Beamforming Design in SWIPT-Based Joint Multicast-Unicast mmWave Massive MIMO with Lens-Antenna Array

Wanming Hao, *Member, IEEE*, Gangcan Sun, Zheng Chu, *Member, IEEE*, Pei Xiao, *Senior Member, IEEE*, Zhengyu Zhu, Shouyi Yang and Rahim Tafazolli, *Senior Member, IEEE*

Abstract—In this letter, we study the beamforming design in a lens-antenna array-based joint multicast-unicast millimeter wave massive MIMO system, where the simultaneous wireless information and power transfer at users is considered. First, we develop a beam selection scheme based on the structure of the lens-antenna array and then, the zero forcing precoding is adopted to cancel the inter-unicast interference among users. Next, we formulate a sum rate maximization problem by jointly optimizing the unicast power, multicast beamforming and power splitting ratio. Meanwhile, the maximum transmit power constraint for the base station and the minimum harvested energy for each user are imposed. By employing the successive convex approximation technique, we transform the original optimization problem into a convex one, and propose an iterative algorithm to solve it. Finally, simulation results are conducted to verify the effectiveness of the proposed schemes.

Index Terms—SWIPT, lens-antenna array, massive MIMO, mmWave, multicast, unicast.

I. INTRODUCTION

Millimeter wave (MmWave), owning the ultra wide bandwidth, is as an effective technique to satisfy the huge capacity demand for future wireless communications [1]. Furthermore, more antennas can be mounted within the limited physical space due to the smaller wavelengths at mmWave. However, to reduce the hardware cost and energy consumption, the hybrid beamforming structure is usually adopted in practice. For example, by employing the discrete lens array, the conventional spatial channel can be transformed into the beamspace channel [2]. Since a single radio frequency (RF) chain can control one beam, a small number of beams can be selected with negligible performance loss due to the sparse beamspace channel in mmWave, reducing the number of RF chains [3].

In addition, to improve the energy efficiency (EE), the simultaneous wireless information and power transfer (SWIPT), i.e.,

both information and energy can be extracted from the same received RF signals, has also attracted great interests [4]–[7]. [4] investigated the power allocation and the power-splitting ratio optimization problem to maximize secure rate. [5] studied the joint optimal power allocation and power splitting ratio to maximize the minimum signal to interference plus noise ratio (SINR) of all users. In [6], the authors investigated the EE maximization problem by jointly optimizing the beamforming and power splitting ratio. Then, a low-complexity zero forcing (ZF) beamforming algorithm is proposed. The authors in [7] first analyzed the performance of the proposed signal space alignment SWIPT scheme, and then investigated the optimal power splitting ratio to maximize the achievable sum rate.

The future cellular network can potentially support a variety of services. Furthermore, the demand for the multicast content deliver service is increasing, as multiple users who have subscribed to the same service intend to receive the same content [8]. Taking the object-based broadcasting scenario as an example, each user wants to simultaneously receive both common message over multicast and private message over unicast. The authors in [9] proposed a suboptimal low-complexity hybrid ZF beamforming algorithm for the joint multicast-unicast mmWave system. [10] studied the joint base station (BS) clustering and beamforming design for the NOMA multicast and unicast transmission with limited backhaul capacity. Then, a low-complexity algorithm was proposed to solve the formulated weighted sum rate maximization problem. In [11], the authors proposed an efficient subcarrier and power allocation scheme to maximize the minimum SINR in a joint multicast-unicast OFDMA system. The authors in [12] developed an efficient antenna selection and hybrid beamforming algorithm to minimize the transmit power for the massive MIMO multiple group multicast transmission system.

