Estimation of bit error rate in 2×2 and 4×4 multi-input multi-output-orthogonal frequency division multiplexing systems

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ABSTRACT

Multiple-input, multiple-output orthogonal frequency-division multiplexing (MIMO-OFDM) systems with multiple input antennas and multiple output antennas in dynamic environments face the challenge of channel estimation. To overcome this challenge and to improve the performance and signal-to-noise ratio, in this paper we used the Kalman filter for the correct estimation of the signal in dynamic environments. To obtain the original signal at the receiver end bit error rate factor plays a major role. If the signal to noise ratio is high and the bit error rate is low then signal strength is high, the signal received at the receiver end is almost similar to the i^{th} transmitted signal. The dynamic tracking characteristic of Kalman filter is used to establish a dynamic space-time codeword and a collection of orthogonal pilot sequences to prevent interference among transmissions in this paper. Using the simulation, the Kalman filter method can be compared to the other channel estimation method presented in this paper that can track time-varying channels rapidly.

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1. INTRODUCTION

There is a tremendous demand for wireless systems at the current time, data rate and frequency spectrum resources are expanding, and the spectral efficiency requirements for wireless communication systems are escalating. In multipath channel propagation, multiple-input multiple-output (MIMO) uses several antennas at the receiver and transmitter to boost system capacity and connection reliability [1], [2]. Single-frequency channels may be divided into several flat subchannels in orthogonal frequency division multiplexing (OFDM). This approach provides maximizing bandwidth utilization, simplified design, and providing good intervention and multipath fading resistance. Using MIMO and OFDM together can fully utilize wireless resources in three domains.

The MIMO-OFDM [3], [4] system enhances performance and channel capacity, ensuring that mobile communication is safe and secure. Space-time block coding (STBC) is used in wireless communication to send numerous copies of the data stream through many antennas and to improve data transfer accuracy by identifying different versions of the data received. STBC uses channel code words at the transmitting end to combat channel fading and corresponding decoding at the receiving end to increase diversity. The STBC method is widespread in MIMO-OFDM.

Obtaining an appropriate channel-state-information (CSI) in STBC systems is difficult because of the prevalence of additive white Gaussian noise and traffic between transmitters in the channel. Therefore, channel estimation alone is vital for improving performance [5], [6]. A method for preventing channel fading called STBC comprises generating codes at the transmitter and encoding them somewhere at the receiving end. In today's communication world, all aspects of wireless transmission are moving at a faster rate, with the high carrier frequency transition and channel moving even faster [7], [8]. CSI estimation in a time-varying channel has become a challenging task. Many experts are working hard to determine the best channel with fastness and accuracy.

Channel estimation based on the Kalman filter (KF) can be used to derive the time-varying channel when the frequency shift is moderate to medium. The bit-error rate is evaluated for the 2×2 and 4×4 OFDM systems in this study. A redesigned orthogonal spatial codeword is used in the 4×4 OFDM system to give increased spectrum efficiency and carrier weakening tolerance, and the pilot sequences are generated to be non-interfering with each other. The predictive and updated characteristics of KF are studied using just a MIMO-OFDM system state-space model.

This paper uses different types of phase-shift keying (M-PSK) modulation to test the performance and to observe the bit error rate (BER) improvement concerning signal to noise ratio (SNR) in the 2×2 and 4×4 MIMO-OFDM systems. The above method in this paper monitors the dynamic channel very well and had improved BER and normalized mean square error (NMSE) outcomes than that of the linear regression error method, according to simulation findings. However, in comparison to 2×2 OFDM, 4×4 OFDM is more capable of avoiding channel fading and has higher diversity gains. Among 4-PSK, 8-PSK, and 16-PSK usage of 16-PSK is preferred. 16-PSK provides more errors, but we can transmit 4 bits at a time, because of this we can save channel bandwidth, and data rate increases. Even though the structure of 4×4 antennas is complex it gives high data rates and high data capacity.

Mishra and Larsson [1] investigated the effectiveness of implementing a MIMO reader to extend the range of communication ranges of monostatic backscatter communication (BSC) systems. As proposed in [2], they adopted the cyclic prefix, which can be used for synchronization purposes, as a repetitive signal structure for OFDM. In study [3], it is shown that using MIMO and OFDM together can fully utilize wireless resources in three domains. STBC is used in wireless communication to send numerous copies of the data stream through so many antennas and to enhance information transmission accuracy by detecting different versions of the data received [4].

