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Comparison of three different optimization objectives for distributed antenna systems

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ABSTRACT

In this paper, we discuss three different optimization objectives for a *distributed antenna system* (DAS). They are: (i) maximize sum-rate under the constraints of the system's minimum spectral efficiency (SE) requirements and overall transmit power of each remote access unit (RAU); (ii) minimize the overall transmit power while satisfying the system's minimum SE requirements and overall transmit power of each RAU; (iii) maximize energy efficiency (EE) while satisfying the system's minimum SE requirements and overall transmit power of each RAU. We use sub-gradient iteration approach to obtain the optimal power allocation algorithms for the maximum sum-rate and minimum the overall transmit power optimization problems. We exploit fractional programming method to investigate energy-efficient power allocation algorithm for the maximum EE optimization problem. Three efficient power allocation algorithms are developed to maximize sum-rate, minimize the overall transmit power, and maximize EE for the downlink multiuser DAS. Simulation results are provided to demonstrate the effectiveness of the developed three power allocation algorithms, and illustrate the EE performance of maximizing EE is higher than the two other optimization objectives.

1. Introduction

Distributed antenna system (DAS) is a promising systems to provide high data rate transmission and multimedia services in future wireless communications. Different from a traditional *collocated antenna system* (CAS) where all antennas of a *base station* (BS) or *central unit* (CU) are centrally collocated, *remote access units* (RAUs) in the DAS are geographically distributed in the cell and connected to a baseband processing unit via optical fibers or cables [1–6]. Since the access distance between RAUs and *mobile stations* (MSs) is reduced, the DAS has many established benefits of increasing capacity [7–9], improving coverage [10,11], and improving *energy efficiency* (EE) [12,13].

One of the key techniques to realize high data rate transmission and multimedia services in wireless networks is power allocation. There are many research works discussed about power allocation for CAS, e.g., [14,15]. However, these algorithms cannot directly applied to multiuser DAS because the multiuser DAS must consider the conditions of multiple channels between MSs and RAUs. So the power allocation in a DAS is much more complex as compared to a CAS. A distributed power allocation algorithm to maximize sum-rate in DAS has been proposed in [16], however the system's minimum SE requirements was not considered. A Pareto optimal *energy-efficient* power allocation solution has been proposed in [12] by exploiting multi-criteria optimization method for the downlink multiuser DAS. However, to the best of our knowledge, there is no publication available discussing the minimum overall transmit power while satisfying the system's minimum SE requirements and overall transmit power of each RAU. What's more, there are no papers comparing the performance between the maximum sum-rate, the minimum overall transmit power, and maximum EE optimization problems in the downlink multiuser DAS.

In this paper, we compare the following three different optimization objectives for DAS. (i) Maximize sum-rate under the constraints of the system's minimum *spectral efficiency* (SE) requirements and overall transmit power of each RAU; (ii) minimize the overall transmit power while satisfying the system's minimum SE requirements and overall transmit power of each RAU; (iii) maximize EE while satisfying the system's minimum SE requirements and overall transmit power of each RAU. For the maximum sum-rate and minimum the overall transmit power optimization problems, we use sub-gradient iteration approach to obtain the optimal power allocation algorithms. For the maximum EE optimization problem, we exploit fractional programming method to investigate *energy-efficient* power allocation algorithm. Because of non-convex nature of the EE optimization problem,

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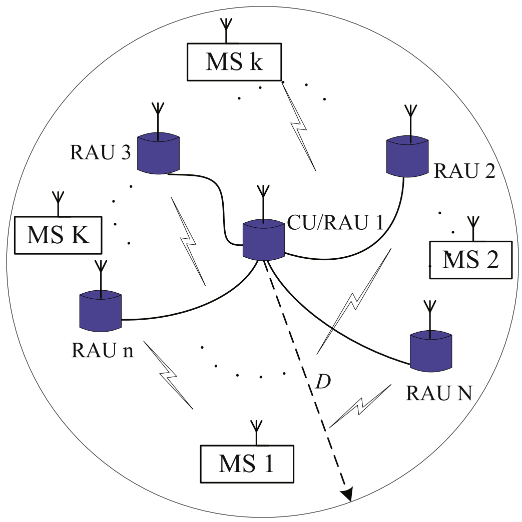

Fig. 1. Circular layout of a single cell multiuser DAS configuration.

obtaining the optimal *energy-efficient* power allocation solution is extremely computationally complex. By exploiting the fractional programming theory, we transform the non-convex objective function in fractional form into an equivalent objective function in subtractive form, which is a convex objective function. Then an optimal *energy-efficient* power allocation algorithm is developed for the downlink multiuser DAS.

