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Massive MIMO and Hybrid Optimization for It's Beamforming

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Abstract: ***The tremendous growth of traffic in wireless communication (WC) system has resulted in inadequate network capacity. 5th Generation (5G) is seen as next generation wireless communication system implemented with massive multiple-input multiple-output (M-MIMO) technology. It will play major role in future communication system. M-MIMO objective is high throughput and high speed. Beamforming technique is a key to high throughput objective - achieved by reduction in errors occurring in data transmission and reception. The intent of this research paper is to review - beam forming techniques implemented in M-MIMO and research work in this particular area. Paper classifies optimized beamforming techniques in detail for determining appropriate techniques that can be deployed in M-MIMO. Understanding limitations of present techniques and suggesting new approach for better throughput is outcome of retrospective analysis.***

Keywords: ***Beamforming Techniques, Massive MIMO, Hybrid beamforming, Beamforming Classifications.***

I. INTRODUCTION

MIMO works on principle of receiving and transmitting more than one signal on same radio channel simultaneously. It uses multiple transmitting (pre-coders) and multiple receiving (detectors) antennas multiply radio link capacity by exploiting multipath communication. M-MIMO will play remarkable role in futuristic cellular wireless network (5G) [1].Wireless generation is an indication of growth in traffic in wireless system. Requirement asks for efficient utilisation of spectrum with energy efficiency. Verities of antennas are available for data transfer, but one can think about smart antenna in M-MIMO. Smart antenna (multiple antennas, adaptive antenna or digital antenna) is an array of antenna. It uses smart signal processing algorithms for identifying direction of arrival (DOA) of signal. Based on DOA it calculates beamforming (BF) vector

The vector is used to locate and track the target. Normally smart antennas are used at mobile stations and at Base Stations (BS). BF is used to produce focused signal radiation pattern which is achieved by addition of phases of signals in the desired direction, based on variable traffic and signal surrounding. This techniques increases signal power received by user. Undesired or interfering signals like multipath interference, channel interference are null in BF technique, it increases capacity of wireless communication.

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This greatly improvises wireless mobile link and hence the performance of the system. Diversity of user equipment and BS is added benefit. Final stage of M-MIMO will now be smart antenna which effectively transmit power in desired direction and suppress undesired user.

Smart antenna concept is used in MIMO relay network. Vouyioukas et al.[2] (2013) used different topologies in MIMO relay network and checked performance of adopted BF technique. The survey was based on challenges faced in opportunistic and cooperative systems, like spectral efficiency, issues of diversity, degree of freedom, power consumption and complexity, feedback and channel estimation, BF channel modeling, interference modeling and alleviation, adaptive BF techniques for multiuser relaying.

In MIMO systems different cognitive BF techniques can be used, was presented by Murray and Zaghloul [3] (2014). Proposing algorithms for the MIMO was considering Quality of service (QoS) metrics and channel state information (CSI) constraints. Genetic algorithms (GA), game theory and Artificial Neural Network (ANN) techniques were evaluated for MIMO.

Millimetre wave (mmwave) communications for different scenarios like indoor and outdoor using BF techniques is also major area of research surveyed by Kutty and Sen[4] (2015). Mm-wave MIMO architecture and required signal processing was surveyed by Heath *et al.* [5].For different propagation model hybrid and analogue BF techniques were discussed. Deep review was presented for beam forming protocol and channel estimation algorithm used for mm-wave communication. Scope of signal processing in mm-wave communication was the derived conclusion.

Zhiguo Ding et al. [6] (2017) surveyed Non-orthogonal multiple access (NOMA) for mm-wave. They considered innovation and research with application. Inference is BF / visible light communications (VLC) can apply NOMA principles in near future.

ShoumanBarua [7] (2015) addressed Direction of Arrival (DoA) techniques for improvising path Delays, precise channel estimation for MIMO system. 2D harmonic model was used to estimate channel in Long Term Evolution (LTE) standard.

