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Interference alignment with receive antenna partitioning for SWIPT-enabled fog RANs

Yongjae Kim[a], Janghyuk Youn[b], Bang Chul Jung[c,*]

[a] Maritime ICT R&D Center, Korea Institute of Ocean Science and Technology (KIOST), Busan 49111, South Korea
[b] Satellite Anti-Jammming Group, Duksan Navcours Co., Ltd., Daejeon 34014, South Korea
[c] Department of Electrical Engineering, Chungnam National University, Daejeon 34134, South Korea

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Abstract

We propose a novel interference alignment (IA) technique with receive antenna partitioning (RAP) for simultaneous wireless information and power transfer (SWIPT)-enabled downlink fog radio access networks (F-RANs). The basic idea of the proposed scheme is to apply a generalized downlink IA for each access point (AP) and to divide receive antennas at each user into two groups for information decoding (ID) and energy harvesting (EH), respectively. With the proposed scheme, an optimal receive antenna configuration at each user is obtained to maximize the weighted sum of achievable rate and the sum of harvested energy of the network. Also we develop an antenna configuration selection algorithm to obtain near-optimal performance with low computational complexity. Through extensive computer simulations, it is shown that the proposed scheme significantly improves a rate-energy region compared with existing techniques.

Keywords: Simultaneous wireless information and power transfer (SWIPT); Receive antenna partitioning (RAP); Fog radio access networks (F-RANs); Interference alignment (IA)

1. Introduction

Recently, fog radio access networks (F-RANs) have received much attention as a promising network architecture in beyond the fifth generation (B5G) mobile communication systems to accommodate quality of service (QoS) such as spectral efficiency (SE), latency, etc. [1]. The basic idea of F-RANs is to judiciously exploit both edge and cloud computing, and thus interference problem in F-RANs can be effectively alleviated via relatively low-complexity radio resource management among small number of remote radio heads (RRHs) [2]. On the other hand, [3] proposed a concept of simultaneous wireless information and power transfer (SWIPT) that enables battery-powered IoT devices to harvest energy and receive data signal simultaneously via RF signals. Various SWIPT techniques have been investigated including [4,5]. Among them, beamforming techniques have been proposed to improve SE or energy harvesting (EH) performance of SWIPT-enabled networks [6].

Interference has been long regarded as a major performance limiting factor in conventional wireless networks, but it can be used as a useful resource for EH in SWIPT-enabled networks [7]. In particular, interference alignment (IA) techniques have been recently applied to SWIPT-enabled networks for exploiting interference as an energy harvesting source [8,9]. In [10], a novel artificial noise assisted IA scheme in SWIPT-enabled networks to improve anti-eavesdropping performance by jointly optimizing the transmit power and power splitting (PS) ratio. In [8], a receive antenna selection (RAS) technique was adopted with IA-based transmit beamforming technique in SWIPT-enabled K-user multiple-input multiple-output (MIMO) interference networks, where it was shown that RAS technique outperforms uniform PS (UPS) technique in terms of rate-energy (R-E) tradeoff. In [9], a PS optimization algorithm at each receiver was proposed with IA-based transmit beamforming technique in SWIPT-enabled K-user MIMO interference networks. However, two existing techniques [8,9] were proposed only for K-user MIMO interference networks.

* Corresponding author.
E-mail addresses: yongjaekim@kiost.ac.kr (Y. Kim), jhyoun@oneduksan.com (J. Youn), bcjung@cnu.ac.kr (B.C. Jung).

