



Lens Assisted Massive Antenna for mm-Wave Communication Systems

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Abstract: It is believed that the massive multiple-input multiple-outputs (mMIMO) paradigms are a considerably favorable approach for the upcoming generation of communication systems (with high spectral efficiency) that have aided through the mm-wave (millimeter-wave) technique. However, due to the large number of components (i.e., chains of radio-frequency, a.k.a. RF for short), such paradigm schemes (i.e., mmWave mMIMO) face challenges in terms of energy and hardware implementation costs. In this context, the Lens Antenna technique can help reduce the number of radio-frequency components needed while maintaining considerable performance. In addition, increasing the number of users that can be served within the same beam and frequency/time resource element can be achieved through the idea of non-orthogonal multiple access (NOMA for short) to overcome the number of radio frequency components employed in the system, such that the entire number of supported users will be more than the available radio frequency components. This research considers enhancing the throughput metric for a Lens-Assisted Massive Antenna NOMA system. In particular, the work introduces an uncomplicated iterative approach with sub-optimal spectral performance via a simple Block Diagonalization and

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a mid-point optimization method. The bandwidth efficiency gains for the suggested approach, if compared to the classical orthogonal multiple access technique and interference nulling beam-forming, are about 13.5 % enhancement.

Keywords: Non-Orthogonal Multiple Access (NOMA); Orthogonal Frequency-Division Multiple Access (OFDMA); Millimeter Wave (mmWave); Lens Antenna; Massive MIMO (Massive Multiple-Input Multiple-Output)

1. Introduction

The next generation of wireless communication systems requires a large number of hardware elements to achieve the desired performance. Mm-wave communication (30GHz through 300 GHz) qualifies a more significant dimensional compact antenna array, which in turn leads to the introduction of what is known as a massive multiple-input multiple-output scheme or mMIMO for short, and also increases the number of the multiplexed users within the same resource element of the Time/Frequency grid (Busari et al., 2017; Maljević et al., 2024; Wang et al., 2017a). Nevertheless, due to the complexity of the transceiver hardware and the total number of elements (radio-frequency elements, or RF-chains for short; each chain requires about 250 mW of power), implementing massive multiple-input multiple-output-based mmWave techniques in real-time systems is impractical. Thus, to implement the massive multiple-input multiple-output principle, a large number of radio-frequency elements is required, leading to the aforementioned challenge. These RF elements account for almost 70.0% of the transceiver component's total energy cost. Consequently, to address this issue, various approaches have been proposed to reduce the number of employed RF elements (Al-Rubaye et al., 2023; Amadori & Masouros, 2015; Gao et al., 2023; Sanayei & Nosratinia, 2007). Recently, a new paradigm emerged: the Lens-antenna mMIMO system, which makes the implementation of massive MIMO more practical in real systems (Wang et al., 2017a). In such systems, the typical multiple-input multiple-output channels can be forced into beam-space channels, thereby effectively capturing the sparsity of the mmWave channel and resulting in a notable reduction in hardware complexity and energy consumption. The beam-space channel is the straightforward result of selecting the prevailing beams and thereby limiting the number of RF elements. It is noteworthy that employing both Lenses with massive antenna

elements will result in a high-resolution beam and, consequently, an effective beamforming technique, which can also help in mitigating inter-beam interference and lead to a more reliable communication system. Hence, the emerged Lens-aided MIMO approach is proposed to achieve very tight-to-ideal performance compared to traditional multiple-input multiple-output systems, with some additional design efforts. On the other hand, the noteworthy drawback of this approach is that only a single user is supported within the same resource element of the Time/Frequency grid, and consequently, the entire number of clients cannot surpass the number of available radio frequency elements (Al Ammar & Hburi, 2024; Gao et al., 2016a; Viji et al., 2024). To conquer this restriction, a lot of work has been done recently to combine the technology of Non-orthogonal multiple access (NOMA) into the Lens-based antenna arrays, which can also help in enhancing the connection latency performance and other metrics of customer quality of service (ALRikabi et al., 2025; Liu et al., 2019; Van Damme et al., 2024; Wang et al., 2017b). The basic concept of NOMA technology is the user-multiplexing in the power domain. On the transmitter side, NOMA implements superposition coding and SIC-based decoding (successive interference cancellation) at the receiver (Choi, 2017).

