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ACE based Energy Efficient Hybrid MMSE Precoding for mmWave Massive MIMO Systems

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***Abstract*: Hybrid Precoding is a promising technique for millimeter (mm) wave massive Multiple Inputs Multiple Output (MIMO) systems. Less number of Radio Frequency (RF) chains is required for hybrid precoding to achieve without any loss in the performance. Phase shifter network is used in many existing precoding methods which involve high energy consumption and high complexity. To overcome this problem, small numbers of switch and inverter new architecture are used. Previously Cross Entropy (CE) algorithm is used in SI based architecture to achieve sum rate in the system. The problem of CE algorithm is all elite are treated as equal. In this paper, Adaptive Cross Entropy (ACE) based Energy Efficient Hybrid Minimum Mean Square Error (MMSE) Precoding for mmwave massive MIMO systems is proposed. The new architecture contains small number of switches and inverters in the analog part. The probability distributions of the elements in hybrid precoder generate randomly several candidate. The achievable sum rates adaptively weights these candidate by minimizing ACE. By iterating this process we are able to achieve high efficiency. Simulation results prove that the proposed method can achieve higher spectral efficiency and energy efficiency than CE optimization methods.**

***Keywords*: Adaptive Cross Entropy, Cross Entropy, Minimum Mean Square Error.**

1. Introduction

5G wireless communication mm wave MIMO system is examined as a promising technology, where it can yield a wider bandwidth and attain high spectral efficiency. Hybrid Precoding is a combination of analog and digital domains which is beneficial to improve cost in mm wave massive MIMO systems. In existing hybrid precoding architecture, the analog part is made of a complicated phase shifter network where all antennas are connected to each RF chain with high resolution phase shifters [1]. In this way, it experiences significant expense of hardware and utilization of energy. Previously, the convention two-stage hybrid precoding method is designed with 4-bit finite-resolution phase shifters. To overcome the disadvantage fortunately, we design the switches(SW) based hybrid precoding architecture [7]. Rather than phase shifters, the SW based architecture utilizes changes to reduce the expense of equipment and utilization of energy. From this design, the Antenna Selection(AS) based hybrid precoding method has been designed. The AS-based scheme reduces the hardware complexity in massive MIMO [3] architecture. From this, the hardware cost and energy utilization is reduced but it is affected by noticeable performance loss. To overcome these issues, proposed a SI based hybrid precoding architecture using MMSE where the analog part is replaced by small number of SI in place of phase shifters. Therefore, it reduces hardware cost and achieve a stable performance. The focus of the CE algorithm is managing the issue of joining SI through iteration. The CE calculation chooses optimal hybrid precoder Selite as "elite"[2] as indicated by the target value of every hybrid precoder. There are a few issues with the CE algorithm. The issue in CE algorithm is it treats the contribution of all elites as the equivalent. ACE based hybrid precoding using MMSE technique is proposed. The ACE based hybrid MMSE precoding technique gives flexibility and quantify the weight of the elites dependent on their values to attain optimal execution.

2. System model

In this section, consider a mmwave massive MIMO system with hybrid precoding [3] , where the base station(BS) consists of number of antenna 'N' and N_{RF} denotes the number of RF chain to serve 'K' active users. Each user is provided with single antenna. The number of RF chain $N_{RF}=K$, to achieve multiplexing gain. The received signal vectors in the system for every users is expressed as

$y = [y_1 , y_2, \ldots, y_K]^T$

$$y = HAx + n \tag{1}$$

$A = F_{RF}F_{BB}$

$H = [h_1, h_2, \ldots, `_K]^H$

$x = [x_1, x_2, \ldots x_K]^H , x_k \in x \; k = 1, 2, \ldots, K$

$n = [n_1, n_2, \ldots n_K]^H , n_k \in n \; k = 1 ,2 , \ldots K$

where the channel matrix H is of dimension N*K with h_K is

N*1 channel vector between BS and K. F_{RF} is the analog precoder with dimension $N*N_{RF}$, F_{BB} is the baseband digital precoder with dimension of $N_{RF}*K$ [4] where it satisfies the total transmit power constraint as

$$P = \| F_{RF}F_{BB} \|^2_F$$

where P denotes the total transmit power , x denotes the transmit signal vector between the BS and K, it is considered that $\mathbb{E}(xx^H) = I_K$, Finally n is an additive white Gaussian noise vector, $n \sim \mathcal{C}\mathcal{N}(0,\sigma^2 I_K)$ of dimension K*1 where σ^2 represents noise power, n_k represents noise received by the k^{th} user.

