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Beam-space MIMO-NOMA Technique for mm-Wave Communication Systems

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Abstract

The multiple input multiple output antenna Scheme is believed to be the most promising strategy for next-generation wireless communication networks that utilize millimeter-wave (mm-wave) frequencies and enable them to have a large information rate. As a result of the large number of radio frequency chains, MIMO mm-wave technology has difficulty with energy consumption. The beam space MIMO (or BS-MIMO for short) reduces the total number of radio frequency components or chains (RF-Chains) without degrading performance significantly. However, BS-MIMO restricts the number of users that can be supported at the same time-frequency domain that cannot exceed the overall RF-chains number. With the concept of non-orthogonal beam space-MIMO (NOMA-BS-MIMO the base station can support the service for more than one user through the same beam through the same radio frequency chain, causing the total number of users greater than the number RF-Chains.

In this work, the Spectral performance of a proposed non-orthogonal beam space-MIMO has been addressed. More specifically, the research proposes and develops a simple iterative algorithm with near-perfect performance in terms of system Spectral Efficiency. To attain rate balancing across users, the Signal-to-Leakage-Plus-Noise Ratio and the Intermediate Value (SLNR-IV) approach is applied in the proposed structure. According to the obtained results, the proposed method enhances bandwidth efficiency by almost (15%) in comparison to the traditional approach based on OFDM and Zero-forcing digital precoder.

Keywords: Millimeter-wave; MIMO-NOMA; Beam space-channel; RF-chains; Power Allocation; precoder Matrix; Rate-Balance.

الخلاصة: يعتبر نظام متعدد هوائي الادخال والإخراج بمثابة الطريقة الواعدة للاتصالات اللاسلكية الحالية التي تستخدم ترددات الموجة الملميترية (mm-wave) وتوفر عمليا الكثير من متطلبات الجيل الخامس (5G). رغم ذلك فانه نتيجة للعدد الكبير من الوحدات الراديوية ، تواجه تقنية الموجات المليمترية متعددة الادخال والإخراج مشكلة في مقدارالطاقة المستهلكة. ومن هنا جاءت تقنية الاشعاع المكاني (BS-MIMO) لتقلل عدد هذه المكونات الراديوية دون تدهور الأداء بشكل كبير. ومع ذلك ، فان تقنية الاشعاع المكاني تحدد عدد العملاء المخدومين باستخدام نفس التردد والزمن (لا يمكن أن يتجاوز العدد الإجمالي لسلاسل التردد الراديوي). ومن اجل التعامل مع هذه المشكلة ،تم تضمين تقنية الوصول المتعدد غير المتعامد (NOMA) مع مفهوم مساحة الحزمة لإنشاء نموذج إضافي لمساحة الحزمة غير المتعامدة (NOMA-BS-MIMO). وبالتالي ، يمكن أن يساعد العديد من المستخدمين عندما تقترن متجهات القناة ببعضها البعض في ارتباط معين بحيث يصبح من الممكن عندها خدمة اكثر من مستخدم واحد بنفس الحزمة او الشعاع. يقترح هذا البحث ويطور خوارزمية تكرارية بسيطة ذات أداء شبه مثالي. لتحقيق معدل نقل للمعلومات متوازن بين جميع المستخدمين ، حيث تستخدم هذه الطريقة المقترحة (SLNR-IV) نسبة الإشارة إلى التسرب زائد الضوضاء وطريقة القيمة المتوسطة. تحقق الإستراتيجية المقترحة مستوى من تحسين كفاءة عرض النطاق الترددي مقداره حوالي 15٪ مقارنة بالنهج التقليدي القائم على تقنية (OFDM) التقليدية و تقنية توجيه الحزمة الرقمي (ZF).

1. INTRODUCTION

These days communication schemes, such as 5G and beyond, require masses of components to deliver the appropriate level of performance, as has been declared in [1]. Also, Ref. [2] specified that the utilization of mm-wave technology within the frequency range of 30-300 GHz enables the using of additional antenna components on the same physical dimensions, resulting in massive MIMO (m-MIMO) that provides precoding and multiplexing benefits. However, the employment of "mm-wave MIMO" approaches is ineffective because of the total number of radio frequency components and consequently increases the complexity of the hardware where a particular type of electrical components required at both the transmitter and receiver ends of the communication channel. They are referred to as "RF-Chains," and they consume 250 mW of power on a per-RF-Chain basis.

The application of "mMIMO" techniques accordingly leads to a massive RF chain range, which creates the issues that were stated earlier. Radio frequency components are responsible for up to 70% of the overall power consumption at both the transmitter and receiver ends, according to the findings of a previous study in Ref. [3]. In this regard, a lot of work has been carried out to handle the challenging of beam-selection strategy to cut down on the overall number of RF chains [4][5]. In the most recent few years, a different way of thinking has emerged that can be characterized as follows: "BS-MIMO" is an exciting new paradigm that has the potential to drastically reduce the number of RF chains needed for "mMIMO" in mm-wave communications. This reduction in the number of RF chains is necessary in order to accomplish "mMIMO". Application of the lens-antenna array is one way this size reduction could be accomplished [2]. Where by leveraging the BS-MIMO, the standard MIMO channel can be moved to beamspace channel and hence attractively seize the sparsity feature that exist in the mm-wave channel. Because of this, there will be a significant decrease in both the amount of the power and the system hardware. This is because selecting the dominant beams will result in the overall RF chain being cut back, leading to the beam space channel. In addition, because it employs lens antenna arrays, “BS-MIMO” contributes to the preservation of narrow beams, which helps to ensure that the precoding process is effective. This not only lowers the amount of power consumed by each beam but also lowers the amount of interference between the beams [3].

