Low Complexity Channel Estimation Method for IEEE 802.11p Vehicle Communications

Chi-Min Li
Dep. of Communications, Navigation and Control Engineering,
National Taiwan Ocean University, Taiwan

Feng-Ming Wu
Dep. of Communications, Navigation and Control Engineering,
National Taiwan Ocean University, Taiwan

***Abstract*—Modern Intelligent Transportation System (ITS) uses the wireless communication technologies to increase the traffic safety and the transportation efficiency. However, the doppler effect and the multipath fading problems severely attenuate the received signal in the vehicle communication environments. Therefore, channel estimation is a critical issue should be solved properly to improve the Bit Error Rate (BER) performance at the receiver. Basically, ITS adopted the IEEE802.11p standard as its protocol and it defines the preamble with a specific format to conduct the channel estimation. Besides, four pilot subcarriers transmitted along with the Orthogonal Frequency Division Multiplexing (OFDM) system can also be used during the channel estimation. In this paper, a low computational complexity channel estimation method is proposed for the IEEE802.11p vehicle communications. The proposed method belongs to the frequency domain channel estimation and uses the preamble and pilot subcarriers defined in IEEE802.11p for the initial estimation and the time-varying adjustment for the channel. The method has the low-complexity advantage and a satisfactory BER performance compared with the related Cyclic Prefix (CP) based channel estimation method.**

Keywords—Channel Estimation; IEEE802.11p; OFDM

I. INTRODUCTION

Intelligent Transportation System (ITS) is a smart system that integrates the telecommunication, information, electronics technologies, and traffic management to efficiently manipulate public transportation in many modern metropolises. It adopts the mobile communication techniques to increase the traffic and the transportation efficiency in many applications such as the vehicle-to-vehicle communications (V2V) and the vehicle-to-road communications (V2R). For both the V2V and V2R communications, the signal transmitted at the Transmitter (Tx) will suffer the severe channel distortion due to the doppler effect and the multipath fading channel. To decode the transmitted symbols correctly, Receiver (Rx) has to conduct the channel estimation properly to improve the Bit Error Rate (BER) performance for further information manipulation.

ITS has adopted the IEEE802.11p standard as its protocol [1]. Besides, IEEE 802.11p also known as the Wireless Access in the Vehicular Environment (WAVE) can be applied in the Dedicated Short Range Communications (DSRC). Basically, IEEEE 802.11p is an Orthogonal Frequency Division Multiplexing (OFDM) system with the frequency band from 5.850GHz to 5.925GHz. The data rate can up to 3Mbps to 27Mbps within the coverage 300m to 1000m. Six data channels and one control channel have been defined in the IEEE 802.11p. Each channel consists of 64 sub-carriers within the 10MHz frequency band. In fact, 802.11p is an extension from the commercial IEEE 802.11a Wi-Fi system. However, the Guard Interval (GI) for the 802.11p is twice as the IEEE 802.11a that can be very helpful to avoid the Inter-symbol Interference (ISI) for the multipath vehicular communication environments. Table.1 lists the comparisons between the 802.11a and the 802.11p systems.

Table.1 Comparisons of the IEEE 802.11a and IEEE802.11p

Parameters	IEEE802.11a	IEEE802.11p	Changes
Bit rate (Mbit/s)	6,9,12,18,24,36,48,54	3,4,5,6,9,12,18,24,27	Half
Modulation mode	BPSK,QPSK, 16QAM,64QAM	BPSK, QPSK, 16QAM, 64QAM	No change
Code rate	1/2, 2/3,3/4	1/2, 2/3,3/4	No change
Number of subcarriers	52	52	No change
Guard Time	0.8μs	1.6μs	Double
Symbol duration	4μs	8μs	Double
FFT period	3.2μs	6.4μs	Double
Preamble duration	3.2μs	6.4μs	Double
Subcarrier spacing	0.3125 MHz	0.15625 MHz	Half

In the literatures, many channel estimation for an OFDM system have been proposed to conduct the channel compensation at the Rx. Channel estimation can be achieved in the frequency domain or in the time domain [2]. The frequency domain estimations include the Inverse Fast Fourier Transform (IFFT) [3] and the Minimized Mean Square Error (MMSE) method [4] while the Finite and Infinite Length MMSE estimation [5] and the Linear Interpolation estimation [5] can be performed in the time domain [6].

