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RESEARCH ARTICLE

Semi-Blind Beamforming in Beam Space MIMO NOMA for mmWave Communications

MUHAMMAD AHSAN SHAIKH[1], ANWAAR MANZAR[1], MUHAMMAD MOINUDDIN[2,3], SADIQ UR REHMAN[1], AND HALAR MUSTAFA[1]

[1]Faculty of Engineering Sciences and Technology, Hamdard University, Karachi 74600, Pakistan
[2]Electrical and Computer Engineering Department, King Abdulaziz University, Jeddah 21589, Saudi Arabia
[3]Centre of Excellence in Intelligent Engineering Systems (CEIES), King Abdulaziz University, Jeddah 22254, Saudi Arabia

Corresponding author: Muhammad Ahsan Shaikh (ahsanshaikh27989@gmail.com)

ABSTRACT Non-orthogonal multiple access (NOMA) scheme has gained remarkable consideration from researchers as it is a favorable technique for the future release of 5G and beyond. Recently proposed beamspace MIMO NOMA for mmWave communication has shown further improvement in its spectrum efficiency by employing beamforming with the aid of instantaneous channel state estimation. But, practically the downlink and the uplink channel state information (CSI) are not identical as the channel reciprocity is no more valid in the fast-varying environment of mmWave communication. Thus, this increases the transmission overhead due to pilot transmission in both uplink and downlink communication. To overcome this issue, we propose a semi-blind technique to design beamforming in downlink power-domain NOMA for mmWave communication which only requires statistical CSI. In the first step, the sum outage probability is derived by using the exact characterization of ratio of the indefinite quadratic form (IQF). In the second step, a heuristic approach with the aid of the interior point (IP) algorithm is developed to find the optimal solution for beam vectors by minimizing the derived sum outage probability. Moreover, a closed-form statistical beamforming solution is derived which is established on statistical signal-to-leakage-noise-ratio (SLNR) maximization. These two proposed methods are compared with the classical principle eigenvector-based solution. Monte Carlo simulations are used to validate the derived analytical expression of outage probability. The results of optimization demonstrate that the performance of both proposed beamforming is higher than the classical eigenvector-based solution. However, the heuristic-based beamforming algorithm via interior-point optimization is significantly better than the SLNR-based solution.

INDEX TERMS MIMO NOMA, beamforming, indefinite quadratic form, optimization, mmWave communications.

I. INTRODUCTION

The worldwide data traffic of mobile communication is predicted to rise by seven times in the near future as compared to the data traffic in 2017. The applications which utilize high data rates such as augmented reality, virtual reality, etc., have increased and they also principally need a higher order of quality of service (QoS) [1]. Every year, the number of devices linked to the internet network increases. There will likely be 30 billion connected devices by the year 2025, resulting in a need for large bandwidth, little latency, and high accuracy [2]. These devices are regarded as part of the internet of things (IoT), and they will be a crucial part of future smart cities. However, with a surge in the quantity of devices, co-channel interference, end-to-end delays, and link failures occurred. Multiple access techniques have always been crucial for large-scale wireless network development. Code division, frequency division, and time division multiple access techniques (CDMA, FDMA, TDMA) are commonly known as orthogonal multiple access (OMA) schemes [3], where each user is allotted a certain amount of orthogonal resources [4]. Although OMA approaches have been utilized to reduce the effects of interference, but their use in extremely large-scale IoT networks is insufficient. In the

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OMA approach, orthogonal resources are allocated to users or devices, however, it is unable to expand as the number of devices rises due to the limited availability of orthogonal resources. Thus, scalable and spectrum-efficient access approaches are needed to provide sustainable communication in future smart cities, to satisfy the tremendous needs of end-user growth [5]. The efficient use of the spectrum can be attained by using the non-orthogonal multiple access (NOMA) technique [6]. NOMA employs successive interference cancellations at the receiver end and superposition coding at the transmitter end, allowing users to use the resources concurrently and resulting in a large increase in spectral efficiency [7]. The throughput of the NOMA technique is much superior than OMA schemes, and in addition to the increased spectral efficiency, the NOMA can competently handle large connections. Thus, it is important for the future release of 5G networks and can support IoT functionality [8].

Contrarily, the NOMA can be employed with a variety of technologies to attain superior performance, including millimeter wave (mmWave), orthogonal frequency division multiple access (OFDMA), cognitive radios [9], and massive multiple-input multiple-output (MIMO) schemes [10], [11]. The wireless communication spectral efficiency is increased by combining NOMA with mmWave transmission techniques [12]. This development occurs as a result of increased bandwidth resources in the very high-frequency mmWave transmission channels [13]. The basic drawback of beamspace MIMO is that only 1 user is served by one RF chain at the same frequency or time which means the number of users cannot surpass the quantity of radio frequency chains [12], [14], [15]. The new concept for the integration of beamspace MIMO and NOMA is investigated in [16] for energy and spectrum-efficient mmWave communication. The NOMA has been acknowledged to be a good choice for 5G, with the opportunities to enhance the connective density and spectrum efficiency [16].

In the literature, research has been done on the beamforming design, the authors in [17], investigated NLMS and LMS-based beamforming algorithms. The two-stage beamforming was proposed in [18] and semidefinite programming based on NOMA beamforming is investigated in [19]. All these beamforming techniques required perfect information about the channel. Practically, CSI is not present at the BS and the process called channel estimation is performed to know the channel state information. Algorithm-based channel estimation is not ideal and further creates a huge burden to the system as an overhead. The pilot-based estimation is also performed which is also overhead and not bandwidth efficient. The channel estimation is performed at the BS station side during the uplink as processing power at the base station is higher than the user equipment (UE) and the same CSI is utilized for the downlink as well. This method is suitable for static or slow-changing channels. However, in the case of mmWave, the CSI information for uplink will not be valid for the downlink as the mmWave channel is fast changing.

Therefore, we propose a semi-blind beamforming technique for the beamspace MIMO NOMA for mmWave communication networks which do not require exact information of the channel and only rely on the statistical information of the channel and do not require CSI estimation, therefore reducing the transmission overhead, which eventually enhances the spectral efficiency. For this purpose closed-form expression for the outage probability in the beamspace NOMA system is derived using the characterization of indefinite quadratic form (IQF) [20]. The optimum beamforming vectors are then obtained by minimizing the sum outage probability using the heuristic technique. Moreover, another beamforming solution is proposed which maximizes the statistical SLNR. Since both the proposed methods rely only on statistical CSI in terms of the channel correlation matrix but our proposed methods do not need separate downlink pilot transmission. Thus, our proposed beamforming solutions can provide low-latency communication and better bandwidth efficiency.

The rest of the paper is structured as follows. The related work is deliberated in section II and the system model of beamspace MIMO NOMA for mmWave communication is given in section III. The expression for the probability of outage is derived in section IV. The proposed Heuristic-based statistical beamforming and proposed statistical SLNR per beam maximization-based beamforming are discussed in sections V and VI, respectively. The results of the simulation and analysis are discussed in section VII. In the end, the paper is concluded in section VIII.

