Adaptive Cross Entropy-Based Kalman Filter Hybrid Precoding For Frequency Selective mmWave MIMO Channel: Time Domain approach

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Abstract: In Millimetre Wave (mmWave) Multiple-Inputs Multiple-Output (MIMO) systems, hybrid precoders are introduced the reduced number of Radio Frequency (RF) chains. In the existing hybrid precoder using Phase Shifter (PS) network consume high energy, the cost of hardware and the performance loss in the system is high. In this paper, Adaptive Cross-Entropy (ACE) based Kalman Hybrid Precoder for the frequency selective mmWave MIMO channel in time domain approach is proposed. ACE based kalman hybrid precoder is designed and develops for Switch and Inverter (SI) based architecture. In addition, Kalman based digital precoder is develop and compare with MMSE digital precoder. Simulation results show the ACE based kalman hybrid precoding for SI architecture is provide the low energy consumption, and higher Spectral Efficiency (SE) compares to the existing Two-Stage (TS) hybrid precoder, Antenna Selection (AS) and Cross-Entropy (CE) based hybrid precoders.

Keywords: Zero Forcing, Cross Entropy, Adaptive Cross Entropy, Antenna Selection, Switch and Inverter

1. INTRODUCTION

A next-generation network requires wider bandwidth, low latency, High speed, high SE and the massive number of antennas [1]. In mmWave MIMO systems provide high sum rate and high Energy Efficiency (EE) in [2]. Analog/Digital precoder combined form is called as Hybrid Precoder, which gives low complexity and cost-effective mmWave MIMO architecture [3]–[5]. In typical PS based hybrid precoder, the analog part is made of N number of phase shifter network where all antennas are connected to each RF chain [6]. PS based hybrid precoding technique need more number of RF chains. This technique experiences the significant expense of hardware and utilization of energy. Here, the TS hybrid precoder technique is designed for PS. Switches (SW) based hybrid precoder is consume low energy consumption and cost of hardware is minimal [7]. The Antenna Selection (AS) based hybrid precoder reduces the computational complexities, consume low energy, and cost of hardware is minimal. But the loss in the system performance is increases [8]–[11]. To avoid the problems, SI based architecture is introduced [12]. Switches and inverters consume a small amount of energy compare to the phase shifters. From this, it reduces the hardware cost and consumes low energy with reasonably stable system performance.
1.1 Prior Work

Further, the CE algorithm chooses finest hybrid precoders ‘Selite’ from the target value ‘elite’ of every hybrid precoder. There are a few issues of the CE algorithm is discussed. For example, the contributions of all elites are equally divided. The analysis of ACE based hybrid precoder is considered [12]. To attain an optimal solution, the ACE algorithm is used, which compute the weights of the elites adaptively depend on their values. ACE based hybrid precoding technique is performing well compared to the CE algorithm [13-14].

1.2 Contributions of the work

In the last few years, the ACE based hybrid precoder technique is discuss using narrowband channel model or frequency flat channel model in time domain approach. In this paper, presented an ACE based Kalman Hybrid Precoder for a frequency selective mmWave MIMO system in time domain is proposed and discuss the performance analysis of EE and SE for proposed technique. ACE based kalman hybrid precoder technique is developed for SI architecture.

The organization of the paper is given as: mmWave MIMO system model is discussed in Section 2. In section 3, discussed the performance of different hybrid precoding architecture. In section 4, presented the ACE Based Kalman Hybrid Precoder technique. A simulation result is discussed for proposed architecture in section 5. At last, conclusion is discussed in 6.

2. SYSTEM MODEL

Design of hybrid precoder for frequency selective mmWave MIMO channel model is considered, where the Base Station (BS) consists of the number of M antennas and RFN denotes the number of RF chains to serve ‘ K ’ active single-antenna users. The RFN= K , is equal to the number of users is assumed to attain multiplexing gain.