In this aspect, it is expected that BS-MIMO will be able to provide near-optimal performance despite the need for much more engineering than conventional MIMO. In addition to a performance that is greatest to that of the primary beam-selection systems when compared to that performance, however, BS-MIMO suffers from a fundamental drawback, which is that there is a limited number of users that can be served at a constant time-frequency resource, which must not exceed the limited number of RF-Chains. This is a significant limitation of the technology. This is due to the fact that the Degree-of-Freedom (DOF) produced by RF chains ought to be higher than the DOF of users in order for this to be possible [2]-[7]. Recently, researchers interested in a brand new topic that combines the benefits of “BS-MIMO” and subsequently of “MIMO-NOMA” to deliver the “BS-MIMO-NOMA” concept [8][9]. Massive connectivity, decreased latency, and increased quality of service are all outcomes that will follow from NOMA's ability to provide service to a consistent number of users on the same resources regarding the time, frequency, and code, regardless of location with an acceptable quality of service (QoS) [8]-[9].

Power domain multiplexing is utilized in this approach, successfully achieving the aforementioned objectives. Through the implementation of the idea of superposition coding in conjunction with “(Successive-Interference-Cancellation or SIC for short) at both the transmitting and receiving ends, respectively” [10]. Because of this, [8] uses a strategy known as the second-order cone trick in conjunction with the sequential convex approximation to get around the challenges linked with the NOMA-BS-MIMO power allocation challenge. However, looking at it from another angle, ref. [11] combines the optimization approaches of Gray Wolf and Beetle Swarm to attain the multi-objective growth of performing metrics in NOMA-BS-MIMO from spectral, and energy efficiency (EE) points of view. Ref. [12] developed a simple iterative technique that, after some iterations, achieves a performance that is nearly on par with that of the ideal. This technique, which is based on the Mean Square-Error Dynamic Power Allocation Algorithm, offers an improvement in energy efficiency of roughly 85% when compared to the standard OFDM systems’ EE.

In contrast to the study in [12], which optimizes the rate of NOMA systems subject to the minimum rate (min_QoS) required by individual users, this study maximizes the rate of NOMA systems with power-allocation constraint employing a simple approach for this task. This work focuses on the rate balance of beam space NOMA systems. Moreover, unlike [13], which adopts a Mean Square-Error-Based Dynamic Power Allocation, this study uses a simple interval halving method for the Power control using the Signal-to-Leakage-Plus-Noise Ratio (SLIN) digital beamforming. Accordingly, this study has the following contributions:

- This article presents a method for optimizing the quality of service (QoS) while adhering to the constraints of power allocation in mm-wave NOMA-BS-MIMO. Wherever the difficulty (non-convex problem) has been built taking into consideration the most important necessary constraints for each user, such as power budget and minimum rates.

- The proposed approach takes advantage of the signal-to-leakage-plus-noise ratio (SLNR) and the intermediate value method to achieve the quality of service, also known as rate balancing for all of the customers.

- Through simulation, the system performance criterion known as bandwidth efficiency has been justified for a variety of different configurations of system parameters.

The remaining parts of the paper have been organized in the following manner: The BS-MIMO and BS MIMO-NOMA system model is introduced in the second section, the down link rate formulation is presented in the third section, and the numerical and simulation analysis is shown in the fourth section. The last part of this work is the conclusion, which is presented in section five.

Notation: The capital letters and small letters in this context are typically used to denote matrices and vectors throughout the article, respectively. Whereas the operation $[-]^{T}$ seeks to represent the transpose of the matrix, $[-]^{H}$ for complex-conjugate (Hermitian), and $[-]^{-1}$ for matrix inversion. The representation of the norm operation with a length of p is written as $[-]_{p}$. alternate matrix representations that are comparable to the diagonal of matrix P are represented by exploitation diag [p], expectation matrix is indicated by E[-], and unit matrix of dimensions NxN is denoted by I_N.

2. SYSTEM MODEL

The downlink (DL) of one cell, i.e., a single AP (access point) is the primary subject of this investigation, which is based on a mm-wave technology. The research assumes that the AP includes N-antennas and N_{RF}-radio chains that give service to K clients each one holding a single antenna.

2.1 BS-MIMO System Model

The vector of the received signal {y1, y2, , y3…,yK } for the usual MIMO system, can be expressed as follows:

$$\boldsymbol{y} = \boldsymbol{H}^{\boldsymbol{H}}\boldsymbol{F}.s + \boldsymbol{z}\,,\ \ldots\ldots(1)$$

where H is the channel matrix, $\mathrm{H} = \{\mathrm{h}_1, \mathrm{h}_2, \ldots, \mathrm{h}_K\}$ is the channel vector between the AP and kth user, F is the transmission precoder matrix, s is the vector of the transmitted signal, also, $\mathrm{s} = [\mathrm{s}_1, \mathrm{s}_2, \ldots, \mathrm{s}_\mathrm{k}]$ for all K clients and z is the Additive-White-Gaussian-Noise (AWGN). It is interesting to note that the channel model developed by Saleh and Valenzuela has been assumed [2], [3], [9] with the following gain,

$$\boldsymbol{h}_k = \beta_k^{(0)}.\,a\,[\theta_k^{(0)}] + \sum_{l=1}^{L} \beta_k^{(1)}.\,a\,\left[\theta_k^{(1)}\right]\ldots\ldots\ldots\ldots(2)$$

