COMPARATIVE ANALYSIS OF MIMO SYSTEM BY USING SIGNALING CONDITION FOR WIRELESS COMMUNICATION SYSTEM

DR. Ratnesh Kumar Jain[1] and Dr. Virendra Singh Chaudhary[2]
[1]RKDF University, Bhopal, (MP), INDIA, *[1]ratneshjain29@rediffmail.com*
[2]RKDF College of Technology and Research, RKDF University, Bhopal, (MP), INDIA ,*[2]virgwl@gmail*

Abstract

Multiple Input Multiple Output is prime technologies that can be achieve the goal of high speed data. The necessary requirement to reduce the fading resulting from signal fluctuations in the channel. Comparison of bit error rate (BER) performance in Zero Forcing and MMSE equalization techniques. The MIMO (multiple input multiple output) creates the diverse space of the wireless communication system. The MIMO system used different types of signalling methods for modulation and sampling for transmission. The performance of the MIMO system depends on various parameters such as channel capacity, fading of signal, sampling of frequency, beamforming, and reuse of channel. The diverse parameters create a diverse situation of a MIMO system. Nowadays used the concept of a massive MIMO system. The major issue and challenge are minimization of noise and channel error for the on-air transmission medium. The process of fading also decreases the performance of MIMO System. This Paper analysed the various condition of noise and error estimation technique such as ZF (zero forcing) is an ideal condition for transmission of signals. Also analysed the process of MSME for decoding of signals. The major issue of how to improve throughput or outage probability of transmitted signals. The minimization of noise and signals error increase the gain value of signals. For the validation of signalling process used MATLAB software and evaluated standard parameters.

Keywords: - Wireless Communication, MIMO, ZF, MSME, BER, Interference, Throughput

I. Introduction

The Next Generation of Wireless communication design and dedicated to increasing capacity of the network in the process of enhanced users' behaviors and applicability like real-time data streaming. There is various approach to improve network capacity, such as multiple input multiple output, frequency reuse, massive MIMO system and reduction of interference in local communication models[4, 5]. The enormous ghostly efficiencies related with MIMO channels depend on the reason that a rich dissipating climate gives autonomous transmission ways from each send reception apparatus to each get radio wire. Along these lines, for single-client frameworks, a transmission and gathering technique that misuses this structure accomplishes limit on roughly separate channels, where is the quantity of communicate reception apparatuses and is the quantity of get radio wires. Consequently, limit scales directly with comparative with a framework with only one send and one get reception apparatus. This limit increment requires a dissipating climate with the end goal that the grid of channel gains among communicate and get receiving wire sets has full position and in-subordinate sections and that ideal assessments of these additions are accessible at the beneficiary [9, 13]. Ideal appraisals of these additions at both the transmitter and beneficiary gives an expansion in the steady multiplier related with the straight scaling. Much resulting work has been pointed toward portraying MIMO channel limit under more practical presumptions about the hidden channel model and the channel gauges accessible at the transmitter and collector[18, 19]. MIMO limit results are known for some cases, where the comparing multiuser issues stay unsolved. Specifically, next to no is thought about multiuser limit without the supposition of amazing channel state information at the transmitter (CSIT) and at the recipient (CSIR). While there stay many open issues in getting the single-client limit under broad presumptions of CSI and CDI, for a few intriguing cases the arrangement is known. This segment will give an outline of known outcomes for single-client MIMO channels with specific spotlight on extraordinary instances of CDI at the transmitter, just as the beneficiary[26].

Precoding is a potential technique to overcome the detection complexity issue at the downlink receivers. Based on the CSI at the transmitter, precoding provides high capacity and full transmit diversity. Meanwhile, the co-channel interference (CCI) among antennas/users can also be completely eliminated, the signal flows at different antennas/users therefore can be orthogonal, which enables low-complexity detection at the receiver and also empowers the application of space division multiple access (SDMA) in multi-user MIMO (MU-MIMO) systems. Thus, precoding has been considered as one of the core technologies for the downlink massive MIMO systems. Previous efforts to combine precoding with SM in single carrier MIMO systems have been well discussed in point-to-point and broadcast channels, which select the receiver-side active antennas to carry information and are reported to have improved performance relative to conventional pre-coded single carrier MIMO schemes. The above-mentioned works exploit the space domain degree of freedom to perform index modulation and indicate a promising future of the PIM schemes. However, to date, no related work has extended the precoding idea to explore the frequency domain potential or to jointly design the PIM scheme in MIMO-OFDM systems.