Unlike the previous work, in this paper, we investigate the beamforming design problem in a mmWave massive MIMO system with lens-array antenna structure, where each user can simultaneously obtains information and energy from the received signals. In addition, there are two new contributions in comparison with [12], *i*) we consider the lens-antenna array structure at the BS and thus beam selection is needed, *ii*) We consider the joint multicast-unicast transmission, which is more challenging in terms of beam design in comparison to the multicast-only transmission considered in [12]. Based on this, we firstly develop a beam selection scheme. Next, the ZF precoding technique is applied to cancel the inter-unicast interference. To this end, we formulate a joint unicast power allocation, multicast beamforming and power splitting ratio

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W. Hao, Z. Chu, P. Xiao, and R. Tafazolli are with the 5G Innovation Center, Institute of Communication Systems, University of Surrey, Guildford GU2 7XH, U.K., and W. Hao is also with the School of Information Engineering and Institute of Industrial Technology, Zhengzhou University, Zhengzhou 450001, China (Email: {w.hao, zheng.chu, p.xiao, r.tafazolli}@surrey.ac.uk).

G. Sun, Z. Zhu and S. Yang are with the School of Information Engineering and Institute of Industrial Technology, Zhengzhou University, Zhengzhou 450001, China (E-mail: iegcsun@zzu.edu.cn, zhuzhengyu6@gmail.com, iesyyang@zzu.edu.cn).

allocation optimization problem to maximize the sum rate of the system. Meanwhile, the minimum harvested energy for each user is considered, and the maximum transmit power at the BS is imposed. Due to its difficulty to directly solve the formulated nonconvex optimization problem, by variables substitution and successive convex approximation technique, we transform the original optimization problem into a convex one and propose an iterative algorithm to solve the formulated problem.

Notations: Following notations are used throughout this letter: $(\cdot)^H$, $(\cdot)^T$ and $(\cdot)^*$ denote Hermitian transpose, transpose and conjugate, respectively, $\|\cdot\|$ represents the Frobenius norm, $\text{Re}(\cdot)$ denotes real number operation.

II. SYSTEM MODEL

We consider a joint multicast-unicast mmWave massive MIMO system with SWIPT, where K single-antenna users simultaneously receive the private and common data streams. The BS is equipped with N antennas and N_{RF} ($N_{\text{RF}} \geq K$) RF chains based on the lens-antenna array structure. The received signal by the k th user can be expressed as

$$y_k = [\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|} \mathbf{v}_k x_k + [\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|} \mathbf{v}_0 x_0 + [\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|} \sum_{i \neq k}^K \mathbf{v}_i x_i + n_k, \quad (1)$$

where $\mathbf{h}_k \in \mathbb{C}^{1 \times N}$, x_k and x_0 , respectively, denote the downlink channel, private signal and common signal for the k th user. $\mathbf{v}_k \in \mathbb{C}^{N_{\text{RF}} \times 1}$ and $\mathbf{v}_0 \in \mathbb{C}^{N_{\text{RF}} \times 1}$ are the precoding for x_k and x_0 , respectively. n_k is an independent and identically distributed (i.i.d.) additive white Gaussian noise (AWGN) defined as $\mathcal{CN}(0, \delta_0^2)$. $[\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|}$ denotes the selection of $|\mathcal{L}|$ elements from $\mathbf{h}_k \mathbf{F}$ and $\mathcal{L}$ is the set of index for selected elements, where $|\mathcal{L}| = N_{\text{RF}}$. $\mathbf{F} \in \mathbb{C}^{N \times N}$ is the spatial Fourier transform matrix due to the use of the lens-antenna array, which includes a group of orthogonal basis as [13], $\mathbf{F} = [\mathbf{a}(\theta_1), \dots, \mathbf{a}(\theta_N)]$, where $\mathbf{a}(\theta_n)$, $n = 1, \dots, N$, represents a steering vector denoted as $\mathbf{a}(\theta_n) = \frac{1}{\sqrt{N}} [e^{-j2\pi\theta_n z}]_{z \in \mathcal{J}(N)}$, where $\theta_n = \frac{1}{N} (n - \frac{(N+1)}{2})$, $n = 1, \dots, N$ and $\mathcal{J}(N) = \{m - (N+1)/2, m = 1, \dots, N\}$.