wherever the “Line-of-Sight (LOS) of the kth user is denoted by the component $\beta_k^{(0)}.\,a\,[\theta_k^{(0)}]$, with $\beta_k^{(0)}$ is the complex gain, and $a\,[\theta_k^{(0)}]$ “denotes to the spatial direction. The “L overall number of (Non-Line-of-Sight NLoS)” components is shown by "$\sum_{l=1}^{L}\beta_k^{(1)}.\,a\,[\theta_k^{(1)}]$" for “$1 \leq l \leq L$” is the l-th N LoS path of the kth client. The number of radio chains is comparable to the number of antennas contained inside the AP. Yields, "$N_{RF} = N_t$" which is a huge radio chains number when mm-wave large-scale MIMO systems are applied [7]. Thus, the employment of mm-wave large-scale MIMO in intelligent systems is deemed ineffective because of its high complexity generated by the vast quantity of radio chains. As stated previously, each radio chain consumes around 250mW; for a system with 256 antennas, the radio chain intensity is approximately 64W, which is not a little amount of power to lose [14]. This issue is addressed by the introduction of the “BS-MIMO” concept, which makes use of the lens-antenna array to shorten the range of the radio chain without causing a discernible drop in the system's overall performance. In light of this, the “MIMO special-domain” is mapped onto the beam space channel where the received signal (BS-MIMO vector) can be stated as below [15],

$$\bar{\mathbf{y}} = \mathbf{H}^{\mathbf{H}}\,\mathbf{A}^{\mathbf{H}}\,\mathbf{F}.s + \boldsymbol{z} \;=\; \overline{\mathbf{H}}^{\mathbf{H}}\,\mathbf{F}\,s + \boldsymbol{z},\ldots..(3)$$

where, $\mathbf{\overline{H}^{H}}$=$\mathbf{H^{H}}$ $\mathbf{A^{H}}$ is the channel matrix of beamspace, and it's stated as,

$$\boldsymbol{\overline{H}^{H}}=\{\boldsymbol{\overline{h}_1^{H}}, \boldsymbol{\overline{h}_2^{H}}, \ldots.\boldsymbol{\overline{h}_K^{H}}\}\boldsymbol{\ldots\ldots}\ , (4)$$

and here, the vector $\boldsymbol{\overline{h}_K^{H}}$ is the BS-MIMO path between the access point and kth client, and **A** offers the orientation vectors of the lens antenna (that cover the total angle space [6] So, $\boldsymbol{h}_k$ is the vector of the spatial channel that Fourier-transformer to $\boldsymbol{\overline{h}}_{k"}$. Furthermore, each row of the beam space channel matrix $\boldsymbol{\overline{H}}$ refers to a single beam that was sent from the transmitter to the receiver. In a similar fashion, each row of the $\boldsymbol{\overline{H}}$ matrix is paired with a B-beam that has the spatial direction θ_1, θ_2…, θ_B. As a direct result of this, it is generally knowledge that mm-wave communication routes only provide a constrained variety of link scatters to choose from. Because of this, “NLoS” approaches May ultimately end up falling short of the expectations set by B-beams [7]. In light of the fact that this is the situation, the research will conclude that there is an exiguity behavior existing within the beam matrix of the beam space. This is due to the fact that the number of current components that are present in each vector of the beam space channel frequently does not correspond to the number of beams. Accordingly, and also because of the explanation that came before it, this is the direct consequence of both. As a consequence of this, academics are in a position to assert that there is a sparsity behavior in the channel matrix of beam space [15]. Because of this demanding behavior, a "BS-MIMO" design with much-reduced dimensions and near-optimal performance can be attained. This is possible since the dimensions can be greatly diminished. Now, as previously indicated, the beam space fundamental limit is, which means that the number of radio chains must be equal to or more than the number of provided clients within the same time/frequency resources. The incontrovertible truth that the "DoF" offered by radio chains should exceed the minimal "DoF" demanded by users [2-3], [5-6] and [15]. To overcome this limitation, a new technology that mixes NOMA approach with the idea of beam space-MIMO has been designed [16]. which can be clarified within the next sub-section.

2.2 BS-MIMO-NOMA System Model

To cope with the previous limitation of BS-MIMO, the NOMA-BS-MIMO system depicted in Figure (1) has been suggested, which may simultaneously service multiple clients by using similar resources i.e., (frequency, time, and spatial) domains [16]. Moreover, there is a restriction on selecting several clients inside an equivalent beam, as these shares linked channels. Determining the most efficient use for each beam necessitates the introduction of numerous ways to beam selection, such as those outlined in references such as [3], where a maximum Signal-to-interference-plus-noise (SNIR) technique is introduced

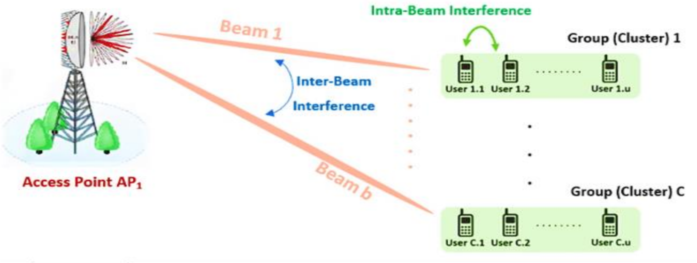

Figure 1 BS-MIMO-NOMA system model.

