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Hybrid Beamforming for Dual Functioning Multi-input Multi-output Radar using Dimension Reduced-baseband Piecewise Successive Approximation

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A reliable and effective hybrid beamforming design for dual functioning multi-input multi-output (MIMO) radar is a challenging research problem because of the concerns related to limited user capacity, interference, and lack of performance trade-off. Due to the shortage of available spectrum, radar frequency spectrum sharing has become vital in emerging 5G communication systems. This will reduce spectrum congestion, therefore receiving significant attention. The existing hybrid beamforming methods reduce the radio frequency (RF) chains but improving user capacity is still a major concern. Future dual radar-communication designs are having challenges in enhancing the user capacity with minimum RF chains, interference mitigation, and hardware cost reduction. This work proposes a novel approach to a hybrid beamforming mechanism for dual-functioning MIMO radar. This mechanism uses the dimension-reduced baseband piecewise successive approximation integrated with a digital precoder. At the analog precoder, the piecewise successive iterative approximation approach is applied to perform the analog beamforming. The novel hybrid beamforming with lens antenna array integration improves the user capacity and reduces power requirement, interference, and expenses. The simulation results showed improved performances compared to existing state-of-the-art methods in terms of bit error rate, spectral efficiency, energy efficiency, and response time.

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NOMENCLATURE

MIMO	Multi-input multi-output	DR-BPSA	Dimension reduced baseband piecewise successive approximation
$I_{(i,k)}$	Input Signal	*MUI*	Mutual user interference
$D_{(i,k)}$	Digital precoding output	*PSIA*	Piecewise successive iterative approximation
$D_{\ddot{(i.k)}}\ RF$	Transmitting signal	σ	Noise vector component
$A_{(i,j)}$	Transmitted Signal	γ_i	The signal-to-interference-plus-noise ratio for ith user
S_i^r	Radar probing signal	H	Communication channel
S_i^c	Communication signal	U^H	Transformation matrix $n \times m$
P_t	Total power	η_{SE}	Spectral efficiency
F_{RF}	The analog precoding weight matrix	η_{EE}	Energy efficiency
F_{BB}	The digital precoding weight matrix	R	Achievable sum rate
$l(\widehat{\theta_1})$	Lens antenna array steering vector	P_{RF}	Power consumed by RF chain
K	Set of the received signal	P_{SW}	Power consumed by switch
N_{RF}	Total number of transmit antennas	P_{BB}	Power consumed by baseband station

1. INTRODUCTION

The recent progress of wireless communication standards in commercial industry applications needs high-speed communication mechanisms like millimeter-wave (mm-wave) for MIMO systems [1]. The emerging mm-wave interfaces, running from 30-300 GHz, provide a chance to reach such loaded capacity requirements for future

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wireless communications. But the available communication frequency spectrum cannot meet the excess requirement of uplink and downlink frequency [2]. Notwithstanding the large transmission data transfer capacities of orders of magnitude, shorter wavelengths at mm-wave permit and aerials in an indistinguishable physical location were obtained [3]. Spectral congestion problems demand the radar frequency band share to fulfill the requirements. The feasibility of sharing the hardware platform between radar functioning and communication system is the highest among the available options [4]. Currently, L-band, S-band, C-band, and mm-wave band are existing cases that share the frequency spectrum. These elements are linked to the massive MIMO, leading to an increase in multiplexing and beamforming. It found that mm-wave and massive MIMO could accomplish the order-of-magnitude increment in the system limit. However, designing the mm-wave massive MIMO is challenging due to high transceiver complexity and energy depletion [5]. The dual-functioning radar communication system design shares the common hardware to reduce weight on shipborne or airborne platforms, making it hardware efficient, cost-efficient, and power-efficient. But at the same time, every antenna in the MIMO configuration requires one dedicated radio frequency (RF) chain. In this case, using an extensive number of antennas in the mm-wave MIMO system leads to an equally vast product of RF chains. This case applies to the dual-functioning MIMO system also. Furthermore, it was observed that the RF chain elements drain around 70% of the overall transceiver energy requirement [6]. As an outcome, the cost and consumption of energy caused by a high number of RF chains in the mm-wave MIMO system turn uneconomic in reality.

