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MIMO-OFDM Channel Prediction Using Pilot Carries

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Abstract: A multiple-input multiple-output (MIMO) communication system combined with the orthogonal frequency division multiplexing (OFDM) modulation technique can achieve reliable high data rate transmission over broadband wireless channels. Channel state information for MIMO systems based on pilot aided arrangement is investigated in this paper. The estimation of channel at pilot frequencies with Least Square (LS) estimation algorithms is carried out and further channel is predicted using kalman filter through Matlab simulation. The performance of MIMO OFDM is evaluated on the basis of Bit Error Rate (BER) and Mean Square Error (MSE) and throughput level.

Keywords: MIMO, Orthogonal Frequency Division Multiplexing (OFDM), bit error rate (BER), Mean Square Error (MSE), Pilot carriers.

I. INTRODUCTION

Currently, orthogonal frequency-division multiplexing (OFDM) systems [1] are subject to significant investigation .It is becoming a very popular multi-carrier modulation technique for transmission of signals over wireless channels. OFDM divides the high-rate stream into parallel lower rate data and hence prolongs the symbol duration, thus helps to eliminate Inter Symbol Interference (ISI). It also allows the bandwidth of subcarriers to overlap without Inter Carrier Interference (ICI) as long as the modulated carriers are orthogonal. OFDM therefore is considered as an efficient modulation technique for broadband access in a very dispersive environment. In this new information age, high data rate and strong reliability in wire-less communication systems are becoming the dominant factors for a successful exploitation of commercial networks. Multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) is a very promising broadband wireless transmission technology for the fourth generation (4G) wireless systems [2]. However, owing to the complicated space-time-frequency channels, channel estimation is a big challenge for implementing MIMO-OFDM in practical systems. A dynamic estimation of channel is necessary before the demodulation of OFDM signals since the radio channel is frequency selective and time-varying for wideband mobile communication systems [3].

II. SYSTEM MODEL

Fig. 2 depicts a high level block diagram of the MIMO OFDM system. We consider MIMO–OFDM systems with two transmit antennas and two receive antennas. Basically, the MIMO-OFDM transmitter has Nt parallel transmission paths which are very similar to the single antenna OFDM system, each branch performing serial-to-parallel conversion, multiplexing by precoded matrix, pilot insertion, N-point IFFT and cyclic extension before the final TX signals are up-converted to RF and transmitted. Subsequently at the receiver, the CP is removed and N-point FFT is performed per receiver branch. Next, the transmitted symbol per TX antenna is combined and outputted for the subsequent operations like digital demodulation and decoding.

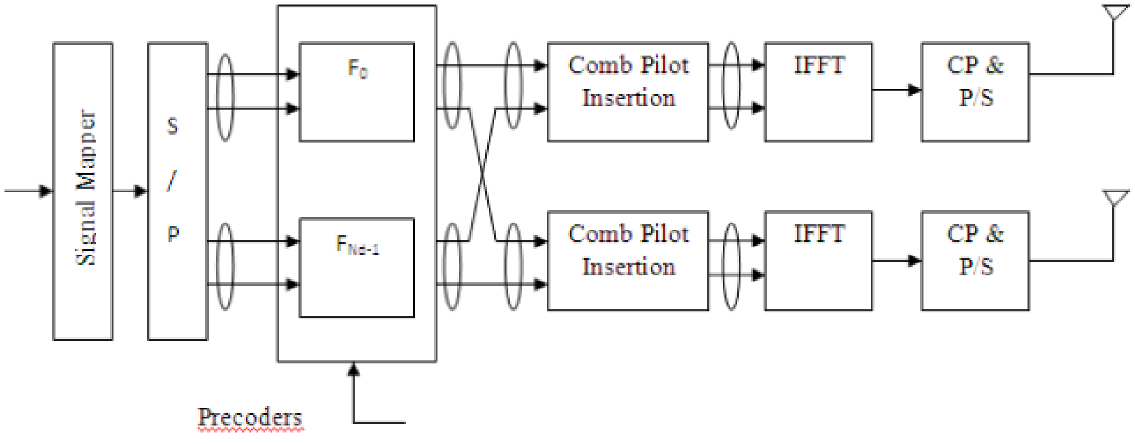
Let Nd be the number of data subcarriers and M be the number of data streams transmitted by each subcarrier, where M is assumed to be $\leq$ min (Nt, Nr). The input data symbols are divided into Nd groups of M symbol streams. Let the vector s_k [n]