In this context, the authors of (Liu et al., 2019) address the issue of power allocation in Lens-aided NOMA systems, which is a non-convex optimization problem, using sequential convex approximation. The authors of (Majeed & Hburi, 2022) designed a straightforward iterative method (which converges in approximately 10 iterations) based on the Mean Squared Error (MSE) and achieved an improved power cost of roughly 85.0% compared to the classical orthogonal multiple access technique. The authors in (Nimmagadda, 2021) achieve the spectral and energy-efficiency multi-objective metrics in Lens-aided NOMA systems by merging the Beetle Swarm and Gray Wolf optimization techniques. In contrast to the work in

reference (Chandrakapure et al., 2024; ALRikabi et al., 2024; Majeed & Hburi, 2022), this research focuses on the throughput balance of Lens-aided NOMA systems, i.e., maximizing the minimum rate required by individual users of Lens-aided NOMA systems, subject to a limited power-allocation constraint. Also, this research considers a simple Block Diagonalization digital beamforming (where we extend the work in (Al Ammar & Hburi, 2024) into a multiple antenna users scenario) and a mid-point Power control optimization method, unlike our previous work in (Das & Das, 2024; Sahib et al., 2024), which assumes the Signal-to-Leakage-Plus-Noise Ratio approach for the digital beamforming process. Consequently, this work has the following contributions:-

This article presents a technique to maximize throughput for the worst user in the system while adhering to the power-allocation limitations of Lens-aided mm-wave NOMA systems, where the non-convex problem can be tractable by introducing new variables. The suggested method benefits from the simple Block Diagonalization digital beamforming and a midpoint Power control optimization strategy (namely, the BD-NOMA algorithm for short) to achieve balanced user throughput in NOMA systems. The performance of the suggested approach has been demonstrated through simulation with various parameter settings.

The other sections of this paper are arranged as follows: the system model of the Lens-aided mm-wave NOMA systems is presented in the next section; the throughput formula for the downlink scenario is introduced in the third section; and the fourth section presents the simulation analysis results. Lastly, the conclusion is illustrated in section five.

Note: Vectors and matrices throughout the paper are denoted by small and capital letters, respectively. The Math operation $[-]^H$ for complex-conjugate (Hermitian), $[-]^T$ means the transpose of the matrix, and $[-]^{-1}$ stands for matrix inversion. $[-]_L$ is the norm operation with a length of L. $\text{diag}[A]$ stands for the diagonal of matrix A, the $N \times N$ dimension identity matrix is denoted by I_N , and the expectation matrix is indicated by $E[-]$.

1. SYSTEM MODEL

In this research, a single access point or base station is considered in the downlink scenario for Lens-aided mm-wave NOMA systems. The study assumes that the base station comprises a massive antenna to serve a K-user, each has multiple antennas, and there are NRF-radio elements in the system.

2.1 Lens-aided mm-wave System Model

For the typical multiple-input multiple-output system the received signal vector can be stated as follows (Al-Rikabi, 2013; Majeed & Hburi, 2022):

$$\mathbf{y} = \mathbf{G}^H \mathbf{F} \mathbf{x} + \mathbf{z} \quad (1)$$

where the channel matrix is \mathbf{G} and the vectors, $\mathbf{g}_1, \mathbf{g}_2, \dots, \mathbf{g}_k$ are the channel vectors from the access point to the corresponding k th user, \mathbf{x} denotes the transmitted data vector, $\mathbf{x} = [x_1, x_2, \dots, x_k]$, \mathbf{z} is the Additive white-Gaussian noise, and \mathbf{F} is the matrix of transmission beamformer. Since the number of radio frequency components is equivalent to the access point's antenna number, therefore, $N_{RF} = N_t$. So, there is an enormous chain number if massive antenna mmWave techniques are involved (Wang et al., 2017b). Every single radio component chain needs nearly 250.0 milli Watt, which is not a small payment of energy to extinguish (Gao et al., 2016b). In this context, lens-antenna-based MIMO schemes are delivered to handle this point and reduce the number of radio components in the chain while keeping the overall system performance. With the concept of Lens-antenna, the multiple input multiple output \mathbf{G} channel matrix (in the special-domain) will be associated with the resulting channel (i.e., beam-space one) as follows, (Zeng & Zhang, 2016),