Traditional baseband digital beamformers in MIMO systems demand that every antenna should have a devoted RF chain containing a digital to analog converter, up-converter, power amplifier, and signal mixer [7]. Thus, energy consumption and expense restrain the implementation of a fully-digital architecture. To overcome such challenges, beamforming practices have been forced to rely on fewer RF chains. Although analog beamforming is implemented for enhancing spatial resolution in the MIMO radars, it is limited in the application of the communication domain since all processing has been done in the RF domain [8]. By utilizing the high gain, the analog beamforming is used in distinctive wireless personal area networks (WPAN) and wireless fidelity (Wi-Fi) to get a high data rate. But the performance of the before-mentioned methods is achieved with an inadequate increment in system complexity of the joint radar-communication systems compared to independent designs [9]. If only an analog structure is used at the transmitter since only one RF chain is equipped for supporting one data in a cycle, the size, cost, and spectrum efficiency are the points to compromise. In such cases, hybrid (analog+digital) beamforming architecture has fetched attention, achieving a reliable trade-off of analog and digital precoding through phase shifters and baseband weights optimization.

A significant amount of research has been initiated to design hybrid beamforming systems using fully connected structures [10]. But considering mm-wave communications, antennas like uniform area array (UPA) and uniform linear array (ULA) have not been practical for a fully connected structure as they require many power amplifiers and phase shifters. The radar-specific design will add more complexity to it. It leads to excessive energy consumption, poor spectral efficiency, and high computational costs [11]. The sub-connected structure performs better than the fully-connected structure, reducing power consumption and hardware complexity with less performance degradation. Still, the current solutions are ineffective for dual-functioning massive MIMO radar systems. Figure 1 illustrates a dual-functioning MIMO radar system, including analog and digital precoding at the transmitter level. The signal processing structure of the receiver is the same as that of the transmitter design. The hybrid beamforming techniques are successful in minimizing the required number of RF chains and aim to improve massive MIMO performance by incorporating parameters such as spectral efficiency (SE) and energy efficiency (EE) [12]. However, for future dual-functioning radar communication systems, the main requirement is user capacity improvement, along with SE, EE, and computational efficiency (CE).

To address these issues, a novel mechanism of hybrid beamforming with lens antenna arrays for the dual-functioning MIMO radar is proposed [13]. The use of lens antennas not only reduces the RF chains but also reduces the interferences while improving the user capacity [14]. Furthermore, narrow beams can be preserved using a lens antenna array with fewer RF

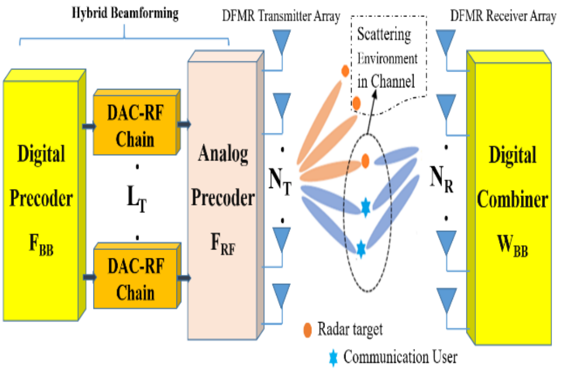

Figure 1. Hybrid beamforming system architecture for DF-MIMO radar

chains, resulting in a significant reduction in the power required per beam and intra-beam interferences [15, 16].

The remainder of the paper consists of sections such as related literature in section 2, proposed methodology in section 3, simulation results in section 4, and conclusion in section 5.

1. 1. Literature Related Work

The hybrid (analog-digital) beamforming approach was proposed by Khalid [17] for the massive MIMO communication systems in the sparse mm-wave channels. They designed a hybrid regularized channel diagonalization approach that combines analog RF precoding with linear digital precoding to observe the performance. Zhang et al. [18] have optimized hybrid beamforming for the massive MIMO relay system by defining the objective function of maximizing the sum rate of the massive MIMO system. The piecewise successive approximation technique was then applied to reduce the information loss. The hybrid beamforming techniques were proposed by Du et al. [19] for the multi-user massive MIMO-OFDM systems. They offered an alternating maximization system in that analogy beamforming had optimized using the Riemannian manifold.

