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Beamforming Design for BackCom Assisted NOMA Systems

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***Abstract*—Backscatter communication (BackCom) assisted non-orthogonal multiple access (NOMA) has received significant attention recently and can be applied to Internet of things (IoT). The BackCom system aims to realize energy cooperation among the devices. NOMA is a well-known technique to enable spectrum cooperation among the devices, which motivates the combination of the two techniques. This work focuses on the beamforming design in BackCom NOMA networks, where an uplink data rate maximization problem is formulated with a constraint to guarantee the downlink user's quality of service requirements. As the formulated optimization problem is not concave, semidefinite relaxation (SDR) is applied to transform the considered problem into a concave form which can be solved efficiently. Simulation results are provided to demonstrate that the proposed algorithm can achieve superior performance over the considered benchmarking scheme.**

I. Introduction

Ultra-massive machine type communications (umMTC) is one of the important applications for the 6G communication network [1], [2]. On one hand, to improve spectral efficiency, the concepts of non-orthogonal multiple access (NOMA) have been proposed by encouraging spectrum cooperation [3]. NOMA has been recognized as the candidate technology for future communication networks for its better connectivity, higher throughput, and higher energy efficiency for multi-user environments [4]. On the other hand, the use of BackCom can support energy cooperation among the users, e.g., a device without a power source can modulate and reflect its received radio-frequency signals and hence achieve battery-less transmission [5]. With the aid of convex optimization concepts [6], and the algorithms for transforming the original problem to convex problem, the maximum sum uplink data rate will be achieved.

In order to enable spectrum and energy cooperation, it is natural to combine NOMA with BackCom, where initial work on reflection indices optimization has been considered in [7], [8]. The aim of this letter is to develop a power allocation scheme by designing beamforming vectors to maximize uplink throughput. The optimization problem is formulated and the power budget and downlink (DL) user data rates are constraints. While exploring the sum-rate of uplink (UL), the low complexity decoding method of QR decomposition is applied to obtain the desired signal. The sum of uplink data rates is selected as the objective function. The power constraint and the DL signal to interference noise ratios (SINR) form the expressions of constraint. Due to it is hard to determine the convexity or concavity of the objective function, it is difficult to find the optimal solution efficiently. After applying SDR [9], the objective function and the constraints are converted to affine form. Hence, the recast convex optimization problem can be solved. Due to the variable being replaced by the beamforming vector multiplied by its hermitian, the rank-one constraints should be added. The rank-one constraints are not convex, so for simplifying the problem, these constraints are relaxed. To decouple the vector from the solved semidefinite hermitian matrix, the Gaussian randomization technique is applied to generate sub-optimal beamforming vectors. Therefore, the sub-optimal UL throughput is obtained. Compared with BackCom-assisted orthogonal multiple access (OMA) networks, the advantage of BackCom NOMA systems, which is higher UL data rate, is demonstrated.

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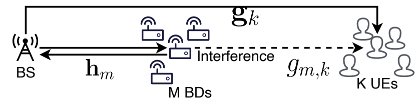

Fig. 1. System model of the BackCom NOMA system.

II. System Model

Consider a NOMA assisted BackCom network with an N-antenna base station, K single-antenna user equipments (UEs) and M single-antenna BackCom devices (BDs). In this communication system, the channel coefficients between the BS and U_k, BS and BD_m, BD_m and U_k are denoted by $\mathbf{g}_k \in \mathbb{C}^{N\times 1}$, $\mathbf{h}_m \in \mathbb{C}^{N\times 1}$ and $g_{m,k} \in \mathbb{C}^{1\times 1}$, respectively. The symbol $\mathbf{x} = [x_1, \cdots, x_K]^T$ transmitted by the BS activates the BDs. And the BS broadcasts the symbol of $\mathbf{s}_0$ directly to the UEs at the same time. And the BD_m reflects the normalized signal of s_m which is unknown to the DL users. The signal received by UE_k is given by:

$$y_k = \sqrt{P_0}\mathbf{g}_k^T\mathbf{W}\mathbf{x} + \sum\nolimits_{m=1}^{M} \sqrt{P_0\eta_m} g_{m,k}\mathbf{h}_m^T\mathbf{W}\mathbf{x}s_m + n_k, \tag{1}$$