There is an interpolation filter introduced in study [5] that can be used to estimate downlink channels in high-mobility situations i.e., KF. A decision-feedback mechanism is implemented to linearize the model of the system using extended KF to compute the channel frequency response (CFR) at the symbol. On the other hand, the decision feedback mechanism may generate information loss, lowering the system's BER. To create a more precise weighting matrix, the extended Kalman filter (EKF) utilizes the Turbo decoder, which reduces errors propagating through the channel [6]. With the turbo decoder, on the other hand, the system becomes even more complex. With the EKF channel estimate according to a basis expansion model (BEM), Dai *et al.* [7] proposed a basis expansion model (BEM), as well as a superimposed pilot. The channel's response to the system (CIR) and discrete-time coefficients are predicted by using EKF to follow the channel's changes.

The simulation advantages of this technique have erroneous limits when the noise ratio is sufficient. The EKF is used to calculate the temporal correlation coefficients and CIR [8] as they change over time. Rauch-Tung-Striebelsmoother (RTSS) could be used to smooth out EKF calculations, improving channel estimation accuracy. The EKF measurement matrix, on the other hand, is obtained through a decision feedback method, which results in error propagation. Researchers from [9]–[11] propose an unscented Kalman filter (UFK), which uses the stinky transformation (UT) to achieve more accuracy and stability than EKF. UKF's application in real-world situations is limited, however, due to its complexity. According to [6]–[12], first-order autoregressive (AR1) models are used to model the time-varying channel. A model for estimation of KF using autoregressive second-order (AR2) has been presented in [13]–[15]. The least exponential variance criterion is being used to solve the optimization problems of the AR2 model in the following theoretical approach.

It increases computational complexity, however, and performance is limited when building second-order autoregressive 1, 2 models. An enhanced EKF-based channel prediction model that can evaluate carrier frequency deviation and carrier signal return was presented in [16], [17]. It enhances the accuracy of EKF measurements by using various consecutive pilot symbols. Most of the references [18]–[26]used least square (LS) and normalization mean square error to evaluate the channels.

Below is an outline of the remaining parts of the paper. Section 2 discussed the literature survey for this paper. Section 3 discussed the proposed method of the paper. Section 4 explained the experimental section, results, and conclusion in section 5.

2. PROPOSED METHOD
2.1. MIMO

A system with single input and output (SISO), in which one transmission antenna transfers data to a particular reception antenna, is featured in most wireless communication systems. To enhance the receiver's efficiency, additional sending and receiving antennas can be added [24]. The above situation is bound to affect in the future as communication networks with multiple input and output become more prominent. MIMO techniques are commonly divided into three categories. The very first category comprises developing spatial variety in an attempt to improve performance and efficiency. Some other category employs a multilayer technique to increase the capacity [24]. Hence, by analyzing the transmission channel's characteristics MIMO wireless systems [21], [22], which utilize the same bandwidth spectrum as a SISO system and boost capacity utilization by spatial modulation, frequently include multiple transmitters and receiver antennas. Unlike classic SISO systems, using unpredictable decaying and crosstalk latency spread, the MIMO system uses mm wave to almost double the flow of data. Furthermore, MIMO enables spatial variety at both the transmitter and receiver, resulting in higher error rate transmission quality [24]. Spatial multiplexing is a technique for improving the capacity of a MIMO system by transmitting multiple independent streams of data near one another.

Future standards [24] should establish maximum throughput including the mode of transmission that accomplishes the data rate required for the lowest level of quality. Spatial multiplexing has been utilized to enhance the capacity of a MIMO link by transmitting independent data streams in the same time slot and frequency range concurrently from each transmit antenna and multiple streams of data at the receiver which uses channel information for each transmission path.

Figure 1 represents the basic architecture of a M×N MIMO communication model [24]. The channel is a N×M matrix with MN sub-channels, as can be shown. The MIMO system can also be considered as a collection of many transmit beamformers, each of which transmits to one of the m Rx antennas. As per the authors, the MIMO system is a great way to maximize channel and network performance.

The multiple antenna receiver splits and demodulates the stream of data using sophisticated spatial coding and selects the most appropriate processing method [24]. Since N sub-streams are transmitted to the channel around the same time and every delivered information comprises the same frequency band, the frequency band is not enhanced. MIMO system can generate many parallel space channels if the channels are independent. The transmission of data will be improved by using these channels to broadcast information at the same time.