The received signal vectors in the frequency domain for all K user is expressed as

\[ Y = HAX + w \]  

\[ A = F_{RF}F_{dB} \]  

\[ H = \begin{bmatrix} h_1, h_2, \ldots, h_k \end{bmatrix}^H \quad h_k \in H \text{ k=1,2,...,K} \]  

\[ X = \begin{bmatrix} x_1, x_2, \ldots, x_k \end{bmatrix}^H \quad x_k \in X \text{ k=1,2,...,K} \]  

\[ w = \begin{bmatrix} w_1, w_2, \ldots, w_k \end{bmatrix}^H \quad w_k \in W \text{ k=1,2,...,K} \]  

\[ Y = \begin{bmatrix} y_1, y_2, \ldots, y_k \end{bmatrix}^H \quad y_k \in Y \text{ k=1,2,...,K} \]  

The dimension of the channel matrix \( h_k \) is representing as \( M*K \). Where \( x \) is the Kx1 transmitted signal vector for all K users which satisfying the condition of \( E\{xx^H\} = I_k \). \( F_{RF} \) is the analog precoder with dimension of \( M*N_{RF} \). \( F_{dB} \) is the digital precoder with dimension of \( N_{dB}*K \), which satisfies the condition as \( \|F_{RF}F_{dB}\|^2 = P \), where P denotes the total transmitted power of the system. Finally \( w \) is an AWGN vector \( w \sim (0,\sigma^2I_K) \) with the dimension of \( K*1 \) where \( \sigma^2 \) represents the noise power and \( n_k \) represents noise received by the \( K^{th} \) user. Hybrid precoder is done in the time domain in the form of \( A = F_{RF}F_{dB} \in C^{MK} \).
The frequency selective mmWave channel model for the delay tap of the channel is represented as [15-16]

\[ h_k = \sum_{i=0}^{N-1} \sum_{l=1}^{L_k} \alpha_k^{(i)} a(\phi_k^{(i)}, \theta_k^{(i)}) p_{\alpha}(dT_k - \tau_k^{(i)}) \]  

(7)

The mmWave channel for the \( k \)th user is given as

\[ h_k = \sum_{i=0}^{N-1} \sum_{l=1}^{L_k} \alpha_k^{(i)} a(\phi_k^{(i)}, \theta_k^{(i)}) p_{\alpha}(dT_k - \tau_k^{(i)}) \]  

(8)

where \( L_k \) represents the number of the path for the \( k \)th user, \( \alpha_k^{(i)} \) denotes the complex channel gain for the \( k \)th user, \( \phi_k^{(i)}, \theta_k^{(i)} \) denotes the azimuth Angle of Departure (AoD) of the \( i \)th path of the \( k \)th user with the dimension of \( M^1 \) antenna array steering vector and \( p_{\alpha}(\tau_k^{(i)}) \) denotes the pulse shaping filter response evaluated at \( \tau_k^{(i)} \) of the \( i \)th path for the \( k \)th user.

\[ a(\phi, \theta) = \frac{1}{\sqrt{M}} \left[ e^{\frac{2\pi i \phi}{\lambda}} e^{\frac{2\pi i z_1 (\sin(\phi) \sin(\theta) + z_1 \cos(\theta))}{\lambda}} \right]^{-M_1} \left[ e^{\frac{2\pi i \phi}{\lambda}} e^{\frac{2\pi i z_1 (\sin(\phi) \sin(\theta) + z_1 \cos(\theta))}{\lambda}} \right]^{-M_2} \]

(9)

Where \( M_1 * M_2 = M \) for UPA, \( M_1 \) denotes the elements of the horizon and \( M_2 \) denotes the elements of vertical. \( d \) is the antenna spacing and \( \lambda \) represents signal wavelength is considered [17].

3. PERFORMANCE OF HYBRID PRECODER ARCHITECTURE

3.1 SI Based Architecture

To overcome the energy consumption and array gains problem arises in conventional architecture. SI based architecture is shown in Figure 1. SI based architecture, each RF chain is connected to a each subset of BS antennas and this can be defined by \( M = N/N_{RF} \) switches, rather than connecting to all \( N \) antennas. The consumption of energy for Switch and Inverter based architecture is expressed as

\[ P_{SI} = P + N_{RF} + P_{RF} + N_{RF} + P_{SW} + P_{BB} \]  

(10)
Figure 1. Switch and Inverter based architecture

Where $p_{IN}$ and $p_{SW}$ represents the Inverter energy consumption and switch energy consumption respectively. Digital chip is used to realize the consumption of energy for Inverter, and it is same as that of the switch $p_{IN} = p_{SW}$. The SI based architecture consumes low energy when compared to PS based architecture. For all $N$ antennas are used in the proposed architecture, which gives the array gains of mmWave MIMO systems.

