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Citation: Shahjehan, Waleed, Riaz, Asad, Khan, Imran, Sadiq, Ali Safaa, Khan, Suleman and Khan, Muhammad Khurram (2020) Bat algorithm-based beamforming for mmWave massive MIMO systems. *International Journal of Communication Systems*, 33 (2). e4182. ISSN 1074-5351

Published by: Wiley-Blackwell

URL: <https://doi.org/10.1002/dac.4182> <<https://doi.org/10.1002/dac.4182>>

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# BAT Algorithm based Beamforming for mmWave Massive MIMO Systems

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**Abstract**—In this paper, an optimized analog beamforming scheme for millimeter-wave (mmWave) massive MIMO system is presented. This scheme aims to achieve the near-optimal performance by searching for the optimized combination of analog precoder and combiner. In order to compensate the occurrence of attenuation in the magnitude of mmWave signals, the codebook dependent analog beamforming in conjunction with precoding at transmitting end and combining signals at the receiving end is utilized. Nonetheless, the existing and traditional beamforming schemes involve more difficult and complicated search for the optimal combination of analog precoder/ combiner matrices from predefined codebooks. To solve this problem, we have referred to a modified Bat Algorithm to find the optimal combination value. This algorithm will explore the possible pairs of analog precoder/ combiner as a way to come up with the best match in order to attain near-optimal performance. The analysis shows that the optimized beamforming scheme presented in this paper can improve the performance that is very close to the beam steering benchmark that we have considered.

**Index Terms:** Beamforming optimization, BAT algorithm, Massive MIMO, Millimeter-wave

## I. INTRODUCTION

The rapid increase in the number of users and demand for better quality-of-service is the major reason which requires newly proposed standards in wireless communications. The 5th generation wireless systems are referred to as an ideal fit to meet business and consumer demands. Considering the scenarios and use-cases, fifth-generation (5G) Mobile Networks Alliance requires some basic requirements [1-6].

- 1) Huge high data rates
- 2) Very low latency rate
- 3) Large capacity for the number of connected devices
- 4) High reliability

All of these requirements have initiated the motivation to explore the underutilized frequency spectrum of millimeter waves (mmWave) for deployment in the future networks of broadband cellular communication networks [2]. Millimeter Wave utilizes the frequency spectrum ranges from 30 GHz to

300 GHz. The capacity of wireless communication networks is increasing exponentially. This rapid rise is the result of increasing demands for high-speed data transfer. The most recent 5G networks claim the ability to bring about 1000 times expansion in the capacity by the year of 2020 [3]. One possible way to enhance capacity is to increase spectral efficiency, which includes methods having massive MIMO (multiple input multiple output) and advanced channel coding schemes [4]. Area spectral efficiency can be further improved by network densification, for example by permitting device-to-device (D2D) communications [5], or by deploying small cells [6] [7] also by enabling advanced cooperation, such as Cloud Radio Access Networks (RANs) [8-9]. This makes it essential to exploit the spectrum bands which are underutilized. These are the bands which are under no usage of any cellular communications by 2020 [3].

Millimeter wave operates on minimum 30 GHz To the maximum of 300 GHz bands. These waves had previously been used only for the purpose of carrying the indoor high-resolution multimedia streams [10] or any point-to-point backhaul links in the outdoors [11]. Hence mmWave are the most feasible option for the application of outdoor cellular communications which is now backed up by some experimental proofs as well [12-16].

The basic obstacles in mmWave systems includes the great amount of path loss and the attenuation caused by rain. These obstacles arise because the carrier frequency increases by ten-fold [2]. Since mmWave MIMO has small wavelengths, therefore precoding techniques provides significant beamforming gains that efficiently tackle this path loss caused at the transceivers antennas.

In traditional MIMO systems, precoding takes place at baseband level using digital precoders scheme. This scheme helps to adjust the signal magnitude as well as the signal phase. On the other hand, to perform fully digital precoding it requires the RF chains and analog-to-digital converter (ADCs).

Recently, a hybrid precoding architecture has emerged, which involves few RF chains. The high dimensional analog and a low dimensional digital precoder are interfaced with RF chains [14-18]. The high dimensionality of analog precoders

renders it not suitable for use in RF domain that utilizes variable voltage amplifiers (VGA) with very high power [2], whereas they can still be used alongside the more economical phase shifters.

The considerable reason for the increment of interest in research works for mmWave is that the bandwidth of the mmWave spectrum is very large compared to the bandwidth of the spectrum used by **fourth-generation (4G)** and older wireless network technologies. Since these mmWave frequencies have a very small wavelength, therefore, they exploit polarization well along with other novel spatial processing techniques, including adaptive beamforming as well as massive MIMO [15].

In standard MIMO systems, each antenna element is directly connected to the baseband processor. This requires a dedicated mixer, an ADC or a digital-to-analog converter (DAC), filters and amplifiers per antenna. The basic purpose of beamforming is to direct the signal transmission and reception. Beamforming basically steers the signal in a particular direction. Its elemental principle is to change the signals amplitude and phase for power variation and beam steering.

