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Topics
MATLAB

REFERENCES

1. Zhong, Ke, Xia Lei, and Shaoqian Li. "Iterative channel estimation and data detection for MIMO-OFDM systems operating in time-frequency dispersive channels under unknown background noise." *EURASIP Journal on Wireless Communications and Networking* 2013.1 (2013): 1–14.

2. 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. https://doi.org/10.1109/TWC.2017.2717406
Google Scholar Crossref

3. Prasad, Ranjitha, Chandra R. Murthy, and Bhaskar D. Rao. "Joint channel estimation and data detection in MIMO-OFDM systems: A sparse Bayesian learning approach." *IEEE Transactions on signal processing* 63.20 (2015): 5369–5382. https://doi.org/10.1109/TSP.2015.2451071
Google Scholar Crossref

4. Jiang, Peiwen, Chao-Kai Wen, Shi Jin, and Geoffrey Ye Li. "Dual CNN-based channel estimation for MIMO-OFDM systems." *IEEE Transactions on Communications* 69, no.9 (2021): 5859–5872. https://doi.org/10.1109/TCOMM.2021.3085895
Google Scholar Crossref

5. Wang, Kun, Hong Shen, Wenhao Wu, and Zhi Ding. "Joint detection and decoding in LDPC-based space-time coded MIMO-OFDM systems via linear programming." *IEEE Transactions on Signal Processing* 63, no.13 (2015): 3411–3424. https://doi.org/10.1109/TSP.2015.2422681
Google Scholar Crossref

6. Park, Sunho, Byonghyo Shim, and Jun Won Choi. "Iterative channel estimation using virtual pilot signals for MIMO-OFDM systems." *IEEE Transactions on Signal Processing* 63, no.12 (2015): 3032–3045. https://doi.org/10.1109/TSP.2015.2416684
Google Scholar Crossref

7. Pham, Tri, Tho Le-Ngoc, Graeme K. Woodward, and Philippa A. Martin. "Channel estimation and data detection for insufficient cyclic prefix MIMO-OFDM." *IEEE Transactions on Vehicular Technology* 66, no.6 (2016): 4756–4768. https://doi.org/10.1109/TVT.2016.2613894
Google Scholar Crossref

8. Li, Li, Rodrigo C. de Lamare, and Alister G. Burr. "Dynamic pilot allocation with channel estimation in closed-loop multi-input-multi-output orthogonal frequency division multiplexing systems." *IET Communications* 8, no.11 (2014): 2017–2025. https://doi.org/10.1049/iet-com.2013.0830
Google Scholar Crossref

9. Liao, Yong, Yuanxiao Hua, and Yunlong Cai. "Deep learning based channel estimation algorithm for fast time-varying MIMO-OFDM systems." *IEEE Communications Letters* 24, no.3 (2019): 572–576. https://doi.org/10.1109/LCOMM.2019.2960242
Google Scholar Crossref

10. Ruizhe Yang, Siyang Ye, Pengbo Si, Yinglei Teng, and Yanhua Zhang, “Iterative Channel Estimation and Detection for High-Mobility MIMO-OFDM Systems: Mitigating Error Propagation by Exploiting Error Information”, *Wireless Pers Commun* (2015) 84:1907–1931. https://doi.org/10.1007/s11277-015-2641-6
Google Scholar Crossref

11. Lin, Jia-Chin. "Least-squares channel estimation for mobile OFDM communication on time-varying frequency-selective fading channels." *IEEE Transactions on Vehicular Technology* 57, no. 6 (2008): 3538–3550. https://doi.org/10.1109/TVT.2008.919611
Google Scholar Crossref

12. Alihemmati, R., and M. E. Kalantari. "On channel estimation and equalization in OFDM based broadband fixed wireless MAN networks." in The 7th International Conference on Advanced Communication Technology, 2005, ICACT 2005., vol. 1, pp. 224–229. IEEE, 2005.
Google Scholar Crossref

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Performance Evaluation of Channel Estimation Methods for MIMO-OFDM Systems using Various Detection Methods

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Abstract. MIMO-OFDM systems provide better performance, but complexity increases with multiple antennas and arbitrary multichannel delay profile. This paper presents the designing of pilot structure and estimation of the channel, based on this an accurate detection technique is presented. The performance of MIMO OFDM system is then analyzed by merging the channel estimation and data detection into one iterative algorithm. MATLAB simulation results shows that the DFT channel estimation with ML detection gives the better performance than the other channel estimation – detection combinations.

