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Advanced Nonlinear Channel Estimation Techniques for 5G Wireless Communication Systems

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Abstract:

In this paper, 5G wireless communication systems requirement, standards and practical challenges are studied thoroughly. Multicarrier modulation schemes for 4G wireless communication systems were applied to 5G wireless communication systems for better suitability. Traditional channel estimation techniques for 4G were applied to 5G wireless communication systems and observed better applicability. An M-estimator method waveforms for 5G in Gaussian and non-Gaussian environments is proposed, studied and analyzed. 5G networks transceiver model both Gaussian and non-Gaussian environments for various multicarrier modulation schemes was studied and analyzed. Comparison of 5G candidate waveforms in terms of excess emissions, peak to average power ratio, Flexibility, complicated and spectral efficiency was done and suitability for 5G systems with Gaussian and non-Gaussian environments was observed. Bit error rate comparisons were performed on all candidate waveforms with respect to SNR. MSE versus SNR simulations for proposed estimator-based channel estimation method in various non-Gaussian channel environments was carried out and studied. In simulations, proposed channel estimation technique was compared with other techniques and the proposed method outperforms in 5G networks in non-Gaussian environments with various candidate multicarrier waveforms.

Keywords: MSE, SNR, M-estimator, Gaussian and non-Gaussian.

1. INTRODUCTION

There is a rapid increase in number of mobile devices, enormous amount of data and higher rate of data are making present generation of communication system to think about it. The next or fifth generation networks are expected to meet these high-end requirements [1]. The fifth generation is mainly characterized by three unique features. They are very low latency, ubiquitous connectivity and transfer of data is very high. The fifth generation is going to provide novel architectures and technologies beyond the previous one as well [2]. Hence, detailed of fifth generation / new regulation deployment were studied and observed [3]. Then, the architecture, the air interface, and the 3rd Generation Partnership Project (3GPP) deployment options of 5G/NR were analyzed [4]. The 5G Quality of Service was discussed 58]. Comparison of 1G to 5G wireless communication systems in terms of technical specifications for better reception presented in table 1, and better technique for 5G wireless communications was described [6]. Simultaneous presence of multipath shadowing and fading tends to the deterioration of wireless communication channels [7]. Equations for system model for various channel models were applied for testing and simulation. One of the extensive challenges is the selection of candidate waveform (CW) for massive MIMO wireless communications systems [8]. The new continuous wave (CW) or multi carrier modulation (MCM) techniques is deployed to support the base station (BS) for efficacy utilizing the limited frequency spectrum the CW is adopted [9].

In this paper, conclusions were drawn for optimum implementation of suitable multi carrier modulation techniques practically to 5G/ 6G systems through non-Gaussian & Gaussian channels [10]. A study of the many possible waveform types, as well as the advantages and disadvantages of each, is also included for 5G systems. A new M-estimator was proposed mathematically to estimate channel parameters for 5G systems in both Gaussian and non-Gaussian environments [11]. This study focuses on channel estimating approaches, one of the major issues of 5G systems, coupled with wireless channel modeling [12].

2. SYSTEM MODEL

OFDM is used on both uplink and downlink in New Radio (NR) 5G systems [13]. Utilizing subcarriers in up to 3300 Hz, the carrier's frequency may range from 15kHz, 30kHz, 60kHz,120 kHz, 240kHz and 480kHz [14]. For subcarrier modulation BPSK, QPSK, 16QAM, 64QAM, or 256QAM implemented. The obtained signal is

$$Y=HX+W$$

Channel vector is H= [H [0], H [1] ……. H [N-1]]T

Noise vector W= [W [0], W [1]……..W [N-1]]T with 0 mean and υ^2 variance and

$$X = \begin{bmatrix} X(0) & 0 & \cdots & 0 \\ 0 & X(1) & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & X(N-1) \end{bmatrix}$$

Filter Bank Multicarrier (FBMC): is a modality employed in wireless communication systems, especially at which OFDM (Orthogonal Frequency Division Multiplexing) isn't practical. Here's a brief overview of an FBMC transceiver as shown in fig 1 [15].

- FBMC modulates the frequency spectrum by dividing it into subbands utilizing a filter bank. While OFDM requires subcarrier orthogonality, FBMC does not, improving spectrum containment & reducing out-of-band emissions [16].

- FBMC employs a prototype filter that is duplicated across subbands to generate the modulated signals. The prototype filter's characteristics determine the spectral shaping and overall performance of the FBMC system [17].
- In an FBMC transmitter, data symbols are modulated onto subbands using the filter bank.
- Each subband carries its modulated symbols, and these are combined to form the transmitted signal.
- The transmitter may include additional processing stages such as pulse shaping and precoding to optimize performance.
- The FBMC receiver comprises a bank of filters that divides the receiving signal into subbands.
- Each subband undergoes demodulation to recover the transmitted symbols.
- Signal processing techniques like equalization and interference cancellation may be employed to mitigate channel impairments and improve performance.
- FBMC offers several advantages over OFDM, including enhanced resilience to frequency-selective fading & increased spectral efficiency
- Its ability to handle non-orthogonal subcarriers makes it suitable for scenarios with tight spectral constraints or where traditional OFDM suffers from high sidelobe levels.
- FBMC finds applications in various wireless communication systems, including 5G and beyond, cognitive radio, and wireless sensor networks.
- It is particularly well-suited for scenarios requiring efficient spectrum utilization and high resilience to interference and multipath propagation.