With a power splitter, the received signal can be split into the information decoder (ID) and energy harvester (EH) [14]. We assume that the ρ_k portion of received signal power is divided into the ID, and the remaining $1 - \rho_k$ portion of the received signal power is transformed into the EH. As a result, the received signal for EH at the k th user can be represented as

$$y_k^{\text{EH}} = \sqrt{1 - \rho_k} y_k, \quad (2)$$

and the harvested energy is

$$E_k = \xi(1 - \rho_k) \left(\sum_{i=0}^K |[\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|} \mathbf{v}_i|^2 + \delta_0^2 \right), \quad (3)$$

where $\xi \in (0, 1]$ is the energy conversion efficiency at each user. Meanwhile, the received signal for the ID can be written as

$$y_k^{\text{ID}} = \sqrt{\rho_k} y_k + n'_k, \quad (4)$$

where $n'_k \sim \mathcal{CN}(0, \delta_1^2)$ is the addition noise caused by the ID.

¹In addition, it is possible to set $|\mathcal{L}| < N_{\text{RF}}$, namely some of RF chains are inactive. From the perspective of the EE, it may be better to inactivate some RF chains to save circuit power consumption. However, from the perspective of the spectrum efficiency (SE), activating all RF chains is optimal. Therefore, different objections have the different schemes. In this paper, we mainly focus on the SE maximization, therefore we focus on the case when all RF chains are activated ($|\mathcal{L}| = N_{\text{RF}}$).

Algorithm 1: The Proposed Beam Selection Scheme

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1 Initialize  $\mathcal{L} = \{\emptyset\}$ ,  $\mathcal{L}' = \{1, \dots, N\}$ ,  $Q_{\max} = N_{\text{RF}}$ .
2 while  $Q_{\max} > 0$  do
3   for  $k=1 : K$  do
4      $\{s\} = \arg \max_{s \in \mathcal{L}'} \text{abs}(\mathbf{h}_k \mathbf{F})$ ,  $\mathcal{L} = \mathcal{L} \cup \{s\}$ ,  $\mathcal{L}' = \mathcal{L}' / \{s\}$ .
5      $Q_{\max} \leftarrow Q_{\max} - 1$ .
6     if  $Q_{\max} = 0$  then
7       Break;
8     end if
9   end for
10 end while
11 where  $\text{abs}(\mathbf{h}_k \mathbf{F})$  denotes the absolute value of each element in
    the vector  $\mathbf{h}_k \mathbf{F}$ .

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By using the principle of layered division multiplexing (LDM) [10], the successive interference cancellation (SIC) can be used to decode the private signals. In general, the decoding order of the multicast and unicast messages at each receiver can be optimized according to the instantaneous channel condition. In this work, since multicast message is intended for multiple users and should have a higher priority, each user firstly decodes the common signal and treats all unicast signals as noise and then, decodes the private signal by canceling the decoded common signal. To this end, the achievable SINR for the common signal at the k th user can be expressed as

$$\gamma_k^0 = \frac{\rho_k |[\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|} \mathbf{v}_0|^2}{\rho_k (\sum_{i=1}^K |[\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|} \mathbf{v}_i|^2 + \delta_0^2) + \delta_1^2}, \quad (5)$$

and the SINR for the private signal can be written as

$$\gamma_k = \frac{\rho_k |[\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|} \mathbf{v}_k|^2}{\rho_k (\sum_{i \neq k}^K |[\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|} \mathbf{v}_i|^2 + \delta_0^2) + \delta_1^2}. \quad (6)$$

