USING LMS WEIGHTING VALUES AS THE CHANNEL STATE INFORMATION FOR OFDM BASED SYSTEMS

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ABSTRACT

In this paper, the Viterbi decoder with aided channel state information (CSI) for OFDM based system is investigated. The CSI is obtained from the weighting values of one-tap frequency domain LMS equalizers on different subcarriers. Comparing to the conventional soft decision Viterbi decoding, the proposed method has better performance due to the different reliabilities. In the simulations, we also compare the circumstances with various CSI sources. By keep updating weighting values, we could observe that the proposed method gains the better performance in contrast to other manners. In addition, the time-average method is used to estimate the CSI more precisely.

1. INTRODUCTION

In high data rate wireless applications, the Orthogonal Frequency Division Multiplexing (OFDM) technique has been played a major role. OFDM modulation has adopted by the IEEE for the extension of 802.11 wireless local network (WLAN) standard to the 5-GHz band (IEEE 802.11a) [1], provided data rates up to 54 Mbps. The other standard of IEEE, e.g. 802.11g [2], 802.16 [3], also adopted the OFDM scheme as well.

The basic idea of OFDM is to divide the available spectrum into several sub-channels (subcarriers). By making each subcarrier narrowband, we could regard it as experiencing almost flat fading, which is easier to implement for the equalizer. Later, the application of discrete Fourier transform makes each subcarrier orthogonal in frequency domain. This procedure not only achieves the modulation and multiplexing at the same time, but also greatly reduces the bandwidth required. Furthermore, the insertion of cyclic prefix helps the OFDM signal to combat inter-symbol interference (ISI) and keep orthogonality under multi-path fading channel.

In presence of channel fading, each subcarrier is experiencing different channel condition. Some subcarriers will undergo deep fading, while others are going to be enhanced. Accordingly, we give the higher reliability for the data transmitted through the subcarrier with higher signal-to-noise ratio (SNR). And the data modulated onto a subcarrier with lower SNR will having a lower reliability. This extra reliability information is called channel state information (CSI).

Here we utilize the weighting values of one-tap frequency domain LMS equalizers as CSI. Through updated process and time-average method, it could reflect the channel effect more accurately. In other papers, CSI is derived from the known signals of OFDM standardization [4] and the error signals from adaptive filter [5]. However, these methods have drawbacks. When use the known signals, like long training symbols as CSI, since they only estimate the channel condition with long training symbols and will not be updated in every OFDM symbols, estimation incorrect always happens. And the usage of error signal will come with the problem that the error bit spreads because of once hard decision error. We will also compare the performances influenced by different CSI sources.

The paper is organized as follows. In section 2, the weighting value aided OFDM system is described. The Viterbi decoder theory and mathematic formulation is presented in section 3. Simulation results with different modulations and case comparisons are contained in section 4. Section 5 concludes the paper.

2. SYSTEM BLOCK

The baseband block diagram of the receiver used in this paper is presented in Fig. 1. The framework and the simulations are under IEEE 802.11a standardization. We use the exponentially decaying Rayleigh fading channel as channel model [6]. Moreover, we also add the effects that OFDM receiver will encounter: carrier frequency offset (CFO) and sampling frequency offset (SFO) [7].

At the receiver side, cyclic prefix part is removed before entering FFT. After FFT, CSI is obtained by calculating the value of the long training symbols on each subcarrier [8]. Frequency domain equalizer we used

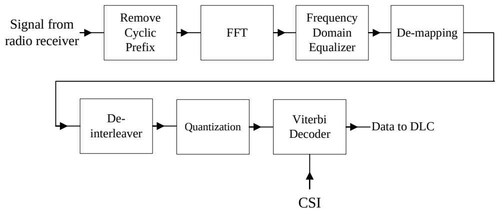

Fig.1. Baseband model for CSI aidedOFDM receiver.

here is one-tap least mean square (LMS) equalizer, which the initial value is also estimated by long training symbols. From [9] we knew that the weighting value for one-tap frequency domain LMS equalizer not only updates every OFDM symbol interval, but also reflects the channel condition. Therefore, we applied this characteristic as CSI. In the statistic point of view, it results in with more accurate CSI compare to two long training symbols.