After reviewing different surveys presented by researcher it has been found that requirement of BF is accepted by all but befit technique to be employed for massive MIMO is not explored. Objective of presenting this paper is to consider beamforming techniques those are used in wireless communication (WC) and to evaluate those for massive MIMO system with expected outcome of technique suitable for massive MIMO (M-MIMO).

This paper provides an in-depth overview of up-to-date research on classifications of beamforming techniques that can be deployed for massive MIMO systems. Several key elements are discussed to show the importance of beamforming techniques in reducing and resolving many technical complications that disallow massive MIMO implementation. Section II discusses QoS parameters and benefits of beamforming in M-MIMO citing references. In which direction beam has to be formed is identified by DOA algorithms. Section III discusses two DOA techniques those are widely used. After DOA, revealing classification BF techniques considering M-MIMO is important. Latest trend is smart antenna where BF is adaptively adjusted using *Weights.* Weights may be optimized to make BF process fast and more accurate. Section IV highlights different optimization techniques. Section V presents scheme proposed by author about BF in M-MIMO with hybrid of standard BF techniques with optimization algorithms.

II. BENEFITS OF BEAMFORMING IN MASSIVE MIMO

In smart antenna system phased arrays are used to radiate beam in desired direction and suppress interference signal. Finite Impulse Response (FIR) filter is the base for this technique where weights are controlled adaptively by signal processing technique. Resultant radiated beam should be narrow as possible which increases power transmission in specific direction increasing throughput hence energy efficient. It improves spectral efficiency with secured transmission. QoS parameters are Half Power Bandwidth (HPBW), signal to Interference plus noise ratio (SINR) and power.

A. *Quality Of Service Parameters*

Maximum radiation takes place in the main lobe (main beam). Nearby to main lobe few lobes smaller in size compared to main lobe are also present. Those lobes are referred as minor lobe(s) or side lobes. Side lobes are those lobes where power is radiated in unintended direction. Minimum number of lobes with smaller or fairly zero power is the best directive antenna. To check performance of antenna few parameters or figure of merits are defined, listed as follows.

a. Directivity

This parameter is the most important parameter and signifies capability of radiator or antenna array to focus a beam or to radiate maximum energy in a specific direction.

$$Directivity = \frac{Power\ transmitted\ in\ desired\ direction}{average\ of\ power\ of all\ the\ directions}$$

Where,

$$Average\ of\ power = \frac{total\ Power\ transmitted\ by\ an\ antenna}{4\ \pi}$$

Directivity may also be defined as,

$$Directivity = \frac{Power\ density\ of\ an\ an\ isotropic\ antenna}{power\ density\ of an\ isotropic\ antenna}$$

Here both antennas should transmit same power.

b. Half Power Bandwidth (HPBW)

One can define this parameter with reference to peak effective power radiation in desired direction. In an antenna radiation patter, in the main lobe angle between two *half power points* or -3DB point is referred as HPBW [8]. This angle should be minimum value. It signifies that power transmitted is narrow beam or wider beam. Wider beam means loss of power in undesired direction. Narrow beam means focused power in desired direction.

c. Side Lobe Level (SLL) Or Minor Lobe Level (MLL)

Typically main lobe has greater power and angle is of desire, whereas side lobes should be minor (minimum power radiation) and are nearby to main lobe. Antenna power concentration is defined with respect to main lobe and side lobe.

$$Power\ concentration\ = \frac{SLL\ peak}{main\ lobe\ peak}$$

For a normalized DB plot, main lobe peak should be near to 0 DB and SLL should have greater negative value in DB.

d. Back Lobe Level (BLL)

Side lobe which is in opposite direction ($180^o out\ of phase$) to the main lobe is called BLL. This lobe should be minimum as possible.

e. Array Factor

Array Factor (AF) is also important parameter in relation to antenna. AF depends upon, Physical placement of antennas in the array and Weights used to position beam

