

Remote Radio Head Selection for Power Saving in Cloud Radio Access Networks

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Abstract—Cloud radio access network (C-RAN) is considered as a cost- and energy-efficient architecture to meet the ever-increasing mobile data traffic, where baseband processing is decoupled from the remote radio head (RRH) and conducted in a centralized baseband unit (BBU) pool. Though C-RAN enables efficient resource allocation and reduces network operation cost, the optical transport network power consumption between the RRHs and the BBU pool is usually enormous. In this paper, we focus on the minimization of the total power consumption by jointly considering the transport network power and the transmission power of the RRHs. We formulate a general RRH selection task that falls into the form of capacitated facility location problem (CFLP) and propose an efficient local search algorithm to address it. Numerical results validate that our proposal can significantly reduce the total power consumption of the C-RAN.

Index Terms—Cloud radio access network (C-RAN), power saving, RRH selection, traffic density.

I. INTRODUCTION

With the rapid increase of traffic demands of mobile equipments, one of the most important challenges is that of mitigating power consumption [1]. Densely deploying small cells is deemed as a promising approach to cope with the challenge [2]. The system capacity can be dramatically enhanced by exploiting the spatial reuse of the small cells. In addition, significant power saving can be achieved due to the lower distance from access points (APs) to users. However, efficient resource allocation and interference management becomes to a challenging issue for the densely deployed small cells scenario, as well as the consequential increase of capital expenditure (CAPEX) and operating expense (OPEX).

Cloud radio access network (C-RAN) has been proposed as a novel network architecture, which has the potential to answer the challenges [3, 4]. In C-RAN architecture, remote radio heads (RRHs) and baseband units (BBUs) are separated. The BBUs are centralized into a BBU pool, which greatly enables an efficient utilization of resources, reduces the CAPEX and OPEX, and increases the flexibility in network upgrade. On the other hand, the BBUs can interact with low-latency. Interference management mechanisms, such as enhanced intercell interference coordination (eICIC) and coordinated multi-point (CoMP), can be significantly benefited [5, 6].

Since RRHs and BBUs are separated, C-RAN architecture brings a huge signal overhead over the fronthaul links. The fronthaul transport network is required to not only support

huge transport capacity, but also meet strict latency requirements. Passive optical network (PON) [7], which comprises an optical line terminal (OLT) that connects a set of optical network units (ONUs) through a single fiber, can provide cost-effective connections between the RRHs and the BBU pool. However, the transport network power consumption occupies an important position in C-RANs [8]. Implementing a sleep mode in each ONU is proposed to save the transport network power consumption as can be seen in [7]. Due to the variation of spatial traffic, it would be feasible to switch off some RRHs. In addition, such an RRH selection strategy is easy to implement in C-RAN architecture.

It is worth noticing that switching off a part of RRHs will inevitably increase the total transmission power to meet the same traffic demand. It is necessary to find a tradeoff between the transmission power and the transport network power consumption [9, 10]. In [9], the objective is to minimize the total power consumption of C-RANs while satisfying the quality of service (QoS) guarantee. A greedy algorithm and two iterative algorithms based on a three-stage group sparse beamforming framework are developed. In [10], joint user association and beamforming design is investigated. The defined problem has similar formulation except that both downlink and uplink transmissions are considered jointly. A virtual downlink transmission is established to convert the original problem into an equivalent form, which can be solved by relaxed-integer programming.

Note that the RRH selection strategies proposed in [9] and [10] are based on the user requirements. Due to the user mobility, the BBU pool may switch the on/off states of the RRHs with high frequency. Different from the fact that user location changes in a short time, the traffic density keeps approximately invariable in a long time [11]. An RRH selection strategy based on the traffic density is preferable to only considering users' traffic demands, which forms the main motivation of this work. Our optimization task is to find the tradeoff between the minimization of transport network power consumption and transmission power while satisfying a series of network constraints, such as transmission power budget, spectrum limitation, traffic and spectral efficiency requirements. We develop an efficient local search algorithm address the formulated problem and prove that the proposed algorithm can always find a locally optimal solution.