In addition, a "Maximum-Magnitude" approach is suggested in reference [17]. Ref. [7] states that the proportion of the probability of clients possessing a correlative channel in a common mm-wave system scenario with 256 components of antenna and 32 client equipment is 87%. In contrast to BS-MIMO, in which the system must select a single client for each radio chain, NOMA-BS-MIMO is capable of simultaneously servicing all correlated users with a single beam and RF-Chain. This ends up in served users range being more significant than the RF-Chains number, i.e., the key advantage of NOMA-BS-MIMO [16]. As was previously said, the NOMA system utilizes the same frequency/time/spatial domains for all of the clients that are within same radio chain i.e., the same beam. So, the multiplexing takes into account the structure budget for each user that is part of the cluster of users who have conflicts [15]. It is common practice to write the received signal of the NOMA-BS-MIMO that is depicted in Figure .1 as follows:

$$y_{kb} = \underbrace{\boldsymbol{\overline{h}_{kb}^{H}}\, \boldsymbol{F_{kb}} \,.\sqrt{P_{kb}}\,.s_{kb}}_{Useful\ Signal} + \underbrace{\boldsymbol{\overline{h}_{jb}^{H}}\, \boldsymbol{F_{jb}} \,. \sum_{j\in K\ \ j\neq k} \sqrt{P}\,.s_{jb}}_{intra-beam\ interferences} + \underbrace{\boldsymbol{\overline{h}_{kb}^{H}} \sum_{\substack{i\in B\\ i\neq b}} \sum_{k\in |K|} \boldsymbol{F_{kb}}\cdot\sqrt{P_{ki}}\,.s_{ki}}_{inter-beam\ interferences} + \underbrace{\boldsymbol{z_{kb}}}_{AWGN} ..(5)$$

where y_{kb} is the received signal of the kth client from the bth beam, is the beam space channel vector, s_{ki} is the data signal, P_{kb} is the power specified for the kth client, and $\boldsymbol{F_{kb}}$ is the precoder matrix. The second term of equation (5) stands for the interference between uses that associated to the same cluster or beam. The 3rd term in eq. (5) characterizes the interference between users that related to neighbor clusters or beams. In [18], the authors mentioned the thought of removing intra-beam interference through the technique of SIC. Due to the superposition technique employed in NOMA which results in intra-beam interference, it's necessary to develop an accurate strategy of precoder and power management to improve the total throughput as well as "SINR" and terminate the interference. According to eq. (5), the "SINR" of the above pattern can be characterized as below,

$$\Gamma_{kb} = \frac{\left\|\boldsymbol{\bar{h}_{kb}^{H}}\,\boldsymbol{F_{kb}}\right\|_2^2 .\ P_{kP}}{\boldsymbol{I}^{inter\_beam} + \boldsymbol{I}^{intra\_beam} + \boldsymbol{z_{kb}^2}}, \ldots\ldots (6)$$

and here, Γ_{kb} denotes to "SINR of the kth client in the bth beam, $\left\|\boldsymbol{\bar{h}_{kb}^{H}}\,\boldsymbol{F_{kb}}\right\|_2^2$ matches to the straight beam space channel gain. The expressions of the divisor of this equation are drawn as below,

$$\boldsymbol{I}^{intra\_beam} = \left\|\boldsymbol{\bar{h}_{jb}^{H}}\,\boldsymbol{F_{jb}}\right\|_2^2 . \sum_{j\in K \ \ j\neq k} P_{jb} \ldots\ldots (7\_a)$$

$$\boldsymbol{I}^{inter\_beam} = \sum_{i\neq b} \sum_{k\,\in\,|K|} \|\ \boldsymbol{\bar{h}_{kb}^{H}}\ \boldsymbol{F_{ki}}\ \|^2 . P_{ki} \ldots\ldots (7\_b)$$

Next, the logarithmic function of the data rate of k^{th} client in b^{th} beam can be expressed in terms of $nats/sec/Hz$ as follows,

$$R_{kb} = \ln[1 + \Gamma_{kb}] \ldots\ldots (8)$$

given that, R_{kb}, is the k^{th} client data rate within *the* b^{th} beam. Figure 2 shows the block diagram of the proposed BS-MIMO-NOMA System Model and the corresponding signaling details.

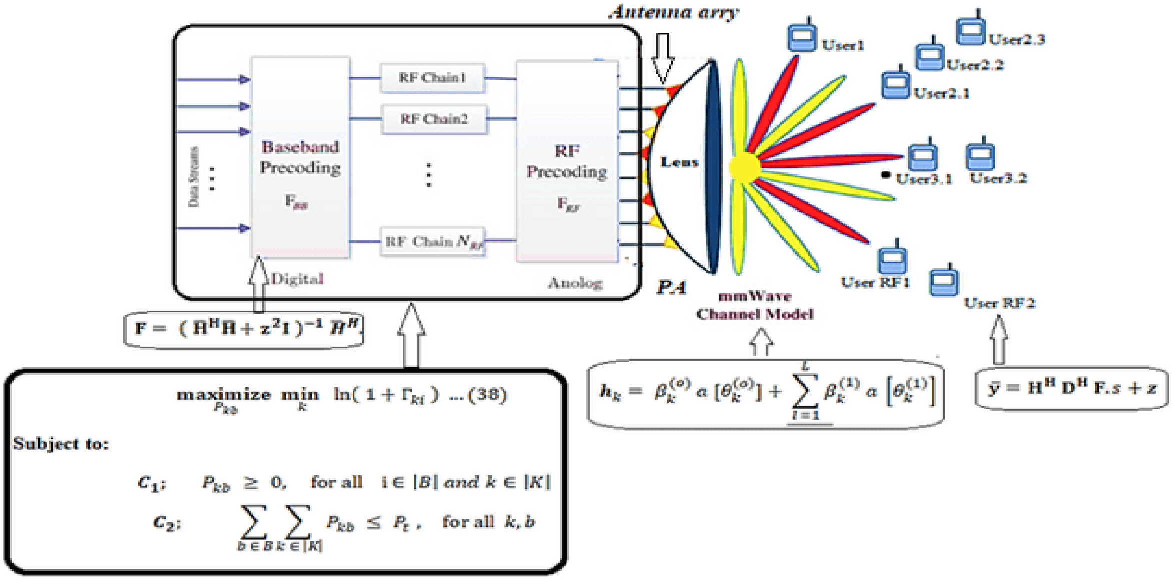

Figure 2 The BS-MIMO-NOMA System block diagram.