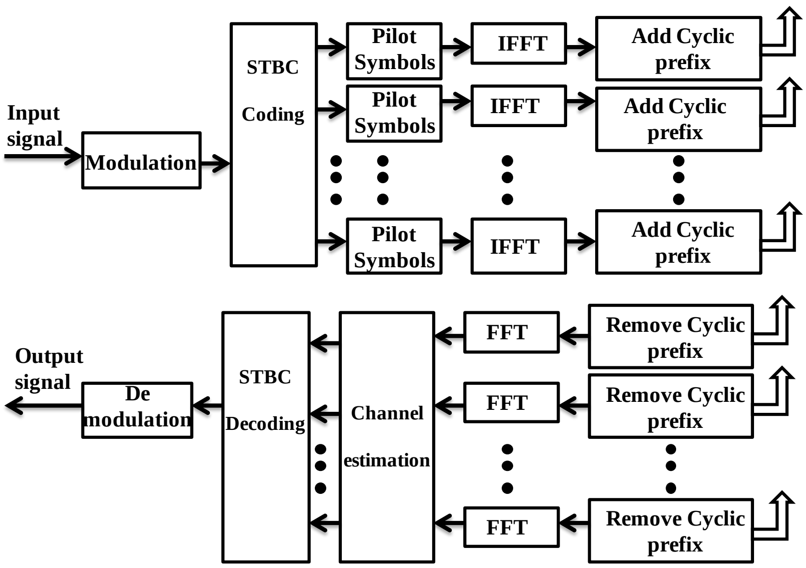

Figure 1. STBC MIMO-OFDM system model

2.1.1. MIMO channel capacity

The bandwidth in the case of MIMO will be estimated by (1),

$$C = log_2[det(I_N + \rho hh^H)] \quad (1)$$

where I_N is the matrix of identity, the vector h represents the carrier signal between both the individual transmitter antenna and the receiver external array, and h^H is the transpose of h, the $N \times M$ channel matrix is denoted by H [20].

2.2. Orthogonal frequency division multiplexing

Orthogonal frequency-division multiplexing (OFDM) [25] is an extremely versatile and effective modulation mechanism that is utilized in the development of all major wireless and wired standards today. In 4G technology, OFDM is a multicarrier and parallel transmission system which is a variant of the multicarrier modulation system frequency-division multiplexing (FDM) [25]. With its high-speed data transmission capability, high information measuring capacity, and resistance to multipath attenuation and latency, OFDM is broadly utilized in wireless communications systems.

The main schematic diagram of an OFDM transmitter to the receiver can be in Figure 1. It is a modulation and multiplexing technique. Multiplexing, in general, refers to the transmission of independent signals generated by various sources [24]. Multiplexing is a mechanism that is capable of integrating several communication signals for one of them to transmit an otherwise single signal communication method sequentially, that is used to differentiate signals in the system. The signal is divided into distinct channels in OFDM, modulated with data, and then re-multiplexed to generate the OFDM carrier [24]. To manage multimedia services, orthogonal frequency division multiplexing can support large data rates in mobile wireless networks. To estimate the channel study of the OFDM technology is necessary by improving system performance [24]. OFDM technology may be utilized efficiently in mobile networks to mitigate the disadvantages of frequency-selective fading and narrowband interference from parallel, closely spaced frequencies. If there is no orthogonality between two overlapping channels, internal channel interference would occur between the signals. Due to these important advantages, OFDM technology has been widely utilized by several wireless protocols, especially wireless local area network (WLAN), wireless metropolitan area network (WMAN), and digital video broadcasting (DVB). Complex filters are used in the modulation scheme [24].

2.2.1. Orthogonality's importance

The core aspect of the orthogonal system is the orthogonality of the subcarriers [26]. The "orthogonal" aspect of the OFDM title emphasizes a mathematical association between the system's carriers' frequencies. It is possible to rearrange the carriers in an OFDM signal when only similar sidebands of the individual carriers overlap. The information, on the other hand, can be received without disturbance from the other transmitters. The transmitters must be theoretically orthogonal to effectively carry out this operation. If the carrier's separation is a multiple of 1/Ts, the carriers are linearly independent [24]. Ts represents the symbol duration. If the OFDM signal is defined using Fourier transform algorithms, the component's orthogonality can be retained. The OFDM transmitter transmits out a large number of tightly packed bandpass carriers. It is important to remember that there is no crosstalk from other subchannels at the central frequency of each subchannel.