The remainder of this paper is organized as follows. In Sec-

tion II, the network model and the RRH selection problem are illustrated. In Section III, the algorithm is proposed in detail. In Section IV, numerical results are given with discussions. Conclusions are drawn in Section V.

II. NETWORK MODEL AND PROBLEM FORMULATION

A. Network Model

We consider a region $\mathcal{D} \in \mathbf{R}^2$ served by a C-RAN, consisting of a set of RRHs and a single BBU pool, where the set of the RRHs is denoted by $\mathcal{N} = \{1, 2, \dots, N\}$. For each RRH $n \in \mathcal{N}$, the maximum transmission power is P_n^{max} and the total available bandwidth is B_n^{max} . Without loss of generality, the transport link between the RRH n and the BBU pool is denoted by n . In other words, \mathcal{N} also denotes the set of the transport links. We adopt the common power model of the transport network in [7], given by

$$P_{tn} = P_{olt} + \sum_{n \in \mathcal{N}} P_{tl,n}, \quad (1)$$

where P_{olt} is the power consumption of the OLT, $P_{tl,n}$ is the power consumed by the transport link n with

$$P_{tl,n} = \begin{cases} P_{tl,n}^s & \text{the RRH } n \text{ is inactive,} \\ P_{tl,n}^a & \text{otherwise.} \end{cases} \quad \forall n \in \mathcal{N}. \quad (2)$$

If we switch off the RRH n , the power consumption that can be saved on the transport link n is

$$P_n = P_{tl,n}^a - P_{tl,n}^s. \quad (3)$$

One important issue of the RRH selection is to meet the traffic demand of the considered region. Let $x \in \mathcal{D}$ be a location in the region. We use $\zeta(x)$ to represent the average rate requirement¹ at the location x . Assuming that the total rate requirement of the considered region is R_D , we have

$$\iint_{\mathcal{D}} \zeta(x) d\sigma = R_D. \quad (4)$$

We divide the consider region into K traffic demand areas (TDAs) of same small area, denoted by \mathcal{K} . Denote the region of the TDA k as \mathcal{D}_k . We use R_k^{min} to denote the rate requirement of the TDA k , that is,

$$R_k^{min} = \iint_{\mathcal{D}_k} \zeta(x) d\sigma. \quad (5)$$

According to (4), we also have $\sum_{k \in \mathcal{K}} R_k^{min} = R_D$.

Denote $h_{k,n}$ as the power gain between the RRH n and the TDA k . Define $b_{k,n}$ and $p_{k,n}$ as the bandwidth and power of the RRH n allocated to the TDA k , respectively, the achievable rate of the RRH n to the TDA k can be calculated as

$$r_{k,n} = b_{k,n} \log_2 \left[1 + \frac{p_{k,n} h_{k,n}}{b_{k,n}(N_0 + I_{k,n})} \right], \quad (6)$$

where $I_{k,n}$ are the interference throne by adjacent RRHs with unit bandwidth. Interference management techniques, such as

¹Traffic density can be changed to the density of rate requirements through dividing the traffic density by the given time interval [11].

eICIC and CoMP, can be employed to reduce intercell interference [5, 6]. Benefiting from centralizing the BBU resources in a BBU pool, these techniques are greatly facilitated since signal processing from many cells can be done over the BBU pool. Moreover, due to the low transmission power of RRH, large propagation loss of high frequency band and penetration loss, the intercell interference is usually slight. We can put aside the inter-cell interference for the traffic density based RRH selection. Thus we assume $I_{k,n} \approx 0$ in this work.

We assume that each TDA can be assigned to multiple RRHs and the power is equally distributed over the whole spectrum for each RRH. We have $p_{k,n}/b_{k,n} = P_n^{max}/B_n^{max}$. For notation brevity, let $P_n^{avg} = P_n^{max}/B_n^{max}$ and $H_{k,n} = h_{k,n}/N_0$. The achievable rate from the RRH n to the TDA k can be written as

$$\begin{aligned} r_{k,n} &= b_{k,n} \log_2 (1 + p_{k,n} H_{k,n} / b_{k,n}) \\ &= b_{k,n} \log_2 (1 + H_{k,n} P_n^{avg}) \\ &= \varphi_{k,n} p_{k,n}, \end{aligned} \quad (7)$$

where

$$\varphi_{k,n} = \frac{1}{P_n^{avg}} \log_2 (1 + H_{k,n} P_n^{avg}) \quad (8)$$

is the achievable rate from the RRH n to the TDA k with unit power.