These two factors are variable and should be trimmed or optimized to achieve better performance. Weights (w) of an antenna array has capability to steer antenna and hence plays highly important role [9].

f. Antenna Array Geometry

The radiation pattern of a single antenna element is relatively wide and the values of directivity are normally low. Adaptive antenna arrays must be able to radiate power towards a desired angular sector to allow long distance transmissions and to avoid interference with undesired signals. One way to increase the gain is to enlarge the dimension of the antenna element but this could be a problem with mobile devices due to their size. Another way to enlarge the dimension of the antenna system is to create a collection of two or more antennas in an electrical and geometrical configuration. This set of antenna elements is an antenna array and has a unique radiation pattern which is dictated by five factors:

1. The geometrical configuration of the array
2. The individual elements relative distance
3. The individual elements excitation phase
4. The individual elements excitation amplitude
5. The individual elements relative pattern

g. Signal to Interference Plus Noise Ratio (SINR)

This parameter is a ratio of two important parameters which are variable in nature i.e. signal and noise.

$$SINR = \frac{Power_{Required\_signal}}{Power_{interference} + Power_{Noise}}$$

Signal power in desired direction is actual signal of interest and power from undesired direction is noise. Thus maximum value of power in desired direction and minimum value of power in undesired direction will improve this parameter [10].

B. *Advantages of Beamforming*

1. Improved SINR
2. Improved Security – Data packet is transmitted only in direction where target device is placed
3. Mm-band feasibility
4. Efficient Spectrum usage

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5. Energy Saving – Transmission in specific direction only
6. Position Identification (Localization of device) - Triangulation method may be used for locating device after getting beam direction information

III. BEAMFORMING TECHNIQUES

It has been observed that for single source of transmission there will be many propagation paths in a channel resulting in different Angle of Arrival (AoA). If the transmitter sources are more and operating simultaneously then receiver will have numerous data reception paths creating multipath components. This issue highlights on important aspect that receiver antenna array should have capability to identify and estimate AoA (also referred as DOA) to understand presence of different transmitters with their angular position and then to decipher it. Based on this information receiver will be able to eliminate unwanted signal, suppress interference, and combine wanted signal to get greater fidelity.

Every signal is made up of complex frequency components. Estimating the signal with the noise is referred as Spectral Estimation (SE). Number of components of signal is assumed before estimation. Noise subspace is identified to estimate or extract frequency components. The method uses autocorrelation matrix and then applies Eigen decomposition to separate out noise and signal subspace. Frequency components from noise subspace are estimated using popular methods like Multiple Signal Classification (MUSIC),Pisarenko's method, Estimation Of Signal Parameters Via Rotational Invariance Techniques (ESPRIT) minimum norm method and Eigen vector method.

A. Music algorithm

Narrowband Signal Sources

- A complex sinusoid
$$s_{input}(t) = \alpha e^{j\beta} e^{j\omega t} \quad = p e^{j\omega t}$$
- summation of two sinusoids is real sinusoid
$$\alpha\cos(\omega t + \beta) = \frac{\alpha}{2} e^{j\beta} e^{j\omega t} + \frac{\alpha}{2} e^{-j\beta} e^{-j\omega t} = p_1 e^{j\omega t} + p_2 e^{-j\omega t}$$
- Phase shift is delay of a sinusoid
$$s_{input}(t - t_0) = e^{-j\omega t_0} p e^{j\omega t} = e^{-j\omega t_0} s_{input}(t)$$
- Apply approximately to narrowband signals
- Narrowband signal sources taken into considerations are I
$$s_{input_1}(t) = p_1 e^{j\omega_1 t}, s_{input_2}(t) = p_2 e^{j\omega_2 t}, \; . \; . \; . \; , s_{input_I}(t) = p_I e^{j\omega_I t}$$
- It has been assumed that there is no correlation in all the amplitudes as well, all the frequencies are different
$$E\{p_i p_j\} = \{\sigma_i^2; \;\; i = j, \qquad 0; i \neq j$$