Keywords— MIMO-OFDM, Channel estimation, Data detection.

INTRODUCTION

MIMO-OFDM is a promising technology to attain high data rates with high spectrum efficiency in future wireless communications [1]. Capacity can be maximized using spatial multiplexing. Coherent receiver model needs accurate CSI (channel state information) like Channel Impulse response is mandated to guarantee diversity gain to achieve acceptable SER (symbol error rate). However, the main challenge in MIMO-OFDM implementation is estimation of channel. Hence estimation of channel is still a main research problem to achieve accurate, efficient, reliable, and cost-effective solutions of MIMO-OFDM systems [2].

In-spite of advantages of MIMO-OFDM system, allocation of pilot is more complex for SISO (single-input single-output)-OFDM, due to superposition of signal data from different transmitting antennas. Many wireless standard communications employed comb-type UPA (uniform pilot allocation), where pilots hold subcarriers only for estimation of channel without any additional advantage. Many methods are proposed to estimate the channel under inter-antenna interference. A correlation between received pilot and original signals was proposed in channel estimation method based on superimposition of pilot [2-3].

In wireless communication transmission, because of multipath effects, the signal gets attenuated and distorted. This can be compensated by obtaining the knowledge of wireless channel using channel estimation [4]. This estimate can be used for detection of the information symbols transmitted subsequently.

RELATED WORK

For detection and decoding of signals coded with space time, a linear programming method is developed by considering the data symbols, training symbols, noise subspace, and channel code in [5]. In [6], author has been developed a decision-directed CE design for improving the quality of CE in MIMO-OFDM system. To attain this, soft symbol decisions have been obtained to use in IDD (iterative detection and decoding). The selection of optimal data tone is examined to describe the reliability of symbol decisions and correlation of channels between the pilot and data tones.

Graeme K. Woodward et al [7] have developed an iterative structure design for channel detection and estimation for MIMO-OFDM. This design utilizes a limited number of subcarriers of pilot and insufficient CP (cyclic prefix) to improve inter carrier and inter symbol interference. In [8], authors presented a dynamic pilot allocation for DFT based channel estimation with spatial multiplexing to increase BER performance of MIMO-OFDM system.

An IDD approach with LDPC (low-density parity-check) codes called BP (Belief Propagation) decoding was presented in [9]. This approach utilizes the concept of short cycle and obtains re-weighting components from hyper graph expansion. An iterative channel estimation and detection technique with weight optimization is introduced in [10] to reduce the unexpected outcomes of channel estimation and detection errors.

In this work, the performance of MIMO-OFDM system is analyzed by merging the channel estimation and data detection into one iterative algorithm.

The main work of the paper is summarized as:

- Design the pilot structure and estimate the accurate channel using estimation algorithms.
- Based on the estimated channel impulse response, design accurate detection techniques using maximum likelihood (ML), Minimum Mean Square Error (MMSE), and zero forcing (ZF) for the detection of the information symbols.

PROPOSED METHOD

Consider an un-coded spatial multiplexing MIMO-OFDM system with N_s number of subcarriers, N_t is the transmit and N_r is the receive antennas as presented in Figure 1. With pilot allocation, the modulated symbols and pilots are inserted. After the pilot allocation, the signal is passed along IFFT and included with Cyclic Prefix (CP) to transmit. Reverse operation is performed at the receiver in Figure 2. By removing CP and passing the signal through FFT. Channel estimation is performed by the pilots and the estimated channel is used for detection process. The received signals are $Z = \left[Z_1, ..., Z_i, ..., Z_{N_r} \right]^T$ is expressed as

$$Z = HS + \eta \tag{1}$$

Where H_{df} is represented as $N_r N_S \times N_t N_S$ matrix

$$H = \begin{bmatrix} H_{11} & H_{21} & \cdots & H_{N_t 1} \\ H_{12} & H_{22} & \cdots & \vdots \\ . & . & . & . \\ H_{1N_r} & H_{2N_r} & \cdots & H_{N_t N_r} \end{bmatrix} \tag{2}$$

The channel matrix of the mth transmitting and nth receiving antenna in H is represented as H_{mn}, so frequency response of the channel is similar to

$$H_{mn} = diag\left\{ F_L h_{tl}^{mn} \right\} = diag\left\{ h_{mn} \right\} \tag{3}$$

$$m = 1, 2, 3, ..., N_t, \quad n = 1, 2, 3, ..., N_r$$

Where, $diag\{\bullet\}$ represents a diagonal matrix with respect to corresponding vector.