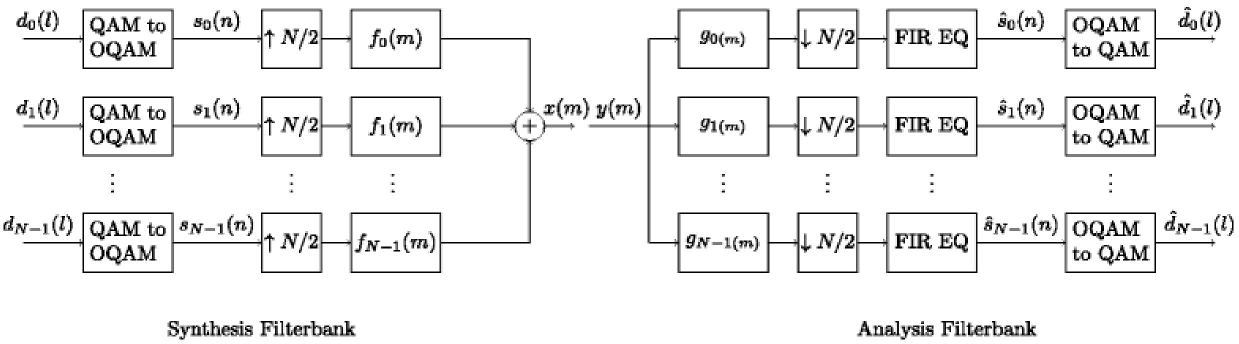


Fig. 1 FBMC transceiver

Universal Filtered Multicarrier (UFMC) is a modulation technique designed to address the drawbacks of wireless communication systems using orthogonal frequency division multiplexing (OFDM) [18]. Here's a brief overview of a UFMC transceiver as shown in fig 2 [19].

- UFMC divides the frequency spectrum into multiple subbands using a filter bank, similar to FBMC [20].
- Unlike OFDM, UFMC employs filter banks with overlapping subbands, allowing for better spectral containment and reduced out-of-band emissions.
- UFMC utilizes more sophisticated filters compared to FBMC, allowing for flexible shaping of the transmitted spectrum [21].
- The filters are designed to have overlapping passbands, which improves spectral efficiency and enables better interference mitigation.

- In a UFMC transmitter, data symbols are modulated onto subbands using the filter bank.
- Each subband carries its modulated symbols, and these are combined to form the transmitted signal [22].
- Additional processing stages such as pulse shaping and precoding may be incorporated to optimize performance.
- A filter bank in the UFMC receivers divides the received signal. into subbands.
- Each subband undergoes demodulation to recover the transmitted symbols.
- Signal processing techniques like equalization and interference cancellation are employed to mitigate channel impairments and improve performance.
- UFMC offers several advantages over OFDM, including improved spectral efficiency, better interference mitigation, and reduced out-of-band emissions.
- Its ability to utilize overlapping subbands enables more efficient use of the available spectrum, making it suitable for scenarios with stringent spectral constraints.
- UFMC is utilized in upcoming wireless communication systems, such as 5G and beyond, where efficient spectrum utilization and robustness to interference are critical.
- It is particularly well-suited for scenarios with high data rates, dynamic channel conditions, and heterogeneous deployment environments [23].