4. ACE BASED KALMAN HYBRID PRECODER TECHNIQUE

ACE based kalman hybrid precoder is proposed for SI architecture to reduce the difficulty of CE algorithm. The objective of ACE algorithm is used to design the optimal $F_{RF}$ and $F_{BB}$ to enhance the data rate $R$. The optimal digital precoder $F_{BB}$ is computed using kalman based approach, which improves the achievable sum rate $R$. It is expressed as

$$ (F_{RF}^{opt}, F_{BB}^{opt}) = \arg \max_{F_{RF}, F_{BB}} R $$

s.t. $F_{RF} \in \nu$ and $\|F_{RF} F_{BB}\|_F^2 = P$  \hspace{1cm} (11)

The achievable sum rate $R$ is given by

$$ R = \sum_{k=1}^{K} R_k $$

(12)

Where $R_k$ denotes the sum rate for the $N$ subcarrier of the $k^{th}$ user, and it is expressed as

$$ R_k = \log_2 (1 + \gamma_k) $$

(13)

Where $\gamma_k$ represents the SINR for the $k^{th}$ user, and it is given by
\[ \gamma_k = \frac{|H_k^H F_{RF} f_k^{BB}|^2}{\sum_{k=1}^{K} |H_k^H F_{RF} f_k^{BB}|^2 + \sigma^2} \]  

(14)

Where \( f_k^{BB} \) is the \( k \)-th column of \( F_{BB} \).

At first, ACE-based kalman hybrid precoder technique are introduces the nonzero components of \( F_{RF} \) as a \( M \times 1 \) vector as follow.

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

(15)

Then followed to that the likelihood parameter (Probability parameter) \( \mathcal{R} \) as a \( M \times 1 \) vector as

\[ \mathcal{R} = [\mathcal{R}_1, \mathcal{R}_2, \ldots, \mathcal{R}_M]^T \quad 0 \leq \mathcal{R}_m \leq 1 \]  

(16)

The ACE based kalman hybrid precoder technique is discussed in Algorithm 1.

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**Algorithm 1**

Initialization: \( i = 0 \)

For \( 0 \leq i \leq I \) do

2. According to \( \mathcal{R}^{(i)} \) during the \( i \)-th iteration, \( S \) are generated randomly, after that change them as \( \nu \) matrices

3. Calculate the digital precoder \( F_{RF}^{(i)} \) using kalman filter with respect to the \( H \) [18-20].

   \[ F_{RF}^{(i)}(n|n) = F_{BB}^{(i)}(n|n-1) + K(n) \frac{I-H_k^H F_{RF}^B(n|n-1)}{||H_k^H F_{RF}^B(n|n-1)||_F^2} \]

   \[ R(n|n) = [I-K(n)H_k^H]R(n|n-1) \]

   \[ K(n) = R(n|n-1)(H_k^H)^H[H_k^H R(n|n-1)(H_k^H)^H + Q_n]^{-1} \]

4. Compute the sum-rate \( R(F_{RF}^{(i)}) \) by \( F_{RF}^{(i)} \) and \( F_{BB}^{(i)} \).

5. Sort \( R(F_{RF}^{(i)}) \) in descending order \( R(F_{RF}^{(i+1)}) \geq R(F_{RF}^{(i)}) \)

6. Choose the best \( S_{\text{elite}} \) as elites.

7. Evaluate the weight \( W_s \) for elite \( F_{RF}^{(i)} \), \( 1 \leq s \leq S_{\text{elite}} \)

8. Based on \( W_s \) and \( F_{RF}^{(i)} \), \( 1 \leq s \leq S_{\text{elite}} \), update the \( \mathcal{R}^{(i)} \)

9. \( i = i + 1 \)

END
5. SIMULATION RESULT

ACE based kalman hybrid precoder technique is developed for SI architecture in time domain. The performance analysis of the ACE based kalman hybrid precoder technique is discussed and compared with the existing hybrid precoder. The simulation results of EE Vs SNR and SE Vs SNR is discussed for proposed technique. Simulation specification is given in table 1.