In analog beamforming, the signal's phase and amplitude variation is activated along the analog signal at transmitting end whereas in digital beamforming the signal's phase and amplitude is varied along the digital signal before DAC at the transmitter end. The received signals coming out of antennas are first fed into the ADC converters and digital down converters (DDCs) before summation operation. Analog Beamforming is typically preferred by the mmWave massive MIMO. The direction of the steering signal at both ends i.e. at transmitter and receiver end is monitored using the analog phase shifter (PS) network which is considered to have very low hardware cost [2]. Existing dominant analog beamforming schemes are generally branched into two groups of codebook-based beamforming and another group is the non-codebook-based beamforming. This CSI is effectively a collection of the spatial transfer functions between each user terminal and each antenna but the collection of the CSI is quite a difficult task to do, chiefly when there is limited count of RF chains [2]. It can achieve the optimal and best combination of analog precoder that can be found by searching in the predefined codebooks. On the downside, in order to successfully transfer the information between the BS and user, the systems require a large number of iterations. Furthermore, complexity increases exponentially with the increase in quantified bits along the angles of arrival as well as angles of departure (AoA/ AoDs) and the total number of RF chains [16]. In this work, an optimized scheme for beamforming is proposed which searches for the optimized combination of analog precoder/ combiner to attain best performance with low complexity.

## II. MODIFIED BAT ALGORITHM FOR OPTIMIZING BEAMFORMING IN MMWAVE MASSIVE MIMO SYSTEMS

Metaheuristic algorithms are high-level problem-independent algorithms. They are basically stochastic algorithms with the capability to perform local search and randomization. The two major composing elements for metaheuristic algorithms are regarded as the randomization and selecting the fittest. The process to select the fittest makes

sure that all the selected solutions converge to the optimum solution, whereas randomization ensures global uniqueness and prevents the solution from being trapped in local optimum [17-19]. Reason for such success is their quality of being tolerant to non-differentiable as well as non-convex search spaces in addition to obtaining acceptable solutions in a feasible practical time [20]. Most of the techniques of metaheuristic algorithms have been inspired by nature like animals, plants, natural phenomena and laws, etc. The objective of nature-inspired algorithms is to extract and attain the finest features in nature and then design them effectively using different mathematical operators.

Primarily the performance and efficiency of algorithms which are nature-inspired banks on the balance between exploitation and exploration. Exploration is referred to a process to search the space globally and the process of exploitation is referred to search the space locally considering the given best solutions. To achieve the global optimality there should be a good balance between these two [21].

The authors in [22] proposes a scheme based on the echolocation property of bats. These pulses have varying rates of emission and pulse loudness. This nature-inspired algorithm scheme has been used in different applications [23]. However, BA has a possibility to stuck in local optima therefore it is important to improve its convergence performance [21]. The major two shortcomings of Bat Algorithm are:

1. The original algorithm fails to depict the bats' self-adaptive capability in true sense which they have with respect to surroundings. Studies explain that how bats can discriminate their targets by slightly changing the Doppler effect that is caused due to wing-flutter rates of their target insects [24].
2. The other is that the formulae of the Bat Algorithm do not clarify the balance between exploitation and exploration.

In our research, we used an improved and modified version of the bat algorithm, namely **Novel Bat Algorithm (NBA)**, which better reflects the bats' characteristics. It was devised by Xian-Bing Meng et al [25] in 2015.

The performance of NBA is far better compared to that of typical Bat Algorithm because it replicates the behavior of bats more ideally, hence enhancing optimization results. The proposed algorithm integrates into the basic BA and helps in compensation for Doppler effect in echoes and their habitat selection. Moreover, the NBA simulates the echolocation characteristics of bats are more precisely. A local search strategy is the main feature of the NBA in which the BAT adapt themselves which leads to enhancing the results to a further degree.

### **Pseudo Code for NBA:**

#### **Algorithm 1: NBA**

##### **Inputs:**

- N: The total population (No. of individuals)
- M: The total No. of iterations
- P: Probability for habitat selection
- C: Doppler Effect rates for echo compensation

$\theta$ : Coefficient of Constraint Expansion  
 G: Frequency of pulse emission as well as loudness  
 W: Presents Inertia (weight)  
 $r_i$  original BA parameters  
 $t=0$ ; Initialize population corresponding parameters.  
 Assess the value of each bat-solution of the objective function.  
 While ( $t < M$ )  
   Generate new solutions  
     If ( $\text{rand}(0,1) > r_i$ )  
       For given best solution, a local solution is generated,  
     End if  
   For each value of objective function for each individual Solutions, an objective function is evaluated; also the loudness as well as pulse emission rate are updated  
   Find the current best  $g^t$  by ranking the solutions and  
   If  $g^t$  shows no improvement in the time step of G.  
     Reinitialize the loudness variable  $A_i$ . Also the set of temporary pulse rate  $r_i$  is set. Here  $r_i$  presents a uniform random number  $[0.85, 0.9]$   
 End  
 $t=t+1$ ;  
 End

### Results:

The individual from the total population having the best objective function value.

