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# An energy efficient covariance optimization scheme for distributed antenna systems in broadcast channel

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ABSTRACT

In this paper, we discuss energy efficient covariance optimization scheme for the downlink multiuser distributed antenna systems in broadcast channel (DAS-BC). The energy efficiency (EE) optimization problem for DAS-BC is a non-convex optimization problem. Therefore, according to the duality between *multiple-input multiple-output* (MIMO)-BC and MIMO-*multi-access channel* (MAC), we first transform the non-convex EE optimization problem to a convex optimization problem. Then exploiting the theory of fractional programming, we convert the EE optimization problem of DAS-BC in fractional form into an equivalent optimization problem in subtractive form. Next, an optimal energy efficient covariance matrix algorithm is developed to maximize EE in DAS-BC. Through computer simulation, we demonstrate that the performance of EE and SE (spectral efficiency) for DAS-BC are better than co-located antenna systems in broadcast channel (CAS-BC).



## 1. Introduction

The research of the *distributed antenna systems* (DAS) in both academia and industry has been of interest in recent years. In the DAS, *remote access units* (RAUs) are geographically distributed in each cell, so it can bring macro-diversity gain because of the dispersion of the antennas, and it can be effective against fast fading, shadowing and path loss. It has been proved in [1] that, compared with the traditional *co-located antenna systems* (CAS), the average access distance between the RAU and *mobile stations* (MSs) in DAS is decreased. So the transmit power is also decreased and the system performance of the DAS can be improved, e.g., compared with the CAS, the DAS can increase capacity [2,3], improve coverage [1], and improve *energy efficiency* (EE) [4,5]. So the DAS techniques have been paid intensive attention and proposed as a promising candidate for future wireless communication systems.

In this paper, we investigate the EE of the downlink multiuser DAS in broadcast channel. It has been proved that the sum rate capacity of the *multiple-input multiple output* (MIMO) can be achieved by *dirty paper coding* (DPC) [6,7]. The EE of the co-located MIMO systems has been studied in [8]. In our previous work, we have studied the energy efficient power allocation for DAS in [4,5,9]. However, to the best of our knowledge, there is no publication available discussing the EE in the distributed antenna systems in broadcast channel (DAS-BC). So in this paper, we focus on the energy efficient covariance optimization scheme in the DAS-BC. We consider the composite fading channels when formulate the EE optimization, which consisting of small-scale and large-scale fading. The power consumption in the DAS-BC systems consists of four parts, which includes transmit power, the dynamic power consumption, the static power consumption, and the dissipated power consumption by the optical fiber transmission. The EE optimization problem for DAS-BC is a non-convex optimization problem. So we first convert the non-convex EE optimization problem to a convex optimization problem according to the duality between *multiple-input multiple-output* (MIMO)-BC and MIMO-*multi-access channel* (MAC) [6,7], Then exploiting the theory of the fractional programming, we convert the EE optimization problem of DAS-BC in fractional form into an equivalent optimization problem in subtractive form. Next, an optimal energy efficient covariance matrix algorithm is developed to maximize EE in DAS-BC.

This paper is organized as follows. In Section 2, we first briefly describe the DAS-BC and the power consumption models, then the EE of the DAS-BC are introduced. An optimal energy efficient covariance matrix algorithm is developed to maximize EE in DAS-BC in Section 3. Simulation results are presented to demonstrate the effectiveness of the proposed energy efficient covariance matrix algorithm in Section 4. Section 5 concludes the paper.

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## 2. System models

In this section, we will discuss the DAS-BC and the power consumption models, then we introduce the EE of the DAS-BC systems.