In the de-mapping block, we used BPSK and QPSK demodulation. Each input value has to transfer to a sequence of soft decision values, which is suitable for Viterbi decoder to calculate the branch metric [10].

6-bit quantization level is used here. In many papers [5], 6-bit quantization is approximate to floating point quantization. In the last Viterbi decoder block, the CSI for each subcarrier is derived by taking the absolute value and reciprocal of LMS weighting value. This information is added after branch metric calculation in the Viterbi algorithm. The subcarrier with higher CSI means the data transmitted on that frequency has higher reliability. Thus, a higher CSI is multiplied to enlarge the metric difference after branch metric calculation, which makes the Viterbi decoder easier to distinguish the correct and error bits. For the same reason, lower CSI represents the lower reliability. So the CSI is multiplied to limit the branch metric. Finally, the data forms the received bit stream passed to the data link control (DLC) layer.

3. VITERBI DECODING USING CSI

A. LMS ALGORITHM

The LMS algorithm is the most widely used adaptive filtering algorithm in practice. This wide spectrum of applications of the LMS algorithm can be attributed to its simplicity and robustness to signal statistics. In our one-tap LMS frequency domain adaptive equalizer, the filter input $X_{k,l}$, hard decision output of filter output $d_{k,l}$, and the filter output

$$Y_{k,l} = w_{k,l}^{*} X_{k,l} \tag{1}$$

are assumed to be complex values, where *k* and *l* are represented as the *k-th* subcarrier and *l-th* OFDM symbol respectively.

The tap weight $w_{k,l}$ is selected so that when calculate the mean square of error signal

$$e_{k,l} = d_{k,l} - Y_{k,l}, \tag{2}$$

it is minimized. The recursively updated tap weights are

$$w_{k,l+1} = w_{k,l} + \frac{\tilde{\mu}}{\langle P_k \rangle} e_{k,l}^{*} X_{k,l}, \tag{3}$$

where $\tilde{\mu}$ is called the initial step size and $\langle \cdot \rangle$ is the time-average function. P_k is the signal power on *k-th* subcarrier first estimated by long training symbols, then will be time-averaged by incoming input signal power.

The structure of one-tap frequency domain LMS equalizer is from [11] [12]. There is a one-tap frequency domain LMS equalizer on each subcarrier after FFT. The initial weighting value of filter is estimated by long training symbols after FFT. Meantime, the data value in frequency domain is passing through the equalizer. First, the pilot signals of equalized signal are calculated to estimate the amount of phase shift and compensate simultaneously. Then, the hard decision value is feedback to updated weighting block to calculate the error signal and acquire the next equalizer weighting value.

B. CSI aided Viterbi decoding

The optimum decoding of a convolution encoder involves a path searching through the trellis with greatest probability, or minimum accumulated metric in other words. Thus, in Viterbi decoder, we could model the probability of received bits as a likelihood function [13]

$$p(r_1, r_2, \ldots, r_K \mid \mathbf{s}^{(m)}) = \prod_{k=1}^{K} p(r_k \mid s_k^{(m)}), \tag{4}$$

where r_k represents the *k-th* equalized bit and $\mathbf{s}^{(m)}$ is the transmitted bit sequence. As we known from the central limit theorem (CLT), when under AWGN channel, we could rewrite the equation (4) as

$$\begin{aligned} p(r_1, r_2, \ldots, r_K \left| \mathbf{s}^{(m)} \right.) &= \prod_{k=1}^{K} \frac{1}{\sigma_n \sqrt{2\pi}} \exp[-\frac{(r_k - \bar{s})^2}{2\sigma_n^2}] \\ &= (\frac{1}{\sigma_n \sqrt{2\pi}})^K \exp[-\sum_{k=1}^{K} \frac{(r_k - \bar{s})^2}{2\sigma_n^2}], \end{aligned} \tag{5}$$

where σ_n is the standard deviation of Gaussian noise. For BPSK and QPSK signal, $\bar{s}$ is the equalized mean value {+1,-1} on one subcarrier. By taking the natural log of equation (5)

$$\ln(p(r_1, r_2, ..., r_K \left| \mathbf{s}^{(m)} \right.)) = K \ln(\frac{1}{\sigma_n \sqrt{2\pi}}) - \sum_{k=1}^{K} \frac{(r_k - \overline{s})^2}{2\sigma_n^2}, \quad (6)$$