### III. SYSTEM MODEL

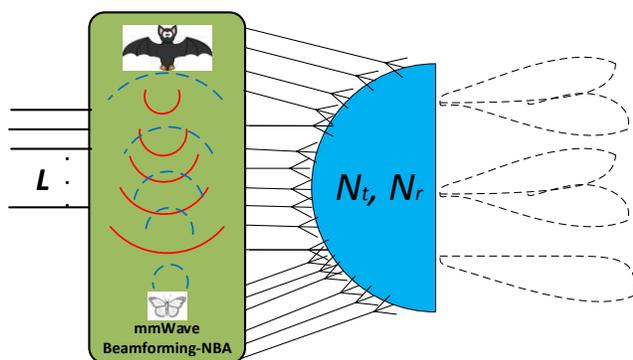


Figure 1 MmWave MIMO transmitter architecture

Here, the system model of our proposed method is presented and discussed. For the reference of our readers, Fig. 1 demonstrates the architecture of mmWave MIMO transmitter that we have adopted in our designed system to maintain the transceiver antennas used in our simulation. We have considered in this work a beamforming via massive MIMO system which is depicted in Fig. 2 and 3. The BS has a total of  $N_t$  antennas with  $N_t^{RF}$  RF chains. Using these  $N_s$  number of data streams, data are simultaneously transmitted to a user that

has  $N_r$  antennas and  $N_r^{RF}$  RF chains. In order to get full spatial multiplexing gain, we have [23]:

$$N_t^{RF} = N_r^{RF} = N_s \quad (1)$$

The  $N_s$ , which represents data streams in eq.1, are first converted into baseband by passing through  $N_t^{RF}$  RF chains which converts them into analog signals. In the next step the output signals by an  $N_t \times N_t^{RF}$  analog precoder  $P_A$  will be pre-coded as  $\mathbf{x} = P_A \mathbf{s}$ , where 's' shows the  $N_s \times 1$  number of vectors of the transmitted signal with the normalized value of power as  $E(\mathbf{s}\mathbf{s}^H) = \frac{1}{N_s} \mathbf{I}_{N_s}$ .

All the elements of the analog precoder should satisfy  $|p_{i,j}^A|^2 = \frac{1}{N_t}$  [25]. In case of narrowband block-fading massive MIMO channel [14], if  $\mathbf{r}$  is the  $N_r \times 1$  received signal vector, then [23]:

$$\mathbf{r} = \sqrt{\rho} \mathbf{H} P_A \mathbf{s} + \mathbf{n} \quad (2)$$

Here  $\rho$  represents the power that is transmitted and  $\mathbf{H} \in \mathbb{C}^{N_r \times N_t}$  denotes the channel matrix, and  $\mathbf{n} = [n_1, \dots, n_{N_r}]^T$  is the AWGN noise vector with  $CN(0, \sigma^2 \mathbf{I}_{N_r})$ . At the other end, an  $N_r \times N_r^{RF}$  analog combiner  $C_A$  processes the signal vector  $\mathbf{r}$  at the receiving end as [23]:

$$\mathbf{y} = C_A^H \mathbf{r} = \sqrt{\rho} C_A^H \mathbf{H} P_A \mathbf{s} + C_A^H \mathbf{n} \quad (3)$$

where the elements of  $C_A$  have identical constraints similar to that of  $P_A$ , i.e.,  $CN(0, \sigma^2 \mathbf{I}_{N_r})$ .

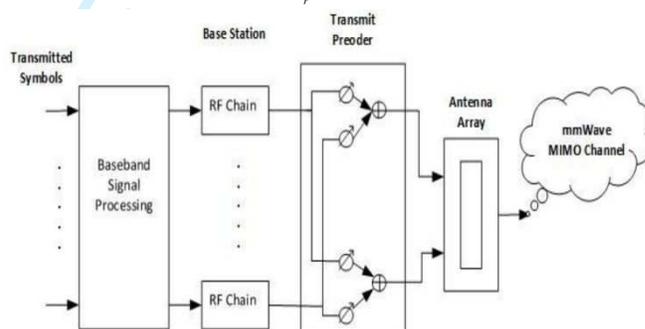


Figure 2 Beamforming of Massive MIMO at Transmitting end

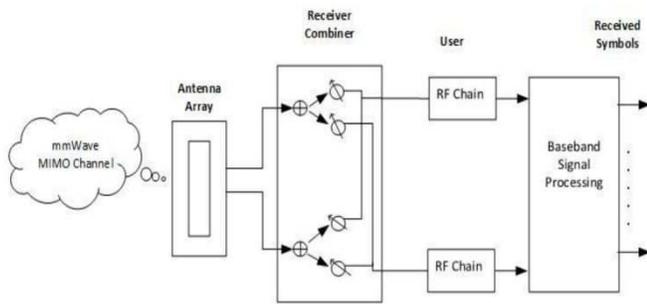


Figure 3 Beamforming of Massive MIMO at Receiving end

#### IV. METHODOLOGY

In this section, the methodological steps that were applied to conduct our study presented in details. Fig. 4 shows the