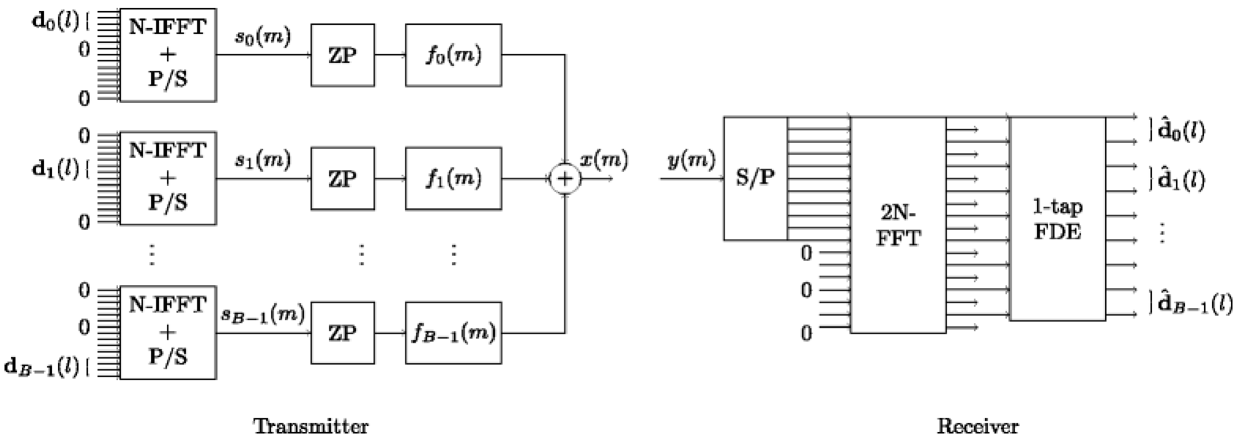


Fig. 2 UFMC Transceiver

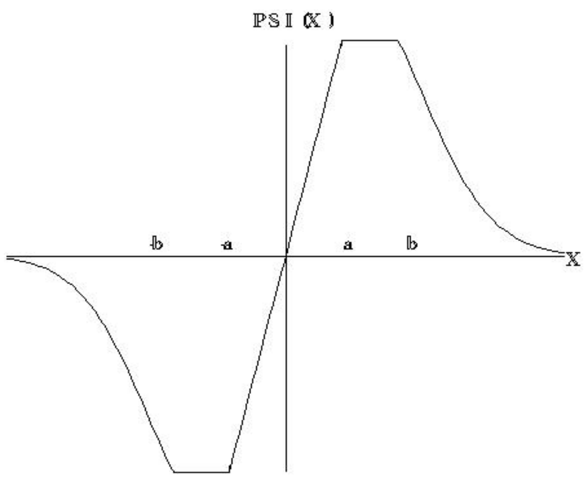


Fig. 3 The suggested M-estimator's effect functions

In statistics, particularly in robust estimation theory, M-estimators are used to estimate parameters of a statistical model. These estimators are robust to outliers and heavy-tailed distributions. The effectiveness of M-estimators is influenced by their associated effect functions [23]. Here's some information on suggested M-estimator's effect functions is shown in figure 3.

- The choice of the effect function affects the trade-off between robustness and efficiency [24].
- More aggressive effect functions provide higher robustness to outliers but may sacrifice efficiency in the absence of outliers.
- Conversely, less aggressive effect functions may offer better efficiency but may be more sensitive to outliers [25].

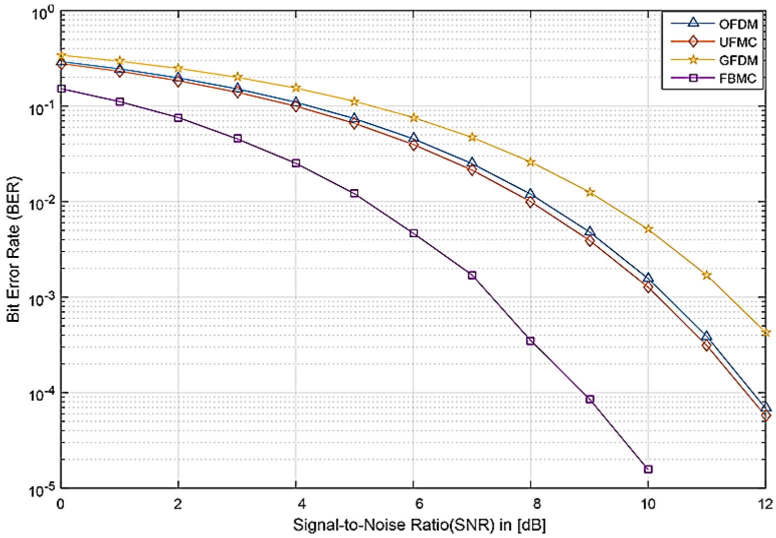


Fig. 4 SNR Vs BER for various 5G candidate waveforms

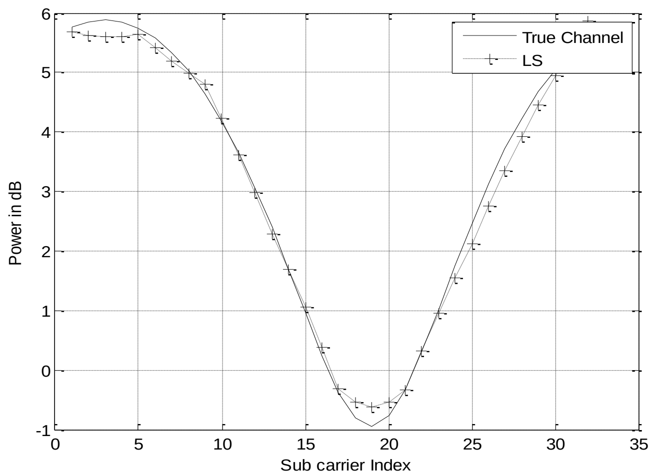
In Table 1 of 5G communication systems, the correlation between Signal-to-Noise Ratio (SNR) and Bit Error Rate (BER) changes according to the modulation waveform and access technique employed [26]. SNR denotes the ratio of signal power to noise power within the communication channel, while BER measures the likelihood of incorrect bit transmission, typically due to noise or interference [27]. As SNR increases, BER generally decreases, indicating improved communication reliability are shown above figure 4 [28].

Table 1: Analysis for 5G Candidate waveforms

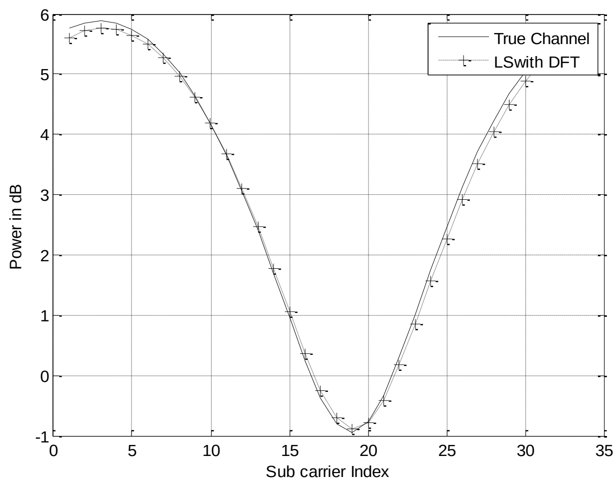
	OFDM	FBMC	UFMC	GFDM
OOBE	H	L	L	M
PAPR	H	M	H	L
FLEXIBILITY	H	M	M	H
COMPLEXITY	M	H	M	H
SPECTRAL EFFICIENCY	L	H	H	M