For the characteristics of mmwave[6], the channel is given as

$$h_k = \sqrt{\frac{N}{L_k}} \sum_{l=1}^{L_k} \alpha_k^{(l)} a(\varphi_k^{(l)}, \theta_k^{(l)}) \tag{2}$$

As L_k represents no of path for users k, $\alpha_k^{(l)}$ is the complex gain for k user while $\varphi_k^{(l)}$ is the azimuth angle of departure (AoD) and $\theta_k^{(l)}$ is the elevation of angle of departure of path l for k user for $1 \leq l \leq L_k$ with dimension of N*1 which represents the response vector of base station antenna array for the typical uniform planar array (UPA) with N elements , $a(\varphi, \theta)$ with φ *and* θ is given as

$$a(\varphi, \theta) = \frac{1}{\sqrt{N}} [\, 1, \ldots, e^{j\frac{2\pi}{\lambda}d(m*\sin(\varphi)\sin(\theta) + n*\cos(\theta))}, \ldots, e^{j\frac{2\pi}{\lambda}d((N_1-1)*\sin(\varphi)\sin(\theta) + (N_2-1)*\cos(\theta))} \,]^T,$$
$$1 \leq m < N1, \; 1 \leq n < N_2 \tag{3}$$

where $N_1*N_2=N$. In addition $d=\lambda/2$, d is the antenna spacing and λ represents signal wavelength.

3. Energy efficient hybrid precoding

A. Switch and Inverter(SI) based hybrid precoding architecture

In this section, the traditional Phase Shifter(PS)-based architecture [5] is shown in Figure 1. This method requires large number of complicated phase shifter network where each RF chain is connected with all antenna [1]. This architecture enjoys high design freedom to achieve ideal performance with N x N_{RF} phase shifter but it suffer from high energy consumption expressed as

$$P_{PS} = P + N_{RF}P_{RF} + NN_{RF}P_{PS} + P_{BB} \tag{4}$$

where P_{RF}, P_{PS}, P_{BB} are the energy consumption of RF chain, finite resolution phase shifters and baseband.

The switch(SW) based architecture [7] is shown in the Figure 2. The problem in PS based architecture is high energy consumption, it can be solved by employing small amount of energy efficient (N_{RF}) Switches in this architecture. The energy consumption of SW-based architecture is given as,

$$P_{SW} = P + N_{RF}P_{RF} + N_{RF}P_{SW} + P_{BB} \tag{5}$$

Where P_{SW} is the energy consumption of switch where it is lower than P_{PS}. Therefore, only N_{RF} antennas are active synchronously so it cannot acquire array gain completely so it leads to obvious performance loss.

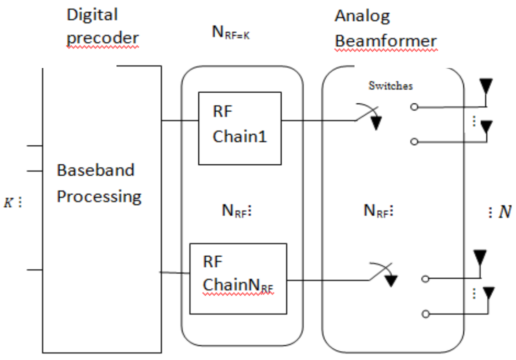

Fig. 2. Switch- based architecture

The SI based architecture is shown in Figure 3, which can solve the problems faced by previous architecture. In this architecture each RF chain is connected with subset of base station antenna, instead of all N antenna. The dimension of subset of base antenna is M, where $M=N/N_{RF}$[2]. The energy consumption of SI based architecture is denoted as,

$$P_{SI} = P + N_{RF}P_{RF} + N_{RF}P_{IN} + NP_{SW} + P_{BB} \tag{6}$$

Where P_{IN} and P_{SW} represents the energy consumption of inverter and switch. Moreover, the energy consumption of inverter can be achieved by digital chip which is related to that of switch. The advantage of SI based architecture is it consume less energy when compared to PS based architecture [5] in addition to it, all N antennas are included to achieve complex array gain.