$$\bar{\mathbf{G}}^H = \mathbf{G}^H \mathbf{A}^H \quad (2)$$

where matrix \mathbf{A} represents the vectors (span the entire angle space) of alignment of the lens antenna [6], the beamspace channel matrix $\bar{\mathbf{G}}$ Include the following vectors, $\bar{\mathbf{g}}_1, \bar{\mathbf{g}}_2, \dots, \bar{\mathbf{g}}_k$, and each vector $\bar{\mathbf{g}}_k$ denotes the path of the beam-space from the AP to the k th user (i.e., the vector \mathbf{g}_k denotes the spatial channel that can be changed into the vector $\bar{\mathbf{g}}_k$ by applying the Fourier-transform). Consequently, the received signal (beam-space vector) can be expressed as follows,

$$\bar{\mathbf{y}} = \bar{\mathbf{G}}^H \mathbf{F} \mathbf{x} + \mathbf{z} \quad (3)$$

It is worth noting that every single row of the $\bar{\mathbf{G}}$ matrix is associated with a single beam (with index-b) that has the spatial orientation given by the following angles, $\theta_1, \theta_2, \dots, \theta_B$. It is well known that mmWave channels exhibit sparsity, as do the matrices of beam-space channels (Zeng & Zhang, 2016). Therefore, a beam-space MIMO system with near-optimal performance and reduced dimensions can be designed. As stated earlier, the weakness of the Lens-based antenna approach is that only a single user is backed within the same resource element of the Time/

Frequency grid, and consequently, the entire number of clients cannot surpass the number of available radio frequency elements (Al Ammar & Hburi, 2024; Verma & Ali, 2025). To overcome this limitation the technology of Non-orthogonal multiple access (NOMA) is incorporated into the Lens-based antenna arrays, which can be explained in the next sub-section.

2.2 Lens-aided MIMO-NOMA System Model

The Lens-aided MIMO-NOMA technique (see Figure 1) has been proposed to overcome the limitation of traditional Lens-aided MIMO systems, which support only a single user within a single resource element of the Time/Frequency grid. The Lens-aided MIMO-NOMA will ensure efficient benefits for each beam by considering an efficient beam selection algorithm. In (Amadori & Masouros, 2015), the authors proposed an SNIR-based (maximum Signal-to-interference-plus-noise) algorithm for beam selection.

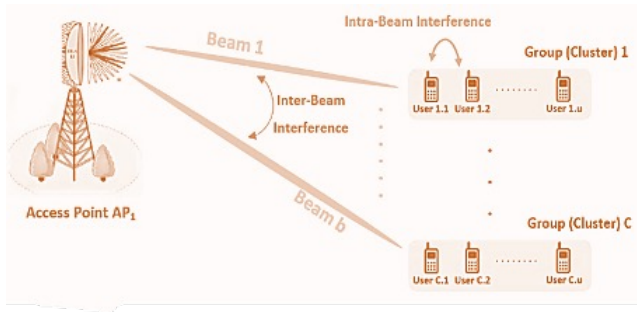


Figure 1. Lens-aided MIMO-NOMA System Model.

