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Movable Antenna-Enhanced Multiuser Communication: Optimal Discrete Antenna Positioning and Beamforming

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Abstract Abstract

Movable antennas (MAs) are a promising paradigm to enhance the spatial degrees of freedom of conventional multi-antenna systems by flexibly adapting the positions of the antenna elements conventional multi-antenna systems by flexibly adapting the positions of the antenna elements within a within a given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit area. In this paper, we model the motion of the MA elements as discrete given transmit gressource allocation problem for MA-enabled multiuser multiple-input single-multiple-input single-output (MISO) communication systems. Specifically, we jointly optimize the beamforming and the MA positions at the base station (BS) for the minimization of the positions at the base station (BS) for the minimization of the total transmit power while guaranteeing the minimum required signal-to-interference-plus-noise the minimum required signal-to-interference-plus-noise ratio (SINR) of each individual user. To obtain the globally optimal solution to the formulated resource allocation problem, we develop an iterative algorithm capitalizing on the generalized the globally optimal solution to the formulated resource allocation problem, we develop an iterative algorithm capitalizing on the generalized Bender's decomposition with guaranteed convergence. Our mumerical results demonstrate that the proposed MA-enabled communication system can si

I.I.Introduction

Multiple-input multiple-output (MIMO) Oransmission is nwidely lehvisioneid as daskey technique in a fulfilling of the mendous data usaffic adematids dimesinth-generation (663), twine (663) networks.

Byt utilizing multiplic antenhasleMilMonoan MffetOvely, leffertage the spatial tesospecial fewireless of aminelless deliveresignificative persognificant monowements; including improved data transmission rlates (2) nembarioed aphysical daylen secupity sical lande realize the w? paradignalization as pintagigned sensing iantdgcotradianication in the control of th parallel radibifrequency (RF), that is deading to light hardware dost and computational complexity E3Im Totamitigate other plost and? complexity antended eds by and argen plumber in fr Rifuebairtsy antenna selection (ARFhabiteen advocated also at practical) approach for the creatization of a MHM Opsystem Indeed; the ligation of as is to the possible the possible the possible for an analysis of the possible the p MHMOt system rhyltselecting gasmall subgetent lattermasysticm favorable tehannelnehlar actesistics from a darget set for condidate antennal athe rebistric ducing the frequired number of RE chains (23). However, in conventional MIMO systèms with Erobithout AS Hhe antennas are deployed at fixed positions. At such, which inhere fit, variations of the acharholl across the spatial stimuous transmitter imbærgartnotarbetfulls æk phoiteklarwhilcheliosist lsystont iperfortiangers transmitter area cannot be full to dulibie within a given spatial svariation of owireless, channels within a given spatial transmitter are To the contribute holographical MIMO decliniques blas above spiropose diverbe diteratures [2]tt In particular, drolographicoMEMO surfades Consistrof murherous eminiatures ed sixive le le linerats, apaded an sub-twavelength distances, Which can be electrosically controlled to manipulate the electromagspaticed repesties will will be a considered the control of the co continuous cantennai elements tithe of valiable aspatiialt of egreese (for free down (DoFs) Inf the ospatially continuousetransmitter area ir anulsea fully mever ged thy tholographic MIMIOL digweven f the clarge (iDmbe) of tantesprat islements tiequired for sholographic MIMQ public discretificative hallenges bloc botMCharther estimation lande data process in growhich leinders i te quactic aloin libberg at attion NAMO prespired by the spatialeDoFf of a ciditated by blog raphic MIMO surfaces cassew, MIMO bondept based on indvable antennasi (MAS) has been proposed as a bridge technology between holographic MIMO and conventional iMIMOF \$? In ditiMA-enabled kystemisice adh Antennafalement is convided to torac and ibastreturency (RH) a that im rais (a flexible stable prodpits of hysical riples it for head one before the control of the control within applies ight and open the partial cregion temploith fight one electron behanded device in such as a stepper chetoent? Is This enablity allow is the greposition of a the vMA. Element at the optimist phostion forsitistablishing afayorablewipatiah alutegnatedroplationsegora exploitaninsizer the ecapacityho fiithak NEIMO systems. In contrast to convertio fili MIMO is the compart so an action of the contrast to convert to co elements amounted ian alixed aborations, eMalisals tegra accommunity pathic lifeth tegration for the elements amounted ian alixed aborations, eMalisals tegras accommunity to the elements amounted ian alixed aborations, eMalisals tegras accommunity to the elements amounted ian alixed aborations are the elements amounted the elements are the elem avaihablienspatible teansmitte platea by léveraging other flexibles movement no fothed MAsl. OM or cover,

sithéeh M-Amsysitems sequirée aon byna a sniath entraber confit adtentuaixelemient stiton explicit sive taxailable DoFse the conhomational observe that already the pregular charge and the consoler the conhomation of the conformal control of the conhomation of the conformal conform fieldibed compared to hellogidulisic NHMO csystèmes [B1A] skstêms require only a small number of Toutfully unleasing the potential of the MAD and bled, systems up few initial works explored the joint design of bleagoforming and agtenra positioning r Fon instance, for F21, to subbottimal algorithm basednon alternating optimization (AO) was proposed for MA-enabled MIMO systems, where boffiotffelbaserstation t/BS) and triultiple lusers Avena lequipped ewith MAsy Alista the outshors; ibuf21 considered as imultituser. MA-enabled a plinter communication, system scomprising? multiple single-Meanishers and a BS requirement with an fixed antenna Act a water BS completed Metro-forteled (ZEVIO) systimus where souther dra(MMSE) or of BSi ping danduthip MA spositions were padjusted husing sa gradient descent (GD) Methods However politically draid 4? drass land uptink stically that the positions of MA selements in benedicted freely a within BS give in pregion; it which is maly another practical line IBS protitoryed designs rein M/X-Enabled is istems released in a [2] candr [2] M MeEmotion bontz of the Amployed ielectrome chamical devices a se disbrete skishe finit@Drecision of Thus whe or absorbited aned [8] quantized intimipated Pt, tleading to as if inite spallar resolution dasted af just in finitely resolution gissumedgiio if ?]v|i|?dh [ft]a Moredve p thetiAOl-blasch al govithtupin d?signd tifeNGD-baselbonettsodnin \$10 various guardnice the joint optimality of the BSobeard observand the MA desitions, discheir performance highly ore lies on, the selection of the initial point. Thus, in this paper, we investigate for the partie i me other i or intly ted do all the ptirial tested of the about the ab plositAon-s) fored mightitistem MiA-{ehabledt blownDakasystemethidal airsp@tiaHyadiscgetertransmitterjarea top fully lifeyed the BStentian for MeA-endbled by steps if The smaint boint piloutions and this glober class be subminated as of other initial point. Thus, in this paper, we investigate for the first time the Trighthe glubale countritied discipre of after Rff state of the earliest iron and hard a loss of the countritied discipre of after Rff state of the earliest iron and hard a loss of the countritied discipre of after Rff state of the earliest iron and the earlie multiware, McAintrobline downth Maystositi orithodeb that lfacilisates the position popularization lbf revealed MA celements of MA-enabled systems. The main contributions of this paper can be sum Taxibtal natheologists globally optimal MA positions and BS beamforming matrix, we propose

- Takries oftmathematicahtralisformationsuthat falloweusftöhrecast theconsidered ichållenging hesolwer allocation problem intock tvååtableitniskednindegethatnfindlit.programpingt(MINDR) problem of the MA elements.
- We propose the iterative glightly mexiphalting the getteralized BBfder's ideomposition (GBD) to obtain the globally roptimal solution of the considered joint litesigns problems (The proposed eightight) and capital cap

programming (MINLP) problem.

• We propose an iterative algorithm exploiting the generalized Bender's decomposition (GBD) to obtain the globally optimal solution of the considered joint design problem.

The proposed algorithm can serve as a performance benchmark for any suboptimal design, e.g., those in [2] [3].

