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A REVIEW OF CHANNEL PREDICTION TECHNIQUES FOR MIMO-OFDM SYSTEM

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Abstract

MIMO-OFDM (multiple input multiple output-orthogonal frequency division multiplexing) is used to improve the spatial diversity and efficiency of the present wireless communication systems. In present era, channel prediction techniques are the most appealing methods to find the channel coefficients at the receiver which helps to improve the performance of the system. Channel prediction techniques help to reduce the feedback delay of channel state information (CSI), thus improve performance and reduce the computational burden of the system. In this paper, the comparative study of various channel prediction techniques is made for MIMO-OFDM system.

1. Introduction

MIMO stands for multiple input multiple output and OFDM stands for orthogonal frequency division multiplexing. MIMO is nothing but multiple inputs at the transmitter and multiple output at the receiver, whereas OFDM (orthogonal frequency division multiplexing) converts the frequency selective channels into a set of parallel flat fading channels [1]. However, by

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combining these two technologies, we achieve much higher throughput and much easier processing at the receiver that converts the selective channels into a set of parallel flat fading channels [15]. MIMO-OFDM converts the time domain channel in MIMO frequency selective channels. Hence, MIMO-OFDM [2] significantly simplifies baseband receiving processing by eliminating the need for a complex MIMO equalizer and thus eliminates the MIMO inter symbol interference. Various MIMO channels are described as follows:

(a) Frequency selective MIMO channel

A MIMO frequency selective channel can be modeled as a MIMO FIR filter

$$\bar{y}(L) = \sum_{k=0}^{K-1} H(k)\bar{x}(L-l) + \bar{n}(L),$$

where

$\bar{y}(L) =$ symbol vector $r \times 1$ receiver,

$\bar{x}(L-l) =$ transmitted $k \times 1$ symbol vector,

$\bar{n}(L) =$ noise vector $r \times 1$,

$H(k) =$ channel matrix corresponding to L$^{\text{th}}$ tap $(r \times t)$ matrix,

$$\bar{y}(L) = H_0(0)\bar{x}(L) + H_1(1)\bar{x}(L-1) + H_2(2)\bar{x}(L-2)$$
$$+ H_N(K-1)\bar{x}(L-K+1) + \bar{n}(L),$$

and

$\bar{x}(L) =$ transmit vector at time *k*,

$\bar{x}(L-1) =$ transmit vector at time $k-1$,

$\bar{x}(L-K+1) =$ transmit vector at time $k-L-1$.

That $\bar{Y}(L)$ depends on the transmit vectors $\bar{x}(L), \bar{x}(L-1), \ldots,$ $\bar{x}(L-K+1)$ which is essentially the previous transmit symbol vector.

Hence, this is an L-tap frequency selective MIMO channel and ISI (inter symbol interference) occurring between current and previous transmitted symbol vectors.

In MIMO-OFDM system, one needs to perform the IFFT or IDFT operation at each transmit antenna.

(b) Flat fading MIMO-channel

Flat fading MIMO channels across each subcarrier and the output of each subcarrier are as follows:

$$\overline{y_n}(0) = \hat{H}(0)\overline{x_n}(0)$$

$$\overline{y_n}(1) = \hat{H}(1)\overline{x_n}(1)$$

$$\vdots$$

$$\overline{y_n}(N-1) = \hat{H}(N-1)\overline{x_n}(N-1)$$

$$\overline{y}(k) = \hat{H}(k)\overline{x}(k).$$

2. MIMO-OFDM System

MIMO-OFDM is a prior interface for 4G and 5G broadband, in today's wireless communication systems. Hence, multiple antennas have been used for interference cancellation. Through coherent combination, one can realize the diversity gain and array gain by using antennas at both the sides, i.e., at the transmitter side and the receiver side can increase the fundamental gain which further increases the spectral efficiency of the system. The benefit of the combination of these two technologies is to give accurate channel state information at the transmitter side [1, 2]. If the frequency division duplexing (FDD) system is considered at the receiver, then the channel state information is estimated. It becomes feedback to the transmitter. But in today's wireless environment with the time-varying channel, there is an occurrence of delay in the feedback to the transmitter and this delay in feedback causes degradation in the performance of the system. To overcome with these feedback delays, channel prediction technique are used to predict the coefficient of the future channel data based on the previous data.

