https://doi.org/10.5392/IJoC.2018.14.1.039

Advanced Channel Estimation Schemes Using CDP based Updated Matrix for IEEE802.11p/WAVE Systems

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ABSTRACT

Today, cars have developed into intelligent automobiles that combine advanced control equipment and IT technology to provide driving assistance and convenience to users. These vehicles provide infotainment services to the driver, but this does not improve the safety of the driver. Accordingly, V2X communication, which forms a network between a vehicle and a vehicle, between a vehicle and an infrastructure, or between a vehicle and a human, is drawing attention. Therefore, various techniques for improving channel estimation performance without changing the IEEE 802.11p standard have been proposed, but they do not satisfy the packet error rate (PER) performance required by the C-ITS service. In this paper, we analyze existing channel estimation techniques and propose a new channel estimation scheme that achieves better performance than existing techniques. It does this by applying the updated matrix for the data pilot symbol to the construct data pilot (CDP) channel estimation scheme and by further performing the interpolation process in the frequency domain. Finally, through simulations based on the IEEE 802.11p standard, we confirmed the performance of the existing channel estimation schemes and the proposed channel estimation scheme by coded PER.

***Key words**: V2X, IEEE 802.11p, C-ITS, CDP.*

1. INTRODUCTION

Recently, with the spread of automobiles and the development of wireless communication industry, rapid transportation system suitable for information society is required. Cooperative-Intelligent Transport Systems (C-ITS) is a system designed to actively respond to traffic situations through real-time intercommunication with surrounding vehicles and infrastructure while the vehicle is moving [1]-[8]. Currently, automobiles have developed into intelligent automobiles that combine advanced control equipment and information & telecommunication technology to provide driving assistance and convenience to drivers. For example, infotainment service can be provided for the driver but it cannot be enough to improve the safety of the driver. Accordingly, vehicle-to-everything (V2X) communication that forms a network between a vehicle and a vehicle, between a vehicle and an infrastructure or between a vehicle and a human is received attention.

To support the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, the IEEE 802.11p was developed, defining the physical (PHY) and medium-access layers (MAC) of the wireless communications [1]. IEEE 802.11p was created by modifying the frequency bandwidth of the IEEE 802.11a standard from 20 MHz to 10 MHz. Since the IEEE 802.11p structure is almost the same as IEEE 802.11a, IEEE 802.11p also transmits only four pilot subcarriers during one symbol period. However, it cannot accurately estimate the channel occurring in the frequency domain with only four pilot subcarriers. Therefore, it is necessary to accurately estimate the rapidly changing channel in order to stably provide the traffic information to the moving vehicle. Accordingly, techniques for improving the channel estimation performance without changing the IEEE 802.11p standard have been developed [3]-[7]. Least Square (LS), Spectral Temporal Averaging (STA), Construct Data Pilot (CDP), and Time Domain Reliable Test Frequency Domain Interpolation (TRFI) channel estimation techniques have been proposed [4], [5]. However, it cannot provide the Packet Error Rate (PER) performance required by C-ITS service [3].

This is an excellent paper selected from the papers presented at ICCC 2017.
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Manuscript received Oct. 17, 2017; revised Mar. 27, 2018; accepted Mar. 27, 2018

Consequently, in this paper, we propose a new channel estimation schemes that satisfy PER performance required in C-ITS service. The proposed schemes combine the CDP channel estimation scheme with the updated weighting matrix for the data pilot symbols, and additionally interpolate in the frequency domain. Then, it is verified by simulations the proposed schemes can improve the accuracy of channel estimation over the existing CDP and TRFI channel estimation schemes.