The authors of ref. (Hburi et al., 2021) introduced a Maximum-Magnitude strategy for a common mmWave scenario, in which 87.0% is the ratio of the possibility of customers owning a correlated channel for 256 elements of the antenna and 32 users. In (Wang et al., 2017b), the authors proved that Lens-aided MIMO-NOMA is qualified to support the correlated users (simultaneously) through a single RF-Chain and consequently employing a single beam. The received signal for the Lens-aided MIMO-NOMA system that is shown in Figure .1 can be expressed as follows:

$$y_{kb} = \underbrace{\frac{-H}{g_{jb} F_{jb}} \cdot \sqrt{P_{kb}} \cdot x_{kb}}_{\text{UsefulSignal}} + \mathbf{I}^{\text{intra_beam}} + \mathbf{I}^{\text{inter_beam}} + \underbrace{z_{kb}}_{\text{AWGN}} \quad (4)$$

where x_{ki} is the information sequence, y_{kb} is the received data signal of the (kth) - user by the (bth) - beam, F_{kb} is the beamforming vectors, P_{kb} is the power allocated to the kth - user, and g are the vectors of beam-space channel.

The 2nd part of eq. (4) denotes the inter-cluster or inter-beam users interference signal (i.e., users that associated to the same beam or cluster):

$$\mathbf{I}^{\text{intra_beam}} = \|\frac{-H}{g_{jb} F_{jb}}\|_2^2 \cdot \sum_{j \in K_{j \neq k}} P_{jb} \quad (5)$$

while the 3rd part in eq. (4) is the interference signal of users that belong to different beams or clusters;

$$\mathbf{I}^{\text{inter_beam}} = \sum_{i \neq b} \sum_{k \in |K|} \|\frac{-H}{g_{kb} F_{ki}}\|_2^2 \cdot P_{ki} \quad (6)$$

According to (Hburi et al., 2021), the intra-beam interference signal (i.e., 3rd term in eq.(4) can be eliminated via the process of successive interference cancellation (SIC). It's important to rely on a good algorithm for the beam-forming design and power allocation to increase the data rate and reduce the intra-beam interference produced by the superposition process. The signal-to-interference-plus-noise ratio (SINR) of the proposed model can be expressed, depending on equation 4 as follows,

$$\Gamma_{kb} = \frac{\frac{-H}{g_{kb} F_{kb}} \cdot \sqrt{P_{kb}}}{\underbrace{\frac{-H}{g_{jb} F_{jb}} \cdot \sum_{j \in K_{j \neq k}} \sqrt{P_{jb}}}_{\text{intra-beaminterferences}} + \underbrace{\frac{-H}{g_{kb} F_{kb}} \cdot \sum_{i \in B} \sum_{k \in |K|} \sqrt{P_{ki}} \cdot x_{ki} + z_{kb}^2}_{\text{inter-beaminterferences}}} \quad (7)$$

where, $\|\frac{-H}{g_{kb} F_{kb}}\|_2^2$ is the straight beam space channel gain, and Γ_{kb} stands for the kth - user SINR within the bth-beam. It is noticeable that the model of channel introduced by Saleh and Valenzuela has been considered in this work (Al Ammar & Hburi, 2024),

$$g_k = \beta_k^0 \cdot a[\theta_k^0] + \sum_{l \in L} \beta_k^1 \cdot a[\theta_k^1] \quad (8)$$

here the β_k^0 is the complex gain of the LoS for the kth - user, $a[\theta_k^0]$ is to the spatial direction of the LoS, and $\sum_{l=1}^L \beta_k^1 \cdot a[\theta_k^1]$ are L components of the non-LoS.

2. Users' Throughput Balancing Problem Formulation (BD-NOMA algorithm)

For an efficient Lens-aided MIMO-NOMA technique, the power allocation process has to be designed for the overall users in different beams where the scheme considers the leverage of the same time, frequency, and spatial domains to support multiple users simultaneously within the same beam via the utilizing of the power domain.