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In this paper, we propose a novel generalized downlink IA with receive antenna partitioning (GDIA-RAP) scheme for a SWIPT-enabled F-RAN consisting of a fog-access point (F-AP) with multi-antenna RRHs and multi-antenna users who has two groups of antennas: EH and information decoding (ID) antennas. The R-E tradeoff significantly depends on RAP at users, and thus the optimal antenna configuration at users is also obtained to maximize the weighted sum of achievable sum-rate and the sum of harvested energy of the network. In the GDIA-RAP scheme, the optimal antenna configuration at user can be obtained to maximize the weighted sum of rate and the sum of harvested energy by exhaustive search method. To reduce the computational complexity, we propose an antenna configuration selection (ACS) algorithm that achieves near-optimal R-E performance. Through extensive computer simulations, it is shown that the proposed algorithm significantly outperforms the existing technique in terms of R-E tradeoff in SWIPT-enabled F-RANs. Our contributions of this work are summarized as follows: (i) we propose SWIPT receiver scheme, namely GDIA-RAP, possible to be simply implemented for F-RAN where multi-antenna RRHs and multi-antenna users are considered (i.e., multi-cell multi-user MIMO); (ii) the proposed GDIA-RAP can be exploited in F-RANs to solve battery-limitation issues of IoT devices while satisfying the spectral efficiency (SE); (iii) and the proposed ACS algorithm shows the considerable improvement of R-E tradeoff region performance compared to other existing techniques through extensive simulations.

2. System model

In this paper, we consider an F-RAN which consists of an F-AP, K RRHs having M antennas and S ($S \leq M$) users with L rectennas. The rectenna is a special type of antenna, consisting of a diode and a low-pass filter, which is used for converting RF signals into a direct current (DC) signal to recharge the battery. Hereafter, rectennas and receive antennas can be used interchangeably. We assume that each RRH transmits a single data stream to each user. Also, time division duplex (TDD) system is considered. All users can harvest energy in their batteries from anonymous RF signals. At each user, received signals are exploited as information decoding (ID) and EH simultaneously, and receive antennas are divided into two groups: ID antennas and EH antennas.

The channel from jth user in ith RRH to kth RRH is denoted by $\sqrt{\beta_k^{[i,j]}}\mathbf{H}_k^{[i,j]}$, where $\beta_k^{[i,j]}$ and $\mathbf{H}_k^{[i,j]} \in \mathbb{C}^{L\times M}$ denote the large-scale path-loss gain and the small-scale fading channel matrix, respectively, from the jth user in the ith RRH to the kth RRH for $i,k \in \mathcal{K} = \{1,\ldots,K\}$ and $j \in \mathcal{S} = \{1,\ldots,S\}$. Here, $0 < \beta_k^{[i,j]} = \left(d_k^{[i,j]}\right)^{-\alpha} \leq 1$, where $\left(d_k^{[i,j]}\right)^{-\alpha} > 0$ denotes the distance from user j in RRH i to RRH k and α denotes the path-loss exponent. Also, it is assumed that each element of $\mathbf{H}_k^{[i,j]}$ is independent and identically distributed (i.i.d.) with $\mathcal{CN}(0,1)$. In addition, we assume time-invariant frequency-flat fading, i.e., the channel coefficients are constant during a transmission block and independently change to new values for every transmission block. The user j in RRH i estimates channel $\mathbf{H}_k^{[i,j]}$, $k = 1,\ldots,K$, by using pilot signals from all RRHs.

The received signal at user j in RRH i is given as follows:

$$\mathbf{y}^{[i,j]} = \underbrace{\sqrt{\beta_i^{[i,j]}P_i}\mathbf{H}_i^{[i,j]}\mathbf{V}_i\mathbf{x}_i}_{\text{desired signal}} + \underbrace{\sum_{k=1,k\neq i}^{K}\sqrt{\beta_k^{[i,j]}P_k}\mathbf{H}_k^{[i,j]}\mathbf{V}_k\mathbf{x}_k}_{\text{interference}} + \mathbf{z}^{[i,j]}, \tag{1}$$

where P_k denotes the transmit power of RRH k and $\mathbf{V}_k \in \mathbb{C}^{M\times S}$ denotes the zero-forcing (ZF) filtering-based transmit beamforming matrix. The construction of ZF-based beamforming matrices will be explained in Section 3. Also, $\mathbf{x}_k \in \mathbb{C}^{S\times 1}$ and $\mathbf{z}^{[i,j]} \in \mathbb{C}^{L\times 1}$ is the transmit signal vector and the additive white Gaussian noise (AWGN) with zero mean and the variance of N_0.