In IEEE 802.11p, a pre-defined preamble with specific format has been defined to conduct the channel estimation (Fig.1). Besides, four pilot subcarriers transmitted along with the OFDM system can also be used during the channel estimation. In this paper, a low complexity channel estimation method based on the Correlation Invariant (CI) assumption within two successive training preambles is proposed for the IEEE802.11p vehicle communications. The proposed method belongs to the frequency domain channel estimation and uses the preamble and pilot subcarriers for the initial estimation and the time-varying adjustment for the channel. The paper is organized as follows, Section II describes a similar time domain Cyclic Prefix-based (CP) channel estimations and the proposed CI scheme in detail. Performance analysis of the proposed CI method and the CP-based method are evaluated in

Section III. Finally, some conclusions for this paper are summarized in Section IV.

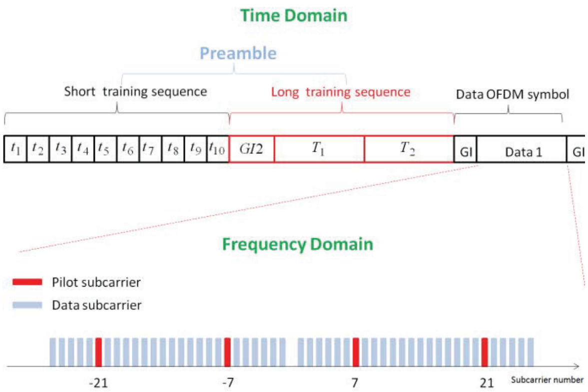

Fig.1 IEEE802.11p Preamble and Data Format

II. Methods Descriptions

In this section, the time domain Cyclic-Prefix (CP) based channel estimation and the proposed CI channel estimation methods are presented. Both methods use the preamble in time domain to conduct the channel estimation for the initial prediction. Then, the CP-based method adopts the duplicated feature of the CP with the tail sequences in OFDM symbols while the proposed CI method uses the correlation invariant assumption to complete the channel estimation (Fig.2).

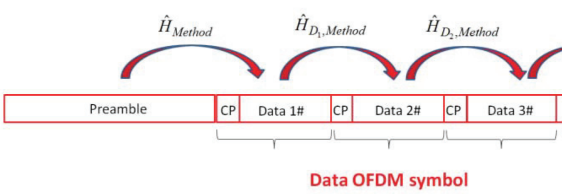

Fig.2 Channel Estimation Scheme for the CP-based and the Proposed CI Method

A. *Cyclic-Prefix (CP) based Channel Estimation [5]*

To avoid the Inter-Symbol Interference (ISI) due to the wireless transmission, OFDM system has to insert a Guard Interval (GI) at the beginning of each OFDM symbol before transmission. Usually, the GI can be the Cyclic-Prefix (CP) of the OFDM to avoid the ISI distortion (Fig.3).

Let the received OFDM symbol at time g be y_{D_g}, the corresponding frequency response of the received symbol can be expressed as

$$Y_{D_g}(k) = \sum_{n=0}^{N-1} y_{D_g}[n] e^{-\frac{2\pi jkn}{N}} \tag{1}$$

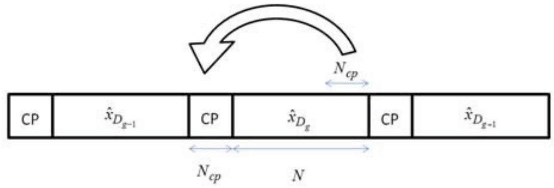

Fig.3 Illustration of the CP-based Channel Estimation

Eq.(1) is the N-point Discrete Fourier Transform (DFT) of the received symbol, where N is the number of subcarrier for the OFDM system. Besides, if the channel frequency response can be estimated via the preamble of the previous OFDM, the estimated transmitted symbol can be determined as

$$\hat{x}_{D_g}[n] = \frac{1}{N} \sum_{n=0}^{N-1} \hat{X}_{D_g}(k) e^{\frac{2\pi jkn}{N}} \tag{2}$$

$$\hat{X}_{D_g}(k) = \frac{Y_{D_g}(k)}{\hat{H}_{D_{g-1}}(k)} \tag{3}$$

Where $\hat{H}_{D_{g-1}}(k)$ is the estimated channel at the previous time $g-1$. After determining the transmitted symbols, Rx has to reconstruct a $N_{cp} \times N_{cp}$ matrix M_{cp_g} shown in Eq.(3) and uses Eq.(4), Eq.(5) to complete the frequency response estimation of the channel $\hat{H}_{D_g}(k)$. Note that usually a zero-padding step is carried out in Eq.(5), N_{cp} is the length of sample for the inserted CP and y_{cp_g} denotes the received signal for the CP at time g.

