Channel Prediction for Limited Feedback Precoded MIMO-OFDM Systems

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Abstract—In this paper, the performance of limited feedback precoded spatial multiplexing multiple-input multiple-output orthogonal frequency division multiplexing (MIMO – OFDM) systems is investigated in time varying fading channels. Most studies into limited feedback precoded (MIMO – OFDM) systems are based on the notion of time invariant channels throughout transmission. Therefore, the precoding matrix for each subcarrier can be designed at the receiver in terms of the current channel state, fed back to the transmitter, and used for the subsequent block of data symbols. However, in time varying channels, the feedback information becomes outdated, which results in significant system performance degradation. To mitigate this system performance degradation caused by outdated information due to a delay in the feedback channel, this paper considers a more practical system, where the channel varies from one block of symbols to another. A method is proposed based on modelling the channel as an autoregressive (AR) model and using a Kalman filter linear predictor at the receiver to predict the channels states, required to design the precoding matrices for the next OFDM symbol carriers whose indexes are fed back to the transmitter. The performance of this method is investigated using computer simulation, and the results obtained for the proposed channel prediction demonstrate improved bit error rate performance for time-varying Rayleigh fading channels, even in systems with high mobility.

Keywords—Channel prediction, Limited feedback, Kalman filter, MIMO, OFDM, Precoding matrix.

I. INTRODUCTION

The greatest challenge facing future wireless communication systems is to provide high data rate and high quality of service QoS. To meet these requirements more bandwidth needs to be allocated, which is not always possible due to spectral limitation. Spatial multiplexing multiple-input multiple-output (MIMO) wireless systems offer high spectral efficiency by de-multiplexing the input data stream into multiple substreams that are transmitted on different antennas in the same frequency band. Orthogonal frequency division multiplexing (OFDM) is an efficient modulation technique able to transform the broadband frequency selective channels into a set of parallel frequency flat channels. Furthermore, the intersymbol interference (ISI) can be completely eliminated by adding a cyclic prefix (CP) with a length greater than the channel delay spread [1]. The combination of the multiple-input multiple-output (MIMO) and the orthogonal frequency division multiplexing (OFDM), known as multiple-input multiple-output orthogonal frequency division multiplexing (MIMO – OFDM), is considered to be a solution to the challenges facing future broadband wireless communication. MIMO – OFDM provides high spectral efficiency and high data rate transmission over frequency selective channels [1]. Precoded spatial Multiplexing MIMO systems are proven to provide better system performance and increased capacity with simplified receivers. However, precoding requires channel state information (CSI) at the transmitter (CSIT) [2]. In frequency division duplex systems (FDD), channel state information (CSI) at the transmitter can only be made available through feedback from the receiver. However, the feedback information grows as the number of transmit and receive antennas increase, which results in huge overhead. Hence, the limited feedback issue becomes of more interest.

The studies in [3], [4], [5], and [6] focus on designing precoding techniques for MIMO systems that use only limited feedback. The precoding techniques proposed in these studies for narrowband MIMO channels can be extended to MIMO – OFDM by treating the OFDM subcarriers as a set of parallel narrowband MIMO channels [7]. However, applying the narrowband precoding techniques directly to MIMO – OFDM systems will result in increased data rate in the feedback channel, and the system will become prohibitively costly as the number of subcarriers increase. This has motivated further research to investigate low-rate feedback schemes for MIMO – OFDM systems. Vector quantization and smart interpolation has been proposed, for example in [7], [8], [9], where the receiver sends back only the precoder matrices of a subset of the subcarriers. At the transmitter, the precoders for all other subcarriers are computed using smart interpolation. A much simpler limited feedback technique based on clustering was proposed in [10] and [11], where the subcarriers are divided into clusters and one precoder matrix is used for each cluster. A reduced feedback algorithm based on the fact that highly correlated channels have highly correlated feedback values is proposed in [12]. However, all these works assume a quasi static channel. Thus, the precoding matrix for each subcarrier can be designed at the receiver, fed back to the transmitter, and used for the subsequent block of data symbols. However, in time varying channels the feedback information becomes outdated, which results in system performance degradation. Hence, channel prediction becomes essential to alleviate this problem. A channel prediction scheme based on a Kalman filter for MIMO – OFDM systems operating in TDD...
mode is proposed in [13]. In this work we propose a channel prediction scheme for MIMO – OFDM systems operating in FDD mode. The proposed scheme is based on modelling the channel as an autoregressive (AR) model and using a Kalman filter predictor to predict the channel state information for the next block of symbols. It is composed of the following steps: firstly, channel estimation at the receiver based on comb-type pilot distribution to estimate the channels at the pilot subcarriers; secondly, channel prediction based on a Kalman filter to predict the future channels at the pilot subcarriers; finally, interpolation is used to obtain the estimated and predicted channels at the data subcarriers. Simulations show that the proposed scheme improves the system bit error rate (BER) performance at the same system complexity.