The remainder of this paper is organized as follows. The DAS model is presented in Section 2. In Section 3, we first formulate the maximum *sum-rate* optimization problem, and then an optimal power allocation algorithm is developed to maximum *sum-rate*. In Section 4, after formulate the minimize overall transmit power optimization problem, and we propose an optimal power allocation algorithm to minimize the overall transmit power. In Section 5, we first describe the circuit and optical fiber power consumption, and EE models, then an optimal *energy-efficient* power allocation algorithm is developed to maximum EE. Simulation results are presented to demonstrate the effectiveness of the proposed power allocation algorithms in Section 6. Section 7 concludes the paper.

2. DAS model

Fig. 1 shows the multiuser DAS in a single cell with K MSs and N RAUs. We assume that MS and RAU are equipped with single antenna. Extending the results to multiple antennas is a very interesting topic for future research. The CU can be regarded as a special RAU and is denoted by RAU 1. The RAUs are low-power and low-cost BSs, and only equipped with *low-noise amplifiers* (LNA) and up/down converters, which are all physically connected to CU via optical fiber. We assume that the perfect *channel state information* (CSI) is available at both the transmitter and receiver side. We also assume that the channels are orthogonal, so there is no interference among MSs, which is reasonable for *Code Division Multiple Access* (CDMA), *Frequency Division Multiple Access* (FDMA), and *Time Division Multiple Access* (TDMA) systems. The data transmission rate of MS k when using the continuous rate adaptation can be expressed as [12]

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

where $p_{n,k}$ and $h_{n,k}$ denote the transmit power and the composite fading channel impulse response between the RAU n to MS k, respectively, σ_z^2 denotes the power of the complex *additive white Gaussian noise* (AWGN), $\beta = -\frac{1.2}{\ln(5P_{BER})}$ is a constant for a specific probability of bit-error rate (P_{BER}) requirement [17].

In this paper, channel frequency response, $h_{n,k}$, which includes a small and a large scale fading, in (1) is modeled as [12]

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

where $g_{n,k}$ represents the small-scale fading of a wireless channel and is an independent and identically distributed complex Gaussian random variables for different n's and k's with zero mean and unit variance [12], and $w_{n,k}$ is the large scale fading and is independent of $g_{n,k}$. The large scale fading can be written as [11,18]

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

where c is the median of the mean path gain at a reference distance $d_{n,m}$ = 1 km, $d_{n,m}$ is the distance between RAU n and MS k, α is the path loss exponent and is typically between 3 and 5, and $s_{n,k}$ is log-normal shadow fading variable, i.e., $10\log_{10} s_{n,k}$ is a zero-mean Gaussian random variable with standard deviation σ_{sh} [12,19].

3. Maximum sum-rate optimization

We will discuss the maximum *sum-rate* optimization and the corresponding optimal power allocation algorithm for DAS.

3.1. Sum-rate optimization model

The objective of maximizing *sum-rate* optimization for the downlink multiuser DAS under the constraints of satisfying the system's minimum SE requirements and overall transmit power of each RAU can be modeled as

$$\max_{\mathbf{p}} \sum_{k=1}^{K} \log_2\left(1+\beta\frac{\sum_{n=1}^{N} p_{n,k}|h_{n,k}|^2}{\sigma_z^2}\right), \tag{4}$$

$$\text{s.t.} \quad p_{n,k} \in [0, p_n^{\max}], \quad \forall k \in \{1,2,\ldots,K\}, \quad \forall n \in \{1,2,\ldots,N\}, \tag{4a}$$

$$R_k \geq R_{\min}, \quad \forall k \in \{1,2,\ldots,K\}, \tag{4b}$$

$$\sum_{k=1}^{K} p_{n,k} \leq p_n^{\max}, \quad \forall n \in \{1,2,\ldots,N\}, \tag{4c}$$

where $p_n^{\max}$ denotes the maximum transmit power of RAU n. R_k is the data transmission rate of MS k. R_{min} is the system's minimum data transmission rate or SE requirement.

We can obtain the optimal *sum-rate* power allocation solution of (4) as following, which is proved in Appendix A.

$$p_{n,k}^{opt} = \min\{T1, p_n^{\max}\}, \tag{5}$$

where

$$T1 = \left[\frac{(1+\lambda_k)}{\mu_n \ln 2} - \frac{\sigma_z^2}{\beta|h_{n,k}|^2} - \frac{\sum_{i=1, i\neq n}^{N} p_{i,k}|h_{i,k}|^2}{|h_{n,k}|^2}\right]^+. \tag{6}$$

Adopting the sub-gradient iteration approach, we can obtain the optimal *sum-rate* power allocation solution. The multipliers λ_k and μ_n can be solved by using the sub-gradient method [20] which leads to the following two Lagrange multipliers update equations:

$$\lambda_k^{(i+1)} = \left\{\lambda_k^{(i)} - \vartheta^{(i)}\left[\log_2\left(1+\beta\frac{\sum_{n=1}^{N} p_{n,m}|h_{n,m}|^2}{\sigma_z^2}\right) - R_{\min}\right]\right\}^+, \tag{7}$$