II. Literature Survey

Mahesh Shankar Pandey and Virendra Singh Chaudhary Et al. [1] This research article proposes a Defected Star-Shaped Microstrip Antenna (DSSMSA) for wideband applications. A designed monopole antenna has a defected star-shaped tuning stub with a defected ground structure energised with a microstrip feed line. An appropriate tuning of resonating modes wideband frequency effect has been achieved by optimising the dimensions of the tuning stub and the dimensions of the defected ground and its notch. Surface current distribution plays a vital role in optimising the antenna geometry and developing mathematical resonating frequencies equations. The simulated and experimental results show that the DSSMSA radiates under the frequency band from 1.6638 GHz to 6.652 GHz with measured fractional bandwidth of 119.9692% for *jS11j* < -10 dB. Optimised DSSMSA resonates at frequencies 2.05 GHz, 3.382 GHz, and 5.494 GHz. As the geometry of DSSMSA is symmetrical, the symmetric far-_eld pattern has been found in the far-field.

Al-Askery, Ali J. Et al. [6] creators determine the digit mistake rate and pairwise blunder likelihood (PEP) for MIMO-OFDM frameworks for various Mary regulations dependent on the rough commotion appropriation after channel balance. The PEP is utilized to acquire the upper-limits for convolutionally coded and turbo coded huge MIMO-OFDM frameworks for various code generators and get receiving wires. Moreover, intricacy examination of the LLR values is performed utilizing the estimated commotion likelihood thickness work. The inferred LLR calculations can be tedious when the quantity of get radio wires is enormous in monstrous MIMO-OFDM frameworks. Subsequently, a decreased intricacy estimate is presented utilizing Newton's addition with various polynomial requests and the outcomes are contrasted and the specific recreations. Reproductions are utilized to exhibit that the outcomes acquired utilizing the determined conditions coordinate intently the Monte Carlo re-enactments.

Elwekeil, Mohamed Et al. [18] A profound learning approach for versatile regulation and coding in down to earth MIMO-OFDM frameworks is introduced. The talked about methodology utilizes a profound convolutional neural organization that is prepared utilizing the assessed channel coefficients and the clamor standard deviation as the information highlights. The examined approach dependably predicts the proper adjustment and coding plan even within the sight of reasonable weaknesses, for example, flawed planning synchronization, transporter recurrence counterbalance and channel assessment at the MIMO-OFDM beneficiaries. Recreation results uncover that the examined approach beats both k-NN, SVM and DNN approaches regarding the bundle blunder rate and the framework throughput.

Fedosov, V. P. Et al. [20] In the article a reproduction was made of a remote information transmission framework on radio wire exhibits for a submerged acoustic channel. A versatile calculation for the handling of room time signals was examined, in light of the development of an identical directional example of the abundancy cluster radio wire toward the appearance of the sign with the best force along one of the proliferation ways in the channel. Because of the utilization of the versatile calculation, the limit of the reception apparatus exhibit directivity design was framed on the way through which the sign with the best force comes. The utilization of the versatile calculation was implied uniquely on the accepting side.

Hu, Die Et al. [26] Creators have talked about a reasonable and efficient technique to assess the downlink channel at the BS for FDD multi-client monstrous MIMO OFDM frameworks. The examined technique doesn't need priori data of the channels. In view of the parametric wideband MIMO channel model, creators first gauge the quantity of channel ways, way postponements, and way points at the BS in uplink. Two reasonable calculations named "Calculation 1" and "Calculation 2" are examined to acquire the assessment of the previous two and the last one, individually. creators at that point gauge the channel way gains at the client side in downlink by utilizing some ordinary CS calculation. After clients taking care of back the assessed way gains, the BS can reproduce the downlink channel.

III. MIMO System

The multiple signal processing techniques applied on MIMO system. The behaviours of channel know at the transmitter, after the precoding done to the signal before transmission. Signal processing methods may be divided into linear and non-linear methods. This section is concerned with the effectiveness of linear receive combining methods in

MIMO implementations. This section looks at four linear receive combining methods; after a briefly description of the signal model used, we will explain these combining methods in more detail[15].

The signal model describes as

$$y = Hx + n \quad (1)$$

Where, H is the channel matrix, x is the transmitted signal vector, n is noise vector, and y is the received signal vector.