denote the M x 1 transmitted symbols vector on subcarrier k. The symbol vector s_k [n] is multiplied by Nt x M precoding matrix $F_k[n]$ generating.

$$s_k [n] =[s^1{}_k [n], s^2{}_k [n],\ldots. s^M{}_k [n]]^T \qquad \textbf{(1)}$$

$$D_k = F_k[n] \cdot s_k[n] \qquad \textbf{(2)}$$

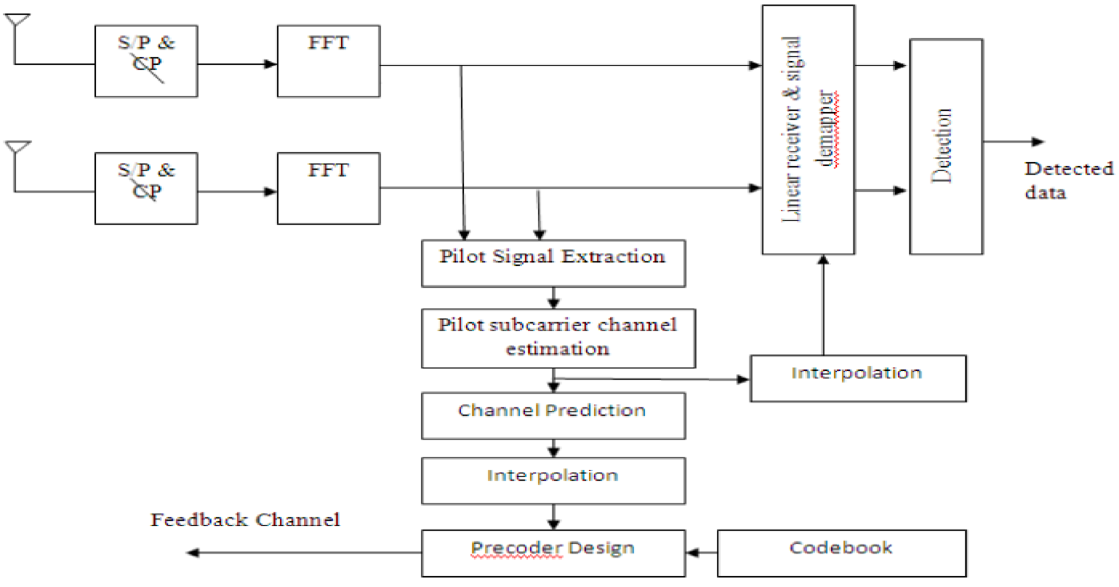
where D_k is the precoded data vector of length Nt x 1, and $F_k[n]$ € U (Nt, M) the set of Nt x M complex unitary matrices. $F_k[n]$ is selected at the receiver from a finite set of possible precoding matrices $F = \{F_1, F_{2,} \ldots F_{Nc}\}$, represented by a limited number of bits and conveyed to the transmitter through a limited feedback channel.



(a) Transmitter

Fig. 1a OFDM system block diagram with Comb pilot-based LS channel prediction

Let d_j^k *be* the j^{th} element of the precoded data vector D_k, where $j = 1, 2, . . . , Nt$. The precoded data is then rearranged to form the data blocks $Dj = [d^1{}_j,\ d^2{}_{j,\ldots\ldots}\ . . . ,d^{Nd}]^T$. *NP* pilot symbols are uniformly inserted with K subcarriers apart from each other in *Dj* giving a block *Xj* of dimension *N* x 1, where $K = N/NP$ is the interval of pilot signals. Each block is then converted into a time domain signal *xj* using inverse fast Fourier transform (IFFT) of length *N*. Finally, a cyclic prefix of length *Ng* symbols is appended to each block to avoid the effect of inter-symbol interference (ISI). A vector ˜*xj* of dimension (*N* +*Ng*) x 1 is obtained, which is then parallel to serial converted and transmitted by the j^{th} transmit antenna through the channel.