where the transmit power is denoted by P_0, the reflection index for BD_m is denoted by η_m, the beamforming vector for UE_k is denoted by $\mathbf{w}_k$ and $\mathbf{W} = [\mathbf{w}_1, \mathbf{w}_2, \cdots, \mathbf{w}_K]$, n_k is the additive noise for UE_k. The term, $\Im \triangleq \sum_{m=1}^{M} \sqrt{P_0\eta_m} g_{m,k}\mathbf{h}_m^T\mathbf{W}\mathbf{x}s_m$, can be treated as interference, whose power is given by:

$$\mathbb{E}_{x_k,x_m}\{\Im\Im^*\} = P_0 \sum\nolimits_{m=1}^{M} \eta_m |g_{m,k}|^2 \left|\mathbf{h}_m^T\mathbf{W}\right|^2, \tag{2}$$

where $g_{m,k}$ denotes the channel gain between the m^{th} BD to the k^{th} downlink user.

Therefore, the data rate of DL users is:

$$R_k^{\text{D}} = \log\left(1 + \frac{P_0\left|\mathbf{g}_k^T\mathbf{w}_k\right|^2}{P_0 \sum\limits_{i=1, i\neq k}^{K} \left|\mathbf{g}_k^T\mathbf{w}_i\right|^2 + \mathbb{E}_{x_k,x_m}\{\Im\Im^*\} + \sigma^2}\right). \tag{3}$$

The received signal at the BS is given by:

$$\mathbf{y}_{\text{BS}} = \sum\nolimits_{m=1}^{M} \sqrt{P_0\eta_m}\mathbf{h}_m\mathbf{h}_m^T\mathbf{W}\mathbf{x}s_m + \mathbf{s}_{\text{SI}} + \mathbf{n}_{\text{BS}}, \tag{4}$$

where $\mathbf{s}_{\text{SI}}$ is self-interference symbol which is complex Gaussian distributed, i.e., $\mathbf{s}_{\text{SI}} \sim \mathcal{CN}(0, \alpha P_0\mathbf{C}_{\text{SI}})$. $\mathbf{C}_{\text{SI}}$ is covariance of the self-interference channel and α is determined by self-interference coefficient with $0 \leq \alpha \leq 1$ [7].

III. Resource Allocation Strategy

The aim of this this letter is to maximize the sum UL data rate meanwhile guaranteeing the DL sum data rate is no lower than its requirement. Due to multi-antenna BS deployment, the part of self-interference should be added to the received signal as well as the thermal noise. Hence, the sum of thermal noise and self-interference is no longer considered as 'white' noise. The detection matrix for signal pre-whitening is $\left(\sigma^2 \mathbf{I}_N + \alpha P_0 \mathbf{C}_{SI}\right)^{\frac{1}{2}}$. The signal is modified as:

$$\begin{aligned}\widetilde{\mathbf{y}}_{\text{BS}} &= \sqrt{P_0} \sum_{m=1}^{M} \sqrt{\eta_m} \mathbf{h}_m^T \mathbf{W} \mathbf{x} \widetilde{\mathbf{h}}_m s_m + \widetilde{\mathbf{n}}_{\text{BS}} \\ &= \sqrt{P_0} \widetilde{\mathbf{H}} \mathbf{D} \mathbf{s} + \widetilde{\mathbf{n}}_{\text{BS}},\end{aligned} \tag{5}$$

where $\widetilde{\mathbf{h}}_m = \left(\sigma^2 \mathbf{I}_N + \alpha P_0 \mathbf{C}_{\text{SI}}\right)^{-\frac{1}{2}} \mathbf{h}_m$, $\widetilde{\mathbf{H}} = \left[\widetilde{\mathbf{h}}_1, \cdots, \widetilde{\mathbf{h}}_M\right]$ and $\widetilde{\mathbf{n}}_{\text{BS}} = \left(\sigma^2 \mathbf{I}_N + \alpha P_0 \mathbf{C}_{\text{SI}}\right)^{-\frac{1}{2}} (\mathbf{s}_{\text{SI}} + \mathbf{n}_{\text{BS}})$. $\mathbf{D}$ is a diagonal matrix with the elements on its main diagonal as $D_{m,m} = \sqrt{\eta_m} \mathbf{h}_m^T \mathbf{W} \mathbf{x}$, and $\mathbf{s} = [s_1, s_2, \cdots, s_M]^T$.

