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Hybrid Beamforming for Dual Functioning MIMO Radar Using Enhanced-Social Ski Drivers Algorithm

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Abstract: Inflated communication traffic and expanding radar applications result in frequency congestion and require extra spectrum resources. Dual-functioning multi input multi output radar benefits both sensing and communication operations via real-time cooperation. This decongests the radio frequency environment and allows a single hardware platform for both functionalities. Analog beamforming fails to provide multiplexing gain and digital beamforming is not preferred practically because of heavy power consumption. A reliable hybrid beamforming design is an inherent requirement due to the concerns related to limited RF chains, interference and the cost of fully-digital beamforming. In this paper, Enhanced-Social Ski Driver's algorithm is presented to investigate the performance of hybrid beamforming in dual-functioning MIMO radar. This study investigates location-based direction sensing for Rayleigh and Rician fading channels. This amendment provides improved performance with a minimal bit error rate, maximum gain, and significant normalized array power distribution. The simulation results show 24% reduction in bit error rate, 15% improvement in gain and persistent array power than existing social ski driver's algorithm.

Keywords: Optimization algorithm, Hybrid beamforming, Dual functioning radar communication, Signal processing, Spectrum sharing.

1. Introduction

Recently, radar and communication systems have progressed in several multi-purpose applications due to a tremendous increase in system performance. This is directly leading to the shortage of spectral resources and frequency congestion. So the price of the existing wireless spectrum is sharply increased as a consequence of demand. Sharing the available frequency spectrum is an affordable solution in the current scenario [1]. At the hardware level, radar and communication systems have a similar design yet do not share any frequency band for dual application. Due to specific reservations of the frequency spectrum, some of the spectrum resources are under-utilized. Thus sharing the frequency of the under-utilized spectrum attracted the user's attention. This sharing will not only avail the frequency but also reduce the cost of hardware configuration [2]. Currently, a substantial portion of radar frequencies is available and found suitable to utilize in communication services. This field is open to attempting the communication and radar spectrum sharing (CRSS) challenges [3]. Modern radar already expanded its applications in the areas of monitoring, traffic control, and surveillance. In MIMO radar, this variety tends to be spatial, which reduces the radar cross-section scintillation and improves target echo detection. This diversity is established in the form of waveform diversity, which improves localization, identifiability, and the ability to unswervingly apply adaptive methods and digital beamforming [4, 5].

Current wireless 5G new radio (NR) technology prefers a higher frequency band like millimeter (mm)-wave for speedy signal transmission. So availing frequencies above the wireless spectrum raised concerns about the interference in critical radar operations. To tackle this issue, communication and radar spectrum sharing (CRSS) research is highly prioritized by the researchers. The design of a dual functioning radar-communication (DFRC) system is identified as one of the research directions [2, 5]. The use of dedicated hardware for the individual application under the same frequency band to manage interference effectively is not a feasible solution as it will lead to a huge hardware setup with extra space and also increased cost. Alternately, the design of Dual Functioning MIMO radar (DFMR) prefers the joint platform to execute both sensing as well as communication. This will counter the above-mentioned issues related to dedicated hardware.

Currently, different radar frequency bands like L-Band (1-2 GHz), S-band (2-4 GHz), C-band (4-8 GHz), mm-Wave (30-300 GHz) band are shared by wireless 802.11b/g/n/ax/y wireless local area network (WLAN) network and similar communication technologies [6, 7]. The beamforming technique was adapted to control the direction of signals generated by radio channels. It is utilized in the transmission and reception stages to achieve spatial selectivity. The primary function of radar remains unaffected by the use of communication function. This is due to MIMO array configuration and orthogonal waveforms.

In DFMR, the waveform orthogonality and diversity are only required for communication function. When a single beam is directed towards the target, the side lobe beams are used to communicate with the user. The design of analog and digital precoding and combining weights are reformulated as an optimization problem and addressed through various optimization techniques in the literature as seen in [9 - 12].

Classical beamforming with phased-array antennas faces challenges due to the orthogonal signals transmitted by each antenna element, which hinders simultaneous interference mitigation and target identification. [13]. MIMO radar is evolving to optimize interference alleviation and target detection through transmit-beam pattern construction and virtual beamforming. However, large aperture and low-cost subarray designs are needed to address design challenges. [14-17]. Phase-only approaches incorporate nonlinear optimization algorithms, to estimate the signal but fail to address the false alarms due to major side-lobes. Genetic algorithms are broadly adapted to optimization problems and synthesizing the antenna arrays but having issues of premature convergence and computational complexity [18, 19].

Optimization problem modeling becomes critical when constraints, objectives, number of decision variables, and solution space are not set. Because of the inefficiency of classical optimization algorithms in solving large-scale combinative problems, metaheuristic optimization algorithms have been proposed to inspect the performance. This attempt goes well on the criteria of multifunctional requirements such as flexibility, gradient-free mechanism, and local optima avoidance [20]. The Salp Swarm algorithm's effectiveness in hybrid beamforming is similar to the behavior of Salp Swarms searching for food in the marine environment. However, the algorithm's limitations include limited exploration of the search space, slow convergence, and a large number of iterations. [21, 22]. According to studies, Monarch butterflies have several migration theories to address specific optimization problems but have issues of population degeneration and time complexity. Similarly, Dolphins have proved their smartness and intelligence in food hunting and navigation. These strategies inspire to address the optimization problems with effective solutions [23, 24]. On a comparable premise, the Social Ski Drivers likewise search and take the optimal path towards the downhill. So These algorithms have the capacity to acquire the best or near-optimal solutions with better-guided exploration ability [25].