### 2.1. DAS-BC model

The circular layout configuration for DAS-BC is shown in Fig. 1 [1,4]. It employs $K$ MSs, $N$ antennas for each MS, and $L$ RAUs, $M$ antennas per RAU, which is referred to as $(K, N, M, L)$. When $L = 1$, it becomes a traditional co-located antenna systems. We assume that the MS is uniformly distributed in the cell and the cell shape is approximated by a circle of radius $R$ for simplicity of analysis. We also assume the bandwidth is normalized 1 Hz. Based on the above DAS-BC model, the overall received signal of the downlink multiuser DAS-BC is given by [8]

$$Y = \mathbf{H}(d)X + Z, \tag{1}$$

where $Y$ and $X$ are the $NK \times 1$ dimensional received signal vector and the $ML \times 1$ transmitted signal vector, respectively. $Z$ is the $NK \times 1$ dimensional complex AWGN vector with covariance matrix $E(ZZ^H) = \sigma_z^2 \mathbf{I}_{NK}, \mathbf{I}_{NK}$ denotes identity matrix of size $NK \times NK, \sigma_z^2$ denotes the power of the AWGN.

$$\mathbf{d} = \begin{bmatrix} d_{1,1} & d_{1,2} & \cdots & d_{1,L} \\ d_{2,1} & d_{2,2} & \cdots & d_{2,L} \\ \cdots & \cdots & \cdots & \cdots \\ d_{K,1} & d_{K,2} & \cdots & d_{K,L} \end{bmatrix}$$

denotes the distance from each MS to each RAU, where $d_{k,l}$ is the distance from the $l$th RAU to the $k$th MS.

$$\mathbf{H}(\mathbf{d}) = \begin{bmatrix} \mathbf{H}_1(d_{1,1}) & \mathbf{H}_1(d_{1,2}) & \cdots & \mathbf{H}_1(d_{1,L}) \\ \mathbf{H}_2(d_{2,1}) & \mathbf{H}_2(d_{2,2}) & \cdots & \mathbf{H}_2(d_{2,L}) \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{H}_K(d_{K,1}) & \mathbf{H}_K(d_{K,2}) & \cdots & \mathbf{H}_K(d_{K,L}) \end{bmatrix}$$

is the channel matrix, where subchannel matrix $\mathbf{H}_k(d_{k,l})$ in the composite fading channel, which is the same as [1,4].

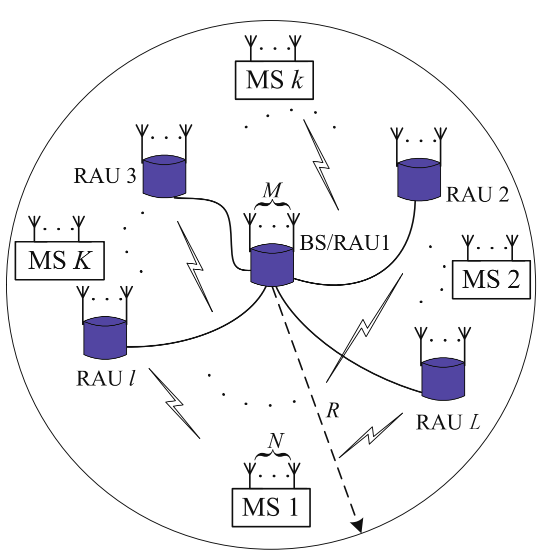


**Fig. 1.** Circular layout DAS-BC configuration.

### 2.2. Power consumption model

As we have discussed in [5], the power consumption in the distributed DAS-BC systems consists of four parts and can be expressed as,

$$P_{Total} = \frac{P_t}{\eta} + MLP_{dyn} + P_{sta} + P_o, \tag{2}$$

where $P_t$ is the overall transmit power and $\eta$ denotes the radio frequency power amplifier efficiency, $P_{dyn}, P_{sta}$, and $P_o$ are the dynamic power consumption, the static power consumption, and the dissipated power consumption by the optical fiber transmission [10], respectively.