Similar to [7], a method of QR decomposition for decoding the received is used in this letter. For the approach, QR composite is applied to decode the received signal. By assuming that the composite channel matrix $\widetilde{\mathbf{H}}$ can be decomposed via QR decomposition as follows: $\widetilde{\mathbf{H}} = \mathbf{Q}\mathbf{R}$, where $\mathbf{Q} \in \mathbb{C}^{N \times N}$ is a unitary matrix and $\mathbf{R} \in \mathbb{C}^{N \times M}$ is an upper triangular matrix. Therefore, the matrix $\mathbf{Q}^H$ is selective as the detector, which means that the system model can be rewritten as follows:

$$\mathbf{Q}^H \widetilde{\mathbf{y}}_{\text{BS}} = \mathbf{R}\mathbf{D}\mathbf{s} + \mathbf{Q}^H \widetilde{\mathbf{n}}_{\text{BS}}. \tag{6}$$

By using the upper triangular structure of $\mathbf{R}$, successive interference cancellation can be implemented with low-complexity. In particular, during the $(M - m + 1)$-th step, the signal from BD_m can be decoded with the following data rate:

$$R_m = \log\left(1 + P_0 R_{m,m}^2 \eta_m \left|\mathbf{h}_m^T \mathbf{W} \mathbf{x}\right|^2\right), \tag{7}$$

where $R_{m,m}$ is defined similar to $D_{m,m}$. To further reduce system overhead, it is ideal to formulate the resource allocation problem based on the following average sum rate [7]:

$$\bar{R}_m = \log(e) f\left(P_0 R_{m,m}^2 \eta_m \left|\mathbf{h}_m^T \mathbf{W}\right|^2\right), \tag{8}$$

where $f(x) \triangleq -e^{\frac{1}{x}} E_i\left(-\frac{1}{x}\right)$, $x \geq 0$ which is a concave function [7]. It is noted that an alternative way to obtain (8) is to treat $\mathbf{h}_m^T \mathbf{W} \mathbf{x}$ in (7) as a complex Gaussian variable with mean zero and variance $\left|\mathbf{h}_m^T \mathbf{W}\right|^2$ [7].

The condition that the data rate for user k in (3) is greater than its threshold is equivalent to the condition that the signal to interference and noise ratio (SINR) of user k is larger than ϵ_k^{NOMA}, $1 \leq k \leq K$, which can be expressed by:

$$\frac{P_0 \left|\mathbf{g}_k^T \mathbf{w}_k\right|^2}{P_0 \sum\limits_{i=1, i\neq k}^{K} \left|\mathbf{g}_k^T \mathbf{w}_i\right|^2 + \mathbb{E}_{x_k, x_m}\left\{\Im\Im^*\right\} + \sigma^2} \geq \epsilon_k^{\text{NOMA}}. \tag{9}$$

The (9) can be further reformulated by:

$$\begin{aligned}&\epsilon_k^{\text{NOMA}} P_0 \sum_{i=1, i\neq k}^{K} \left|\mathbf{g}_k^T \mathbf{w}_i\right|^2 + \epsilon_k^{\text{NOMA}} P_0 \sum_{m=1}^{M} \eta_m \left|g_{m,k}\right|^2 \left|\mathbf{h}_m^T \mathbf{W}\right|^2 + \\ &\quad \epsilon_k^{\text{NOMA}} \sigma^2 - P_0 \left|\mathbf{g}_k^T \mathbf{w}_k\right|^2 \leq 0.\end{aligned} \tag{10}$$