Next, we analyze the characteristic of the mmWave communications, in which the Saleh-Valenzuela channel model is commonly used [13], and $\mathbf{h}_k$ can be represented as

$$\mathbf{h}_k = \mu_k^{(0)} \mathbf{a}^H(\hat{\theta}_k^{(0)}) + \sum_{l=1}^L \mu_k^{(l)} \mathbf{a}^H(\hat{\theta}_k^{(l)}), \quad (7)$$

where $\mu_k^{(0)} \mathbf{a}(\hat{\theta}_k^{(0)})$ is the line of sight (LoS) component from the BS to the k th user, in which $\mu_k^{(0)}$ means the complex gain and $\mathbf{a}(\hat{\theta}_k^{(0)})$ is the spatial direction. In addition, $\mu_k^{(l)} \mathbf{a}(\hat{\theta}_k^{(l)})$ denotes the l th non LoS (NLoS) path from the BS to the k th user, and L denotes the total number of NLoS paths. We define the spatial direction as $\hat{\theta}_k = \frac{d}{\lambda} \sin(\phi_k)$, where d denotes the antenna space, λ represents the signal wavelength and $\phi_k \in [-\frac{\pi}{2}, \frac{\pi}{2}]$ is the physical direction. Here, we assume that perfect channel state information can be obtained via channel estimation.

III. BEAM SELECTION AND PRECODING DESIGN

First, we need to decide $\{\mathcal{L}\}$, namely the beam selection at selection network. In fact, the number of dominant scatters is very limited in mmWave communications so that L is much smaller than the number of beams N . In this case, the number of dominant elements of $\mathbf{h}_k \mathbf{F}$ is much smaller than N , namely $\mathbf{h}_k \mathbf{F}$ has a sparse structure and most of elements are close to zero. Based on this, we can only select the strongest beams for users to minimize the performance loss. Meanwhile, to guarantee the users' fairness, we require that K users only select one strongest

Algorithm 2: The Proposed Iterative Algorithm

1 **Initialize** $\{\rho_k^{(n)}\}, \{\alpha_k^{(n)}\}, \{\beta_k^{(n)}\}, \{\mathbf{v}_0^{(n)}\}$, $n = 0$, the maximum iteration times $T_{\max}$, a small constant ϵ .
 2 **repeat**
 3 Update $n \leftarrow n + 1$.
 4 Solve the optimization problem (18) and obtain the optimal solution $\{\rho_k^{(n)}\}, \{t_k^{(n)}\}, \{\alpha_k^{(n)}\}, \{\beta_k^{(n)}\}, t_0^{(n)}, \{p_k^{(n)}\}, \{\mathbf{v}_0^{(n)}\}$.
 5 **until** $n = T_{\max}$ or $\|\mathbf{\Omega}^{(n+1)} - \mathbf{\Omega}^{(n)}\| \leq \epsilon$;
 6 where $\mathbf{\Omega}^{(n)} = \{\{\rho_k^{(n)}\}, \{t_k^{(n)}\}, \{\alpha_k^{(n)}\}, \{\beta_k^{(n)}\}, t_0^{(n)}, \{p_k^{(n)}\}, \{\mathbf{v}_0^{(n)}\}\}$ is the solution set of problem (18) at the n th iteration.

beam each time. If user k and user k' have the same strongest beam, to avoid the serious multi-user interference, we select next strong beam for user k' from $\mathbf{h}_k \mathbf{F}$. After finishing one loop, K users continue to select the strongest beams one by one from the remained beams, and the above process is repeated until N_{RF} beams are selected. We summarize the above beam selection scheme in Algorithm 1.

After obtaining $\{\mathcal{L}\}$, we define the equivalent channel as $\hat{\mathbf{h}}_k = [\mathbf{h}_k \mathbf{F}]_{1 \times |\mathcal{L}|}$ ($\hat{\mathbf{h}}_k \in \mathbb{C}^{1 \times N_{\text{RF}}}$). To cancel the inter-unicast interference, the low-complexity ZF precoding is adopted. Let $\hat{\mathbf{H}} = [\hat{\mathbf{h}}_1^T, \dots, \hat{\mathbf{h}}_K^T]^T$, which includes the equivalent downlink channel from the BS to K users. Then, the precoding matrix can be written as $\mathbf{V} = \hat{\mathbf{H}}^H (\hat{\mathbf{H}} \hat{\mathbf{H}}^H)^{-1}$, and the digital precoding for the k th user can be expressed as $\mathbf{v}_k = \mathbf{V}_k / \|\mathbf{V}_k\|$, where $\mathbf{V}_k$ denotes the k th column of $\mathbf{V}$. After applying ZF precoding, the user's SINR can be rewritten as