To reduce the inter-beam interference and consequently, the system throughput, developers have to carefully design the power allocation for different users within the same beam. rate of the entire scheme where the power is shared among multiple users that belong to the same beam. Accordingly, a lot of studies have been specified to review the power assignment of NOMA-MIMO (e.g., see the references (Chandra & Borugadda, 2023; Chandra & Borugadda, 2024; Dursun et al., 2023; Islam et al., 2016)). The formulation for enhancing the users' throughput balancing subject to the power-allocation limit can be expressed as follows,

$$\max_{P_{kb}} \min_k \ln(1 + \Gamma_{ki}) \quad (9)$$

S. t.:

$$P_{kb} \geq 0, \forall i \in |B|, \text{ and } \forall k \in |K|$$

$$\sum_{b \in B} \sum_{k \in |K|} P_{kb} \leq P_t, \forall (k, b)$$

The formula in (9) aims to achieve a fair service among all the system's users, P_t is the total power of transmission, Γ_{ki} is the SINR level, and P_{kb} is the allocated power for the k^{th} user. The objective of this problem is to maximize the minimum data rate for the worst user at the cell edge. Hence, the suggested algorithm will achieve a rare balance that improves the worst-case rate under double-power constraints. The first power constraint ensures that the user-allocated power never becomes negative, while the second constraint keeps the total power employed within the acceptable range. The expression of eq. (9) is difficult because of the non-convex attribute and because of the variables' coupling with each other. Exhaustive search optimization is impractical for such large-scale formulas, which are computationally costly. To address this optimization problem, this work presents a method that leverages simple Block Diagonalization digital beamforming and a midpoint power-control optimization to achieve balanced user throughput in a simple iterative procedure. In this study, a closed-form expression for digital coefficients F is suggested, which is the Block Diagonalization algorithm (Nguyen et al., 2012), since the direct solution of jointly solving for beamforming filter F and power allocations P is difficult to find. The Block Diagonalization technique mitigates the multi-user interference by designing the beamforming such that, $\mathbf{g}_i \mathbf{f}_j = \mathbf{0}$, for all $i \neq j$ which in turn converts the down-link multiple-user channel into several parallel single-user channels. First, let us define the matrix, $\hat{\mathbf{G}}$ with a singular value decomposition (SVD) of,

$$\hat{\mathbf{G}} = \mathbf{U} \mathbf{\Lambda} [\mathbf{V}^{(1)} \mathbf{V}^{(0)}] \quad (10)$$

and the columns of the matrix $\mathbf{V}^{(0)}$ represent the orthogonal basis for the null space of $\hat{\mathbf{G}}$. To achieve the interference nulling for the Block Diagonalization scheme, the following has to be satisfied,

$$\mathbf{F} = \mathbf{V}^{(0)} \hat{\mathbf{F}} \quad (11)$$

Also, the effective channel matrix is given by,

$$\hat{\mathbf{G}} = \mathbf{G} \mathbf{V}^{(0)} \quad (12)$$

Next, the sum rate of the downlink channel is given as follows,

$$R = \sum_{k \in |K|} \ln \left(\mathbf{I} + \widehat{\mathbf{G}} \widehat{\mathbf{F}} \widehat{\mathbf{F}}^H \widehat{\mathbf{G}}^H \right) \quad (13)$$

Now, let us suggest a near-optimal solution with low computational complexity for the problem in (9). With no loss of generality, the optimization expression of eq. (9) can be amended by naming a new variable (R_o),

$$\max_{P_{kb}} (R_o) \quad (14)$$

S. t.: $R_{kb} \geq R_o, \forall k$, and $\forall \text{beams } b$

$$P_{kb} \geq 0, \forall i \in |B| \text{ and } \forall k \in |K|$$

$$\sum_{b \in B} \sum_{k \in |K|} P_{kb} \leq P_t$$

where the optimization process is over the variable P_{kb} i.e., individual user power, and 1st constraints are essential for R_o to be the min. attainable rate among the users i.e., the realizable rate of any user is not less than R_o .