II. RELATED WORK

Several beamforming techniques for NOMA in mmWave networks have been investigated by researchers and some of them are discussed in this section. The authors in [21], studied the random beam forming method for mmWave NOMA networks when base station channel information is not necessary for all users. The outcomes also prove that the proposed NOMA mmWave scheme performs better than the OMA mmWave method. The robust hybrid beamforming is proposed in [22] for massive MIMO NOMA downlink mmWave networks. The user's channel vector is orthogonalized to obtain the analog pre-coder and minimizes interference among the users. The limitation of one user per beam is broken by the use of NOMA in each beam by the power domain multiplexing. The multi-beam forming approach is considered in [23] for NOMA mmWave networks, which enhances the robustness and increases the promising performance. The authors in [24], addressed the problem of acquiring complete knowledge of CSI at BS and proposed a strategy for user grouping with statistical CSI with a heuristic hybrid beamforming design. The inter-cluster interference is reduced by the analog beamforming scheme and interference generated due to SCSI is suppressed by two digital beamforming methods first by the ZF approach and the second derived from the SLNR metric extended from OMA. The analytic framework is developed in [25] and beamforming is suggested as a technique to improve secrecy outage probability (SOP) and maximum ratio transmitting (MRT) performance. Agile beamforming is proposed in [26] for the NOMA-based mmWave networks. By using mmWave frequencies for directional transmission, there is a restricted channel coherence time. The hybrid beamforming in NOMA mmWave is considered, by employing the channel coherence time. The combined optimization problem for beam width and allocation of power is solved [27]. In [28], the authors established outage probability closed-form expression and analyzed the working of the MIMO NOMA downlink system for the mmWave cellular network specifically for D2D communication. The performance is assessed using numerical and analytical investigation. The NOMA-based mmWave communication performance analysis includes a two-user scenario with ergodic capacity and outage probability in which the BS concurrently transmits data to two users [29]. The performance of randomly positioned users in the MIMO NOMA-based system is studied in [30] and the Poisson point process (PPP) is followed by the randomly deployed users. The mmWave massive MIMO system-based capacity study of NOMA has been carried out in [31] for both, low and high SNR values. By using the PDF of the channel eigenvalue, the expressions for the low complexity relative capacity and exact capacity are derived. The distributed and cooperative antenna structure for the massive MIMO NOMA based on mmWave communication is invested in [32] and the sum rate analysis was done for the proposed scheme in order to maximize both energy and spectrum efficiency based on the mmWave communications.

III. SYSTEM MODEL

In this paper, the mmWave downlink single-cell system model is considered where single-antenna users K are concurrently supported by the base station (BS). There are N multiple antennas at the base station side and N_{RF} radio frequency (RF) chains [16]. In [33] and [34], the authors investigated the LoS and NLoS communication for the mmWave and showed that the mmWave has poor penetration for lossy objects such as concrete and the human body, and becomes a good reflector at these high frequencies. Therefore, the receiver captures secondary reflections for NLoS communication, and the channel vector $\boldsymbol{h}_{m,n}$ is modeled for the NLoS component only as given below

$$\boldsymbol{h}_{m,n} = \sum_{l=1}^{L} \boldsymbol{h}_{m,n}^{(l)} \odot \boldsymbol{a}\left(\theta_{m,n}^{(l)}\right) \quad (1)$$

where $\boldsymbol{h}_{m,n}^{(l)}$ complex zero-mean circular Gaussian random vector, i.e., $\boldsymbol{h}_{m,n}^{(l)} \sim \mathcal{CN}\left(0, \boldsymbol{R}_{m,n}^{(l)}\right)$ with size $N_{RF} \times 1$, the operation $\odot$ represents the element by element multiplication and for the typical even linear array [35] the steering vector is written as $\boldsymbol{a}\left(\theta_{m,n}\right)$ with size $N_{RF} \times 1$ [16]. The beam space channel between the m^{th} users and BS is $\boldsymbol{h}_{m,n}$ and the channel correlation matrix $\boldsymbol{R}_{m,n}$ size is $N_{RF} \times N_{RF}$ and can

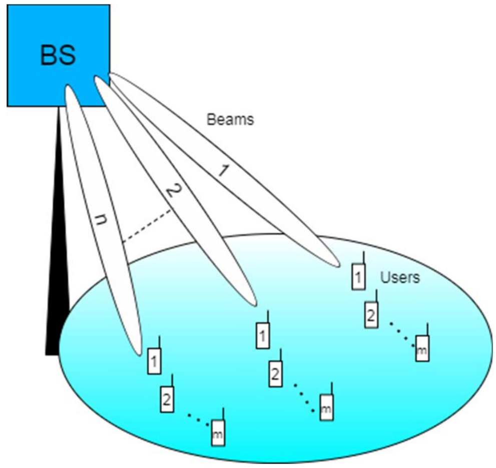

FIGURE 1. Beamspace MIMO NOMA mmWave channel model.

be expressed below.

$$\boldsymbol{R}_{m,n} = E\left[\boldsymbol{h}_{m,n}\boldsymbol{h}_{m,n}^{H}\right] = \sum_{l=1}^{L} \boldsymbol{U}^{\boldsymbol{H}}\boldsymbol{a}\left(\theta_{m,n}^{(l)}\right)\boldsymbol{a}^{H}\left(\theta_{m,n}^{(l)}\right)\bar{\boldsymbol{U}} \quad (2)$$

The transform matrix $\boldsymbol{U}$ with dimension $N \times N$ [12], consists of N directions array steering vectors that cover the entire space and it is used by the array of the antenna to understand the spatial discrete Fourier transform.

$$\begin{aligned} \boldsymbol{U} &= \left[\boldsymbol{a}\left(\bar{\theta}_1\right)\right], \boldsymbol{a}\left(\bar{\theta}_2\right), \ldots, \boldsymbol{a}(\bar{\theta}_N)]^H \\ \bar{\boldsymbol{H}}_n &= \boldsymbol{U}\boldsymbol{H}_n = \left[\boldsymbol{U}\boldsymbol{h}_{1,n}, \boldsymbol{U}\boldsymbol{h}_{2,n}, \ldots, \boldsymbol{U}\boldsymbol{h}_{k,n}\right] \\ &= [\bar{\boldsymbol{h}}_{1,n}, \bar{\boldsymbol{h}}_{2,n}, \ldots, \bar{\boldsymbol{h}}_{k,n}] \end{aligned} \quad (3)$$

where $\bar{\boldsymbol{h}}_{m,n} = \boldsymbol{U}\boldsymbol{h}_{m,n}$ is the beamspace channel vector, which is the Fourier transformation of the spatial channel vector $\boldsymbol{h}_{m,n}$, between the BS and the m^{th} user in the n^{th} beam defined in (1). The system model is shown in Fig. 1, where K multiple users are supported by n beams in the systems and more than one user is supported by the single beam by the use of power domain NOMA. The representation of the received signal for the m^{th} user in the n^{th} beam of the system is given below.

$$y_{m,n} = \boldsymbol{h}_{m,n}^{H} \sum\nolimits_{j=1}^{N_{RF}} \sum\nolimits_{i=1}^{|S_j|} \boldsymbol{w}_j \sqrt{p_{i,j}} s_{i,j} + v_{m,n} \quad (4)$$

The double summation of (4) is expressed in expanded form in (5), where it consists of the required signal, inter-beam interferences, intra-beam interferences, and noise.

$$\begin{aligned} y_{m,n} &= \underbrace{\boldsymbol{h}_{m,n}^{H}\boldsymbol{w}_n\sqrt{p_{m,n}}s_{m,n}}_{desired\ signal} \\ &+ \underbrace{\boldsymbol{h}_{m,n}^{H}\boldsymbol{w}_n \sum\nolimits_{i=1}^{m-1} \sqrt{p_{i,n}}s_{i,n} + \boldsymbol{h}_{m,n}^{H}\boldsymbol{w}_n \sum\nolimits_{i=m+1}^{|S_n|} \sqrt{p_{i,n}}s_{i,n}}_{Intra-beam\ interferences} \\ &+ \underbrace{\boldsymbol{h}_{m,n}^{H} \sum\nolimits_{j\neq n} \sum\nolimits_{i=1}^{|S_j|} \boldsymbol{w}_j\sqrt{p_{i,j}}s_{i,j}}_{Inter-beam\ interferences} + \underbrace{v_{m,n}}_{Noise} \end{aligned} \quad (5)$$

The total number of users supported by the n^{th} beam is expressed as S_n, the $p_{m,n,}$ and $s_{m,n}$ represent the power and transmitted signal for the m^{th} user in the n^{th} beam respectively. The $\boldsymbol{h}_{m,n}$ is the channel vector of the m^{th} user in the n^{th} beam and $\boldsymbol{w}_n$ is the beamforming vector of the n^{th} beam with the dimension $of\, N_{RF} \times 1$ [16]. For the m^{th} user available in the n^{th} beam ($n = 1, 2, \cdots, N_{RF}$ and $m = 1, 2, \cdots, |S_n|$).