3. MIMO-OFDM System Model

Consider the MIMO-OFDM system with the transmit antenna *tx* and the received antenna *rx*, $i_n{}^{\text{th}}$ symbol time and $k_m{}^{\text{th}}$ subcarrier. Symbol at the transmitted side $X_{m_i}(i_n, k_m)$ transformed into time domain signal at the m^{th} transmitted antenna and symbol $i_n{}^{\text{th}}$ time and $k_m{}^{\text{th}}$ subcarrier using iFFT and then add the cyclic prefix to avoid the inter symbol interference. Before the FFT process, the cyclic prefix is removed at the receiver end. Symbols are received by the n_x antennas represented by

$$Y_{n_x, m_x}(i_n, k_m) = \sum_{m=1}^{M} H_{n_x, m_x}(i_n, k_m) X_{m_i}(i_n, k_m) + Z_{n_0}(i_n, k_m),$$

where $H_{n_x, m_x}(i_n, k_m) =$ frequency response of the channel impulse response, $Z_{n_0}(i_n, k_m) =$ background noise and AWGN noise.

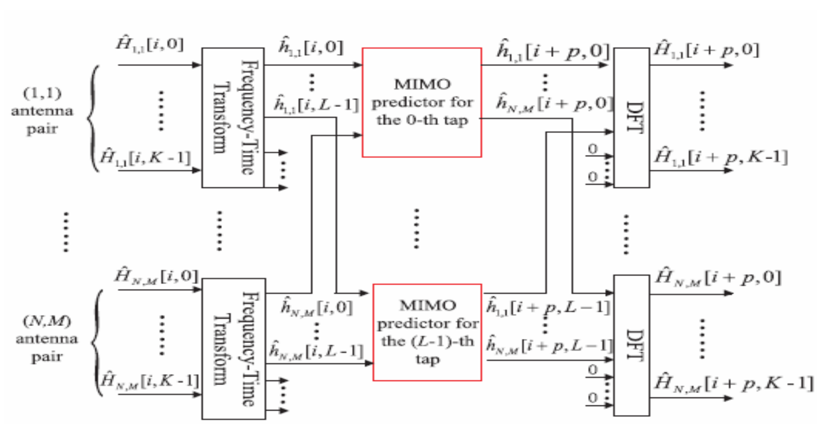

Figure 1. MIMO-OFDM block diagram [1].

4. MIMO-OFDM Channel Model

The channels impulse response is represented by

$$h_{n,m}(t_x, \tau) = \sum_{l=0}^{L_{n,m}-1} h_{n,m}(t_x, l_p)\delta(\tau - \tau_{n,m}(l_p)),$$

where $L_{n,m}$ = number of multiple radio paths of the (m, n) antenna pair,

$\delta(\tau - \tau_{n,m}(l_p))$ = Kronecker delta function,

$h_{n,m}(t_x, l_p)$ = channel impulse response.

Complex-values at time *t* and l^{th} path from (m, n) antenna pairs,

$\tau_{n,m}(l_p)$ = delay (m, n)-antenna pair.

5. Channel Prediction Techniques for MIMO-OFDM

In modern wireless communication systems, channel estimation techniques are used to increase the performance of the system, which is reduced due to feedback delay of the channel state information and this is used to predict the future coefficients based on the previous data. In this, the channel coefficients can be predicted by using autoregressive model [1, 2, 12].

(A) Pilot carrier based channel estimation

In OFDM blocks, the pilot symbols are transmitted on all subcarriers to the receiver to estimate the channel. Depending on the pilot arrangements, there are three types of pilot structures to be considered as comb type, block type and lattice type. In comb type Figure 2(a), parts of subcarriers are always reserved as pilot for each symbol, where s_f denotes the period of pilot tones, whereas in block type Figure 2(b), each subcarrier is used as pilot for a specific period, where s_t denotes the pilot symbols in time domain. And in lattice type Figure 2(c) with a given period of time, both the frequency and time axes of the pilot tones are inserted. For channel estimation, frequency and time axes smoothen the way for frequency/time interpolations, where s_t and s_f denote period of pilot symbols. Block type channel estimation uses the LS (least square estimation) whereas the comb type uses the LS and LMS (least mean square estimation) [3].