Next, for a certain value of R_o , the problem in eq. (12) can be assessed effectively in a distributed way. Also, it is worth noting that this problem is almost convex, and hence a mid-point Power control optimization strategy (Sanayei & Nosratinia, 2007) can be employed to reach the best evaluation for this problem by consecutively resolving the power min. The formula of eq.(14) at a certain required SINR value, " φ_{kb} " over all the deployed users. Firstly, the algorithm set the initial lower and upper limits of the rate as follows,

$$R_{(\max.)}^{(t)} = \ln(1 + \Gamma_{\max}), R_{(\min.)}^{(t)} = 0$$

And the mid-point will be,

$$R_{(\text{temp.})}^{(t)} = (R_{(\max.)}^{(t)} + R_{(\min.)}^{(t)})/2 \quad (15)$$

Next, the value of the rate mid-point can be employed to solve the convex formula in eq.(12),

$$\mathbf{P} : \min_{P_{kb}^{(t)}} \sum_{i \in |b|} \sum_{k \in |K|} P_{ki}^{(t)} \| \mathbf{F}_i \mathbf{F}_i^H \| \quad (16)$$

$$\mathbf{S. t.}: \varphi_{kb}^{(t)} \geq 0, \forall k, b$$

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

Where $P_{kb}^{(t)}$ is the allocated power for the k^{th} user at the (t) iteration, φ_{kb} is the target SINR and can be given as follows,

$$\varphi_{kb}^{(t)} = \frac{P_{kb}^{(t)}}{(1-2^{\varphi_{temp}})} \cdot \left\| \frac{-\mathbf{H}}{\mathbf{g}_{kb}\mathbf{F}_{kb}} \right\|_2^2 - \left\| \frac{-\mathbf{H}}{\mathbf{g}_{kb}\mathbf{F}_{kb}} \right\|_2^2 \cdot \sum_{j \in |S_{group}|} P_{mj}^{(t)}$$

$$- \sum_{i \in |B|, i \neq b} \left\| \frac{-\mathbf{H}}{\mathbf{g}_{ki}\mathbf{F}_i} \right\|_2^2 \cdot \sum_{k \in |K|} P_{ki}^{(t)} - \mathbf{z}_{kb}^2 \quad (17)$$

which is determined by taking the inverse-logarithmic of both sides of eq. (7). Next, the min. Problem (17) can be determined by employing tools of convex optimization, e.g., the CVX tool, and Table 1 shows the pseudo-code steps of the proposed method.

Table 1. Pseudo-codes steps.

Algorithm Initialization:

Set initial values of parameters: transmit power P_t ; number of users, index of iteration: $t = 0$, and number of the beams.

Clusters of users developing:

1. For each beam; assign a number of best-user sets. Determine channel norms for all users.
2. Sort users in descending order according to channel gain. Sort users according to channel correlation.
3. **For** all $n \in S$; **if**; the correlation $\left| \frac{-\mathbf{H}}{\mathbf{g}_m\mathbf{g}_n} \right| < \Theta_{th}$, **Then:** $S_{cluster} = \{ m \in S_{cluster} \}$. **End If**

It's worth noting that in lensed antenna systems, channel estimation is challenging since the number of RF chains is much less than the number of antennas. However, the task of channel estimation is out of the scope of this study (for more information about the topic, see e.g., (Li et al., 2024; Majeed et al., 2023)) and this study assumed that the base station already has full information on the beam space channel for all users.

BD-Digital Beamforming (BDBF);

1. Set the components of the Block Diagonalization scheme: $\mathbf{F} = \mathbf{V}^{(0)}\widehat{\mathbf{F}}$.
2. Set the initial lower and upper limits of the rate: $R_{(min.)}^{(t)} = 0, R_{(max.)}^{(t)} = \ln(1 + \Gamma_{max.})$,

Iterative Sub-optimal approach;

3. Update index of iteration: $t = t + 1$.
4. Determine the rate mid-point: $R_{(temp.)}^{(t)} = (R_{max.}^{(t)} + R_{min.}^{(t)})/2$

5. Determine the rate restriction for each user in each beam employing Eq. (17), $\Phi_{kb}^{(t)}$.
6. Evaluate the convex min-formula of eq. (16) using the CVX software.
7. **Check the budget of the system power:**
8. **If:** $\sum_{i \in |B|} \sum_{k \in |K|} P_{ki}^{(t)} \cdot \|\mathbf{F}_i\mathbf{F}_i^H\| > P_t$ **Then;** Update rate upper bound: $R_{max}^{(t)} = R_{temp}^{(t)}$
9. **Else:** Update rate lower bound & power allocation: $R_{min}^{(t)} = R_{temp}^{(t)}, P_{kb}^* = P_{kb}^{(t)}$
10. **End If**

Check the tolerance of the rate:

11. **If:** $R_{max}^{(t)} - R_{min}^{(t)} \leq \epsilon$, **Then;** end the algorithm.
12. **Else:** (do the next iteration) go back to pace 7.
13. **End If**

Return vector of the *power allocation*.