we have to find the greatest value in the right hand side of the equation (6) to obtain the sequence with maximum probability. In Viterbi algorithm, the first term in the right hand side of equation (6) is equivalent to add the same quantity when calculating the metric. Hence we neglect the effect of it. In general, we also neglect the variance of second term in the right hand side of equation (6) and calculate the Euclidean distance instead. However, in OFDM transmission, except for the noise influence, the standard deviation differs from each subcarrier due to various conditions like CFO, SFO, step size…etc. Consequently, we can not ignore the variance term in the denominator in second term and we will change the parameter σ_n to $\sigma_{n,k}$ Still, an maximum likelihood based algorithm which selects the sequence $\mathbf{s}^{(m)}$ that minimize the Euclidean distance metric is shown

$$D(\mathbf{r}, \mathbf{s}^{(m)}) = \sum_{k=1}^{K} \frac{(r_k - \overline{s})^2}{2\sigma_{n,k}^2}. \quad (7)$$

where $\sigma_{n,k}^2$ is the variance on *k-th* subcarrier. Because the term $\sigma_{n,k}^2$ is influenced by many effects and can not be estimate exactly, we will use the CSI to reflect it.

When data transmitted on subcarriers, every subcarrier suffers distinct channel fading degree. So if we view each subcarrier with the same reliability, except for that the situation will not be reflected, the decoding error probability increases also. Accordingly, we will utilize the weighting value of one-tap frequency domain LMS equalizer to respond the situation. From [9], the optimum mean value for one-tap LMS equalizer is

$$(w_o)_{k,l} = \frac{\left| H_k \right| e^{j\phi_{k,l}}}{\left| H_k \right|^2 + \sigma_N^2}, \quad (8)$$

where H_k represents the channel condition for different subcarrier and $\phi_{k,l}$ is the phase shift according to *k-th* subcarrier and *l-th* OFDM symbol. If we do not consider the noise and phase shift terms, $(w_o)_{k,l}=1/|H_k|^*$. So we took the absolute and reciprocal of equation (8) to reflect the different CSI on each subcarrier. Moreover, since the weighting value of LMS equalizer is an instantaneous value and it will be affected by the noise. So we also used the time-average method in equation (9) to avoid this situation.

$$\overline{C}_{k,l+1} = \alpha \overline{C}_{k,l} + (1-\alpha) \frac{1}{\left| w_{k,l+1} \right|^2}, \quad (9)$$

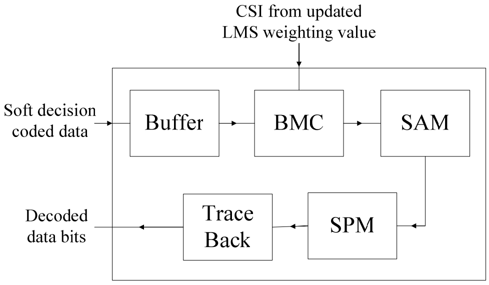

Fig. 2. CSI aided Viterbi decoder.

where $\overline{C}$ and w are absolute value of time-averaged CSI and incoming weight respectively, α is called forgetting factor, $0<\alpha<1$. For more clearly understanding, the block diagram of Viterbi decoder with CSI is shown in Fig. 3. The CSI is multiplied in branch metric calculation (BMC) block, and then the parameter is stored in the state accumulated metric (SAM). Survival path matrix (SPM) is used to record the input data bit and trace back length is equal to 5*K* [14], where *K* is constraint length of the convolution encoder.

4. SIMULATION RESULTS

In IEEE 802.11a standard [1], several different transmission modes are defined by selecting different code rate and modulation schemes. In this paper, we focus on BPSK and QPSK modulation with 1/2 code rate. Convolution encoder with constraint length K=7 is used. FFT length is 64. The power of transmitted data are normalized to unit and 1/4 guard interval length is included. Bit interleaver mechanism and long training symbols are also added.

The simulation results are preformed under Rayleigh fading channel with sampling interval T_s=50*ns* and root-mean-square time T_{RMS}=50*ns*. The CFO and SFO effects are also simulated. The CFO effect is 0.01 with respect to the normalized carrier frequency spacing, which means the CFO is 3.125 KHz and SFO amount is 800 Hz shift. At the receiver side, the 6-bit quantization Viterbi decoder with trace back length 35 is applied.