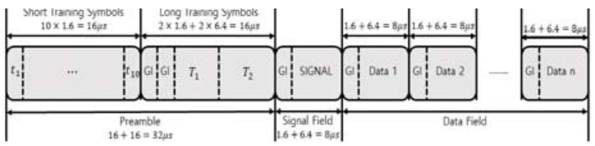

Fig. 1. IEEE 802.11p packet structure

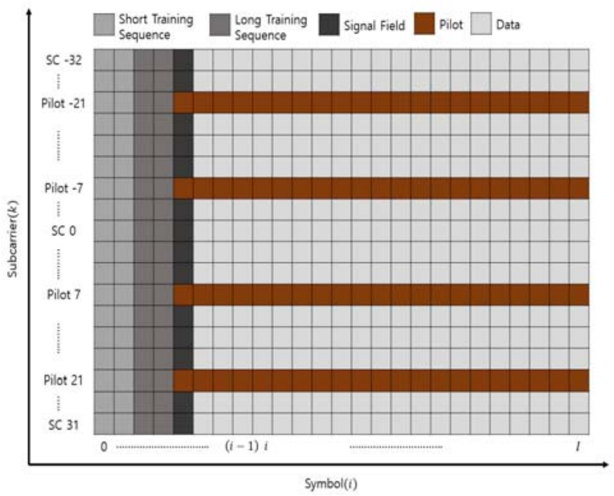

Fig. 2. Packet structure in WAVE frequency and time domain

The composition of the paper is as follows. Section 2 describes the IEEE 802.11p physical layer and the channel model used in the simulation. Section 3 describes existing channel estimation techniques. Section 4 describes the proposed channel estimation schemes. Section 5 shows the performance of the proposed channel estimation methods. Finally, Section 6 concludes.

2. SYSTEM MODEL

2.1 IEEE 802.11p physical layer

IEEE 802.11p has been standardized by modifying some specifications in the physical layer of the existing IEEE 802.11a. IEEE 802.11p uses a frequency of 5.9 GHz (5.850 ~ 5.925) and uses a bandwidth of 10MHz. This is half the bandwidth of 802.11a [1].

Fig. 1 shows the packet structure of IEEE 802.11p. In general, one packet is composed of a preamble, a signal field, and a data field [1]. The preamble located at the beginning of the packet consists of a short training symbol and a long training symbol. Short training symbols are used for time synchronization and long training symbols are used for the initial channel estimation. The IEEE 802.11p physical layer is based on orthogonal frequency division multiplexing (OFDM). The GI (Guard Interval) is arranged to reduce ISI (Inter Symbol Interference) due to the multipath fading channel. The signal field contains information such as modulation information and code rate, and signal field is composed of one OFDM symbol. On the other hand, the data field contains data to be transmitted and the number of OFDM symbols is variable. In this paper, we assume for the data field that the number of OFDM symbols is 100.

Fig. 2 shows the packet structure on the WAVE frequency axis (vertical) and time axis (horizontal) [1], [4]. The pilot tones used for channel estimation can be comb, block, and lattice structures, and IEEE 802.11p has comb structure. The comb structure is suitable for Fast Fading channel environment by arranging pilot symbols in a specific frequency index (i.e., -21, -7, 7, and 21). The remaining subcarriers are null carriers (i.e., -32 to –27, 0, and 28 to 32).

2.2 Channel model

In this paper, we use 'Cohda Wireless channel model' proposed by Malik Kahn [2]. There are five scenarios (Rural LOS with 144km/h, Urban Approaching LOS with 119km/h, Crossing NLOS with 126km/h, Highway LOS with 252km/h, Highway NLOS with 252km/h) according to the driving environment and location of the vehicle. Delay profile and Doppler shift are presented according to the relative speed between vehicles. The Doppler profile is expressed by using a Tapped Delay Line (TDL) model, which is a method mainly used for modeling a multipath channel [2]. In each scenario, the number of tap, the location of each tap in the time domain, and the average power in each tap are defined differently.

3. CHANNEL ESTIMATION SCHEMES FOR THE IEEE 802.11P

In this section, we describe the existing channel estimation schemes such as Spectral Temporal Averaging (STA), Constructed Data Pilot (CDP), and Time domain Reliable test Frequency domain Interpolation (TRFI) [4], [5].

3.1 Spectral Temporal Averaging (STA) scheme

The STA method has been proposed as an estimation technique for adapting to time-varying channels when the vehicle is traveling at high speed [4].

- **Equalization**

The received signal of the kth subcarrier in the *i*th data field, $Y_{D,i}(k)$, is equalized using the $(i-1)$ th estimated channel value of $H_{i-1}(k)$ as follows:

$$\hat{S}_i\left(k\right) = \frac{Y_{D,i}(k)}{H_{i-1}(k)},\ k = -32, -31 \cdots 31 \tag{1}$$

At this time, $H_{i-1}(k)$ depends on the index 'i' of the symbol. If $i-1=0$, we can use the initial channel estimation coefficient by the LS method for two long preambles (i.e., $Y_{T,1}(k)$ and $Y_{T,2}(k)$) as follow:

$$H_0(k)=\frac{Y_{T,1}(k)+Y_{T,2}(k)}{2X(k)}, k=-32,-31\cdots 31 \quad (2)$$

Here, $X(k)$ is the long training symbol of the kth subcarrier and it is known to the receiver.