$$\Upsilon_k^0 = \frac{\rho_k |\hat{\mathbf{h}}_k \mathbf{v}_0|^2}{\rho_k (p_k |\hat{\mathbf{h}}_k \mathbf{v}_k|^2 + \delta_0^2) + \delta_1^2}, \quad \Upsilon_k = \frac{\rho_k p_k |\hat{\mathbf{h}}_k \mathbf{v}_k|^2}{\rho_k \delta_0^2 + \delta_1^2}, \quad (8)$$

where p_k stands for the unicast transmit power for the k th user. Finally, we formulate the following optimization problem

$$\max_{\{\rho_k\}, \{p_k\}, \mathbf{v}_0} \min_{\forall k} \{\log_2(1 + \Upsilon_k^0)\} + \sum_{k=1}^K \log_2(1 + \Upsilon_k) \quad (9a)$$

$$\text{s.t. } \xi(1 - \rho_k) (p_k |\hat{\mathbf{h}}_k \mathbf{v}_k|^2 + |\hat{\mathbf{h}}_k \mathbf{v}_0|^2 + \delta_0^2) \geq E_k^{\min}, \quad (9b)$$

$$\|\mathbf{v}_0\|^2 + \sum_{k=1}^K p_k \leq P_{\max}, \quad (9c)$$

where (9b) denotes the minimum requirement of harvested energy for each user, and (9c) is the total transmit power constraint for the BS. However, the original problem is intractable. Next, by introducing new variables t_0 , t_k , α_k and β_k , (9) can be equivalently transformed into the following problem

$$\max_{\{\rho_k\}, \{t_k\}, \{\alpha_k\}, \{\beta_k\}, t_0, \{p_k\}, \mathbf{v}_0} \sum_{k=0}^K \log_2(1 + t_k) \quad (10a)$$

$$\text{s.t. } \frac{|\hat{\mathbf{h}}_k \mathbf{v}_0|^2}{p_k |\hat{\mathbf{h}}_k \mathbf{v}_k|^2 + \delta_0^2 + \alpha_k \delta_1^2} \geq t_0, \quad (10b)$$

$$\frac{|\hat{\mathbf{h}}_k \mathbf{v}_k|^2}{\delta_1^2} p_k - \frac{\delta_0^2}{\delta_1} t_k \geq \alpha_k t_k, \quad (10c)$$

$$p_k |\hat{\mathbf{h}}_k \mathbf{v}_k|^2 + |\hat{\mathbf{h}}_k \mathbf{v}_0|^2 + \delta_0^2 \geq \beta_k, \quad (10d)$$

$$\alpha_k \geq \frac{1}{\rho_k}, \quad \beta_k \geq \frac{E_k^{\min}}{\xi(1 - \rho_k)}, \quad (10e)$$

$$\|\mathbf{v}_0\|^2 + \sum_{k=1}^K p_k \leq P_{\max}. \quad (10f)$$

Due to the nonconvex constraints (10b)-(10e), (10) is a nonconvex optimization problem. Next, we will transform

all of them into the convex constraints by proposing some approximation schemes. First, we observe that the left side of (10b) is a quadratic-over-affine function, which is joint convex with variables $\{\mathbf{v}_0, p_k, \rho_k\}$. Accordingly, the first order Taylor approximation can be adopted, namely