3. SIMULATION RESULTS

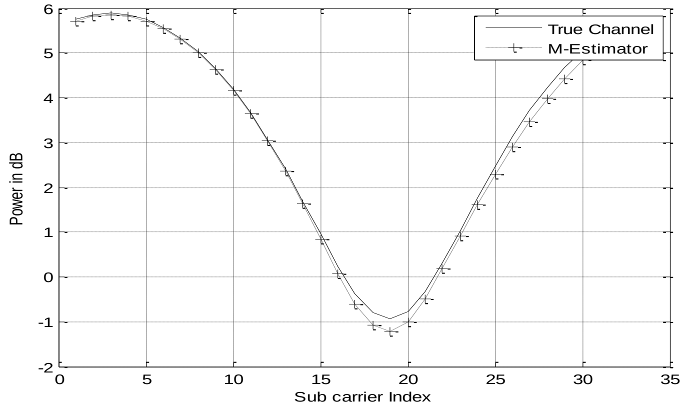
Fig. 5 compares and illustrates the channel estimation methods in simulations utilizing LS & the Suggested M-estimator approaches (with & without DFT) with FFT size 32, pilot spacing is 4. A DFT-method designed for enhance performance with reducing noise beyond the allowable channels delay [29]. The proposed method for channel estimation, with and without Discrete Fourier Transform (DFT) is noted to be a near approximation of the genuine channel in each scenario [30].



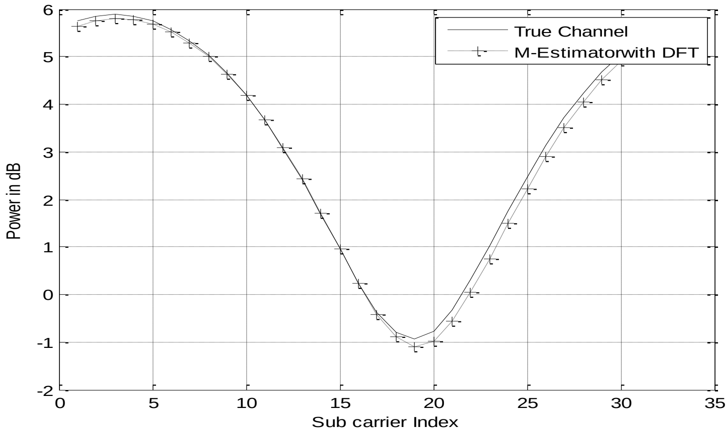
[i]



[ii]



[iii]