Considering the power constraint, the transmit power cannot be larger than power budget, the sum of beamforming vector $\mathbf{w}_k$ multiplied by its hermitian $\mathbf{w}_k^H$ should be equal or less than 1. Therefore, the maximization problem is:

$$\max_{\mathbf{W}} \quad \sum_{m=1}^{M} f\left(P_0 R_{m,m}^2 \eta_m \left|\mathbf{h}_m^T \mathbf{W}\right|^2\right) \tag{11a}$$

$$\text{s.t.} \quad \sum_{k=1}^{K} \mathbf{w}_k^H \mathbf{w}_k \leq 1 \tag{11b}$$

$$(10) \tag{11c}$$

By setting $\mathbf{W}_k = \mathbf{w}_k \mathbf{w}_k^H$, the matrix of $\mathbf{W}$ is rank-one semidefinite hermitian matrix. The method of SDR can be applied to recast (10) as follows:

$$\begin{aligned}&\epsilon_k^{\text{NOMA}} P_0 \sum_{i=1, i\neq k}^{K} \mathbf{g}_k^T \mathbf{W}_i \mathbf{g}_k^* + \epsilon_k^{\text{NOMA}} P_0 \sum_{m=1}^{M} \eta_m \left|g_{m,k}\right|^2 \times \\ &\quad \sum_{k=1}^{K} \mathbf{h}_m^T \mathbf{W}_k \mathbf{h}_m^* + \epsilon_k^{\text{NOMA}} \sigma^2 - P_0 \mathbf{g}_k^T \mathbf{W}_k \mathbf{g}_k^* \leq 0.\end{aligned} \tag{12}$$

By replacing (10) with (12) to finish the process of SDR, problem (11) is recast as:

$$\max_{\mathbf{W}_k \succeq 0, \mathbf{W}_k \in \mathbb{H}} \quad \sum_{m=1}^{M} f\left(P_0 R_{m,m}^2 \eta_m \sum_{k=1}^{K} \mathbf{h}_m^T \mathbf{W}_k \mathbf{h}_m^*\right) \tag{13a}$$

$$\text{s.t.} \quad \sum_{k=1}^{K} \text{tr}\left(\mathbf{W}_k\right) \leq 1 \tag{13b}$$

$$\text{rank}\left(\mathbf{W}_k\right) = 1 \tag{13c}$$

$$(12) \tag{13d}$$

Due to $f(x)$ is concave and the variable for $f(x)$ is affine to $\mathbf{W}_k$, the second order derivative of the objective function must be negative. Therefore, the objective function (13a) is a concave function. (13b) is the expression of linear form and (12) is a form of trace function. (13b) and (12) are affine. Note that the ideal energy harvesting of BDs is considered in the system model, which can also be applied to more practical cases by adding the energy harvesting coefficient in (12) and (13a) [10].

A. Optimization Process in OMA Systems

While in OMA systems, the BS broadcasts its signal to the number of K DL users via the number of K orthogonal subcarriers. A signal reflected by one BD can potentially block all subcarriers. Similar to (2), the power of interference yields:

$$\mathbb{E}_{x_k, x_m}\left\{II^*\right\} = P_0 \sum_{m=1}^{M} \eta_m \left|G_{m,k}\right|^2 \left|\mathbf{h}_m^T \mathbf{w}_k\right|^2, \tag{14}$$

where $G_{m,k}$ denotes the backward channel gain between U_k and BD_m, $\mathbf{h}_m$ denotes to the channel gain between BD_m and the downlink users.

Suppose the SINR of the DL user k is larger than ϵ_k^{OMA}, which leads to the following constraint:

$$\frac{P_0 \left|\mathbf{g}_k^T \mathbf{w}_k\right|^2}{P_0 \sum_{m=1}^{M} \eta_m \left|G_{m,k}\right|^2 \left|\mathbf{h}_m^T \mathbf{w}_k\right|^2 + \sigma^2} \geq \epsilon_k^{\text{OMA}}. \tag{15}$$

Based on the principles of SDR, (15) can be reformulated as:

$$\begin{aligned}&\epsilon_k^{\text{OMA}} P_0 \sum_{m=1}^{M} \eta_m \left|G_{m,k}\right|^2 \mathbf{h}_m^T \mathbf{W}_k \mathbf{h}_m^* - P_0 \mathbf{g}_k^T \mathbf{W}_k \mathbf{g}_k^* \\ &\qquad \leq -\epsilon_k^{\text{OMA}} \sigma^2.\end{aligned} \tag{16}$$

Similarly, $\mathbf{W}_k = \mathbf{w}_k\mathbf{w}_k^H$.

