1-1-2004

An adaptive channel tracking method for MIMO- OFDM systems

Jun Tong

City University of Hong Kong, jtong@uow.edu.au

Yaohuan Gong

University of Electronic Science and Technology

Shengxian Sun

University of Electronic Science and Technology

An adaptive channel tracking method for MIMO- OFDM systems

Abstract

The tracking of the time-varying channel is crucial for MIMO-OFDM wireless communication systems. Aiming at doubly-selective fading MIMO channels, we present a novel pilot pattern and the corresponding adaptive channel tracking algorithm. Compared with the traditional pilot patterns, the new pattern has higher frequency efficiency and is more suitable for large transmit arrays. The computational complexity, frequency efficiency and BER performance of the system assisted by the proposed channel tracking scheme are analyzed. Simulation results demonstrate that the proposed scheme can track the timevarying channel effectively

Keywords

systems, tracking, adaptive, method, channel, mimo, ofdm

Disciplines

Engineering | Science and Technology Studies

Publication Details

J. Tong, Y. Gong & S. Sun, "An adaptive channel tracking method for MIMO- OFDM systems," in Communications, Circuits and Systems, 2004. ICCCAS 2004. 2004 International Conference on, 2004, pp. 354-358.

An Adaptive Channel Tracking Method for MIMO-OFDM Systems

Tong Jun
Department of Electronic Engineering,
City University of Hong Kong,
Tat Chee Avenue, Kowloon, Hong Kong SAR,
Email:eejtong@cityu.edu.hk

Gong Yaohuan, Sun Shengxian
College of Electronic Engineering,
University of Electronic Science and Technology
Chengdu, 610054, China.

Abstract-- **The tracking of time-varying channel is crucial for MIMO-OFDM wireless communication systems. In this paper aiming at the double-selective fading MIMO channels, a novel pilot pattern and the according adaptive channel tracking algorithm are presented. Compared with the traditional pilot patterns, the new pattern has higher frequency efficiency and is more suitable for large transmit arrays. The computation complexity, frequency efficiency and BER performance of the system assisted by the proposed channel tracking scheme are analyzed. Simulation results demonstrate that the proposed scheme can track the time varying channel effectively.**

Keywords: Space Frequency Codes, MIMO-OFDM, Adaptive Channel Tracking

I. INTRODUCTION

Future broadband wireless communication systems should be able to provide reliable high-data-rate transmissions at low cost in time and frequency selective wireless channel. Space frequency coded MIMO-OFDM systems can take advantages of the multipath fading effect to provide significant diversity gain and even coding gain [1] ,and have been regarded as one of the key techniques for B3G/4G wireless network. However, the accurate tracking of time varying MIMO channels is crucial for the performance of the systems. The channel tracking methods for MIMO OFDM systems have been well documented [2] [3] [4].But due to their high computation requirement [2] [4] or high spectral efficiency loss [3], these methods need to be further improved. In this paper, with analyzes of the signal model of MIMO OFDM systems, we proposed a novel adaptive channel estimation method based on pilot symbol assistance (PSA). When applied to MIMO environments, compared with the traditional PSA methods whose spectral efficiency loss increases linearly with the number of transmitter antennas, the proposed scheme has higher spectral efficiency and is especially attractive to systems with a large number of transmit antennas.

This paper is organized as follows. In section II we present the signal model for MIMO-OFDM systems in double-selective channels. In section III the novel adaptive channel tracking method is derived, and the computer simulation results are given in section IV. Conclusions are obtained in section V.