Signal Model

- All the N sensors output signals are combined together.
$$x(t) = \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ \vdots \\ x_N(t) \end{bmatrix} = \begin{bmatrix} 1 \\ e^{-j\omega \frac{dsin\theta}{c}} \\ e^{-j\omega \frac{2dsin\theta}{c}} \\ \vdots \\ e^{j\omega \frac{(N-1)dsin\theta}{c}} \end{bmatrix} s_{input}(t) = SV(\theta) s_{input}(t)$$
- ***Steering vector*** is $SV(\theta)$
- If there are I sources signals recieved by the array "signal model" will be:
$$x_{receive}(t) = A s_{input}(t) + n(t)$$
$x_{receive}(t)$ --- Received ignal vector of dimentsion N by 1
s_{input} (t) --- Input signal vector of dimension I by 1
$n(t)$ --- Noise vector of dimentsion N by 1
$A = [SV(\theta_1), \cdots, SV(\theta_I)] \quad dimension\ N\ by\ 1,$
$s_{input}(t) = \left[s_{input_1}(t), \cdots, s_{input_I}(t)\right]^T$
- As mentioned noise signal is correlated where as input signal is independent
- Column of A may be normalized

The MUSIC Algorithm

- Correlation matrix of size N x N is computed
$$R_x = E\{x_{receive}(t) x_{receive}{}^H(t)\} = A R_S A^H + \sigma_0^2 I$$
$$where R_S = E\{s(t) x_{receive}{}^H(t)\} = diag.\{\sigma_1^2, \cdots, \sigma_1^2\}$$
- R_S may not be diagonal as received signal are somewhat correlated. It will still work if R_S has full rank.
- There will be a problem if R_S is not full ranked in case the sources are correlated. The solution over the problem is '***Spatial smoothing***'.

B. Esprit algorithm

ESPRIT ALGORITHM

- Assume N sets of doublets, i.e., $2N$ sensors
- Assume I sources, $N > I$
- This array consists of two identical sub arrays, $Z_x$and Z_y, displaced from each other by Δ.

$$x(t)\sum_{i=1}^{I} SV(\theta_i)s_i(t) + n_x(t) = As(t) + n_x(t)$$

$$y(t) = \sum_{i=1}^{I} SV(\theta_i)e^{j\gamma i}s_i(t) + n_x(t) = A\Phi s(t) + n_x(t)$$

$$\gamma_i = \omega_0 \Delta sin\theta_i | c\Phi = diag.\{e^{j\gamma 1}, e^{j\gamma 2}, \cdots, e^{j\gamma I}\}$$

- On similar line to MUSIC, array geometry should be known as $SV(\theta)$ depends on the same.
- The objective is to estimate Φ , thereby obtaining θ_i
- Define $z(t) = \begin{bmatrix} x(t) \\ y(t) \end{bmatrix} = \begin{bmatrix} A \\ A\Phi \end{bmatrix} s(t) + \begin{bmatrix} n_x(t) \\ n_y(t) \end{bmatrix} = As(t) + n_z(t)$

  - Correlation matrix of size 2N x 2N is Computed
  $$R_z = E\{z(t)z^H(t)\} = AR_sA^H + \sigma_0^2 I$$
  - Since there are I sources ,the I eigenvectors of R_z corresponding to the I largest eigen values form the signal subspace U_s; the remaining 2N-I eigenvectors form the noise subspace U_n
  - U_s is 2N x I , and its span is the same as the span of A
  - Therefore ,there exists a unique non-singular I x I matrix T such that (A needs to be known here), $U_s = AT$
  - Partition U_s into two N x I sub matrices
  $$U_s = \begin{bmatrix} U_x \\ U_y \end{bmatrix} = \begin{bmatrix} AT \\ A\Phi T \end{bmatrix}$$
  - The columns of both $U_x and U_y$ are linear combinations of A, so each of them has a column rank I
  - Define an N x $2I$ matrix, which has rank I
  $$U_{xy} = [U_x U_y]$$
  - Therefore, U_{xy} has a null space with dimension I , that is , there exists a $2I$ x I matrix F such that
  $$U_{xy}F = 0 \Leftrightarrow [U_x U_y]\begin{bmatrix} F_x \\ F_y \end{bmatrix} = U_xF_x + U_yF_y = 0 \Leftrightarrow ATF_x + A\Phi TF_y = 0 \Leftrightarrow A\Phi TF_y = -ATF_x$$
  - Then the above gives, since T has full column rank
  $$A\Phi T = -ATF_xF_y^{-1} \Leftrightarrow A\Phi = ATF_xF_y^{-1}T^{-1} \Leftrightarrow \Phi = TF_xF_y^{-1}T^{-1}$$
  - The final algorithm is
  $$\Phi = TF_xF_y^{-1}T^{-1}$$