The non-orthogonal multiple access (NOMA) had adopted by Lee et al. [20] for the efficient hybrid beamforming in massive MIMO systems. The NOMA was applied by selecting two users with the higher channel correlation, and then RF beamforming and digital beamforming were applied to both users. The power allocation was used to achieve intra-pair user fairness. The transmission of the mm-wave system was examined by Ozbek et al. [21] via the linear beamforming methods for physical layer systems. They designed secure multi-user mm-wave massive MIMO systems using hybrid beamforming at the legitimate users, eavesdroppers, and base stations. The massive MIMO system was exploited by Zhai et al. [22] with hybrid beamforming to improve the computational efficiency of over-the-air computation at minimum cost. They have designed the scenario of scalable multi-antenna devices sending data simultaneously to the access point. The access point had integrated with massive antennas. The downlink mm-wave massive MIMO system was investigated by Zhan and Dong [23] with a novel interference cancellation approach on hybrid beamforming. They have designed different successive interference cancellation techniques to address the intra-user and inter-user interference in dual communication systems. Gao et al. [24] have proposed novel wideband two-hybrid beamforming techniques according to true-time-delay lines and virtual sub-array lines to discard the beam squint effect. The transmit beamforming focused by Vlachos and Thompson [25] with the novel approach of low-end elements to improve the EE with reduced impacts on SE. They designed a novel analogy precoder where the RF chains were deactivated according to the optimization algorithm rather than reduction.

The framework for approximating the optimal fully-digital beamformer with a suitable hybrid one has been proposed by Fortunati et al. [26] for efficient hybrid beamforming. But dedicated RF chains to each antenna including power amplifiers, digital to analog, and up-converters consume excess power, and the cost of a complete hardware setup is unbearable. To overcome these issues, the RF chains are reduced using fully analog or hybrid configuration, but this increases the system complexity. Ioushua and Eldar [27] designed the alternating minimization of approximation gap (Alt-MaG) framework using the hybrid beamforming for the massive MIMO systems. But the infinite resolution of phase shifters and network switches makes its hardware implementation impractical. Then, Zhang et al. [28] made an attempt to maximize the entire mm-wave communication system's sum rate. They designed piecewise successive iterative approximation (PSIA) for analog precoder to perform analog beamformer and combiner but failed to handle the system complexity. The piecewise successive approximation (PSA) method was used in the digital precoder stage to prevent data loss. Another novel hybrid beamforming model had designed by Zhang et al. [29] for a multi-user mm-wave massive MIMO communication system with the objective function of sum-rate maximization. They adopted a two-stage design technique for joint transmitter and receiver design in sub-connected configuration to avoid system complexity due to fully connected configuration. The analog beamformer and combiner were designed using the piecewise dual joint iterative approximation (PDJIA) technique. The baseband piecewise successive approximation (BPSA) was designed for digital beamforming to satisfy the criterion of information loss prevention. But this compromises the computational efficiency. Thus there is a need for an efficient hybrid beamforming design that will achieve the best trade-off between achievable sum rate and energy efficiency.”

1. 2. Contribution

The work presented in this paper has background of hybrid beamforming using piecewise successive iterative approximation (PSIA) and baseband piecewise successive approximation (BPSA) techniques as described by Zhang et al. [28, 29]. In addition to this, reduction in dimensions of sparse beamspace channel of the MIMO system using lens antenna array is proposed aa s novelty. This not only reduces the required number of RF chains but also increases the energy efficiency required in most of the RF systems. The contributuion is listed as follows:

- To address the lower spectrum efficiency performance of existing hybrid beamforming methods, the dimension reduction of beamspace channel matrices and lens antenna technology are investigated to improve SE performance through successive approximation interference cancellation.

- To reduce the required number of RF chains, the novel hybrid beamforming design incorporates the dimension reduction-baseband piecewise successive approximation (DR-BPSA) beamforming technique at baseband precoding and the optimal piecewise successive iterative approximation (PSIA) technique at analog precoding. This novel hybrid beamforming design ensures reduced RF chains with higher energy efficiency without loss of information.

The performance of the designed DR-BPSA hybrid beamforming approach is compared with the existing methods by simulations. This ensures the effectiveness of the proposed design as it can achieve a higher spectrum and energy efficiency against the variable number of users.