IV. DERIVATION OF OUTAGE PROBABILITY

The system model in (5) is considered to derive the expression of SINR, and there are three main terms in the system model. The first term represents the m^{th} user's desired signal in the n^{th} beam, and the intra-beam interference is the second term when the other users are considered in the n^{th} beam other than the m^{th} user. In the case of the last term which is an inter-beam interference total users of all the beams are considered except the n^{th} beam and the SINR is represented as $\gamma_{m,n}$ which is expressed below.

$$\gamma_{m,n} = \frac{\left|\boldsymbol{h}_{m,n}^H \boldsymbol{w}_n \sqrt{p_{m,n}}\right|^2}{\sigma_{m,n}^2 + \sum_{i=1,i\neq m}^{|S_n|} \left|\boldsymbol{h}_{m,n}^H \boldsymbol{w}_n \sqrt{p}_{i,n}\right|^2 + \sum_{j\neq n} \sum_{i=1}^{|S_j|} \left|\boldsymbol{h}_{m,n}^H \boldsymbol{w}_j \sqrt{p}_{i,j}\right|^2} \tag{6}$$

Applying the quadratic form approach $\|\boldsymbol{h}\|_{\boldsymbol{A}}^2 = \boldsymbol{h}^H \boldsymbol{A} \boldsymbol{h}$ the (6) can be simplified as in (7).

$$\gamma_{m,n} = \frac{\left\|\boldsymbol{h}_{m,n}\boldsymbol{w}_n\right\|_{p_{m,n}}^2}{\left\|\boldsymbol{h}_{m,n}\boldsymbol{w}_n\right\|^2 \sum_{i=1,i\neq m}^{|S_n|} p_{i,n} + \sum_{j\neq n} \left\|\boldsymbol{h}_{m,n}\boldsymbol{w}_j\right\|^2 \sum_{i=1}^{|S_j|} p_{i,j} + \sigma_{m,n}^2} \tag{7}$$

Now, $\gamma_{m,n}$ can be written with whitened $\boldsymbol{h}_{m,n} = \bar{\boldsymbol{h}}_{m,n} \boldsymbol{R}_{m,n}^{\frac{H}{2}}$ and further simply the above equation as

$$\gamma_{m,n} = \frac{\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{A}_{m,n}}^2}{\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}}^2 + \sigma_{m,n}^2} \tag{8}$$

where

$$\boldsymbol{A}_{m,n} = \boldsymbol{R}_{m,n}^{\frac{1}{2}} \boldsymbol{w}_n \boldsymbol{w}_n^H p_{m,n} \boldsymbol{R}_{m,n}^{\frac{H}{2}}$$
$$\boldsymbol{B}_{m,n} = \boldsymbol{R}_{m,n}^{\frac{1}{2}} \boldsymbol{w}_n \boldsymbol{w}_n^H \sum_{i=1,i\neq m}^{|S_n|} p_{i,n} \boldsymbol{R}_{m,n}^{\frac{H}{2}} + \boldsymbol{R}_{m,n}^{\frac{1}{2}} \sum_{j\neq n} \boldsymbol{w}_j \boldsymbol{w}_j^H \sum_{i=1}^{|S_j|} p_{i,j} \boldsymbol{R}_{m,n}^{\frac{H}{2}}$$

By using (8) for a given threshold γ_{th}, $\Pr(\gamma_{m,n} < \gamma_{th})$ is the outage probability of m^{th} user available in the n^{th} beam (denoted as $\mathrm{P_{m,n}}(\gamma_{th})$), that is,

$$\mathrm{P_{m,n}}(\gamma_{th}) = Pr\left(\frac{\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{A}_{m,n}}^2}{\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}}^2 + \sigma_{m,n}^2} < \gamma_{th}\right) \tag{9}$$

By multiplying the term $\left(\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}}^2 + \sigma_{m,n}^2\right)$ on the other side of the inequality sign we get

$$\mathrm{P_{m,n}}(\gamma_{th}) = Pr\left(\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{A}_{m,n}}^2 < \gamma_{th}(\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}}^2 + \sigma_{m,n}^2)\right) \tag{10}$$

Taking all the terms on one side of the inequality sign as below

$$\mathrm{P_{m,n}}(\gamma_{th}) = Pr\left(\gamma_{th}\sigma_{m,n}^2 + \gamma_{th}\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}}^2 - \left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{A}_{m,n}}^2 > 0\right) \tag{11}$$

Simplifying $\gamma_{th}\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}}^2 - \left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{A}_{m,n}}^2$, which is equivalent to write as

$$\mathrm{P_{m,n}}(\gamma_{th}) = Pr\left(\gamma_{th}\sigma_{m,n}^2 + \left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}\gamma_{th} - \boldsymbol{A}_{m,n}}^2 > 0\right) \tag{12}$$

The CDF of (9) can be written as (14) by using the definition of unit step function $u(\cdot)$ in (13).

$$\int_0^\infty x dt = \int_{-\infty}^\infty x(t) \cdot u(t)\, dt \tag{13}$$

$$\mathrm{P}_{m,n}(\gamma_{th}) = \int_{-\infty}^\infty p(\bar{\boldsymbol{h}}_{m,n}) u \times \left(\sigma_{m,n}^2 \gamma_{th} + \left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}\gamma_{th} - \boldsymbol{A}_{m,n}}^2\right) d\bar{\boldsymbol{h}}_{m,n} \tag{14}$$

The integration in (14) is on the complete $\boldsymbol{h}_{m,n}$ plane, and therefore, the existence of u (.) supports the analysis in the work. The Fourier demonstration of the unit step function [36] is given below

$$u(x) = \frac{1}{2\pi} \int_{-\infty}^\infty \frac{e^{x(j\omega+\beta)}}{j\omega + \beta} d\omega; \quad \beta > 0 \tag{15}$$

Applying the PDF of the channel vector of $\bar{\boldsymbol{h}}_{m,n}$

$$p(\bar{\boldsymbol{h}}_{m,n}) = \frac{1}{\pi^N} e^{-\left\|\bar{\boldsymbol{h}}_{m,n}\right\|^2} \tag{16}$$

In (14), substitute the PDF of $p(\bar{\boldsymbol{h}}_{m,n})$ from (16) and replace the unit step function with its Fourier transformation using (15), we get

$$\mathrm{P_{m,n}}(\gamma_{th}) = \int_{-\infty}^{-\infty} \frac{1}{\pi^N} e^{-\left\|\bar{\boldsymbol{h}}_{m,n}\right\|^2} \times \frac{1}{2\pi} \int_{-\infty}^\infty \frac{e^{\left(\sigma_{m,n}^2\gamma_{th} + \left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{\boldsymbol{B}_{m,n}\gamma_{th} - \boldsymbol{A}_{m,n}}^2\right)(j\omega+\beta)}}{j\omega + \beta} \times d\bar{\boldsymbol{h}}_{m,n} d\omega \tag{17}$$