2.2.2. Fading

The capacity of OFDM to deal with a multi-path disturbance at the recipient is one of the reasons for the growth. This phenomenon is called multipath [27], [28]. It provides two effects: i) frequency selective fading and ii) intersymbol interference (ISI). Frequency-selective fading can be overcome mostly by observed "uniformity" of a narrow-band channel [29], [30]. On the other hand, the symbols modulation at a very low rate enables the symbols to be significantly longer than the channel response, minimizing the interference.

2.3. Orthogonal pilot symbols

Pilot symbols are reference symbols that are used to compare the transmitted symbols with them to estimate the errors. Pilot sequences are ideal sequences [31], [32]. In the orthogonal pilot symbols, the pilot symbols of the antenna do not influence the pilot symbols of another antenna in the network system in Figure 1. The transmission of pilot symbols at four antennas could be formulated as (2).

$$H_p = \begin{pmatrix} H_p & 0 & 0 & 0 \\ 0 & H_p^* & 0 & 0 \\ 0 & 0 & -H_p^* & 0 \\ 0 & 0 & 0 & -H_p^* \end{pmatrix} \tag{2}$$

Every column shows the pilot codes that are sent out by every antenna. *t* is the time when the first antenna transmits pilot symbols H_p and the remaining values in that column are zero. The second columns represent the transmitted pilot symbols at time *t+1*. By flowing through the multipath channel, the OFDM without additive white Gaussian noise can be formulated as (3).

$$\begin{pmatrix} H_p & 0 & 0 & 0 \\ 0 & H_p^* & 0 & 0 \\ 0 & 0 & -H_p^* & 0 \\ 0 & 0 & 0 & -H_p^* \end{pmatrix} \begin{pmatrix} \mathrm{X1,1} \\ \mathrm{X2,1} \\ \mathrm{X3,1} \\ \mathrm{X4,1} \end{pmatrix} = \begin{pmatrix} \mathrm{Y1(1)} \\ \mathrm{Y1(2)} \\ \mathrm{Y1(3)} \\ \mathrm{Y1(4)} \end{pmatrix} \tag{3}$$

The anticipated CFR will be given in terms using the LS network prediction model as (4).

$$\begin{pmatrix} \mathrm{X1,1} \\ \mathrm{X2,1} \\ \mathrm{X3,1} \\ \mathrm{X4,1} \end{pmatrix} = \begin{pmatrix} H_p & 0 & 0 & 0 \\ 0 & H_p^* & 0 & 0 \\ 0 & 0 & -H_p^* & 0 \\ 0 & 0 & 0 & -H_p^* \end{pmatrix}^{-1} \begin{pmatrix} \mathrm{Y1(1)} \\ \mathrm{Y1(2)} \\ \mathrm{Y1(3)} \\ \mathrm{Y1(4)} \end{pmatrix} \tag{4}$$

By using the above designed orthogonal pilot symbols, we can remove interference from the antennas.

2.4. Kalman filter

The KF is used to reduce noise and to upgrade the quality of the signal that is transmitted. MIMO systems are used in 4G technology. Multiple data streams are delivered through multiple antennas in MIMO systems, causing interference between the symbols and increasing the BER. The KF is operated to analyze and upgrade the errors. It is a quick procedure that is similar to other channel estimation methods like least squares and minimum mean squares. The averaging method is used in the LS and minimum mean square error (MMSE) procedures, but the KF is an iterative process that distinguishes it from all other channel estimating techniques [33]–[36].

The KF is analogous to a hidden Markov model having Gaussian distributions for state variables. The multiplication of one Gaussian distribution with another Gaussian distribution generates another Gaussian distribution. The KF argument predicts that the system's state at time t progressed from its former state at time *t-1*. The system state can be formulated as (5):

$$Z_t = A_t Z_{t-1} + B_t S_t + \mathrm{Q}_t \tag{5}$$

where Z_t is a state vector at time *t* containing information about states. A_t is transition matrix of the state which put on each system state at time *t-1* has an influence on the state of the system at time *t*. S_t stands for exterior control systems. B_t is the external control matrix. Q_t is a covariance matrix. The system's measurement can be done in a variety of ways as (6):

$$\mathrm{X}_t = \mathrm{D}_t \mathrm{Z}_t + \mathrm{R}_t \tag{6}$$

where X_t is the measurement vector D_t is the transformation matrix of measurements. R_t is the vector containing the AGWN for every observation in the measurement matrix and its covariance is V_t. In the case of a well-designed, single-dimensional linear system with an estimation of errors drawn from a zero-mean Gaussian distribution, the KF will be contemplated as a perfect estimator.