2. PROPOSED METHODOLOGY

Here, a dual functioning MIMO radar system is considered, which transmits communication signal and radar probing signal simultaneously to the downlink mm-wave users and target, respectively. It uses the lens antenna array to minimize the RF chains and improve the user capacity of the mm-wave massive MIMO communication function. The number of RF chains and base stations to the number of users concerns constraints, as mentioned by Zhang et al. [29].

2. 1. System Model

Figure 2 shows the proposed hybrid beamforming design blocks. In this design, the input $I_{(i,k)}$ is passed to the digital precoder block, where we applied the Dimensional Reduced-BPSA approach to satisfy the objective of avoiding information loss. The BPSA approach of the digital precoding is adapted from literature [26] with modification in channel matrix dimensions to reduce the number of required RF chains that produced $D_{(i,\,k)}$. After that, DAC is applied on $D_{(i,\,k)}$ to convert the digital signals to analog signals before allocating the RF channels. In analog beamforming, the transmitted signals $(D_{(i,k)}RF)^{\cdot\cdot}$ are mapped by performing the analog beamformer and combiner using the PSIA approach. Here the PSIA technique is adopted from literature [25] to maximize the sum rate performance. The output vector $A_{(i,j)}$ is further transformed for antenna array allocation using power allocations.

The lens antenna arrays transform the spatial domain channel into a beam space channel matrix. The lens antenna array signals are mathematically represented to realize the spatial discrete Fourier transformation FT using transform matrix U of size n × n. The input signal S_i is given by:

$$S_i = FT\,[\,U\,S_i^r + (I-U)\,S_i^c\,] \tag{1}$$

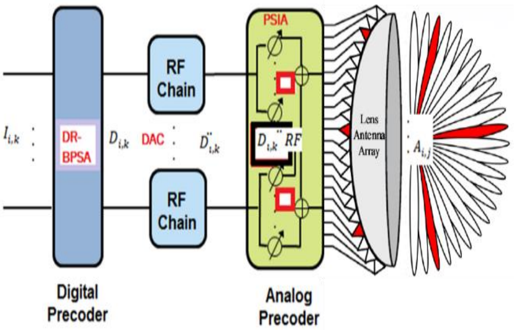

Figure 2. Proposed hybrid beamforming design block-diagram for DF-MIMO radar

where, S_i^r and S_i^c represent the radar and communication signals, respectively. In the hybrid beamforming model, the transmitted signal $A_{(i,j)}$ with maximum alloted power constraint P_t is given by:

$$A_{(i,j)} = W_{RF}\,W_{BB}\,P\,S_i \tag{2}$$

W_{RF} and W_{BB} are the analog and baseband (digital) beam weight matrix, respectively. P is a power allocation matrix with $||P||^2 = P_t$. Without loss of generality, the flat Rayleigh fading environment is considered as transmission channel H. The transform matrix U contains the n directional array steering vectors for channel matrix H, represented as:

$$U = [l(\widehat{\theta_1})\;\; l\left(\widehat{\theta_1}\right) \ldots, l(\widehat{\theta_n}\,)]^H \tag{3}$$

The lens antenna array steering vector $l(\widehat{\theta_1}\,)$ is represented as:

$$l(\hat{\theta}) = \frac{1}{\sqrt{n}}[e^{-j\pi\theta_z}] \tag{4}$$

where, $\widehat{\theta_\iota} = \frac{1}{n}\left(j - \frac{n+1}{2}\right)$, j = 1, 2, …$n$ and $z \in q\frac{n\text{-}1}{2}$, q=0,1,2,.. n-1 represents the predefined spatial direction. Then, the received signal vector Y using the lens antenna arrays is expressed as:

$$Y = W_{RF}\,H^H U^H DPK + \sigma \tag{5}$$

where H^H is the $n \times m$ channel matrix, U^H is the transformation matrix of size $n \times m$, $D = f(W_{BB})$ represents the BPSA precoding matrix, P represents the power allocation matrix for all users, and K represents the set of received signals for each user as $K=[k_1, k_2, \ldots, k_m]$. The $\sigma \sim \mathbb{C}N(0, \sigma_0 I_N)$ represents the noise vector. The mutual user interference (MUI) at the receiver is estimated as $(HX\text{-}S_i)$, which is a key measure of performance and closely related to the achievable sum rate. Thus, the achievable sum rate R is inversely proportional to mutual user interference [30], and it is given as:

$$R = \sum_{i=0}^{K} \log_2 (1+\gamma_i) \tag{6}$$

where, γ_i is the signal-to-interference-plus-noise ratio of the i^{th} user.