The remainder of this paper is of partized as follows: M Section M Section M introduce the system model for the considered MA-enabled multiuser multiple-input single-output (MISO) communication system with a spatially discrete transmitter area and formulate the corresponding Fig. 1. Transmission from M = 2 movable antenna elements with N = 16 possible discrete positions to K = 2 users (** resource allocation problem. In Section III, the globally optimal solution for the MA positions symbols represent feasible antenna positions). and the BS beamforming matrix is provided. Section IV evaluates the performance of the proposed optimal design via numerical simulations, and Section V concludes this paper.

Notation: Vectors and matrices are denoted by boldface lower case and boldface capital The remainder of this paper is organized as follows: In Section II, we introduce the system represent the space of two II, real-varied and complexmodel for the considered MA-enabled multiuser multiple input single-output (MISO) communication system with a spatially discrete transmitter rarea and formulate the corresponding resource and the land of the transmitter rarea and formulate the corresponding resource and the land of the transmitter rarea and formulate the corresponding resource allocation problem. In Section III, the globally optimal solution for the MA positions and the BS confugate, and the confugate transpose of their arguments, respectively. In beamforming matrix is provided. Section IV evaluates the performance of the proposed optimal identity matrix of time issuit W. Section IV evaluates the performance of the proposed optimal identity matrix of time issuit W. Section IV. design via numerical simulations and Section V concludes this paper. The spectively A > 0 indicates that A is a positive semidefinite matrix, diagral denotes a diagonal matrix whose main diagonal certificity are respectively. $\mathbb{R}^{N \times M}$ and $\mathbb{C}^{N \times M}$ represent the space of $N \times M$ real-valued and complex-valued from the space of $\mathbb{R}^{N \times M}$ and $\mathbb{R}^{N \times M}$ and $\mathbb{R}^{N \times M}$ represent the space of $\mathbb{R}^{N \times M}$ the leaf-valued and complex valued of matrices respectively, and the absolute value of a complex scalar and the l_2 -norm of a vector, respectively. $(\cdot)^T$, $(\cdot)^*$, and $(\cdot)^H$ denote the transpose, the conjugate, and the conjugate transpose of their arguments, respectively. I_N refers to the identity matrix of dimension A. Ω and Ω_L represent the all-zeros and all-ones vector of Wengths I derespectively er Avivel @sindicates it that i A six sterpositive rise imide fit it to the lateral derespectively er Avivel @sindicates it that i A six sterpositive rise imide fit it to the lateral derespectively expectively expectiv Behotescaviting duratith all axis who seemaths diagonal interference per silven by uther sentiles possibictor of Re(M And dimenter epresent disesteal singularization agriculture a perfers To istatistical expectation all possible performance of the considered MA-enabled system, we assume that perfect channel state information (CSI) with respect to the transmitter area is available at the BS [?], [?] ¹. Since practical electromechanical devices can only provide a

¹The robust design of MA-enabled systems taking into account imperfect CSI is an interesting topic for future work.

II. MA-ENHANCED MULTIUSER SYSTEM MODEL

A. Channel Model

We consider a multiuser wireless communication system comprising a BS and K users. The BS is equipped with M MA elements for serving K single-antenna users. The positions of the MA elements can be adjusted simultaneously within a given two-dimensional transmitter area. To investigate the maximal possible performance of the considered MA-enabled system, we assume that perfect channel state information (CSI) with respect to the transmitter area is available at the BS [?], [?] 1. Since practical electromechanical devices can only provide a horizontal or vertical thoughter the modern transmitter area of the MA-enabled communication system is quantized $[?]^2$. We collect the N possible discrete positions of the MAs in set $\mathcal{P} = \{\mathbf{p}_1, \dots, \mathbf{p}_N\}$, where the distance between the neighboring positions is equal horizontal or vertical movement by a fixed increment d in each step [?], the transmitter to d in horizontal or vertical direction, as shown in Fig. ??. Here $p_{W} = \begin{bmatrix} x_1 & y_n \end{bmatrix}$ represents the area of the MA-enabled communication system is quantized [?]. We collect the N possible n-th candidate position with horizontal coordinate x_n and vertical coordinate y_n . In other words, discrete positions of the MAs in set $\mathcal{P} = \{\mathbf{p}_1, \cdots, \mathbf{p}_N\}$, where the distance between the the feasible set of the position of the m-th MA element, \mathbf{t}_m , is given by \mathcal{P} , i.e., $\mathbf{t}_m \in \mathcal{P}$. In the neighboring positions is equal to d in horizontal or vertical direction, as shown in Fig. considered MA-enabled MIMO system, the physical channel can be reconfigured by adjusting ??. Here, $\mathbf{p}_n = [x_n, y_n]$ represents the *n*-th candidate position with horizontal coordinate the positions of the MA elements. The channel vector between the m-th MA element and the K and vertical coordinate y_n . In other words, the feasible set of the position of the musers is denoted by $\mathbf{h}_m(\mathbf{t}_m) = [h_{m,1}(\mathbf{t}_m), \dots, h_m, p(\mathbf{t}_m)]^T$ and depends on the position of the th MA element, \mathbf{t}_m , is given by \mathcal{P} , i.e., $\mathbf{t}_m \in \mathcal{P}(\mathbf{t}_m)]^T$ and depends on the position of the m-th MA element \mathbf{t}_m , where $h_{m,k}(\mathbf{t}_m) \in \mathbb{C}$ denotes the channel coefficient between the m-th system, the physical channel can be reconfigured by adjusting the positions of the MA MA element and the k-th user. Next, we define a matrix $\hat{\mathbf{H}}_m = [\mathbf{h}_m(\mathbf{p}_1), \dots, \mathbf{h}_m(\mathbf{p}_N)] \in \mathbb{C}^{K \times N}$ elements. The channel vector between the m-th MA element and the k-th users is denoted by to collect the channel vectors from the m-th MA element to all K users for all N feasible $\mathbf{h}_m(\mathbf{t}_m) = [h_{m,1}(\mathbf{t}_m), \cdots, h_{m,K}(\mathbf{t}_m)]^{\mathsf{T}}$ and depends on the position of the m-th MA element discrete MA locations. Then, $\mathbf{h}_m(\mathbf{t}_m)$ can be expressed as \mathbf{t}_m , where $h_{m,k}(\mathbf{t}_m) \in \mathbb{C}$ denotes the channel coefficient between the m-th MA element and the k-th user. Next, we define a matrix $(\hat{\mathbf{H}}_m) = [\hat{\mathbf{H}}_m(\mathbf{p}_k), \cdots, \mathbf{h}_m(\mathbf{p}_N)] \in \mathbb{C}^{K \times N}$ to collect the channel vectors from the m-th MA element to all K users for all N feasible discrete MA where $\mathbf{b}_m = \begin{bmatrix} b_m[1], \cdots, b_m[N] \end{bmatrix}$. Here, $b_m[n] \in \{0, 1\}$ with $\sum_{n=1}^N b_m[n] = 1$ is a binary locations. Then, $\mathbf{h}_m(\mathbf{t}_m)$ can be expressed as variable defining the position of the m-th MA element. For the considered MA-enabled multiuser MISO system, the channel matrix between the BS and the K users, $\mathbf{H} = [\mathbf{h}_1(\mathbf{t}_1), \cdots, \mathbf{h}_M(\mathbf{t}_M)]$ $\overset{\mathbb{C}^{K \times M}}{\text{where}}, \overset{\text{is then given}}{\text{b}_m} \overset{\text{eiven}}{=} \begin{bmatrix} b_m[1], \cdots, b_m[N] \end{bmatrix}^T. \text{ Here, } b_m[\underline{n}] \in \{0, 1\} \text{ with } \sum_{n=1}^N b_m[n] = 1 \text{ is a bisonal problem}$ nary variable defining the position of the m-th MA element. For the considered MA-

¹The robust design of MA-enabled systems taking into account imperfect CSI is an interesting topic for future work.

²The value of step size *d* depends on the precision of the employed electromechanical devices and may vary in different MA-enabled systems.