The KF algorithm consists of two steps: prediction and measurement update. The equations for the KF projection part can be constructed as (7) and (8):

$$\hat{\mathrm{Z}}_{t|t-1} = A_t \hat{\mathrm{Z}}_{t-1|t-1} + B_t S_t \tag{7}$$

$$P_{t|t-1} = A_t \hat{\mathrm{Z}}_{t-1|t-1} + Q_t \tag{8}$$

where $\mathrm{Z}_{t|t-1}$ is the state information of the predicted system at time t; $\mathrm{P}_{t|t-1}$ is the predicted error matrix correlate to $\mathrm{Z}_{t|t-1}$. The measurement revised expressions for KF can be evolved as (9)-(11):

$$K_t = P_{t|t-1}\ {D_t}^T \left(D_t P_{t|t-1} {D_t}^T + V_t\right)^{-1} \tag{9}$$

$$\hat{Z}_{t|t} = \hat{Z}_{t-1|t-1}K_t\left(X_t - D_t\hat{Z}_{t|t-1}\right) \tag{10}$$

$$P_{t|t} = P_{t|t-1} - K_t D_t P_{tt|t-1} \tag{11}$$

where K_t is Kalman gain, $X_{t|t}$ is state information of updated system, and $P_{t|t}$ is updated error matrix. KF creates a statement framework and a statistical model for a linear system for the estimation of system state information. Using projection and data enrichment, the estimated uncertainty of the system state is decreased. As a result, KF is given more importance for better-estimated performance.

Algorithm 1. KF estimation

```
Input: tn: number of transmitting antennas; rn: number of receiver antennas;
m: symbol number of OFDM; NS: total OFDM symbols
Output: Required channel for Kalam filter
Initialization:
T0, X̂0=1, P0=1
for tn=0 to NT do
    for rn=1 to NR do
        for m=1 to NS do
           Estimation of the forecast CFR X̂m|m-1 with (7)
           Estimation of projected error Pm|m-1 with (8)
           Estimation of the Kalman gains Km with (9)
           Upgrade CFRX̂m with (10)
           Precise the error Pm with (11)
           if X̂m ≥ Tσn2 then
              X̂m keep
           else
              X̂j=0
           end
        end
    end
end
```

3. RESULTS AND DISCUSSION

3.1. Comparison of channel estimation in the least square method and minimum mean square method using mean square errors

From Figure 2, MMSE channel estimation implementation will be better when analyzed with the least mean square error (LSE) method. LSE uses the interpolation concept where values are estimated between adjacent samples' positions. In MMSE the errors are reduced by calculating the mean square error (MSE) of the reference and observed data.

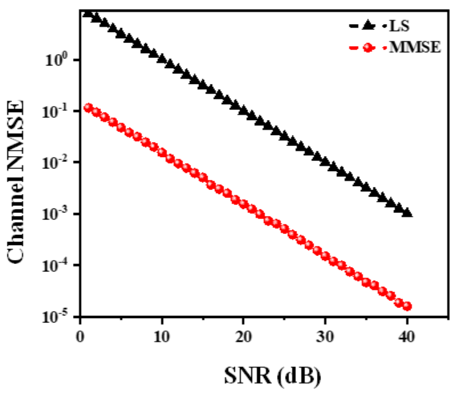

Figure 2. Comparison of channel estimation in MMSE and LS using MSE

From Table 1, it is observed that the normalized mean square error of the least square method has more errors compared to minimum mean square error method. When the signal-to-noise ratio increases the occurrence of errors decreases and at the receiver, we receive better quality of the signal. In Figure 3, the BER performance for 4×4 antennas are better.

Table 1. Comparison of channel estimation in the least square method and minimum mean square method using MSE

SNR	NMSE of LSE	NMSE of MMSE
0	9.9	0.14
10	1.0	0.016
20	0.1	0.0015
30	0.01	0
40	0	0

When the number of antennas at the transmitter and receiver sides increases, the less number of data bits get corrupted. Hence the BER is less for 4×4 antennas than for 2×2 antennas. In Figures 3(a) to 3(c) 4-PSK, 8-PSK, and 16-PSK is used. When the number of bits transmitted per sec in PSK modulation increases the BER values are increased. When the number of bits transmitted per sec increases interfaces increase. So, BER value increases.