II. SYSTEM MODEL

Suppose that the MIMO-OFDM system is equipped with M_T transmitter antennas and M_R receiver antennas. The Single Input Single Output (SISO) channel between the qth transmitter antenna and the ith receiver antenna can be described as:

$$\mathbf{h}_{i,q}[n] = [h_{i,q}[n,0], h_{i,q}[n,1], \cdots, h_{i,q}[n,L-1]]^T \qquad (1)$$

where n is the OFDM symbol index, $i = 1,2,\cdots,M_R$, $q = 1,2,\cdots,M_T$, L is the order of Finite Impulse Response(FIR) channels and $[\bullet]^T$ means transpose. When the guard interval (N_g) exceeds the maximum time delay of the channel, the Inter-Symbol-Interference (IBI) can be neglected and the signal model in frequency domain can be described as:

$$Y_i[n,k] = \sum_{q=1}^{M_T} H_{i,q}[n,k] S_q[n,k] + V_i[n,k]$$
$$i = 1,2,\cdots,M_R, k = 0,1,\cdots,N-1 \qquad (2)$$

where $Y_i[n,k]$ donates the received signal at ith antenna,

$S_q[n,k]$ is the symbol transmitted by the qth transmitter antenna, and $H_{i,q}[n,k]=\sum_{l=0}^{L-1}h_{i,q}[n,l]e^{-j\frac{2\pi kl}{N}}$ is the channel frequency response at the kth subcarrier of nth OFDM symbol between the qth transmitter antenna and the ith receiver antenna. $V_i[n,k]$ is assumed to be the additive white Gaussian noise with mean zero and variance σ_V^2. The maximum likelihood decoding algorithm is employed to recover the transmitted symbols.

III. THE ADAPTIVE CHANNEL TRACKING METHOD FOR MIMO-OFDM SYSTEMS

A. The novel pilot pattern for MIMO-OFDM systems

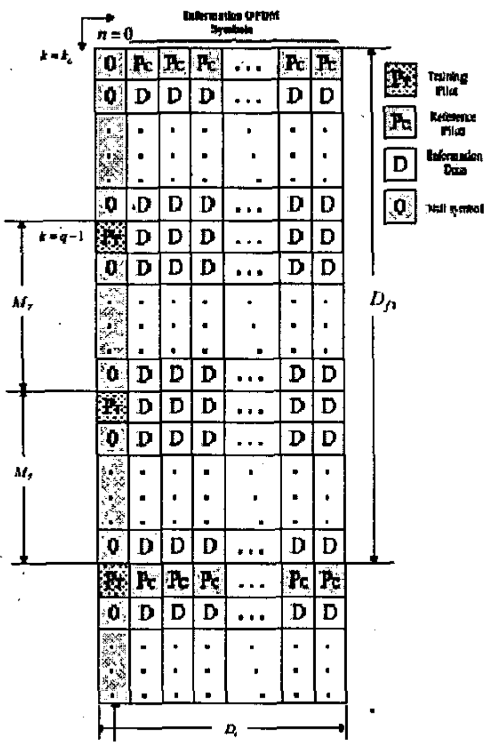

Fig.1 The pilot pattern for the q th transmitter antenna

Considering the characteristics of space frequency coded systems, we proposed the novel pilot pattern depicted in Fig.1. The OFDM symbols should be organized in frames each containing D_t OFDM symbols, and the first OFDM symbol in each frame should be the *Training OFDM Symbol* followed by D_t-1 *Information OFDM Symbols*. In training OFDM symbols, different subcarriers are allocated to different transmitter antennas. For simplicity, for the qth transmitter antenna the following $\overline{k}_{q,p}$th subcarrier can be selected to transmit the Training Pilots:

$$\overline{k}_{q,p}=q-1+pM_T,\ p=0,1,\cdots,\overline{P}-1,\ q=1,2,\cdots,M_T \qquad (3)$$

where $\overline{P}=\lfloor N/M_T\rfloor$ indicates the number of *Training Pilots* for each transmitter antenna and N donates the number of subcarriers of each OFDM symbol. The signal transmitted on the remaining subcarriers should be *Null Symbols* with zero amplitude. The following OFDM symbols in each frame are *Information OFDM Symbols*. In our scheme, all the transmitter antennas share the same $P=\lfloor N/D_{f1}\rfloor$ subcarriers to undertake the *Reference Pilots*, the indexes of the subcarriers allocated are:

$$k_p=pD_{f1},\ p=0,1,\cdots,P-1 \qquad (4)$$

where D_{f1} is the distance between two adjacent *Reference Pilot subcarriers*. Thus, the spectral efficiency loss is:

$$\xi=\frac{N+(D_t-1)P}{D_tN} \qquad (5)$$

Notice that the transmitter antenna number M_T has no influence on ξ that distinguishes the novel scheme from the one introduced in [3] where the loss is proportional to M_T.