$$M_{cp_g} = \begin{bmatrix} \hat{x}_{D_g}[N-N_{cp}] & \hat{x}_{D_{g-1}}[N] & \hat{x}_{D_{g-1}}[N-1] & \cdots \; \cdots & \hat{x}_{D_{g-1}}[N-(N_{cp}+1)] \\ \hat{x}_{D_g}[N-N_{cp}-1] & \hat{x}_{D_g}[N-N_{cp}] & \hat{x}_{D_{g-1}}[N] & & \hat{x}_{D_{g-1}}[N-(N_{cp}+2)] \\ \vdots & \hat{x}_{D_g}[N-N_{cp}-1] & \hat{x}_{D_g}[N-N_{cp}] & & \vdots \\ \hat{x}_{D_g}[N-2] & \vdots & \hat{x}_{D_g}[N-N_{cp}-1] & \ddots & \hat{x}_{D_{g-1}}[N-1] \\ \hat{x}_{D_g}[N-1] & \hat{x}_{D_g}[N-2] & \vdots & \ddots & \hat{x}_{D_{g-1}}[N] \\ \hat{x}_{D_g}[N] & \hat{x}_{D_g}[N-1] & \hat{x}_{D_g}[N-2] & \cdots \; \cdots & \hat{x}_{D_g}[N-N_{cp}] \end{bmatrix}_{N_{cp} \times N_{cp}} \tag{3}$$

$$\hat{h}_{D_g} = (M_{cp_g}{}^H M_{cp_g})^{-1} M_{cp_g}{}^H y_{cp_g} \tag{4}$$

$$\hat{h}'_{D_g} = [\hat{h}_{D_g}{}^T 0_{N-N_{cp}}]$$

$$\hat{H}_{D_g} = \sum_{n=0}^{N-1} \hat{h}'_{D_g} e^{-\frac{2\pi j}{N} kn} \tag{5}$$

B. *Proposed Correlation Invariant (CI) Channel Estimation Method*

The main concern of the CP-based channel estimation is that there will be an error propagation problem of the estimated transmitted symbols to cause the estimated channel response inaccurately. This comes from the fact that the generated M_{cp_g} matrix has to take the estimated OFDM symbols into consideration. Once these estimated OFDM symbols are in errors, it will greatly degrade the final channel estimation accuracy. And this problem will become more and more seriously if the number of the OFDM symbols between two successive preambles is increasing. Another drawback for this method is the intensive computational complexity required due to the inverse matrix calculation in Eq.(4).

In most of the OFDM systems, after sending the preamble to conduct the initial channel estimation, some pilot sub-carriers are transmitted along with the OFDM data symbol afterward. For example, Long Term Evolution (LTE) and IEEE 802.11a Wi-Fi systems have the Reference Signal (RS) or pilot sub-carriers transmitted with the OFDM symbols. It is the same for the IEEE802.11p vehicular system. Therefore, it is reasonable and intuitively that after the preamble conducts the initial channel estimation and synchronization, the following RS or pilot sub-carriers can help to mitigate the varying timing characteristic of the multi-path fading channel.

Fundamental to the proposed method is the assumption that the correlations between the data sub-carriers with respect to the nearest pilot sub-carrier are unchanged during the two successive preambles. The validity of this assumption comes from the fact that the coherent time of the wireless channel is proportional to the inverse of the maximum of the Doppler shift [7]. For example, if there is a high speed rail train with 300 km/hr speed, the maximum Doppler shift is 1.611 KHz in 5.8GHz carrier and the coherent time of such scenario is 0.62 msec approximately. In this 0.62msec interval, the fading or the frequency response of the channel can be regarded as invariant or highly correlated.