MA-enabled systems.

where the tride is $\mathbb{H}_{\Gamma} \in \mathbb{M}^{r} \cap \mathbb$

$$\mathbf{H} = [\mathbf{h}_1(\mathbf{t}_1), \cdots, \mathbf{h}_M(\mathbf{t}_M)] \in \mathbb{C}^{K \times M} \text{ is then given by } \mathbf{H} = [\hat{\mathbf{H}}_1, \cdots, \hat{\mathbf{H}}_M],$$
(3)

$$\begin{bmatrix} \mathbf{b}_1 & \mathbf{b}_N^{\mathbf{I}} = \hat{\mathbf{b}}_N^{\mathbf{I}} \mathbf{B}, \dots & \mathbf{0}_N \end{bmatrix} \tag{2}$$

where matrices
$$\hat{\mathbf{H}} \in \mathbb{C}^{K \times MN}$$
 and $\mathbf{B} = \mathbf{B} \underbrace{\mathbf{Q} \times \mathbf{M} \mathbf{b}_{\mathbf{2}} \times M \mathbf{0}}_{\mathbf{M}}$ are defined as follows, respectively, (4)

$$\hat{\mathbf{H}} = \begin{bmatrix} \hat{\mathbf{H}}_1, \cdots, \hat{\mathbf{H}}_M \end{bmatrix}, \\ \mathbf{0}_N & \mathbf{0}_N & \mathbf{0}_N & \cdots & \mathbf{b}_M \end{bmatrix}$$
(3)

Next, we define $\hat{\mathbf{h}}_k \in \mathbb{C}^{1 \times MN}$ as the y_k is given by $\mathbf{\hat{H}} = \begin{bmatrix} \hat{\mathbf{H}}_1, \cdots, \hat{\mathbf{H}}_M \\ \mathbf{0}_N & \mathbf{0}_N & \mathbf{0}_N & \cdots & \mathbf{b}_M \\ \mathbf{b}_1 & \mathbf{0}_N & \mathbf{0}_N & \cdots & \mathbf{0}_N \\ k_t - \mathbf{th} & \mathbf{row} & \mathbf{0} & \hat{\mathbf{H}} & \mathbf{Then}, \\ \mathbf{0}_N & \mathbf{b}_2 & \mathbf{0}_N & \cdots & \mathbf{0}_N \\ \mathbf{0}_N & \mathbf{b}_2 & \mathbf{0}_N & \cdots & \mathbf{b}_M \end{bmatrix}$ received signal of the k-th user $\mathbf{u}_k = \hat{\mathbf{h}}_k \mathbf{B} \mathbf{W} \mathbf{S} + n_k, \\ \mathbf{0}_N & \mathbf{0}_N & \mathbf{0}_N & \cdots & \mathbf{b}_M \end{bmatrix}$ (5)

where $\mathbf{s}_{e} = \mathbf{d}_{e}$ in $(\mathbf{h}_{k} \mathbf{s}_{e}) \in \mathbf{h}_{k} \mathbf{s}_{e}) \in \mathbf{h}_{k} \mathbf{s}_{e}$ in $(\mathbf{h}_{k} \mathbf{s}_{e}) \in \mathbf{h}_{k} \mathbf{s}_{e}$ $to cthe_{j} users iv Here_{j} s_{j} \in \mathbb{C}$ denotes the symbol transmitted to the j-th user and $\mathbb{E}[|s_{j}|^{2}] = 1$,

$$\mathbb{E}[s_j^*s_i] = 0, j \neq i, \forall j, i \in \{1, \cdots, K_j\}$$
. When $\mathbf{w}_k + n_k$, we denote the linear beamforming

matrix at the BS, where $\mathbf{w}_k \in \mathbb{C}^{M \times 1}$ represents the linear beamforming vector for the k-th where $\mathbf{s} = [s_1, \cdots, s_K]^T \in \mathbb{C}^{K \times 1}$ represents the information-carrying symbol vector transuser. $n_k \in \mathbb{C}$ stands for the additive white Gaussian noise at the k-th user with zero mean and mitted to the users. Here, $s_j \in \mathbb{C}$ denotes the symbol transmitted to the j-th user and variance σ_k^2 . For notational simplicity, we define sets $K \in \{1, \cdots, K\}$, $M \in \{1, \cdots, M\}$, and $\mathbb{E}[|s_j|^2] = 1$, $\mathbb{E}[s_j^*s_i] = 0$, $j \neq i$, $\forall j, i \in \{1, \cdots, K\}$. $\mathbf{W} = [\mathbf{w}_1, \cdots, \mathbf{w}_K]$ denotes the linear $N \in \{1, \cdots, N\}$ to collect the indices of the users, MA elements, and candidate positions of the beamforming matrix at the BS, where $\mathbf{w}_k \in \mathbb{C}^{M \times 1}$ represents the linear beamforming vector MA elements, respectively MA elements, respectively. for the k-th user. $n_k \in \mathbb{C}$ stands for the additive white Gaussian noise at the k-th user

with zero mean and variance σ_k^2 . For notational simplicity, we define sets $\mathcal{K} \in \{1, \dots, K\}$, B. Resource Allocation Problem $\mathcal{M} \in \{1, \dots, M\}$, and $\mathcal{N} \in \{1, \dots, N\}$ to collect the indices of the users, MA elements, and

By introducing an auxiliary matrix X = BW, $X \in \mathbb{C}^{MN \times K}$, the received signal of the k-th candidate positions of the MA elements, respectively. user can be rewritten as follows

B. Resource Allocation Problem
$$y_k = \hat{\mathbf{h}}_k \mathbf{X} \mathbf{s} + n_k$$
. (6)

They, introductive interference plustnois exation (NNR) of the k-th user required by gnal of the

k-th user can be rewritten as follows
$$SINR_{k} = \frac{|\hat{\mathbf{h}}_{k}^{H}\mathbf{x}_{k}|^{2}}{y_{k}\sum_{k'}\hat{\mathbf{h}}_{k'}\mathbf{x}_{k}|\hat{\mathbf{h}}_{k'}^{H}\mathbf{x}_{k'}|^{2} + \sigma_{k}^{2}}, \tag{7}$$

where x_k denotes the k-th column of X. Due to the limitation of antenna size, two MA elements Thus, the signal-to-interference-plus-noise ratio (SINR) of the k-th user is given by cannot be placed arbitrarily close to each other. Thus, the center-to-center distance between any

pair of MA elements must be greatly than a minimum distance D_{\min} . We define distance matrix $\mathbf{D} \in \mathbb{C}^{N \times N}$, where element $D_{n,n'}$ in the n-th row and n'-th column of \mathbf{D} denotes the distance where \mathbf{x}_k denotes the k-th column of \mathbf{X} . Due to the limitation of antenna size, two MA

elements cannot be placed arbitrarily close to each other. Thus, the center-to-center distance

between they palir candidate position and the gréatheath didate position in Pan Thu P

In this paper, we a minimize the problem of the paper with a sum of the paper, we are allocation problem of the paper with a sum of the paper, we are paper with a sum of the paper with a sum of the paper, we are paper as a sum of the paper, we are paper as a sum of the paper, we are paper as a sum of the paper, we are paper as a sum of the paper, we are paper as a sum of the paper, we are paper as a sum of the paper, we are paper as a sum of the paper as a

$$\underset{\mathbf{X},\mathbf{W},\mathbf{B}}{\text{minimize}} \quad \underbrace{\sum_{k \in \mathcal{K}} \mathbf{W}_{k}^{\top} \|_{2}^{\mathbf{B}} \mathbf{W}}, \\
\mathbf{C3:} \quad b_{m}[n] \in \{0_{H}^{-1}\}, \forall n \in \mathcal{N}, \forall m \in \mathcal{M}, \\
\mathbf{h}_{k}^{-1} \mathbf{x}_{k} \|_{2}^{2} \Rightarrow \gamma_{k}, \forall k \in \mathcal{K}, \\
\mathbf{C4:} \quad \underbrace{\sum_{k'} b_{k'}[m]} \|\hat{\mathbf{h}}_{k}^{H} \mathbf{x}_{k} \|_{2}^{2} \neq g_{\mathcal{M}}^{2}, \\
\mathbf{C2:} \quad \mathbf{X}^{-1} = \mathbf{BW}, \\
\mathbf{C5:} \quad \mathbf{b}_{m}^{T} \mathbf{Db}_{m'} \geqslant D_{\min}, \quad m \neq m', \quad \forall m, m' \in \mathcal{M}. \\
\mathbf{C3:} \quad b_{m}[n] \in \{0, 1\}, \quad \forall n \in \mathcal{N}, \forall m \in \mathcal{M},
\end{cases} \tag{9}$$

Optimization problem (??) is nonconvex due to bilinear constraint C2, binary constraint C3, and binary quadratic constraint C5. Therefore, problem (??) is an NP-hard combinatorial problem. In the next section, we develop a GBD based iterative algorithm to rebtain the global optimum of (??). Optimization problem (??) is nonconvex due to bilinear constraint C2, binary constraint C3, and binary quadratic constraint C5. Therefore, problem (??) is an NP-hard combinatorial III. Solution of Optimization Problem In the next section, we develop a GBD-based iterative algorithm to obtain the In this section, we leverage the GBD method in [?] to obtain the globally optimal solution global optimum of (??). In the following, we first transform (??) into an equivalent MINLP problem, which provides a foundation for the Ides elopators for the Interprepaged IGBD based optimal algorithm.