By rearranging similar terms, we get

$$\mathrm{P_{m,n}}(\gamma_{th}) = \frac{1}{2\pi^{N+1}} \int_{-\infty}^\infty \frac{e^{\sigma_{m,n}^2\gamma_{th}(j\omega+\beta)}}{j\omega + \beta} \times \int_{-\infty}^\infty e^{-\left\|\bar{\boldsymbol{h}}_{m,n}\right\|_{I + (\boldsymbol{A}_{m,n} - \boldsymbol{B}_{m,n}\gamma_{th})(j\omega+\beta)}^2} d\bar{\boldsymbol{h}}_{m,n} d\omega \tag{18}$$

The above integration can be solved using the approach given in [20] which will result in the following expression for the outage probability

$$\mathrm{P_{m,n}}\left(\gamma_{th}\right) = u\left(\sigma_{m,n}^{2}\gamma_{th}\right) - \sum_{k=1}^{N_{RF}} \frac{\lambda_{\mathrm{k}}^{N_{RF}}}{\prod_{i=1,i\neq k}^{N}\left(\lambda_{\mathrm{k}}-\lambda_{\mathrm{i}}\right)} \times \frac{1}{|\lambda_{\mathrm{k}}|} e^{-\frac{\sigma_{m,n}^{2}\gamma_{th}}{\lambda_{\mathrm{k}}}} u\left(\frac{\sigma_{m,n}^{2}\gamma_{th}}{\lambda_{\mathrm{k}}}\right) \tag{19}$$

where $\{\lambda_{\mathrm{k}}\}$ are the Eigenvalues of the matrix $\boldsymbol{A}_{m,n} - \boldsymbol{B}_{m,n}\gamma_{th}$. Thus, the sum outage probability (denoted by $P_{out,sum}$) in beamspace MIMO-NOMA mmWave communication is given by

$$P_{out,sum} = \frac{1}{N_{RF}|S_n|}\sum_{n}^{N_{RF}}\sum_{m}^{|S_n|}\mathrm{P_{m,n}}\left(\gamma_{th}\right) \tag{20}$$

V. PROPOSED HEURISTIC-BASED STATISTICAL BEAMFORMING VIA MINIMIZATION OF SUM OUTAGE PROBABILITY

The optimal beamforming vector is designed for the beamspace MIMO NOMA mmWave communication. The technique is based on a statistical approach as it only relies on the Eigenvalues of the channel correlation matrix. We propose to design beamforming in beamspace MIMO-NOMA by minimizing the sum outage probability while constraining the beam norm to unity, that is, the objective function for the proposed optimization task is

$$J\left(\{\boldsymbol{w}_n\}, \gamma_{th}\right) = \underbrace{minimize}_{\{\boldsymbol{w}_n\}} P_{out,sum} \quad s.t.\ \|\boldsymbol{w_n}\|^2 = 1 \quad \forall n \tag{21}$$

The above optimization task is non-convex and highly non-linear. Thus, we propose to solve it by a heuristic approach using an IP algorithm. This is achieved by the repeated implementation of the IP algorithm until the absolute change in the objective function $\boldsymbol{J}\left(\{\boldsymbol{w_n}\}, \boldsymbol{\gamma_{th}}\right)$ compared to the last iteration is less than a specified tolerance (denoted as tolerance). An outline of the proposed heuristic-based statistical beamforming is provided in the pseudo-code of Algorithm 1.

VI. PROPOSED STATISTICAL SLNR PER BEAM MAXIMIZATION-BASED BEAMFORMING

The SLNR per beam optimization is derived by defining the expected value of $SLNR_{m,n}$ in (22).

$$E\left[SLNR_{m,n}\right] = \frac{E\left[\left|\boldsymbol{h}_{m,n}^{H}\boldsymbol{w}_{n}\sqrt{p}_{m,n}s_{m,n}\right|^{2}\right]}{E\left[\sum_{i\neq m}\left|\boldsymbol{h}_{i,n}^{H}\boldsymbol{w}_{n}\sqrt{p}_{m,n}s_{m,n}\right|^{2}\right]+\boldsymbol{\sigma}_{m,n}^{2}} \tag{22}$$

$$E\left[SLNR_{m,n}\right] = \frac{p_{m,n}\boldsymbol{w}_n^H\boldsymbol{R}_{m,n}\boldsymbol{w}_n}{\boldsymbol{w}_n^H\left(p_{m,n}\sum_{i\neq m}\boldsymbol{R}_{i,n}+\sigma_{m,n}^2\mathbf{I}\right)\mathbf{w}_n} \tag{23}$$

Algorithm 1 Heuristic-Based Beamforming

Setting optimization algorithm to Interior-Point
Set maximum iteration count and precision level (e)
Initialize $\{\boldsymbol{w}_n\}$ random vectors
Compute $J\left(\{\boldsymbol{w}_n\}, \gamma_{th}\right)$ by (21)

repeat for all n
repeat for all m
repeat
  t = t + 1

  find $J\left(\{\boldsymbol{w}_n\}, \gamma_{th}\right)$
  If $|J_t\left(\{\boldsymbol{w}_n\}, \gamma_{th}\right) - J_{t-1}\left(\{\boldsymbol{w}_n\}, \gamma_{th}\right)| \geq tolerance$
    Update $\boldsymbol{w_n} = \boldsymbol{w_n^{opt}}$
  else

    condition = true

until condition = true

until m
until n

We propose to design beamforming via the following constraint optimization:

$$\max_{\boldsymbol{w}_n} E\left[SLNR_{m,n}\right] \quad \text{s.t. } \|\boldsymbol{w_n}\|^2 = 1$$

This optimization task is the well-known generalized Rayleigh quotient (G-RQ) optimization problem [37] whose solution is given by the maximum Eigenvector of the matrix $\left[p_{m,n}\sum_{i\neq n}\boldsymbol{R}_{i,n}+\sigma_{m,n}^2\boldsymbol{I}\right]^{-1}p_{m,n}\boldsymbol{R}_{m,n}$, that is,

$$\boldsymbol{w_n} = \text{ma x}\ eigenvector \times\left[p_{m,n}\sum_{i\neq n}\boldsymbol{R}_{i,n}+\sigma_{m,n}^2\boldsymbol{I}\right]^{-1}p_{m,n}\boldsymbol{R}_{m,n} \tag{24}$$

This method will be applied to all the beams. A summary of the proposed statistical SLNR-based beamforming is provided in the pseudo-code of Algorithm 2.

The total outage probability per beam is shown below

$$G\left(\{\boldsymbol{w}_n\}, \gamma_{th}\right) = \underbrace{minimize}_{\{\boldsymbol{w}_n\}} \frac{1}{|S_n|}\sum_{m}^{|S_n|}\mathrm{P_{m,n}}\left(\gamma_{th}\right) \quad s.t.\ \|\boldsymbol{w}_n\|^2 = 1 \tag{25}$$

The proposed algorithms are compared with the classical principle Eigenvector based solution. In which $\boldsymbol{w}_{n,opt}$ is obtained by finding the maximum value of $(\boldsymbol{\lambda})$ of $\boldsymbol{R_{m,n}}$ and $\boldsymbol{w}_{n,opt} = eigenvector\{\boldsymbol{R_{m,n}}\}$.

VII. RESULTS AND ANALYSIS

In this section, the results of the outage probability of beamspace MIMO NOMA for mmWave communication are discussed and the performance of a system is evaluated

Algorithm 2 Beam Leakage-Based Beamforming

Initialize $\{\boldsymbol{w}_n\}$ random vectors
Define $\boldsymbol{w}_T$
Choose n

Repeat for all users in beam n

Compute $\{\boldsymbol{w}_n\}$ by *max eigenvector* $\left[p_{m,n} \sum_{i \neq n} \boldsymbol{R}_{i,n} + \sigma^2_{m,n}\boldsymbol{I}\right]^{-1} p_{m,n}\boldsymbol{R}_{m,n}$

Store all $\boldsymbol{w_n}$ in $\boldsymbol{w}_T$

Repeat for all users in beam n

Compute SLNR for each user by (23)

Untill m

Find index of max SLNR
$\boldsymbol{w}_{n,opt} = \boldsymbol{w}_T\ (:, Index)$

Until m

TABLE 1. Simulation parameters.