Fig.3 is the performance curve in BPSK modulation. Transmission data amount are 1000 packets with 256 bytes in each packet. The $\tilde{\mu}$ in equation (3) for LMS equalizer is 0.1, which differs from subcarriers due to different channel conditions and the forgetting factor for the time-average function is 0.8. The legend ‘error’ represents the error signal from equation (2) to obtain the CSI

$$CSI_{e,k} = \frac{1}{\left\langle \left| e_{k,l} \right|^2 \right\rangle} \quad (10)$$

And the legend 'long train' means the CSI is estimated from long training symbols [8], where long training symbol is derived after FFT. Our proposed method is marked as legend 'weighting'. These legends will be used in the following figures also. Fig.3(a) and 3(b) are *Eb/No* v.s. bit error rate and packet error rate respectively. Three different CSI sources are presented: the error signal from LMS equalizer, two long training symbols and the weighting values of LMS equalizer.

From Fig.3, we could observe that under low signal-to-noise ratio (SNR) environment, the CSI from LMS weighting and long training symbols performs about the same. The reason is because when SNR is low, the main behavior of one-tap equalizer is to suppress the noise, not to compensate the channel effect [15]. Therefore, the LMS weighting can not reflect the channel condition correctly. But when SNR is getting higher, the LMS weighting could reflect the channel more clearly. In Fig.3(a), under BER=10^{-4}, the proposed method gains about 0.3dB and 8dB comparing to CSI from long training symbols and LMS error signal. Fig.3(b) shows the PER v.s. *Eb/No* plot. When under PER=10^{-2}, 0.6dB and 5.8dB gain are earned by proposed approach comparing to CSI from long training symbols and LMS error signal.

The QPSK modulated performance curve is shown in Fig4 and the simulation settings are the same as in Fig.3. Also, the differences of three CSI sources are plotted. The QPSK modulation scheme has the same trend as BPSK modulation. In Fig.4(a), about 0.8dB and 6dB gain are obtained in contrast to CSI from long training symbol and LMS error signal under BER=10^{-4}. Fig.4(b) shows that when PER=10^{-2}, there are about 0.3dB and 3.3dB difference.