In this section, we leverage the GBD method in [?] to obtain the globally optimal solution A. Problem Reformulation to (??). In the following, we first transform (??) into an equivalent MINLP problem, which problem application is obtained by obtained by the OBD campor by obtained by the OBD camporately in the facilitate line application of the OBD approach.

The globally optimal solution of (??) cannot be obtained by the GBD approach directly due to coupled constraint C2 [?] [?]. Thus, we present Lemma 1 to reformulate constraint C2 to facilitate the application of the GBD approach. **Lemma 1.** Equality constraints CDB isquivalenter the followolkgolingalismatrix interpreting (LMH) bhstraints.

C2a:
$$\begin{bmatrix} \mathbf{U} & \mathbf{X} & \mathbf{B} \\ \mathbf{X}^{H} & \mathbf{V} & \mathbf{W}^{H} \\ \mathbf{B}^{H} & \mathbf{W} & \mathbf{I}_{K} \end{bmatrix} \geq \mathbf{0}, \tag{10}$$

C2b:
$$\operatorname{Tr}(\mathbf{U}) - M \leq 0$$
, (11)

where $\mathbf{U} \in \mathbb{C}^{N \times N}$ and $\mathbf{V} \in \mathbb{C}^{N \times N}$ are two auxilliary applimization variables with $\mathbf{U} \geq \mathbf{0}$ and $\mathbf{V} \geq \mathbf{0}$.

Proof. Based on [?], Lemma 1], equality constraint £23 equivalente to LML vonstraint a G2a and inequality sobstraint raint:

$$\overline{\text{C2b}}$$
: $\text{Tr} \left(\mathbf{U} - \mathbf{B} \mathbf{B}^H \right) \leq 0.$ (12)

The left-flandsideof(??) cambb countrint as as

$$\operatorname{Tr}\left(\mathbf{U} - \mathbf{B}\mathbf{B}^{H}\right) \stackrel{(a)}{=} \operatorname{Tr}\left(\mathbf{U}\right) - \sum_{m=1}^{M} \operatorname{Tr}\left(\mathbf{b}_{m}\mathbf{b}_{m}^{H}\right) \stackrel{(b)}{=} \operatorname{Tr}\left(\mathbf{U}\right) - M,$$
 (13)

where the above equalities (a) and d(b) hold dust to the hadditivity of the limit is trace and a the definition in the interpretation of the proof.

Note that tC22 and tC252 reaboth convex constraints a Dust ho other hands the minimum distance doststraint (C5. str. (2.2) is still not 12 years in the new endorm there, the quadratic alacquality constraint (C5. str. (2.2) is still not 12 years in the new endorm the quadratic alacquality constraints by inxploiting the following become it he proof following banche, following of which can be found in [?].

Lemma 2. The inaquality-constraint C5Cts is quivalenteta the full of with god in equality as any straints into

C5a:
$$\sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{N}} D_{i,j} y_{m,m',i,j} \geq D_{\min}, \quad m \neq m', \quad \forall m, m' \in \mathcal{M},$$
C5b:
$$y_{m,m',i,j} \leq \min \left\{ b_m[i], b_m[j] \right\}, \quad m \neq m', \quad \forall m, m' \in \mathcal{M}, \quad \forall i, j \in \mathcal{N},$$
C5c:
$$y_{m,m',i,j} \geq b_m[i] + b_m[j] - 1, \quad m \neq m', \quad \forall m, m' \in \mathcal{M}, \quad \forall i, j \in \mathcal{N},$$
(14)

where $y_{m,m',i,j}$ is a bimary auxiliary variable. For the sake of matation simplicity, we define a binary vector $\mathbf{y} = [y_{1,2,1,1}, \cdots, y_{m,m',i,j}, \cdots, y_{M-1,M,N,N}], m \neq m', \forall m, m' \in \mathcal{M} \text{ and } \forall i, j \in \mathcal{N}$ to collect all binary auxiliary variables.

In addition, we observe that SINRNE instraints Ght scals is not seconvex. We note that differ harbitrary addition, we observe that SINRNE instraints Ght scals is not seconvex. We note that differ harbitrary addition that is the constraints in (132) a internal production and the constraints in (132) a internal production and the constraints of the constr

Lemma 3. Without losss off apptinality, y we assume that $h_k^H h_k^H x \in \mathbb{R}$ \mathbb{R} \mathbb{R}

C1a:
$$\sqrt{\sum_{k' \in \mathcal{K} \setminus \{k\}} |\hat{\mathbf{h}}_k^H \mathbf{x}_{k'}|^2 + \sigma_k^2} - \frac{\operatorname{Re}\{\mathbf{h}_k^H \mathbf{x}_k\}}{\sqrt{\gamma_k}} \le 0, \ \forall k \in \mathcal{K},$$
(15)

C1b:
$$\operatorname{Im}\{\mathbf{h}_{k}^{H}\mathbf{x}_{k}\}=0, \ \forall k \in \mathcal{K}.$$
 (16)

Cla and Clb are both convex constainints.

Thus, resource allocation optimization problem (??) can be equivalently reformulated as follows

$$\begin{array}{ll}
\underset{\text{XXWEBUVVy}}{\text{minimize}} & \sum_{k \in \mathcal{K}} \|\mathbf{w}_k\|_{2}^{22} \\
\text{sstt.} & \text{C1a. C1b. C2a. C2b. C3. C4. C5a. C5b. C5c.}
\end{array} \tag{17}$$

Remark 1. The MINUP problem in i(??) is conven continuitation problem which respect continuous viariables XiaWesUXanN , Wif the laber it hardisblest B continuous viariables XiaWesUXanN , Wift the laber it hardisblest B continuous viariables and syrift the axial linear viables the analysis of the axial linear variables the Winth work Variables X, Nente, the laber product His nguaranteed Do approach is the gland bally top timal solution of (??) [?].

B. GBD Procedime

In order to obtain the globally optimal solution of the MILINP problem (P?); We verely an iterative targorigani based and the GBD method Ispecifically, also MILINP problem like (P) (3 first descriptions of an interaction of the GBD method Ispecifically, also MILINP problem like (P) (3 first description of a primary problem of the master problem. The each Iteration, two tipulates are undependently on the UB) extitle folding in the splining photoein which the description of the variables Beautifolding Bixett In addition, and solve the tipulates problem to fining the continuous facilities beautifolder plants. It was about the tipulate (P) with the utollowing of we detail

the forhowlation and lookulich to father plainian and drashet ip to blembe in the althriteration to father plainian and drashet ip to blembe in the althriteration to father plainian and drashet ip to blembe in the althriteration to father plainian and drashet ip to blembe in the althriteration to father plainian and drashet ip to blembe in the althriteration to father plainian and drashet in the althriteration and drashet in the ingolithinth followed by fath explanation of the overall GBD algorithmation of the overall GBD algorithmal Problem: Using the discrete variables $\mathbf{B}^{(i-1)}$ and $\mathbf{y}^{(i-1)}$ obtained from the master problem in the roblem th Uteration ethersprintal problem in the literation is beginn by from the master problem in the (i-1)-th iteration is given by $\mathbf{w}_{k,\mathbf{w},\mathbf{u},\mathbf{v}} = \mathbf{w}_{k,\mathbf{w},\mathbf{u},\mathbf{v}} = \mathbf{w}_{k,\mathbf{u},\mathbf{v}} = \mathbf{w}_{k,\mathbf{u},\mathbf{v}$ by

s.t. Cla, Clb, C2b (18)

minimize
$$\sum_{\mathbf{X}, \mathbf{W}, \mathbf{U}, \mathbf{V}} \|\mathbf{w}_{k}\|_{2}^{2} \mathbf{U} \mathbf{X} \mathbf{B}^{(i-1)}$$

s.t. C2a, Clb, $\mathbf{X}^{i}\mathbf{D}^{b} \mathbf{V} \mathbf{W}^{H}$

$$\left[(\mathbf{B}^{(i}\mathbf{U}^{1)})^{T} \mathbf{W} \mathbf{B}^{i}_{K}^{-1} \right] \geq \mathbf{0}.$$
(18)