ZERO FORCING (ZF) EQUALIZATION

ZF is a least squares approximation method which is use to approximate the solution for an overdetermined linear system where there are more equations than there are variables. For massive MIMO, there are more antennas at the transmitter than there are at the receiver. The linear system that relates the received signals y, the transmitted signals x, and the channel matrix H is an overdetermined linear system. ZF seeks to approximate the transmitted signals from the received noisy signals. The method seeks to minimize the square of the error between the received and the transmitted signals. It is thus called a least squares method[17, 19]. From the signal model earlier, this means minimizing the norm

$$\|y - Hx\|^2$$

Finding the minimum means choosing x such that the differential of the norm with respect to x is zero.

$$\frac{d}{dx}\|y - Hx\|^2 = 0 \quad (2)$$

$$x^- = (H^T H)^{-T} H^T y \quad (3)$$

x^- is used here to show that it is an approximation of x. The quantity $(H^T H)^{-T} H^T$ is usually denoted H^+ and is called the pseudo-inverse. The channel matrix is generally complex and is thus its pseudo-inverse is given by:

$$H^+ = (H^H H)^{-1} H^H \quad (4)$$

where $(.)^H$ denotes the Hermitian transpose. Zero Forcing is simple to implement but it however has a problem of amplifying the noise. ZF needs high SNR values for it to perform well.

REGULARIZED ZERO FORCING (RZF)

Direct inversion of the channel matrix, as done in the ZF equalization method, may lead to poor results when the channel matrix rank is low. This is when the channel matrix becomes close to being singular and matrix inversion becomes impossible. The receiver will therefore not be able to distinguish between different MIMO paths. In order to mitigate this, the RZF method was designed. For RZF the inversion of the channel matrix is regularized by adding a scaled identity matrix to HH^H before matrix inversion[20, 22]. The receive combining vector as given is:

$$T_{RZF} = H^H(\beta I + HH^H)^{-1} \quad (5)$$

where β is the regularization factor?

MINIMUM MEAN SQUARE ERROR (MMSE)

The linear MMSE equalizer utilizes the Bayesian approach to estimating the transmitted signal vector x^- from the observed signal vector y at the receiver[23, 25].

The MMSE estimator is the matrix C in Eq. below that minimizes the mean of the square of the error vector between the estimated signal x^- and the transmitted signal x:

$$x^- = C^H y \quad (6)$$

The MMSE estimator seeks to minimize the objective function below:

$$x^- = argmin_c E\{\|x^- - x\|^2\} \quad (7)$$

$$= E\{\|C^H y - x\|^2\} \quad (8)$$

where E is statistical the expectation. The cross covariance and covariance matrices for x and y are respectively as:

$$R_{xy} = E(xy^H) \quad (9)$$

$$R_{yy} = E(yy^H) \quad (10)$$

Differentiating Eq. 9 with respect to and equating to C zero gives us the MMSE estimator as

$$C = R_{yy}^{-1} R_{yx} \quad (11)$$

Substituting $Hx + n$ for y in Eq.11 leads to:

$$R_{yy} = E((Hx + n)^H (Hx + n)) \quad (12)$$

Noting that y and the noise n are uncorrelated, and the expectation $E(nn^H)$ is the noise variance σ_n^2, the correlation R_{yy} in Eq.13 is given by:

$$R_{yy} = HR_{xx}H^H + \sigma_n^2 I \quad (13)$$

Where, I is an identity matrix, similarly:

$$R_{yx} = E(yx^H) \quad (14)$$

$$= HE(xx^H) \quad (15)$$

Taking consideration of the fact that noise is uncorrelated with the signal and assuming the unity for transmit power, and substituting R_{yy} and R_{yx} for expressions in Eq.14 and Eq.16 respectively into Eq.12 leads us to the final MMSE estimator C as given by as :

$$C = H^H (HH^H + \sigma^2 I)^{-1} \quad (16)$$

where σ^2 is the noise variance? At high SNR values, MMSE converges to ZF equalizer while at low SNR it converges to the matched filter equalizer.

IV. Adaptive Model

Adaptive model is basically concept of frequency reuse concept in MIMO system. The concept of frequency reuse increases the channel capacity and throughput of communication channel. The description of adaptive model is described here.

1. Let $h_{m,n}$ be a complex number corresponding to the channel gain between transmit antenna *n* and the receive antenna *m*. If at a certain time instant adaptive signals $\{x_1, x_2, ..., x_{nt}\}$ are transmitted via the n_t antennas, the received signals at antenna *m* can be expressed as

$$y_m = \sum_{n=1}^{n_t} h_{m,n} x_n + e_m \quad .....(1)$$

where e_m is a noise term. The relation is easily expressed in a matrix framework. Let *x* and *y* be n_t and n_r vectors containing the transmitter and receiver data, respectively. Define the following n_r xn_t adaptive channel gain matrix:

$$H = \begin{bmatrix} h_{1,1} \text{.........} h_{1,nt} \\ \text{..................} \\ . \\ h_{nr,1} \text{.......} h_{nr,nt} \end{bmatrix}$$