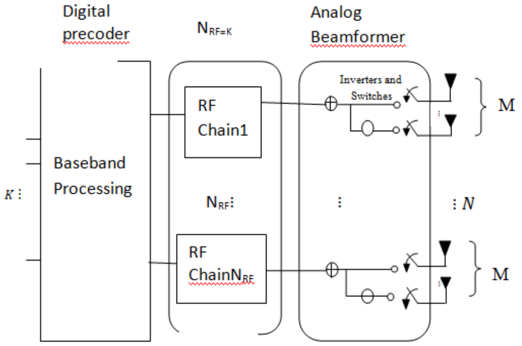

Fig. 3. Switch and inverter-based architecture

The SI based architecture leads to two hardware constraints. The first one in analog precoder F_{RF} should be a block diagonal matrix as a substitute of full matrix [1]

$$\boldsymbol{F}_{RF} = \begin{bmatrix} f_1 & 0 & \cdots & 0 \\ 0 & f_2 & \cdots & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & f_{N_{RF}} \end{bmatrix}_{N\times N_{RF}} \quad (7)$$

Where f_n is of dimension M x1 analog precoder on the n-th sub array of antenna. The second constraint is that the SI-based architecture employs only inverter and switches, all N non zero elements of F_{RF} belongs to,

$$\frac{1}{\sqrt{N}}\{-1,+1\} \quad (8)$$

B. ACE Based Hybrid MMSE Precoding

The ACE based hybrid MMSE precoding is proposed for SI- based architecture with switch and inverter [2]. The ACE based hybrid MMSE precoding is an improved version of CE which reduces the complexity. By designing the F_{RF} and F_{BB} the ACE algorithm can achieve the maximum sum-rate (R). It can be provided as

$$(F_{RF}^{opt}, F_{BB}^{opt}) = \arg \max_{F_{RF}, F_{BB}} R \quad {}_{F} \in \text{Ʊ} \text{ and } \|F_{RF}F_{BB}\|_F^2 = P \quad (9)$$

where Ʊ represents the group of all F_{RF} satisfying the two constraint (7) and (8) described above, sum rate R [1] is acquired as,

$$R=\sum_{k=1}^{K}\log_2(1+\gamma_K) \quad (10)$$

where γ_k represents signal-to-interference-plus-noise ratio (SINR) of the k_{th} user as,

$$\gamma_k = \frac{|h_k^H F_{RF} f_k^{BB}|^2}{\sum_{k'\neq k}^{K}|h_k^H F_{RF} f_{k'}^{BB}|^2+\sigma^2} \quad (11)$$

where f_k^{BB} is the kth column of F_{BB}.

At First, in the ACE-based Hybrid MMSE precoding architecture, initialize the nonzero elements of F_{RF} as an N x 1 vector as follow.

$$f = [(f_1)^T, (f_2)^T, \ldots, (f_N)^T]^T$$

Then followed to that the probability parameter P as an Nx1 vector as

$$\mathcal{P} = [\mathcal{P}_1, \mathcal{P}_2, \ldots, \mathcal{P}_N]^T \quad 0 \le \mathcal{P}_n \le 1$$

where $\mathcal{P}_n$ represents the probability that $f_n = 1/\sqrt{N}$ and f_n is the nth element of f.

When the number of iterations i=0, the probability parameter $\mathcal{P}^{(0)} = \frac{1}{2} \times 1_{N\times 1}$, where 1 is a vector with all-one elements. Besides, all the $f_n (1 \le n \le N)$ are assumed to correspond to the set of $\frac{1}{\sqrt{N}}\{-1,+1\}$ with the equal probability no prior information available.

```
Algorithm 1  ACE Based Hybrid MMSE precoding
    Initialization: i=0;
    For 0≤ i ≤ I do
As stated in $\mathcal{P}^{(i)}$ during the i-th iteration, S candidate analog precoders are generated randomly after that change them as matrices Ʊ
As stated in H the digital precoders $F_{BB}^{S}$ are determined .
Compute the sum-rate R($F_{RF}^{S}$) by $F_{RF}^{S}$ and $F_{BB}^{S}$.
Sort R($F_{RF}^{S}$) in descending order.
$R(F_{RF}^{[1]}) \ge R(F_{RF}^{[2]}) \ge \cdots \ge R(F_{RF}^{[S]})$
Choose the best $S_{\text{elite as}}$ elites.
Evaluate the weight $w_S$ for elite $F_{RF}^{[S]}$ , $1 \le S \le S_{elite}$
Update $\mathcal{P}^{(i)}$ based on $w_S$ and $F_{RF}^{[S]}$ , $1 \le S \le S_{elite}$
i = i+1
    END
  Attainment :Analog precoder $F_{RF}^{[1]}$ and digital precoder $F_{BB}^{[1]}$
```

