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Spectral efficiency and energy efficiency of distributed antenna systems with virtual cells

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A B S T R A C T

In this paper, we consider user centric virtual cells model in distributed antenna systems (DAS). We investigate different power allocation optimization problems with interferences in DAS with and without user centric virtual cells model, respectively. The first objective problem is maximizing spectral efficiency (SE) of the DAS with user centric virtual cells model under the constraints of the minimum SE requirements of each user equipment (UE), maximum transmit power of each remote access unit (RAU). We firstly transform this non-convex objective function into a difference of convex functions (D.C.) problem, and then we obtain the optimal solutions by using the concave-convex procedure (CCCP) algorithm. The second objective problem is maximizing energy efficiency (EE) of the DAS with user centric virtual cells model under the same constraints as the first objective problem. Firstly, we exploit fractional programming theory to obtain the equivalent objective function of the second problem with subtract form, and then transform it into a D.C. problem and use CCCP algorithm to obtain the optimal power allocation. In each part, we propose the corresponding optimal power allocation algorithm and also use similar method to obtain optimal solutions of the same optimization problems in DAS without using user centric virtual cells model. Simulation results are provided to demonstrate the effectiveness of the DAS with user centric virtual cells model, which can significantly improve the SE and the EE of the communication systems.

1. Introduction

The exponential growth of data exchange demands bring huge challenge to the designers of the next generation (5G) mobile communication systems. In order to support the ever increasing number of user equipments (UEs) with high data transmit rate, researchers are seeking new schemes to revolutionize the traditional communication technologies to satisfy the using demands in 5G [1–4]. It's well known that spectral efficiency (SE) and energy efficiency (EE) are important impact factors of evaluating the performance of wireless systems. But with the development of communication systems and the hope of internet of things (IoT) to connect all the things together, the energy consumption of communication systems is sharply increased [5]. So SE and EE are the key performance indicators (KPIs) in the future mobile networks. Therefore, it is necessary to improve the SE and EE of the communication systems to adapt the ever increasing data transmission demands.

There are many innovative approaches have been proposed, such as massive multiple-input multiple-output (MIMO) [6–9], millimeter wave (mmWave) [10], device-to-device communication (D2D) [11–14] and distributed antenna systems (DAS) [15–18] to improve the performance of communication systems. Among these technologies, DAS has drawn much attention due to its unique advantages in enhancing system performance. Different from the traditional cellular antenna systems (CAS), remote antenna units (RAUs) in the DAS are geographically distributed in the cellular and connect to a center unit (CU) by fiber [19]. Since this architecture can effectively decrease the distances between UEs and RAUs, the large path loss of signals can be effectively avoided, which directly improve the system's SE and EE [20,21]. However, it also causes severely interference among UEs and high computational complexity at the CU, which bring huge burden to the communication systems.

In order to alleviate the interference and computational complexity, we propose a user centric virtual cells model in DAS, where UEs automatically choose the most appropriate surrounding RAU as the service base station (BS). One UE is only served by a RAU by exploiting proposed choosing algorithm, which can greatly

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decrease the interference from other RAUs and also reduce the computational complexity. We investigate the problems maximizing SE and EE of the user centric virtual cells model in DAS and DAS with traditional model, respectively. We also discuss the relationship between the UE number and SE, EE of the user centric virtual cells model in DAS.

The organization of this paper is presented as follows. Section 2 introduces the DAS model and the user centric virtual cells model in DAS. In Section 3, we formulate the maximum SE optimization problems of user centric virtual cells model in DAS. We develop an optimal power allocation algorithms to solve it and use the similar algorithm to solve the same problem as above in DAS. In Section 4, after formulate the maximum EE optimization problems of DAS with user centric virtual cells model, we propose an optimal power allocation algorithm to maximize EE of the system and discuss the same problem in DAS. Section 5 presents numerical results to verify the effectiveness of the developed algorithms. We conclusion the paper in Section 6.

2. System model

2.1. DAS

We consider DAS with N RAUs and K UEs in a single cell, which RAUs are uniformly and UEs are randomly distributed in the cellular, respectively. We take the center RAU as the special CU and the system model is showed in Fig. 1. RAUs and UEs are equipped with only one antenna. We assume that all the UEs use the same spectrum to communicate and normalize the total system bandwidth into unit. The kth UE's SE of DAS can be written as

$$R_k = \log_2\left(1 + \frac{\sum_{n=1}^{N} p_{n,k}\left|h_{n,k}\right|^2}{\sum_{n=1}^{N}\sum_{j=1,j\neq k}^{K} p_{n,j}\left|h_{n,k}\right|^2 + \sigma^2}\right), \tag{1}$$

where $p_{n,k}$ denotes the transmit power of the nth RAU to the kth UE and $h_{n,k}$ is the composite fading channel between them. σ^2 represents the power of complex additive white Gaussian noise (AWGN) of UE.