The primal problem in (??) is a convex problem, which can be setved by a standard convex programming solver such as CVX [?]. How Wer, the problem (??) is not feasible for all possible discrete yariables Brand y? If the primal problem (??) in the anth iteration is feasible the optimal solution of n(2.8) list denoted by $(X^{(i)})$. $(X^{(i)})$ $(X^{(i)})$ by $(X^{(i)})$ by $(X^{(i)})$ by $(X^{(i)})$ $(X^{(i)})$ by $(X^{(i)})$ $(X^{(i)})$ by $(X^{(i)})$ $(X^{(i)})$ $(X^{(i)})$ $(X^{(i)})$ by $(X^{(i)})$ $(X^{(i)}$ the circle x_i set lotes the feasible literations nT_{al} Next left (Λ^2) in $\{\mu_h \in \mathcal{F}_i, f_i\}$ denotes the application of diagrangian ionultipliers of dealer where $\mathbf{X}^{(i)}$, $\mathbf{R}\mathbf{X}^{(i)}$, $\mathbf{R}\mathbf$ represent the thurby ariables of or loon straints Colar Cib. \$24\ and \$C2bArespectively \(\text{Elle Hagrangian} \) Enthetion of the again align oblique by?), where $\mu_k \in \mathbb{R}, \nu_k \in \mathbb{R}, \Xi \in \mathbb{C}^{(N+K+M)\times (N+K+M)}$, and & entire dual variables for constraints Clar C1b2 162 arand 620 = respectively. The Lagrangian function of the primal problem is given by where

where
$$\mathcal{L}(\mathbf{X}, \mathbf{W}, \mathbf{U}, \mathbf{V}, \mathbf{A}) = \sum_{k \in \mathcal{K}} \|\mathbf{y}_{k}\|_{\mu_{k}}^{2} + \left(f(\mathbf{X}, \mathbf{W}, \mathbf{U}, \mathbf{V}, \mathbf{A}) + 2\operatorname{Re}_{k} \frac{\operatorname{Re}(\mathbf{\hat{L}}(\mathbf{\hat{L}}(\mathbf{\hat{L}}, \mathbf{\hat{L}}, \mathbf{\hat{L}}))}{\sqrt{\gamma_{k}}} \mathbf{\hat{L}}_{31})\right), \quad (19)$$
where
$$f(\mathbf{X}, \mathbf{W}, \mathbf{U}, \mathbf{V}, \mathbf{A}) = \sum_{k \in \mathcal{K}} |\mu_{k}(\mathbf{\hat{L}}(\mathbf{\hat{L}}, \mathbf{\hat{L}}, \mathbf{\hat{L}})) \mathbf{\hat{L}}_{k} \mathbf{\hat{L}}(\mathbf{\hat{L}}, \mathbf{\hat{L}}, \mathbf{\hat{L}}) \mathbf{\hat{L}}_{k} \mathbf{\hat{L}}(\mathbf{\hat{L}}, \mathbf{\hat{L}}, \mathbf{\hat{L}}) \mathbf{\hat{L}}_{k} \mathbf{\hat{L}}(\mathbf{\hat{L}}, \mathbf{\hat{L}}, \mathbf{\hat{L}}) \mathbf{\hat{L}}_{k} \mathbf{\hat{L}}(\mathbf{\hat{L}}, \mathbf{\hat{L}}, \mathbf{\hat{$$

$$+2\operatorname{Re}\left\{\operatorname{T}_{\underline{1}132}^{\underline{H}}\underbrace{\Sigma_{21}^{H}}\right\}+\operatorname{Tr}_{\underline{3}1}^{\underline{L}}(X\Xi_{21})\right\}.$$
 Here, the dual matrix Ξ is decomposed $\underline{\Xi}_{11}$ or $\underline{\Xi}_{12}$ substantives as follows:
$$\Xi_{31} \quad \Xi_{32}^{\underline{H}} \quad \Xi_{33}^{\underline{H}} \quad \Xi_{33}^{\underline{H}}$$
 where $\Xi_{11} \in \mathbb{C}^{N \times N}$, $\Xi_{21} \in \mathbb{C}^{K \times N}$, $\Xi_{22} \in \mathbb{C}_{21}^{K \times K} \Xi_{231}^{\underline{H}} \subseteq \mathbb{C}_{32}^{\underline{H}^{-M}} \times \mathbb{N}$, $\Xi_{32} \in \mathbb{C}^{M \times K}$, and $\Xi_{33} \in \mathbb{C}^{M}(20)$ denote the corresponding sub-matrices of $\Xi_{31} \quad \Xi_{32} \quad \Xi_{33}$

whomether other hand, and the official problem (??), in the fall iteration is able to the first pour dolves the following of a billion of the problem:

On the other hand, if the primal problem (??) in the *i*-th iteration is not feasible for the given $\mathbf{B}^{(i-1)}$ and $\mathbf{y}^{\mathbf{X}_{i},\mathbf{Y}_{i}}$, we solve the following feasiblity-check problem:

s.t. C1b, C2a, C2b,

minimize
$$\mathbf{x}, \mathbf{w}, \mathbf{u}, \mathbf{v}, \lambda$$
s.t. C1b, \mathbf{v}

$$\mathbf{x}, \mathbf{v}, \mathbf{v}, \mathbf{v}, \lambda$$
s.t. C1b, \mathbf{v}

$$\mathbf{x}, \mathbf{v}, \mathbf{v}, \mathbf{v}, \lambda$$

$$\mathbf{x}, \mathbf{v}, \mathbf{v}, \mathbf{v}, \lambda$$

$$\mathbf{x}, \mathbf{v}, \lambda$$

$$\mathbf{x}, \mathbf{v}, \lambda$$

$$\mathbf{x}, \mathbf{v}, \lambda$$

$$\mathbf{x}, \lambda$$

$$\mathbf{$$

$$\frac{\nabla 10, \forall \mathbf{z}, \forall \mathbf$$

where $\lambda = [\lambda_1, \cdots, \lambda_K]$ denotes an auxiliary optimization variable. Note that $(\ref{Complete})$ is always feasible and convex. Thus, we can solve $(\ref{Complete})$ with a standard CVX solver. Similar to $(\ref{Complete})$, the optimal solution of $(\ref{Complete})$ is denoted by $\widetilde{\mathbf{X}}^{(i)}$ in $\widetilde{\mathbf{V}}^{(i)}$ at $\widetilde{\mathbf{V}}^{(i)}$ at $\widetilde{\mathbf{V}}^{(i)}$ and $\widetilde{\mathbf{V}}^{(i)}$. Then, the iteration index i is included in $\widetilde{\mathbf{V}}^{(i)}$ and $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$. Then, the iteration index i is included in $\widetilde{\mathbf{V}}^{(i)}$ and $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$. Then, the iteration index i is included in $\widetilde{\mathbf{V}}^{(i)}$ and $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$, $\widetilde{\mathbf{V}}^{(i)}$. Then, we formulate the Lagrangian function of $(\ref{Complete})$ as

the Lagrangian function of (??) as $+2\text{Re}\left\{\text{Tr}\left(\mathbf{B}^{(i-1)}\tilde{\Xi}_{31}\right)\right\}$, where $\tilde{\Lambda}=\left[\tilde{\mu}_{k},\tilde{\nu}_{k},\tilde{\Xi},\tilde{\xi}\right]$ is the collection of the dual variables $\tilde{\mu}_{k},\tilde{\nu}_{k},\tilde{\Sigma}\in\mathbb{C}^{(N+K+M)\times(N+K+M)}$ (22) and $\tilde{\xi}$ for constraints $\overline{\text{C1a}}$, C1b, C2a, and C2b,+r2spectively $(\tilde{\Sigma}_{k}^{(i)})$ to the notation in $(\tilde{\Sigma}_{k}^{(i)})$, $\tilde{\Xi}_{k}^{(i)}$ for $\tilde{\Sigma}_{k}^{(i)}$ is the resulting the feasibility of the solution of $\tilde{\Sigma}_{k}^{(i)}$ is the resulting the feasibility of the feasibility of the resulting the resulting and $\tilde{\Sigma}_{k}^{(i)}$ is the resulting $\tilde{\Sigma}_{k}^{(i)}$ in $\tilde{\Sigma}_{$