2. 2. Proposed DR-BPSA Approach

Now, according to Equation (5), the terms for each i^{th} user is further elaborated as:

$$\left.\begin{array}{l} \mathrm{H}_{\mathrm{i,\,j}}=\mathrm{HU}_{\mathrm{i}} \\ \mathrm{D}_{\mathrm{i,k}}=\mathrm{D}_{\mathrm{i}} \end{array}\right\} \tag{7}$$

where HU_{i} represents the beam space channel vector using lens antenna arrays and D_{i} represents BPSA digital precoding vector for the i^{th} user.

DR-BPSA approach uses the beamspace MIMO system to convert the traditional spatial channel to beamspace channel. For this purpose, it uses a lens antenna array to capture channel sparsity with the intention of reducing the required number of RF chains. Since the scattering in mm-wave communications is not rich, the number of effective prorogation paths is limited and less than the total number of RF chains at the transmitter. This occupies only a small number of dominant beams. As a result, the mm-wave beamspace channel is sparse. Thus a small number of dominant beams is selected to significantly reduce the dimension of the MIMO system and the number of required RF chains without obvious performance loss. This selection is made by choosing the strongest element amongst the non-zero elements in the sparse channel vector. Then the influence of the selected channel component is ignored from the total beamspace channel estimation. Beam selection is depending upon the total number of users. As the one beam attend only one supporting user at the same frequency. The total number of user should be equal to the available number of RF chains. This is considered as fundamental limit if the beamspace MIMO system. The received signal vector from Equation (5) is represented using the DR approach as:

$$\mathrm{Y}=\mathrm{W}_{\mathrm{RF}}\ \mathrm{H}_{\mathrm{DR}}^{\mathrm{H}}\mathrm{U}_{\mathrm{DR}}^{\mathrm{H}}\mathrm{D}_{\mathrm{DR}}\mathrm{PK}+\sigma \tag{8}$$

where, $\mathrm{H}_{\mathrm{DR}}=\mathrm{H}_{\mathrm{DR}}^{\mathrm{H}}\mathrm{U}_{\mathrm{DR}}^{\mathrm{H}}$ is the Dimension-Reduced beamspace channel matrix with the selected number of beams with their index set of size $r \times m$. D_{DR} is the BPSA precoding vector according to dimensionality reduced beam space channel vector. The original size $n \times m$ is reduced to $r \times m$ after applying the DR technique where $r < n$. As the number of dimensions is reduced in D_{DR}It reduces the required number of RF channels, directly affecting cost and energy efficiency. The elements in Equation (6) are then revised after applying Dimension Reduction (DR) as:

$$\left.\begin{array}{l} \mathrm{H}_{\mathrm{i,\,j}}=\mathrm{HU}_{\mathrm{DR}}^{\mathrm{i}} \\ \mathrm{D}_{\mathrm{i,k}}=\mathrm{D}_{\mathrm{DR}}^{\mathrm{i}} \end{array}\right\} \tag{9}$$

Therefore, the above novel design of modified BPSA scheme at digital precoder ensures energy efficiency with improved user capacity and without data loss. Then, the below steps are performed for each $\mathrm{D}_{\mathrm{i,k}}$ with its corresponding $\mathrm{H}_{\mathrm{i,j}}$ to update the hybrid beamforming weights using successive approximations [29] to get optimized weights for beamformers in the mm-wave massive MIMO communication system. The design steps and flowchart of the proposed hybrid beamforming are illustrated in Figure 3.

2. 3. Flowchart of the Proposed Methodology

The functionality of PSIA has already proven effective with the hybrid beamforming approach [27]. But it suffered from the challenges of performance trade-offs considering the parameters EE, SE, and CE. The proposed novel hybrid beamforming design with the lens antenna arrays technique overcomes these challenges.