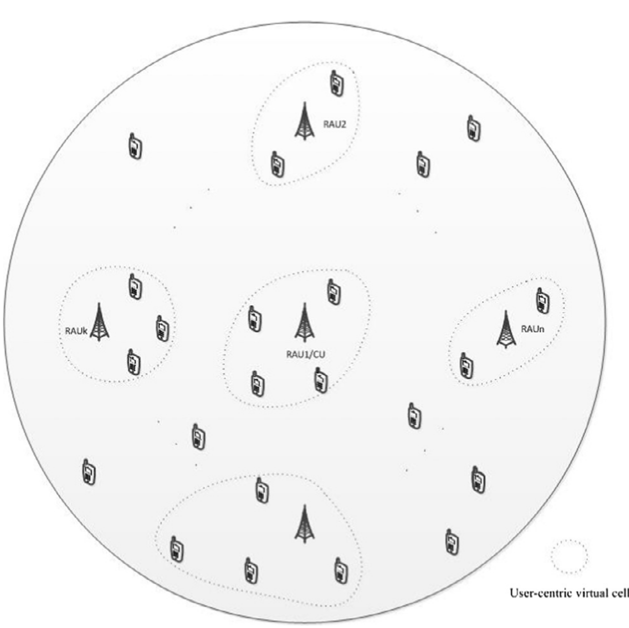

Fig. 1. User centric virtual cells model.

According to the existing works, the composite fading channel can be included as a small and a large scale fading [22], which is expressed as

$$h_{n,k} = g_{n,k} w_{n,k}, \tag{2}$$

where $g_{n,k}$ denotes the small scale fading between the nth RAU and the kth UE, which can be modeled as independent and identically distributed complex Gaussian random variables with zero mean and unit variance. $w_{n,k}$ represents the large scale fading which is independent of $g_{n,k}$. The large scale fading coefficient can be written as [23]

$$w_{n,k} = \sqrt{\frac{c s_{n,k}}{d_{n,k}^{\alpha}}}, \tag{3}$$

where c is the median of the mean path gain at a reference distance of 1 km. $d_{n,k}$ is the distance between the nth RAU and the kth UE. α is the path loss factor and $s_{n,k}$ is log-normal shadow fading variable, which means $10\log_{10} s_{n,k}$ is a zero mean Gaussian random variable with standard deviation σ_{sh} [23,24].

2.1.1. User centric virtual cells model in DAS

In DAS, the proactive communication model is usually used by each RAUs that serves all the UEs. But in this model, when all RAUs serve the kth UE, it also bring interference from the communication of RAUs to the other UEs. In this part, different from the proactive communication of DAS, we propose a user centric virtual cells model in DAS that is based on the reactive communication. With the user centric virtual cells model in DAS, UEs automatically choose the most appropriate RAU before communicating with RAUs, which can significantly decrease the interference in the communication systems and decrease the computational complexity. After the process of choosing RAU by all the UEs, the $n$the RAU only serves those UEs that choose it as the only one service BS. The detail steps of reactive communication are described in Table 1.

After the choosing algorithm, it's easy to obtain the number of served UE of the jth RAU $\left|\mathcal{B}_j\right| = B_j, j \in [1, N]$. UEs can use the reactive communication to form the user centric virtual cells model in DAS, when the ith UE served by the jth RAU, SE of the ith UE can be modeled as

$$R_i = \log_2\left(1 + \frac{p_i\left|h_{i,j}\right|^2}{\sum_{k=1,k\neq i}^{B_j} p_k\left|h_{i,j}\right|^2 + \sum_{n=1,n\neq j}^{N}\sum_{t=1}^{B_n} p_t\left|h_{i,n}\right|^2 + \sigma^2}\right), \tag{4}$$

where p_i denotes the transmit power of the transmitter of the jth RAU to the ith UE and $h_{i,j}$ is the composite fading channel between them. p_t denotes the transmit power of nth RAU to the tth UE in the nth virtual cell. $h_{i,n}$ denotes the composite fading channel between the $i$the UE and the RAU of the nth virtual.

Table 1
UE reactive communication choosing algorithm.

Algorithm 1 UE reactive communication choosing algorithm

1: Initializing the RAUs set $\mathcal{B}_i = \emptyset, i \in [1, N]$,
the UEs set $|\mathcal{K}| = K, k = 1, i = 1$.
2: **while** $i \leqslant N$ **do**
3: **while** $\mathcal{K} \neq \emptyset$ and $k \leqslant K$ **do**
UE k chooses the most appropriate RAU i
as the serving RAU (based on distance).
delete kth UE from set $k \leqslant K$ and put UE k
into set $\mathcal{B}_i$
$k = k + 1$
end
$i = i + 1$
end
4: Return $\mathcal{B}_i, i \in [1, N]$.