2) Master Problem: The master problem is formulated based on nonlinear convex duality $\underset{\text{minimize } \eta}{\text{minimize } \eta}$ theory [?]. Whenout loss of generality, we recast the master problem into the following epigraph form by introducing auxiliary optimization variable η :

minimize
$$\eta$$
:
$$\begin{array}{l}
\text{C7a: } \eta \geqslant \min_{\mathbf{X}, \mathbf{W}, \mathbf{U}, \mathbf{V}} \mathcal{L}(\mathbf{X}, \mathbf{W}, \mathbf{U}, \mathbf{V}, \mathbf{B}, \mathbf{\Lambda}^{(t)}), \forall t \in \{1, \dots, i\} \cap \mathcal{F}, \\
\mathbf{U}, \mathbf{V}
\end{array}$$
(23)

s.t.
$$\begin{array}{ll}
\mathbf{C7b}; \mathbf{C4} & \mathbf{C7b}; \mathbf{C4} & \mathbf{C7c}, \mathbf{C7c},$$

where $\Lambda^{(t)}$ and $\widetilde{\Lambda}^{(t)}$ denoted the wolless (\widetilde{X}) where \widetilde{X} , \widetilde{W} , and \widetilde{X} and \widetilde{X} and feasibility check problem (??) in the t-th iteration, respectively. Constraints $\Lambda^{(t)}$ and $\widetilde{\Lambda}^{(t)}$ becorresponded the optimality optimal feasibility and respectively. [Charlie interal initial initial and in the feasibility check position of the theorem is a constraint of the feasibility check problem (??) in the theorem is a constraint of the feasibility check problem (??) and the feasibility check problem (??) he applied in the following lemmass pectively problem (??) and the feasibility check problem (??) he applied in the following lemmass pectively problem (??) and the feasibility check problem (??) he applied in the following lemmass pectively in the feasibility check problem (??) and the feasibility check problem (??) he applied in the following lemmass pectively in the feasibility check problem (??) and the feasibility check problem (??) he applied in the feasibility check problem (??) and the feasibility check problem (??) he applied in the feasibility check problem (??) and the feasibility check problem (??) he applied in the feasibility check problem (??) and the feasibility check problem (??) he applied in the feasibility check problem (??) and the feasibility check problem (??) he applied in the feasibility check problem (??) and the feasibility check problem (??) he applied in the feasibility check problem (??) and the feasibility check problem (??) he applied in the feasibility check problem (??) and the feasibility check problem (??) he applied in the feasibility check problem (??) he applied

[?]. The inner minimization in C7a and C7b can be obtained from the optimal solutions **Lemma 4.** Inequality constraints C7a and C7b can be recast as the following two linear of the primal problem (??) and the feasibility-check problem (??) exploiting the following inequalities:

lemma:

 $\overline{\text{C7a:}} \ \eta \geqslant \sum_{k} \left\| \mathbf{w}_{k}^{(t)} \right\|_{2}^{2} + f(\mathbf{X}^{(t)}, \mathbf{W}^{(t)}, \mathbf{U}^{(t)}, \mathbf{V}^{(t)}, \mathbf{\Lambda}^{(t)}) + 2\text{Re}\left\{\text{Tr}\left(\mathbf{B}\boldsymbol{\Xi}_{31}\right)\right\},$ Lemma 4. Inequalities: $\forall t \in \{1, \dots, i\} \cap \mathcal{F},$ (24)

$$\frac{\overline{C7b}}{C7a}: 0 \geqslant \sum_{k \in \mathcal{K}} |\mathbf{W}_{k}^{(t)}| \mathbf{V}_{2}^{(t)} + f(\mathbf{X}^{(t)}, \mathbf{W}^{(t)}, \mathbf{U}^{(t)}, \mathbf{V}^{(t)}, \mathbf{V}^{(t)}, \mathbf{V}^{(t)}, \mathbf{X}^{(t)}) + 2Re \{ \text{Tr}(\mathbf{B}\Xi_{31}) \}, i \} \cap \mathcal{I}, (25)$$
respectively.

 $\forall t \in \{1, \dots, i\} \cap \mathcal{F},\tag{24}$

Proof. We first study (the inner iminimization problems in §67 a Box sible iteration index t; (25)

respectively. $\min_{\mathbf{X}, \mathbf{W}, \mathbf{U}, \mathbf{V}} \mathcal{L}(\mathbf{X}, \mathbf{W}, \mathbf{U}, \mathbf{V}, \mathbf{B}, \mathbf{\Lambda}^{(t)})$

Proof. We first study the $\lim_{k \in \mathcal{K}} \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{X} \cap \mathbf{X}| = \lim_{k \to \infty} |\mathbf{X} \cap \mathbf{$

$$\stackrel{(a)}{=} \underset{k \in \mathcal{K}}{\underset{||\mathbf{W}_{k}^{(t)}|}{\underset{||\mathbf{W}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{X}_{k}^{(t)}|}{\underset{||\mathbf{$$

where equality (a) the optimality condition of the Lagrangian function of a convex

optimization problem. Similarly, we can also prove that
$$= \sum_{k \in \mathcal{K}} \|\mathbf{w}_{k}^{(t)}\|_{2}^{2} + f(\mathbf{X}^{(t)}, \mathbf{W}^{(t)}, \mathbf{U}^{(t)}, \mathbf{V}^{(t)}, \mathbf{\Lambda}^{(t)}) + 2\operatorname{Re}\left\{\operatorname{Tr}\left(\mathbf{B}\mathbf{\Xi}_{31}^{(t)}\right)\right\}, \tag{26}$$
where equality (a) hold $\tilde{\mathbf{X}}\tilde{\mathbf{W}}$ to the optimality condition of the Legrangian function for a

where equality (a) holds to the optimality condition of the Lagrangian function for a

convex optimization problem
$$(t)$$
 Similarly, (t) we can also prove that $(\mathbf{B}\tilde{\Xi}_{31}^{(t)})$, (27)

if the primal problem
$$(??_{\hat{\mathbf{X}},\hat{\mathbf{W}}}^{\min},\widetilde{\mathcal{L}}(\hat{\mathbf{X}},\widehat{\mathbf{W}},\hat{\mathbf{U}},\hat{\mathbf{V}},\mathbf{B},\widetilde{\boldsymbol{\Lambda}}^{(t)})$$
 \square

Note that by replacing inequality constraints $\overline{C7a}$ and $\overline{C7b}$ by constraints $\overline{C7a}$ and $\overline{C7b}$ respectively, optimization problem (??) is recast as a mixed integer linear programming (MILP) if the primal problem (??) is infeasible in the *t*-th iteration solvers for MILPs, e.g., MOSEK [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., MOSEK [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., MOSEK [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., MOSEK [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., MOSEK [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved by employing standard numerical solvers for MILPs, e.g., mosek [?]Note that indicate solved in the solven solved by employing standard numerical solven solve