- **Constructing Data Pilot**

The constructed data pilot, $\widehat{X}_i(k)$, can be determined as a modulation symbol after demapping as follow:

$$\widehat{X}_i(k)=D\left(\hat{S}_i(k)\right), k=-32,-31,\cdots 31 \quad (3)$$

where $D(r)$ is a function that maps the equalized signal to the corresponding modulation scheme. Then, the modulation symbols for the four pilot subcarriers $(k=-21,-7,7,21)$ of $\widehat{X}_i(k)$ are replaced with predefined frequency domain values in the standard.

- **Least Square (LS) Method**

The initial channel estimated value, $\widehat{H}_i(k)$, for the ith OFDM symbol can be obtained by equalizing $Y_{D,i}(k)$ with $\widehat{X}_i(k)$ as $\widehat{H}_i(k)=Y_{D,i}(k)/\widehat{X}_i(k)$.

- **Frequency Domain Averaging**

In order to mitigate the channel estimation error due to demapping error, the average of the estimated channel in the frequency domain and the time domain can be obtained. The averaged channel value, $H_{up,i}(k)$, in the frequency domain is expressed as follows:

$$H_{up,i}(k)=\sum_{\lambda=-\beta}^{\beta}\omega_\lambda \widehat{H}_i(k+\lambda), k=-32,-31,\cdots 31 \quad (4)$$

where $2\beta+1$ represents the number of averaging subcarriers and ω_λ is a set of weighting coefficients with a unit sum and $\omega_\lambda=1/(2\beta+1)$ is used in [4].

- **Time Domain Equalization**

Next, the channel averaging can be performed in the time domain. This gives the final channel estimation coefficient of

$$\widehat{H}_i(k)=\left((1-\frac{1}{\alpha}\right)H_{i-1}(k)+\frac{1}{\alpha}H_{up,i}(k), \;\; k=-32,-31,\cdots 31 \quad (5)$$

where α is the average weight in the time domain. In this paper, we use $\alpha=\beta=2$ as shown in [7].

3.2 Constructed Data Pilot (CDP) scheme

Two adjacent OFDM symbols in the time domain have a high channel correlation. By using this characteristic, the reliability of the initially estimated channel value can be determined, and the estimated channel value with higher reliability is selected [4]. The CDP is similar to the STA scheme from equalization to LS.

- **Equalization and Demapping**

Using the initially estimated channel value of $\widehat{H}_i(k)$ and $(i-1)$th OFDM symbol channel estimation value of $H_{i-1}(k)$, we can equalize the previous received data symbols as follows:

$$\hat{S}'_{i-1}(k)=\frac{Y_{D,i-1}(k)}{\widehat{H}_i(k)}, k=-32,-31\cdots 31 \quad (6)$$

$$\hat{S}''_{i-1}(k)=\frac{Y_{D,i-1}(k)}{H_{i-1}(k)}, k=-32,-31\cdots 31 \quad (7)$$

$\hat{S}'_{i-1}(k)$ and $\hat{S}''_{i-1}(k)$ can be then demapped to $\widehat{X}'_{i-1}(k)$ and $\widehat{X}''_{i-1}(k)$ according to the modulation scheme as

$$\widehat{X}'_{i-1}(k)=D\left(\hat{S}'_{i-1}(k)\right), \; k=-32,-31,\cdots 31 \quad (8)$$

$$\widehat{X}''_{i-1}(k)=D\left(\hat{S}''_{i-1}(k)\right), \; k=-32,-31,\cdots 31. \quad (9)$$

- **Comparison**

If $\widehat{H}_i(k)$ is correctly estimated, $\widehat{H}_i(k)$ and $H_{i-1}(k)$ can be similar because of the high channel correlation characteristics of two adjacent subcarriers in the time domain. Using this characteristic, the final channel estimation coefficient of the CDP method can be obtained as follows:

$$H_i(k)=\begin{cases}\widehat{H}_i(k) & \text{if } \widehat{X}'_{i-1}(k)=\widehat{X}''_{i-1}(k), \; k=-32,\cdots,31 \\ H_{i-1}(k) & \text{else}\end{cases} \quad (10)$$

In (10), if $\widehat{X}'_{i-1}(k)=\widehat{X}''_{i-1}(k)$, $\widehat{H}_i(k)$ is relatively accurate, and therefore, we can obtain the updated channel gain as $H_i(k)=\widehat{H}_i(k)$. Otherwise, i.e., $\widehat{X}'_{i-1}(k)\neq\widehat{X}''_{i-1}(k)$, $H_{i-1}(k)$ is relatively accurate than $\widehat{H}_i(k)$, so that we can select the previous estimated channel gain as $H_i(k)=H_{i-1}(k)$.