The rest of this paper is organized as follows: In section II we describe the proposed system model. In section III the proposed channel prediction approach for precoded MIMO – OFDM is introduced. Simulation results are presented in section IV to illustrate the effectiveness of the proposed scheme. Finally, concluding remarks are provided in section V.

II. SYSTEM MODEL

A. Transmitter

A block diagram of the precoded spatial multiplexing MIMO – OFDM system with \( N_t \) transmit, and \( N_r \) receive antennas is depicted in Fig. 1. Let \( N_d \) be the number of data subcarriers, and \( M \) be the number of data streams transmitted by each subcarrier, where \( M \) is assumed to be \( \leq \min(N_t, N_r) \). The input data symbols are divided into \( N_d \) groups of \( M \) symbol streams. Let the vector \( s_{k}[n] = [s_{k,1}^{1}[n], s_{k,2}^{1}[n],..., s_{k,M}^{1}[n]]^{T} \) denote the \( M \times 1 \) transmitted symbols vector on subcarrier \( k \), where \( T \) denotes transpose operation, and \( n \) is the time index. The symbol vector \( s_{k}[n] \) is multiplied by \( N_t \times M \) precoding matrix \( F_{k}[n] \) generating

\[
D_{k} = F_{k}[n] \cdot s_{k}[n]
\]

(1)

where \( D_{k} \) is the precoded data vector of length \( N_t \times 1 \), and \( F_{k}[n] \in \mathcal{U}(N_t, M) \) the set of \( N_t \times M \) complex unitary matrices. \( F_{k}[n] \) is selected at the receiver from a finite set of possible precoding matrices \( \mathcal{F} = \{F_{1}, F_{2},..., F_{I_{F}}\} \), represented by a limited number of bits and conveyed to the transmitter through a limited feedback channel.

Let \( d_{k}^{j} \) be the \( j^{th} \) element of the precoded data vector \( D_{k} \), where \( j = 1,2,\ldots,N_t \). The precoded data is then rearranged to form the data blocks \( D^{j} = [d_{1}^{j}, d_{2}^{j},\ldots,d_{N_{d}}^{j}]^{T} \). \( N_{p} \) pilot symbols are uniformly inserted with \( K \) subcarriers apart from each other in \( D^{j} \) giving a block \( X^{j} \) of dimension \( N \times 1 \), where \( K = N/N_{p} \) is the interval of pilot symbols. Each block is then converted into a time domain signal \( x^{j} \) using inverse fast Fourier transform (IFFT) of length \( N \). Finally, a cyclic prefix of length \( N_{g} \) symbols is appended to each block to avoid the effect of inter-symbol interference (ISI). A vector \( x^{j} \) of dimension \( (N + N_{g}) \times 1 \) is obtained, which is then parallel to serial converted and transmitted by the \( j^{th} \) transmit antenna through the channel.