It is also necessary to take spectral efficiency into consideration for the RRH selection. We define the spectral efficiency function $S_{k,n}$ for $k \in \mathcal{K}, n \in \mathcal{N}$ as

$$S_{k,n} = \frac{r_{k,n}}{b_{k,n}} = \log_2 (1 + H_{k,n} P_n^{avg}) = \varphi_{k,n} P_n^{avg}, \quad (9)$$

where the third equation follows by (8). A minimum spectral efficiency requirement, denoted by S^{min} , is required to satisfy, that is, the TDA k can be assigned to the RRH n only if $S_{k,n} \geq S^{min}$. We usually take the cell-edge user spectral efficiency requirement as the minimum spectral efficiency in the C-RAN.

B. Problem Formulation

According to the definition of z_n , we can rewritten P_{tn} as follows,

$$\begin{aligned} P_{tn} &= P_{olt} + \sum_{n \in \mathcal{N}} (P_{tl,n}^a - P_{tl,n}^s) z_n + \sum_{n \in \mathcal{N}} P_{tl,n}^s \\ &= P_{olt} + \sum_{n \in \mathcal{N}} z_n P_n + \sum_{n \in \mathcal{N}} P_{tl,n}^s. \end{aligned} \quad (10)$$

Note that P_{olt} and $\sum_{n \in \mathcal{N}} P_{tl,n}^s$ are fixed for the variables z_n 's. Let $P_{fixed} = P_{olt} + \sum_{n \in \mathcal{N}} P_{tl,n}^s$, then $P_{tn} = \sum_{n \in \mathcal{N}} z_n P_n + P_{fixed}$. On the other hand, the total transmission power can be counted by

$$P_{rf} = \sum_{n \in \mathcal{N}} \frac{z_n}{\varpi_n} \sum_{k \in \mathcal{K}} p_{k,n}, \quad (11)$$

where ϖ_n is the drain efficiency of the radio frequency power amplifier.

The optimization task of this work is to find the tradeoff between the minimization of transport network power consumption and the minimization of transmission power. We define the RRH selection problem as follows:

$$\begin{aligned}
& \underset{z_n, p_{k,n}}{\text{minimize}} && P_{tn} + \eta \cdot P_{rf} \\
& \text{s.t. } C_1 : && \sum_{k \in \mathcal{K}} p_{k,n} \leq z_n P_n^{\max}, \forall n \in \mathcal{N}, \\
& && C_2 : \sum_{n \in \mathcal{N}} p_{k,n} \varphi_{k,n} = R_k, \forall k \in \mathcal{K}, \\
& && C_3 : p_{k,n} = 0, \forall k, n, \varphi_{k,n} P_n^{\text{avg}} < S^{\min}, \\
& && C_4 : p_{k,n} \geq 0, \forall k, n, \varphi_{k,n} P_n^{\text{avg}} \geq S^{\min}, \\
& && C_5 : z_n \in \{0, 1\}, \forall n \in \mathcal{N}.
\end{aligned} \tag{12}$$

where $\eta \geq 0$ is the parameter that balances the transport network power consumption and the transmission power. C_1 is the transmission power limits for the selected RRHs. $C_2 \sim C_4$ ensure the rate requirement and spectral efficiency requirement of each TDA. Since P_{fixed} is constant, the objective of problem (12) is equivalent to

$$\underset{z_n, p_{k,n}}{\text{minimize}} \sum_{n \in \mathcal{N}} z_n P_n + \sum_{n \in \mathcal{N}} q_n \sum_{k \in \mathcal{K}} p_{k,n} \tag{13}$$

where $q_n = \eta / \varpi_n$. Problem (12) is a generalized form of many optimization problems in cellular networks. For instance, if we only minimize the transport network power consumption, i.e. $\eta = 0$, (12) becomes a minimum cost cell planning problem [12]. Meanwhile, (12) is also a generalized form of the classical CFLP [13, 14], which is a well-known NP-hard problem.