Channel Impulse response of the L^th channel is represented as vector

$h_{tl}^{mn} = \left[h_{tl}^{mn}(0), h_{tl}^{mn}(1), \ldots, h_{tl}^{mn}(L-1)\right]^{T}$ between the m^th transmit antenna and the n^th receive antenna, which is modeled as tapped delay line. Every entry in vector can be modelled as an independent identically distributed (i.i.d.) complex Gaussian random variable with $\eta\left(0, \sigma^{2}_{h_{tl}^{mn}(l)}\right)$. It is assumed that power delay of transmitter and receiver are same. The correlation matrix with the given assumptions is illustrated as $R_H = F_L \mathrm{E}\left\{h_{tl}^{mn} h_{tl}^{mnH}\right\} F_L$.

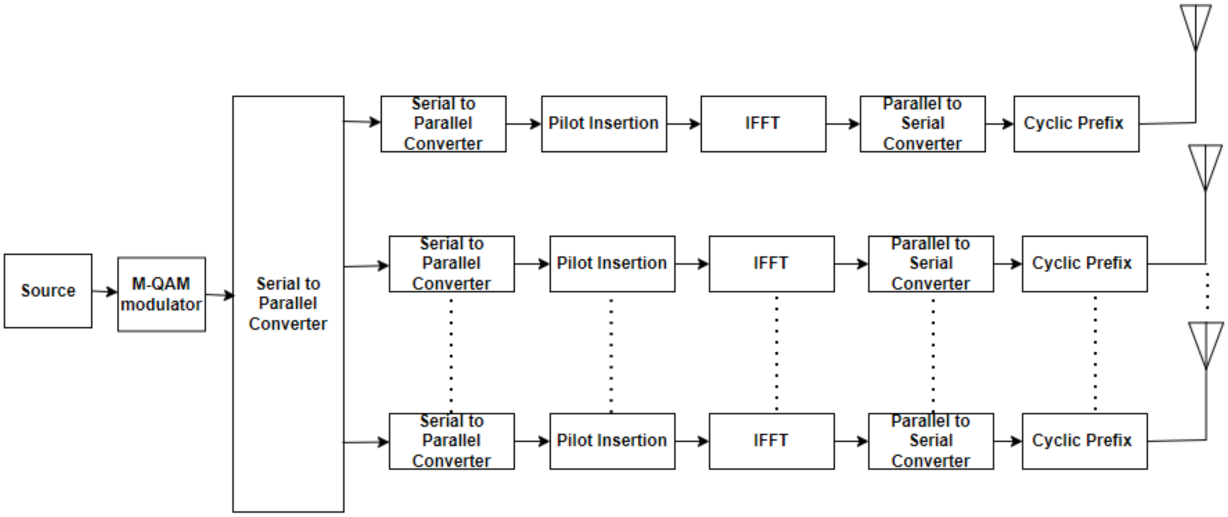

FIGURE 1.MIMO-OFDM Transmitter

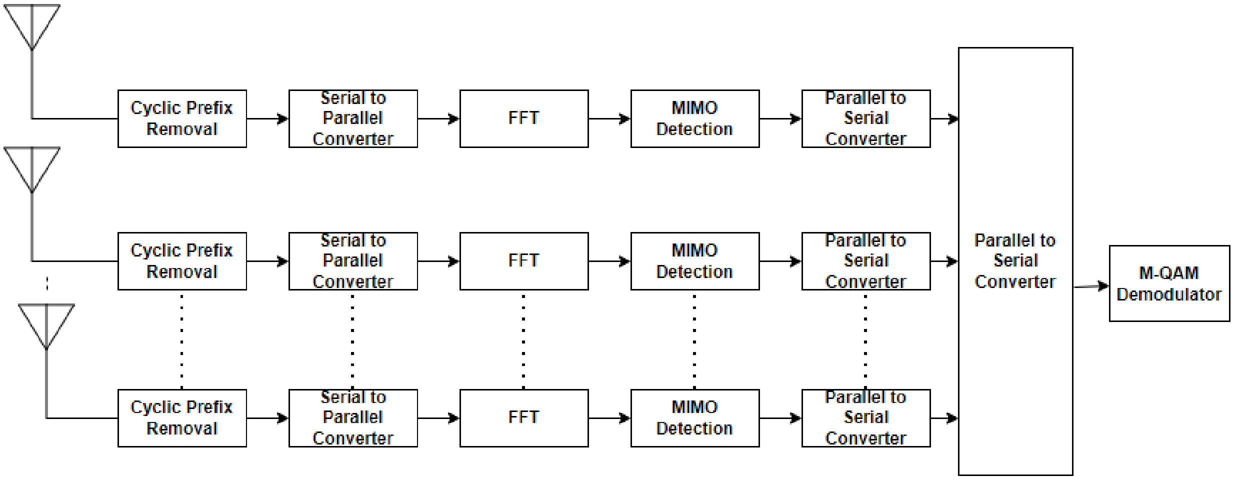

FIGURE 2.MIMO-OFDM Receiver

A. LS Channel Estimation

In this estimation, channel can be estimates by taking the product between received pilot symbols (Yp) with the inverse of known pilot symbols (Sp).Since this method doesn't use any information about statistics of channel, estimator of LS has very less computational complexity. Because of its simplicity, this method has been widely used in channel estimation [11-12].

$$\tilde{H}_{LS} = \frac{y_p}{S_p} = \left(S_p\right)^{-1} . y_p \tag{4}$$

B. MMSE Channel Estimation

In this estimation method, statistical information of the channel is considered to minimize the MSE (Mean Square Error), because of this computational complexity of the estimator increased exponentially with the samples [13]. The channel response is modelled as

$$\tilde{H}_{MMSE} = R_H (R_H + \sigma_\eta^2 (S_p S_p^H)^{-1})^{-1} \tilde{H}_{LS} \tag{5}$$