B. Receiver

At the receiver, \( N_r \) receiving antennas are used, as shown in Fig. 1(b). The signal that arrives at the \( i^{th} \) \((i = 1,2,\ldots,N_r) \) receiving antenna \( r^{i} \) is the summation of the signals sent from the \( N_t \) transmitting antennas, and the contribution of the \( j^{th} \) transmitting antenna is given as the convolution of the transmitted signal \( x^{j} \), with the channel impulse response \( h_{i,j}[n] \) between the \( j^{th} \) transmit and the \( i^{th} \) receive antennas, where \( h_{i,j}[n] = [h_{0,i,j}[n], h_{1,i,j}[n],..., h_{L-1,i,j}[n]]^{T} \) and \( L \) is the channel order. The received signal at the \( i^{th} \) receiver can be expressed as

\[
r^{i} = \sum_{j=1}^{N_t} (x^{j} \oplus h_{i,j}) + n^{i}
\]

(2)

where \( \oplus \) denotes the convolution operation and \( n \) is a complex additive Gaussian noise vector, which is modelled as \( \mathcal{CN}(0, N_{0}) \).

\( N \) point fast Fourier transform (FFT) is employed to convert the received signal \( r^{i} \) to frequency domain signal after removing the cyclic prefix. Then \( y^{i} \) is given by

\[
y^{i} = W \cdot r^{i},
\]

(3)

where \( W \) is \( N \times N \) Discrete Fourier Transform matrix. By substituting (2) into (3) and using simple mathematics
manipulations it can be shown that

\[ y_k^i = \sum_{j=1}^{N_i} w_k \cdot h^{i,j} \cdot X_k^j + v_k^i \]  

(4)

where \( y_k^i \) is the signal received by the subcarrier \( k \) at the receiving antenna \( i \), and

\[ w_k = [1, e^{-j2\pi k/N}, ..., e^{-j2\pi(L-1)k/N}] \]

(5)

Let \( y_k = [y_k^1, y_k^2, ..., y_k^{N_r}] \)^T denote the frequency domain signal received by the \( k^{th} \) subcarrier over all receiving antennas. Using (4) we can write

\[ y_k = \begin{bmatrix} w_k h_{k,1}^{1,1} & \ldots & w_k h_{k,1}^{1,N_t} \\ \vdots & \ddots & \vdots \\ w_k h_{k,N_r,1} & \ldots & w_k h_{k,N_r,N_t} \end{bmatrix} \begin{bmatrix} X_k^1 \\ \vdots \\ X_k^{N_r} \end{bmatrix} + \begin{bmatrix} v_k^1 \\ \vdots \\ v_k^{N_r} \end{bmatrix} \]

(6)

Recalling (1) we have

\[ D_k = [X_k^1, X_k^2, ..., X_k^{N_r}] = F_k \cdot s_k, \]

(7)

Finally \( y_k \) can be written as

\[ y_k = H_k F_k s_k + v_k \]

(8)

where \( v_k = [v_k^1, v_k^2, ..., v_k^{N_r}] \)^T is the \( k^{th} \) subcarrier frequency domain noise vector and \( H_k \) is the \( N_r \times N_t \) frequency response channel matrix of the \( k^{th} \) subcarrier given by

\[ H_k = \begin{bmatrix} w_k h_{k,1}^{1,1} & \ldots & w_k h_{k,1}^{1,N_t} \\ \vdots & \ddots & \vdots \\ w_k h_{k,N_r,1} & \ldots & w_k h_{k,N_r,N_t} \end{bmatrix} \]

(9)

In this paper, the MIMO channel is assumed to be an uncorrelated multipath time varying Rayleigh fading channel. The channel impulse response \( h^{i,j}[n] \) between the transmitting antenna \( j \) and the receiving antenna \( i \) is described as \( h^{i,j}[n] = [h_0^{i,j}[n], h_1^{i,j}[n], ..., h_{L-1}^{i,j}[n]] \)^T. A slow fading environment is assumed where the channel impulse response \( h^{i,j}[n] \) is assumed to remain constant for the duration of the OFDM symbol and varying from one symbol to another.