(b) Receiver

Fig. 1b OFDM system block diagram with Comb pilot-based LS channel prediction

At the receiver, N_r receiving antennas are used, as shown in Fig. 1(b). The signal that arrives at the i^{th} ($i = 1, 2, . . . , N_r$) 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 ˜xj , with the channel impulse response $h_{i,j}$ $[n]$ between the j^{th} transmit and the i^{th} receive antennas, where $h^{i,j}$ $[n] = [h^{i,j}_0$ $[n]$, $h^{i,j}_1$ $[n]$, ..., $h^{i,j}_{L-N}$ $[n]]^T$ and L is the channel order. The received signal at the i^{th} receiver can be expressed as

$$r^i = \sum_{j-1}^{Nt}(x^t \ * \ h^{i,j}) + n^i \qquad \textbf{(3)}$$

where (*) denotes the convolution operation and n is a complex additive Gaussian noise vector, which is modelled as $CN(0,N0)$. 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

$$y^i = W \cdot ri, \qquad \textbf{(4)}$$

Where W is N x N Discrete Fourier Transform matrix. Further channel estimation is performed. In this work LS algorithm is adopted, because it is the simplest. Another reason for using LS is because the 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 NP pilot symbols with known data are uniformly inserted into each OFDM symbol at each transmit antenna. It has been shown in [4] and [5] 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. 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 $H_m^{i,j} = Y_m^{i,j} \ / \ X_m^{j}$ 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 receive antennas is expressed as

$$H_p^{i,j} = [H_0^{i,j} , H_1^{i,j},\ldots\ldots\ldots\ldots\ldots\ldots\ H_{Np-1}^{i,j}] \ = [\ \frac{Y_0^{i,j}}{X_0^{i,j}}, \frac{Y_1^{i,j}}{X_1^{i,j}}, \ldots\ldots\ldots\ldots . . \frac{Y_{Np-1}^{i,j}}{X_{Np-1}^{i,j}}] \qquad \textbf{(5)}$$

Where $Y_m^{i,j}$ 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. The output of the channel estimation is given to a Kalman filter which is employed to predict the future state of the channel at the pilot subcarriers based on the collection of the estimated channels. The predicted channel states can be found by

$$H_p^{i,j} \ [n+1] = a \ H_p^{i,j} \ [n/n] \qquad \textbf{(6)}$$

To estimate the channels at the data subcarriers and predict their next states, an efficient interpolation technique is needed. The channel frequency response at the data subcarriers can be obtained using time-domain interpolation. The optimal precoding matrix $F_k[n + 1]$ for each subcarrier is selected at the receiver from a given codebook $F = \{F1, F2, . . . , F_{Nc}\}$ known to both transmitter and receiver as a function of the predicted channel ˆH_k $[n + 1]$ by searching through all codebook matrices.

III. SIMULATION RESULTS & DISCUSSION

The simulation of MIMO –OFDM with channel prediction system has been performed using Matlab programming language. The parameters used for the simulation are listed in Table 1. The graphical representation of simulation results are shown in Figures 3 to 5.