3. QoS-Balance Problem Formulation

In contrast to the traditional "beam space-MIMO" in which only one-customer is served by means of each RF-Chain and any linear precoder strategies, e.g., channel pseudo inverse (i.e., zero-forcing), can be utilised as beamform to eliminate interference caused by inter-beam interactions, since we have "$K \geq N_{RF}$ " this method only serves one-customer at a time. On the other hand, the classical method of the ZF cannot be leveraged inside the suggested scheme of NOMA-BS-MIMO due to the fact that "$K \geq N_{RF}$". This shows that pseudo-matrix-inversion of the beam space channel cannot be attained. Furthermore, for efficient system, energy allocation ought to be optimized for numerous consumers in numerous beams. As cited earlier, the NOMA-MIMO scheme relies upon sharing identical time, frequency, and spatial domain names to serve multiple consumers concurrently on the same beam through the usage of the energy domain. Therefore, the energy allocation for the same beam and several customers plays an important role in reducing the interference of the inter-beam and also increases the statistics rate of the entire scheme. This is because the energy is shared between multiple users of the same beam. Therefore, a lot of research has been revealed to study the energy allocation of NOMA-MIMO see for example the references, [17], [19-22]. The formula for optimizing the QoS with power-allocation constraint can be written as follows,

$$\underset{P_{kb}}{\textbf{maximize}}\ \underset{k}{\textbf{min}}\ \ln(\,1+\Gamma_{ki}\,). \ldots (9)$$

Subject to:

$$\boldsymbol{C_1};\quad P_{kb}\ \geq\ 0,\quad \text{for all}\quad i\in|B|\ and\ k\in|K|$$
$$\boldsymbol{C_2};\quad \sum_{b\,\in\,B}\ \sum_{k\,\in\,|K|} P_{kb}\ \leq\ P_t\,,\quad \text{for all}\ \ k,b$$

The optimization expression in (9) aims to attain a fair quality of service (i.e., best QoS) among all the users, "$R_{th} = \underset{k}{\textbf{min}}\ \ln(\,1+\Gamma_{ki}\,)$" denotes the minimum amount of data rate that each user should have, or in other words, it represents the QoS to confirm the user's fairness performance, Γ_{ki} refers to SINR, and P_t stands for the total power transmitted by the whole system. So, the proposed formula will achieve a rate balance that maximizes the smallest of all user rates under the per-user power constraints. The above optimization expression is challenging, not only due to the non-convex formulation but also due to that the variables to be optimized are entangled with each other. It is computationally unaffordable to directly search for the optimal solution because the dimension of the optimization variables is N + K, which is large in general. To solve this optimization expression, this study suggests a method, namely "SLNR-IV", that leverages the signal-to-leakage-plus-noise ratio (SLNR) and the intermediate value method in an iterative method. As the traditional solution is difficult to be found i.e., jointly solve in terms of digital transmit filter coefficients F and power allocations P_k, therefore, in this work, a closed-form expression [12], namely SLNR-MAX-precoder, is introduced to determine the precoder $\boldsymbol{F}$ components as follows,

$$\mathbf{F} =\ (\,\mathbf{\overline{H}^{H}\overline{H}} + \mathbf{z^2 I}\,)^{\mathbf{-1}}\ \boldsymbol{\overline{H}^{H}} \ldots. \qquad (10).$$

Next, the study will propose a sub-optimal solution with promising performance but low computational complexity. Without loss of generality, the optimization expression of eq. (9) can be rewritten by introducing a new variable, "namely R_o, "to simplify the Problem which can be re-written as follows,

$$\underset{P_{kb}}{\textbf{maximize}}\ (R_o) \ldots\ldots\ldots. \qquad (11)$$

Subject to: $\boldsymbol{C_0};\ R_{kb}\ \geq R_o,$ for all users k and beams b

$$\boldsymbol{C_1};\quad P_{kb}\ \geq\ 0,\ \ for\ all\ \ i\in|B|\ and\ k\in|K|$$
$$\boldsymbol{C_2};\quad \sum_{b\,\in\,B}\ \sum_{k\,\in\,|K|} P_{kb}\ \leq\ P_t$$

where the constraints $\boldsymbol{C_0}$ are necessary and sufficient conditions for R_o to be the minimum achievable rate among the served users. On the one hand, since R_o is the minimum rate, the achievable rate of each user must not be less than R_o. On the other hand, there is at least one user whose reachable rate of R_{km} is equal to R_o; otherwise, we can always improve R_o to minimize the gap between R_{km} and r. Now, with a fixed value of R_o, this problem can be evaluated efficiently using advanced methods in a distributed manner to achieve any point on the Pareto boundary on the total rate region. It is easy to show that problem of Eq. (11) is nearly convex. Therefore, the intermediate value approach [4],[5] can be used to obtain the optimal solution to this problem by sequentially solving the power minimization problem of Eq. (14) for a given target SINR, namely "φ_{kb}, "across all users. In every iterate of this method, the operating interval is reduced to (0.5) that of the previous interval by computing the midpoint, namely $\mathrm{R_{temp}}$. So, firstly we set the initial upper and lower boundaries of the root search working domain,

$$\mathrm{R_{max}}^{(\mathrm{t})} = \ln(1+\ \boldsymbol{\Gamma}_{\max})\,,\qquad and\ \ \mathrm{R_{min}}^{(\mathrm{t})} =\ 0 \ldots..(12)$$

then, divide the interval working domain as follows,

$$\mathrm{R_{temp}}^{(\mathrm{t})} = \frac{\mathrm{R_{max}}^{(\mathrm{t})} +\ \mathrm{R_{min}}^{(\mathrm{t})}}{2} \ldots..(13)$$