### III. THE PROPOSED CHANNEL PREDICTION SCHEME

In this paper, we propose a prediction technique that is able to improve the bit error rate (BER) performance of precoded spatial Multiplexing MIMO – OFDM systems. A Kalman filter is used to predict the channel state of the next OFDM symbol \( H_{P}[n+1] \) at the training subcarriers based on the collection of the past estimated channel values. The channel prediction scheme will overcome the dynamics of the channel and alleviate the feedback delay effects. The proposed scheme comprises three different steps; firstly, Least Square Estimation (LS) is performed to estimate the channel at pilot frequencies \( H_{P}[n] \); Secondly, a Kalman filter is used to predict the next channel state at the pilot subcarriers \( H_{P}[n+1] \); finally, time domain interpolation (TDI) is performed to find the estimated \( \bar{H}_k[n] \) and predicted \( \bar{H}_k[n+1] \) channels at the data subcarriers. More detailed discussion on these points is given in the following subsections.

#### A. channel estimation

The channel estimation technique of MIMO – OFDM systems is a crucial issue as a good channel estimation technique results in less estimation errors and consequently good signal detection. Least Square (LS), Least Mean Square (LMS), and Minimum Mean Square Error (MMSE) algorithms are the most well known training based channel estimation technique for MIMO – OFDM systems. In this work we adopt the LS algorithm, because it is the simplest and its performance approaches MMSE for higher SNR values. Another reason for using LS is because our aim of this paper is to design an effective prediction technique which is able to overcome the dynamics of the channel and mitigate the feedback delay effect in MIMO – OFDM systems, not to design a high performance channel estimation technique. Comb-type pilot structure channel estimation is adopted in this work, where \( N_P \) pilot symbols with known data are uniformly inserted into each OFDM symbol at each transmit antenna. It has been shown in [14] and [15] that a comb-type pilot structure performs better than a block type structure for fast fading channels. The pilot sequences from each antenna are assumed to be orthogonal with other sequences from other antennas.

The frequency domain signal \( X^j \) at the \( j^{th} \) transmit antenna can be expressed as

\[ X^j(k) = X^j(mK + k) = \begin{cases} X^j(m), & k = 0; m = 0, 1, ..., N_P - 1 \\ Data, & k = 1, 2, ..., K - 1 \end{cases} \]

(10)

where \( K = N/N_P \) and \( X^j(m) \) is the \( m^{th} \) \((m = 1, 2, ..., N_P - 1)\) pilot carrier value on the \( j^{th} \) transmit antenna. At the receiver the pilot signals are first extracted from the received signal. Then the transfer function at the pilot subcarriers is obtained using the received signal and the predetermined pilot values. Let \( Y_{m,j} = |X_{m,j}|^2 \) be the channel frequency response of the \( m^{th} \) pilot subcarriers between the \( j^{th} \) transmit antenna and the \( i^{th} \) receive antenna.

The LS estimation of the channel at pilot subcarriers between the \( j^{th} \) transmit and the \( i^{th} \) receive antennas is expressed as

\[ \hat{H}_{P}^{i,j} = \frac{Y_{m,j}}{X_{m,j}^2} \]

(11)

where \( Y_{m,j} \) is the received signal at the \( i^{th} \) receiver on the \( m^{th} \) pilot subcarrier from the \( j^{th} \) transmit antenna, and \( X_{m,j} \) is the
signal transmitted from the $j^{th}$ transmit antenna at the $m^{th}$ pilot subcarrier.

B. Channel prediction

As we mention above, in this paper we consider a time-varying environment where the channel changes from one OFDM symbol to another. Hence, the precoding matrix chosen at the receiver from the current OFDM symbol becomes outdated due to signal processing and feedback delay. Consequently, the outdated information results in system performance degradation. As a solution we used a Kalman filter to predict the channel state for each subcarrier, utilizing the collection of the past estimated channel values. The predicted channel state is used to design the precoding matrices for the next OFDM symbols, and the indices of the precoding matrices are fed back to the transmitter through the limited feedback channel. It is well known that a dynamic system can be modeled as an autoregressive (AR) process of order $U$. An $U^{th}$ order AR model for $H^{i,j}[n]$ is presented as:

$$H^{i,j}[n] = \sum_{u=1}^{U} a(u) H^{i,j}[n-u] + w^{i,j}[n]$$

(12)

where $a(u)$ are the coefficients of the AR process, and $w^{i,j}[n]$ is a white Gaussian process vector. The AR process coefficients can be solved by solving the Yule-Walker equation [16]. However, it is not the aim of this paper to find these coefficients, and therefore it is assumed that they are known. The choice of $U$ is a trade off between the accuracy of the model (12) and the parameter estimation complexity. For simplicity in this paper we model the channel as a first order AR process. Furthermore, a first order AR model provides an adequate model for time varying channels [17]. Therefore, (12) can be written as

$$H^{i,j}_p[n] = a H^{i,j}_p[n-1] + w^{i,j}_p[n]$$

(13)

Consequently, $a$ is $N_P \times N_P$ diagonal matrix of the AR model factor $\alpha$, where

$$\alpha = E \left[ (H^{i,j}_p[n+1]) \cdot (H^{i,j}_p)^*[n] \right]$$

(14)

According to Jakes model

$$E \left[ (H^{i,j}_p[n+1]) \cdot (H^{i,j}_p)^*[n] \right] = J_0(2\pi f_d T_s)$$

(15)

Then, $a$ can be expressed as

$$a = J_0(2\pi f_d T_s) \cdot I_P$$

(16)

where $J_0(\cdot)$ represents a zeroth-order Bessel function of the first kind, $f_d$ which is the maximum Doppler frequency, and $T_s$ is the OFDM symbol duration. The input output relationship at the pilot subcarrier can be written as

$$Y^{i,j}_p[n] = C^{i,j}_p[n] H^{i,j}_p[n] + v^{i,j}_p[n]$$

(17)

where $Y^{i,j}_p[n] = [Y_0^{i,j}, Y_1^{i,j}, \ldots, Y_{N_P-1}^{i,j}]^T$ is the signal vector received at the pilot subcarriers of the $i^{th}$ receiver from the $j^{th}$ transmit antenna, $C^{i,j}_p$ is a diagonal matrix with the transmit pilot signal vector $X^{i,j}_p = [X_0^{i,j}, X_1^{i,j}, \ldots, X_{N_P-1}^{i,j}]^T$ being its diagonal, and $v^{i,j}_p$ is the white Gaussian noise vector.

In this section, a Kalman filter is employed to predict the future state of the channel at the pilot subcarriers based on the collection of the estimated channels. In order to employ a Kalman filter the state space equations are needed. Combining (13) and (17) gives the state space model for the channel between the transmitter $j$ and the receiver $i$ as

$$H^{i,j}_p[n] = a H^{i,j}_p[n-1] + w^{i,j}_p[n]$$

$$Y^{i,j}_p[n] = C^{i,j}_p[n] H^{i,j}_p[n] + v^{i,j}_p[n]$$

(18)

where the first equation represents the process equation and the second represents the measurement equation. $a$ denotes the time varying transition matrix, and $C^{i,j}_p[n]$ is known $N_P \times N_P$ measurement matrix. $v^{i,j}_p[n]$ and $w^{i,j}_p[n]$ are the process and the measurement noise vectors respectively. The noise vectors $v^{i,j}_p[n]$ and $w^{i,j}_p[n]$ are mutually uncorrelated noise sequences with covariance matrices $\Phi_v[n]$ and $\Phi_w[n]$.