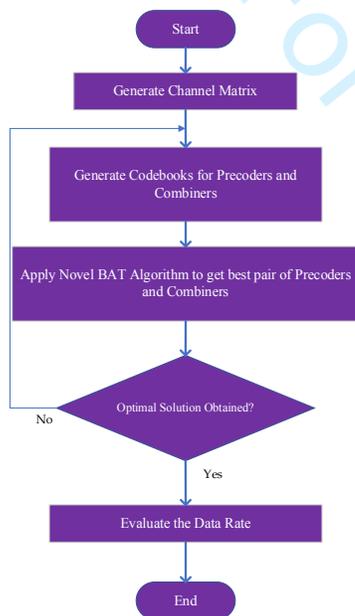


Figure 4 Flow Diagram for this research work

##### A. Channel Simulations

The initial step in the process of simulation is the generation of a channel for transmission. In our simulation, we have considered the geometric model of channel in order to carry out the modelling of propagation environment, as there is the very finite number of significant scatters ( $L \leq \min(N_t, N_r)$ ) and there exists genuine antenna correlation in mmWave systems [28], so we choose the widely popular geometric Saleh-Valenzuela channel model [29]. Saleh and Valenzuela in their work explained the clustered characteristic in the indoor environment of measured received power delay profiles. The statistical model proposed by them is an extension of the well-known Turin model. The Saleh and Valenzuela channel matrix represented by  $\mathbf{H}$  is as follows [23]:

$$\mathbf{H} = \sqrt{\frac{N_t N_r}{L}} \sum_{l=1}^L \alpha_l f_r(\phi_l^r) f_t^H(\phi_l^t) \quad (4)$$

Here  $\alpha_l \in \mathcal{E}$  presents the net gain of the  $l^{\text{th}}$  path.  $\phi_l^t$  and  $\phi_l^r$  represents the azimuth of  $l^{\text{th}}$  path AoDs/AoAs.  $f_t(\phi_l^t)$  and  $f_r(\phi_l^r)$  are the response vectors of the antenna arrays which are highly dependent upon the structure of the antenna array employed both at BS as well as user ends. With uniform structure of linear arrays (ULAs), it follow as [23]:

$$f_t(\phi_l^t) = \frac{1}{\sqrt{N_t}} \left[ 1, e^{jkd \sin(\phi_l^t)}, \dots, e^{j(N_t-1)kd \sin(\phi_l^t)} \right]^T \quad (5)$$

$$f_r(\phi_l^r) = \frac{1}{\sqrt{N_r}} \left[ 1, e^{jkd \sin(\phi_l^r)}, \dots, e^{j(N_r-1)kd \sin(\phi_l^r)} \right]^T \quad (6)$$

Here

$$k = \frac{2\pi}{\lambda},$$

$\lambda$  is signal's wavelength while  $d$  denotes the spacing in antennas.

##### B. Generation of Codebooks

Codebooks can be considered as a matrix where the columns are termed as the beamforming weight vector and also give the information about the pattern or the direction of beams. The columns set extends along entire space. In order to support beamforming both 1-D phased antenna and 2-D phased antenna are utilized. These codebook matrices are generated in a symmetric order and they create a near-circle pattern for minimum gain loss along the intersecting boundaries of the two adjacent patterns as shown in Fig. 5.

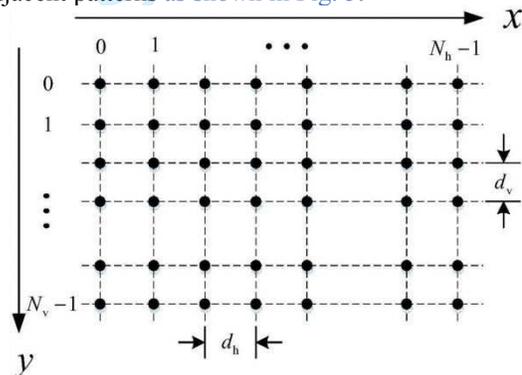


Figure 5. Generation of codebook.

The beam steering codebook [30] is broadly used since it presents special characteristics of the mmWave channel. Suppose  $\mathbf{F}$  represents the beam steering codebook for analog precoder and contains all possible analog precoder matrices (PA).  $\mathbf{W}$  represents the beam steering codebook for analog combiner and contains all possible analog combiner matrices

(CA).  $B_i^{RF}$  ( $B_r^{RF}$ ) represents the number of bits to compute AoD (AoA). Each precoder and combiner matrix will be of the form [23]:

$$P_A = [f_t(\bar{\phi}_1^t), f_t(\bar{\phi}_2^t), \dots, f_t(\bar{\phi}_{N_t^{RF}}^t)] \quad (7)$$

$$C_A = [f_r(\bar{\phi}_1^r), f_r(\bar{\phi}_2^r), \dots, f_r(\bar{\phi}_{N_r^{RF}}^r)] \quad (8)$$

where the computed AoD  $\bar{\phi}_i^t$  for  $i = 1, \dots, N_t^{RF}$  at BS has  $2^{B_i^{RF}}$

possible candidates, i.e.  $\bar{\phi}_i^t = \frac{2\pi n}{2^{B_i^{RF}}}$  where  $n \in \{1, \dots, 2^{B_i^{RF}}\}$ .