Number of beams N_{RF}	4
Number of users K	8
Noise Variance $\sigma^2_{m,n}$	1
λ_k Eigenvalues of matrix $\{\boldsymbol{A}_{m,n} - \boldsymbol{B}_{m,n}\gamma_{th}\}$	0.0056
Monte Carlo Runs	1e5
n	2
m	3

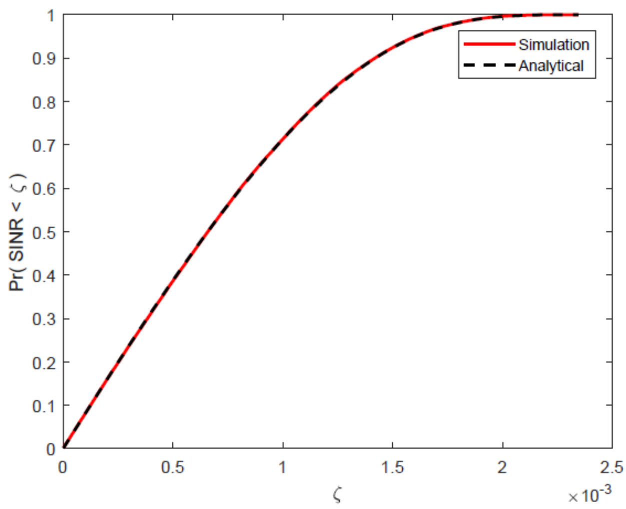

FIGURE 2. Simulation and Analytical Outage Probability of m = 3 and n = 2.

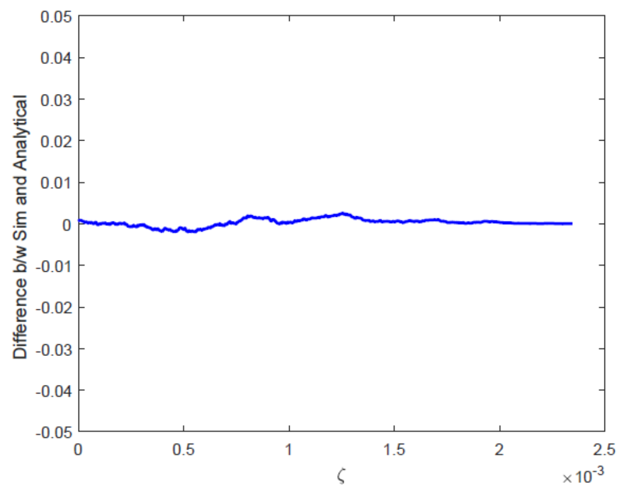

FIGURE 3. Difference in Simulation and Analytical outage probabilities.

by considering different scenarios. The results of the proposed semi-blind beamforming techniques with the conventional classical principle Eigenvector-based solution are also discussed.

A. COMPARISON OF SIMULATION AND ANALYTICAL RESULTS

The outage probability for the derived analytical expression (19) is compared with the Monte Carlo simulation in Fig. 2. The performance of the derived outage probability expression is evaluated by the simulation result and both outage probability curves are alike. Thus, this validates the derived analytical outage probability expression. The simulation parameters for Fig. 2 are given in Table 1.

To further understand and visualize the performance of outage probability curves. The difference in outage probabilities is plotted against all threshold values. It can be seen from the plot that the difference is minimum throughout all threshold values.

The performance of the sum outage probability expression (20) is evaluated in Fig. 4, which is a sum of outage probabilities of all the users in each beam. The curves show that the Monte Carlo simulation and derived analytical expression are similar for all the threshold values. Thus, this result validates the sum outage probability expression.

B. EFFECT OF NUMBER OF USERS ON OUTAGE PROBABILITY

The different number of users and their effect on the outage probability of the m^{th} user in the n^{th} beam is analyzed in Fig. 5 with 8, 16, and 128 users in the beamspace MIMO NOMA mmWave communication system. In this performance evaluation, the number of beams is fixed and the

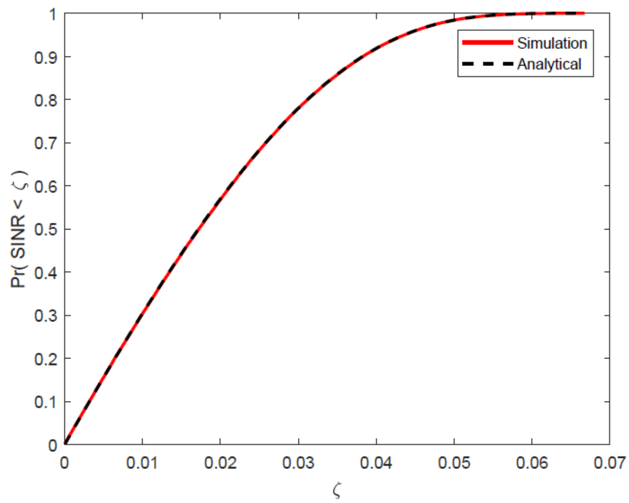

FIGURE 4. Sum outage probability (20).

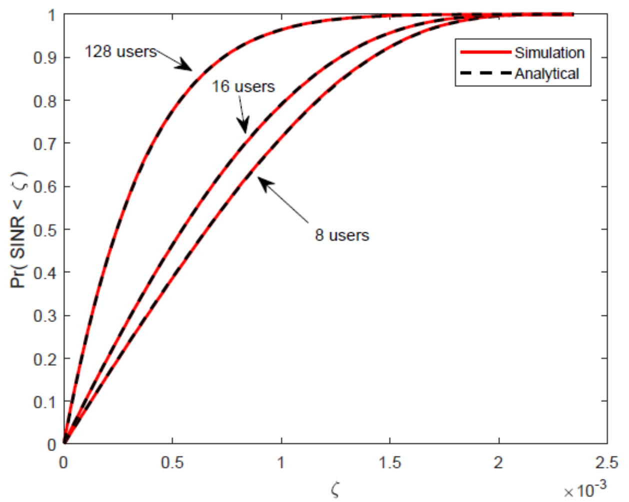

FIGURE 5. Effect of the number of users on the probability of outage for m=3 and n = 2.

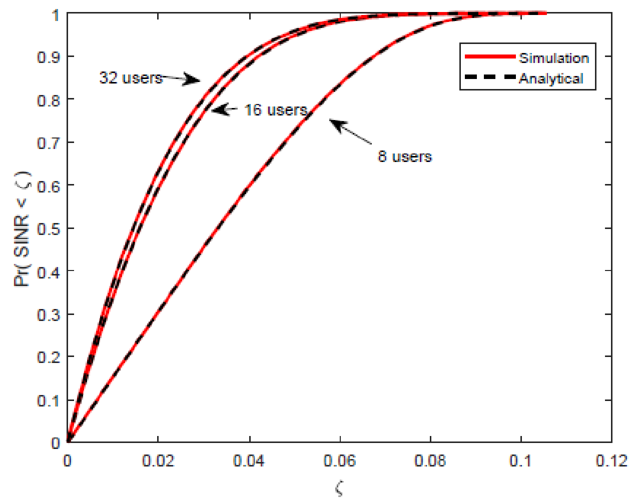

FIGURE 6. Effect of the number of users on sum outage probability.