Then we have

2. y = Hx + e ....(2)

   where e = $[e_1 .... e_{nr}]^T$ is a vector of noise samples. If several consecutive vectors $\{x_1,..,x_N\}$ are transmitted, the corresponding received data can be arranged in a matrix

3. We can express as adaptive signal as Y = [y_1 ...... y_N] ....(3)
4. We can write as Y = HX + E..............................(4)
5. We can characterize channel selective as adaptive channel as follows:

$$H(z^{-1}) = \sum_{l=0}^{L} H_l z^{-l} \quad ....(5)$$

   where H_l are the n_r xn_t adaptive channel matrices corresponding to the time delays *l* = 0, ..,L. Here the channel is assumed to have (L+1) number of taps. Also, L = 0 corresponds to channel fading model.
6. Now we can define selective of adaptive channel are

y = GX + e ....(6)

where x = $[x^T(-L) \; ... \; x^T(N_0 + L - 1)]^T$

$$y = [y^T(0) \; ... \; y^T(N_0 + L - 1)]^T$$

$$e = [e^T(0) \; ... \; e^T(N_0 + L - 1)]^T$$

and

$$G = \begin{bmatrix} H_L H_{L-1} \text{.....} H_1 H_0 0 \text{..................} 0 \\ 0 H_L H_{L-1} \text{.......} H_1 H_0 \text{.................} \\ \text{.......} \\ \text{...} 0 \\ 0 \text{.............} H_L H_{L-1} \text{.............} H_1 H_0 \end{bmatrix}$$

7. Finally select the transmitted signal

Find the value of outage probability and BER in consideration of SNR value.

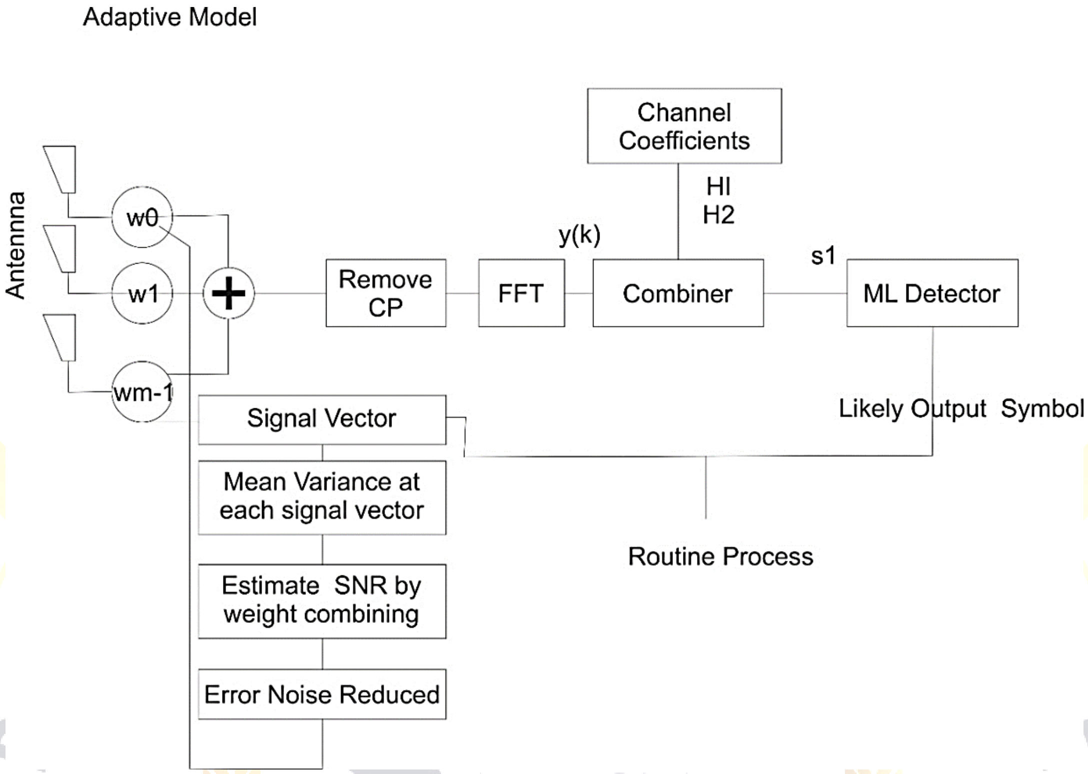

Figure 1: Process block diagram of adaptive model for the selection of frequency on the basic of adaptive model.