The proposed channel estimation method is conducted within the coherent time of the considered channel. The preamble is used for the initial channel estimation and calculates the correlation coefficients between the pilot sub-carriers with the nearby data sub-carriers via Eq.(6).

$$C_k = \frac{\hat{H}_k{}' \hat{H}_p}{\left|\hat{H}_p\right|^2} \tag{6}$$

In Eq.(6), p and k denote the index of the pilot and its nearby data-subcarriers. Then, Rx uses the pilot to estimate the exact frequency responses during the transmission of the OFDM symbols at these pilot sub-carriers and predict the response for the data sub-carriers with the help of the correlation coefficients via Eq.(7).

$$\hat{H}_{CI}(k) = C_k \times H_p \tag{7}$$

An example based on the IEEE 802.11p OFDM system can be depicted as Fig.4. The pilot sub-carriers are located at the -21, -7, 7, 21 sub-carriers. First of all, using the preamble to estimate the whole channel frequency response and calculate the correlation coefficients for the pilot sub-carrier with its nearby data sub-carriers enclosed in the dashed region. Then, Rx uses the pilots during the following OFDM data symbol to estimate the exact frequency response at these pilot sub-carriers, and predicts the response via Eq.(7) at the data sub-carriers according to the correlation estimated at the preamble.

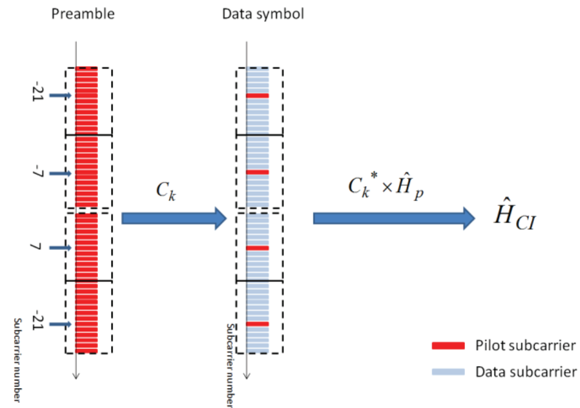

Fig.4 Illustration of the Proposed CI Channel Estimation

III. SIMULATION RESULTS

In this section, BER performance analysis of the proposed CI method and the CP-based method are evaluated under the time-invariant and time-varying fading channels. Table.2 lists the simulation parameter. It can be noted that with these parameters, the channel can be assumed highly correlated within 0.62 msec which proportional to 155 OFDM symbols duration. The channel model in this simulation is provided by Table.3 [5]. Besides, computational complexity of the proposed method is also provided.

Table.2 Simulation Parameters

Parameters	Value
Number of multipath (L)	8
Modulation	QPSK
Number of Subcarrier(N)	52
Carrier Frequency	5.8GHz
Speed of the Mobile	0, 300km/hr
Guard Time	0.8μs
Symbol duration	4μs
FFT period	3.2μs
Preamble duration	3.2μs
Subcarrier spacing	0.3125 MHz

Table.3 Channel Model [5]

Tap	Delay (ns)	Power (dB)
1	0	0, Rician, K=3.3 dB
2	100	-9.3
3	200	-14.0
4	300	-18.0
5	400	-19.4
6	500	-24.9
7	600	-27.5
8	700	-29.8

A. BER Analysis

Fig.5 and Fig.6 are the BER performance for the CP-based and the proposed CI channel estimation methods under the time-invariant multipath fading channel in Table.3. The number of the OFDM data symbols between two successive preambles changes from 2 to 32. In Fig.5, it is clear that the CP-based method has the serious error propagation method that will degrade the accuracy of the estimated channel and cause the BER performance to be very poor if the number of the OFDM symbols between two successive preamble is increasing. However, in Fig.6, we can note that if the channel condition is highly correlated within two successive preambles, the proposed CI method outperforms the CP-based method and has almost the same performance regardless the number of the OFDM data symbols. Fig.7 is the case if the speed of the mobile is 300Km/hr, and the number of the OFDM symbols between two successive preambles is 2. It shows that even in time-varying fading channel, the proposed method still has a better performance than the CP-based method.