Table 1. Simulation Parameters

Parameters	Specifications
Number of transmit antennas	2
Number of receive antennas	2
Number of data streams	2
FFT size	64
OFDM subcarriers	48
Number of pilots/OFDM symbol	4
Signal Constellation	BPSK,QPSK,8QAM,16 QAM,32 QAM

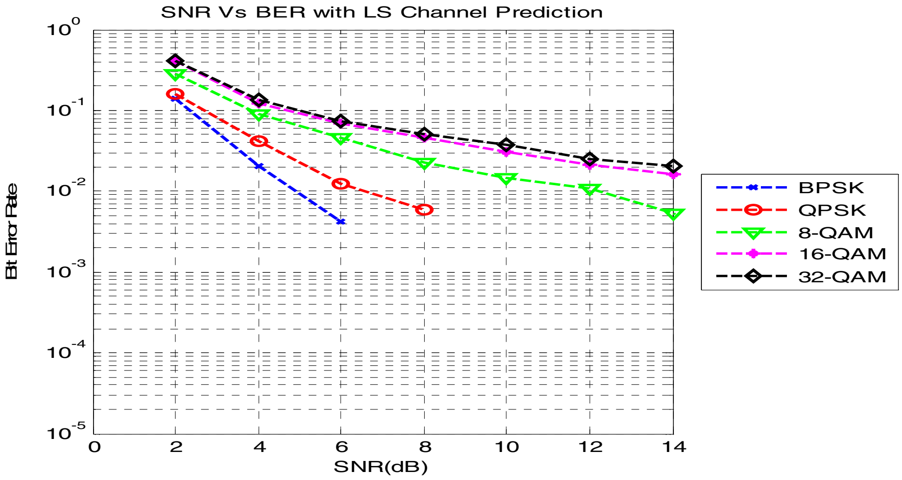


Fig 3.Plot of SNR Vs BER with LS channel prediction

Table 2. Comparison Of modulation techniques using SNR Vs BER

MOD	BPSK	QPSK	8QAM	16QAM	32QAM
SNR	BER	BER	BER	BER	BER
0	-0.236474	-0.300966	-0.351128	-0.45145	-0.472947
2	0.141462	0.161671	0.282924	0.414282	0.412261
4	0.0206209	0.0412419	0.0893574	0.123726	0.133349
6	0.00414107	0.0124232	0.0455518	0.069363	0.0728829
8	0	0.00592622	0.0227172	0.0459282	0.0503729
10	0	0	0.0146103	0.0305664	0.0373717
12	0	0	0.0107023	0.0212471	0.02493

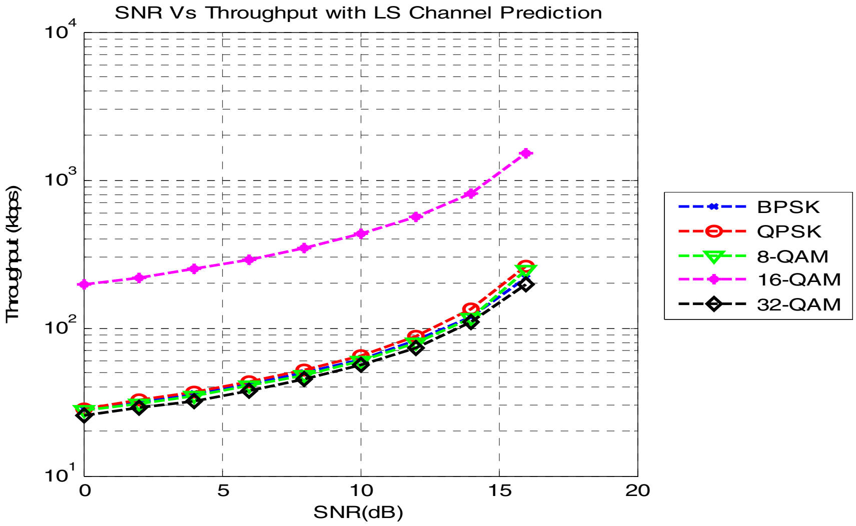


Fig 4. Plot of SNR Vs Throughput with LS channel prediction

Table 3. Comparison Of modulation techniques using SNR Vs Throughput

MOD	BPSK	QPSK	8QAM	16QAM	32QAM
SNR	**Throughput**	**Throughput**	**Throughput**	**Throughput**	**Throughput**
0	28.0253	28.5696	27.5468	195.332	25.4967
4	31.5263	32.3421	30.5075	219.306	28.6275
10	35.9347	37.1014	34.4914	249.519	32.2476
14	41.7435	43.0113	40.3209	290.018	37.5402
16	50.1016	52.1119	47.5766	346.211	45.0634
18	61.1343	64.4648	59.6411	429.412	56.1439
20	82.2744	87.3202	78.4898	564.058	73.8308
22	118.804	133.52	115.354	816.671	110.15