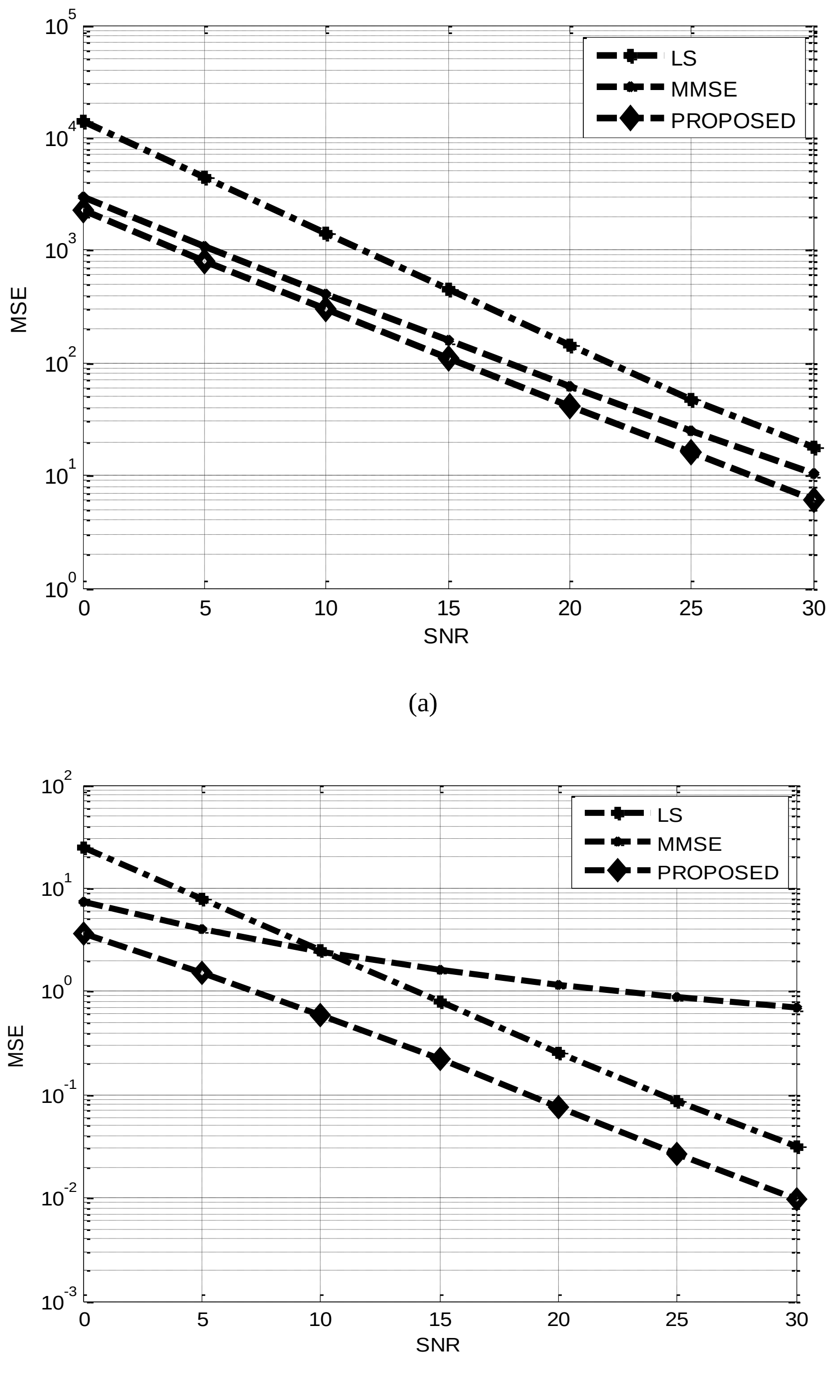


[iv]

Fig. 5 Estimating channels by the use of i) LS method

ii) LS with DFT iii) *M*-estimator and iv) *M*-estimator with DFT.

The proposed method's performance gains are compared with those of LS and MMSE approaches for 5G in Rayleigh and Rician fading channel [31]. For 5G networks, the suggested M-estimator approach performs better compared to above methods. understanding the performance metrics like Mean Squared Error (MSE) and Signal-to-Noise Ratio (SNR) is crucial, especially in fading channels like Rayleigh and Rician.as it can be displayed in below figure 6 [32].



(a)

(b)

Fig. 6 Efficiency of Mean Squared Error vs Signal-to-Noise Ratio in (a) Rayleigh and (b) Rician Fading Channels

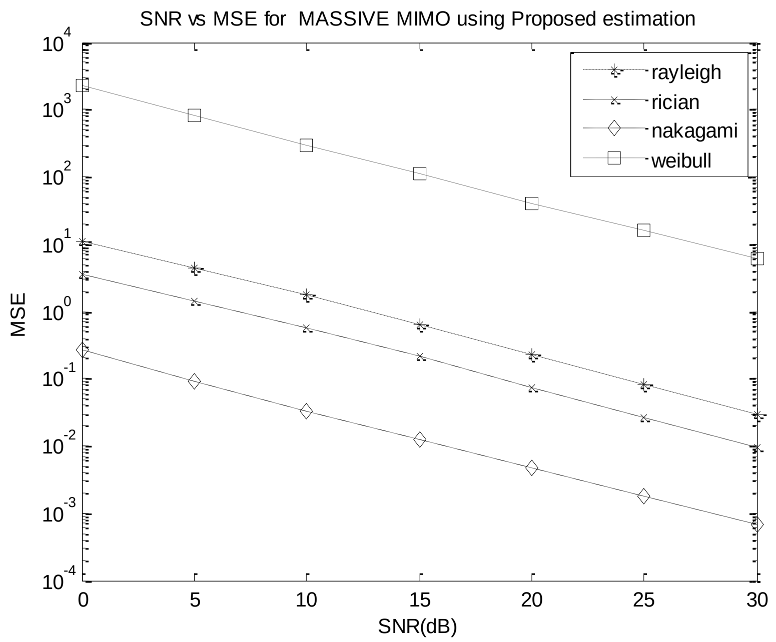


Fig.7 MSE Vs SNR in massive MIMO systems using proposed channel estimate for different channel models.

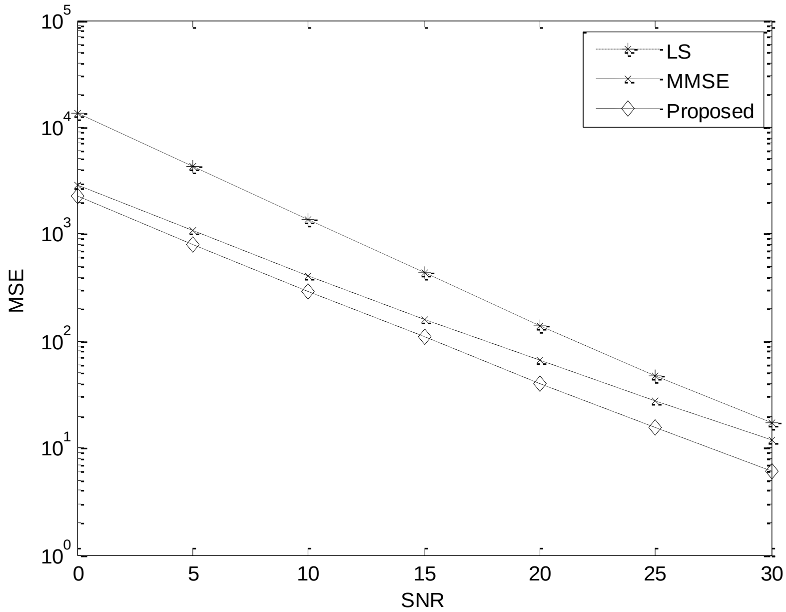


Fig. 8 MSE Vs SNR in massive MIMO systems for proposed, LS and MMSE channel estimate.