1.1 Motivation

Hybrid beamforming faces limitations such as complicated infrastructures or complex signal processing with heavy power consumption [16, 18]. There exist several issues while operating with high frequencies and huge bandwidth accessible at mm-wave, but the potential of providing high resolution and improved collision detection and avoidance are the points of motivation in dual functioning MIMO radar applications. While scanning, the base station faces difficulty to isolate the side lobes, because the radar beam pattern can shift arbitrarily as the target moves and may obstruct the communication functioning [27-29]. Hence to cancel mutual interference, stronger approaches like hybrid precoding design are needed. Transmitter gain loss is observed in MIMO configuration and this needs to be avoided to improve the resolution of DF-MIMO radar systems [30-33].

Hanning-window least square-constant modulus algorithm (HW-LS-CMA) outperforms the CMA. but the convergence speed was inferior to that of LS-CMA, and simultaneously, the side lobe level was higher. Thus, an effective method is required to reduce convergence by optimizing the weights of the HW-LS-CMA. [26].

Table 1. Notation list

$(.)^H$	complex conjugate transpose
$E(.)$	Expectation operator
$\|\|(.)\|\|_F$	Frobenius norm
$(.)^T$	Transpose
$tr(.)$	Trace
L_T	Total no. of RF Chain
N_T	Total no. of Transmitter antenna elements
N_R	Total no. of Receiver antenna elements
S_T	Transmitted signal
Ns	Total no. of transmitted signal
I	Identity Matrix
F_{BB}	Baseband Precoder at transmitter
F_{RF}	Analog Precoder at transmitter
W	Baseband Precoder at receiver
f_{Bi}	ith digital weight in baseband precoder
f_{RFi}	ith analog weight in analog precoder
P_{total}	Total alloted power
N_m	Total no. of scattering paths
C	Rician Factor ($C=3$ in this work)
β_l	Gain parameter
a_ϕ	Transmit array response vector
ϕ	Angle of departure
a_θ	Receiver array response vector
θ	Angle of arrival

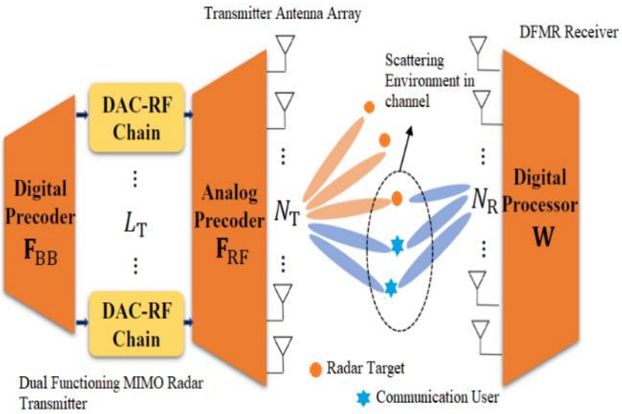


Figure. 1 MIMO radar communication system (DFMR) block architecture for hybrid beamforming [27]

1.2 The main contributions of this paper are as follows:

- A novel hybrid beamforming approach for dual Functioning MIMO radar is proposed and named as Enhanced-Social Ski Drivers algorithm. The Social Ski driver algorithm's position-updating technique is modified by integrating it with the Dolphin Echolocation algorithm.
- The HW-LS-CMA narrowband adaptive beam former presented in [26] is modified using the proposed hybrid beamforming design which yields effective weights using fitness measures.
- The performance evaluation is performed under different subarray configurations for Rayleigh and Rician fading channels on the simulation platform, and the bit error rate, array power, and gain are the parameters examined for the analysis. The methods considered for comparative analysis are uniquely implemented for hybrid beamforming design.

Following Table 1 gives the description of notations used in this paper.

1.3 DF-MIMO Radar System Model:

Fig. 1 shows the block architecture of the DFMR system. It includes the baseband and analog precoding connected via the digital to analog converter (DAC)-RF chain where DAC has full bit resolution. The transmitter transmits N_s data streams against the K users. The design has a fully connected subarray configuration of RF chains and antenna elements $(L_T = N_T)$. At the receiver end total, N_R antennas are located [34].

The transmit signal $S_T \in {}^{Ns} \leq N_T$ and $E\,(S_T\, S_T{}^H) = I$. The digital precoders matrix at baseband is F_{BB} where, $F_{BB} \in {}^{Ns\,\times\, L_T}$ includes the f_{Bi} entries of digital weights where $i = 1 \ldots L_T$. At analog precoding, $F_{RF} \in {}^{L_T \,\times\, N_T}$ matrix contains the phase shift weights f_{RFi} where $i = 1 \ldots N_T$. The total allotted power P_{total} is subject to the constraint $\|\| F_{BB} F_{RF} \|\|^2{}_F$.