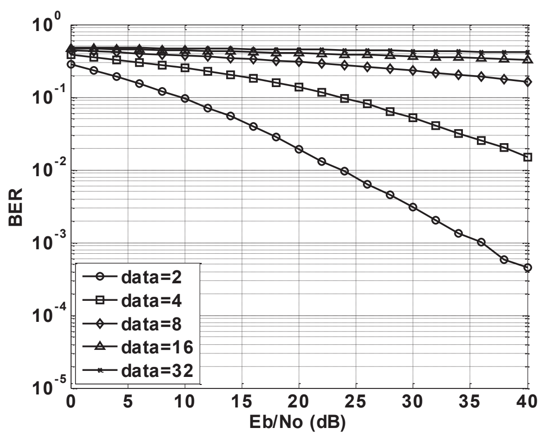

Fig.5 BER Performance of the CP-based Channel Estimation

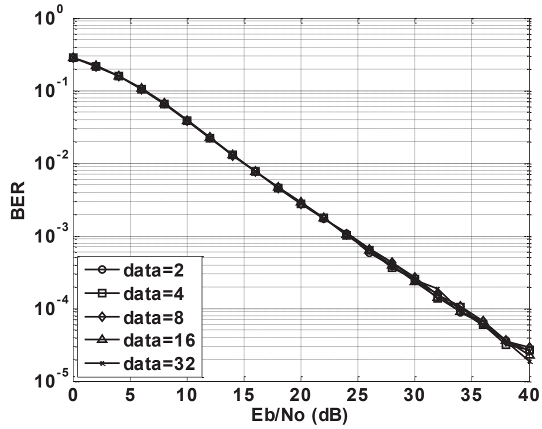

Fig.6 BER Performance of the Proposed CI Channel Estimation

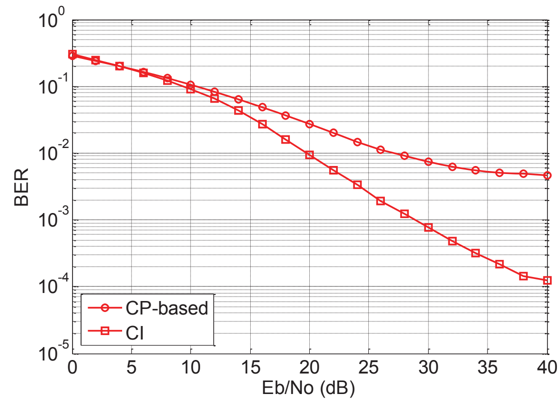

Fig.7 BER Comparison of the Proposed CI and CP-based Method (Mobile Speed=300Km/hr)

B. Complexity Analysis

The main contribution of the proposed method is the low computational complexity advantage. Since that the procedure of the CP-based method follows from Eq.(1) to Eq.(5), define C^{FFT} be the computation complexity to conduct the N-point DFT, G is the number of OFDM symbols between two successive preambles, N_{cp} is the number of sample for the inserted CP and N_u is the number of sub-carriers except the null sub-carriers. Assume also the computation complexity for the product and summation are the same, the CP-based method requires approximately $G(3\times C^{FFT}+4N_{cp}^3+3/2(N_{cp}^2+N_{cp})+N+1)$ computations while the proposed CI method requires only $3N_u+G(C^{FFT}+N_u)$ in computations for the channel estimation within two successive preambles. Take the IEEE802.11p for example, the number of total sub-carriers is $N=64$, the number of sample for CP is $N_{cp}=16$, the number of sub-carriers except the null sub-carriers is $N_u = 52$, and $C^{FFT} \approx N \log_2 N = 384$, if $G = 4$, the proposed CI method requires only less than 6% compared with the CP-based method that is a huge reduction in the computation complexity.

IV. Conclusions

In this paper, a low complexity channel estimation method is proposed for the IEEE802.11p vehicle communications. The proposed method belongs to the frequency domain channel estimation and uses the preamble and pilot subcarriers for the initial estimation and the time-varying adjustment for the channel. Compared with the relative CP-based method, the method has the low-complexity advantage and the good BER performance. It requires only less than 6% computational complexity compared with the CP-based method. Since all these calculations can be easily conducted at the Rx, the proposed method can be easily and efficiently applied to the channel estimation for vehicle communications.

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