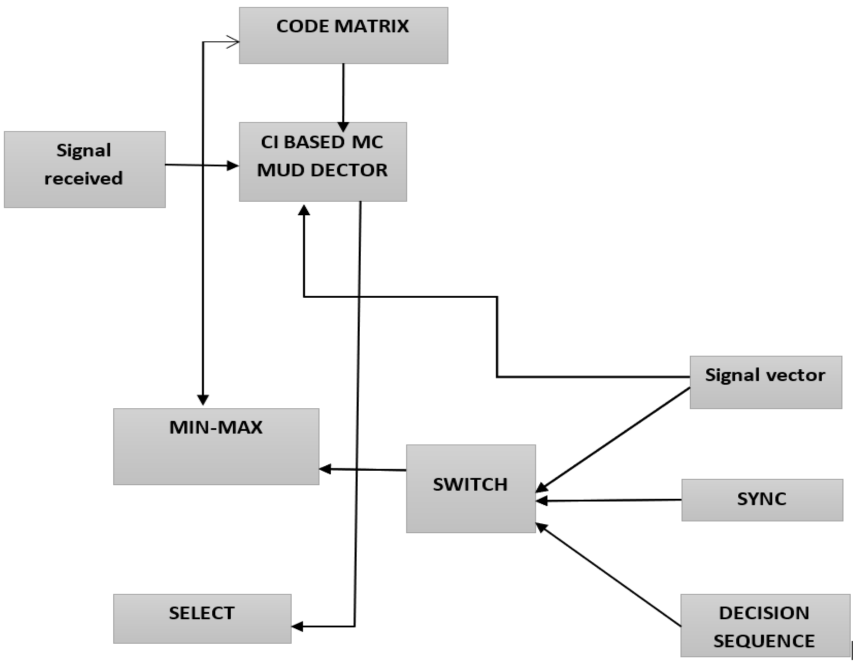

Figure 2: Process block diagram of adaptive model for the selection of weight value for sequence of signal selection.

V. Performance Analysis

Parameter	Value
Number of BS or Cells	1 *and* 16
Pilot Reuse Factors	1,2,4
No. of UEs, K	20
No. of Antennas, M	20: 200
No. of Simulations runs	100
Samples per coherence block	200
UL transmit Power	20 *dBm*
Pathloss Exponent	3.76
Channel gain at 1 *Km*	−148.1*dB*
Shadow fading Standard Dev	10
Cell Area	1 *Km x* 1 *Km*

Table 1: Simulation parameters.

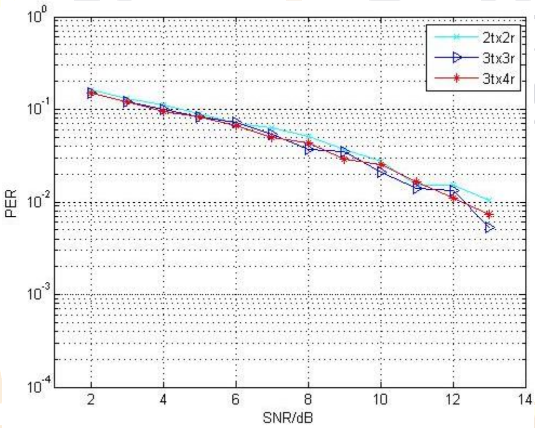

Figure 3: Comparative performance analysis between PER (packet error rate) and SNR (Signal to noise ratio). Here performance consider on the basis of 2tx2r, 3tx3r, 3tx4r.

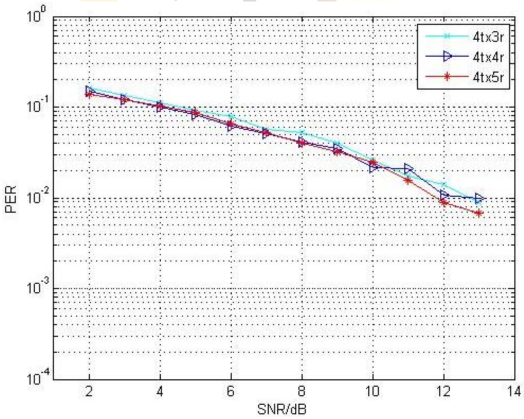

Figure 4: Comparative performance analysis between PER (*packet error rate*) and SNR (*Signal to noise ratio*). Here performance consider on the basis of 4tx3r, 4tx4r, 4tx5r.