$$\frac{|\hat{\mathbf{h}}_k \mathbf{v}_0|^2}{p_k |\hat{\mathbf{h}}_k \mathbf{v}_k|^2 + \delta_0^2 + \alpha_k \delta_1^2} \geq \frac{2(\hat{\mathbf{h}}_k \mathbf{v}_0^{(n)})^*}{\Xi_k^{(n)}} \hat{\mathbf{h}}_k \mathbf{v}_0 - \frac{|\hat{\mathbf{h}}_k \mathbf{v}_0^{(n)}|^2}{(\Xi_k^{(n)})^2} \Xi_k, \quad (11)$$

where $\Xi_k = p_k |\hat{\mathbf{h}}_k \mathbf{v}_k|^2 + \delta_0^2 + \alpha_k \delta_1^2$ and $\Xi_k^{(n)} = p_k^{(n)} |\hat{\mathbf{h}}_k \mathbf{v}_k|^2 + \delta_0^2 + \alpha_k^{(n)} \delta_1^2$. In addition, $\mathbf{v}_0^{(n)}$, $p_k^{(n)}$ and $\alpha_k^{(n)}$ denote the value of $\mathbf{v}_0$, p_k and α_k at the n th iteration, respectively. Accordingly, (10b) can be expressed by the following convex constraint

$$\frac{2(\hat{\mathbf{h}}_k \mathbf{v}_0^{(n)})^*}{\Xi_k^{(n)}} \hat{\mathbf{h}}_k \mathbf{v}_0 - \frac{|\hat{\mathbf{h}}_k \mathbf{v}_0^{(n)}|^2}{(\Xi_k^{(n)})^2} \Xi_k \geq t_0. \quad (12)$$

For (10c), we obtain the upper bound of $\alpha_k t_k$ with [15]

$$\frac{t_k^{(n)}}{2\alpha_k^{(n)}} \alpha_k^2 + \frac{\alpha_k^{(n)}}{2t_k^{(n)}} t_k^2 \geq \alpha_k t_k, \quad (13)$$

where $t_k^{(n)}$ and $\alpha_k^{(n)}$, respectively, are the value of t_k and α_k at the n th iteration. Subsequently, (10c) can be transformed into the following convex constraint

$$\frac{|\hat{\mathbf{h}}_k \mathbf{v}_k|^2}{\delta_1^2} p_k - \frac{\delta_0^2}{\delta_1^2} t_k \geq \frac{t_k^{(n)}}{2\alpha_k^{(n)}} \alpha_k^2 + \frac{\alpha_k^{(n)}}{2t_k^{(n)}} t_k^2. \quad (14)$$

Next, let $\{\hat{\mathbf{v}}_0\}$ be a feasible solution $\mathbf{v}_0 \triangleq \hat{\mathbf{v}}_0 + \Delta \mathbf{v}_0$, we have

$$|\hat{\mathbf{h}}_k \mathbf{v}_0|^2 = (\hat{\mathbf{v}}_0 + \Delta \mathbf{v}_0)^H \hat{\mathbf{H}}_k (\hat{\mathbf{v}}_0 + \Delta \mathbf{v}_0) \geq 2\text{Re}\{(\hat{\mathbf{v}}_0)^H \hat{\mathbf{H}}_k \Delta \mathbf{v}_0\} + (\hat{\mathbf{v}}_0)^H \hat{\mathbf{H}}_k \hat{\mathbf{v}}_0, \quad (15)$$

where $\hat{\mathbf{H}}_k = \hat{\mathbf{h}}_k^H \hat{\mathbf{h}}_k$. As a result, (10d) can be transformed into a convex constraint as

$$p_k |\hat{\mathbf{h}}_k \mathbf{v}_k|^2 + 2\text{Re}\{(\hat{\mathbf{v}}_0)^H \hat{\mathbf{H}}_k (\mathbf{v}_0 - \hat{\mathbf{v}}_0)\} + (\hat{\mathbf{v}}_0)^H \hat{\mathbf{H}}_k \hat{\mathbf{v}}_0 + \delta_0^2 \geq \beta_k. \quad (16)$$