1.4 Channel model information:

The transmission waveform works as radar as well as a communication signal. Once the transmission path is fixed then it establishes the single-user communication path and has a dominant line of sight fading environment. At the same time, the transmission environment is highly congested due to multiple devices. The frequency sharing gives rise to scattering. As more users and the radar targets are present, the device density and Doppler shift component will result in a rich scattering environment. Thus both Rician and Rayleigh fading is relevant in dual functioning radar communication. Here, the narrowband Rician fading channel H is considered as follows:

$$H = \sqrt{\frac{N_T N_R}{N_m}} \sum_l^{N_m} C\, \beta_l\; a_\theta\, a_\phi{}^H \tag{1}$$

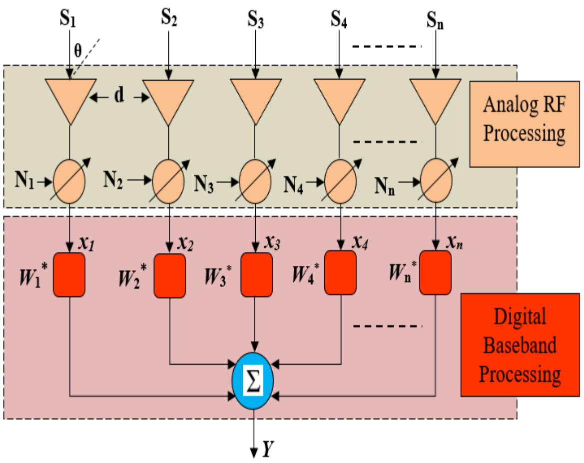


Figure. 2 Joint structure of uniform linear array in DF-MIMO radar

C factor becomes null in the above model when the Rayleigh channel is considered.

Consider MIMO uniform linear array (ULA) as shown in Fig. 2 with *'n'* elements where the spacing between the sensor elements *'d'* is equal to one-half of the incoming signal wavelength λ and the angle of incoming signal θ is estimated concerning antenna bore sight. Without loss of generality, a single-element communication receiver is assumed to be located in direction θ, which is exactly known to the transmitter. The array response vector for the *'n'* element is

$$a = [1, e^{j\left(\frac{2\pi}{\lambda}\right)d\sin\boldsymbol{\theta}} \ldots\ldots\ldots e^{j(n-1)\left(\frac{2\pi}{\lambda}\right)d\sin\boldsymbol{\theta}}]^T \tag{2}$$

The output signal $Y=W^{H.}X$, at the receiver after hybrid beamforming processing, is given as

$$Y=W^H(F_{BB}\,F_{RF}\,H\;S_T)+W^H\,N \tag{3}$$

Where W^H is baseband combiner at receiver. $W^H = [\;W_1^*,\; W_2^{*,}\; W_3^{*,}\; \ldots.\; W_n^*]^T$. The statistical component of desired signal $X = S_T + N$, where, $X = [x_1,\; x_2\ldots.x_n]^T$, $S_T = [S_1,\; S_2\ldots.S_n]^T$ and Noise plus interference signal $N = [N_1,\; N_2,\; \ldots.\; Nn]^T$.

Thus the product of *F*, *H*, and *W* gives optimal precoding and combining weights hence each data stream is reconstructed independently without information loss.

1.5 Radar model in dual functioning MIMO radar:

The radar model is estimated for dual functioning under combinational communication constraints along with guaranteed power transmission, beampattern matching design constraints. MIMO radar has a high degree of freedom than phased array radar. Existing literature [34 - 36] already exploited that the beam pattern matching design problems can be formulated as semidefinite programming optimization problems of probing signal power and addressed by convex optimization. The desired beam pattern is formulated as

$$B(\theta) = a_\theta\, R_{Pre}\, a_\theta^H \;\; s.\,t.\;\; 0 < tr(R_{Pre}) < P_{total} \tag{4}$$

Where R_{Pre} is the covariance matrix of precoding waveform and defined as:

$$\begin{aligned} R_{Pre} &= F_{BB}{}^H F_{RF}{}^H R_{BB} R_{RF} \\ s.t.\; &\|\, F_{BB} F_{RF} \,\|^2_F \le P_{total} \end{aligned} \tag{5}$$

Thus, by designing the hybrid baseband and analog precoding as well as combining weights, the dual function MIMO radar output is improved. But optimizing all weights becomes much more complex and not feasible due to increased computational load and algorithmic complexity. In this work, a hybrid beamforming design for multi-user DF-MIMO radar is presented. To design the baseband precoding weights F_{BB} the joint spatial division multiplexing (JSDM) technique from [37] is adopted. A novel algorithm is proposed to update the analog F_{RF} precoding weights. Thus the new combination of hybrid weights is obtained to enhance the performance of the dual functioning MIMO radar in terms of bit error rate, antenna gain, and normalized array power distribution across the azimuth angle. The primary advantage of the proposed beam former is providing an efficient solution and reasonable tradeoff between communication and radar functionality. Section 2 briefly discusses the proposed hybrid beamforming method and modified HW-LS-CMA beam former. Section 3 discusses the findings of this study. In section 4 the paper is concluded.