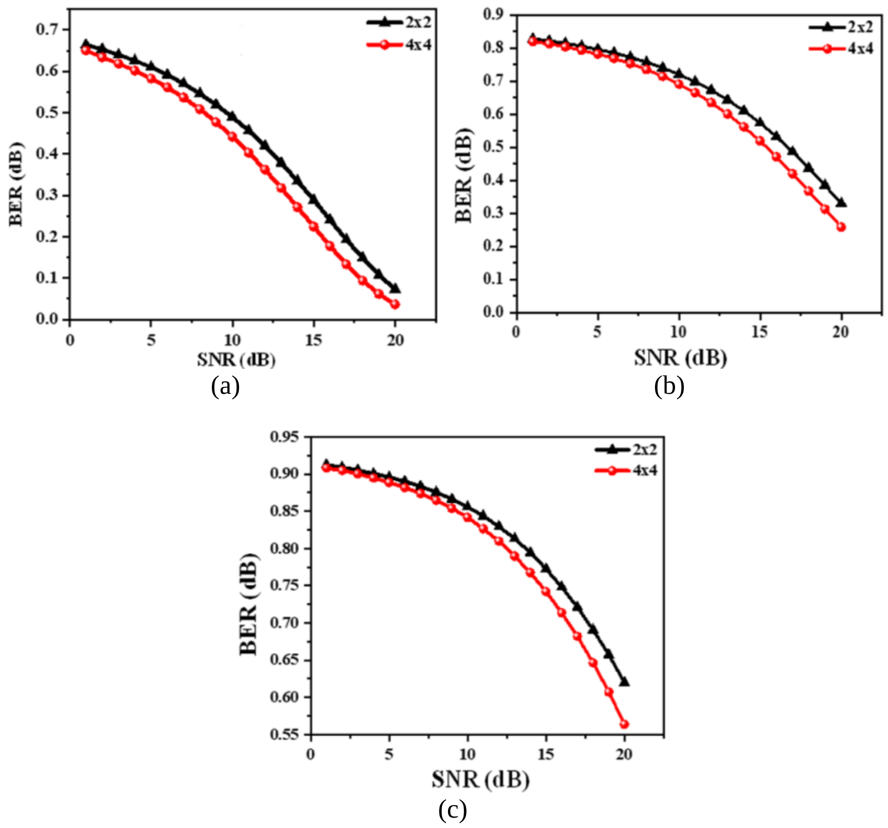

Figure 3. Comparisons of BER performance in 2×2 and 4×4 STBC MIMO-OFDM systems without Kalman filter (a) 4-PSK, (b) 8-PSK, and (c) 16-PSK

3.2. Comparisons of BER performance in 2×2 and 4×4 STBC MIMO-OFDM systems without KF

Even though 4×4 MIMO antenna installation is complex but their high data rates, low latency, and high data capacity provide better performance. 16-PSK provides more errors but we can transmit 4 bits at a time, because of this we can save channel bandwidth, and data rate increases. Therefore, we prefer 4×4 MIMO-OFDM with 16-PSK for better throughput.

In Tables 2 and 3, it is seen that 4×4 antennas have fewer errors when compared to 2×2 antennas. When the number of antennas at both transmitter and receiver sides increases, the same data stream bits are transmitted multiple times because of this reason 4×4 antennas are preferable. A comparison of BER in 4-PSK, 8-PSK, and 16-PSK modulation techniques is done in Tables 2 and 3. In 2×2 and 4×4 MIMO-OFDM systems 16-PSK modulation has more errors when compared to 4-PSK and 8-PSK modulation techniques, but 16-PSK is preferable because it transmits 4-bits at a time which improves data rate and data capacity and saves channel bandwidth.