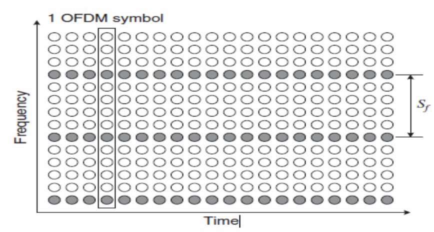

Figure 2(a). Comb type structure [2].

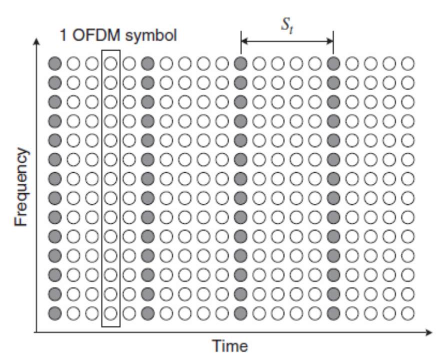

Figure 2(b). Block type structure [2].

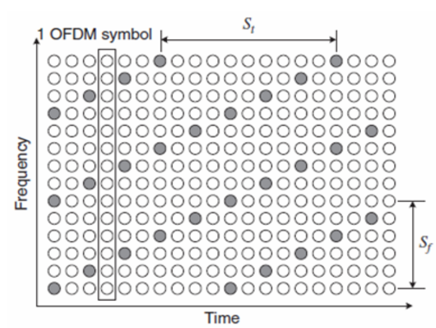

Figure 2(c). Lattice type structure [2].

(B) Training based channel prediction

In this proposed channel estimation technique, training symbols are used for providing the good performance and due to overhead of training symbols, the transmission efficiency is reduced. Comb type and block type pilot subcarrier channel estimation techniques for MIMO-OFDM systems suffer from large mean square errors at the edges of the subcarriers and according to the sampling theorem, the space between pilot subcarriers in frequency domain becomes small. To overcome the problem, Zheng et al. [10], in frequency domain channels, the phase shifted preambles and different transmitted antennas are used. It is useful for transmitting the data simultaneously to be used in this proposed DFT-Based channel estimation technique. Iterative process is used to fine complete channel frequency response in the presence of virtual subcarriers. This technique outperforms least minimum mean square error (LMMSE) algorithm with comb type preamble with less number of constraints.

(C) DFT-based channel estimation

This channel estimation technique based on block type pilot arrangement for OFDM system is carried out. DFT-based operation gives better performance over LS (least square). The MMSE (minimum mean square error) with the same SNR, the BER of DFT-based channel estimation is less than the BER of LS and MMSE based channel estimation [5]. For the fast-fading channels, the block type arrangement is suitable for frequency selective channels.

(D) Decision-directed channel estimation

In decision-directed channel estimation, the channel coefficients are updated in which we do not use the pilots or the preambles. In order to track the time-varying channel, the decision directed uses the detected signal feedback and channel estimate for detection of signals [2, 6].

(E) Semi-blind channel estimation technique

For space time block codes (STBCs), the standard EM algorithm is integrated with the ML decoder [13]. The proposed technique is an unravel semi-blind estimator for STC-MIMO-OFDM system based on EM algorithm [2, 7]. Channel estimation is directly carried out in time domain instead of applying the technique in frequency domain and filtering subsequently. Over a range of the Doppler spreads, this method performs the ideal case of CSI (channel sate information) applicable for antenna correlation parameters.

(F) Blind channel estimation

Blind channel estimation technique is based on the subspace method to improve the transmission bandwidth efficiency. This method converts the existing SISO-OFDM system to blind channel estimation for two different MIMO-OFDM systems, which can be distinguished by the number of transmitter and receiver antennas. The proposed method can accurately estimate the channel coefficients having fast convergence to estimate the channel order truly [8]. This proposed method need no or insufficient cyclic prefix when the virtual carriers are present.