2. Proposed hybrid beamforming design using enhanced-social ski drivers algorithm

The social ski divers (SSD) algorithm [25] offers stochastic exploration, which helps to resemble the paths ski drivers take downhill. The goal of SSD is to discover immediate and optimal solutions. The instantaneous position of the ski driver is updated using the velocity function, and an optimal or near-optimal solution is finalized within the search space. The dimensions of space are fixed by the no. of parameters employed in optimization. The direction of the position change reveals a zig-zag pattern due to sin and cosine function, as shown in Eq. (8). So SSD agents have to find the best three solutions and then go with its mean. This method provides increased exploration capabilities and makes the search directions more diversified. Moreover, the agents of SSD move to the mean of the best three solutions, which makes it more effective than other conventional algorithms but sometimes mean solution may differ from the absolute solution, and obtaining the absolute best solution remains a challenge.

On the other hand, dolphin echolocation (DE) [24] is an optimization technique derived from the Dolphin's behavior in their food hunting process. The Dolphin alters its sonar to detect the target and location. So the position is updated by the direction of the echo signal and the detected target's location. This DE method poses an improved convergence factor which is controlled for performing apposite optimization. Thus, the integration of DE and SSD gives scope to improve the convergence and obtain the absolute best solution for SSD. Here the position of SSD agents is updated using DE's position update approach.

Initially, the agents A_1, A_2 up to A_{dA} are defined where dA is the total no. of solutions, and out of that one optimal solution 'A_e' is opted as a mean of the best three solutions. Then the best solution is evaluated based on the fitness function. As per the Dolphin Echolocation algorithm [24], the best position P_h is derived by

$$P_h=\frac{1}{\alpha_{1h}}\begin{bmatrix} A_h(g+1)-A_h(g)-m_h(g)+\alpha_{1h}A_h(g)-\alpha_{2h}S \\ +\alpha_{2h}A_h(g) \end{bmatrix} \tag{6}$$

Where, h indicate search space index, g represent discrete time index, S indicate global best solution, m_h denote search space dimension of h^{th} location of dolphin in g^{th} time, α_{1h} and α_{2h} indicate random numbers in the interval [0,1] adapted in h^{th} location of dolphin.

Now, as per the SSD algorithm [25], the agent update is performed by adding the velocity function $n_h(g)$ which is expressed as,

$$A_h(g+1)=A_h(g)+n_h(g) \tag{7}$$

The velocity of the current search agent in g^{th} time is formulated as,

$$n_h(g)=\begin{cases} x\sin(u_1)\left(P_h^g-A_h(g)\right)+\sin(u_1) \\ \left(V_h(g)-A_h(g)\right) \\ ;\ u_2\leq 0.5 \\ x\cos(u_1)\left(P_h^g-A_h(g)\right)+\cos(u_1) \\ \left(V_h(g)-A_h(g)\right) \\ ;\ u_2>0.5 \end{cases} \tag{8}$$

Where u_1 and u_2 indicate uniformly produced random numbers in the range [0,1], P_h^g indicates the best solution of h^{th} agent in g^{th} time, V_h signifies the mean global solution of the whole population, and x indicates the parameter utilized for balancing exploration and exploitation. If $u_2 \leq 0.5$, then the update Eq. (7) is represented as,

$$A_h(g+1)=\begin{bmatrix} A_h(g)+x\sin(u_1)\left(P_h^g A_h(g)\right) \\ +\sin(u_1)(V_h(g)-A_h(g)) \end{bmatrix} \tag{9}$$

Substituting Eq. (6) in Eq. (9), the update equation for optimal agent derived is,

$$A_h(g+1)=\begin{cases} \frac{\alpha_{1h}}{\alpha_{1h}-x\sin(u_1)}\begin{bmatrix} A_h(g)+\frac{x\sin(u_1)}{\alpha_{1h}} \\ [\alpha_{2h}A_h(g)-A_h(g)-m_h(g)-\alpha_{2h}S] \\ +\sin(u_1)(V_h(g)-A_h(g)) \end{bmatrix} \\ ;u_2\leq 0.5 \\ \frac{\alpha_{1h}}{\alpha_{1h}-x\cos(u_1)}\begin{bmatrix} A_h(g)+\frac{x\cos(u_1)}{\alpha_{1h}} \\ [\alpha_{2h}A_h(g)-A_h(g)-m_h(g)-\alpha_{2h}S] \\ +\cos(u_1)(V_h(g)-A_h(g)) \end{bmatrix} \\ ;u_2>0.5 \end{cases} \tag{10}$$

Thus using iterative approximation, the values of analog weights F_{RFi} at the precoding level are updated. By considering the channel matrix and using the following fitness function the overall performance of the system is enhanced.