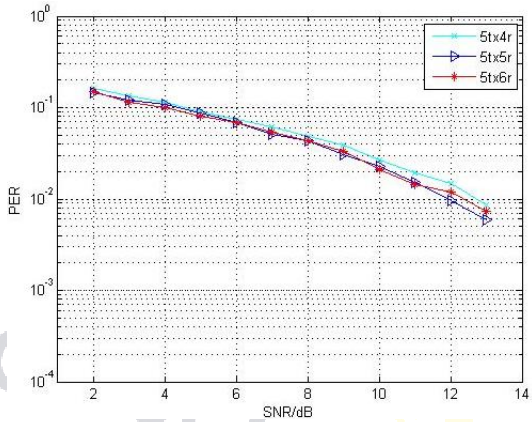

Figure 5: Comparative performance analysis between PER (*packet error rate*) and SNR (*Signal to noise ratio*). Here performance consider on the basis of 5tx4r, 5tx5r, 5tx6r.

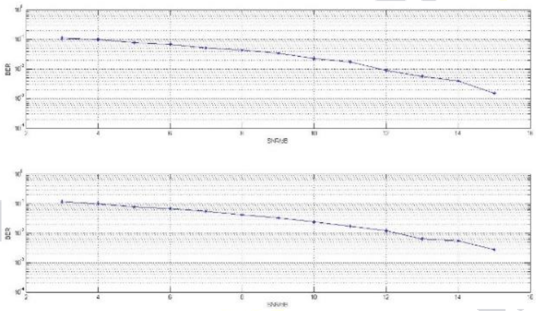

Figure 6: Comparative performance analysis between BER (*Bit Error Rate*) and SNR (*Signal to noise ratio*). Here performance consider on the basis of 4, 6, 8, 10, 12, 14, 16.

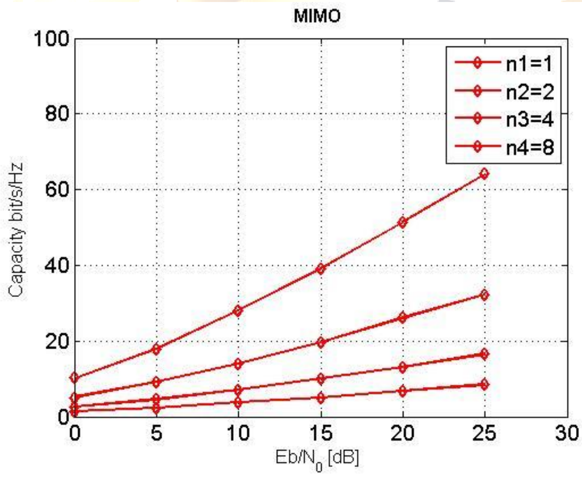

Figure 7: Comparative performance analysis between capacity (*bits/Hz*) and SNR (*Signal to noise ratio*). Here performance consider on the basis of n1=1, n2=2, n3=4, n4=8.

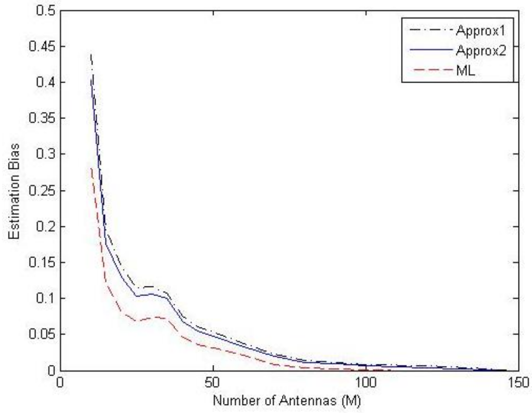

Figure 8: Comparative performance analysis between estimation bias and number of antennas. Here number of antennas 10 to 150 and estimation bias 0.44 to 0.

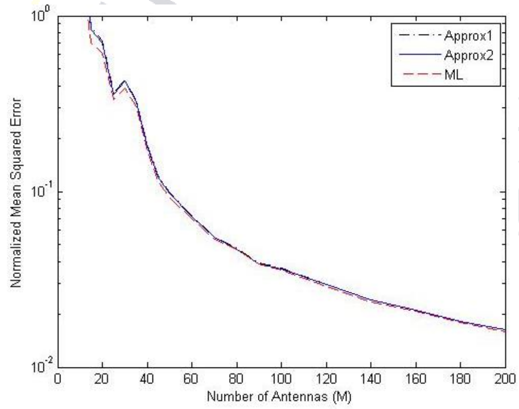

Figure 9: Comparative performance analysis between NMSE (Normalized Mean Squared Error). Type equation here and number of antennas. Here number of antennas 15 to 200 and NMSE 0 to 0.08.