Also, the computed AoA  $\bar{\phi}_j^r$  for  $j = 1, \dots, N_r^{RF}$  at user has the

$2^{B_j^{RF}}$  possible candidates, i.e.,  $\bar{\phi}_j^r = \frac{2\pi n}{2^{B_j^{RF}}}$  where  $n \in \{1, \dots,$

$2^{B_j^{RF}}\}$ . Therefore,  $|F|$  of  $F$  and  $|W|$  of  $W$  cardinalities are  $2^{B_t^{RF} \cdot N_t^{RF}}$  and  $2^{B_r^{RF} \cdot N_r^{RF}}$ , respectively.

### C. Definition of Cost Function

By combinational search for all possible pairs of  $F$  and  $W$ , the selection of the finest combination of the analog combiner and analog precoder can be done on the basis of the maximization of the achievable rate  $R$  is represented as [23]:

$$R = \max_{P_A \in F, C_A \in W} \log_2 \left( \left| I_{N_s} + \frac{\rho}{N_s} R_n^{-1} C_A^H H P_A P_A^H H^H C_A \right| \right) \quad (9)$$

$$R = \max_{P_A \in F, C_A \in W} \log_2 (\varphi(P_A, C_A)) \quad (10)$$

where  $R_n = \sigma^2 C_A^H C_A$  represents the covariance matrix of the noise after combining. So, the final equation of achievable rate can be written as [23]:

$$\varphi(P_A, C_A) = \left| I_{N_s} + \frac{\rho}{N_s} R_n^{-1} C_A^H H P_A P_A^H H^H C_A \right| \quad (11)$$

Thus, the purpose of optimization which is discussed in the next topics is to maximize the above mentioned achievable rate.

### D. NBA Optimization of Precoder and Combiner indices to be selected

In order to maximize the amount of achievable rate an optimal combination of the precoder and combiner must be selected from all possible combinations. For this objective, an improved approach to the Bat Algorithm which was proposed in [25] was used. In this portion, an overview of classic Bat Algorithm is given first. After that, explanation of the modifications is presented that lead to the improved results that mimic Bat behavior more closely.

The basic principle for Bat Algorithm is that  $n$  number of bats flies in a random fashion using echolocation to sense distances through a  $d$  dimensional space. Some approximations as well as some idealized rules proposed by Yang are as follows:

#### Idealized Rule 1:

All bats possess the ability to sense distance by using their feature of echolocation. Also, they can, by using this property, differentiate between their target prey as well as the background.

#### Idealized Rule 2:

Bats use to fly randomly with the velocity  $v_i$  at position  $x_i = [x_{i1}, x_{i2}, x_{i3}, \dots, x_{id}]$  with a fixed frequency  $f_{min}$ . However, they can change the wavelength  $\lambda$  and loudness  $A_0$  in order to find their prey. Bats have the ability to change and adapt the wavelength of the pulses they emit, according to the distance between them and their targets.

#### Idealized Rule 3:

Various steps involved in the Bat Algorithm [22] are as follows:

##### 1) Initialization

The  $N$  bats (solutions where every solution is the possible combination of the analog precoder and combiner) specified by the positions  $x_i$  and the velocities  $v_i$  are distributed randomly in a feasible search space having a  $D$ -dimension. The  $N$  bat velocities might be set to zero.

$$x_{i,j} = x_{jMin} + (x_{jMax} - x_{jMin}) * \text{rand}(0,1),$$

Where  $i \in [1, \dots, N]$ ,  $j \in [1, \dots, D]$ .

##### 2) Create new bats

$$\begin{aligned} f_i &= f_{min} + (f_{max} - f_{min}) \times \beta, \\ v_i^{t+1} &= v_i^t + (x_i^t - x_*) \times f_i, \\ x_i^{t+1} &= x_i^t + v_i^{t+1}, \end{aligned}$$

Here  $\beta \in [0,1]$  presents a random vector. The frequencies  $f_{max}$  and  $f_{min}$  depends on the size of the domain of the given problem.

##### 3) Local search

$$\text{if}(\text{rand}(0,1) > r_i)$$

$$x_{new} = \varepsilon A_{mean}^t + x_{old}$$

Here  $\varepsilon \in [-1,1]$  presents the random value from the uniform distribution, " $A_t$ " is regarded as the mean average value of loudness for all the bats at the time step  $t$ .  $r_i \in [0,1]$ .