2.1 Fitness function

The fitness function is computed to determine the optimal weight from the set of weights. The fitness is evaluated using the enhanced social ski drivers (Enhanced-SSD) algorithm considering transmission channel response and hybrid beamforming weight vectors. Fitness is a maximization function concerning achievable rate and transmission gain. The fitness function is formulated as, Algorithm 1: Proposed hybrid beamforming using enhanced-SSD algorithm

```
Input: $F_{BB}$, $F_{RF}$ and $P_{total}$, $n_h(g)$, $A_h$
Output: Global mean solution $A_e$, $P_h$: best position,
Begin:
    For n^th RF chain element ($n < N_T$)
        Initialize the position of agent $A_h$ and respective velocities $n_h(g)$
        Adjust the velocities using Eq. (8)
        While all agents $A_i$, i = 0, 1, ….d, do
            Compute $A_h(g+1)$ using Eq. (7)
            Sort the agents based on the values of fitness
        End while
        Update Global mean solution $A_e$
        Compute the fitness using Eq. (11)
        Evaluate the fitness of the previous best solution and new mean global solution
        Get new solution by updating the agents using Eq. (10)
    End for
    Return $P_h$ = Best Position, $F_{BB}$, $F_{RF}$
End
```

$$\hat{f}_{HB}=max\|\, F_{RF}.F_{BB}.H_R\|^2 \quad s.t.\ 0<\|\, F_{BB}F_{RF}\, \|^2_F \leq P_{total} \tag{11}$$

Where H_R indicates channel response. The pseudocode of the proposed algorithm is presented as follows.

2.2 Modified HW-LS-CMA beam former using enhanced-SSD algorithm

The drawbacks of the CMA method are addressed in [26] through the LS-CMA and HW-LS-CMA approaches to improve the performance of MIMO radar. The radar functioning in the DF-MIMO radar communication system is advanced by applying modified weights in HW-LS-CMA to minimize side lobe level (SLL) issues. Weight updates also speed up convergence and lower SLL. Here the Eq. (10) is reformulated for the $A_h(g)$ and the weight update equation is derived by the HW-LS-CMA method. By considering $u_2 \leq 0.5$, $A_h(g)$ is expressed as,

$$A_h(g)=\left[\begin{array}{c} \frac{\alpha_{1h}-\alpha_{1h}sin(u_1)+xsin(u_1)(\alpha_{2h}-1)}{\alpha_{1h}-xsin(u_1)} \\ \left[\begin{array}{c} A_h(g+1)-\frac{\alpha_{1h}}{\alpha_{1h}-xsin(u_1)} \\ \left[\begin{array}{c} -\frac{xsin(u_1)}{\alpha_{1h}}(m_h(g)+\alpha_{2h}S) \\ +sin(u_1)(V_h(g)) \end{array}\right] \end{array}\right] \end{array}\right] \tag{12}$$

The weight update equation of HW-LS-CMA given in [26] is modified using the Enhanced–SSD algorithm and is expressed as,

$$\omega_{l+1}=\left[\frac{\alpha_{1h}-\alpha_{1h}sin(u_1)+xsin(u_1)(\alpha_{2h}-1)}{\alpha_{1h}-xsin(u_1)}\right]\omega_{l+1}-\frac{\alpha_{1h}}{\alpha_{1h}-xsin(u_1)} \left[\begin{array}{c} -\frac{xsin(u_1)}{\alpha_{1h}}(m_h(g)+\alpha_{2h}S) \\ +sin(u_1)(V_h(g)) \end{array}\right] -Hanning(B)\left\{\left[\widehat{K}_\omega K_\omega^N\right]^{-1}\widehat{K}_\omega\chi\right\} \tag{13}$$

where, χ indicate an error of data samples, K_ω denote complex Jacobian of error χ,