The received signal by BD at the k^{th} subcarrier is given by:

$$y_k^{\text{BS}} = \sqrt{P_0}\sum\nolimits_{m=1}^{M} F_{m,k}\mathbf{h}_m^T\mathbf{w}_k x_k s_m + s_{\text{SI}} + n_k^{\text{BS}}, \qquad (17)$$

where $F_{m,k}$ denotes to the backward channel of BD_m at subcarrier k. After applying a pre-whitening course using $\left(\alpha P_0 \left|h_k^{\text{SI}}\right|^2 + \sigma^2\right)^{-\frac{1}{2}}$ and introducing $\breve{y}_k^{\text{BS}} = \left(\alpha P_0 \left|h_k^{\text{SI}}\right|^2 + \sigma^2\right)^{-\frac{1}{2}} y_k^{\text{BS}}$, $\breve{\mathbf{h}}_k = \left(\alpha P_0 \left|h_k^{\text{SI}}\right|^2 + \sigma^2\right)^{-\frac{1}{2}} \left[F_{1,k}\mathbf{h}_1^T\mathbf{w}_k, F_{2,k}\mathbf{h}_2^T\mathbf{w}_k, \cdots, F_{M,k}\mathbf{h}_M^T\mathbf{w}_k\right]^H$, $\mathbf{s} = [s_1, \cdots, s_M]^T$, $\boldsymbol{\eta} = \text{diag}\left\{\eta_1, \cdots, \eta_m\right\}$, $\breve{n}_k^{\text{BS}} = \left(\alpha P_0 \left|h_k^{\text{SI}}\right|^2 + \sigma^2\right)^{-\frac{1}{2}} \left(s_{\text{SI}} + n_k^{\text{BS}}\right)$, the received signal can be expressed as follow:

$$\breve{\mathbf{y}}^{\text{BS}} = \sqrt{P_0}\mathbf{D}_x\breve{\mathbf{H}}^H\boldsymbol{\eta}^{\frac{1}{2}}\mathbf{s} + \breve{\mathbf{n}}^{\text{BS}}. \qquad (18)$$

where $\mathbf{D}_x = \text{diag}\left\{x_1, \cdots, x_K\right\}$, $\breve{\mathbf{H}} = \left[\breve{\mathbf{h}}_1, \cdots, \breve{\mathbf{h}}_K\right]$. Assuming detecting matrix is $\boldsymbol{\Gamma} = \text{diag}\left\{\left(\alpha P_0 \left|h_1^{\text{SI}}\right|^2 + \sigma^2\right)^{\frac{1}{2}}, \cdots, \left(\alpha P_0 \left|h_k^{\text{SI}}\right|^2 + \sigma^2\right)^{\frac{1}{2}}\right\}$, the decoded signal for OMA system is:

$$\mathbf{y}^{\text{BS}} = \widetilde{\mathbf{H}}\mathbf{D}\mathbf{s} + \widetilde{\mathbf{n}}_{\text{BS}}, \qquad (19)$$

where $\widetilde{\mathbf{H}} = \boldsymbol{\Gamma}\mathbf{F}$, $\mathbf{D} = \boldsymbol{\eta}^{\frac{1}{2}}\text{diag}\left\{\mathbf{H}^T\mathbf{W}\mathbf{x}\right\}$, $\widetilde{\mathbf{n}}_{\text{BS}} = \boldsymbol{\Gamma}\left(\mathbf{s}_{\text{SI}} + \mathbf{n}_k^{\text{BS}}\right)$, $\mathbf{F}$ contains all elements of $F_{m,k}$ with size $(M \times K)$. Similarly, QR decomposition is applied. The average uplink sum data rate is given by:

$$\bar{R}_{\text{sum}} = \log(e) f\left(P_0 R_{m,m}^2 \eta_m \sum\nolimits_{k=1}^{K} \left|\mathbf{h}_m^T\mathbf{w}_k\right|^2\right). \qquad (20)$$

The constraint of beamforming weights is the same as the one shown in (13b). With SDR, the optimization problem can be formulated as:

$$\max_{\mathbf{W}_k \succeq 0, \mathbf{W}_k \in \mathbb{H}} \quad \sum\nolimits_{m=1}^{M} f\left(P_0 R_{m,m}^2 \eta_m \sum\nolimits_{k=1}^{K} \mathbf{h}_m^T\mathbf{W}_k\mathbf{h}_m^*\right) \qquad (21a)$$

$$\text{s.t.} \quad (16), (13b) \qquad (21b)$$

SDR and Gaussian approximation will also be used to optimize beamforming vectors in BackCom assisted OMA systems, in a manner similar to that presented in Section III.