III. OUR PROPOSED ALGORITHM

A. LP-based Power Allocation

Before introducing our proposed algorithms, we need to answer the following question: How to minimize the objective function of (12) with a given subset of RRHs. Denote $\mathcal{N}_s \subseteq \mathcal{N}$ as the selected RRHs, the power allocation problem is:

$$\begin{aligned}
& \underset{p_{k,n}}{\text{minimize}} && \sum_{n \in \mathcal{N}_s} q_n \sum_{k \in \mathcal{K}} p_{k,n} \\
& \text{s.t. } && C_1 \sim C_4 \text{ in (12)}.
\end{aligned} \tag{14}$$

We convert problem (14) into an equivalent linear programming (LP) problem. Define $P_{k,n}$ as the required power to meet the rate requirement of the TDA k , where

$$P_{k,n} = \begin{cases} +\infty & \varphi_{k,n} P_n^{\text{avg}} < S^{\min}, \\ R_k^{\min} / \varphi_{k,n} & \text{otherwise.} \end{cases} \tag{15}$$

Let $y_{k,n}$ indicate the fraction of the TDA k that is associated with the RRH n . We have $p_{k,n} = P_{k,n} y_{k,n}$. The equivalent problem of (14) is

$$\begin{aligned}
& \underset{y_{k,n}}{\text{minimize}} && \sum_{n \in \mathcal{N}} q_n \sum_{k \in \mathcal{K}} P_{k,n} y_{k,n} \\
& \text{s.t. } C_1 : && \sum_{k \in \mathcal{K}} P_{k,n} y_{k,n} \leq z_n P_n^{\max}, \forall n \in \mathcal{N}_s, \\
& && C_2 : \sum_{n \in \mathcal{N}} y_{k,n} = 1, \forall k \in \mathcal{K}, \\
& && C_3 : 0 \leq y_{k,n} \leq z_n, \forall k \in \mathcal{K}, n \in \mathcal{N}.
\end{aligned} \tag{16}$$

Obviously, (16) defines an LP problem, which can be efficiently solved by LP algorithms or solvers, such as CVX [15].

B. Local Search Algorithm for the RRH Selection Problem

Based on the optimal solution to (14), we can generalize the algorithms in [13, 14] to address the RRH selection problem. Given a subset \mathcal{N}_s of RRHs, define $P_r(\mathcal{N}_s)$ as the optimal value of (14). Without loss of generality, $P_r(\mathcal{N}_s) = +\infty$ if problem (14) is infeasible. Let $P_t(\mathcal{N}_s) = \sum_{n \in \mathcal{N}_s} P_n$. The objective value of (13) is

$$P(\mathcal{N}_s) = P_t(\mathcal{N}_s) + P_r(\mathcal{N}_s). \tag{17}$$

Starting with a feasible solution \mathcal{N}_s , e.g., $\mathcal{N}_s = \mathcal{N}$, we introduce the following three types of local improvement operations:

add(n): In this operation, we try to select an RRH n which is not in the current solution \mathcal{N}_s , i.e. $n \notin \mathcal{N}_s$. If $P(\mathcal{N}_s \cup \{n\}) < P(\mathcal{N}_s)$, we add the RRH n to \mathcal{N}_s , i.e. $\mathcal{N}_s \leftarrow \mathcal{N}_s \cup \{n\}$.

open(n, \mathcal{N}'): In this operation, we try to select an RRH $n \notin \mathcal{N}_s$ and close a subset of RRHs \mathcal{N}' , i.e. $\mathcal{N}_s \leftarrow \mathcal{N}_s \cup \{n\} \setminus \mathcal{N}'$. Note that the possibilities for the set \mathcal{N}' are exponentially large. For the CFLP, to make the procedure polynomial, the ‘‘open’’ operation in [13, 14] do not compute the exact cost of the new solution but only an estimated cost which overestimates the exact cost. In other words, all the rate requirements served by \mathcal{N}' is only reassigned to n , which indicates that the methods in [13, 14] cannot be employed directly. We propose a modified ‘‘open’’ operation for the RRH selection problem based on the following theorem:

Theorem 1. *If there exists a set of RRHs $\mathcal{N}' \subseteq \mathcal{N}_s$ that satisfies*

$$P(\mathcal{N}_s \cup \{n\} \setminus \mathcal{N}') < P(\mathcal{N}_s \cup \{n\}), \tag{18}$$

there must exist an RRH $n' \in \mathcal{N}'$ that satisfies

$$P(\mathcal{N}_s \cup \{n\} \setminus \{n'\}) < P(\mathcal{N}_s \cup \{n\}). \tag{19}$$

Proof: The proof is presented in Appendix A. ■

According to the conclusion of Theorem 1, we do not need to search all possible combinations for the set \mathcal{N}' because if there exists a subset of RRHs that can decrease the objective value of (12), there must exist an RRH that can also lower the objective value. So the key idea of our proposed ‘‘open’’ operation is as follows: Try to find an RRH $n' \in \mathcal{N}_s$ that satisfies (19), if no such RRH exists, the operation cannot improve the current solution; otherwise, close the RRH n' and repeatedly search the remaining RRHs in \mathcal{N}_s until no RRH satisfies (19). It is worth to highlight that we do not need to find a specific \mathcal{N}' . Once we find an RRH that satisfies (19), implying the existence of \mathcal{N}' is confirmed, the local improvement operation can help find a better solution to the RRH selection problem. If no RRH satisfies (19), we can conclude that there does not exist a set \mathcal{N}' that satisfies (18), indicating the operation cannot find any a better solution.

close(n, \mathcal{N}'): In this operation, an RRH $n \in \mathcal{N}_s$ is closed and a subset of RRHs \mathcal{N}' , disjoint from \mathcal{N}_s , is opened, i.e. $\mathcal{N}_s \leftarrow \mathcal{N}_s \cup \mathcal{N}' \setminus \{n\}$. Similar to our proposed ‘‘open’’

operation, the key idea of “close” operation is as follows: Try to find an RRH $n' \notin \mathcal{N}_s$ that can decrease the objective value of (12), if no RRH exists, the operation cannot improve the current solution; otherwise, open the RRH n' and repeatedly search the remaining RRHs in $\mathcal{N} \setminus \mathcal{N}_s$ until no operation can decrease the objective value. We have the following theorem:

Theorem 2. *If there exists a set of RRHs $\mathcal{N}' \subseteq \mathcal{N} \setminus \mathcal{N}_s$ that satisfies*

$$P(\mathcal{N}_s \cup \mathcal{N}' \setminus \{n\}) < P(\mathcal{N}_s \setminus \{n\}), \quad (20)$$

there must exist an RRH $n' \in \mathcal{N}'$ that satisfies

$$P(\mathcal{N}_s \cup \{n'\} \setminus \{n\}) < P(\mathcal{N}_s \setminus \{n\}). \quad (21)$$

Proof: The proof is similar to Theorem 1. ■

Based on Theorem 1 and Theorem 2, we can conclude that \mathcal{N}_s is locally optimal solution if none of the three operations can decrease the total power consumption and the algorithm stops at this point. Therefore, the key idea of our proposed algorithm is: Try to find a better solution by using the three local search operations, repeat the procedure until no better solution can be found. It is worth noticing that “multi” operation, which is generalized the “open”, “close” operations, is introduced in [13, 14]. It is straightforward to generalize our proposed “open”, “close” operations to the “multi” operation. Due to its high computational complexity, we do not employ the operation in this work.

IV. NUMERICAL RESULTS

We give numerical results to evaluate the performance of our proposed algorithms. Simulation parameters of the considered C-RAN are based on the specifications proposed in [16]. The parameters of the fronthaul transport network are the same as they proposed in [7].