#### 4) Bat update upon random flying

The decrease in loudness and increase in the rate of pulse emission follows the following equations

$$\text{if}(\text{rand}(0,1) < A_i \& f(x_i) < f(x))$$

$$A_i^{t+1} = \alpha A_i^t,$$

$$f(x) = f(x_i),$$

$$r_i^{t+1} = r_i^0(1 - e^{-\gamma t})$$

Where the constants are  $\alpha(\alpha \in [0,1])$  and  $\gamma(\gamma > 0)$ .

#### 5) Updating the solution of the current global best

Finally, the best current global solution is updated before moving on to the next iteration.

The following two points make NBA different from traditional Bat Algorithm as it depends on the stochastic selection where all the bats can hunt in individual habitats. Also, all the bats can recover from the Doppler effect that is caused in echoes. In addition, the bats can change the rate of compensation with respect to the target's closeness.

Most of the bats have the unique and state of the art ability to use sound pulse having a constant frequency for echolocation. Whereas some bats use signals that are frequency modulated. The bats use these pulses to hunt down their preys. In addition, the bats can detect their prey, avert the obstructions and find the roosting crevices in the dark [22]. Having the advanced ability of echolocation, the bats can easily recognize the orientation and distance of their prey. In addition, Bats can also vary their sound pulses frequencies and search behavior while they search in different type of habitats [31]. Different bats' species search in different habitats like forests, water environments etc [32]. Different bat species can also search in the same habitat [33].

Different species of bats have different searching habitats. In BA, each bat searches for its prey from different position and with different velocity in a given D-dimensional space. The region for the motion of bats is limited to the finite zone according to the bound state constraint. Therefore, in typical BA, the bats can search only in a single habitat, unlike in NBA. Some of the species have the ability to compensate the partial Doppler's effect encountered in the echoes, some species are able to show near to full compensation [34]. The original Bat Algorithm, however, did not considered the effects caused by Doppler effect.

### V. SIMULATION RESULTS

We used MATLAB to experimentally analyze the proposed work. We compare our work with two recent relevant benchmarks from literature: The upper limit of the proposed beamforming scheme with quantified AoA/AoDs [33] with continuous angles and the scheme in [18]. Both the transmit and receive antennas are considered to be Uniform Linear Arrays (ULAs). The parameters set for the system used for simulation are:

- The carrier frequency is 28GHz.
- Scattering propagation paths (L) is fixed to be 3.
- Antenna spacing (d) is kept to be  $\pi/2$ .

- $N_t^{RF} = N_r^{RF} = N_s = 2$
- The AoAs/AoDs used to generate the channel matrix from [27] are assumed that they pursue the uniform distribution in the limits of  $[0, \pi]$ . The standard deviation of the angles in azimuth and elevation both of Rx and Tx is kept to be  $10/180 * \pi$ .  $\alpha_l$  is the complex gain of the lth path which follows  $\alpha_l \sim \text{CN}(0, 1)$ . SNR is given as  $\rho / \sigma^2$
- Wavelength is kept to be 2 mm.

Simulation results are evaluated at three different cases based on quantized bits per AoAs/AoDs which are enlisted as follows:

- $B_t^{RF} = B_r^{RF} = 4$
- $B_t^{RF} = B_r^{RF} = 5$
- $B_t^{RF} = B_r^{RF} = 6$

The basic purpose of NBA here is to select the optimum pair of indices of F and W codebooks. The selected index of F codebook selects a possible analog precoder and the selected index of W selects a possible analog combiner. The goal is to come across such a pair of these two indices such that achievable rate is maximized.

The parameters of the basic Bat Algorithm (BA) that we used in the NBA are given in table 1.

Table 1 Parameters for BAT Algorithm

Parameters	Values
Number of iterations	100
Population size	30
Factor of speed of increase (gamma)	0.9
Factor of speed of increase (alpha)	0.9
Maximum pulse rate	1
Minimum pulse rate	0
Maximum loudness	2
Minimum loudness	1
Maximum frequency	0.5
Minimum frequency	0
Emission rate	10
The maximal and minimal probability of habitat selection	0.9
The minimal probability of habitat selection	0.6
The maximal contraction expansion coefficient	1
The minimal contraction expansion coefficient	0.5
The maximal inertia weight	0.9
The minimal inertia weight	0.5
The maximal compensation rate for echo-Doppler effect	0.9
The minimal compensation rate for echo-Doppler effect	0.1
The maximal and minimal probability of habitat selection	0.9

Table 2 The additional parameters in Novel Bat Algorithm (NBA)

Parameters	Values
The frequency for updating loudness and pulse emission rate	10
Maximal/ minimal probability of habitat selection	0.9
The minimal probability of habitat selection	0.6
The maximal contraction expansion coefficient	1
The minimal contraction expansion coefficient	0.5
The maximal inertia weight	0.9
The minimal inertia weight	0.5

The maximal compensation rate for echo-Doppler effect	0.5
The minimal compensation rate for echo-Doppler effect	1

Turbo Ts beamforming [18-20] has been shown to give near optimum results in reaching the benchmark of the recently proposed beam steering [35-42] with continuous angles.

According to the Simulation results the proposed NBA scheme gives much better results than its turbo TS counterpart.