Case1:- The comparison of BER performance for five different modulation schemes is stated above. The simulation results in fig.3 shows the graph of SNR Vs BER. For low values of SNR the best modulation technique is BPSK but as the SNR increases 32 QAM is the most suitable modulation technique. At lower SNR value i.e 2db the BER by BPSK is 0.141462 and by 32QAM BER is 0.412261.

Case2:-The simulation results in fig.4 shows the graph of SNR Vs Throughput. For BPSK modulation when SNR is 4db the throughput is 31.5263bps and for 16QAM when SNR is 4db the throughput is 219.306.So from the simulation it's clear that the throughput is maximum for 16QAM.

Case3:- Fig.4 shows the comparison of MSE performance for different modulation schemes. The MSE is maximum for 32QAM.From the simulations we have MSE for 2db SNR with BPSK is 0.000108417 and for 2db SNR with 16QAM is 0.00092047.

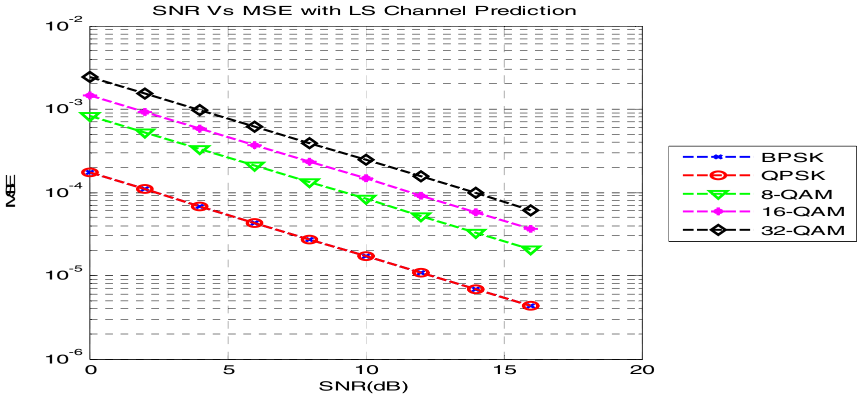


Fig 5. Plot of SNR Vs MSE with MMSE channel prediction

Table 4. Comparison Of modulation techniques using SNR Vs MSE

MOD	BPSK	QPSK	8QAM	16QAM	32QAM
SNR	**MSE**	**MSE**	**MSE**	**MSE**	**MSE**
0	0.000171832	0.000172143	0.000829511	0.00145891	0.00244717
2	0.000108417	0.000108613	0.000523377	0.00092047	0.00154404
4	6.84068e-005	6.85301e-005	0.000330222	0.000580746	0.000974206
6	4.3163e-005	4.32408e-005	0.000208352	0.000366402	0.000614671
8	2.72363e-005	2.72853e-005	0.000131459	0.000231167	0.000387823
10	1.7188e-005	1.72188e-005	8.2945e-005	0.000145844	0.000244695
12	1.08486e-005	1.0868e-005	5.23358e-005	9.20134e-005	0.000154389
14	6.84915e-006	6.86138e-006	3.30238e-005	5.80514e-005	9.74122e-005

IV. CONCLUSION

Channel prediction based on comb type pilot arrangement is presented by giving the channel estimation method at pilot frequency, channel prediction by kalman filter and the interpolation of the channel at data frequency. The simulation result shows that comb type pilot LS channel prediction with BPSK modulation performs best at lower SNR value but as the SNR value goes on increasing higher modulation techniques are preferred amongst mentioned modulation technique.

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