B. The adaptive channel tracking scheme

Based on the pilot pattern described above, the adaptive channel tracking scheme contains the following 2 steps:

Step1: The LS estimation of MIMO channel at the Training OFDM Symbol.

Using the known Training Pilots and the corresponding received symbols, the frequency response for the $\overline{k}_{q,p}$th subcarrier can be estimated using Least Square (LS) method as:

$$\hat{H}_{i,q}[n,\overline{k}_{q,p}]=\frac{Y_i[n,\overline{k}_{q,p}]}{S_q[n,\overline{k}_{q,p}]}$$

$$n=0\,,i=1,2,\cdots,M_R,q=1,2,\cdots,M_T \qquad (6)$$

Let $\hat{\mathbf{H}}_{i,q}=[\hat{H}_{i,q}[n,\bar{k}_{q,0}],\hat{H}_{i,q}[n,\bar{k}_{q,1}],\cdots,\hat{H}_{i,q}[n,\bar{k}_{q,\bar{P}-1}]]^T$, we can easily get the time domain channel response between the qth transmit and the ith receiver antenna:

$$\hat{\mathbf{h}}_{i,q}[n]=\left(1/\bar{P}\right)\mathbf{W}_q^H\hat{\mathbf{H}}_{i,q} \quad i=1,2,\cdots,M_R,q=1,2,\cdots,M_T \qquad (7)$$

where $\mathbf{W}_q$ is a $\bar{P}\times N$ matrix whose (k,m)th element is:

$$[\mathbf{W}_q]_{k,m}=e^{\frac{-j2\pi}{N}(q-1+kM_T)(m-1)} \qquad (8)$$

and $\hat{\mathbf{h}}_{i,q}[n]=[\hat{h}_{i,q}[n,0],\ \hat{h}_{i,q}[n,1],\ \cdots,\ \hat{h}_{i,q}[n,N-1]]^T$ is an $N\times 1$ complex vector consisting of N estimated fading coefficients. However, in real wireless environments, the number of fading paths is limited and thus most of the estimated coefficients in $\hat{\mathbf{h}}_{i,q}[n]$ might be the estimation error. The Significant Taps Catch (STC) technique [2] is employed in the scheme to pick out $\bar{L}$ paths with larger power gains $\left|\hat{h}_{i,q}[n,\bar{l}]\right|^2$. After STC the channel coefficients can be donated by the vector pairs:

$$\left[l_{i,q,1},l_{i,q,2},\cdots,l_{i,q,\bar{L}}\right]^T \qquad (9)$$

and $\hat{\mathbf{h}}_{i,q}[n]=[\hat{h}_{i,q}[n,l_{i,q,1}],\hat{h}_{i,q}[n,l_{i,q,2}],\cdots,\hat{h}_{i,q}[n,l_{i,q,\bar{L}}]]^T$ (10)

for each $q=1,2,\cdots,M_T$ and each $i=1,2,\cdots,M_R$. STC technique is able to reduce the estimation error and the complexity of the adaptive tracking process significantly.

Step 2: The adaptive tracking of the time varying MIMO channel at the Information OFDM Symbols.