(MILP) yandbletgo rithinh The overally procedure politic group oscal optimal algorithme is sum Malitzed ing Algorithm [1]. Before pthe afirst literation, (We) set thin dexthi iterateiron and controllers $\mathbf{B}^{(0)}$ and $\mathbf{y}^{(0)}$ to a feasible solution. In the *i*-th iteration, we begin by solving problem (??). If the problem vis alia subjective upen Elater the adoptional divide the propose of problems in a (23) i blace describe intermediate Algorithm X(1) BM6(1), tW(1) firM(1) teant their corresponding Lagrangian intultiplie B(2) A(d). Furthermore axis lupdate the upper bound IU Ber at (2?) with the objective radue objective radue of len w bb tainedrinbline durfentiliteration generoblethe (22) timiniliteasible fovethurm to stel verticle densibility) checkl problem for (22) littlegeneratent (24) littlegeneratent (25) littlegeneratent (26) littlegeneratent (26 optimially: solve the Fnaster: probleme in p(23) outsing up standard (MTEF) solver? The tlob jective evalue oalthe master problem priorides a performance thouse or both problem for the so riginal lopt mization problem the (72)si Bilyitfollowing this leproced (uff) we giteratively bredeceil the gap to be welcome the sLB amdbleBr.inSuchschatteration.wBaseti.comlf?,sTheorithm 2r4st thepprobasednGBD-basied; algorithmanis Attilizanteed to converge teethis globally optimal solution of (??) in particular number of iterations for begiven LDnVefgende toleringe at the OzaAlthough the worst? Case Boorful itation all is implexity of the proposed GBD based algorithm scales exponentially with the number of MAI elements him our 2irhulation rexperience BD the sproposed i GBD impethod no overgod investignificantly lie well vite pations **shantamenha**(u**st)**v**e**nseafohite number of iterations for a given convergence tolerance $\Delta \geq 0$. Although the worst case computational complexity of the proposed GBD-based algorithm scales exponentially with the number of the clements, the proposed tops with a gorithm with evaluate the performance of the proposed tops which algorithm with numerical simulations. We consider a system where the BS is equipped with $M=4\,\mathrm{MA}$ elements to provide communication service for K=4 single-antenna users. The carrier frequency is set to 5 GHz, i.e., the wavelength is $\lambda = 0.06$ M. The transmitted area is a square area of size $l\lambda \times l\lambda$, where this the homeatized transmitter areas szenanne BS. (Due prothes properties of the MAndriven then teans mitten directions quilibrated sinter discrete positions with Bajual edistance distance distance discrete positions. eleThentai timprovdistanoen Dungi ésticento en Oto for The usets single andomive distributed hance their distance to ithe BS is 5 will mive distributed the tweenis 20 hr= to .000 m. The prosess was lancer of each aserais secracof-stoodBmx t/X; w Ker As in the inthe following the channel too efficients but the BSt Wein to the properties of the MA driver, the transmitter area is quantized into discrete positions with equal distance d as shown in Fig. 1. The minimum distance D_{\min} is set to 0.015 m. The users are randomly distributed, and their distance to the BS is uniformly distributed between 20 m to 100 m. The noise variance of each user is set to -80 dBm, $\forall k \in \mathcal{K}$. As

Algorithm 1 Optimal Resource Allocation Algorithm

```
iterations sindibes SFF = \emptyset \emptyset the last soft inflicatible iterations tindic is A cos \emptyset, an A convergence telerance A cos \emptyset.
       generategarfeasible B(0).
 2: repeat
            Set i = i + 1
 3:
            Solve (??) for given \mathbb{B}^{(i-1)}, and \mathbb{V}^{(i+1)}.
 4:
            if the primal problem (??)?is ife asible thenen
 5:
                 Update:XX^{(i)}VW^{(i)}UU^{(i)} and M^{(i)}V and store the corresponding subjective function value of D_{R-R} and M^{(i)}V of
 6:
                 Construct \mathcal{L}(X, W, U, V, B, \Lambda^{(i)}) based on (??)
 7:
           Update the upper bound of (??) as UB^{(i)} = \min \left\{ UB^{(i-1)}, \sum_{k \in \mathcal{K}} \left\| \mathbf{w}_k^{(i)} \right\|_2^2 \right\}, and update \mathcal{F} by \mathcal{F} \cup \{i\} elsewhere the upper bound of (??) as UB^{(i)} = \min \left\{ UB^{(i-1)}, \sum_{k \in \mathcal{K}} \left\| \mathbf{w}_k^{(i)} \right\|_2^2 \right\}, and update \mathcal{F} by
 8:
                 Solve (??), update \widetilde{\mathbf{X}}^{(i)}, \widetilde{\mathbf{W}}^{(i)}, \widetilde{\mathbf{U}}^{(i)}, \widetilde{\mathbf{V}}^{(i)}
10:
            elsConstruct \widetilde{\mathcal{L}}(X, W, U, V, B, \widetilde{\Lambda}^{(i)}) based on (??)
19:
                 Similar \mathcal{Z} by \mathcal{Z} dat (i) \widetilde{\mathbf{X}}^{(i)}, \widetilde{\mathbf{W}}^{(i)}, \widetilde{\mathbf{U}}^{(i)}, \widetilde{\mathbf{V}}^{(i)}
10:
            end instruct \widetilde{L}(X, W, U, V, B, \widetilde{\Lambda}^{(i)}) based on (??)
13:
            Solve the relaxed master problem (??) and update \eta^{(i)}, \mathbf{B}^{(i)}, and \mathbf{y}^{(i)}.
12:
            Lipid if the lower bound as LB^{(i)} = \eta^{(i)}
13:
16: untible the red and ster problem (??) and update η<sup>(i)</sup>, B<sup>(i)</sup>, and y<sup>(i)</sup>.
            Update the lower bound as LB^{(i)} = \eta^{(i)}
```

Set iteration index i = 0, initialize upper bound UB(S(0)) >>> 11, llower bound LB(0) = 0, the set of feasible

the m-th MA element and the k-th user at \mathbf{p}_n is modeled as follows³,

16: until $UB^{(i)} - LB^{(i)} \leq \Delta$

Where $^{1}P_{p}$, is the diffeone field response vector (FRV) at the k-th user equipped with a single fixed-antenna. Diagonal matrix Σ_{k} $h_{\overline{m},k}^{-1}(\mathbf{p}_{n})[\sigma_{-1},\mathbf{k}_{L_{p}}^{T}\Sigma_{k}\mathbf{g}_{k}(\mathbf{p}_{n})]^{T}$ contains the path responses of \mathbf{x} \mathbf{k} \mathbf{k} \mathbf{k} \mathbf{k} is the all-one field response vector (FRV) at the k-th user. All path response coefficients where $\mathbf{1}_{L_{p}}$ is the all-one field response vector (FRV) at the k-th user equipped with a single $\sigma_{l_{p},k}$ $\forall l_{p} \in \{1,\dots,L_{p}\}$ are independently, and identically distributed and follow complex Gausnix distribution $\mathcal{CN}(0,L_{0}D_{p}^{-\alpha})$, where L_{0} , D_{k} , and $\alpha=2.2$ denote the large-scale fading at of all $L_{p}=16$ channel paths from the transmitter area to the k-th user. All path response reference distance $d_{0}=1$ m, the distance from BS to the k-th user, and the path loss exponent, coefficients $\sigma_{l_{p},k}$, $\forall l_{p} \in \{1,\dots,L_{p}\}$ are independently and identically distributed and follow complex G_{n} and G_{n} is the distance denoted field response channel model in $[2,l_{n}D_{n}^{-\alpha}]$, where L_{n} $[2,l_{n}D_{n}^{-\alpha}]$ is the adopted field response channel model in $[2,l_{n}D_{n}^{-\alpha}]$ where L_{n} $[2,l_{n}D_{n}]$ and L_{n} and

³The adopted field-response channel model in [?], [?] leverages the amplitude, phase, and angle of arrival/departure information on each multipath component under far-field condition to characterize the general multipath channel for MA-enabled systems. pospedtivelyx $\mathbf{g}_{\theta}(\mathbf{p}_{H})$, denotes the lya $\mathbf{g}_{\theta}(\mathbf{p}_{H})$, which is given by [?], [?]