(G) Spatial-temporal correlation based channel estimation

Spatial-temporal correlation based channel estimation is an appealing technique to mitigate the feedback delay. In this technique, the MIMO-OFDM channel prediction framework is made by using spatial and temporal correlation between the antennas. The proposed technique derived two predictors which choose the data for autoregressive (AR) predictors in two different ways [1]. One predictor selects the data via minimizing the mean square error (MSE) for the prediction model. Another predictor can select the data in an interactive-heuristic manner, which reduces the computational burden in the system, improves the pre-coding performance in the multi-user MIMO-OFDM systems and when the channel changes rapidly, it is easy to overcome the feedback delay [9, 10]. Reduced complexity FSS predictor and FSS predictor algorithms are used for channel prediction. By exploiting the spatial correlation, the desired prediction performance can be improved effectively, especially when the spatial correlation is relatively high. When the number of antenna increases up to $4 \times 2,$ the FSS predictor gives better performance as compared with the reduced-complexity FSS predictor [11].

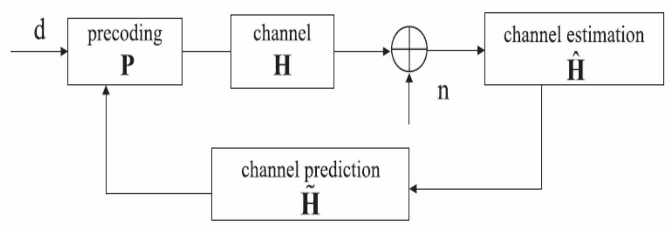

Figure 3. Predicted precoding channel estimation multi-user (MU)-MIMO-OFDM system [1].

Assuming the variance of noise β^2 correlation matrix

$$E\{h_{n,m}(i_x + \Delta i, l) h_{n',m'}(i_x, l)\},$$

the normalized mean square error (NMSE) is used to measure the accuracy of the prediction and is defined as follows:

$$NMSE = 10 \log \left\{ \frac{E\{\| h_{n,m}(i_x + p_y, l) - \hat{h}^{pre}_{n,m}(i_x + p_y, l) \|^2}{E\{\| h_{n,m}(i_x + p_y, l) \|^2\}} \right\}.$$

6. Applications of the Proposed Prediction Technique

There are some applications that are proposed for the prediction and precoding is an efficient way to increase the performance of the system eliminating the interference among different users. The following are the applications:

(a) Zero forcing (ZF)

In this, $Y(i, k)$ is selected in a way that each user not at any time receives the interference from another user. According to [1]:

$$Y(i_n, k_m) = \overline{H}(i_n, k_m)^H (\overline{H}(i_n, k_m)\overline{H}(i_n, k_m)^H)^{-1}.$$

(b) MMSE (minimum mean square error)

This scheme is an improvement of the zero forcing (ZF) [1]:

$$Y(i_n, k_m) = \overline{H}(i_n, k_m)^H (\overline{H}(i_n, k_m)\overline{H}(i_n, k_m)^H + \beta I)^{-1}.$$

(c) Block diagonalization (BD)

This scheme is a theorization of the channel inversion with the multiple antennas per user [1]:

$$\overline{H}_p(i_n, k_m)$$

$$= [\overline{H}_1^L(i_n, k_m), \ldots, \overline{H}_{p-1}^L(i_n, k_m), \overline{H}_{p+1}^L(i, k), \ldots, \overline{H}_p^L(i_n, k_m)]^L.$$

In prediction performance of the spatial correlation in the NMSE algorithm with SNR (dB), 2×2 MIMO-OFDM systems is considered to find the correlation between the antennas. As the time correlation decreases, the velocity increases and the spatial correlation becomes more significant. The reduced complexity FSS predictor and the FSS (forward-stepwise subset) predictor have almost the same performance and the NMSE has the lowest correlation among all the algorithms [14]. The proposed algorithm is really helpful and gives low SNR values.

The performance of the reduced complexity predictor and the FSS predictor are almost the same for 2×2 MIMO-OFDM systems. The FSS predictor gives better performance than the reduced complexity FSS predictor but the reduced complexity FSS predictor gives better performance having less computational burden on the system with smaller number of antennas.

7. Conclusion

A complete review of the channel prediction techniques like pilot carrier, training based channel estimation, blind, semi blind, DFT and spatial-temporal correlation channel prediction is made. It is concluded that the use of spatial-temporal correlation technique for channel prediction gives much better and reliable performance and the computational burden is less in the system. Two predictors are used for driving this technique are the FSS predictor which selects the data optimally but the performance gives large computational burden as the antenna increases 4×2, and the reduced-complexity FSS predictor select the data in the interactive-heuristic way which results into low computational burden. The spatial correlations are relatively high for the exploiting spatial correlation.

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