C. Classification of BF techniques

BF techniques may be classified based on (refer “Fig. 1”):

1. Structure of array viz. Rectangular, circular, linear etc.
2. Fixed weight BF (Switched BF) and adaptive BF (Gotsis et al. [11] (2011))
3. Signal processing technique of BF i.e. analogue or digital or hybrid (Hur et al.[12] (2013), (Bogale et al.[13] (2014))
4. In adaptive BF there are two subcategories based on algorithms viz. blind and non-blind algorithm.

For non-blind algorithms transmitted signal statistics should be known for adjusting the weights and to get desired direction. Blind algorithms are normally self-learning type which will adapt to varying channel conditions. Ultimate goal of adaptation is to focus transmit power in desired direction and nullify unwanted signals.

Refer “Fig. 1”, it provides tree structure of different beam forming techniques. Different algorithms used are Least Mean Square (LMS), Recursive-Least-Square (RLS), Sample Matrix Inversion (SMI), Conjugate Gradient Algorithm (CGA), Constant Modulus Algorithm (CMA), Least Square Constant Modulus Algorithm (LS-CMA), Linearly Constrained Minimum Variance (LCMV), Minimum Variance Distortion less Response (MVDR).

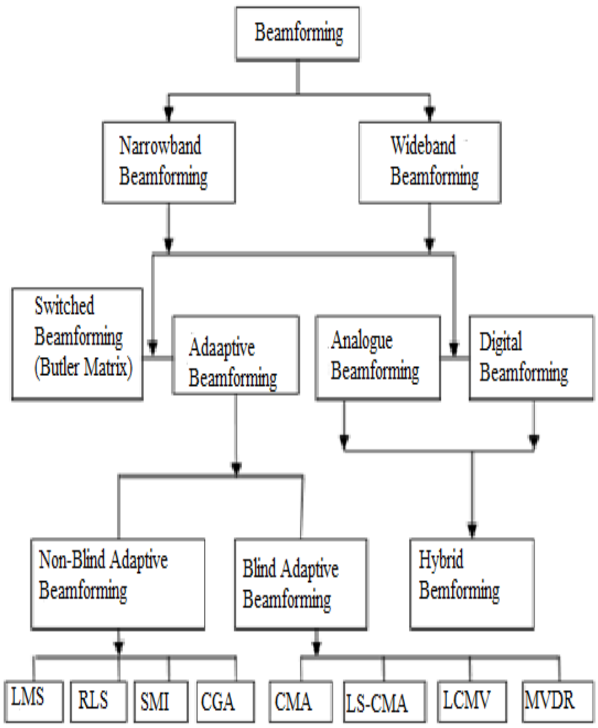

Fig .1. Beamforming Techniques

IV. OPTIMIZATION

Either it is business activity or engineering or industrial design or budget, in each and every field paramount is *Optimization*. Mathematics is backbone for optimization technique. One can design and plan problems using mathematical tool. In case of number of antenna elements with unpredictable receiving signal getting optimal beamforming is very complex problem in space. This complexity asks for usage of highly sophisticated optimization tools. Key to this issue is computer simulation which provides flexibility for implementing various optimization algorithms and give performance analysis. 2D – 3D plots given by simulation software gives clear picture to researcher about performance or efficiency of optimization technique developed to solve practical problem.