B. Gaussian Randomization

Due to the rank function being quasi-concave and subadditive, the rank-one constraint is not guaranteed in the optimization problem of (13). The rank-one constraint is relaxed in (13) and (21), hence the optimal solution $\mathbf{W}_k^{\star}$ cannot always be written as $\mathbf{W}_k^{\star} = \mathbf{w}_k^{\star H}\mathbf{w}_k^{\star}$. Therefore, the approximation method of Gaussian randomization [9] can be implemented to determine the suboptimal solution. To obtain $\mathbf{w}_k^{\star}$ which follows $\mathbf{w}_k^{\star} \sim \mathcal{CN}\left(\mathbf{0}, \mathbf{W}_k\right)$, it is essential to set the number of randomizations L. The generated vectors must satisfy the constraints of (12) and (13b).

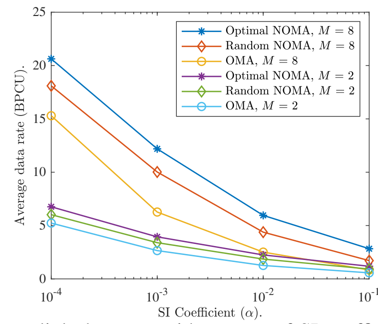

Fig. 2. Average uplink data rate with respect of SI coefficient (α) when the BS locates in the original point $(0, 0)$.

C. Successive Convex Approximation

Optimization problems with SDR are usually solved by using numerical solvers such as CVX. While CVX cannot support the format of `{Constant}/{Affine}`. Therefore, successive convex approximation (SCA) [11] is exploited to solve the maximization problem. The lemma of $f'(x) = e^{-x^{-1}}x^{-2}E_i\left(-x^{-1}\right) + x^{-1}$ is derived in [7]. Therefore, the objective function for n^{th} SCA iteration is expressed by:

$$f_{\text{SCA}}\left(\mathbf{W}_k\right) = \sum_{k=1}^{K}\left\langle \frac{\partial g\left(\mathbf{W}_k^{(n)}\right)}{\partial \mathbf{W}_k^{(n)}}, \mathbf{W}_k - \mathbf{W}_k^{(n)} \right\rangle, \qquad (22)$$

where $<,>$ denotes to inner product. The constraints are similar to the form demonstrated in (13). Armijo rule [6] is applied to estimate the step size of its iteration until the convergence with required accuracy. The optimization problem for SCA is formulated as:

$$\max_{\mathbf{W}_k \succeq 0, \mathbf{W}_k \in \mathbb{H}} \quad (22) \qquad (23a)$$

$$\text{s.t.} \quad (13b), (12) \qquad (23b)$$

IV. Simulation Analysis

In this section, performance of the proposed NOMA system is investigated by using OMA as a benchmarking scheme. To evaluate the performance, a BackCom assisted NOMA system is considered with a base station located either at the origin $(0, 0)$ or on the border of the area. BDs and UEs are randomly scattered in a square area with an original point as its center and a side length of 3. The pathloss exponent is set to 3. The power of thermal noise is -94 dBm and the transmit signal to noise ratio (SNR) is set to 30 dB. The lower bound on the downlink data rate is 1 bit per channel use (BPCU). The number of randomization is 5000.

Fig. 2 depicts the performance of NOMA and OMA with various self-interference coefficient values when $M = N = K = 2$ and 8. The figure shows that the more severe self-interference causes the poorer performance in either NOMA or OMA system. While with the same number of BDs, the UL data rate of NOMA system is higher. Naturally, the beamforming weights optimization assisted NOMA system performs the best among the three strategies of optimal NOMA, random NOMA and OMA. Mathematically, when the value of α increases, the value of $R_{m,m}$ in (13a) decreases, leading to the decreasing of sum UL data rate.