Now, this intermediate value of the rate can be used to evaluate the solution of the convex min-problem in Eq. (11) as follows,

$$\boldsymbol{Problem}:\quad \underset{P_{kb}^{(\mathrm{t})}}{\textbf{minimize}} \sum_{i\in|b|}\ \sum_{k\in|K|} P_{ki}^{\ (t)}\ \|\ \boldsymbol{F_i}\,\boldsymbol{F_i}^{\boldsymbol{H}}\ \| \quad \ldots (14)$$

$$\textbf{Subject to}:\qquad \varphi_{kb}^{\ (\mathrm{t})}\ \geq\ 0\,, \text{for all}\ \ k,b$$

$$P_{ki}{}^{(t)} \geq 0, \ \text{for all} \ \ \mathrm{i} \in |B|, k \in |K|$$

Where φ_{kb} is the target SINR which is attained after taking the inverse logarithmic function for both sides of SINR in eq. (6) and can be given as follows,

$$\varphi_{kb}{}^{(\mathrm{t})} = \frac{P_{kb}{}^{(\mathrm{t})}}{(1-2^{R_{temp}})} \cdot \left\| \overline{\boldsymbol{h}}_{\boldsymbol{kb}}^{\boldsymbol{H}} \, \boldsymbol{F}_{\boldsymbol{kb}} \right\|_2^2 - \left\| \overline{\boldsymbol{h}}_{\boldsymbol{kb}}^{\boldsymbol{H}} \, \boldsymbol{F}_{\boldsymbol{kb}} \right\|_2^2 . \sum_{j \in |S_{group}|} p_{mj}{}^{(\mathrm{t})}$$
$$- \sum_{i \in |B|, i \neq b} \left\| \overline{\boldsymbol{h}}_{ki}^{H} \, \boldsymbol{F}_{\boldsymbol{i}} \right\|_2^2 \cdot \sum_{k \in |K|} P_{ki}{}^{(\mathrm{t})} - \boldsymbol{z}_{\boldsymbol{kb}}{}^2 \ldots .(15)$$

Then, the above minimization problem can be solved using one of the convex optimization tools e.g., engaging the CVX package where the power allocation of the AP-transmission precoder is often upgraded via any package for disciplined convex programs.

The Pseudo code in Table I illustrates the full detailed step of the proposed power allocation algorithm which can attain a minimum quality of service for all users in various beams in just a few iterations.

Table I. The Pseudo-code for the SLNR-IV algorithm.

```
Start Algorithm-I:
    Initialize the set of parameters for the system including: user's number $|\boldsymbol{K}|$, total transmit power $P_t$,
    Beam-space channel matrix, iteration index: $\mathrm{t} = 0$, and Beam's number $\boldsymbol{B}$.
1st STAGE; select best User per beam & Users' clustering:
    1. Set number of Best-user set for each beam: $|\boldsymbol{S}| = \boldsymbol{B}$, Compute user's channel norms:
       $\mathrm{N} = \{ \|\boldsymbol{g_k}\|_2, \ \forall \ k \in |\boldsymbol{K}| \}$,
    2. Sort users according to channel gain $\|\boldsymbol{g_k}\|_2$ in a descending order: $\boldsymbol{\Psi} = sort$ (N, 'descent'), Sort
       users according to channel correlation:
    3. For all $n \in \boldsymbol{S}$ ;
       If; the correlation $|\overline{\boldsymbol{g}}_{\boldsymbol{m}}^{\boldsymbol{H}} \, \overline{\boldsymbol{g}}_{\boldsymbol{n}}| < \Theta_{th}$, Then: $\mathrm{S}_{cluster} = \{ m \in \mathbf{S}_{\boldsymbol{cluster}} \}$.
       End If
    4. Candidate set of strongest users: User with strongest Channel gain is chosen as Best user for the
       corresponding beam: $\boldsymbol{S} = \boldsymbol{\Psi} \, (1, m)$.
2nd STAGE; Digital Beamforming & power allocation;
    5. Determine the SLNR-MAX-beamforming $\boldsymbol{F}$ components: $\boldsymbol{F} = (\boldsymbol{n^2 I} + \overline{\boldsymbol{G}}^{\boldsymbol{H}} \, \overline{\boldsymbol{G}})^{-\mathbf{1}} \, \overline{\boldsymbol{G}}^{\boldsymbol{H}}$
    6. Set the initial upper and lower boundaries of the root search working domain:
           $\mathrm{R_{max}}{}^{(\mathrm{t})} = \ln(1 + \boldsymbol{\Gamma}_{\max}), \ \mathrm{R_{min}}{}^{(\mathrm{t})} = 0$
Iterative Sub-optimal approach;
    7. Update iteration index: $\mathrm{t} = \mathrm{t} + 1$ .
    8. Divide the interval working domain: $\mathrm{R_{temp}}{}^{(\mathrm{t})} = \frac{\mathrm{R_{max}}{}^{(\mathrm{t})} + \mathrm{R_{min}}{}^{(\mathrm{t})}}{2}$
    9. Compute the data rate constraint for the individual users for each beam:
       $\varphi_{kb}{}^{(\mathrm{t})} = \frac{P_{kb}{}^{(\mathrm{t})}}{(1-2^{R_{temp}})} \cdot \|\overline{\boldsymbol{g}}_{kb}^{H} \, F_b\|_2^2 - \|\overline{\boldsymbol{g}}_{kb}^{H} \, F_b\|_2^2 \sum_{j \in |S_{group}|} p_{mj}{}^{(\mathrm{t})} - \sum_{i \in |B|, \ i \neq b} \|\overline{\boldsymbol{g}}_{ki}^{H} \, F_i\|_2^2 \sum_{k \in |K|} P_{ki}{}^{(\mathrm{t})} - z_{kb}{}^2$
    10. Solve the convex min-problem via CVX tool:
           $Problem: \ \min_{P_{kb}{}^{(\mathrm{t})}} \sum_{i \in |b|} \sum_{k \in |K|} P_{ki}{}^{(t)} \, \| F_i \, F_i{}^H \|$
           $Subject \ to: \ \ \varphi_{kb}{}^{(\mathrm{t})} \geq 0 , \quad \forall \, k, b$
                          $P_{ki}{}^{(t)} \geq 0, \ \mathrm{i} \in |B|, \quad k \in |K|$
       Check the power budget:
    11. If : $\sum_{i \in |b|} \sum_{k \in |K|} P_{ki}{}^{(t)} \, \| F_i \, F_i{}^H \| > P_t$ Then; Update rate upper bound: $\mathrm{R_{max}}{}^{(\mathrm{t})} = \mathrm{R_{temp}}{}^{(\mathrm{t})}$
    12. Else: Update rate lower bound & power allocation: $\mathrm{R_{min}}{}^{(\mathrm{t})} = \mathrm{R_{temp}}{}^{(\mathrm{t})}, \ P_{kb}{}^{*} = P_{kb}{}^{(t)}$
    13. End If
       Check rate tolerance limit:
```

```
14. If: $R_{max}^{(t)} - R_{min}^{(t)} \le \epsilon$ , Then; Return power allocation
15. Else: go to step 7   (next iteration).
16. End If
17. Return power allocation vector.
```