3. GDIA with receive antenna partitioning

3.1. Receive beamforming and feedback

In this work, we assume that the channel matrices between each user and all RRHs are estimated at user side. In practical systems, the channel state for downlink channel estimation can be acquired by transmitted channel state information-reference signals (CSI-RS) from RRHs [11]. Based on the estimated channel matrices, each user constructs their receive beamforming vector and feeds it back to associated RRH. Let $\mathbf{u}_{L_{ID},l}^{[i,j]} \in \mathbb{C}^{L\times 1}$ denote a unit-norm receive beamforming vector of user j in RRH i where L_{ID} is the number of ID antennas and l is an index of possible antenna configuration, i.e., $L_{ID} \in \{1,\ldots,L\}$ and $l \in \left\{1,\ldots,{}_{L}C_{L_{ID}}\right\}$. Also, we define $\bar{\mathbf{u}}_{L_{ID},l}^{[i,j]} \in \mathbb{C}^{L_{ID}\times 1}$ as an ID antenna beamforming vector which is eliminated parts of EH antennas from the receive beamforming vector $\mathbf{u}_{L_{ID},l}^{[i,j]}$.

Based on the GDIA technique that minimizes received interference, for given L_{ID} and l, the ID antenna beamforming vector is determined as follows:

$$\begin{aligned}\bar{\mathbf{u}}_{L_{ID},l}^{[i,j]} &= \arg\min_{\bar{\mathbf{u}}_{L_{ID}}} \sum_{k=1,k\neq i}^{K} \left\| \bar{\mathbf{u}}_{L_{ID}}^H \mathbf{U}_{L_{ID},l}^{[i,j]}\mathbf{H}_k^{[i,j]} \right\|^2, \\ &= \arg\min_{\bar{\mathbf{u}}_{L_{ID}}} \left\| \bar{\mathbf{u}}_{L_{ID}}^H \mathbf{G}_{L_{ID},l}^{[i,j]} \right\|^2,\end{aligned} \tag{2}$$

where $\mathbf{U}_{L_{ID},l}^{[i,j]} \in \mathbb{C}^{L_{ID}\times L}$ denotes an antenna configuration matrix and $\mathbf{G}_{L_{ID},l}^{[i,j]} \in \mathbb{C}^{(K-1)M\times L_{ID}}$ denotes an aggregated matrix.

$$\mathbf{G}_{L_{ID},l}^{[i,j]} = \left[\left(\mathbf{U}_{L_{ID},l}^{[i,j]}\mathbf{H}_1^{[i,j]}\right),\ldots,\left(\mathbf{U}_{L_{ID},l}^{[i,j]}\mathbf{H}_{i-1}^{[i,j]}\right), \left(\mathbf{U}_{L_{ID},l}^{[i,j]}\mathbf{H}_{i+1}^{[i,j]}\right),\ldots,\left(\mathbf{U}_{L_{ID},l}^{[i,j]}\mathbf{H}_K^{[i,j]}\right)\right]^H. \tag{3}$$

Let us denote the singular value decomposition (SVD) of $\mathbf{G}_{L_{ID},l}^{[i,j]}$ by

$$\mathbf{G}_{L_{ID},l}^{[i,j]} = \mathbf{\Omega}_{L_{ID},l}^{[i,j]}\mathbf{\Sigma}_{L_{ID},l}^{[i,j]}\left(\mathbf{\Phi}_{L_{ID},l}^{[i,j]}\right)^H, \tag{4}$$

where $\mathbf{\Omega}^{[i,j]}_{L_{ID},l} \in \mathbb{C}^{(K-1)M\times(K-1)M}$ and $\mathbf{\Phi}^{[i,j]}_{L_{ID},l} \in \mathbb{C}^{L_{ID}\times L_{ID}}$ are unitary matrices and $\mathbf{\Sigma}^{[i,j]}_{L_{ID},l} \in \mathbb{C}^{(K-1)M\times L_{ID}}$ is a diagonal matrix. Then, the optimal $\overline{\mathbf{u}}^{[i,j]}_{L_{ID},l}$ in (2) can be obtained as