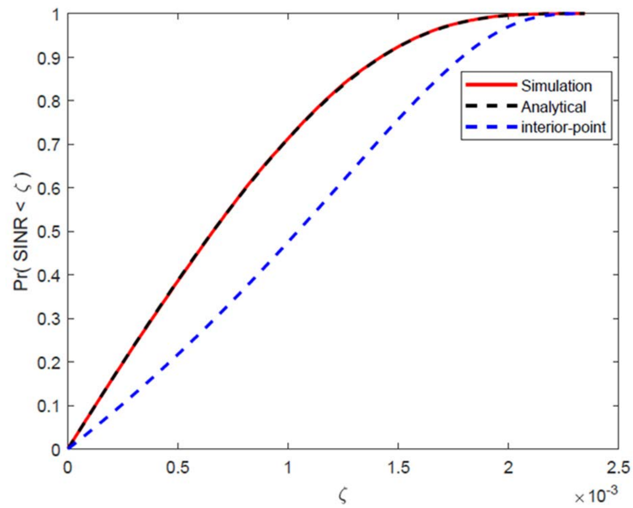

FIGURE 7. Minimization of Outage probability by Optimizing beam vector $\boldsymbol{w}$ for m = 3 and n = 2.

number of users is varied in each beam. It can be witnessed from the curve that the outage probability is low with less number of users in the system and it rises with the rise in the number of users. This shows that the intra-beam interference and inter-beam interferences rise with the increase in the number of users given in (5) and result in degradation of overall system performance.

The impact of the number of users on the sum outage probability is shown in Fig. 6. The effect of the number of users on sum outage probability is the same as the outage probability of a single user as in Fig. 5. Increase in the number of users will rise the interferences. Thus, decreasing the overall system performance.

C. OUTAGE PROBABILITY MINIMIZATION BY BEAMFORMING TECHNIQUES

The outage probability $P_{m,n}$ (19), for m^{th} user in n^{th} beam and sum outage probability $P_{out,sum}$ (20) before and after optimization is shown in Fig. 7 and Fig. 8 correspondingly. In this analysis, 8 users' beamspace MIMO NOMA system is considered and there are 4 beams in the system each serving 2 users simultaneously. The multiple heuristic optimization techniques available in the MATLAB optimization toolbox were tested, such as the sequential quadratic programming (SQP) algorithm and the active set algorithm in addition to the interior point (IP) algorithm. However, we found that the performance of the interior point algorithm is far superior to the other existing heuristic optimization techniques. Therefore, the IP algorithm is used for solving the proposed optimization task to attain the optimum beamforming vector $\boldsymbol{w}$. The significant decrease in outage probabilities is observed with the use of optimum beamforming vector $\boldsymbol{w}$ for all threshold values for both outage probabilities $P_{m,n}$ and $P_{out,sum}$.

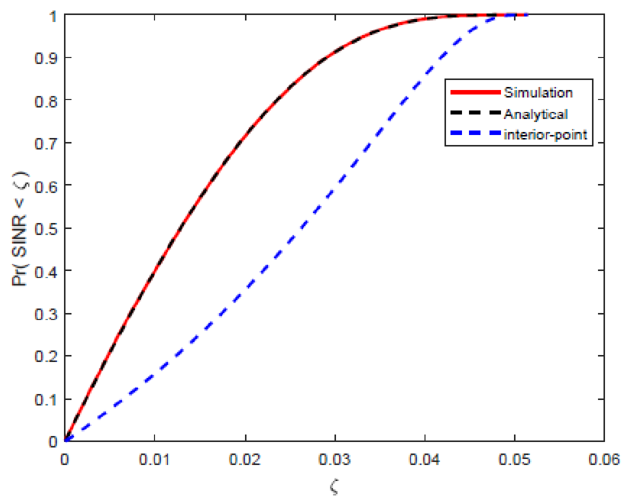

FIGURE 8. The total outage probability J (Before and after optimization).

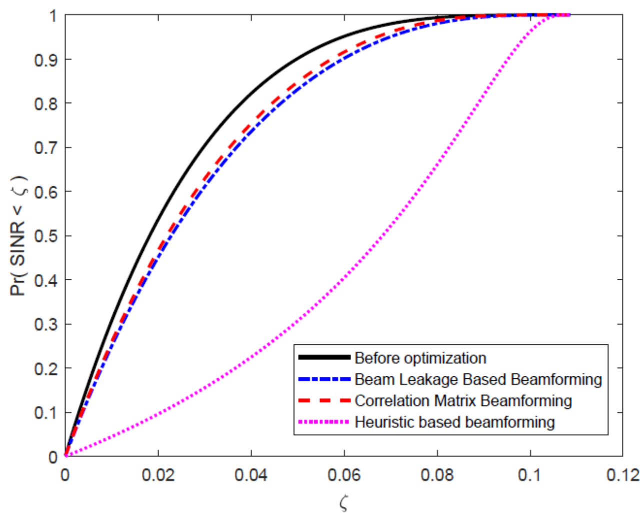

FIGURE 9. The total outage probability of all users in 2nd beam with 8 users in the system.

The performance of two proposed beamforming algorithms compared to the classical principal Eigenvector-based solution with 8 and 12 users' scenarios is shown in Fig. 9 and Fig. 10 correspondingly. The results show the sum outage probability of beam (25) before and after optimization. In this analysis, the 2nd beam n = 2 is considered which consists of 2 and 3 users for Fig. 9 and Fig. 10, respectively. It can be realized from the curves that the performance of both proposed statistical beamforming algorithms, Heuristic-based statistical beamforming, and statistical SLNR per beam maximization-based beamforming is better than the classical principal Eigenvector-based method. The performance of the heuristic-based beamforming algorithm via interior-point optimization is superior as compared to other techniques.

To further understand the performance of proposed algorithms, the mean difference of outage probabilities between

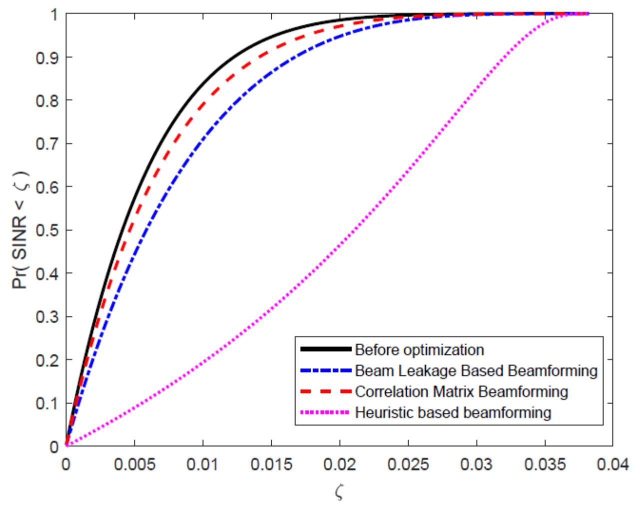

FIGURE 10. The total outage probability of all users in 2nd beam with 12 users in the systems.

TABLE 2. Mean differences between before and after optimization for outage probabilities.

	Optimization Algorithms	Mean difference in 8 users system	Mean difference in 12 users system
1	Heuristic-based beamforming Algorithm	0.3702	0.3781
2	SLNR based beamforming	0.0455	0.0536
3	Correlation Matrix based solution	0.0351	0.0198

before and after optimization for all algorithms with 8 and 12 users' scenarios is shown in Table 2. The Heuristic-based statistical beamforming shows a higher mean difference among the other two techniques. This shows that the Heuristic-based statistical beamforming algorithm performance is superior to the other two techniques for both 8 and 12 users' scenarios.