Algorithm for Proposed Hybrid Beamforming Design

```
Input: $\mathrm{S_i}, \mathrm{W_{RF}}, \mathrm{W_{BB}}$;
For k=1 to K, do
    Obtain $\ddot{\mathrm{D}}_{\mathrm{i,k}} = \mathrm{DAC}(\mathrm{D_{i,k}})$;
    Calculate $\mathrm{H^H}$ by $\mathrm{W_{RF}\ H\ W_{BB}}$;
    Apply DR-BPSA to update $\mathrm{H^H}$ and $\mathrm{D_{i,k}}$ ;
    Obtain $\mathrm{HU_{DR}^{i}}$ and $\mathrm{D_{DR}^{i}}$;
    Allocate RF channel for each $\ddot{\mathrm{D}}_{\mathrm{i,k}}$ to get $\mathrm{D_{i,k}}^{\cdot\cdot}$ RF;
    Normalize $\mathrm{W_{BB}}$ by $\mathrm{W_{BB}(i)} = \frac{\mathrm{W_{BB}(i)}}{\|\mathrm{W_{RF}\ W_{BB}(i)}\|}$ , i=1…. $n$
    Apply PSIA analog beamforming on $\mathrm{D_{i,k}}^{\cdot\cdot}$ RF;
    Get the analog beamformer $\mathrm{D_{i,k}}^{\cdot\cdot}$ RF;
End for
Output: $\mathrm{A_{i,j}}, \mathrm{H_{i,\,j}}$
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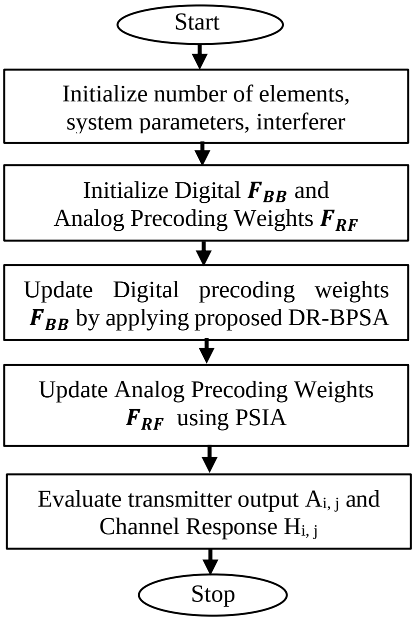

Figure 3. Flowchart for the proposed hybrid beamforming

After the lens array allocation to form the beam space channel matrix and hybrid precoding, the power allocation with lens antenna arrays must be adequate to improve the EE, SE, and CE by mitigating interference.

3. SIMULATION RESULTS AND DISCUSSION

This section presents the experimental results simulated on the MATLAB platform and a comparative analysis of the proposed model. The performances are measured in terms of SE, EE, BER, and CE in terms of response time.

i. Spectrum Efficiency: It is the optimized use of spectrum or bandwidth so that the maximum amount of data can be transmitted with the fewest transmission errors. Spectrum efficiency η_{SE} is defined as the achievable sum rate, and it is calculated as:

$$\text{Spectrum Efficiency } (\eta_{SE}) = \sum_{j=0}^{n} \sum_{i=1}^{|S_n|} R_{i,j} \tag{10}$$

where n is the total number of transmit antennas (256 in this work), S_n is the set of users served by the n^{th} beam. The $R_{i,j}$ is represents the achievable rate of i^{th}user at j^{th}beam.

ii. Energy Efficiency: It is defined as the ratio between the achievable sum rate R_{sum} and the total power consumption. The EE is represented as η_{EE} and computed by:

$$\eta_{EE} = \frac{Rsum}{P + N_{RF}\, P_{RF} + N_{RF}\, P_{SW} + P_{BB}} \text{ (bps/Hz/W)} \tag{11}$$

For BER and CE parameters, the standard formulas are adopted. The BER has been computed among the transmitted and received signals to estimate the errors. For CE, the resource utilization criteria is estimated in terms of the processing speed of each technique. The CE counts the total processing time required to perform the mm-wave MU-MIMO communications in seconds. Complexity of the system is also possible to address using total processing time.

As per the simulation parameters mentioned in Table 1, the mm-Wave MIMO with a varying number of users is designed to check the scalability of the proposed model. The number of users (m) varies from 10 to 50 with constant transmit power and the total number of beams. Figures 4 to 6 demonstrates the outcome of SE, EE, and BER rates using different hybrid beamforming techniques and the conventional baseline (FD-MIMO) method [26].