$$\overline{\mathbf{u}}^{[i,j]}_{L_{ID},l} = \mathbf{q}^{[i,j]}_{L_{ID},l}, \tag{5}$$

where $\mathbf{q}^{[i,j]}_{L_{ID},l}$ is the last column vector of $\boldsymbol{\Phi}^{[i,j]}_{L_{ID},l}$. Consequently, the receive beamforming vector of user j in RRH i is given by

$$\mathbf{u}^{[i,j]}_{L_{ID},l} = \left(\mathbf{U}^{[i,j]}_{L_{ID},l}\right)^H \overline{\mathbf{u}}^{[i,j]}_{L_{ID},l}. \tag{6}$$

After the construction of receive beamforming vector, users send their receive beamforming vectors to associated RRH and they are transferred to the F-AP. Based on feedback information, the F-AP designs ZF filtering-based transmit beamforming matrices and chooses the optimal antenna configurations of each user, and it will be explained following sections.

3.2. Transmit beamforming

In the proposed scheme, we adopt a linear ZF filtering-based transmit beamforming at RRHs to perfectly eliminate intra-cell interference when $M \geq S$. For given L_{ID}, let us denote $\mathcal{L}(L_{ID}, i)$ is the set of antenna configurations for S users in RRH i, i.e., $\mathcal{L}(L_{ID}, i) = \left\{l^{[i,1]}_{L_{ID}}, \ldots, l^{[i,S]}_{L_{ID}}\right\}$, where $l^{[i,s]}_{L_{ID}} \in \left\{1, \ldots, {}_L C_{L_{ID}}\right\}$ for $s \in \mathcal{S}$. Based on the receive beamforming vectors and the channel matrix, RRH i construct ZF transmit beamforming matrix, $\mathbf{V}^{[i]}_{\mathcal{L}(L_{ID},i)} \in \mathbb{C}^{M\times S}$, as follows:

$$\mathbf{V}^{[i]}_{\mathcal{L}(L_{ID},i)} = \left[\mathbf{v}^{[i,1]}_{\mathcal{L}(L_{ID},i)}, \ldots, \mathbf{v}^{[i,S]}_{\mathcal{L}(L_{ID},i)}\right]$$
$$= \begin{bmatrix} \left(\mathbf{u}^{[i,1]}_{L_{ID},l^{[i,1]}_{L_{ID}}}\right)^H \mathbf{H}^{[i,1]}_i \\ \vdots \\ \left(\mathbf{u}^{[i,S]}_{L_{ID},l^{[i,S]}_{L_{ID}}}\right)^H \mathbf{H}^{[i,S]}_i \end{bmatrix}^{-1} \cdot \begin{bmatrix} \sqrt{\gamma^{[i,1]}_{L(L_{ID},i)}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sqrt{\gamma^{[i,S]}_{L(L_{ID},i)}} \end{bmatrix} \tag{7}$$

where a normalization factor $\gamma^{[i,s]}_{L(L_{ID},i)} = (1/S)/\left\|\mathbf{f}^{[i,s]}_{i,L_{ID},l^{[i,s]}_{L_{ID}}}\right\|^2$ and an effective ID channel vector $\mathbf{f}^{[i,s]}_{k,L_{ID},l} = \left(\left(\mathbf{u}^{[i,s]}_{L_{ID},l}\right)^H \mathbf{H}^{[i,s]}_k\right)^H \in \mathbb{C}^{1\times M}$.