Where σ_v^2 represents noise variance and represents correlation matrix, defines as $R_H = E\left\{HH^H\right\}$

C. Channel Estimation using DFT

To increase performance of the Channels estimators (LS or MMSE), new form of estimation technique has been derived, known as DFT based Channel Estimation. This estimation technique eliminates the noise effect outside the maximum channel delay (M). After estimating the channel (using LS or MMSE method), it evaluates finite impulse response of channel by taking IFFT.

$$IFFT\left\{\tilde{H}_{LS}\right\} = \tilde{h}[n] \square\ h[n] + \eta[n] \qquad n = 0,1,........N-1 \tag{6}$$

The impulse response samples for maximum channel delay are obtained by excluding the noise samples, which is given by:

$$\hat{h}[n] = \begin{cases} \tilde{h}[n] & n = 0,1,2,3,........M-1 \\ 0 & else \end{cases} \tag{7}$$

The frequency response of channel using DFT channel estimation technique is obtained by converting finite impulse response into frequency domain.

$$\tilde{H}_{DFT} = FFT\left\{\hat{h}[n]\right\} \tag{8}$$

The performance of Channel Estimator with DFT based channel estimation is summarized in algorithm 1

Algorithm1: DFT Based Channel Estimation

Input: Modulated data through noisy channel

Output: Channel estimation at the receiver

1: Estimate the channel $\tilde{H}_{LS} / \tilde{H}_{MMSE}$

2: Obtain $\tilde{h}[n]$ using IFFT

3: Reduce the effect of noise by removing noise samples

$$\hat{h}[n] = \begin{cases} \tilde{h}[n] & n = 0,1,2,3,........M-1 \\ 0 & else \end{cases}$$

4: Obtain $\tilde{H}_{DFT}$ from $\hat{h}[n]$ using DFT

DETECTION TECHNIQUES

In this section we present, some of the linear Detection techniques for pilot allocated MIMO-OFDM system.