The service region is $2 \times 2 \text{ km}^2$, which is divided into 100 TDAs with same area. The total rate requirement is 1 Gbps. We set the rate requirement and the spectral efficiency requirement of each TDA to 10 Mbps and 0.1 bit/Hz for simplicity. The site of each RRH is distributed uniformly in the considered region. The maximum transmission power is 1 W and the available bandwidth is 100 MHz for each RRH. $q_n = 1$ for all RRHs for simplicity. The power of the OLT is 20 W. The powers consumed by each transport link in the active mode and the sleep mode are 3.85 W and 0.75 W, respectively. Thus P_n is 3.1 W for each RRH and P_{fixed} can be calculated as $20 + 0.75N$ (in W). Path loss (in dB) from an RRH to a TDA is calculated as $140.7 + 36.7 \log_{10}(D)$, where D (in km) is the distance between them. The standard deviation of lognormal shadowing is 10 dB. The noise PSD is -184 dBm/Hz.

First, we investigate the convergence of our proposed local search algorithm, as shown in Fig. 1. Fig. 1 illustrates the power consumption during each iteration with different number of RRHs. We can observe from Fig. 1 that our proposed algorithm converges rapidly. It requires about 20 iterations and 46 iterations for the cases that $N = 20$ and $N = 40$, respectively. The results are reasonable because more RRHs are switched off for the latter one. As seen from Fig. 1, we

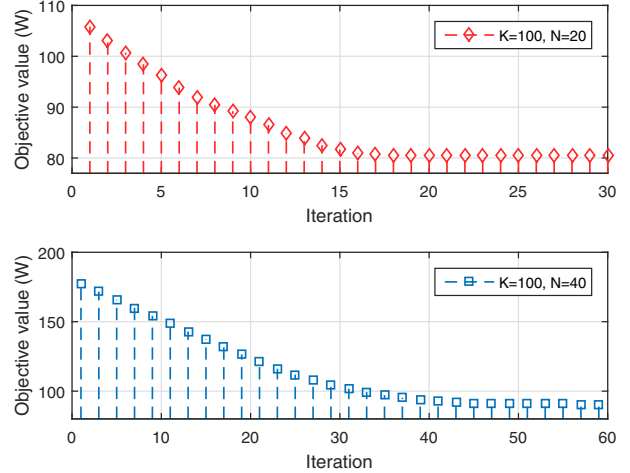


Fig. 1. Objective value of (12) during each iteration with different number of RRHs.

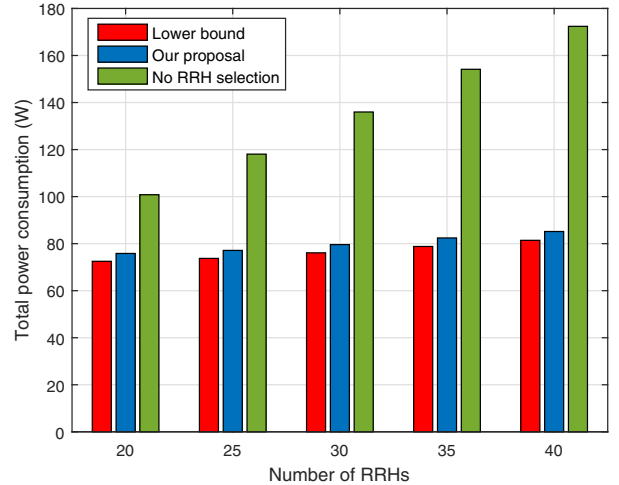


Fig. 2. Total power consumption as a function of number of RRHs.

can preliminarily conclude that our proposal can reduce the power consumption of the C-RAN.

Then, we evaluate the performance of the proposed algorithm. Fig. 2 illustrates the total power consumption of the C-RAN as a function of number of RRHs. For comparison, we take the optimal solution to the relaxation of (12) (yielded by CVX solver) as the lower bound. The power consumption without proposed RRH selection scheme is also given. As we can see from Fig. 2 can save the power consumption compared with no RRH selection scheme for the all cases. With the increase of the RRHs, the total power consumption increases slightly by using our proposal. As same as the results illustrated in Fig. 1, our proposal can save about 25% and 50% power consumption of the network for the cases that $N = 20$ and $N = 40$, respectively. Moreover, our proposed algorithm is close to the lower bound. The gap is always less than 5%.