3.3. Optimal antenna configuration

At the F-AP, the optimal antenna configuration of each user can be obtained through an exhaustive search based on feedback data from each RRH using the following weighted sum objective function is used with the weight value Δ.

$$\mathcal{L}(L_{ID})^* = \arg\max_{\mathcal{L}(L_{ID})} \Delta \cdot \sum_{i=1}^{K}\sum_{j=1}^{S} \overline{R}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}} + (1-\Delta) \cdot \sum_{i=1}^{K}\sum_{j=1}^{S} \overline{Q}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}, \tag{8}$$

where $\mathcal{L}(L_{ID}) = \{\mathcal{L}(L_{ID},1), \ldots, \mathcal{L}(L_{ID},K)\} = \left\{l^{[1,1]}_{L_{ID}}, l^{[1,2]}_{L_{ID}}, \ldots, l^{[K,S]}_{L_{ID}}\right\}$ and $l^{[i,j]}_{L_{ID}} \in \left\{1, \ldots, {}_L C_{L_{ID}}\right\}$ for $i \in \mathcal{K}$ and $j \in \mathcal{S}$. Also, $\overline{R}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}$ and $\overline{Q}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}$ denote the normalized achievable data rate and normalized harvested energy of user j in RRH i for given the number of ID antennas L_{ID} and antenna configuration index $l^{[i,j]}_{L_{ID}}$, respectively. The achievable data rate and harvested energy are obtained as follows:

$$R^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}} = \log_2\left(1 + \frac{\beta^{[i,j]}_i P_i \gamma^{[i,j]}_{\mathcal{L}(L_{ID},i)} \left|x^{[i,j]}\right|^2}{\left|\left(\mathbf{u}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}\right)^H \mathbf{z}^{[i,j]}\right|^2 + I^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}}\right), \tag{9}$$

$$Q^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}} = \left\|\sum_{k=1}^{K} \sqrt{\beta^{[i,j]}_k P_k} \widetilde{\mathbf{U}}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}} \mathbf{H}^{[i,j]}_k \mathbf{V}^{[k]}_{\mathcal{L}(L_{ID},k)} \mathbf{x}_k\right\|^2, \tag{10}$$

where $I^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}} = \sum_{k=1,k\neq i}^{K} \beta^{[i,j]}_k P_k \left|\mathbf{f}^{[i,j]}_{k,L_{ID},l^{[i,j]}_{L_{ID}}} \mathbf{V}^{[k]}_{\mathcal{L}(L_{ID},k)} \mathbf{x}_k\right|^2$. The normalized data rate and normalized harvested energy can be determined based on (9) and (10), respectively. In (10), $\widetilde{\mathbf{U}}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}} \in \mathbb{C}^{(L-L_{ID})\times L}$ denotes an indicator matrix which shows indices of EH antennas. $\widetilde{\mathbf{U}}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}$ can be easily obtained from the following relation: $\boldsymbol{\Pi}_L = \left[\mathbf{U}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}, \widetilde{\mathbf{U}}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}\right]$ and $\left(\mathbf{U}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}\right)^H \mathbf{U}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}} + \left(\widetilde{\mathbf{U}}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}}\right)^H \widetilde{\mathbf{U}}^{[i,j]}_{L_{ID},l^{[i,j]}_{L_{ID}}} = \mathbf{I}$, where $\boldsymbol{\Pi}_L$ denotes an arbitrary $L \times L$ permutation matrix. Since the AWGN and additional conversion noise are much smaller than the desired signals and interference signals in practice, thus they can be omitted in (10).

In each RRH, achievable data rate and normalized harvested energy of each user are calculated based on feedback information from each user according to the antenna configuration. Then, the F-AP finds the optimal solution of (8) based on received weighted sum of achievable rate and the sum of harvested energy from RRHs. Since RRHs transmit the scalar values to the F-AP, there is no burden for feedback. Furthermore, the proposed technique does not overburden the F-RANs and it can be easily used for the network even if limited backhaul is assumed, because there are no many computational tasks and the number of RRHs to be served by a F-AP in F-RANs is remarkably less than that of cloud-RAN.