Fig. 3 shows the phenomenon that when the number of BDs varies and the self-interference index values are fixed, the data rate increases with the growth of the number of BDs

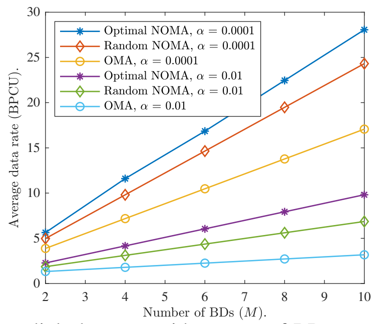

Fig. 3. Average uplink data rate with respect of BD quantity (M) when the BS locates in the original point $(0, 0)$.

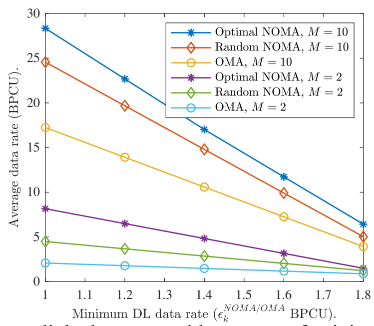

Fig. 4. Average uplink data rate with respect of minimum DL data rates ($\epsilon_k^{\text{NOMA/OMA}}$) when the SI coefficient is set to $\alpha = 0.0001$.

cluster, regardless of whether NOMA or OMA is employed. However, as the values of $M = N = K$ grow, the performance advantages of NOMA are becoming more and more significant compared with OMA. Even in the small number of BDs, the superior performance can be well stated in optimal algorithm with BackCom NOMA. If the number of BDs increases, the average uplink data rate will be improved. The reason is that more UL data rate is accumulated linearly in (13a). As the result, the UL throughput increases.

Fig. 4 illustrates the impact of the minimum DL data rate on the presentation of the proposed resource allocation schemes. In this environment, the BS is located in the middle of the Cartesian coordinate system, and the self-interference coefficient is set to $\alpha = 0.0001$. Fig. 4 shows that the average UL data rate decreases due to the increasing demand of DL users. As the minimum data rate increases, the constraint of the optimization problem becomes stricter, resulting in a reduction of the feasible area. Consequently, the average UL data rate decreases.

Fig. 5 illustrates a scenario where the BS is not centrally located within the square, specifically at the coordinates $(3, 0)$ when self-interference coefficient is $\alpha = 0.0001$. The data rate is reduced when the distances between BS and BDs or UEs increase, resulting in increasingly severe pathloss. Even with different BS locations deployed, the performance of OMA is still inferior to that of optimal algorithm assisted NOMA. The longer distance weakens the channel gain, i.e., the value of $\mathbf{h}_m$ becomes lower. Therefore, central BS deployment leads to better performance than border BS deployment.

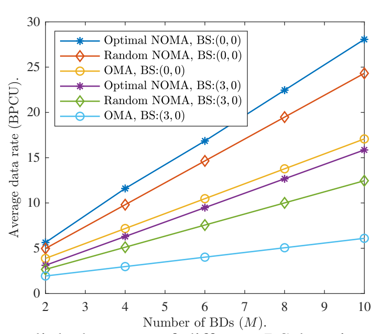

Fig. 5. Average uplink data rate of different BS location with respect of SI coefficient (α) when the SI coefficient is set to $\alpha = 0.0001$.

V. Conclusion

In this study, we have analyzed three power allocation schemes, namely optimization algorithm assisted allocation scheme with NOMA, random allocation with NOMA, and OMA, in BackCom-assisted wireless communication systems. The proposed sum-rate maximization problem with BackCom-assisted NOMA allocates power to optimize the UL data rate by applying SDR to transform the objective function to concave form so that the optimization problem can be efficiently solved by CVX solver. The results show that increasing the BD and reducing the SI coefficient result in increased UL throughput. Furthermore, the proposed optimization algorithm achieves the goal of updating the UL data rate as much as possible while maintaining a given power budget. The BackCom-assisted NOMA scheme with the proposed technique, SDR and Gaussian randomization is applicable for future communication platforms.

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