Behind any computer simulation and computational methods, there are always some algorithms at work. The basic components and the ways they interact determine how an algorithm works and the efficiency and performance of the algorithm.

Following mathematical model provides generic form of optimization problem.

$$\frac{minimize}{x \in \Re^d} f_i(x), \quad (i = 1,2,\dots,M),$$
$$subject\ to\ H_j(x) = 0, (j = 1,2,\dots,J),$$
$$g_k(x) \leq 0, (k = 1,2,\dots,K),$$
$$where\ f_i(x), h_j(x)\ and\ g_k(x)\ are\ functions$$
$$of\ the\ design\ vector$$
$$x = (x_1, x_2, \dots, x_d)^T$$

x has components i.e. x_i *Decision variables or design. Variables*

x_i may be discrete, continuous or mix of both. $\Re^d$ is search space or design space. This space is spanned by x_i components.

$f_i(x), \quad (i = 1,2,\dots,M) \rightarrow$ $Cost\ function\ or\ Objective\ function.$

The function will be single objective for $M = 1$. $Cost\ function\ or\ Objective\ function$ creates Response space or solution.

Constraints are formed by the g_k function inequalities and h_j function equalities. g_k function inequalities may be represented as ≥0. One can construct maximization problem form the objective function. In worst case scenario where only constraints are there, no objective present then the situation is referred as *feasibility problem.* In this situation optimal solution will be nothing but any feasible solution

Method of Operation is the base of the classification. Typically optimization algorithms are divided into two major classes,

1. Deterministic algorithms (DA) and
2. Probabilistic algorithms (PA)

As name indicates Deterministic algorithms should be only used if characteristics of the possible solutions and their use for a given problem, clear relationship exists. Only this condition can efficiently explore search space. One may use different schemes e.g. divide and conquer scheme, Akra-bazi method, Fork-joint method etc.

Probabilistic algorithms (PA) will come into picture when

a) Relating solution candidate and it's *fitness* is pretty complicated Or relation between two is not obvious
b) Search space dimension is too high

Point (a) and (b) makes issue of deterministically solving a problem harder. It simply results into non feasible issue of considering comprehensive summary of search space. This is even not feasible for small problems. PA is the solution for this.

A. Hybrid Beamforming

Li et al.[14] (2014), Bogale et al. [15](2016), and Dai and Clerckx[16] (2016) and other [17]-[22] have discussed briefly hybrid beamforming (Table I and Table II). They drew the conclusion that digital beamforming is not suitable for massive MIMO and proposed some schemes of hybrid beamforming that can avoid digital beamforming implementation problems and improve system performance.

Table I. Hybrid Beamforming

Reference	Objective	Methodology
Li *et al.[14]* (2014)	Evaluating average SINR using HB, keeping weights of analogue beam former fixed.	Investigation of the maximization of the minimal SINR over all of the considered subcarriers under total power constraints, which are considered as a typical optimization problem for 60 GHz multiuser hybrid beam forming
Bogale et al.[15] (2016)	Sub carrier allocation and scheduling algorithm performance was analysed	Comparison between the proposed hybrid beam forming and digital beam forming in terms of the average sum rate of the selected existing antenna beam forming, where in approaches under ZF pre-coding and equal power allocation are evaluated
Dai and Clerckx[16] (2016)	Analysing performance of system with limited number of RF chains	Investigation of a hybrid pre-coding method for multicasting with a limited number of RF chains to propose a low-complexity search algorithm to determine the RF pre-coder and validate its near optimality in terms of the max-min rate
Andreas F. Molisch et al.[17] (2017)	Surveyed all the techniques based on, CSI required, complexity and carrier frequency	Suggested use of B-MIMO and beam selection concept to be used for MU-MIMO
Daniel C. Ara´ujo et al.,[18] (2017)	Digital beam forming requires one RF chain per antenna element. Objective was to reduce number of RF chains	Hybrid architecture implemented using phase shifter (analog beam former) and low dimensional digital bean former