Table 2. Comparisons of BER performance in 2×2 STBC MIMO-OFDM systems without KF in dBs

SNR	BER (4-PSK)	BER (8-PSK)	BER (16-PSK)
4	0.62	0.8	0.9
8	0.54	0.75	0.87
12	0.41	0.67	0.82
16	0.24	0.53	0.74
20	0.071	0.3	0.61

Table 3. Comparisons of BER performance in 4×4 STBC MIMO-OFDM systems without KF in dBs

SNR	BER (4-PSK)	BER (8-PSK)	BER (16-PSK)
4	0.6	0.79	0.89
8	0.51	0.73	0.86
12	0.3	0.63	0.80
16	0.17	0.47	0.71
20	0.03	0.25	0.5

3.3. Comparisons of BER performance in 2×2 and 4×4 STBC MIMO-OFDM systems with KF

From Figure 4, KF is an iterative process. KF predicts and estimates errors. Other techniques like averaging methods. KF reduces errors fast when compared with other techniques. Because of this we are getting low latency. From Figures 4(a) to 4(c), BER implementation for 4×4 antennas are preferable. When the number of antennas at the transmitter and receiver side increases, the number of data bits gets corrupted. Hence the BER is less for 4×4 antennas than for 2×2 antennas. In Figures 4(a) to 4(c), 4-PSK, 8-PSK, and 16-PSK are used. When the number of bits transmitted per sec in PSK modulation increases the BER values are increased. When number bits transmitted per sec increases interface increases. So, BER value increases. Even though 4x4 MIMO antenna installation is complex but their high data rates, low latency, and high data capacity provide better performance. 16-PSK provides more errors but we can transmit 4 bits at a time, because of this we can save channel bandwidth, and data rate increases. Therefore, we prefer 4×4 MIMO-OFDM with 16-PSK for better throughput.

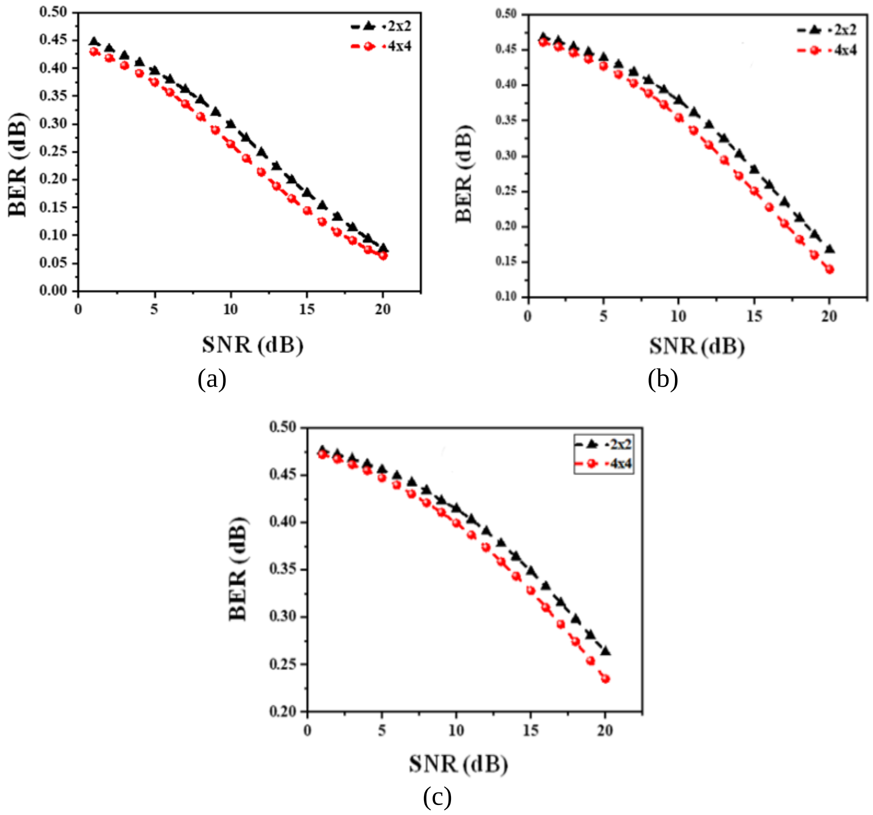

Figure 4. Comparisons of BER performance in 2×2 and 4×4 STBC MIMO-OFDM systems with KF (a) 4-PSK, (b) 8-PSK, and (c) 16-PSK

In Tables 4 and 5, it is seen that 4×4 antennas have fewer errors when compared to 2×2 antennas. When the number of antennas at both transmitter and receiver sides increases, the same data stream bits are transmitted multiple times because of this reason 4×4 antennas are preferable. A comparison of BER in 4-PSK, 8-PSK, and 16-PSK modulation techniques is done in Tables 2 and 3. In 2×2 and 4×4 MIMO-OFDM systems 16-PSK modulation has more errors when compared to 4-PSK and 8-PSK modulation techniques.

But 16-PSK is preferable because it transmits 4 bits at a time which improves data rate and data capacity and saves channel bandwidth.