3. Results and discussion

Assuming the base station has full information on the beam-space channel for all users, this section considers the worst-case minimum bandwidth efficiency in the Lens-assisted mmWave MIMO-NOMA system. Table II shows the setting of the system parameters. The supposed benchmark is the standard orthogonal multiple-access technique and interference-nulling beamforming. The subsequent outcomes are obtained by implementing the pseudo-code using the MATLAB package (R2019b) and the full CVX optimization tool, which is run on a 2.40 GHz, 8 GB, Core i7, 64-bit Windows operating system.

Firstly, Figure 2 examines spectral efficiency as a function of transmission power when deploying 16 users ($K=16$). This figure shows that the proposed scheme (BD-NOMA) can significantly improve bandwidth efficiency for the worst-channel-condition user (cell-edge user). For instance, there is a performance gain of nearly 13.5% (for a transmit power of 10.0 dB and 3 radio components). Also, as we increase the number of radio components (from 4 chains to 8 chains), the number of created beams will increase, and, in turn, users' bandwidth efficiency will improve. In such cases, each beam will support fewer users, and consequently, will alleviate intra-interference (i.e., the interference within the same beams), which in turn boosts the efficiency. Moreover, in this figure, two regions can be distinguished: the area of high-power beyond 10 dB, the performance of the classical orthogonal multiple access technique and interference nulling beamforming (ZF-OFDM) increases with increasing the transmission power, while the performance

Table 2. Setting of Simulation Parameters.

Parameter	Setting value
BS's antenna elements number	128 antennae
User's antenna elements number	2 antennae
Power of Transmission	$P_t = (-5 : 30)$ (in dB)
Number of users	(5 through 55) users
Power of the Noise	$n^2 = -165$ (in dBm)
Transceivers' chain number	$N_{Rf} = (2, 4, \text{ and } 8)$
RF-Chains Power losses	$p^{RF} = 25.0$ (in dBm)
Losses of the base band network	$p^{BB} = 23.0$ (in dBm)
Losses of the switch network	$p^{SN} = 1.60$ (in dBm)
Order of the modulation	16 QAM
(Environment of the propagation)	
Model of the channel	Saleh Valenzuela model ref. (Brady et al., 2013) with, LoS channel path var. $\sigma_{ij}^2 = 1.0$, N-LoS var. $\sigma_{ij}^2 = 1 \times 10^{-2.0}$, and LoS/N_LoS = 20.0 dB, Gauss_dist.
Paths' number/	$N_{path} = 10$ (rays).
Clusters' number	$N_{cluster} = 6$ (clusters).
The distribution of the AoD & AoA	Uniform dist. in the range $(-\pi/2, \pi/2)$, with cluster azimuths' spread angles of 10.0 degrees.
Comparison benchmarks approach	1) The classical orthogonal multiple access technique and interference nulling beamforming (Hburi et al., 2021). 2) Optimal non-orthogonal multiple access beamforming.

of the proposed approach (BD-NOMA, which is based on non-orthogonal multiple access) declines in this area. The reason for this performance is the rank deficiency of the suggested approach, since the number of users exceeds the number of RF chains. Therefore, the proposed algorithm is unable to compact interference among users across various beams; on the other hand, the ZF-OFDM approach relies on time-division multiplexing and offers greater interference compacting. Consequently, to mitigate this defect of the proposed scheme in a high-power