In Figure 6, the results of the proposed method for the case is presented, where  $N_r=16$  and  $N_t=64$ . Figure 7 shows results for the case where  $N_r=32$  and  $N_t=128$ .

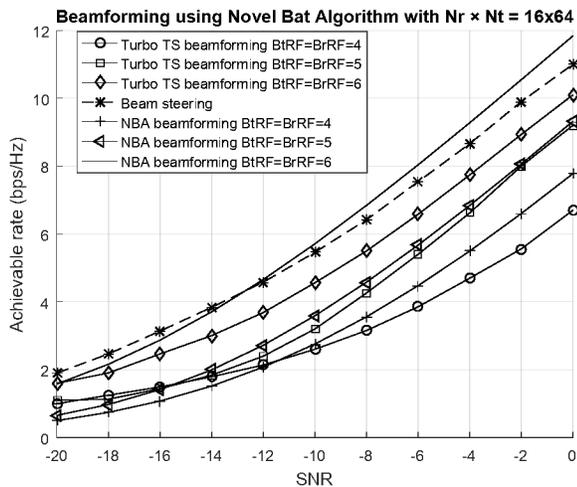


Fig. 6 Beamforming using BAT Algorithm  $N_r \times N_t = 16 \times 64$

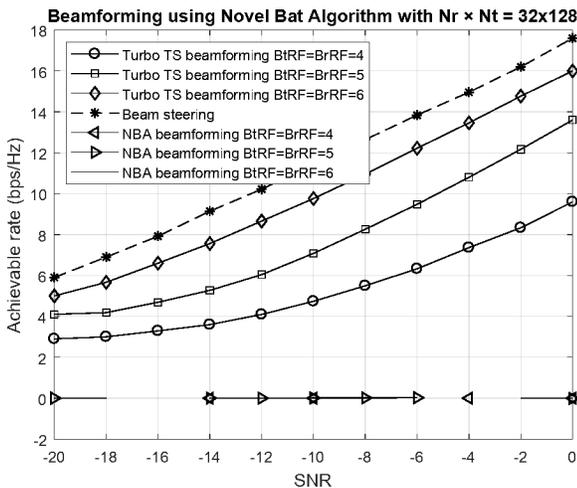


Fig. 7. Beamforming using BAT Algorithm  $N_r \times N_t = 32 \times 128$

In Fig. 6, the achievable rate for  $N_r \times N_t = 16 \times 64$  with

$$N_t^{RF} = N_r^{RF} = N_s = 2$$

Fig. 7 depicts the comparison of achievable rate  $N_r \times N_t = 32 \times 128$ . In this case the amount of RF chains are

$$N_t^{RF} = N_r^{RF} = N_s = 2$$

Figures 6 and 7 shows that the performance of NBA beamforming (like that of Turbo TS beamforming) improves as the total number of quantified bits per AoAs and AoDs is increased. NBA outperforms Turbo TS and approaches the results of beam steering method much more closely. In addition, we found that in order to enhance the performance of the proposed NBA beamforming scheme, the number of antennas should be incremented rather than incrementing the number of RF chains. This improvement is much more pronounced for NBA than it was for Turbo TS. It can have a profound effect on reducing the overall cost of the system.

## VI. CONCLUSION

In this research, we proposed the use of Novel Bat Algorithm (NBA) to choose the best combination of analog precoder and combiner to achieve wireless communication in an mmWave massive MIMO channel. First, the codebooks were generated for analog precoder and combiner. Then out of those codebooks, the most optimum pair for analog precoder and combiner was selected via Novel Bat Algorithm. It is concluded from the simulation results that the proposed approach is superior to the Turbo TS scheme, in terms of the achievable rate, yielding results that are closer to the beam steering benchmark. The proposed method's advantages are two-fold. Firstly, the NBA optimization scheme has a self-adaptive capability. Possible solutions- which are the possible combinations of precoder and combiner matrices from the  $F$  and  $W$  codebooks- imitate bats as they can adaptively recover the changes due to the Doppler effect in echoes. As for the local search, the algorithm to update solutions is self-adaptive and does not involve any parameters defined by the user. Similarly, this optimization method combines optimal diversity with efficient convergence capabilities. Considering the methodology of the bats' habitat selection, the solution diversity for this algorithm can be increased by employing two different search strategies. Current work was based on ULAs and for a single user scenario. In the future work can explore the domain of UPAs (uniform planar arrays) [24] and also extend it to multiple user domain. Furthermore, other channels of Massive MIMO [34] [35] can be analyzed and compared.

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## **Authors Response to Reviewers Comments**

Manuscript ID: IJCS-18-1125

**NOTE: *The reviewer issues have been answered in the same order as they were formulated.***

***The number of pages, references, equations and figures are always referred to the original draft unless otherwise specified.***

We would like to thank the reviewers and editor for the effort and time devoted in the reviewing process. We sincerely appreciate the comments, the remarks on the original manuscript and the evaluation of the work. They have been very useful to further improve the clarity, completeness and argumentation of the paper. Below, we provide detailed answers to the required changes/modifications and explain how they have been taken into consideration in the revised manuscript.