KF is an iterative process. It predicts and estimates errors. It resembles the hidden Markov model because of its current and previous state matrixes. It has two stages prediction and estimation. KF estimates the current state from the previous state. KF is a faster process when compared with other techniques because of its iterative nature. It provides fewer errors because of its dynamic channel tracking property.

Table 4. Comparisons of BER performance in 2×2 STBC MIMO-OFDM systems with KF

SNR	BER (4-PSK)	BER (8-PSK)	BER (16-PSK)
4	0.41	0.44	0.46
8	0.34	0.40	0.43
12	0.24	0.34	0.39
16	0.15	0.25	0.33
20	0.07	0.16	0.26

Table 5. Comparisons of BER performance in 4×4 STBC MIMO-OFDM systems with KF

SNR	BER (4-PSK)	BER (8-PSK)	BER (16-PSK)
4	0.39	0.43	0.4
8	0.31	0.38	0.42
12	0.21	0.31	0.37
16	0.12	0.22	0.30
20	0.05	0.13	0.23

3.4. Comparison of SNR, BER in 2×2 and 4×4 in both cases with and without filter

From Tables 6 and 7, in conventional MIMO-OFDM, BER Performance is worst compared to MIMO-OFDM with KF. In MIMO-OFDM multiple antennas are used at both transmitters and receivers and several data streams are transmitted at once. This causes interference among adjacent data symbols, and errors occur. KF is an iterative process. It uses dynamic channel estimation and tracking property to update and estimate the errors.

Table 6. For 2×2 MIMO antennas with 4-PSK modulation

SNR	BER (MIMO-OFDM STBC without KF)	BER (MIMO-OFDM STBC with KF)
4	0.62	0.41
8	0.54	0.34
12	0.41	0.24
16	0.24	0.15
20	0.071	0.06

Table 7. For 4×4 MIMO antennas with 4-PSK modulation

SNR	BER (MIMO-OFDM STBC without KF)	BER (MIMO-OFDM STBC with KF)
4	0.6	0.39
8	0.51	0.31
12	0.3	0.21
16	0.17	0.12
20	0.03	0.01

3.5. Comparison of SNR, BER in 2×2 and 4×4 in both cases with and without filter, LSE, MMSE

Figure 5 analyzes the effect of MSE with respect to SNR in 2×2 and 4×4 with and without the filter. In view of MSE, the ideal case (MIMO-OFDM) without a filter offers very high MSE even for a small change in SNR changes. The MSE is more against the least-squares method against differential change in the signal-to-noise ratio frequency. Accordingly, the least-squares complex exponential (LSCE) is the least preferable for MIMO applications. Similarly, 2×2 KF CE offers less MSE in comparison with the LSCE. However, the changes in the frequency of SNR are improvable in comparison with 4×4 MIMO-OFDM structure. As a result, the different resultant values of MSE and SNR show the effectiveness of the proposed 4×4 MIMO-OFDM with STBC using the KF approach applied to STBC using the KF.

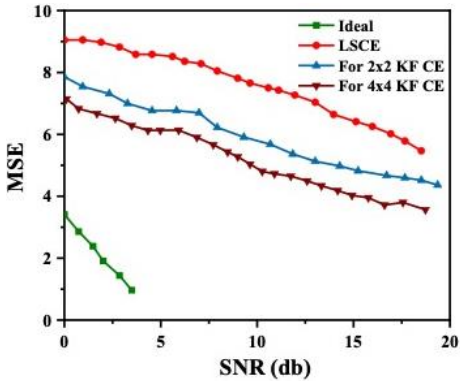

Figure 5. Signal noise ratio for NMSE

4. CONCLUSION

In this paper, the Kalman channel estimation method is applied to 2×2, 4×4 MIMO-OFDM antennas. KF is an iterative process that reduces the errors which occur due to interference. When the number of bits transmitted per second increases in the PSK modulation technique, then errors also increase. Even though errors are increased, the more bit PSK modulation is preferable because, when the number of bits transmitted per second increases, the data rate also increases, and channel bandwidth is reduced. KF dynamic tracking property makes it unique from others in predicting and estimating errors. The 4×4 MIMO–OFDM system has better performance when correlated to 2×2 MIMO-OFDM systems. When the number of transmitting and receiving antennas increases, multiple data streams are transmitted at once. So, the implementation of a 4×4 MIMO-OFDM system with STBC using the KF is preferable. STBC provides high diversity gains.

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