3.3 Time domain Reliable test Frequency domain Interpolation (TRFI) scheme

The TRFI scheme was proposed to improve the accuracy of the channel estimates by utilizing the time correlation characteristics between two adjacent symbols and then, exploiting the frequency correlation between the adjacent subcarriers [5], [6].

The TRFI scheme is similar to the CDP from equalization to equalization and demapping. Then, the following additional process is performed. If $\widehat{X}'_{i-1}(k)=\widehat{X}''_{i-1}(k)$, the channel gain is updated as $H_i(k)=\widehat{H}_i(k)$. If not, $H_i(k)$ is obtained by frequency domain interpolation using the estimated channel coefficients which pass the reliability test.

The TRFI scheme reduces the demapping error of the channel estimation using time and frequency correlation characteristics. Therefore, although the channel estimation accuracy is improved in the high SNR, it can't provide a satisfactory performance due to the demapping error in the low SNR region.

4. PROPOSED CHANNEL ESTIMATION METHODS

The new channel estimation scheme is similar to the CDP scheme. It combines the updated matrix for the data pilot symbols with the existing CDP scheme and shows better performance than the existing channel estimation techniques.

4.1 WSUM (Weighted Sum using Update Matrix) Reliability test

The WSUM (Weighted Sum using Update Matrix) scheme is a weighted sum channel estimation scheme using an updated matrix. Equation (1) to Equation (9) are similar to the existing CDP technique.

$H_{i-1}(k)$ and $H_i(k)$ are similar according to the high channel correlation characteristics of two adjacent subcarriers in the time domain. If $\widehat{H}_i(k)$ is estimated correctly, $\widehat{H}_i(k)$ and $H_{i-1}(k)$ should be similar. This property is used to determine the $\widetilde{H}_i(k)$ and the updated matrix $M_{up,i}(k)$ which indicates the existence of updated channel coefficient.

$$
\begin{aligned}
\widetilde{H}_i(k) &= \begin{cases} \widehat{H}_i(k) & \text{if } (k=\text{pilot}) \text{ or } \left(\widehat{X}'_{i-1}(k)=\widehat{X}''_{i-1}(k)\right) \\ H_{i-1}(k) & \text{else} \end{cases} \\
M_{up,i}(k) &= \begin{cases} 1 & \text{if } (k=\text{pilot}) \text{ or } \left(\widehat{X}'_{i-1}(k)=\widehat{X}''_{i-1}(k)\right) \\ 0 & \text{else} \end{cases}
\end{aligned} \tag{11}
$$

In the case of $k\in\{-21,-7,7,21\}$ or $\widehat{X}'_{i-1}(k)=\widehat{X}''_{i-1}(k)$, the $\widehat{H}_i(k)$ is determined to be a relatively reliable channel estimation and so that $\widetilde{H}_i(k)=\widehat{H}_i(k)$, and the update matrix $M_{up,i}(k)$ is selected as 1. In the case of $\widehat{X}'_{i-1}(k)\neq\widehat{X}''_{i-1}(k)$, $\widehat{H}_i(k)$ is judged to be unreliable. Therefore, it is determined that the previous channel estimation value is reliable, and so that $\widetilde{H}_i(k)=H_{i-1}(k)$, and the update matrix $M_{up,i}(k)$ is selected as 0.

■ **Weighted Sum**

Using the channel correlation characteristic of adjacent subcarriers in the frequency domain, the final channel estimate $H_i(k)$ can be determined by weighted sum as follows:

$$
H_i(k)=\begin{cases} \sum_{\lambda=-\beta}^{\beta}\widetilde{H}_i(k+\lambda)M_{up,i}(k+\lambda)\omega_\lambda \Big/ \sum_{\lambda=-\beta}^{\beta}M_{up,i}(k+\lambda)\omega_\lambda \\ \qquad\qquad \text{if } \sum_{\lambda=-\beta}^{\beta}M_{up,i}(k+\lambda)\geq N \\ H_{i-1}(k) \qquad \text{else} \end{cases} \tag{12}
$$