3.4. Antenna configuration selection algorithm

To reduce computational complexity of exhaustive search for optimal antenna configuration, we develop an ACS

Algorithm 1: ACS algorithm

Input: $\mathbf{H}_k^{[i,j]}$ for $i, k \in \mathcal{K}$ and $j \in \mathcal{S}$
Output: asdf
Initialize $\mathbf{u}^{[i,j]} = \frac{1}{\sqrt{L}}\mathbf{1}_{1\times L}$ for $i \in \mathcal{K}$ and $j \in \mathcal{S}$. **for** $iter = 1$ *to iterMax* **do**
  for $i = 1$ *to* K **do**
    for $j = 1$ *to* S **do**
      for $L_{ID} = 1$ *to* L **do**
        for $l = 1$ *to* ${}_{L_{ID}}C_L$ **do**
          if $iter > 1$ **then**
            Update $\mathbf{u}_{L_{ID},l}^{[i,j]}$ based on (2).
          end
          Update $R_{L_{ID},l}^{[i,j]}$ and $Q_{L_{ID},l}^{[i,j]}$ based on (9) and (10), respectively.
        end
      end
      $(L_{ID}^*, l^*) = \arg\max_{L_{ID},l} \left(\Delta \overline{R}_{L_{ID},l}^{[i,j]} + (1-\Delta)\,\overline{Q}_{L_{ID},l}^{[i,j]}\right).$
      Update $\mathbf{u}^{[i,j]} = \mathbf{u}_{L_{ID}^*,l^*}^{[i,j]}$.
    end
    Update $\mathbf{V}^{[i]}$ based on (7).
  end
end

algorithm that achieve near-optimal R-E tradeoff performance with low complexity. Firstly, the user selects a beamforming vector that maximizes the weighted sum of the achievable data rate and the harvested energy for all possible antenna configurations in turn, after all users' receive beamforming vectors are initialized to uniform beamforming. This procedure is repeated to a predefined number of iterations of outer loop, $iterMax$. Detail of the algorithm is described in Algorithm 1.

4. Simulation results

In this section, we evaluate the R-E region of proposed GDIA-RAP scheme with conventional schemes such as RAS [8] scheme and ZF-RAS scheme. In the RAS scheme, a simple antenna selection method was exploited at the receiver, and the concept of IA was adopted at the transmitter. Therefore, the receive beamforming was constructed from an arbitrary permutation matrix and the transmit beamforming was designed to minimize the leakage interference, as (2)–(6). For more details on RAS scheme, refer to [8]. The ZF-RAS is an extended RAS technique in which receive antenna is selected in the receiver and ZF-based transmit beamforming is used in each RRH to eliminate the intra-cell interference as the GDIA-RAP. Then, both conventional schemes use the weighted sum objective function (8) to determine the optimal antenna configurations of all users. For simplicity, we assume that $\beta_k^{[i,j]} = 0.8$, $\forall i, k \in \mathcal{K}$, and $\forall j \in \mathcal{S}$. Also, the transmit power of RRH is set to be 1 W, i.e., $P_k = 1$ W, $\forall k \in \mathcal{K}$.

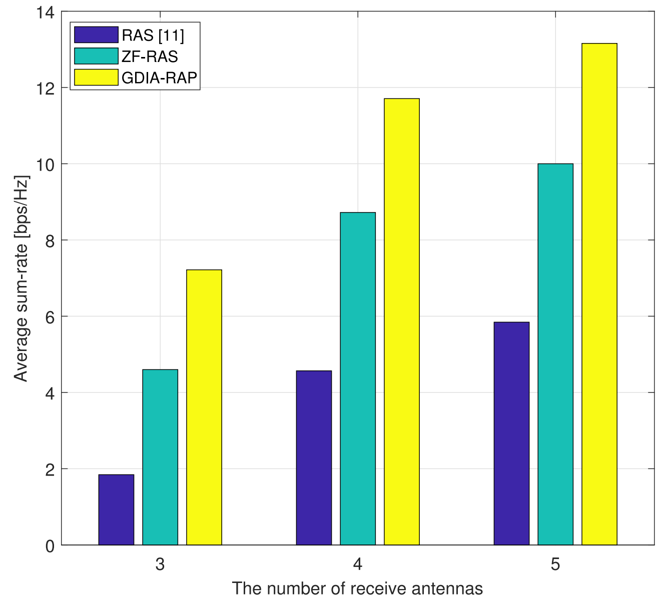

Fig. 1. Average sum-rate comparison when $K = 2$, $M = 3$, $L_{ID} = 2$, $S = 2$, SNR = 10 dB, and $Q_{req} = 0.3$.