VIII. CONCLUSION

In this paper, the expression for the probability of outage for the beam space MIMO NOMA in mmWave communication is derived by employing the indefinite quadratic form approach. The derived expression of outage probability is validated by Monte Carlo simulations. Further, the outage probability performance of the system is evaluated with different numbers of users per beam. The results showed that the increase in the number of users per beam increases the outage probability and decreases the overall system performance. First, a heuristic technique using the IP algorithm is proposed to design beam vectors by minimizing the derived sum outage probability. Second, a statistical SLNR maximization-based beamforming solution is derived. Results show that both proposed optimization techniques are superior to the classical eigenvector-based method. However, the heuristic-based beamforming algorithm via interior-point optimization is significantly best among other techniques.

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REFERENCES

[1] Y. Liu, W. Yi, Z. Ding, X. Liu, O. Dobre, and N. Al-Dhahir, ''Developing NOMA to next generation multiple access (NGMA): Future vision and research opportunities,'' 2021, *arXiv:2103.02334*.

[2] W. U. Khan, F. Jameel, M. A. Jamshed, H. Pervaiz, S. Khan, and J. Liu, ''Efficient power allocation for NOMA-enabled IoT networks in 6G era,'' *Phys. Commun.*, vol. 39, Apr. 2020, Art. no. 101043, doi: 10.1016/j.phycom.2020.101043.

[3] T. Jabeen, Z. Ali, W. U. Khan, F. Jameel, I. Khan, G. A. S. Sidhu, and B. J. Choi, ''Joint power allocation and link selection for multi-carrier buffer aided relay network,'' *Electronics*, vol. 8, no. 6, p. 686, Jun. 2019, doi: 10.3390/electronics8060686.

[4] Q. Wu, W. Chen, D. W. K. Ng, and R. Schober, ''Spectral and energy-efficient wireless powered IoT networks: NOMA or TDMA?'' *IEEE Trans. Veh. Technol.*, vol. 67, no. 7, pp. 6663–6667, Jul. 2018, doi: 10.1109/TVT.2018.2799947.

[5] M. Shirvanimoghaddam, M. Dohler, and S. J. Johnson, ''Massive non-orthogonal multiple access for cellular IoT: Potentials and limitations,'' *IEEE Commun. Mag.*, vol. 55, no. 9, pp. 55–61, Sep. 2017, doi: 10.1109/MCOM.2017.1600618.

[6] F. Alavi, K. Cumanan, Z. Ding, and A. G. Burr, ''Beamforming techniques for non-orthogonal multiple access in 5G cellular networks,'' 2018, *arXiv:1807.03293*.

[7] M. R. G. Aghdam, B. M. Tazehkand, and R. Abdolee, ''On the performance analysis of mmWave MIMO-NOMA transmission scheme,'' *IEEE Trans. Veh. Technol.*, vol. 69, no. 10, pp. 11491–11500, Oct. 2020, doi: 10.1109/TVT.2020.3012516.

[8] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan, and V. Bhargava, ''A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends,'' 2017, *arXiv:1706.05347*.

[9] J. Kaur and M. L. Singh, ''User assisted cooperative relaying in beamspace massive MIMO NOMA based systems for millimeter wave communications,'' *China Commun.*, vol. 16, no. 6, pp. 103–113, Jun. 2019, doi: 10.23919/JCC.2019.06.009.

[10] J. Jiang, M. Lei, and H. Hou, ''Downlink multiuser hybrid beamforming for MmWave massive MIMO-NOMA system with imperfect CSI,'' *Int. J. Antennas Propag.*, vol. 2019, pp. 1–10, May 2019, doi: 10.1155/2019/9764958.

[11] W. A. Al-Hussaibi and F. H. Ali, ''Efficient user clustering, receive antenna selection, and power allocation algorithms for massive MIMO-NOMA systems,'' *IEEE Access*, vol. 7, pp. 31865–31882, 2019, doi: 10.1109/ACCESS.2019.2902331.

[12] X. Gao, L. Dai, Z. Chen, Z. Wang, and Z. Zhang, ''Near-optimal beam selection for beamspace mmWave massive MIMO systems,'' *IEEE Commun. Lett.*, vol. 20, no. 5, pp. 1054–1057, May 2016, doi: 10.1109/LCOMM.2016.2544937.

[13] S. A. R. Naqvi and S. A. Hassan, ''Combining NOMA and mmWave technology for cellular communication,'' in *Proc. IEEE 84th Veh. Technol. Conf. (VTC-Fall)*, Montreal, QC, Canada, Sep. 2016, pp. 1–5, doi: 10.1109/VTCFall.2016.7880935.

[14] J. Brady, N. Behdad, and A. M. Sayeed, ''Beamspace MIMO for millimeter-wave communications: System architecture, modeling, analysis, and measurements,'' *IEEE Trans. Antennas Propag.*, vol. 61, no. 7, pp. 3814–3827, Jul. 2013, doi: 10.1109/TAP.2013.2254442.

[15] A. Sayeed and J. Brady, ''Beamspace MIMO for high-dimensional multiuser communication at millimeter-wave frequencies,'' in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Atlanta, GA, USA, Dec. 2013, pp. 3679–3684, doi: 10.1109/GLOCOM.2013.6831645.

[16] B. Wang, L. Dai, Z. Wang, N. Ge, and S. Zhou, ''Spectrum and energy-efficient beamspace MIMO-NOMA for millimeter-wave communications using lens antenna array,'' *IEEE J. Sel. Areas Commun.*, vol. 35, no. 10, pp. 2370–2382, Oct. 2017, doi: 10.1109/JSAC.2017.2725878.

[17] U. Mallaparapu, K. Nalini, P. Ganesh, T. Raghavendra, H. U. Khan, D. L. Prasanna, and B. T. P. Madhav, ''Non-blind adaptive beamforming algorithms for smart antennas,'' *IJRRAS*, vol. 6, no. 4, pp. 491–496, 2011.

[18] J. Choi, ''Minimum power multicast beamforming with superposition coding for multiresolution broadcast and application to NOMA systems,'' *IEEE Trans. Commun.*, vol. 63, no. 3, pp. 791–800, Mar. 2015, doi: 10.1109/TCOMM.2015.2394393.

[19] J. Choi, ''On generalized downlink beamforming with NOMA,'' *J. Commun. Netw.*, vol. 19, pp. 319–328, Aug. 2017, doi: 10.1109/JCN.2017.000056.

[20] T. Y. Al-Naffouri, M. Moinuddin, N. Ajeeb, B. Hassibi, and A. L. Moustakas, ''On the distribution of indefinite quadratic forms in Gaussian random variables,'' *IEEE Trans. Commun.*, vol. 64, no. 1, pp. 153–165, Jan. 2016, doi: 10.1109/TCOMM.2015.2496592.

[21] Z. Ding, P. Fan, and H. V. Poor, ''Random beamforming in millimeter-wave NOMA networks,'' *IEEE Access*, vol. 5, pp. 7667–7681, 2017, doi: 10.1109/ACCESS.2017.2673248.

[22] F. Alraddady, I. Ahmed, and F. Habtemicail, ''Robust hybrid beam-forming for non-orthogonal multiple access in massive MIMO downlink,'' *Electronics*, vol. 11, no. 1, p. 75, Dec. 2021, doi: 10.3390/electronics11010075.

[23] L. Zhu, Z. Xiao, X.-G. Xia, and D. O. Wu, ''Millimeter-wave communications with non-orthogonal multiple access for B5G/6G,'' *IEEE Access*, vol. 7, pp. 116123–116132, 2019, doi: 10.1109/ACCESS.2019.2935169.

[24] J. Zhu, Q. Li, H. Chen, and H. V. Poor, ''Statistical CSI based hybrid mmWave MIMO-NOMA with max-min fairness,'' 2021, *arXiv:2101.01985*.