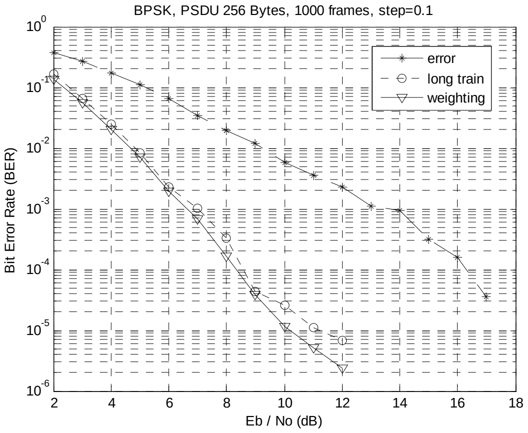

Fig. 3(a). *Eb/No* v.s. BER in BPSK

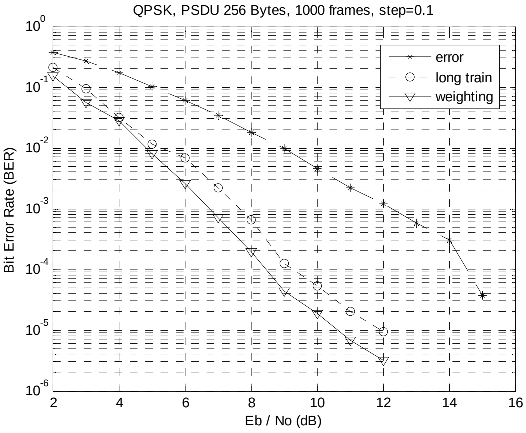

Fig. 4(a). *Eb/No* v.s. BER in QPSK

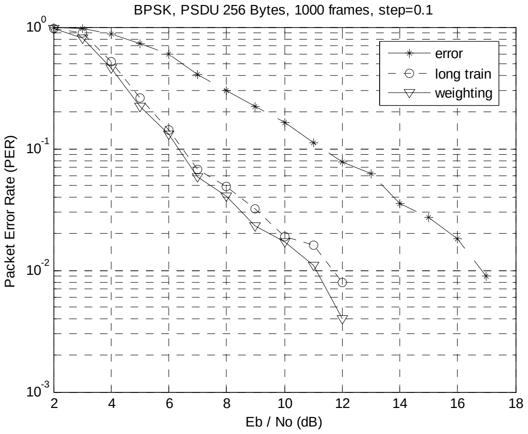

Fig. 3(b). *Eb/No* v.s. PER in BPSK

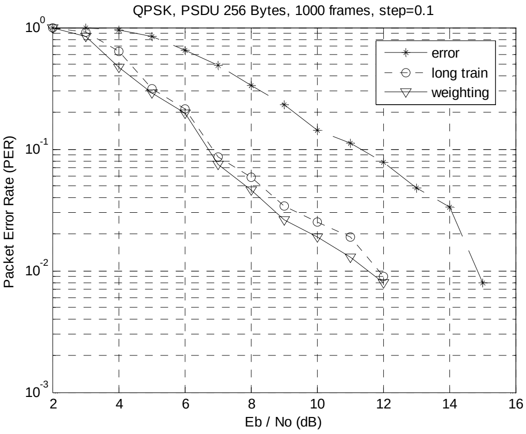

Fig. 4(b). *Eb/No* v.s. PER in QPSK

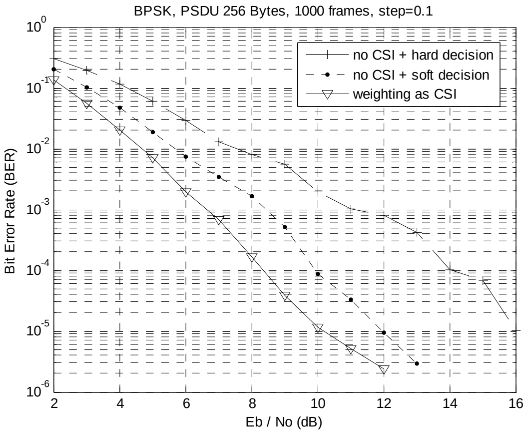

Fig. 5(a). Conventional v.s. CSI aided in BPSK

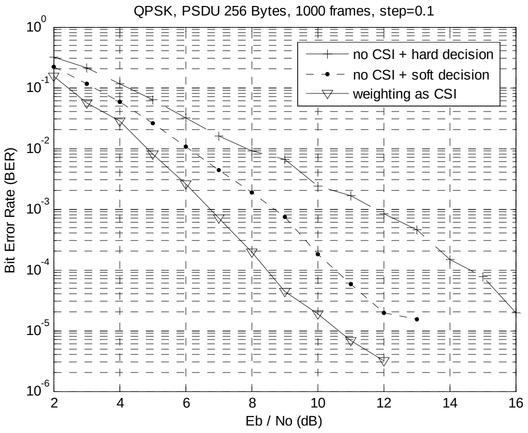

Fig. 5(b). Conventional v.s. CSI aided in QPSK

Fig.5 presents the simulation results of the conventional Viterbi decoding with hard and soft decision and our method. The traditional soft decision Viterbi decoding and CSI aided Viterbi decoding are quantized by 6 bits. The simulation surroundings are identical in Fig. 5(a) and 5(b). As we could observe in both charts, under the BER=10^{-4} state, CSI aided Viterbi decoding has about 6dB and 1.5dB gain compare to conventional hard and soft decision decoding respectively.

In Fig. 6, we analyzed the performance of forgetting factor for time-average function v.s. BER under E_b/N_o = 5dB in QPSK modulation. As shown in the plot, though the BER dissimilarity between every forgetting factor is not obvious, the system achieves the best performance when forgetting factor is 0.8. That means for each incoming weighting value, we combine the 20% of it and 80% of previous time-averaged one to form the new weighting value.