For each Information OFDM Symbol ($n=1,2,\cdots,D_t-1$), based on the results obtained by step 1 the time domain adaptive tracking algorithm presented below is resorted to tracking the time varying channels. The following procedure will be repeated for each receiver antenna to update the channel estimation. Taking the STC results into consideration, the estimation of the MISO channel between the M_T transmitter antennas and receiver antenna i can be rewritten as:

$$\hat{\mathbf{h}}_i[n]=[\hat{\mathbf{h}}_{i,1}^T[n],\hat{\mathbf{h}}_{i,2}^T[n],\cdots,\hat{\mathbf{h}}_{i,M_T}^T[n]]^T \qquad (11)$$

Assuming that the Minimum Mean Square Error (MMSE) criterion is employed, the cost function of the estimation is:

$$J(\hat{\mathbf{h}}_i[n])=E\{|Y_i[n,k_p]-\hat{Y}_i[n,k_p]|^2\} \qquad (12)$$

where

$$\hat{Y}_i[n,k_p]=\sum_{q=1}^{M_T}S_q[n,k_p]\hat{H}_{i,q}[n,k_p]=\hat{\mathbf{h}}_i^T[n]\mathbf{w}_p[n] \qquad (13)$$

for $p=0,1,\cdots,P-1$ and

$$\mathbf{w}_p[n]=\left[\mathbf{w}_{1,p}^T[n],\mathbf{w}_{2,p}^T[n],\cdots,\mathbf{w}_{M_T,p}^T[n]\right]^T \qquad (14)$$

$$\mathbf{w}_{q,p}[n]=\begin{bmatrix} S_q[n,k_p]e^{\frac{-j2\pi}{N}k_pl_{i,q,1}},S_q[n,k_p]e^{\frac{-j2\pi}{N}k_pl_{i,q,2}}, \\ \cdots,S_q[n,k_p]e^{\frac{-j2\pi}{N}k_pl_{i,q,\bar{L}}} \end{bmatrix}^T \qquad (15)$$

Substitute (13) into (12), we arrive at the new cost function:

$$J(\hat{\mathbf{h}}_i[n])=E\{|Y_i[\mathrm{n},k_p]-\hat{\mathbf{h}}_i^T[n]\mathbf{w}_p[n]|^2\} \qquad (16)$$

In order to approximate the optimal estimation of the channel coefficients in the sense of minimizing the cost function (16), random gradient method and the according LMS-Like algorithm is employed. Let $\hat{\mathbf{h}}_i[n,p]$ be the estimation of optimal $\hat{\mathbf{h}}_i[n]$ after p times iteration, the instantaneous estimate of the gradient vector of

$$J(\hat{\mathbf{h}}_i[n,p])=|Y_i[n,k_p]-\hat{\mathbf{h}}_i^T[n,p]\mathbf{w}_p|^2 \qquad (17)$$

is:

$$\hat{\nabla}J(\hat{\mathbf{h}}_i[n,p])=-2\mathbf{w}_p^*[n]Y_i[n,k_p]+2\mathbf{w}_p[n]\mathbf{w}_p^H[n]\hat{\mathbf{h}}_i[n,p] \qquad (18)$$

Here $[\bullet]^*$ donates the vector conjugate.

Let $$e[n,p]=Y_i[n,k_p]-\mathbf{w}_p^T[n]\hat{\mathbf{h}}_i[n,p] \qquad (19)$$

The estimation is updated as:

$$\hat{\mathbf{h}}_i[n,p+1]=\hat{\mathbf{h}}_i[n,p]+\mu[-\hat{\nabla}J(\hat{\mathbf{h}}_i[n,p])]$$

$$=\hat{\mathbf{h}}_i[n,p]+2\mu\mathbf{w}_p^*[n]e[n,p] \qquad (20)$$

where μ donates the step size of the LMS-like adaptive algorithms, to ensure the convergence of algorithm, μ should be carefully selected to satisfy (21) [6]:

$$0<\mu<\frac{2}{\mathbf{w}_p^H[n]\mathbf{w}_p[n]} \tag{21}$$

With analyzing (14), μ is selected to satisfy

$$0<\mu<\frac{1}{M_T\tilde{L}} .$$

Since usually the channel varies continuously between successive OFDM symbols, it's reasonable to initialize the estimation in the current OFDM symbol by the estimation results in the previous OFDM symbol, i.e.

$$\hat{\mathbf{h}}_i[n,0]=\hat{\mathbf{h}}_i[n-1] \tag{22}$$

For each of the M_T receiver antennas, after P times iterations the ultimate estimation in nth OFDM symbol is obtained by (23):

$$\hat{\mathbf{h}}_i[n]=\hat{\mathbf{h}}_i[n,P] \tag{23}$$

With the time domain estimation results, using FFT we can easily get the estimation of the frequency response $\hat{H}_{i,q}[n,k]$ of the time varying MIMO channels [5].