A Kalman filter is well described in [16]. Using the estimated channel values given by (11) and the measurement data of (17), the channel at the pilot subcarriers of the next OFDM symbol can be obtained using the following recursive computation:

$$\tilde{H}^{i,j}_p[n/n-1] = a \tilde{H}^{i,j}_p[n-1/n-1]$$

$$P^{i,j}_p[n/n-1] = a P^{i,j}_p[n-1/n-1] a^H + \Phi_w[n]$$

$$\alpha^{i,j}_p[n] = Y^{i,j}_p[n] - C^{i,j}_p \tilde{H}^{i,j}_p[n/n-1]$$

$$K^{i,j}_p[n] = P^{i,j}_p[n/n-1] = (C^{i,j}_p)^H \times$$

$$\left[ C^{i,j}_p P^{i,j}_p[n/n-1] (C^{i,j}_p)^H + \Phi_w[n] \right]^{-1}$$

$$\tilde{H}^{i,j}_p[n/n] = \tilde{H}^{i,j}_p[n/n-1] + K^{i,j}_p[n] \alpha^{i,j}_p[n]$$

$$P^{i,j}_p[n/n] = [I_P - K^{i,j}_p[n] C^{i,j}_p] P^{i,j}_p[n/n-1]$$

(19)

(20)

(21)

(22)

(23)

(24)

Where $K^{i,j}_p[n]$ is the Kalman gain, $P^{i,j}_p[n]$ is the error correlation matrix, and $\alpha^{i,j}_p[n]$ is the innovation vector. The predicted channel states can be found by

$$\tilde{H}^{i,j}_p[n+1] = a \tilde{H}^{i,j}_p[n/n]$$

(25)

C. Interpolation

To estimate the channels at the data subcarriers and predict their next states, an efficient interpolation technique is needed. Different interpolation techniques have been investigated in [14] and [15]; however, in the present work we use the Time Domain Interpolation (TDI) technique because it outperforms linear interpolation in terms of BER [15].

The channel frequency response at the data subcarriers can be
obtained using time-domain interpolation by converting \( \hat{h}^{i,j}_p \) and \( \hat{H}^{i,j}_p \) to time domain vectors \( \hat{h}^{i,j}_p \) and \( \hat{H}^{i,j}_p \) using Inverse Discrete Fourier Transform (IDFT), zero pad each of \( \hat{h}^{i,j}_p \) and \( \hat{H}^{i,j}_p \) to \( N \) point, and finally transform the zero padded time domain vectors back to the frequency domain using Discrete Fourier Transform (DFT) to get \( \hat{H}^{i,j}_k \) and \( \hat{H}^{i,j}_k \).

Using the estimated channel frequency response \( \hat{H}^{i,j}_k \), the MIMO channel for each subcarrier can be constructed as

\[
H_k[n] = \begin{bmatrix}
\hat{H}^{1,1}_k[n] & \hat{H}^{1,2}_k[n] & \cdots & \hat{H}^{1,N_s}_k[n] \\
\hat{H}^{2,1}_k[n] & \hat{H}^{2,2}_k[n] & \cdots & \hat{H}^{2,N_s}_k[n] \\
\vdots & \vdots & \ddots & \vdots \\
\hat{H}^{N_s,1}_k[n] & \hat{H}^{N_s,2}_k[n] & \cdots & \hat{H}^{N_s,N_s}_k[n]
\end{bmatrix}
\]  

(26)

The MIMO channel \( H_k[n] \) is used to design the linear decoding matrix \( G_k[n] \), which is applied to \( Y_k \) to generate the vector \( \tilde{s}_k[n] = Q(G_k[n]Y_k[n]) \), where \( Q(\cdot) \) is a function that performs a single dimensional maximum likelihood decoding for each entry of the vector.

The linear decoding matrix \( G_k[n] \) for MMSE linear receivers [7] is given as

\[
G_k[n] = (F^H_k[n]H_k^H[n]H_k[n]F_k[n]+\frac{M}{N_s}I_M)^{-1}F^H_k[n]H_k^H[n]
\]  

(27)

where \((\cdot)^{-1}\) denotes the matrix inverse.