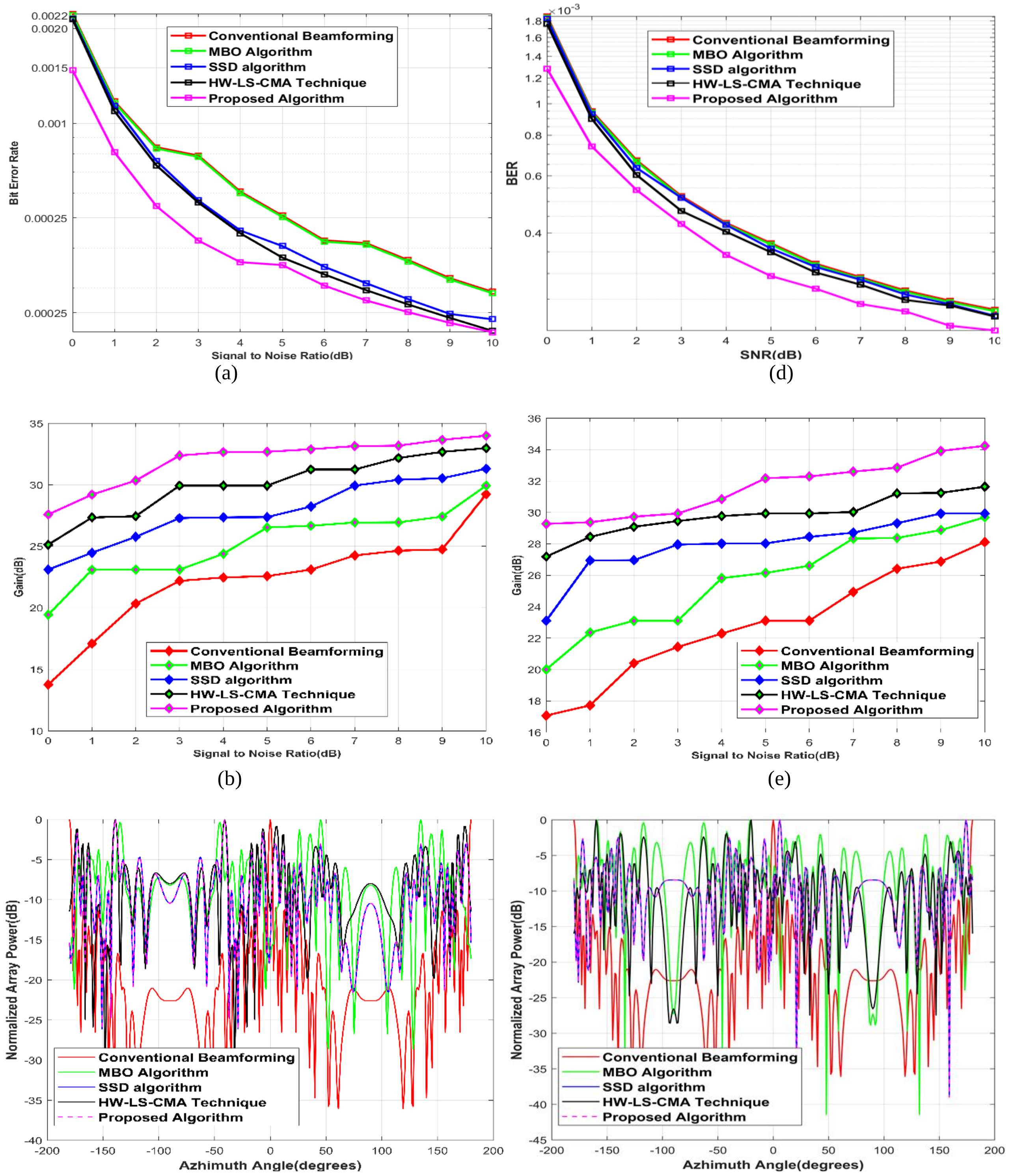
Thus, for fully deployed array configuration in dual functioning MIMO radar, weights of beamformers are modified using the above-proposed approaches.

3. Simulation results and discussion

In this section, the software simulation is shown to represent the performance of the proposed approaches. 4 number of users considered. The total number of independent data streams per user is 8. The operating system frequency is 28 GHz. The total number of transmit antennas and receive antennas are 64 and 32, respectively [17]. The comparative analysis of the methods is done using bit error rate, gain, and normalized array power for Rican and Rayleigh's channels considering sub-arrays = 4 and sub-arrays = 8. In dual functioning MIMO radar applications, the subarray configuration becomes effective in power optimization and cost-efficiency. The methods employed for comparative analysis include Conventional phase shifter Beamforming [15] in which baseband precoding is absent, monarch butterfly optimization [23], social ski diver's optimization algorithm [25], Hanning window-least square-constant modulus algorithm (HW-LS-CMA) technique [26]. The evaluation reveals the effectiveness of the proposed method. The obtained results are shown in the subfigures of Fig. 3 and Fig. 4 below. Table 1 gives the statistical comparison for the performance evaluation.

3.1 Simulation plots for sub-arrays = 4, Channel= Rayleigh

3.2 Simulation plots for sub-arrays = 4, Channel= rician



(a) (d)