### 2.3. EE model

As in [11,8,12], the EE of the DAS-BC systems is defined as the ratio of the capacity and the total power consumption,

$$\eta_{EE}(C) = \frac{C}{\frac{P_t}{\eta} + MLP_{dyn} + P_{sta} + P_o}, \tag{3}$$

where $C$ is the capacity of the DAS-BC systems.

## 3. EE Optimization for the DAS-BC

In this section, we will first define the EE optimization expression and derive the optimal solution of the energy efficient covariance optimization. Then an optimal energy efficient covariance optimization algorithm will be developed to maximize the EE for DAS-BC.

### 3.1. EE optimization model

From (3), the EE optimization for DAS-BC systems can be expressed as

$$\begin{aligned} \max_{\{\mathbf{\Sigma}_i\}_{i=1}^K : \mathbf{\Sigma}_i \geqslant 0} \quad & \eta_{\mathrm{EE}} = \frac{C_{\mathrm{BC}}}{\frac{\sum_{i=1}^K \mathrm{Tr}(\mathbf{\Sigma}_i)}{\eta} + MLP_{dyn} + P_{sta} + P_o} \\ \text{s. t.} \quad & \sum_{i=1}^K \mathrm{Tr}(\mathbf{\Sigma}_i) \leqslant P_{\max}, \end{aligned} \tag{4}$$

where $C_{\mathrm{BC}}$ is the capacity of the DAS-BC, SE is defined as the ratio of the sum rate capacity and the bandwidth. $P_{\max}$ denotes the maximum sum transmit power constraint, $\mathrm{Tr}(\cdot)$ denotes the trace of the matrix, $\mathbf{\Sigma}_i$ is the downlink transmit covariance matrix.

The sum rate capacity of the downlink multiuser DAS-BC can be achieved by *dirty paper coding*(DPC) [6,7]. The sum rate capacity can be written as

$$\begin{aligned} & C_{\mathrm{BC}}(\mathbf{H}_1, \mathbf{H}_2, \ldots, \mathbf{H}_K, \mathbf{\Sigma}_1, \mathbf{\Sigma}_2, \ldots, \mathbf{\Sigma}_K) \\ & = \log_2 \left| \mathbf{I}_N + \frac{1}{\sigma_n^2} \mathbf{H}_1 \mathbf{\Sigma}_1 \mathbf{H}_1^H \right| + \log_2 \frac{\left| \mathbf{I}_N + \frac{1}{\sigma_n^2} \mathbf{H}_2 (\mathbf{\Sigma}_1 + \mathbf{\Sigma}_2) \mathbf{H}_2^H \right|}{\left| \mathbf{I}_N + \frac{1}{\sigma_n^2} \mathbf{H}_2 \mathbf{\Sigma}_1 \mathbf{H}_2^H \right|} + \cdots \\ & \quad + \log_2 \frac{\left| \mathbf{I}_N + \frac{1}{\sigma_n^2} \mathbf{H}_K (\mathbf{\Sigma}_1 + \mathbf{\Sigma}_2 + \cdots + \mathbf{\Sigma}_K) \mathbf{H}_K^H \right|}{\left| \mathbf{I}_N + \frac{1}{\sigma_n^2} \mathbf{H}_K (\mathbf{\Sigma}_1 + \mathbf{\Sigma}_2 + \ldots + \mathbf{\Sigma}_{K-1}) \mathbf{H}_K^H \right|}, \end{aligned} \tag{5}$$

where $\mathbf{H}_k = [\mathbf{H}_k(d_{k,1}), \mathbf{H}_k(d_{k,2}), \ldots, \mathbf{H}_k(d_{k,L})]$, and $\mathbf{H}_k \epsilon \mathbb{C}^{N \times ML}$ is the $k$th MS's fading channel. $\mathbf{\Sigma}_k \epsilon \mathbb{C}^{ML \times ML}$ is the downlink transmit covariance matrix.

### 3.2. Energy efficient covariance optimization solution

The optimization problem of (4) is a non-convex optimization problem [5]. So, we first convert the non-convex optimization