A. ZF Detection

Zero Forcing detection technique doesn't use any information about statistics of the noise as compared to MMSE detection and hence the implementation of the detector is simple. Because of its simplicity, this method has been widely used in MIMO detection. Zero Forcing detection filter can be modelled as

$$W_{ZF} = \left(H^H H\right)^{-1} H^H \tag{9}$$

Thus the estimated symbols can be represented as

$$\hat{s}_{ZF} = W_{ZF} y = s + \left(H^H H\right)^{-1} H^H \eta = s + \hat{\eta}_{ZF} \tag{10}$$

From Eq.(9), it is observed that the ZF detector performance is mainly affected by $\hat{v}_{ZF} = \left(H^H H\right)^{-1} H^H \eta$

The noise power after the detection can decomposed as

$$\mathrm{E}\left\{\left\|\hat{\eta}_{ZF}\right\|^2\right\} = \sum_{i=1}^{N_t} \frac{\sigma_\eta^2}{\sigma_{s,m}^2} \tag{11}$$

Where $\sigma_{s,m}^2$ is the received signal power of m^th^ transmit antenna. If $\sigma_{s,m}^2$ small, the effect of noise will be enhanced, which implies that the m^th^ transmit antenna signals shows the null channel.

B. Minimum Mean Square Error Detection

Linear MMSE detection technique is formulated based on MSE, to maximize post-detector signal to noise ratio (SINR). The MMSE filter can be modelled as:

$$W_{MMSE} = \left(H^H H + \sigma_\eta^2 I_{N_r}\right)^{-1} H^H \tag{12}$$

thus, the estimated symbols of linear MMSE detection is written as

$$\begin{aligned} \hat{s}_{MMSE} = W_{MMSE} &= \left(H^H H + \sigma_\eta^2 I_{N_r}\right)^{-1} H^H y \\ &= \tilde{s} + \left(H^H H + \sigma_\eta^2 IN\right)^{-1} H^H v \\ &= \tilde{s} + \tilde{\eta}_{MMSE} \end{aligned} \tag{13}$$

Similar to ZF detection, noise power after the detection can decomposed using SVD as

$$\mathrm{E}\left\{\left\|\tilde{\eta}_{MMSE}\right\|^2\right\} = \sum_{m=1}^{N_t} \frac{\sigma_\eta^2 \sigma_{s,m}^2}{\left(\sigma_\eta^2 + \sigma_{s,m}^2\right)} \tag{14}$$

From Eq.(14), it can observe that the effect of noise is significantly reduced. The mean square error (equation 14) will reach to zero as equivalent signal power $\sigma_{s,i}^2$ is decreased. Hence the effect of noise in MMSE detection is low as compared with ZF detection.

C. Maximum Likelihood Detection

ML detection is an optimum way; it detects the symbols without iterative process coming from multiple antennas. Let C is the set of constellation points; the estimated symbols using ML can be expressed as

$$\hat{s}_{ML} = \arg\min_{s \in C^{N_t}} \left\| Z - Hs \right\|^2 \tag{15}$$

Where, $C^{N}t$ gives all possible combinations of transmit symbols. This approach obtain all possible combinations of transmit symbols, for every symbol it calculate the mean square error. Finally, it selects one combination which has the minimum MSE. Since it evaluates the MSE for every constellation point, its computational complexity will increase exponentially with number of transmit antennas.

RESULTS AND DISCUSSION

For the simulation, first estimated the channel with LS channel estimation technique and detected with various detection techniques like Zero Forcing, MMSE detection and ML detection. Symbol Error Rate performance of three detectors presented in Figure 3. Since ML detector calculate the error for all possible combinations of transmit symbols, the symbol error rate and Mean square errors are very less with cost of computational complexity.

TABLE 1. Presents parameters used for analysing the system proposed for PA in MIMO-OFDM system.