Conclusion

The Comparative performance of results of MIMO system depends on the number of arrays of antenna and base station. The increasing rate of antenna increase the performance of MIMO system. The major analysis based on different combined methods such as MMSE, ZF, RZF and MR. the simulation results of correlated channel and uncorrelated channel indicates the situation of antenna installation on base station. In an offer to show a more practical proliferation channel, it was in this way esteemed important to do comparative reproductions for a Rayleigh associated fading channel. As was normal, the phantom proficiency execution for all sign preparing techniques was lower for the associated channel contrasted with the previous examined uncorrelated channel case. RZF and MMSE indicated similar patterns as were watched for the uncorrelated channel case. Up until the quantity of radio wire components was double the quantity of users, the unearthly effectiveness for MR was higher than that for ZF. After that specific point, ZF execution improved and moved toward both RZF and MMSE.

References

[1]. Mahesh Shankar Pandey & Dr. Virendra Singh Chaudhry, "Defected Star-Shaped Microstrip Patch Antenna for Broadband Applications", Progress In Electromagnetics Research C, VOLUME- 118, Issue-4, pp:11-24, 05 July 2022, ISSN No.1937-8718, **SCOPUS JOURNAL**

[2]. Poonam Shukla & Virendra Choudhary, "Dual Probability-based energy efficient clustering protocol in wireless sensor Network", Stochastic Modelling & Applications (UGC Care Approved Journal)-Special issue on Innovative Research in Management, Applied Science and Engineering, VOLUME-26, Issue-03 pp: 429- 437, 05 July 2022, January-June- Special Issue Part-08, ISSN No. 0972-3641, **UGC CARE-1 JOURNAL**

[3]. Poonam Shukla & Virendra Singh Choudhary "Optimized Utilization of Energy Using Particle Swarm Optimization in Wireless Sensor Network", Stochastic Modeling & Applications (UGC CareApproved Journal)-Special issue on Innovative Research in Management, Applied Science and Engineering, VOLUME-27, Issue-04 pp: 438-445, 05 July 2022, January-June- Special Issue 2022 Part-09, ISSN No. 0972-3642, **UGC CARE-1 JOURNAL.**

[4]. Miranda, Ricardo Kehrle, João Paulo CL da Costa, Binghua Guo, André LF de Almeida, Giovanni Del Galdo, and Rafael T. de Sousa. "Low-complexity and high-accuracy semi-blind joint channel and symbol estimation for massive MIMO-OFDM." *Circuits, Systems, and Signal Processing* 38, no. 3 (2019): 1114-1136.

[5]. Li, Hongyu, Ming Li, Qian Liu, and A. Lee Swindlehurst. "Dynamic Hybrid Beamforming with Low-Resolution PSs for Wideband mmWave MIMO-OFDM Systems." *IEEE Journal on Selected Areas in Communications* 38, no. 9 (2020): 2168-2181.

[6]. Al-Askery, Ali J., Charalampos C. Tsimenidis, Said Boussakta, and Jonathon A. Chambers. "Performance analysis of coded massive MIMO-OFDM systems using effective matrix inversion." *IEEE Transactions on Communications* 65, no. 12 (2017): 5244-5256.

[7]. Araújo, Daniel Costa, Andre LF De Almeida, João PCL Da Costa, and Rafael T. de Sousa. "Tensor-based channel estimation for massive MIMO-OFDM systems." *IEEE Access* 7 (2019): 42133-42147.

[8]. Ashdown, Jonathan D., Lingjia Liu, Gary J. Saulnier, and Kyle R. Wilt. "High-rate

ultrasonic through-wall communications using MIMO-OFDM." *IEEE Transactions on Communications* 66, no. 8 (2018): 3381-3393.

[9]. Bao, Hengyao, Jun Fang, Qian Wan, Zhi Chen, and Tao Jiang. "An ADMM approach for PAPR reduction for large-scale MIMO-OFDM systems." *IEEE Transactions on Vehicular Technology* 67, no. 8 (2018): 7407-7418.

[10]. Berceanu, Mădălina-Gcorgiana, Carmen Voieu, and Simona Halunga. "Performance analysis of an uplink Massive MU-MIMO OFDM-based system." In *2018 International Conference on Communications (COMM)*, pp. 335-9. IEEE, 2018.

[11]. Bhandari, Renuka, and Sangeeta Jadhav. "Novel spectral efficient technique for MIMO-OFDM channel estimation with reference to PAPR and BER analysis." *Wireless Personal Communications* 104, no. 4 (2019): 1227-1242.