Finally, we apply the Schur complement lemma [2], (10e) can also be transformed into the following convex constraints

$$\begin{bmatrix} \alpha_k & 1 \\ 1 & \rho_k \end{bmatrix} \geq \mathbf{0}, \quad \text{and} \quad \begin{bmatrix} \beta_k & \sqrt{E_k^{\min}} \\ \sqrt{E_k^{\min}} & \xi(1 - \rho_k) \end{bmatrix} \geq \mathbf{0}. \quad (17)$$

To this end, we need to iteratively solve the following convex optimization problem.

$$\max_{\{\rho_k\}, \{t_k\}, \{\alpha_k\}, \{\beta_k\}, t_0, \{p_k\}, \mathbf{v}_0} \sum_{k=0}^K \log_2(1 + t_k) \quad (18a)$$

$$\text{s.t. } (10f), (12), (14), (16), (17). \quad (18b)$$

We can solve the above problem by convex solvers (e.g., CVX), which is summarized as Algorithm 2. Next, we analyze the convergence and the optimality of the proposed Algorithm 2. Since (18) is a convex optimization problem, the obtained solutions are optimal at each iteration. Therefore, iteratively updating the variables will increase or maintain the value of the objective function [16]. Due to the limited transmit power, the objective function will be a monotonically non-decreasing sequence with an upper bound. As a result, the proposed Algorithm 2 will converge to at least a local optimal solution. Then, we analyze the complexity of Algorithm 2. The worst-case complexity for solving convex optimization problem (18) is $O(K^{4.5} \log_2(1/\epsilon))$ [17], where $\epsilon > 0$ denotes the solution accuracy. We assume that the maximum iteration number is $T_{\max}$, the complexity of the proposed iterative Algorithm 2 is at most $O(T_{\max} K^{4.5} \log_2(1/\epsilon))$.

Fig. 1: (a) SE versus iteration. (b) SE versus maximum transmit power. (c) SE versus $E^{\min}$.

IV. SIMULATION RESULTS

Simulation results are provided to verify the performance in terms of the SE of the system. The max distance between the BS and user is 10 meters. We assume that there are 1 LoS component and 2 NLoS components, and the path loss at LoS and NLoS are, respectively, modeled as $69.4 + 24 \log_{10}(d)$ dB and $69.4 + 30.4 \log_{10}(d)$ dB [18]. The noise power is set to -80 dBm, and the noise power caused by the ID at user is -60 dBm. We set $K = 2$, $N = 64$, $\xi = 0.5$ and $E_k^{\min} = 1$ mW for any k .

Fig. 1(a) shows the convergence behavior under the proposed Algorithm 2, where we set the maximum transmit power $P_{\max} = 10$ dBm and the number of RF chains $N_{\text{RF}} = 4$. It is evident that the proposed iterative algorithm can speedily converge after 4 iterations. In addition, we plot the SE of the system versus the maximum transmit power in Fig. 1(b), where fully digital structure is used as a reference, namely each antenna is connected to one RF chain. It can be observed that the SE increases with the maximum transmit power. In addition, the SE with 8 RF chains is very close to the fully digital structure, which proves the effectiveness of the proposed beam selection scheme. Finally, Fig. 1(c) shows the SE versus the minimum requirement for the harvested energy, where we set the maximum transmit power $P_{\max} = 20$. For simplicity, we assume that all users have the same requirement for the minimum harvested energy. One can see that the SE decreases with $E^{\min}$ due to the fact that more power must be used to charge energy when the requirement of $E^{\min}$ is large.

V. CONCLUSIONS

In this paper, we proposed a beam selection scheme for the lens-antenna array structure at the BS. Meanwhile, the ZF technique was adopted to cancel the inter-unicast interference. Then, an iterative algorithm was developed to solve the formulated jointly optimizing unicast power allocation, multicast beamforming and power splitting ratio problem. Simulation results demonstrated the effectiveness of the proposed scheme in terms of the fast convergence property and high SE which is comparable to the all-digital array solution, but with much lower hardware cost and power consumption.

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