TABLE 1. Simulation parameters for user density scenario

Parameter	SNR	n	Pt	P_{RF}	P_{SW}	P_{BB}	m
User Density Scenario	10 dB	256	32 mW	300 mW	5 mW	200 mW	10:5:50

The SE performance shown in Figure 4 reveals that with the increase in the number of users, the spectral performance gained due to the increasing number of transmitting signals in the mm-wave multi-user MU-MIMO communication system. Among all these methods, the conventional baseline FD-MIMO technique shows a much higher SE rate than all other hybrid beamforming techniques. The FD-MIMO technique delivered the higher SE due to the dedicated RF allocation to each beam in the communication system. But, this has led to significant energy consumption (Figure 5) and an expensive approach (Figure 6). FD-MIMO techniques need many RF chains, limiting the user capacity. The outcomes of EE and BER revealed the limitations of the FD-MIMO technique. The mm-wave massive DF MIMO radar is introduced to overcome these challenges using a hybrid beamforming approach. Therefore, the analysis of all hybrid beamforming methods is presented in this section.

From Figure 4 (SE), Figure 5 (EE), and Figure 6 (BER), it is observed that the proposed DR-BPSA method delivered better performances compared to recent hybrid beamforming techniques. Among four hybrid beamforming methods, the Alt-Mag method [26] shows the worst performance for SE, EE, and BER due to its tedious approach to performing the analog and digital precoding tasks via the alteration minimization for approximation gap. The other two techniques, PSIA [28] and PDJIA [29], failed to achieve the trade-off among SE, EE, and BER rates. PSIA method achieved a better EE than the PDJIA technique but was unable to improve the SE and BER performances compared to the PDJIA method and vice versa. In the proposed DR-BPSA method, these limitations are overcome using a novel hybrid beamforming technique that utilizes the benefits of BPSA (digital precoder) and PSIA (analog precoder) with the mechanism of dimension reduction. Table 2 further demonstrates each method's outcome values of

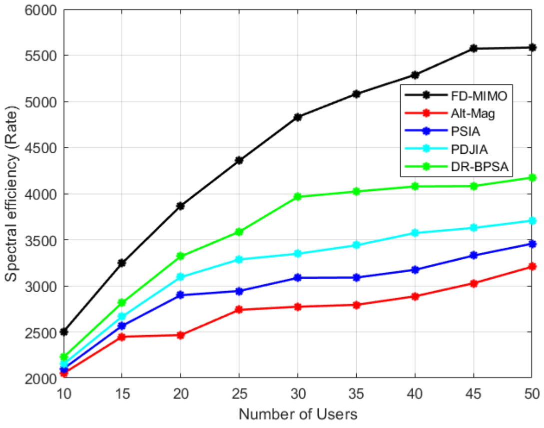

Figure 4. Spectral efficiency analysis for user density scenario

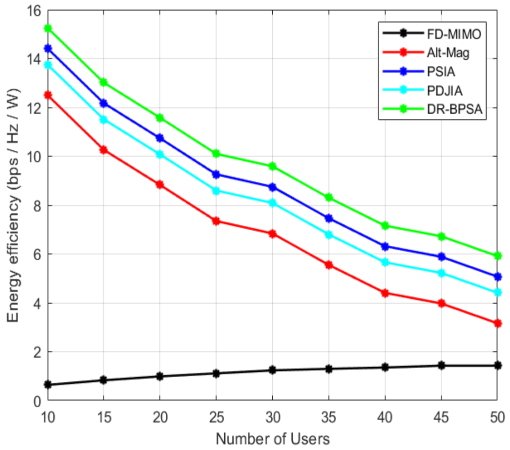

Figure 5. Energy efficiency analysis for user density scenario

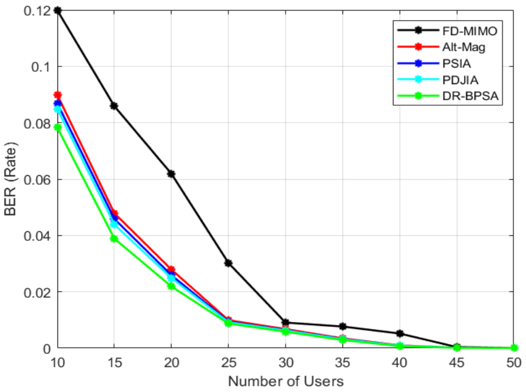

Figure 6. BER analysis for user density scenario

TABLE 2. Performance analysis for user density scenario

Methods	Energy Efficiency (bps/Hz/W)	Spectral Efficiency (bps/Hz)	Bit Error Rate	Cost-Efficiency (Seconds)
FD-MIMO [26]	1.1744	4.5983×10^{03}	0.0356	1.92
Alt-Mag [27]	7.2719	2.7854×10^{03}	0.0208	1.79
PSIA [28]	9.1819	3.0354×10^{03}	0.0199	1.67
PDJIA [29]	8.5219	3.2854×10^{03}	0.0193	1.76
DR-BPSA	10.0219	3.6604×10^{03}	0.0175	1.58