We can conclude that our proposal can save the C-RAN power consumption efficiently and effectively.

V. CONCLUSIONS

In this paper, we studied the RRH selection for power saving in C-RANs, where our goal is to find the tradeoff between the transport network power consumption and the transmission power of the RRHs while satisfying the rate and spectral efficiency requirements. We first formulate the power allocation task and yield an equivalent LP problem. By exploiting the characteristics of the optimal solutions to the problem, we develop a local search algorithm to solve it, where three modified local improvement operations are proposed to find out the locally optimal solution efficiently. Numerical results validate the effectiveness and efficiency of our proposal.

APPENDIX

If all RRHs in \mathcal{N}' do not satisfy (19), i.e.,

$$P(\mathcal{N}_s \cup \{n\} \setminus \{n'\}) \geq P(\mathcal{N}_s \cup \{n\}), n' \in \mathcal{N}', \quad (22)$$

based on the definition of $P(\mathcal{N}_s)$, we can obtain

$$-P_{n'} + P_r(\mathcal{N}_s \cup \{n\} \setminus \{n'\}) \geq P_r(\mathcal{N}_s \cup \{n\}), n' \in \mathcal{N}'. \quad (23)$$

Inequality (23) is equivalent to

$$\sum_{n' \in \mathcal{N}'} [-P_{n'} + P_r(\mathcal{N}_s \cup \{n\} \setminus \{n'\})] \geq \sum_{n' \in \mathcal{N}'} P_r(\mathcal{N}_s \cup \{n\}). \quad (24)$$

Since $\sum_{n' \in \mathcal{N}'} P_{n'} = P_t(\mathcal{N}')$, we have

$$-P_t(\mathcal{N}') + \sum_{n' \in \mathcal{N}'} [P_r(\mathcal{N}_s \cup \{n\} \setminus \{n'\}) - P_r(\mathcal{N}_s \cup \{n\})] \geq 0. \quad (25)$$

Notice that $P_r(\mathcal{N}_s \cup \{n\}) - P_r(\mathcal{N}_s \cup \{n\} \setminus \{n'\})$ denotes the transmission power that can be saved by activating n' , indicating that

$$\begin{aligned} & \sum_{n' \in \mathcal{N}'} [P_r(\mathcal{N}_s \cup \{n\}) - P_r(\mathcal{N}_s \cup \{n\} \setminus \{n'\})] \\ & \geq P_r(\mathcal{N}_s \cup \{n\}) - P_r(\mathcal{N}_s \cup \{n\} \setminus \mathcal{N}'). \end{aligned} \quad (26)$$

Inequality (26) always holds because the transmission power saved by the RRH $n' \in \mathcal{N}'$ when \mathcal{N}' is active is always no bigger than the saved transmission power by exclusively activating the RRH n' . Then, we have

$$\begin{aligned} & -P_t(\mathcal{N}') + P_r(\mathcal{N}_s \cup \{n\} \setminus \mathcal{N}') - P_r(\mathcal{N}_s \cup \{n\}) \\ & \geq -P_t(\mathcal{N}') + \sum_{n' \in \mathcal{N}'} [P_r(\mathcal{N}_s \cup \{n\} \setminus \{n'\}) - P_r(\mathcal{N}_s \cup \{n\})] \\ & \geq 0. \end{aligned} \quad (27)$$

With simple mathematical operations, we can obtain

$$\begin{aligned} P(\mathcal{N}_s \cup \{n\} \setminus \mathcal{N}') &= P_t(\mathcal{N}_s \cup \{n\}) - P_t(\mathcal{N}') \\ &\quad + P_r(\mathcal{N}_s \cup \{n\} \setminus \mathcal{N}') \\ &\geq P_t(\mathcal{N}_s \cup \{n\}) + P_r(\mathcal{N}_s \cup \{n\}) \\ &= P(\mathcal{N}_s \cup \{n\}). \end{aligned} \quad (28)$$

Eq.(28) violates condition (18). Therefore, we can conclude that there must exist an RRH $n' \in \mathcal{N}'$ that satisfies (19).

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