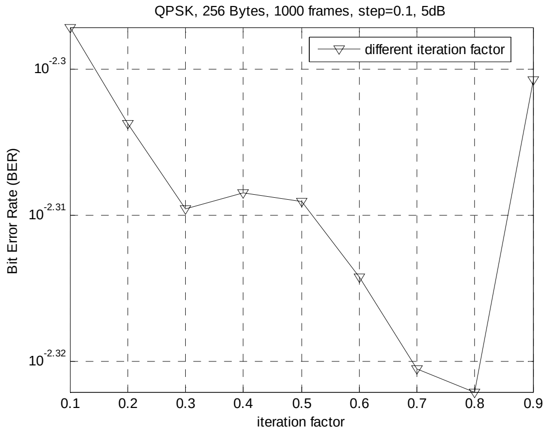

Fig.6. Forgetting factor v.s. BER

5. CONCLUSIONS AND FUTURE WORKS

In this paper, the updated CSI aided Viterbi decoder is presented. From every receiving OFDM symbol, the CSI could be renewed from the weighting value of one-tap frequency domain LMS equalizer. By using this extra reliability, we could give different weights on branch metric calculation in Viterbi decoder. We also compared some other CSI acquired methods mentioned in other papers. The CSI from two long training symbols can not estimate the channel state exactly due to its limited symbol points. Using LMS error signal as CSI has the error spreading problem. Besides, we used the simulation to assist our argument. As shown in the figures, the proposed method has better achievement than two other methods.

In the future, we will simulate the environments with different modulation constellations like 16 QAM, 64 QAM and code rates like 2/3, 3/4 as defined in [1]. Furthermore, we are going to analysis the different time-average methods to find the perfect one for this system.

REFERENCES

[1] IEEE Std. 802.11a-1999, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High Speed Physical in the 5 GHz Band.

[2] IEEE Std. 802.11g-2003, Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications: Further Higher-Speed Physical Layer Extension in the 2.4 GHz Band.

[3] IEEE Std. 802.16-2001, Part 16: Air interface for fixed broadband wireless access systems.

[4] Weon C. Lee, Hyung M. Park, Kyung J. Kang and Kuen B. Kim, "Performance Analysis of Viterbi Decoder Using Channel State Information in COFDM System," *IEEE Transactions on Broadcasting*, vol. 44, no.4, Dec. 1998.

[5] M.R.G. Butler, S. Armour, P.N. Fletcher, A.R. Nix and D.R. Bull, "Viterbi Decoding Strategies for 5 GHz

Wireless LAN Systems," *IEEE VTC 54th*, vol. 1, pp. 77-81, 2001.

[6] Nafali Chayat, Task Group A Chair, "Tentative Criteria for Comparison of Modulation Methods," IEEE 802.11-97/96

[7] Shou-Yin Lin, Jong-Wha Chong, "A study of joint tracking algorithms of carrier frequency offset and sampling clock offset for OFDM-based WLANs," in Proc. *IEEE 2002 Int. Conf. on Communications, Circuits and Systems and West Sino Expositions*, vol.1, pp. 109-113, 2002.

[8] Max Belotserkovsky, "An equalizer initialization algorithm for OFDM receivers," *IEEE Transactions on Comsumer Electronics*, vol. 48, isu. 4, Nov, 2002.

[9] Fang-Wei Huang, Yung-An Kao, "Analysis of one-tap frequency domain LMS equalizer on OFDM systems," master thesis, Chang-Gung University, pp.25-28, 2004.

[10] Richard van Nee and Ramjee Prasad, *OFDM for wireless multimedia communications*, Artech house universal personal communications library, pp.60-70, 2002.

[11] Y. A. Kao, S. K. Lee, C. L. Hsiao and P. L. Chio, "One-Tap Frequency Domain LMS Equalizer for OFDM systems," *ISCOM*, Taiwan, 2003.

[12] Y. A. Kao, C. H. Su, S. K. Lee, C. L. Hsiao and P. L. Chio, "A robust design of inner receiver structure for OFDM systems," *Digest of technical papers, ICCE*, pp.377-378, 2005.

[13] John G. Prokis, *Digital Communications 4th edition*, McGraw-Hill, 2001.

[14] Shu Lin, Daniel J. Costello, *Error Control Coding: Fundamentals and Applications*, Prentice-Hall, 1983.

[15] Saeed V. Vaseghi, *Advanced Digital Signal Processing and Noise Reduction 2nd edition*, John Wiley & Sons, pp. 192-195, 2000.