IV SIMULATION RESULTS

Notice that when the results of STC and the Reference Pilots are fixed, the adaptive tracking problem is an adaptive filtering problem with determined input signals. The performance analyses of such problems can be referred to [7]. For the LMS-Like algorithm, the ultimate estimation for nth OFDM symbol is given by (24)

$$\hat{\mathbf{h}}_i[n]=\mathbf{F}_{P-1,0}[n]\hat{\mathbf{h}}_i[n,0]+2\mu\sum_{m=0}^{P-1}Y[n,k_m]\mathbf{F}_{P-1,m+1}[n]\mathbf{w}_m^*[n] \tag{24}$$

where $\mathbf{F}_{i,m}[n]=\begin{cases}\prod_{k=m}^{j}(\mathbf{I}-2\mu\mathbf{w}_k^*[n]\mathbf{w}_k^T[n]), & j\geq m\\ \mathbf{I}, & j<m\end{cases}$

To demonstrate the performance of the scheme proposed, computer simulations have been conducted. A space frequency trellis coded MIMO-OFDM system with QPSK constellation, 16 states, 2 transmitter antennas and 2 receiver antennas is used. The channel is generated following the ITU-Vehicular Channel B [8] Raleigh fading channel model. The 5MHz wideband channel is divided into $N=1024$ subchannels, $N_g=40$ and $f_c=2150\,\mathrm{MHz}$. The receiver signal-to-noise-ratio (SNR) is defined as:

$$\mathrm{SNR}=\frac{E\left\{\sum_{q=1}^{M_T}\left|H_{i,q}[n,k]\right|^2\left|S_q[n,k]\right|^2\right\}}{\sigma_V^2}$$

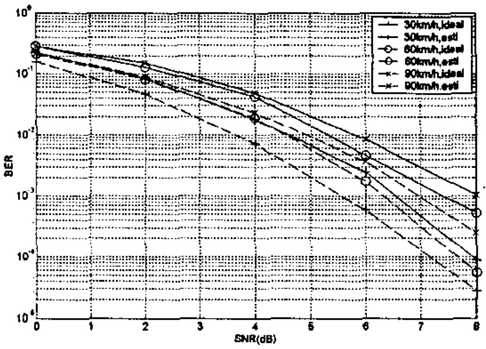

Fig.2 BER versus SNR with different vehicular speed

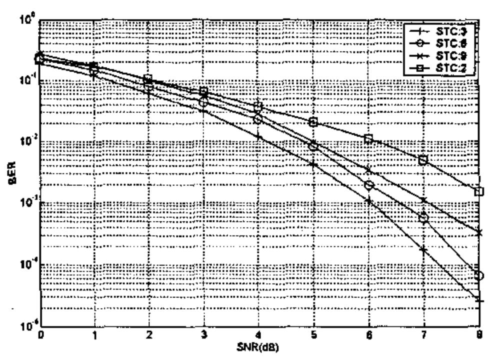

Fig.3 BER versus SNR with different $\tilde{L}$ (30km/h)

Fig.2 shows the Bit Error Rate (BER) results of the system with the tracking approach proposed in this work. In each information OFDM symbol, 64 reference pilots are used for the LMS-Like tracking algorithm with $\mu=0.02$ and $\tilde{L}=6$. The spectral efficiency loss is 8.6%. There is about 1dB SNR gap for the systems using the ideal and estimated channel coefficients with different Doppler frequency (60Hz, 120Hz, and 180Hz). To obtain the estimation $\hat{H}_{i,q}[n,k]$, $(2P\tilde{L}+N/2\log_2[N])/N$ (=5.744) times complex multiplication are required. However, only 0.744 time complex multiplication of them is consumed by the adaptive algorithm and the remaining are necessary for all FFT assisted channel estimation schemes.