[12]. Chen, Xiaoming, Hua Wang, Wei Fan, Yaning Zou, Andreas Wolfgang, Tommy Svensson, and Jian Luo. "Phase noise effect on MIMO-OFDM systems with common and independent oscillators." *Wireless Communications and Mobile Computing* 2017 (2017).

[13]. Saraereh, Omar A., Imran Khan, Qais Alsafasfeh, Salem Alemaishat, and Sunghwan Kim. "Low-Complexity Channel Estimation in 5G Massive MIMO-OFDM Systems." *Symmetry* 11, no. 5 (2019): 713.

[14]. Chen, Chih-Yu, and Wen-Rong Wu. "Joint AoD, AoA, and channel estimation for MIMO-OFDM systems." *IEEE Transactions on Vehicular Technology* 67, no. 7 (2018): 5806-5820.

[15]. Cheng, Xiantao, Ke Xu, and Shaoqian Li. "Compensation of phase noise in uplink massive MIMO OFDM systems." *IEEE Transactions on Wireless Communications* 18, no. 3 (2019): 1764-1778.

[16]. Demeechai, Tanee, and Pratana Kukieattikool. "Performance limit of AOA-based localization using MIMO-OFDM channel state information." *EURASIP Journal on Wireless Communications and Networking* 2017, no. 1 (2017): 1-10.

[17]. Quan, Zhi, and Jie Liu. "Efficient complex matrix inversion for MIMO OFDM systems." *Journal of Communications and Networks* 19, no. 6 (2017): 637-647.

[18]. Elwekeil, Mohamed, Shibao Jiang, Taotao Wang, and Shengli Zhang. "Deep convolutional neural networks for link adaptations in MIMO-OFDM wireless systems." *IEEE Wireless Communications Letters* 8, no. 3 (2018): 665-668.

[19]. Eraslan, Eren, and Babak Daneshrad. "Low-complexity link adaptation for energy efficiency maximization in MIMO-OFDM systems." *IEEE Transactions on Wireless Communications* 16, no. 8 (2017): 5102-5114.

[20]. Fedosov, V. P., A. A. Legin, and A. V. Lomakina. "Adaptive algorithm for data transmission in wireless channels based on MIMO—OFDM technique." In *2017 Radiation and Scattering of Electromagnetic Waves (RSEMW)*, pp. 218-221. IEEE, 2017.

[21]. Gao, Shijian, Meng Zhang, and Xiang Cheng. "Precoded index modulation for multi-input multi-output OFDM." *IEEE Transactions on Wireless Communications* 17, no. 1 (2017): 17-28.

[22]. Ha, Chang-Bin, Young-Hwan You, and Hyoung-Kyu Song. "Machine learning model for adaptive modulation of multi-stream in MIMO-OFDM system." *IEEE Access* 7 (2018): 5141-5152.

[23]. Hu, Die, and Lianghua He. "Channel estimation for FDD massive MIMO OFDM systems." In *2017 IEEE 86th Vehicular Technology Conference (VTC-Fall)*, pp. 1-5. IEEE, 2017.

[24]. Huang, Yuan, Yigang He, Qiwu Luo, Luqiang Shi, and Yuting Wu. "Channel estimation in MIMO–OFDM systems based on a new adaptive greedy algorithm." *IEEE Wireless Communications Letters* 8, no. 1 (2018): 29-32.

[25]. Chen, Ru, and Jianping Zheng. "Index-modulated MIMO-OFDM: Joint space-frequency signal design and linear precoding in rapidly time-varying channels." *IEEE Transactions on Wireless Communications* 17, no. 10 (2018): 7067-7079.

[26]. Jeya, R., and B. Amutha. "Optimized semiblind sparse channel estimation algorithm for MU-MIMO OFDM system." *Computer Communications* 146 (2019): 103-109.

[27]. Ji, Wei, Chenhao Ren, and Ling Qiu. "Common sparsity and cluster structure-based channel estimation for downlink massive MIMO-OFDM systems." *IEEE Signal Processing Letters* 26, no. 1 (2018): 59-63.

[28]. Kakkar, Ashna, Sai Nitesh Garsha, and Ojasvi Jain. "Improvisation in BER and PAPR by using hybrid reduction techniques in MIMO-OFDM employing channel estimation techniques." In *2017 IEEE 7th International Advance Computing Conference (IACC)*, pp. 170-173. IEEE, 2017.

[29]. Ladaycia, Abdelhamid, Anissa Mokraoui, Karim Abed-Meraim, and Adel Belouchrani. "Performance bounds analysis for semi-blind channel estimation in MIMO-OFDM communications systems." *IEEE Transactions on Wireless Communications* 16, no. 9 (2017): 5925-5938.