$$\mathbf{g}_k(\mathbf{p}_n) = \left[e^{j\rho_{k,1}(\mathbf{p}_n)}, \cdots, e^{j\rho_{k,L_p}(\mathbf{p}_n)}\right]^T, \tag{29}$$

where $\rho_{kklp}(\mathbf{p}_n) = \frac{2\pi 2t}{\lambda} \left(\left(\eta_k x_k \cdot x_1 \right)_1 \cos\theta_k \theta_{kk,k} \sin\phi_k \phi_{kk,l} + \left(y(y_k \cdot y_1)_1 \sin\theta_k \theta_{kk} \right)_p \right)$ represents the tylina sphdister. ference of the dp-th perhander path between type and the first those first those from $p_{\Omega} s \theta_{kl} g_{n}$ and $\theta_{kl} g_{n}$ denote the elevation land aziniuth anglesion departures of the pathuchannel paths for the well pushes fespeloti keth $\text{ and } \text{r, followed the eprobability lidensity: } \text{ fund tiddility}_{X \circ \mathcal{O}}(\theta) \text{ sity}_{\phi} \text{ fund tiddility}_{p} \text{ of } \text{ then}_{\frac{\cos\theta_{k_i, l_p}}{2\pi^{-1}}}(\theta) \theta_{k_i, l_p} \phi \in l_p [-\pi/\frac{\cos\theta_{k_i, l_p}}{2\pi^{-2}}],$ $\theta_{k,l_p} \in [-\pi/2,\pi/2]$. In this work $2 \text{verk}/2 \text{v$ and the basedines schemes as a per the experimental esetup in f2: the addition in wet about der also? stepudilitei dno five/20ms0103 alsto ainstestigate the feffect of \$18pnsize onveystgat openforaffence of step sizWerconsider three baseline schemes for comparison. For baseline scheme 1, the MA elements areWixed as iderpositions that satisfy the enform on opistione constraint and archesely randowly from At The beamforming vectorit what but aimed by solving the beamforming problem for fixed antenhasarrayarehanlbyifra iserfildefihitebrelaxfationing ly Forobasyline ischemeing dwb vadobt ithe tAs technilqueniwhere obdeBS forequipped rightna 2 xxxly anifophoyilan arcaniale (IUPA) right africad-position lanteninas splaced by \(\frac{\psi_2}{2}\) adopto3\lm \(\frac{\psi_2}{2}\) and alternate of the antennal splaced by \(\frac{\psi_2}{2}\) and alternate of the antennal splaced by \(\frac{\psi_2}{2}\) and \(\frac{\psi_2}{2} are statistically independent AWevsblv extre-bearing problem for all yposs 2 ble subsets of utilities. ahtentalelements and sefected the optimal Subset that minimizes the BS transmindower. Note that the vanteum expading of annot delaudifusted lim baseline scheme 2f. For baseline scheme 3 and designed shboptimalaterative algorithmibased the ABS Specifically, owe advoiteration, the amforming practing Whiso phimized stord a dixeas blimary decision in fatrix a Belibta and cinetile bast designor. Afterwards Be is tundaded rightan black-board in the State should (BCD) a chairment from the sixed r Wing brain eit i Witie opticalization, fixed binary decision matrix B obtained in the last iteration. Afterwards, B Figur Casholwin the lawer age BS in a psychite power (EQU) enter the considered so the Mes becisus the **users'uminitmarequired** SINR values $\gamma_k = \gamma$, $\forall k$, where the transmitter area of the MA at the BSFig 2X×20ows 0.112 average 25th tFonstheir considered SINR fangelands deid 0.00 milithe proposed schensene qui resnonna verager appsolvi in atelyet 20/i teration stoodbraint like tylobahi optimale solution; Which tist lmuElS faste \(than \ample than \ample ample \) extra than \(than \ample ample than \ample than \ampl is observed thateas sheemin incoming required. Settle Revalup incincased, the BS to assume stong transition glower topsatisfy sheution; rigirous quality-of-servideare qui rentents to f the casers. Further possible also tobserve that the proposed is the molour performation through the entire

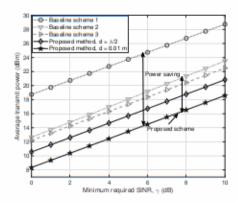


Fig. 2. AverageBSSransmitrity overwersus the thin minimequired SINR of NR users.

range of so the particular for spaseline is chemic bother BS is a tight product with carried tense are discovered by fixed can tennal position sofit the threspat fair correlation we take transmittent a larray of sorot optimals Although baseline lso he has 2 iemploys nAS fto the reaser the appatial DoFs partice BS, which selads sohæperformlancB Sniprovenigent de contidared ton baseliners che met ll., fikedspatilahres obuticitio (1/2) cis quite speaks duer that lier fixed thosition santen as setting a As for sbaseline ticheme At hher adopted IAO adportibility optimizes Affect positions coff the pMtAe blook at statide tBS beamforwards treatrix collections to an 5 odB egain temparate dot base kirlin schement. However, tast the oAQ based / algist ithin is generally subdottifinal due stoi dts. Jordali searcht iitemas get trappled eins stationaryt beinds opresult fire i ale ar it ldB petformanch gapositionared to the learning time to the learning the le dffully exploiting the DoFs browided by the Broposed MAtlen abled systemal Mointdowers increasing such step is size of other electronne change and all idevice $\cot t = 2\pi t$ de adsstation performance, loss of inquightly 2 dB, pindfonting other trade not fabetive on the ptraps and power adness that oMA who ritrollighties tent line Michigan of the DoFs provided by the proposed MA-enabled system. M Figov22 depicts the relationships between the BS transmit power land the normalized transmitter area for the size of the size the BSA transmitt powers idec mases Assemble Indranatized transmitter area size increases. This can be att Fibried? to the cfact that reliangers trians mittere are shall boos trighten flexibility for the position in izof ther MAitelements for slifaping the desired Wpatible correlation for atting to postential eperformable AGD DONG the bother than B State line is the mess deanth 2 swith the interior fixed zonte man a position are carried benefits from hikurgen thansutiftlenacek, tindleating that the selling schemes thiated 2: cannol fully luightee the spatial DoFs provided by a larger than smitter area of is sworth that its print over optimal

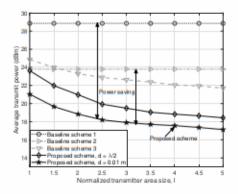


Fig. 3. Average BS 9 ransmit pityperwersus the abomalized lizard natites are a size of this MA-chebled system.

scheing dutperfortnatilite threfo basetine gehemes int berms loft the BS than shire powern Specifically. foit llargeir transmitteerareap, othe ogap chetween ethefit A Debased exchemic anschitterop timal indesigning entarged since the MO approach 2 is more tikely to thin verge to a tioda Dopting and Furthermore, the performance of the proposed scheing sharrates when the normalized transmitter afea size reaches Baindicating that the performance Bof MA-seniable discusses damley, bourflother improved by auxing evenglapgere transmitter areasased scheme and the optimal design is enlarged since the AO approach is more likely to converge to a local optimum. Furthermore, the performance of the proposed scheme saturates when the Normalized transmitter area size reaches 3, indicating than this work, we never ig at the first time of the optimal resource allocation design forea handtinsera Makietabled adownlink MISO communication system. Due to the practical hardware limits, we modeled the movement of the MA elements as a discrete motion. Then, we formulated an optimization problem for the minimization of the BS transmit power while guaranteeing a millionation SINR of the vestiga Wel showled theat the golden popularisation all the free medical borning attitution and the could be described with an generalize iGBD based at no Frant Othes invaration results are district the superficited by the proposed of ultimed MA regarded MISO system attitude bottmalify of the or opes of the painted by the composition of the control of the composition efficient subopening scheme from Stacken Ma-enapted Vosten with the befree Chally optimal solution of the formulated optimization problem could be obtained with an iterative GBDbased algorithm. Our simulation results revealed the superiority of the proposed multiuser MA-enabled MISO system and the optimality of the proposed GBD-based algorithm. In future work, we will develop a computationally efficient suboptimal scheme for a practical MA-enabled system with imperfect CSI.