Name	Quantity
Number of Transmitters and Receivers	02
Number of Subcarriers	512
Data Subcarriers	240
Pilot Subcarriers	48
Cyclic Prefix Length	9
Type of channel	Rayleigh fading
Subcarrier Spacing	15 KHz
Modulation	4-QAM

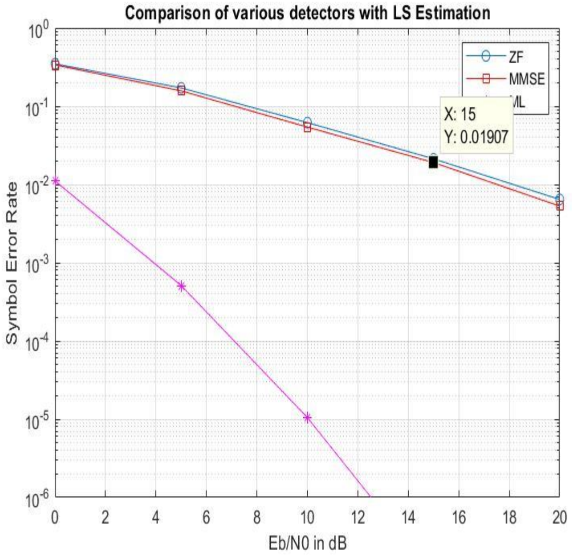

FIGURE 3. Comparison of Various detectors with LS Channel Estimation.

Similarly, the performance of MIMO-OFDM for various detectors with MMSE estimation and DFT Channel estimation are presented in Figure 4 and 5 respectively. Since DFT base estimation method eliminates the noise effect outside the maximum channel delay by ignoring the noise samples, the SER and MSE performance of the MIMO-OFDM system even improved over LS and MMSE estimation techniques. Numerical comparison of various detection approaches with LS, MMSE and DFT channel estimation are given in Table 2.

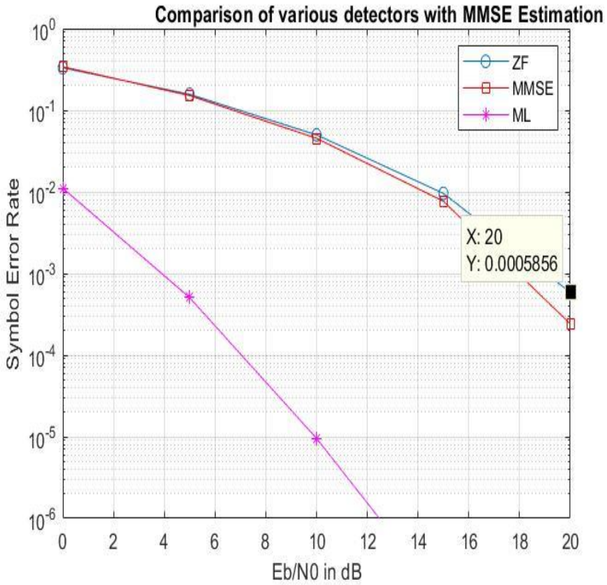

FIGURE4. Comparison of Various detectors with MMSE Channel Estimation

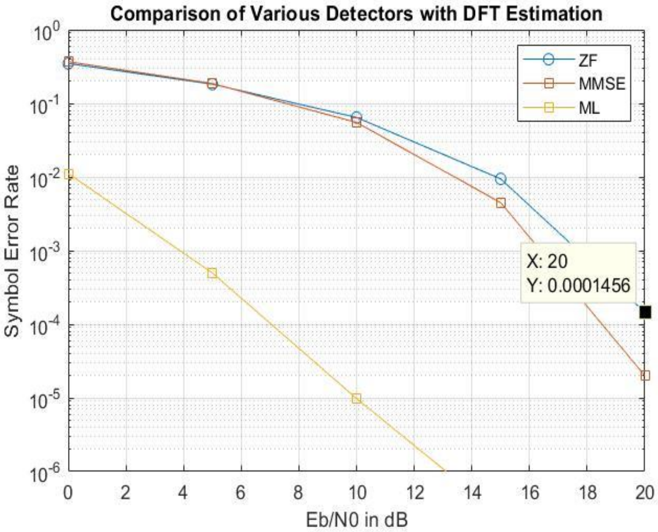

FIGURE 5. Comparison of Various detectors with DFT Channel Estimation.