Fig. 1 illustrates the average sum-rate according to the number of receive antennas for given required harvested energy when $K = 2$, $M = 3$, $L_{ID} = 2$, $S = 2$, SNR = 10 dB, and $Q_{req} = 0.3$, where Q_{req} denotes required harvested energy by normalized maximum harvested energy. The maximum harvested energy can be obtained when $L_{ID} = 0$, i.e., all antennas are used for EH. In all schemes, the average achievable sum-rate is improved as the number of receive antennas increases. Also, for given required harvested energy, the GDIA-RAP shows the highest performance in terms of achievable sum-rate.

Fig. 2 shows the R-E region when $K = 2$, $M = 3$, $L = 4$, $S = 2$, and SNR = 10 dB. The R-E regions of GDIA-RAP and conventional schemes according to the change in Δ with different value of L_{ID} are compared. When $L_{ID} = 1$, the performance of GDIA-RAP and ZF-RAS schemes are exactly same, since there is no difference between the receive beamforming vectors of both schemes. When $L_{ID} = 4$, the achievable data rate is the highest for the GDIA-RAP, while that of RAS and ZF-RAS schemes show the lowest performance because antenna selection diversity gain is not available in RAS scheme. In all values of L_{ID}, the RAS scheme shows the smallest R-E region, and the GDIA-RAP with the value of L_{ID}^*, which denotes the optimal antenna configuration is adopted when L_{ID} is not fixed, has the widest R-E region. Also, the proposed ACS algorithm shows the near-optimal R-E performance with the low computational complexity.

5. Conclusion

We proposed a novel generalized downlink interference alignment with receive antenna partitioning (GDIA-RAP) scheme for SWIPT-enabled fog radio access networks. In

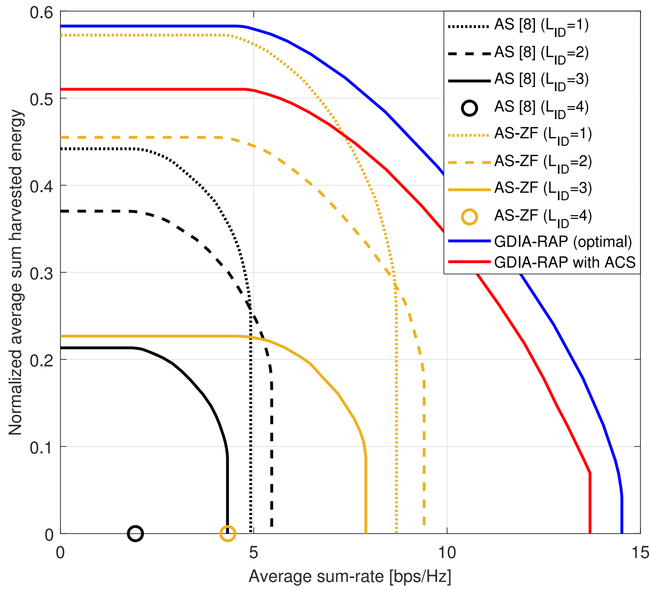

Fig. 2. R-E region when $K = 2$, $M = 3$, $L = 4$, $S = 2$, and SNR = 10 dB.

the scheme, the optimal RAP configuration was obtained to maximize the rate-energy (R-E) tradeoff region. Also, an antenna configuration selection algorithm was developed to obtain near-optimal R-E performance with low computational complexity. Extensive simulations showed that the proposed GDIA-RAP significantly improves the R-E region compared with the conventional scheme regardless of the number of antennas used for information decoding. We leave the joint power and antenna partitioning technique at receive antennas for a further study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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