In Step 1 for the ith iteration, S candidate analog precoders [2] are generated randomly as stated in $\mathcal{P}(i)$ after that convert it into Ʊ matrices in Algorithm 1. Then in Step 2, we generate the respective digital precoders F_{BB}^{S} as stated in the effective channel H,

$$H_{eq}^{S} = HF_{RF}^{S} \qquad 1 \le S \le S$$

As stated in the ZF digital precoder, the F_{BB}^{S} [4]can be estimated as $F_{BB}^{S} = \beta^S G^S$, $G^S = (H_{eq}^{S})^H (H_{eq}^{S}(H_{eq}^{S})^H)^{-1}$ (12)

$$\beta^S = \sqrt{P}/ \|F_{RF}^{S} G^S\|_F$$

where β^S represents power normalized factor.

Similarly for Minimum Mean Square Error the F_{RF}^{S} can be estimated as,

$$F_{RF}^{S} = \beta S G S,\ GS = (H_{eq}^{S})\,(H_{eq}^{S}(H_{eq}^{S})^{-1}) + Q \quad (13)$$

In steps 3 to 5, we evaluate the sum-rate R(F_{RF}^{S}) by F_{RF}^{S} and F_{BB}^{S} (10) and choose the best S_{elite} as elites by arranging R($F_{RF}^{[S]}$) in descending order. Next in Step 5 , the weight w_S is evaluated for elite $F_{RF}^{[S]}$, $1 \le S \le S_{elite}$

$$\gamma = \frac{1}{S_{elite}}\sum_{S=1}^{S_{elite}} R(F_{RF}^{[S]}),$$
$$w_S = R(F_{RF}^{[S]})_{/\gamma} \quad 1 \le S \le S_{elite} \quad (14)$$

In the next step, we update $\mathcal{P}(i)$ based on wS and $F_{RF}^{[S]}$[2],

$$\mathcal{P}^{(i+1)} = \arg max \frac{1}{S}\sum_{S=1}^{S_{elite}} w_S ln \prod_{n=1}^{N}\left(\mathcal{P}_n^{(i)}\right)^{\frac{1}{2}\left(1+\sqrt{N f_n}^{[S]}\right)} (1-\mathcal{P}_n^{(i)})^{\frac{1}{2}(1-\sqrt{N}f_n^{[S]})} \quad (15)$$

where $f_n^{[S]}$ represents the nth element of $f^{[S]}$. Besides, $f_n^{[S]} = 1/\sqrt{N}$ must be the with probability $\mathcal{P}_n^{(i)}$ as $f_n^{[S]} = -1/\sqrt{N}$ must be with the probability $1-\mathcal{P}_n^{(i)}$.

After that, the first derivative of $\mathcal{P}^{(i+1)}$ can be represented as follow.

$$\frac{1}{S}\sum_{S=1}^{S_{elite}} w_S \left(\frac{1+\sqrt{N}f_n^{[S]}}{2\mathcal{P}_n^{(i)}} - \frac{1-\sqrt{N}f_n^{[S]}}{2(1-\mathcal{P}_n^{(i)})}\right) \tag{16}$$

Set (17) to zero, then update $\mathcal{P}^{(i+1)}$ as

$$\mathcal{P}_n^{(i+1)} = \frac{\sum_{S=1}^{S_{elite}} w_S(\sqrt{N}f_n^{[S]}+1)}{2\sum_{S=1}^{S_{elite}} w_S} \tag{17}$$

Then the steps 1 to 8 will be repeated till i=I. Atlast, the analog precoder $F_{RF}^{[1]}$ and the digital precoder $F_{BB}^{[1]}$ are acquired

4. Simulation result

In this paper, the simulation of energy efficiency Vs SNR and spectral efficiency Vs SNR is discussed for ACE based hybrid MMSE precoding. The energy efficiency [2] is defined as,