The Simulations of MSE Vs SNR is shown in Fig. 7 for proposed channel estimation technique in various non-Gaussian channel environments [33]. In massive MIMO (Multiple Input Multiple Output) systems, the selection of channel estimation technique plays a crucial role in system performance, especially in terms of Mean Squared Error (MSE) and Signal-to-Noise Ratio (SNR) [34]. MSE measures the average squared disparity between the estimated and actual channel state information (CSI). Lower MSE values indicate more accurate channel estimation, crucial for optimal system performance in massive MIMO setups. SNR measures The proportion of signal power to noise power within the communication channel [35].

Higher SNR values imply better quality of received signals relative to the noise level, essential for reliable communication [36]. The effectiveness of proposed channel estimation methods varies across different channel models, such as Rayleigh, Rician, and others [37]. In Fig. 8 proposed channel estimation technique is compared with other techniques. In both simulations, proposed estimation technique in 5G systems proved better results [38].

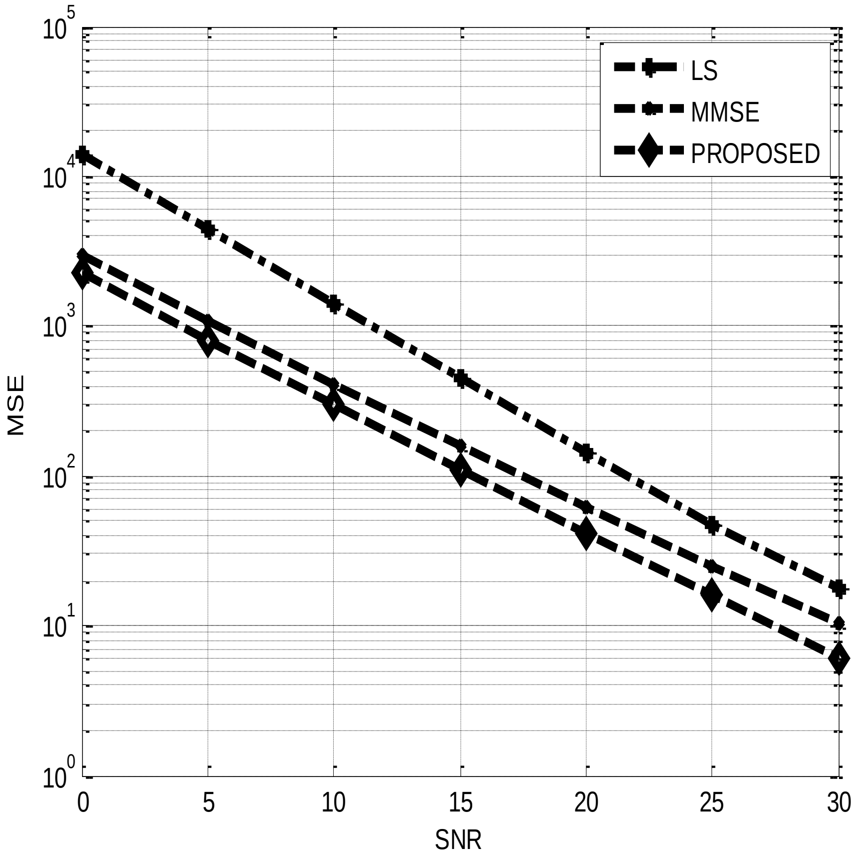


Fig.9 MSE Vs SNR Performances

In massive MIMO (Multiple Input Multiple Output) systems, the selection of channel estimation method significantly impacts system performance, particularly in terms of Mean Squared Error (MSE) and Signal-to-Noise Ratio (SNR). Here's a concise comparison focusing on proposed, Least Squares (LS), and Minimum Mean Squared Error (MMSE) channel estimation techniques. MSE quantifies the average squared disparity between the estimated and actual channel state information (CSI) [39]. Lower MSE values indicate more precise channel estimation, which is crucial for optimal system performance in massive MIMO configurations. SNR measures the ratio of signal power to noise power within the communication channel. Higher SNR values signify better quality of received signals relative to the noise level, which is essential for reliable communication [40].

Furthermore, all the techniques are analyzed in Fig. 9. Divide the pilot by 4, add up all the sub carriers to 128; apply BPSK modulation; and set CP to 8. Each tap in a tapped-delay line channel is described by a Gaussian distribution. The power delay profile ranges from 1 to 0.125, and the fractional delays are from 2.7 to 4.9. Plotting of MSE in relation to SNR is done for all the examined

CE approaches, From these results, it's evident that the proposed M-estimator exhibited significant performance.

4. CONCLUSION

Comparison of 1G to 5G wireless communication systems in terms of technical specifications was carried out first in this paper. Next, analysis and simulations of OFDM, FBMC, UFMC, and GFDM methods are carried. The M-estimator for various waveforms were studied, analyzed and extended to Rayleigh, Rician, Weibull and Nakagami fading channels. Comparison of its illustrate The suggested M-estimation channel estimation algorithm outperforms other 5G methods in simultaneous fading and shadowing for impulsive noise.

REFERENCES

[1] Malik, P.K., Wadhwa, D.S. & Khinda, J.S. A Survey of Device to Device and Cooperative Communication for the Future Cellular Networks. Int J Wireless Inf Networks (2020). https://doi.org/10.1007/s10776-020-00482-8.

