where \( N_m \) is the number of users which are associated with macro cell before small cell switching to sleep. \( B_i \) denotes band used to service user \( i \) in macro cell. \( W_m \) is the total band of macro cell. \( B = B_i \). The KKT condition is derived as follow:
\[
(M p_s N_t + N_m) B - W_m = 0
\]

Then maximum \( N_t \) can be expressed as follow formula:
\[
N_t = \frac{1}{M p_s} \left( \frac{W_m}{B} - N_m \right)
\]

V. PERFORMANCE EVALUATIONS

A. Simulation Environment and Parameter Setting

In the simulations, The BS and users are deployed by PPP model. Each user selects the traffic cell according to the largest downlink RSRP. Besides, small cells and macro cells are deployed in the same frequency band. The frequency reuse factor of MBS is 1. Moreover, the Resource Block (RB) is the basic resource granularity in the simulations. The detailed simulation parameters are also according to 3GPP LTE-Advanced small cell HetNet evaluation methodology [24]. Some of the parameters are listed in the Table I.

<table>
<thead>
<tr>
<th>System Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier Frequency</td>
<td>2 GHz</td>
</tr>
<tr>
<td>System Bandwidth</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Maximum Transmission Power of Macro Cell</td>
<td>46 dBm</td>
</tr>
<tr>
<td>Maximum Transmission Power of Small Cell</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Radius of Macro Cell</td>
<td>500 m</td>
</tr>
</tbody>
</table>

![Fig. 3. Relationship between \( r_m \) and \( r_v \).](image)

B. Simulation Results and Analyses

1) Performance of Traffic Cell Zooming: The relationship between \( r_s \) and \( r_m \) is shown in Fig. 3. Assuming the density of user is \( \lambda_u = 0.05/m^2 \). In order to reduce the transmission power, users are encouraged to associate with small cell under the condition of meeting user traffic requirement. As a result, we observe the small cell coverage changes on the basis of zooming macro cell coverage. While the CZF of macro cell increases, small cell coverage decreases and the number of user serviced by small cell is reduced. In order to preferentially associate with small cell, macro cell servicing area has a tendency to decrease. As the channel getting worse, users would not like to associate with small cell. Moreover, channel continues to deteriorate, the coverages of both macro cell and small cell will be reduced. In this way, some users will be removed from serving coverage.

Simulation results in Figs. 4 and 5 provided the user throughput CDF with and without zooming. Comparing the Figs. 4 and 5, macro cells lose users at the low data-rate area with about 60% throughput, because those macro cell users are offloaded to small cells under the proposed scheme. Meanwhile, the small cell throughput increases 16%. The curves of all user throughput CDF are almost the same in the Figs. 4 and 5, which means that all users’ requirements could be guaranteed with and without zooming.

Simulation results in Figs. 6 and 7 provide the user SINR CDF with and without zooming. The Fig. 6 shows that all three curves are almost similar under the maximum RSRP strategy.
Comparing the Figs. 6 and 7, the macro cell user SINR are improved significantly through the cell zooming, because the lower SINR users are offloaded to small cells through the proposed scheme. The small cell user SINR is also varying but the scope is much smaller. It means that small cells can accept relatively more users within their capacities. The curves of all user SINR CDF are almost the same in the Figs. 6 and 7, which also shows that all users’ requirements could be guaranteed.

Simulation results in the Figs. 8 and 9 show the percentage of macro cell users and small cell users. The horizontal axis is the number of simulation times. In Fig. 8, the number of users changes intensely without zooming. The percentage of small cell users varies within 60% ~ 70%. The percentage of macro cell users varies within 30% ~ 40%. Comparing with the Figs. 8, 9 shows that the percentage of small cell users varies within 72% ~ 89%. The percentage of macro cell users varies within 11% ~ 28%. Comparing the Figs. 8 and 9, the percentage of macro cell users is reduced while small cell users are markedly increased after zooming process for power savings.
It can be seen that after macro cell traffic coverage shrinking, the macro cell is concentrated in serving a small amount of high data rate users, while other users are served by small cells. In this zooming process, the power consumption reduction is formulated by $1 - \sum_{k} \frac{N^*_k P_k}{\sum_{k} N_k P_k}$, where $N^*_k$ and $N_k$ are the number of users associated to the cell $k$ with and without zooming respectively. $P_k$ is the transmission power of cell $k$. The percentage of power consumption saving is shown in Fig. 10, where the average power saving is about 41%.

2) Performances of Small Cell Sleeping: In Fig. 11, cell sleeping probability have the maximum value when $N_t$ is a fix. And the maximum sleeping probability increases with $N_t$. But $N_t$ does not increase unlimited. Because the users served by sleeping small cells are offloaded to macro cell, macro cell cannot exceed its capacity after receiving offloaded users. Fig. 12 shows that the small cell sleeping probability is getting bigger and bigger while more and more small cells go to sleep, the channels get worse and the receiving power of macro cell users is reducing. This is because more and more users are offloaded to macro cell, but macro cell service ability is limited, so the performance is in decline. As a result, there will be a maximum $N_t$ value. Under this value, macro cell cannot exceed its service capacity and small cells have a maximum sleeping probability.

VI. CONCLUSION

In order to fulfill user traffic demand and improve network energy efficiency in H-UDNs, this paper research on the adaptive cell zooming scheme for optimized user association through adjusting cell coverages. The cell sleeping scheme is further applied to turn off light traffic load cells for BS power saving. The CZF is defined to express the cell coverage, which is derived as a closed-form expression. The user association probability with one typical cell is also derived, where the probability is related with the transmission power and cell coverage. The game theory is applied to optimize the CZF based on reduction of area power consumption. The small cell sleeping scheme is further implemented to improve the network energy efficiency, while the sleeping small cell users will be offloaded to macro
cells. The sleeping probability is defined and derived with influences of different sleeping thresholds. The threshold is also optimized with maximized energy saving performance. System-level simulation results are provided to verify the performance improvements.

REFERENCES


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