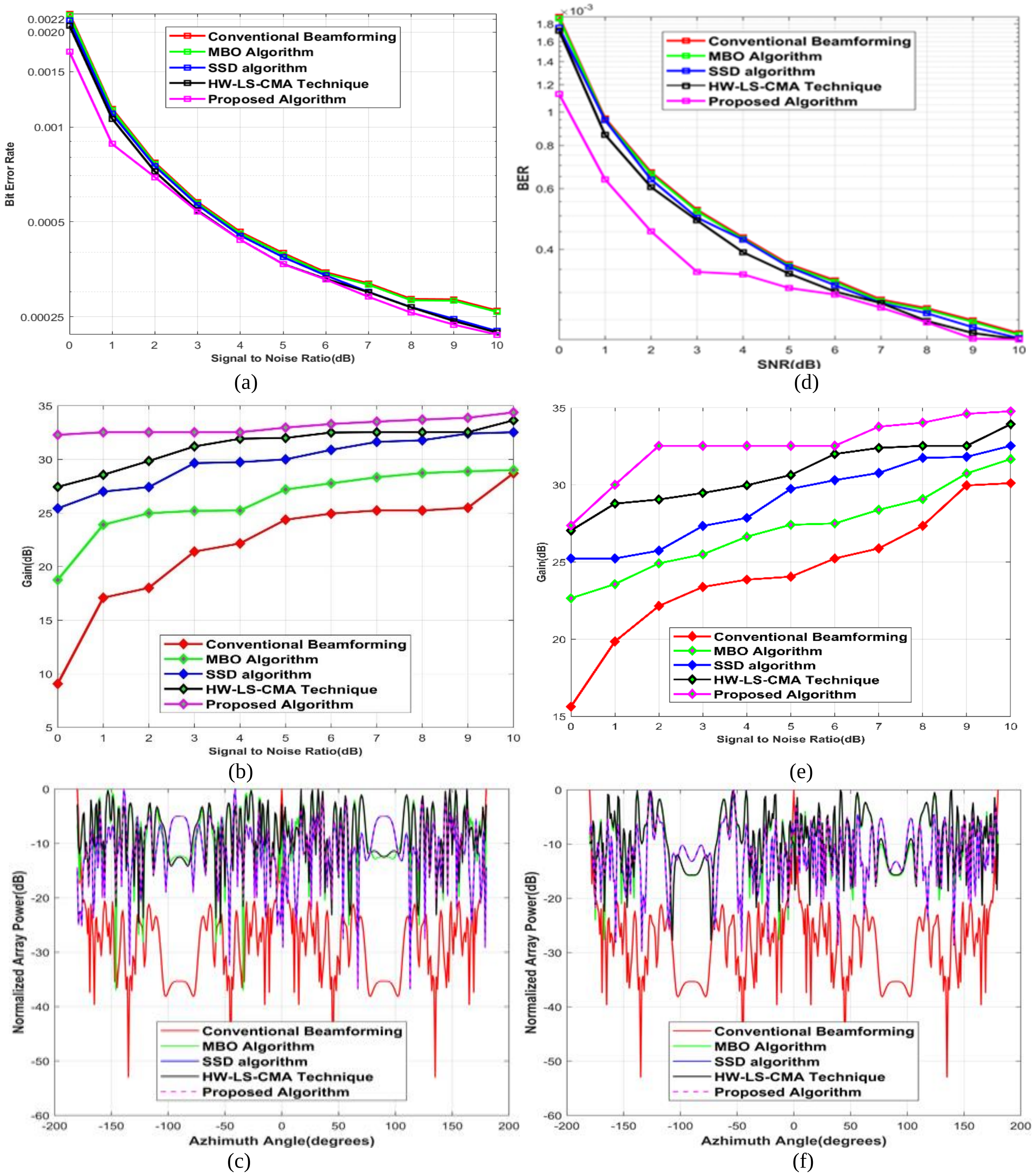
(b) (e)

(c) (f)

Figure. 3 Comparative simulation for Subarray 4 and Rician channel: (a) Bit error rate against signal to noise ratio, (b) Gain against signal to noise ratio, (c) Array power against azimuth angle, (d) Bit error rate against signal to noise ratio, (e) Gain against signal to noise ratio, and (f) Array power against azimuth angle

3.3 Simulation plots for sub-arrays = 8, Channel= Rayleigh

3.4 Simulation plots for sub-arrays = 8, Channel= Rician



(a) (d)

(b) (e)

(c) (f)

Figure. 4 Comparative simulation for Subarray 8 and Rician channel: (a) Bit error rate against signal to noise ratio, (b) Gain against signal to noise ratio, (c) Array power against azimuth angle, (d) Bit error rate against signal to noise ratio, (e) Gain against signal to noise ratio, and (f) Array power against azimuth angle

3.5 Discussion

The simulated plots and statistical results shown in this study, validates the robust performance of the proposed hybrid beamforming design under different subarray configurations and fading environments. Both Rayleigh and Rician fading channels are considered for evaluation. This proposed method also performs well on merits compared to other existing optimization algorithms. Statistical analysis confirms the effectiveness of the proposed method as the minimum bit error rate and the maximum gain is observed in the simulation. BER is a promising parameter in communication channel performance characterization. An analysis of BER vs SNR for 4 and 8 subarrays is shown in Fig. 3 (a), Fig. 3 (d), Fig. 4 (a), and Fig. 4 (d) justifies that the proposed method effectively boosts signal and transmission quality. The existing SSD algorithm shows a reduction in BER than conventional phase shift and MBO beamformers but the further reduction in BER for variable SNR is achieved by applying the HW-LS-CMA beamformer. The proposed design shows much-improved performance than the HW-LS-CMA beam former. The response pattern is robust for the different subarray configurations. Thus it is possible to achieve cost efficiency by managing the active subarray at a particular time. Due to the orthogonality of the input signal, multiuser communication is achieved without affecting radar operations. In radar operations, the gain parameter response signifies the efficient radiation towards the target and in the case of communication, the gain is the key figure of merit which proves the antenna efficiency and directivity. High gain ensures the strength of the signal when transmitted via communication channel. So for shared hardware platform in a dual-functioning MIMO radar system, and the gain parameter must be efficient to complete the requirements. As shown gain vs SNR plots in Fig. 3 (b), Fig. 3 (e), Fig. 4 (b), and Fig. 4 (e) it can be seen that the proposed hybrid beamforming design shows maximum gain against the varying SNR. The variable configuration of subarray does not affect the gain of the antenna and thus the efficiency can be maintained for multitasking in dual functioning MIMO radar. The low performance seen in conventional phase-shift beamforming is due to the absence of digital weight optimization. So this is improved by using the MBO algorithm but it randomly switches to local optima from global minima thus affecting the performance. The SSD algorithm outperforms MBO but is not able to match the performance of HW-LS-CMA. The proposed hybrid beamforming design gives an optimal combination of analog and digital precoding weights which further increases the gain of the system.