SE, EE, and BER rates. From these outcomes, it is claimed that the proposed DR-BPSA technique successfully addressed the limitations of existing methods concerning the performance trade-off. The novel approach of hybrid beamforming with its integration with lens antenna arrays method reduces the required number of RF channels with maximum system throughput and higher user capacity support.

4. CONCLUSION

This paper proposes the novel hybrid beamforming approach called Dimension Reduced Baseband Piecewise Successive Approximation in Hybrid Beamforming for the dual functioning MIMO radar system with a core focus on hybrid beamforming improving the performances in terms of spectral efficiency, energy efficiency, bit error rate, and cost-efficiency. The proposed hybrid beamforming technique overcomes the challenges of existing hybrid beamforming solutions, such as lack of performance trade-off and limited user capacity. This hybrid beamforming technique is integrated with the lens antenna array system to improve the user capacity with minimum resource utilization and computational efforts without data loss. The DR-assisted digital beamformer produced the reduction of RF channels with energy efficiency. The analog beamformer further performed the ZF-based analog precoding through PSIA operations to mitigate the inter-beam interferences. The experimental results showed the proposed design achieved an acceptable trade-off among all the parameters compared to the state-of-art techniques. The energy efficiency performance improved by 18 %, spectral efficiency performance improved by 19 %, and Bit Error Rate reduced by 17.5 %. The response time of the proposed method reduces effectively, so it is beneficial in terms of cost-efficiency. Applying the swarm intelligence or optimization algorithms for analog and digital beamformers will be an exciting extension of this work.

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Persian Abstract

چکیده

یک طراحی پرتوهای هیبریدی قابل اعتماد و موثر برای رادار چند ورودی چند خروجی دو کاره (MIMO)یک مشکل تحقیقاتی چالش برانگیز است زیرا نگرانی‌های مربوط به محدودیت ظرفیت کاربر، تداخل، و عدم تبادل عملکرد وجود دارد. به دلیل کمبود طیف در دسترس، اشتراک گذاری طیف فرکانس رادار در سیستم های ارتباطی نوظهور ۵G حیاتی شده است. این امر ازدحام طیف را کاهش می دهد، بنابراین نکات قابل توجهی را به خود جلب می کند. روش‌های هیبریدی شکل‌دهی پرتوهای موجود، زنجیره‌های فرکانس رادیویی (RF) را کاهش می‌دهند، اما بهبود ظرفیت کاربر همچنان یک نگرانی اصلی است. طرح‌های ارتباطی دوگانه راداری آینده با چالش‌هایی در افزایش ظرفیت کاربر با حداقل زنجیره‌های RF، کاهش تداخل و کاهش هزینه سخت‌افزار مواجه هستند. این کار یک رویکرد جدید به یک مکانیسم ترکیبی شکل‌دهی پرتو برای رادار MIMO با عملکرد دوگانه پیشنهاد می‌کند. این مکانیسم از تقریب متوالی تکه‌ای باند کاهش‌یافته استفاده می‌کند که با یک پیش‌کدگذار دیجیتال ادغام شده است. در پیش کدگذار آنالوگ، رویکرد تقریب تکراری تکه تکه برای انجام شکل دهی پرتو آنالوگ اعمال می شود. شکل دهی پرتو هیبریدی جدید با ادغام آرایه آنتن لنز ظرفیت کاربر را بهبود می بخشد و نیاز به برق، تداخل و هزینه ها را کاهش می دهد. نتایج شبیه‌سازی عملکرد بهتری را در مقایسه با روش‌های پیشرفته موجود از نظر نرخ خطای بیت، بازده طیفی، بازده انرژی و زمان پاسخ نشان داد.