The formula for EE is given as

\[ \eta = \frac{R}{P_X} \]

Where, \( P_X \) = consumption of energy, \( R = \) Sum-rate or SE

| Parameters       | Values |
|------------------|--------|
| \( \lambda \)    | 1      |
| \( \frac{\lambda}{2} \) |        |
| \( L_k \) (Path) | 3      |
| SNR              | 10db   |
| Power            | 0.03W  |
| \( P_{RF} \)     | 0.3W   |
| \( P_{BB} \)     | 0.2W   |
| \( P_{PS} \)     | 0.04W  |
| \( P_{SW} \)     | 0.005W |
| \( P_{IN} \)     | 0.005W |
| Number of Candidates | 200   |

Table 1: Specifications for simulation
The EE VS SNR performance comparison of ACE based kalman, ACE, CE, AS, Two-stage hybrid precoder and fully digital precoding are shown in Figure 2, with the required simulation parameters are, $M=64$, $K=4$, $S=200$, $S_{\text{init}}=40$, $I=20$. The energy efficiency is higher for ACE based kalman hybrid precoder when compared to other ACE, CE, AS and two-stage hybrid precoder. EE Vs Number of antennas for ACE based kalman and other existing methods are shown in Figure 3. The graph illustrates that up to $M=40$ give higher energy efficiency for the proposed method. The result maintains the stable condition up to $M=40$. This infers that $M=40$ antennas can be used in this architecture.
Figure 3. EE Vs No. of. Antennas

Figure 4. SE Vs SNR

SE Vs SNR for ACE based kalman hybrid precoder, ACE, CE, AS, two-stage hybrid precoder and fully ZF digital precoding is shown in Figure 4, with the required simulation parameters are, M=64, K=4, S=200, $S_{inc}=40$, I=20 . From Figure 4, it is inferred that ACE based kalman hybrid precoder is achieved high SE compared to existing hybrid architecture.

6. CONCLUSION

ACE based kalman hybrid precoder technique for a frequency selective mmWave MIMO system in time domain is discussed. ACE based kalman hybrid precoder is designed for SI architecture. In the analog part of this architecture, switches and inverters consume a small amount of energy compare to the phase shifters. This reduces the hardware cost, energy consumption and provides high energy efficiency in the architecture. The proposed architecture performs better than other existing architecture.

References
[1] J. G. Andrews et al., “What will 5G be?” IEEE J. Sel. Areas Commun., vol. 32, no. 6, pp. 1065–1082, Jun. 2014.
[2] J. Zhang, L. Dai, Z. He, S. Jin, and X. Li, “Performance analysis of mixedADC massive MIMO systems over Rician fading channels,” IEEE J. Sel. Areas Commun., vol. 35, no. 6, pp. 1327–1338, Jun. 2017.
[3] A. Alkhateeb, J. Mo, N. Gonzalez-Prelcic, and R. W. Heath, Jr., “MIMO precoding and combining solutions for millimeter-wave systems,” IEEE Commun. Mag., vol. 52, no. 12, pp. 122–131, Dec. 2014.
[4] O. El Ayach, S. Rajagopal, S. Abu-Surra, Z. Pi, and R. W. Heath, Jr., “Spatially sparse precoding in millimeter wave MIMO systems,” IEEE Trans. Wireless Commun., vol. 13, no. 3, pp. 1499–1513, Mar. 2014.
[5] R. W. Heath, N. González-Prelcic, S. Rangan, W. Roh, and A. M. Sayeed, “An overview of signal processing techniques for millimeter wave MIMO systems,” IEEE J. Sel. Topics Signal Process., vol. 10, no. 3, pp. 436–453, Apr. 2016.
[6] A. Alkhateeb, G. Leus, and R. W. Heath, “Limited feedback hybrid precoding for multi-user millimeter wave systems,” IEEE Trans. Wireless Commun., vol. 14, no. 11, pp. 6481–6494, Nov. 2015.