[2]] J. -. vande Beek, O. Edfors, M. Sandell, S. K. Wilson and P. O. Borjesson, "On channel estimation in OFDM systems," 1995 IEEE 45th Vehicular Technology Conference. Countdown to the Wireless Twenty-First Century, Chicago, IL, USA, 1995, pp.815-819vol.2. doi: 10.1109/VETEC.1995.504981.

[3] L. Tomba, "On the effect of Wiener phase noise in OFDM systems," in IEEE Transactions on Communications,vol.46,no.5,pp.580-583,May1998.doi: 10.1109/26.668721.

[4] Y. Li, L. J. Cimini and N. R. Sollenberger, "Robust channel estimation for OFDM systems with rapid dispersive fading channels," in IEEE Transactions on Communications, vol. 46, no. 7, pp. 902-915,July1998.doi: 10.1109/26.701317.

[5] Ye Li, "Pilot-symbol-aided channel estimation for OFDM in wireless systems," in IEEE Transactions on Vehicular Technology, vol. 49, no. 4, pp. 1207-1215, July 2000. doi: 10.1109/25.875230.

[6] Praveen Kumar Malik, Harish Parthasarthy, M. P. Tripathi “Axisymmetric Excited Integral Equation Using Moment Method for Plane Circular disk”, International Journal of Scientific and Engineering Research, pp 1-3, Volume 3, Issue 3, March 2012 ISSN 2229-5518

[7] Wireless Communications, Andrea Goldsmith, Cambridge University Press, and 2009 ISBN 10: 0521704162 / ISBN 13: 9780521704168.

[8] Songping Wu and Y. Bar-Ness, "OFDM systems in the presence of phase noise: consequences and solutions," in IEEE Transactions on Communications, vol. 52, no. 11, pp.1988-1996, Nov.2004. doi: 10.1109/TCOMM.2004.836441.

[9] Navid daryasafar; Aboozar lashkari; Babak ehyaee. Channel estimation in MIMO-OFDM systems based on comparative methods by LMS algorithm. IJCSI International Journal of Computer Science Issues, Vol. 9, Issue 3, No 3, May 2012.

[10] D. Lee, "MIMO OFDM Channel Estimation via Block Stagewise Orthogonal Matching Pursuit," in IEEE Communications Letters, vol. 20, no. 10, pp. 2115-2118, Oct.2016. doi: 10.1109/LCOMM.2016.2594059 [16] Qin, Qibo et al. “Sparse Channel Estimation for Massive MIMO-OFDM Systems Over Time-Varying Channels.” IEEE Access 6 (2018): 33740-33751.

[11] C. Chen and W. Wu, "Joint AoD, AoA, and Channel Estimation for MIMO-OFDM Systems," in IEEE Transactions on Vehicular Technology, vol. 67, no. 7, pp. 5806-5820, July 2018. doi: 10.1109/TVT.2018.2798360.

[12] X. Kuai, L. Chen, X. Yuan and A. Liu, "Structured Turbo Compressed Sensing for Downlink Massive MIMO-OFDM Channel Estimation," in IEEE Transactions on Wireless Communications, vol. 18,no.8,pp.3813-3826,Aug.2019.doi: 10.1109/TWC.2019.2917905.

[13] D. C. Araújo, A. L. F. de Almeida, J. P. C. L. Da Costa and R. T. de Sousa, "Tensor-Based Channel Estimation for Massive MIMO-OFDM Systems," in IEEE Access, vol. 7, pp.42133- 42147,2019. doi: 10.1109/ACCESS.2019.2908207.

[14] A. N. Uwaechia and N. M. Mahyuddin, "Spectrum-Efficient Distributed Compressed Sensing Based Channel Estimation for OFDM Systems Over Doubly Selective Channels," in IEEE Access, vol. 7,pp.35072-35088,2019.doi: 10.1109/ACCESS.2019.2904596.

[15] J. Mirzaei, R. S. Adve and S. Shahbazpanahi, "Semi-Blind Time-Domain Channel Estimation for Frequency-Selective Multiuser Massive MIMO Systems," in IEEE Transactions on Communications, vol.67,no.2,pp.1045-1058,Feb.2019.doi: 10.1109/TCOMM.2018.2875724.

[16] A. Akbarpour-Kasgari and M. Ardebilipour, "Massive MIMO-OFDM Channel Estimation via Distributed Compressed Sensing," in IEEE Wireless Communications Letters, vol.8, no.2, pp.376-379, April2019. doi: 10.1109/LWC.2018.2873339.

[17] Y. Huang, Y. He, Q. Luo, L. Shi and Y. Wu, "Channel Estimation in MIMO–OFDM Systems Based on a New Adaptive Greedy Algorithm," in IEEE Wireless Communications Letters, vol. 8, no. 1,pp.29-32,Feb.2019.doi: 10.1109/LWC.2018.2848916.

[18] Tarun, G., Nikhil, K. S., Rohit, C., Kavya, K. C. S., & Saikumar, K. (2023, April). Exploration of CNN with Node Centred Intrusion Detection Structure Plan for Green Cloud. In 2023 IEEE International Conference on Contemporary Computing and Communications (InC4) (Vol. 1, pp. 1-7). IEEE.