**The area where changes are made, are highlighted in the paper of the modified manuscript.**

**Reviewer: 1**

Comments to the Author

first of all, the paper is poorly formatted, for example on page 1 second paragraph:

[7]and also by enabling advanced cooperation, such as Cloud-RANs [8] [9].

**Author Response 1:** Thank you very much for your solid technical comments. The correction has been made.

space is missing after [7]. Then another line break in front of cooperation. Pls check through the paper to correct all these error.

**Author Response 2:** Thank you very much for your constructive comments. The correction has been made.

The equations are not aligned properly, e.g. (1) is aligned to center, but some are to the left .e.g (2) (3) etc...

All these prevent ppl to read the manuscript carefully.

**Author Response 3:** Thank you very much for your comments. The corrections have been made.

some relevant literature can be included, e.g.

"Iterative Channel Estimation Using LSE and Sparse Message Passing for MmWave MIMO Systems", IEEE TSP, vol. 67, Jan 2019, pp. 245-259.

"Energy Efficient Downlink Transmission for Multi-cell Massive DAS with Pilot Contamination", IEEE TVT, vol. 66, Feb 2017, pp. 1209 - 1221.

"Multi-Cell Multi-User Massive MIMO Transmission with Downlink Training and Pilot Contamination Precoding", IEEE TVT, Aug 2016, pp. 6301 - 6314.

**Author Response 4:** Thank you very much for your solid technical comments. The mentioned literature has been added to the manuscript with proper citations.

We hope that the modification in the revised manuscript is appropriate as far as the paper is concerned. Once again, thank you very much for your valuable and helpful comments.

**Reviewer: 2**

## Comments to the Author

(1) The reviewer thinks the contribution of the manuscript is not sufficient to be published in the journal.

**Author Response 1:** Thank you very much for your solid technical comments. We have revised the manuscript which will now highlight the contribution of the manuscript that gives sufficient information.

(2) In Fig. 1, is NtRF a typo?

**Author Response 2:** Thank you very much for your constructive comments. The NtRF represents the number of RF chains in Fig. 1 so it is important to show it.

(3) In the introduction section, the literatures review for the hybrid precoding Architecture may be not enough, e.g, the following works on the hybrid precoding Architecture can be added:

[1] X. Gao, L. Dai, S. Han, C. L. I, and R. W. Heath, "Energy-efficient hybrid analog and digital precoding for mmWave MIMO systems with large antenna arrays," IEEE J. Sel. Areas Commun., vol. 34, no. 4, pp. 998-1009, Apr. 2016.

[2] D. Zhang, Y. Wang, X. Li and W. Xiang, "Hybridly connected structure for hybrid beamforming in mmWave massive MIMO systems," IEEE Trans. Commun., vol. 66, no. 2, pp. 662-674, Feb. 2018.

**Author Response 3:** Thank you very much for your solid technical comments. We have added the above mentioned literature to our manuscript with proper citations.

(4) The used abbreviation have not defined, e.g. Cloud-RANs, BS, 5G, and 4G no definition in paper, and some abbreviations are defined but not used in paper, e.g. mmWave, PS, and. Moreover, some abbreviations are repeated many times, e.g. DAC, NBA. Please check the whole paper to avoid the same problem.

**Author Response 4:** Thank you very much for your remarkable comments. The corrections have been made in the entire manuscript.

(5) The authors claim to compare the proposed algorithm with turbo TS algorithm, but the reviewer did not find the results of the comparison in the paper.

**Author Response 5:** Thank you very much for your comments. We have compared the proposed NBA algorithm with turbo TS algorithm in additional Figure.

(6) The representation of mathematical symbols is not standardized, the authors should use upper-case and lower-case boldface letters to denote matrices and vectors, respectively.

**Author Response 5:** Thank you very much for your remarkable comments. The corrections have been made in the entire manuscript.

We hope that the modification in the revised manuscript is appropriate as far as the paper is concerned. Once again, thank you very much for your valuable and helpful comments.

**Reviewer: 3**

Comments to the Author

This paper proposed a BAT algorithm based beamforming inspired by the bats' behavior, which is novel to me.

However, first of all, the presentation of this paper indicates that the authors are not prepared to publish it. Several lines are cut, the equations are ugly and the figures are not clear.

Author Response 1: Thank you very much for your constructive comments. The corrections have been made in the entire manuscript and proofreading is performed, after which the manuscript is improved for better readership.

For the performance of the proposed algorithm, I prefer to see how much the improvement of the proposed algorithm is comparing to other state-of-the-art algorithms in the figures. Besides, no benchmark is presented in the figures.

Author Response 2: Thank you very much for your solid technical comments. We have compared the proposed NBA algorithm with turbo TS algorithm in additional Figures.

We hope that the modification in the revised manuscript is appropriate as far as the paper is concerned. Once again, thank you very much for your valuable and helpful comments.

Editor's Comments to the Author:

Associate Editor

Comments to the Author:

(There are no comments.)