Table II. Adaptive Beamforming

Reference	Objective	Methodology
Huang *et al.[19]*(2015)	To reduce steering vector errors	Projection matrices algorithm
Wu *et al.[20]*(2015)	Comparing performance of conventional Algorithm and developed algorithm	Development of RLS algorithm for improvising the reduced rank beamformer
Sivasundarapandian [21](2015)	Interference capability and convergence time, these QoS parameters were analysed with proposed scheme and conventional algorithms	Merging a pure conjugate gradient method (CGM) into pure normalised least mean square (NLMS)
Qi Xi et al.[22] (2017)	Obtaining user equipment beamforming vector	Implemented semi definite relaxation method

V. PROPOSED SCHEME FOR MASSIVE MIMO BF USING HYBRID OPTIMIZATION

"Fig. 2" depicts proposed scheme by author. DOA algorithms (MUSIC / ESPRIT) will be used to set BF angle where maximum power is to be transmitted. BF algorithms like LMS, RLS and MVDR will be used to generate initial weights. User can select either of these techniques. Generated weights are further processed by optimization algorithms like Particle Swarm Organization Algorithm (PSO) or Mon-dominated sorting genetic algorithm (NSGA-II) or Simulated Annealing (SA). Performance of M-MIMO will be analysed for different combinations of BF and optimization algorithms viz LMS+PSO, LMS+NSGA-II, LMS+SA, RLS+PSO, RLS+NSGA-II, RLS+SA, MVDR+PSO, MVDR+NSGA-II and MVDR+SA.

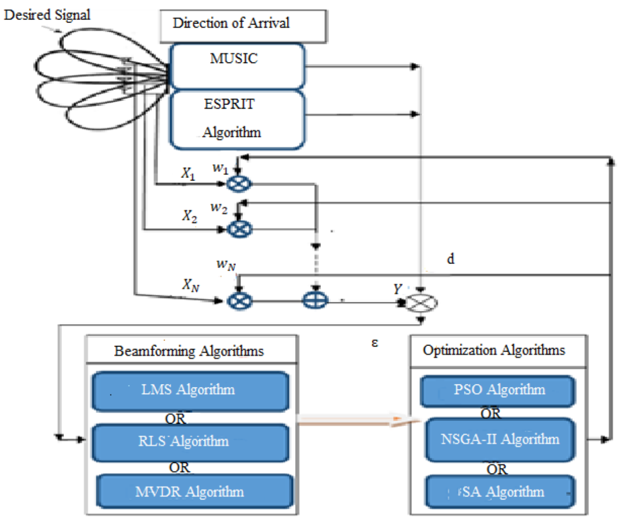

Fig. 2. Hybrid optimization for Massive MIMO BF

VI. CONCLUSION

The paper presents all-embracing review of BF techniques in M-MIMO system. For communication system QOS parameters are of utmost importance. Paper reviewed research work carried out in BF technique keeping in mind points like:

1. Mm-wave i.e. broadband BF
2. Feasibility of the technique in M-MIMO
3. Antenna structure viz linear, circular etc.
4.QOS parameters like Energy efficiency (Crucial parameter in today's scenario), spectrum efficiency, SINR

Channel characteristics are variable, so instead of switched BF, digital based adaptive BF is more suitable. Verities of algorithms are there to adapt changing channel model and provide focused beam in user direction as well null at interference. Weights in adaptive BF can be trimmed to get super califragilistic expialidocious performance.

Author has proposed system in which DOA is estimated by MUSIC or ESPRIT. Cascading of BF algorithm with optimization algorithms like PSO, NSGA-II and SA may help in getting optimal BF for M-MIMO. This system will greatly improvise system performance satisfying next generation wireless communication.

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