4. Numerical Analysis

This section considers the bandwidth efficiency performance of the worst user in Lens-aided MIMO-NOMA that employs mm-Wave and power allocation mechanisms. The system parameters set are illustrated in table II with the assumption that the AP has perfect information on the beam pace channel for all users. The considered baseline is the traditional OFDM with ZF-baseband precoder.

The following figures are obtained throughout the interpreting of the pseudo-code of table-1 in the corresponding Matlab code (version R2019b with full CVX optimization package) which in turn is run on a core-I7, 2.40 GHz, 8 GB, and 64-bit operating system.

First, in figure (3), in terms of spectral efficiency concerning the transmit power, Figure.3 (for the case K = 15 users) indicates that the proposed technique can greatly enhance the bandwidth efficiency for the transmit power for the user with the worst channel condition. For example, we have a performance gain of almost 15% when the transmit power is 10 dB and the number of radio frequency chains is put to 2. Besides, it can be delivered from this figure that the bandwidth efficiency is increased when the number of chains is increased from 2 up to 8 where the number of beams will also grow.

Accordingly, each beam will serve fewer users, which in turn, will mitigate the interference within one beam (Intra- interference), hence improving width efficiency. In addition, in the high-power region, the performance of the traditional “Beam space-MIMO (that is based on OMA multiplexing) remains unaffected, while the proposed technique (that is based on NOMA multiplexing)” decays in this region. This fact can be interpreted in terms of the rank deficiency of the latter scheme, where the chain's number is less than the user, number (the rank of the matrix of the digital pre-coder is no more than the user's number and based on the strongest user in each beam). Consequently, the interference between different beams of the NOMA scheme is unable to be mitigated by the digital baseband precoding, while the OMA scheme is based on time division multiplexing with the zero-forcing-precoding and this can mitigate the interference. It is worth noting that to overcome this drawback of our approach in high SINR regions one suggestion is to employ the traditional approach (baseline-1 in our study) in these regions.

Table II. Simulation system setting.

Parameter	setting
Total transmitted power	$P_t = [-5 : 30]$ dB
Noise power	$n^2 = -100$ dBm
RF-Chains Power losses	$P^{RF} = 25$ dBm
Base band network losses	P^{BB} = “23 dBm”
Switch network losses	”P^{SN} = 1.6 dBm”
Number of BS’s antenna	64 elements
Users’ number (K)	[5 - 55] users
Power for each user (P_k)	According to algorithm-I which returns the power allocation vector.
Number of the Transceivers’ chain	$N_{Rf} = \{2, 4, \text{and } 8\}$
Modulation order	16-QAM
The propagation environment:	
Geometric Channel model ref. [2]	Saleh Valenzuela clustered channel model with LoS/NLoS = 20 dB, Gauss_distribution, LoS channel path variance σ_{ij}^2 =1, and NLoS variance $\sigma_{ij}^2 = 10^{-2.0}$
Number of the clusters	$N_{cluster} = 6$ clusters
Number of the paths	$N_{path} = 10$ rays

The AoA &AoD distribution	Uniform distribution {-π/2, π/2}, with 10 degrees cluster azimuths' spread angles.
Baseline or benchmarks algorithms for comparison	1) Traditional Algorithm (OFDM with ZF-baseband precoder) [13]. 2) Optimal precoder (NOMA)

Next, in terms of the number of users who can be served in the event that there is no clear line of sight, figure 4 shows the figure of merits of the proposed method, which is based on "NOMA multiplexing" in terms of the efficiency of using bandwidth when the number of users is increased. Whereas the classic "Beam space-MIMO", which is based on OFDM multiplexing, does not suffer from the interference between different users inside the same beam to the same extent. In conclusion, we can realize from figure 5 that the efficiency of the bandwidth can be improved by the method that has been proposed in comparison to the OFDM scheme, despite the fact that the OFDM scheme here is based on time division multiplexing. This is the case for the scenario in which there is an existing direct line of sight. When compared to the conventional "beamspace-OFDM" approach, the proposed method exhibits a superiority percentage in the bandwidth efficiency of around 16.6% when applied to a hypothetical scenario involving 10 users. Because of the constraint placed on the amount of total transmit power, the performance of the bandwidth decreases as the number of users increases.