[19] T. Anil Kumar and K. Deergha Rao, “A New M–Estimator Based Robust Multiuser Detection in Flat-Fading Non-Gaussian Channels,” IEEE Trans. On Comm., pp. 1908- 1913, Vol. 57, No. 7, July 2009.

[20] T. L. Marzetta, "Noncooperative Cellular Wireless with Unlimited Numbers of Base Station Antennas," in IEEE Transactions on Wireless Communications, vol. 9, no. 11, pp. 3590-3600, November 2010, doi: 10.1109/TWC.2010.092810.091092.

[21] M. Mandloi and V. Bhatia, "Low-Complexity Near-Optimal Iterative Sequential Detection for Uplink Massive MIMO Systems," in IEEE Communications Letters, vol. 21, no. 3, pp. 568- 571, March 2017, doi: 10.1109/LCOMM.2016.2637366.

[22] E. G. Larsson, O. Edfors, F. Tufvesson and T. L. Marzetta, "Massive MIMO for next generation wireless systems," in IEEE Communications Magazine, vol. 52, no. 2, pp. 186-195, February 2014, doi: 10.1109/MCOM.2014.6736761.

[23] F. R. Hampel, E. M. Ronchetti, P. J. Rousseeuw, and W. A. Stahel, Robust Statistics: The Approach Based on Influence Functions, Wiley, New York, 1986.

[24] Imran Khan et.al., “A robust channel estimation scheme for 5G massive MIMO systems,” J. Wireless Communications and Mobile Computing, pp.1-8, 2019.

[25] O. E. Ijiga, “Review of channel estimation for candidate waveforms of next generation networks,” J. Electronics, Vol. 8, pp. 1-50, 2019.

[26] R. K. Saha, P. Saengudomlert and C. Aswakul, “Evolution toward 5G mobile networks – A survey on enabling technologies,” Engineering Journal, vol. 20, 2015.

[27] Michel Saideh, Marion Berbineau and Iyad Dayoub, “On the performance of Sliding Window TD-LMMSE Channel Estimation for 5G Waveforms in High Mobility Scenario,” IEEE Trans. Vehicular Technology, Vol. 67, No.9, pp. 8974- 8977, Sept 2018.

[28] D. Middleton, “Channel modeling and threshold signal processing in underwater acoustics: An analytical overview,” IEEE J. Oceanic Engineering, vol. OE-12, 4-28, Jan. 1987.

[29] D. Middleton and A. D. Spaulding, “Elements of weak-signal detection in non-Gaussian noise, in Advances in Statistical Signal Processing –Vol. 2: Signal Detection,” H. V. Poor and J. B. Thomas, Eds. Greenwich, CT: JAI Press, 1993.

[30] E. Moulines, P. Duhamel, J. F. Cardoso, and S. Mayrargue, “Subspace methods for the blind identification of multichannel FIR filters,” IEEE Transactions on Signal Processing, vol. 43, 516-525, Feb. 1995.

[31] G. A. Tsihrintzis and C. L. Nikias, “Performance of optimum and suboptimum receivers in -stable process,” IEEE Transactions onαthe presence of impulsive noise modeled as an Communications, vol.43, 904–914, Feb./ Mar./ Apr. 1995.

[32] Jr. Collins, Robust estimation of a location parameter in the presence of asymmetry, The Annals of Statistics 4 , 68—85, 1976.

[33] T.Anilkumar, and K.Deergha Rao, “Improved robust techniques for multiuser detection in non- Gaussian channels,” Circuits Systems and Signal Processing J.

[34] T. Fukami, D. Umehara, M. Kawai, and Y. Morihiro, “Noncoherent PSK Optimum Receiver over Impulsive Noise Channels,” Intl. Symp. on Information Theory and Its Applications Xi’an, PRC, October 7–11, 2002.

[35] Kailasam, S., Achanta, S.D.M., Rama Koteswara Rao, P., Vatambeti, R., Kayam, S. (2022). An IoT-based agriculture maintenance using pervasive computing with machine learning technique. International Journal of Intelligent Computing and Cybernetics, 15(2), pp. 184–197.

[36] X. Wang and H. V. Poor, Wireless Communication Systems: Advanced Techniques for Signal Reception, Prentice-Hall PTR, NJ, 2004.

[37] G. Surendher, T. Anil kumar and Dhiraj Sunehra, “A Review of Various Channel Estimation Techniques for Multicarrier Systems in 5G/6G Wireless Communications” in 6th International Conference on Intelligent Computing and Control Systems (ICICCS), May 2022, DOI: 10.1109/ICICCS53718.2022.9788425.

[38] G. Rajender, T. Anil Kumar and K. Srinivasa Rao, “ Dual bound Kalman filter for signal estimation in multipath fading for MIMO-OFDM Communication system” International Journal of Innovative Technology and Exploring Engineering, 2019, 8(7), pp. 690–696.

[39] Saikumar, K., Ahammad, S. H., Vani, K. S., Anwer, T. M. K., Hadjouni, M., Menzli, L. J., ... & Hossain, M. A. (2023). Improvising and enhancing the patterned surface performance of MIMO antenna parameters and emphasizing the efficiency using tampered miniature sizes and layers. Plasmonics, 18(5), 1771-1786.

[40] Singamaneni, K., Reddy, K. N., Yamsani, N., Sarada, K., & Saikumar, K. (2020). Exploration of convolutional neural network with node-centred intrusion detection structure plan for green cloud. Journal of Green Engineering.