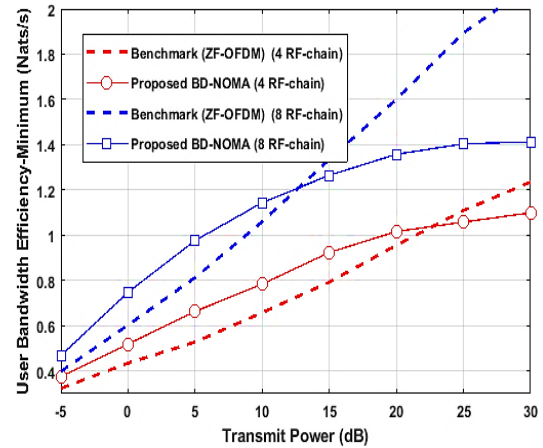


Figure 2. The efficiency of using bandwidth VS. the transmit power.

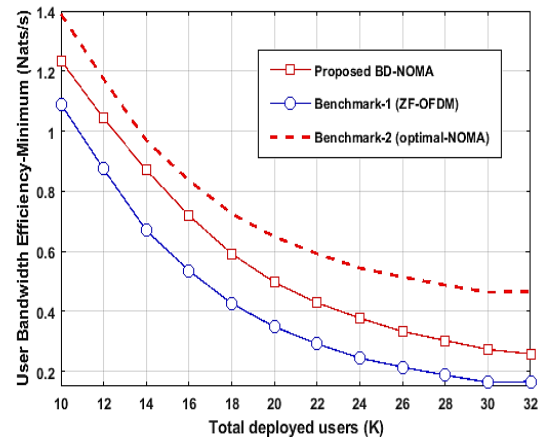


Figure 3. Bandwidth efficiency vs. number of users at 15 dB transmit power with (LoS).

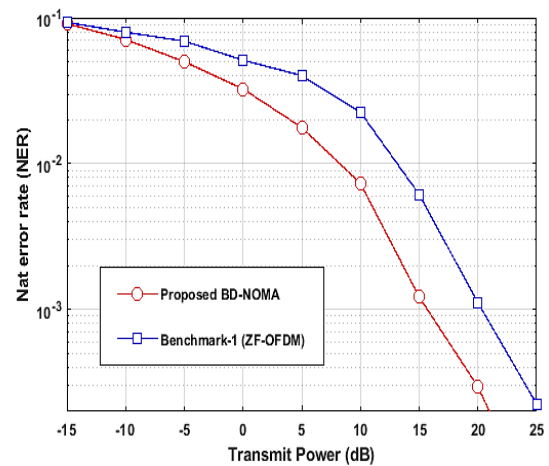


Figure 4. Probability of error performance for the proposed algorithm and the ZF-OFDM with the LoS case.

transmission scenario, the traditional ZF-OFDM scheme can be employed.

Figure 3 shows the impacts of increasing the number of deployed users on bandwidth efficiency. This figure illustrates the figure of merit of the suggested approach compared to the classical orthogonal multiple access technique (ZF-OFDM), which is based on time division multiplexing. Where there is a performance gain of almost 15.5% over the ZF-OFDM benchmark for 10 users. Figure 4 depicts the probability-of-error performance of the proposed algorithm and the ZF-OFDM benchmark. The comparison in this figure is for the direct line-of-sight scenario with 10 users.

Conclusion

The focus of this research is on the bandwidth-efficiency criteria for the worst user in Lens-assisted mmWave MIMO-NOMA systems. More specifically, this study presents a simple iterative technique with an almost perfect rate balancing over the users of the overall system. The suggested method uses the Block Diagonalization scheme and the midpoint method to address the aforementioned issue. These two processes are employed in an iterative strategy to fulfill the user's rate balancing. Furthermore, the suggested approach performs the power allocation task, i.e., assigns the required power level to each user deployed in the system. The resulting outcomes demonstrate that the suggested algorithm achieves significantly higher performance than the benchmark, i.e., the classical orthogonal multiple access technique and interference nulling beamforming. The obtained results shed light on the impact of the number of users on the minimum user bandwidth efficiency.

Conflict of interest

The authors have no conflict of interest to declare.

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