The Fig. 3 (c), Fig. 3 (f), Fig. 4 (c), and Fig. 4 (f) shows the unsteered radiation pattern in terms of normalized array power distribution against the azimuth angle between the range of -180 degree to +180 degrees. Both the subarray configurations, covers complete array aperture when activated individually. Conventional phase shift beamforming has dominant lobe at 0-degree azimuth angle which can perform well for radar functioning but not suitable for communication purpose as the sidelobe having much lower power. The remaining methods provides achievable tradeoff between dominant lobe and side lobes. So while scanning, the power towards the communication user is not compromised. No change in normalized array power is observed between the SSD algorithm and the proposed hybrid design but it shows the fast convergence as compared to the other considered methods. The other considered method shows less deviation between upper and lower peak and thus has optimal power utilization. Referring to the figures mentioned above, it is confirmed that the signal power is available over the entire range of azimuth angles using the proposed technique even if only subarray is activated. So the flexibility to form the highest no. of beams in a multiuser scenario will reduce the requirement for additional hardware. Effective management of subarray configuration will distinguish between radar target detection and communication system. Though the varied patterns appear to have the same aperture, they may not have the same beam and side lobe characteristics, as observed visually. So choosing hybrid weights precisely, the covariance matrix is designed in such a way that it will give highly directive beam. It is also possible to detect the failed array element by identifying the power failure in the array. And the weights applied to the remaining array are adjusted accordingly so that the overall pattern is compensated as resembling the healthy beam pattern.

Table 2 shows the statistical analysis of the average bit error rate, gain, and normalized array power values. It is observed that a 24 % reduction in the bit error rate than the Social Ski Driver algorithm is achieved through the proposed hybrid beamforming design when 4 subarrays and the Rayleigh channel are considered. A 15% improvement is observed in the gain parameter in the same case. No variation was observed in the normalized array power for a similar configuration. Now for the Rician channel, a 20% decrease in BER and a 12% increase in the gain parameter are recorded. The Array power parameter remains unchanged when compared with the Social Ski driver's algorithm. Further observations and statistical readings are presented in Table 2, which justifies the proposed optimization objectives. It also confirms the system's significant consistency and robust performance when the number of sub-arrays increases to 8 under both fading channel environments.

Table 2. Parametric comparison table for statistical analysis of average values

Sub-array And Channel	**Metric**	**Existing Algorithms**				**Proposed Enhanced-SDD algorithm**
		Conv. BF [15]	**MBO [23]**	**SSD [25]**	**HW-LS-CMA [26]**	
Sub-array=4 Rayleigh	BER	7.24×10^{-4}	7.16×10^{-4}	6.27×10^{-4}	6.08×10^{-4}	4.76×10^{-4}
	Gain (dB)	22.218	25.233	27.799	30.006	31.977
	NAP (dB)	-20.925	-9.364	-10.267	-9.323	-10.266
Sub-array=4 Rician	BER	5.59×10^{-4}	5.54×10^{-4}	5.46×10^{-4}	5.24×10^{-4}	4.34×10^{-4}
	Gain (dB)	22.860	25.675	27.941	29.811	31.566
	NAP (dB)	-20.925	-9.246	-10.404	-11.236	-10.405
Sub-array=8 Rayleigh	BER	6.48×10^{-4}	6.42×10^{-4}	6.19×10^{-4}	5.99×10^{-4}	5.44×10^{-4}
	Gain (dB)	21.979	26.185	29.866	31.344	33.111
	NAP (dB)	-28.118	-8.851	-11.165	-8.450	-11.165
Sub-array=8 Rician	BER	5.62×10^{-4}	5.56×10^{-4}	5.39×10^{-4}	5.16×10^{-4}	4.05×10^{-4}
	Gain (dB)	24.322	27.105	28.944	30.766	32.479
	NAP (dB)	-28.118	-9.565	-11.755	-9.209	-11.755

4. Conclusion

This paper presents a novel hybrid beamforming approach based on the enhanced-social ski driver algorithm for dual functioning MIMO radar communication system. The location-based direction searching factor is modified in the social ski driver algorithm using the dolphin echolocation algorithm. The analog precoding weights in the hybrid beamformer are updated with the proposed design to reduce the bit error rate and improve the gain and array power distribution. The digital precoding weights are maintained by keeping the JSDM design. It updates the hybrid beamforming weights present in narrowband adaptive beamformers, rendering an effective solution based on the fitness measure. The proposed hybrid beamforming approach provides a better performance trade-off as compared to the considered algorithms. Improved gain and reduced BER ensure the effective communication and flexibility to form maximum no. of beams in a multiuser dual functioning radar communication environment. The array power parameter remains unchanged when compared with the Social Ski Drivers algorithm, but it confirms the power utilization over the entire range of azimuth angles. A high beamforming gain justifies the improvement in the signal-to-noise interference ratio with respect to link quality in target detection. The simulation results show 24% reduction in bit error rate, 15% improvement in gain and persistent array power than existing social ski driver's algorithm. Future studies should investigate and optimize the covariance matrix with respect to spectral and energy efficiency using bio-inspired algorithms.

Conflicts of interest

The authors declare no conflict of interest.

Author contributions

The work conceptualization, methodology, software implementation and validation, formal analysis, investigation is carried out by first author. Supervision, project administration is done by second author.

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