[7] R. Méndez-Rial, C. Rusu, A. Alkhateeb, N. González-Prelcic, and R. W. Heath, Jr., “Channel estimation and hybrid combining for mmWave: Phase shifters or switches?” in Proc. Inf. Theory Appl. Workshop (ITA), Feb. 2015, pp. 90–97.

[8] N. P. Le, F. Safaei, and L. C. Tran, “Antenna selection strategies for MIMOOFDM wireless systems: An energy efficiency perspective,” IEEE Trans. Veh. Technol., vol. 65, no. 4, pp. 2048–2062, Apr. 2016.

[9] N. Valliappan, R. W. Heath, and A. Lozano, “Antenna subset modulation for secure millimeter-wave wireless communication,” in Proc. IEEE GLOBECOM Workshop, vol. 61, no. 8, 2013, pp. 1258–1263.

[10] F. M. Maciel-Barboza, J. Sanchez-García, S. Armas-Jiménez, and L. Soriano-Equigua, “Uplink and downlink user and antenna selection for mmWave full duplex multiuser systems,” in Proc. 2nd Int. Conf. Frontiers Signal Process. (ICFSP), Oct. 2016, pp. 142–146.

[11] P. Yang, Y. Xiao, Y. L. Guan, Z. Liu, S. Li, and W. Xiang, “Adaptive SMMIMO for mmWave communications with reduced RF chains,” IEEE J. Sel. Areas Commun., vol. 35, no. 7, pp. 1472–1485, Jul. 2017.

[12] X. Gao, L. Dai, Y. Sun, S. Han, and I. Chih-Lin, “Machine learning inspired energy-efficient hybrid precoding for mmWave massive MIMO systems,” in Proc. IEEE Int. Conf. Commun. (ICC), Paris, France, May 2017, pp. 1–6.

[13] X. Gao, L. Dai, Y. Sun, S. Han, and C.-L.I, “Machine learning inspired energy-efficient hybrid precoding for mmWave massive MIMO systems,” in Proc. IEEE Int. Conf. Commun. (IEEE ICC’17), Paris, France, May 2017.

[14] Mengqian Tian ; Jianing Zhang ; Yu Zhao ; Lianjun Yuan ; Jie Yang. “Switch and Inverter Based Hybrid Precoding Algorithm for mmWave Massive MIMO System: Analysis on Sum-Rate and Energy-Efficiency,” April 11, 2019.

[15] A. Alkhateeb and R. W. Heath, Jr., “Frequency selective hybrid precoding for limited feedback millimeter wave systems,” IEEE Trans. Commun., vol. 64, no. 5, pp. 1801–1818, May 2016.

[16] J. R. Fernández, N. G. Prelcic, K. Venugopal, and R. W. Heath, “Frequency-domain compressive channel estimation for frequency selective hybrid millimeter wave MIMO systems,” IEEE Transactions on Wireless Communications, vol. 17, no. 5, pp. 2946–2960, 2018.

[17] Jingbo Tan, Linglong Dai, Jianjun Li, Shi Jin. "Angle-based codebook for low-resolution hybrid precoding in millimeter-wave massive MIMO systems", 2017 IEEE/CIC International Conference on Communications in China (ICCC),2017.

[18] Anna Vizziello et al., “A Kalman based Hybrid Precoding for Multi-User Millimeter Wave MIMO Systems,” IEEE Access, vol. 04, pp. 55712–55722, 2018.

[19] R. W. Heath, Jr., N. González-Prelcic, S. Rangan, W. Roh, and A. M. Sayeed, “An overview of signal processing techniques for millimeter wave MIMO systems,” IEEE J. Sel. Topics Signal Process., vol. 10, no. 3, pp. 436–453, Apr. 2016.

[20] V. S. R. Wong and D. W. K. Ng, Key Technologies for 5G Wireless Systems. Cambridge, U.K.: Cambridge Univ. Press, 2017.