Fig.3 illustrates the BER performance with different $\tilde{L}$. The pilot pattern is the same with that in Fig.2. The order of the simulation channel is 3. As observed, the STC technique is able to improve the performance dramatically.

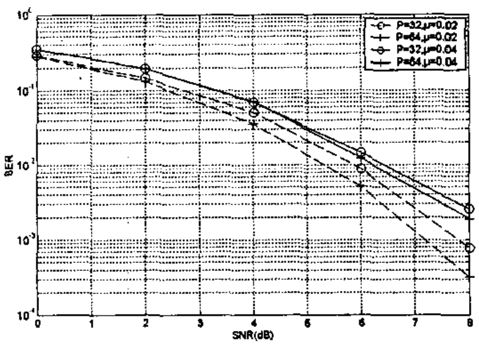

Fig.4 BER versus SNR with different algorithm parameters (60km/h)

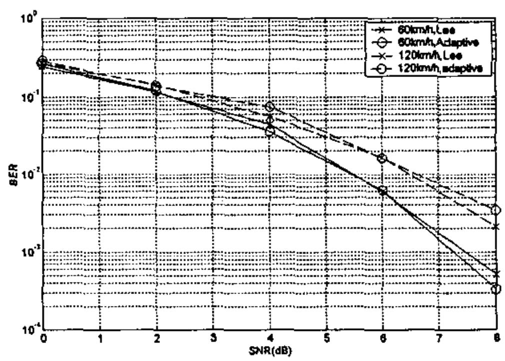

Fig.5 The comparison of the novel scheme with Lee's method

From Fig.4, it is obvious that the performance is more sensitive to step size than to the number of reference pilots. Thus, proper step size can further improve the spectral efficiency.

In Fig.5, the adaptive scheme is compared with Lee's method presented in[3]. The spectral efficiency losses are 8.6% and 10% respectively. μ is set to 0.02. Fig.5 shows that the two schemes have almost the same performance in the term of BER. But the adaptive method is more attractive to systems with large transmitter arrays.

V Conclusions

Based on the signal characteristics of Space Frequency Coded MIMO-OFDM systems, a novel pilot pattern and its corresponding adaptive channel tracking scheme are proposed. Computer simulations show that the scheme work well for time varying MIMO channels. Furthermore, the STC technique and proper step size for LMS-Like tracking algorithm can improve system performance effectively. The scheme has high spectral efficiency since different transmitter antennas share the same reference pilot subcarriers.

References

[1] H. Bolcskei and A.J.Paulraj, "Space-frequency coded broadband OFDM systems", *IEEE WCNC*. vol. 1, 23-28, pp.1-6, Sept. 2000

[2] Y. (G.) Li, "Simplified Channel Estimation for OFDM Systems with Multiple Transmit Antennas", *IEEE Trans. On Wireless Commum*, vol. 1, pp.67-75, Jan.2002

[3] K.F.Lee and D.B.Williamos, "Pilot-Symbol-Assisted Channel Estimation for Space-Time Coded OFDM Systems," *EURASIP Journal on Applied Signal Processing* 2002:5,507-516

[4] H. Bölcskei, R W. Heath, and A. J. Paulraj, "Blind Channel Identification and Equalization in OFDM-Based Multi-antenna Systems", *IEEE Trans on Signal Processing*, vol. 50, pp 96-109, Jan 2002

[5] O.Edfors, et al, "Analysis of DFT-Based Channel Estimations for OFDM", *Wireless Personal Communications* 12 pp55-70, 2000

[6] S. Haykin "*Adaptive Filter Theory*", Third edition, Prentice Hall 1998

[7] S. Olmos and P. Laguna, "Steady-State MSE Convergence of LMS Adaptive Filters with Deterministic Reference Inputs with Applications to Biomedical Signals", *IEEE Trans On Signal Processing*, pp2229-2241 Vol. 48, No. 8, Aug 2000

[8] "Evaluation Methodology for IMT-2000 Radio Transmission Technologies", http://www.arib.or.jp/