In this paper, we use $[\omega_{-1},\omega_0,\omega_1]=[0.5,1.0,0.5]$, $\beta=1$, and $N=2$. If the $\sum_{\lambda=-\beta}^{\beta}M_{up,i}(k+\lambda)\geq N$ is satisfied within the window interval, the finally estimated channel gain of $H_i(k)$ is determined by weighted sum of $\widetilde{H}_i(k)$. On the other hand, if $\sum_{\lambda=-\beta}^{\beta}M_{up,i}(k+\lambda)\geq N$ is not satisfied, it is determined that the reliably estimated channel gain is small in the window, and then, $H_i(k)$ is determined as $H_{i-1}(k)$. Note that by setting $[\omega_0]=[1]$, $\beta=0$, and $N=1$, the proposed scheme can be regarded as the existing CDP scheme.

In addition, the proposed scheme can be applied into the TRFI method so that we can get the additional performance gain.

5. SIMULATION RESULTS

In this section, we show simulation results of the proposed schemes. In simulation with 16QAM and 'Code Rate=1/2', we utilize two scenarios (Rural LOS with 144km/h and Highway LOS with 252km/h) in 'Cohda Wireless channel model' proposed by Malik Kahn [2].

Fig. 3 and Fig. 4 show the PER performance comparison with respect to the conventional schemes under 'Rural LOS with 144km/h' and 'Highway LOS with 252km/h', respectively. In two figures, 'WSUM' indicates the proposed scheme of subsection 4.1 with $[\omega_{-1},\omega_0,\omega_1]=[0.5,1.0,0.5]$, $\beta=1$, and $N=2$. In addition, 'WSUM-FI1', 'WSUM-FI2', and 'WSUM-FI2' denote the applying frequency interpolation to the proposed scheme with $N=1$, $N=2$, and $N=3$, respectively.

From two figures, we can verify that the proposed 'WSUM' scheme gives better PER performance than 'CDP' and 'TRFI' schemes. In addition, by applying frequency interpolation method (i.e., 'WSUM-FI1' and 'WSUM-FI2'), we can get the additional gain over 'WSUM'. Furthermore, it is confirmed that the proposed schemes can be used to obtain better performance than 'STA' scheme over wider SNR region.

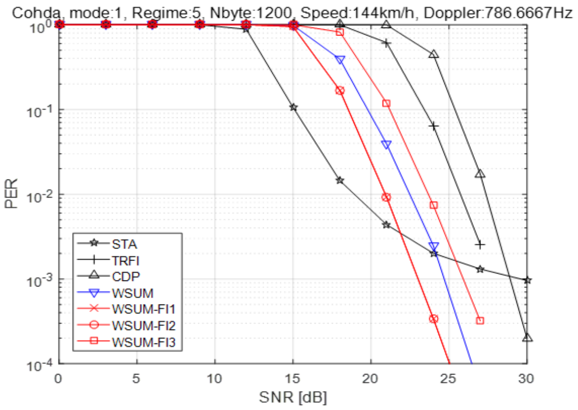

Fig. 3. PER versus SNR (dB) with respect to Channel Estimation Schemes. (16QAM, Code Rate=1/2, Rural LOS, 144km/h)

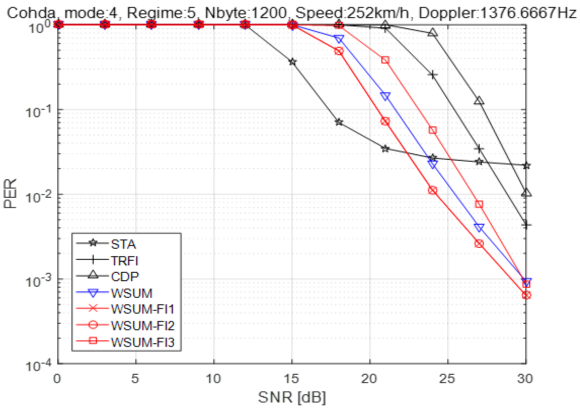

Fig. 4. PER versus SNR (dB) with respect to Channel Estimation Schemes. (16QAM, Code Rate=1/2, Highway LOS, 252km/h)

6. CONCLUSION

In this paper, we proposed novel channel estimation schemes and it is verified that the proposed methods can be used to improve the PER performance over CDP and TRFI schemes in all SNR regions and over STA scheme in wider SNR regions. Note that the proposed schemes utilize an updated matrix which can indicate which candidate channel coefficients are reliable. In addition, it is confirmed that the proposed method with frequency interpolation can get more PER performance gain.

ACKNOWLEDGEMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2017R1A2B4012883).

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