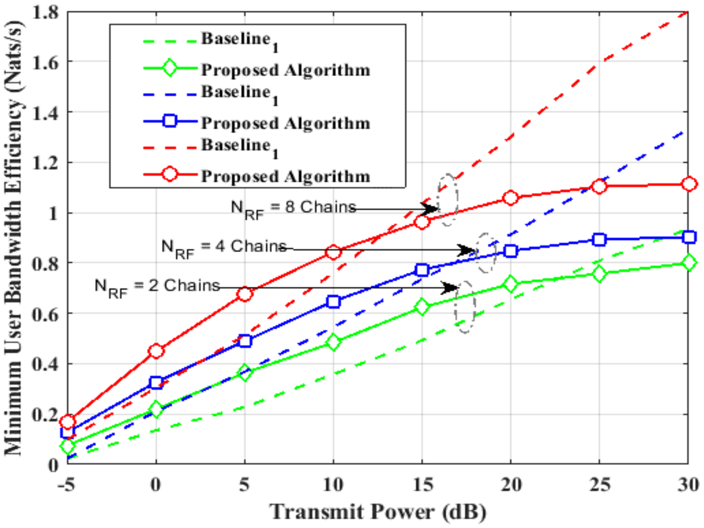

Figure 3. The efficiency of using bandwidth VS. the transmit power.

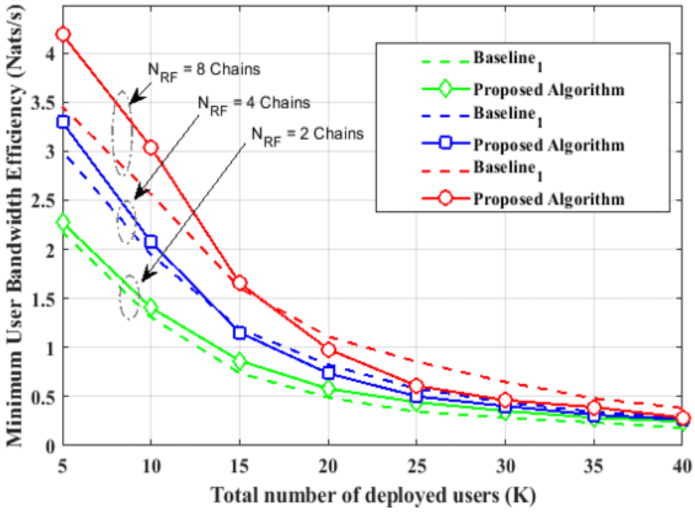

Figure 4. Bandwidth efficiency vs. number of users at 15 dB transmit power without (LoS)

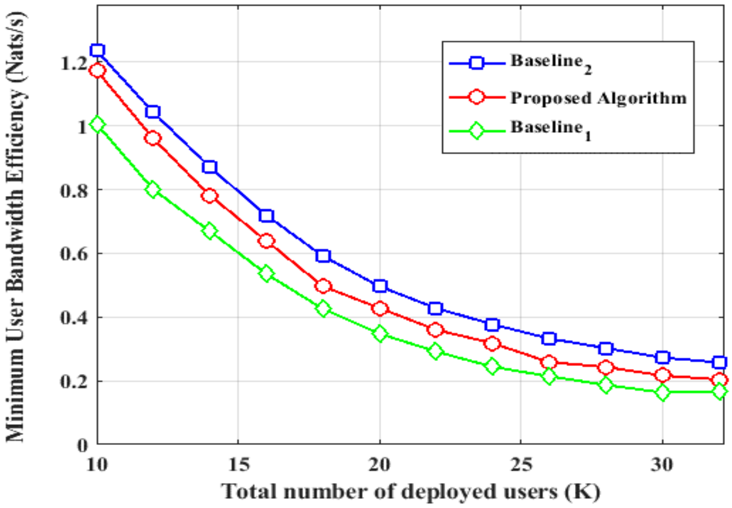

Figure 5. Bandwidth efficiency vs. number of users at 15 dB transmit power with (LoS).

5. Conclusion

Within the technique of the Lens-aided MIMO-NOMA, which enables the use of mm-wave and power allocation techniques, the focus of this work is on the bandwidth efficiency performance of the lower channel gain user. In other words, this work proposes and develops a simple iterative algorithm with near-perfect performance in terms of rate balancing across all the users. The proposed method, namely SLNR-IV, employs the signal-to-leakage-plus-noise ratio (SLNR) technique and the intermediate value method for the above-mentioned task. These two approaches are both utilized in an iterative process to achieve the required measure (i.e., rate balance for all of the users). In addition, for the power allocation task, a straightforward iterative arrangement is being considered to assign the required sufficient power for each user. The results demonstrate a performance that is significantly higher than that of the conventional systems, which are based on the beam-space-OFDM technique and Zero-forcing digital precoder. Also, the results show the robustness of the proposed technique in the region of high Signal-to-Noise Ratio values specifically for the large number of Radio-Frequency Chains i.e., the scenario that corresponded to a large number of beams. Results also shed light on the effects of the number of deployed users on the minimum user bandwidth efficiency, where for the large number of users the performance is very close to that for the legacy beam-space-OFDM techniques.

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