[25] S. Huang, M. Xiao, and H. V. Poor, ''On the physical layer security of millimeter wave NOMA networks,'' *IEEE Trans. Veh. Technol.*, vol. 69, no. 10, pp. 11697–11711, Oct. 2020, doi: 10.1109/TVT.2020.3017086.

[26] J. Li, X. Jing, Y. Zhang, and J. Mu, ''Performance analysis of agile-beam NOMA in millimeter wave networks,'' *IEEE Access*, vol. 8, pp. 6638–6649, 2020, doi: 10.1109/ACCESS.2019.2958337.

[27] M. A. Almasi, L. Jiang, H. Jafarkhani, and H. Mehrpouyan, ''Joint beamwidth and power optimization in MmWave hybrid beamforming-NOMA systems,'' *IEEE Trans. Wireless Commun.*, vol. 20, no. 4, pp. 2442–2456, Apr. 2021, doi: 10.1109/TWC.2020.3042518.

[28] J. Li, X. Li, A. Wang, and N. Ye, ''Performance analysis for downlink MIMO-NOMA in millimeter wave cellular network with D2D communications,'' *Wireless Commun. Mobile Comput.*, vol. 2019, pp. 1–11, Jun. 2019, doi: 10.1155/2019/1914762.

[29] Y. Tian, G. Pan, and M.-S. Alouini, ''On NOMA-based mmWave communications,'' *IEEE Trans. Veh. Technol.*, vol. 69, no. 12, pp. 15398–15411, Dec. 2020, doi: 10.1109/TVT.2020.3041020.

[30] Z. Shi, G. Yang, Y. Fu, H. Wang, and S. Ma, ''Performance analysis of MIMO-NOMA systems with randomly deployed users,'' in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Abu Dhabi, UAE, Dec. 2018, pp. 1–7, doi: 10.1109/GLOCOM.2018.8647702.

[31] D. Zhang, Z. Zhou, C. Xu, Y. Zhang, J. Rodriguez, and T. Sato, ''Capacity analysis of NOMA with mmWave massive MIMO systems,'' *IEEE J. Sel. Areas Commun.*, vol. 35, no. 7, pp. 1606–1618, Jul. 2017, doi: 10.1109/JSAC.2017.2699059.

[32] P. Salehi, N. Parhizgar, and F. Pesaran, ''A new cooperative and distributed antenna structure in massive MIMO-NOMA based on mmWave transmission scheme,'' *Wireless Commun. Mobile Comput.*, vol. 2021, pp. 1–10, Oct. 2021, doi: 10.1155/2021/6717077.

[33] S. Rajagopal, S. Abu-Surra, and M. Malmirchegini, ''Channel feasibility for outdoor non-line-of-sight mmWave mobile communication,'' in *Proc. IEEE Veh. Technol. Conf. (VTC Fall)*, Quebec City, QC, Canada, Sep. 2012, pp. 1–6, doi: 10.1109/VTCFall.2012.6398884.

[34] R. J. Weiler, M. Peter, W. Keusgen, and M. Wisotzki, ''Measuring the busy urban 60 GHz outdoor access radio channel,'' in *Proc. IEEE Int. Conf. Ultra-WideBand (ICUWB)*, Paris, France, Sep. 2014, pp. 166–170, doi: 10.1109/ICUWB.2014.6958971.

[35] P. V. Amadori and C. Masouros, ''Low RF-complexity millimeter-wave beamspace-MIMO systems by beam selection,'' *IEEE Trans. Commun.*, vol. 63, no. 6, pp. 2212–2223, Jun. 2015, doi: 10.1109/TCOMM.2015.2431266.

[36] T. Y. AI-Naffouri and B. Hassibi, ''On the distribution of indefinite quadratic forms in Gaussian random variables,'' in *Proc. IEEE Int. Symp. Inf. Theory*, Jun. 2009, pp. 1744–1748.

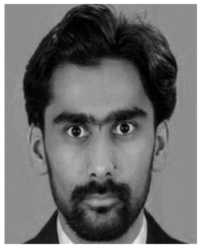
[37] M. V. Pattabhiraman, ''The generalized Rayleigh quotient,'' *Can. Math. Bull.*, vol. 17, no. 2, pp. 251–256, Jun. 1974, doi: 10.4153/CMB-1974-049-4.

MUHAMMAD AHSAN SHAIKH received the B.Eng. degree (Hons.) in electronics majoring in telecommunication from Multimedia University, Cyberjaya, Malaysia, in 2014, and the M.E. degree in electrical engineering from Hamdard University, Karachi, Pakistan, in 2017, where he is currently pursuing the Ph.D. degree in electrical engineering. He served as a Research Assistant at the Wireless Communication Laboratory, Multimedia University, in 2014. He is also serving as a Lecturer at the Faculty of Engineering Sciences and Technology, Hamdard University. He is also associated with Next Generation Mobile Networks Research Cluster, Hamdard University. His research interests include beamforming design of MIMO NOMA and signal processing for communications.

ANWAAR MANZAR received the B.E. degree in electrical engineering and the M.S. degree in electrical engineering from the University of Engineering and Technology (UET), Taxila, Pakistan, and the Ph.D. degree in electronics engineering from International Islamic University, Islamabad (IIUI), Pakistan, in 2008. He is currently working as a Professor at the Department of Electrical Engineering Hamdard University, Karachi, Pakistan. His research interests include electronic engineering, image processing, data mining, and artificial neural networks.

MUHAMMAD MOINUDDIN received the B.S. degree in electrical engineering from the Nadirshaw Edulji Dinshaw University of Engineering and Technology, Karachi, Pakistan, in 1998, and the M.S. and Ph.D. degrees in electrical engineering from the King Fahd University of Petroleum and Minerals (KFUPM), Dharan, Saudi Arabia, in 2001 and 2006, respectively. He was an Assistant Professor with the Department of Electrical Engineering, KFUPM, and the Hafr Al-Batin Community College, Hafr Al-Batin, Saudi Arabia, from 2007 to 2010. He was an Associate Professor at the Telecommunication Engineering Department, Iqra University, Karachi, from 2010 to 2012. He was an Assistant Professor at the Department of Electrical Engineering, King Abdulaziz University (KAU), Jeddah, Saudi Arabia, from 2013 to 2015, where he is currently an Associate Professor. He is also associated with the Center of Excellence in Intelligent Engineering Systems, KAU. His research interests include adaptive filtering, wireless communications, and signal processing for communications.

SADIQ UR REHMAN received the B.E. degree in electronics engineering from the Usman Institute of Technology (UIT), Karachi, Pakistan, in 2008, and the M.S. degree in computer science and communication engineering from University Duisburg-Essen, Germany, in 2015. He is currently pursuing the Ph.D. degree in electrical engineering (specialization in communication systems and networks) with Hamdard University, Karachi. He is also an Assistant Professor at the Electrical Department, Faculty of Engineering Sciences and Technology, Hamdard Institute of Engineering and Technology, Hamdard University. He has been associated with Hamdard University, since April 2016. His current research interests include sensor networks, wireless body area networks, and the IoT.



HALAR MUSTAFA received the Bachelor of Engineering degree in telecom engineering and the Master of Engineering degree in electrical engineering from Hamdard University, Pakistan, where he is currently pursuing the Ph.D. degree in electrical engineering. He is also working as a Lecturer and a Coordinator of the Electrical Engineering Technology Program at Hamdard University. He has received the prestigious, four years of fully funded, Prime Minister National ICT Scholarship for undergraduate studies from the Ministry of IT, Government of Pakistan. Further, he has received a merit-based scholarship during his master's degree. He has also obtained several funding from different agencies for his ongoing projects. His research interests include wireless communication and smart grid technology.