TABLE 2. Comparison of Various Detection Techniques

Detection Technique	Symbol Error Rate at SNR=15dB		
	LS Channel Estimation	MMSE Channel Estimation	DFT Channel Estimation
ZF Detection	0.02126	0.009586	0.00943
MMSE Detection	0.01907	0.00766	0.004483
ML Detection	0.00000025	0.0000001	0.00000005

Table 2 demonstrates that the Symbol Error Rate of LS channel estimation is 0.02126 with the ZF detection, 0.01907 with MMSE detection and 0.00000025 with ML detection. MMSE channel estimation with ZF detection the Symbol error rate is 0.009586, 0.00766 with MMSE detection and 0.0000001 with ML detection. However, the SER performance of DFT channel estimation is 0.00943, 0.004483 and 0.00000005 with ZF, MMSE and ML detections respectively.

CONCLUSION

In this paper, designing of pilot structure for MIMO-OFDM system and estimation of the channel with various techniques like LS, MMSE and DFT based channel estimators was presented. The Symbol Error Rate performance of the MIMO-OFDM receiver is evaluated for every estimation technique with different detection approaches i.e., Zero Forcing (ZF), MMSE and ML detectors. Based on the simulation analysis, Maximum Likelihood (ML) MIMO-OFDM receiver has the better performance with DFT based channel estimation.

REFERENCES

1. Zhong, Ke, Xia Lei, and Shaoqian Li. "Iterative channel estimation and data detection for MIMO-OFDM systems operating in time-frequency dispersive channels under unknown background noise." EURASIP Journal on Wireless Communications and Networking 2013.1 (2013): 1-14.
2. 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.
3. Prasad, Ranjitha, Chandra R. Murthy, and Bhaskar D. Rao. "Joint channel estimation and data detection in MIMO-OFDM systems: A sparse Bayesian learning approach." IEEE Transactions on signal processing 63.20 (2015): 5369-5382.
4. Jiang, Peiwen, Chao-Kai Wen, Shi Jin, and Geoffrey Ye Li. "Dual CNN-based channel estimation for MIMO-OFDM systems." IEEE Transactions on Communications 69, no. 9 (2021): 5859-5872.
5. Wang, Kun, Hong Shen, Wenhao Wu, and Zhi Ding. "Joint detection and decoding in LDPC-based space-time coded MIMO-OFDM systems via linear programming." IEEE Transactions on Signal Processing 63, no. 13 (2015): 3411-3424.
6. Park, Sunho, Byonghyo Shim, and Jun Won Choi. "Iterative channel estimation using virtual pilot signals for MIMO-OFDM systems." IEEE Transactions on Signal Processing 63, no. 12 (2015): 3032-3045.
7. Pham, Tri, Tho Le-Ngoc, Graeme K. Woodward, and Philippa A. Martin. "Channel estimation and data detection for insufficient cyclic prefix MIMO-OFDM." IEEE Transactions on Vehicular Technology 66, no. 6 (2016): 4756-4768.
8. Li, Li, Rodrigo C. de Lamare, and Alister G. Burr. "Dynamic pilot allocation with channel estimation in closed-loop multi-input–multi-output orthogonal frequency division multiplexing systems." IET Communications 8, no. 11 (2014): 2017-2025.
9. Liao, Yong, Yuanxiao Hua, and Yunlong Cai. "Deep learning based channel estimation algorithm for fast time-varying MIMO-OFDM systems." IEEE Communications Letters 24, no. 3 (2019): 572-576.
10. Ruizhe Yang, Siyang Ye, Pengbo Si, Yinglei Teng, and Yanhua Zhang, “Iterative Channel Estimation and Detection for High-Mobility MIMO-OFDM Systems: Mitigating Error Propagation by Exploiting Error Information”, Wireless Pers Commun (2015) 84:1907–1931.
11. Lin, Jia-Chin. "Least-squares channel estimation for mobile OFDM communication on time-varying frequency-selective fading channels." IEEE Transactions on Vehicular Technology 57, no. 6 (2008): 3538-3550.
12. Alihemmati, R., and M. E. Kalantari. "On channel estimation and equalization in OFDM based broadband fixed wireless MAN networks." In The 7th International Conference on Advanced Communication Technology, 2005, ICACT 2005., vol. 1, pp. 224-229. IEEE, 2005.