$\eta = R/ P_X$

Where,

P_X = consumption of energy

R = Sum-rate

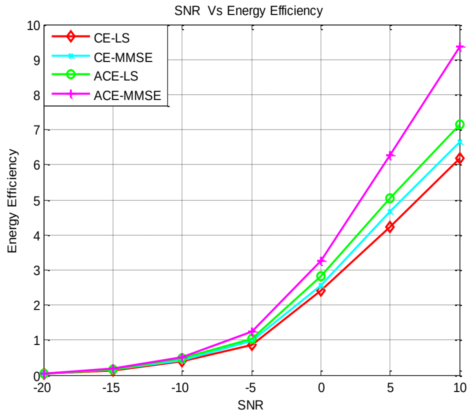

Fig. 4. Energy efficiency vs. SNR

The parameters required for simulation are SNR=10dB, N=64, K=4. The energy efficiency comparison of ACE and CE based hybrid precoding is shown in figure 4, where the energy efficiency is higher for ACE-MMSE when compared to other ACE-LS and CE methods.

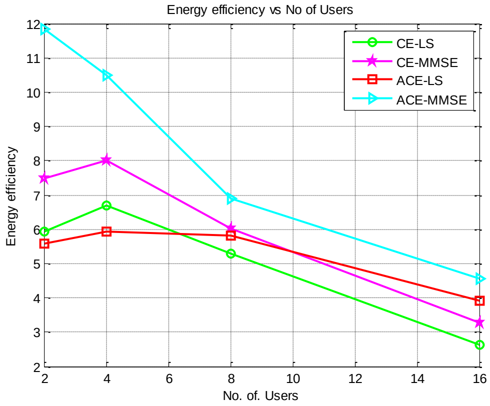

Fig. 5. Energy efficiency vs. No. of. Users

Figure 5 shows the Energy Efficiency comparison of ACE and CE based hybrid precoding with simulation parameter N=64 and N_{RF}=K .Moreover, K changes from 1 to 16. The proposed method is efficient when K=2. This is because as K grows the number of phase shifters(N_{RF}) in the PS-architecture increases.

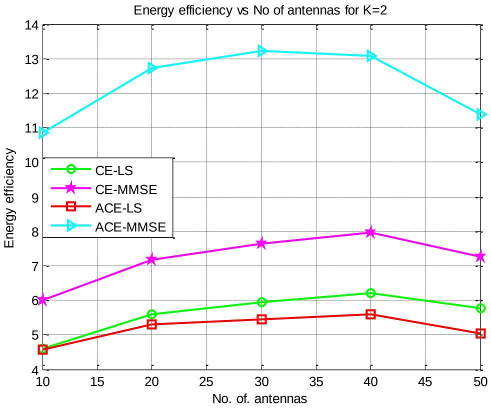

Fig. 6. Energy efficiency vs no. of. Antennas

Energy Efficiency Vs No. of. Antennas for ACE and CE methods is shown in Figure 6, when N changes from 1 to 50. The graph illustrates that when N increases the Energy Efficiency of the proposed method is also increased until N=40.

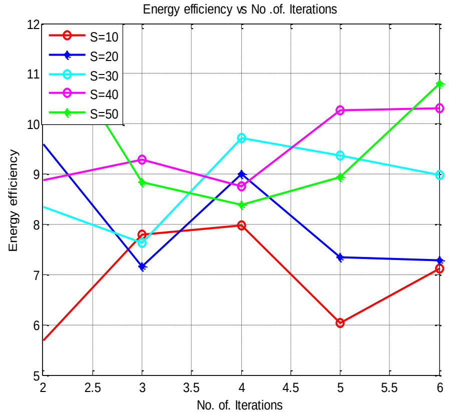

Fig. 7. Energy Efficiency vs. No. of. Iterations

The Energy efficiency of proposed ACE-MMSE is shown in Figure 7. When parameters required for simulation are S_{elite}/S=0.2, N=64, N_{RF}=K=4 and SNR=10 dB. It is observed that increase in S will lead to an obvious improvement in energy efficiency.

5. Conclusion

In this paper, ACE-based hybrid MMSE precoding is proposed for SI based architecture. This architecture contains small number of switches and inverters in the analog part to reduce hardware complexity and high energy efficiency. ACE based hybrid MMSE precoding method is provide effective performance than CE algorithm in terms of energy efficiency and spectral efficiency.

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