The optimal precoding matrix \( F_k[n+1] \) for each subcarrier is selected at the receiver from a given codebook \( F = \{F_1, F_2, \ldots, F_N\} \) known to both transmitter and receiver as a function of the predicted channel \( H_k[n+1] \) by searching through all codebook matrices. The design of the precoders using linear receivers can be carried out using different selection criteria [4] based on the decoding matrix \( G_k[n] \). In this work, the mean square error selection criterion (MSE – SC) with trace-based cost function is used. The MSE for linear MMSE receivers is expressed as

\[
F_k[n+1] = \arg \min_{F_i \in F} tr(MSE(F_i, \hat{H}_k[n+1]))
\]  

(28)

and the mean squared error (MSE) for linear MMSE receiver [7] is given by

\[
MSE(F_i, \hat{H}_k[n+1]) = \frac{\varepsilon_s}{M}I_M + \frac{\varepsilon_s}{MN_0}F^H_i \hat{H}_k^H[n+1]H_k[n+1]F_i^{-1}
\]  

(29)

### IV. Simulation Results

In this section we provide some simulation results to demonstrate the effectiveness of our proposed prediction scheme. We consider a precoded spatial multiplexing MIMO-OFDM system with the basic simulation parameters summarized in Table 1. A three-tap multipath channel between each transmit and each receive antenna is employed, where each tap is modelled as a Rayleigh fading channel. A Normalized Doppler frequency of 0.0024 is used in the simulation. Computer simulations were performed to verify the performance of the proposed system in terms of bit error rate (BER). To show the effectiveness of the proposed scheme, the BER performances of the following situation are compared: 1) Conventional or no channel prediction (NCPRED); The receiver does not perform channel prediction, and the precoders are designed as a function of the current channel states. 2) Channel Prediction (CPRED): A channel prediction is performed at the receiver and the precoders are designed as a function of the future channel states to compensate for the processing and the transmission delay. 3) CSI or Ideal case: Where the channels are assumed to be perfectly known at the receiver and there is zero delay, which represents the ideal unrealistic case.

Simulation result points were obtained by averaging over \( 10^4 \) channel realizations.

**Case 1:** We compare the BER performance for the three situations stated above CPRED, NCPRED, and CSI. The simulation results in Fig. 2 show the BER versus the SNR for a 4 x 2 precoded MIMO-OFDM system using two streams per subcarrier. Two bits of feedback are used for each precoding matrix. A linear MMSE receiver is used and a MSE-SC with trace-based cost function is employed. We observe that the BER performance for a system using channel prediction is better than that with no prediction. It is also observed that at a BER of \( 10^{-3} \), the channel prediction scheme achieves \( \sim 2 \) dB improvement over the conventional or no prediction case. This performance improvement is due to mitigation of the effect of delay in the feedback channel. However, it is still inferior to the unrealistic case of perfect CSI which serves as the benchmark performance, because we used LS estimation in designing the decoding matrix \( G_k[n] \), and the channel prediction is also based on these estimated values.

**Case 2:** In this case we investigate the effect of increasing the number of feedback bits on the BER performance for a 4x2 system using channel prediction. The simulation results in Fig. 3 show that \( \sim 3 \) dB improvement in BER performance is achieved by increasing the number of feedback bits from 2 to 6 bits for each precoding matrix.

**Case 3:** Finally, we investigate BER performance for a 4 x 2 system using different values of the normalized Doppler frequency \( f_N = f_d T_s \). The results in Fig. 4 demonstrate that increasing the receiver speed ten times results in degradation of the BER performance. However, it is still acceptable. It can
also be observed that the proposed channel prediction scheme improves bit error rate performance over the conventional case for time-varying Rayleigh fading channels even for systems with high mobility.

V. CONCLUSIONS

In this paper, a channel prediction scheme based on a Kalman filter has been proposed to overcome the dynamics of channels, mitigating the feedback delay effect in spatial multiplexing MIMO-OFDM systems. Prediction of the precoders is made at the receiver based on the information that would be available for any spatial multiplexing MIMO-OFDM system. Only the indices of the selected optimal matrices are fed back to the transmitter. Therefore, the amount of feedback information is the same as that for the case when no precoder prediction is used. The effectiveness of this method was evaluated using computer simulation. It has been shown through the improved BER performance that the proposed method mitigates the adverse time varying channel impairments and reduces the feedback delay effects.

REFERENCES


