A Guard Interval Assisted OFDM Symbol-Based Channel Estimation for Rapid Time-Varying Scenarios in IEEE 802.11p

Priya Aggarwal, Anubha Gupta, Vivek Ashok Bohara
Department of Electronics and Communication Engineering
Indraprastha Institute of Information Technology (IIIT), Delhi, India
priyaa@iiitd.ac.in, anubha@iiitd.ac.in, vivek.b@iiitd.ac.in

Abstract*—IEEE 802.11p standard is a wireless vehicular communication standard meant for outdoor applications. This standard suffers from the challenge of robust channel estimation due to rapid time-varying nature of the channel. This paper proposes a novel scheme of channel estimation by utilizing the guard interval of every orthogonal frequency division multiplexing (OFDM) symbol. For a typical vehicular wireless communication where the channel fades quite rapidly, inter-symbol-interference (ISI) may not be as significant a problem as time varying nature of the channel due to Doppler effect. Hence, the proposed scheme utilizes the redundant space of guard interval (GI) (other than that required for cyclic prefix (CP) to combat ISI) to insert pseudo-random sequence (PRS) for channel estimation. A decision-directed time-domain least squares channel estimation method is proposed using the inserted PRS with CP. Simulation results show that the proposed scheme can considerably improve the bit error rate (BER) performance compared to the existing techniques.

Keywords- IEEE 802.11p, Time-Varying Channel Estimation, OFDM, Vehicular-to-Vehicular Communication.

I. INTRODUCTION

Every year 1.24 million people lose their lives worldwide due to accidents on road [1]. Road traffic safety can be substantially improved with the help of wireless vehicular communication, e.g., via warnings for abrupt vehicle kinetic changes, traffic and road conditions, etc. [2, 3]. To meet the requirement of reliable data transmission in wireless vehicular communication, IEEE 802.11p [4], a dedicated standard for Wireless Access in Vehicular Environments (WAVE), has been standardized in 2010. Compared to other wireless local area network (WLAN) standards such as IEEE 802.11a/g [4], this standard is meant for dedicated short range communications (DSRC) between vehicular-to-vehicular (V2V) and vehicular-to-infrastructure (V2I) or (I2V) scenarios. This standard modifies the 802.11a/g standard to add support for WLANs in a vehicular environment. However, it is not yet well adapted for the fast time varying channel conditions [5]. For V2V communications, channel tend to change rapidly and hence, the estimated channel may get outdated within an OFDM frame and needs update for the symbol recovery at the receiver end. Although a lot of channel estimation schemes have been proposed for 802.11 standards, most of them will not be applicable for 802.11p due to this fast time varying nature of the channel. Thus, a robust channel estimation method is needed at the receiver end for 802.11p standard.

Conventional channel estimation methods inherently assume channel to be stationary in one OFDM frame and hence, use long preamble inserted in every OFDM frame for channel estimation. However, during rapidly time-varying channel conditions (or high speed V2V communication), the coherence time may reduce considerably causing channel to vary within one OFDM frame that may consist of many OFDM symbols. Hence, the channel estimates obtained using long preamble may not be valid for all of the OFDM symbols within a frame leading to severe ISI and abysmal performance in fast time varying channels [6].

Pilot data inserted within an OFDM symbol can be used for fine tuning of an estimated channel. However, pilot density in IEEE 802.11p is not sufficient to compensate for time varying nature of the channel, especially, in the urban environment where time selectivity and Doppler spread of the channel may be high.

Recently, researchers have proposed techniques to estimate time varying channel in IEEE 802.11p standard. For example, the authors in [7] have proposed a midamble based approach wherein a known midamble data is inserted between OFDM symbols of an OFDM frame to track the channel in IEEE 802.11p standard. However, this approach degrades the performance in terms of availability of less data payload. The authors in [8], [9] use guard interval (GI) for time domain channel estimation by replacing the cyclic prefix with pseudo-random sequence with zero padding (PRwZP). Specifically, in [8], time domain least square method (TDLSE) is employed for channel estimation (PRwZP TDLSE scheme). However, it suffers from the problem of inter-carrier interference (ICI). In [9], the problem of ICI is alleviated by using the overlap-and-add method (OLA) in conjunction with PRwZP TDLSE scheme. Although, ICI is cancelled in OLA only when the channel is time-invariant during one OFDM frame. A smoothing based PRwZP TDLSE OLA scheme is also presented in [9] that utilizes past and future OFDM symbols. However, smoothing estimation will introduce delays in the case of real-time environments and the performance will deteriorate if the channel changes within the smoothing window duration.

Motivated by the work [8, 9], we propose a novel GI assisted channel estimation method and overcome the above limitations via the proposed modifications:

1) We insert short pseudo-random sequence along with cyclic prefix (PRwCP OFDM) instead of replacing the entire guard interval (GI) with the pseudo-random sequence.
2) Since we have a space for short pseudo-random sequence (PRS), for robust channel estimation we use the previous symbol estimate in the current OFDM symbol channel estimation, thus, proposing a decision directed [10] time-domain least squares channel estimation.

The proposed channel estimation method:

a) does not suffer with reduced throughput via midamble insertion.
b) does not suffer with ISI due to cyclic prefix and ICI (as it correctly estimates fast fading channel).
c) does not require channel estimation via long preamble and hence, effective data rate can be increased via removal of long preamble. This may be useful in addressing higher wireless data rate challenge of 5G communication [11].
d) does not require smoothing operation and hence, provides real-time channel estimation with improved performance over channel varying as fast as over one symbol duration.

This paper is organized as follows. Section II describes the proposed PRwCP OFDM transceiver structure. Section III describes the proposed channel estimation method. Simulation results are presented in Section IV. Finally, Section V concludes the paper.

Notations: We use lower case bold letters for vectors, uppercase bold letters for matrices, and lowercase italics letters for scalars.

II. PROPOSED PRWCP OFDM TRANSCEIVER STRUCTURE

Consider Fig.1 that shows the structure of the proposed PRwCP transceiver for the m^{th} OFDM symbol. First 16 samples of every OFDM symbol correspond to the GI, while the last *N*=64 samples denoted as $\{\hat{s}_{m,0}, \hat{s}_{m,1}, \cdots, \hat{s}_{m,N-1}\}$ correspond to the complex data samples to be transmitted in the frequency domain. This data is passed through the inverse discrete Fourier transform (IDFT) block to obtain time domain complex data samples as

$$s_{m,n} = IDFT_N\left(\hat{s}_{m,k}\right) \tag{1}$$

where $n = 0, 1, \cdots N-1$ and $k = 0, 1, \cdots N-1$.

In the proposed work, for length *L* channel, a cyclic prefix (CP) of length *L*-1 (the last *L*-1 time domain samples $s_{m,n}$ of the m^{th} OFDM symbol) and a pseudo-random (PN) sequence of length *D* $\{p_0, p_1, \cdots, p_{D-1}\}$ are inserted in the guard interval of m^{th} OFDM symbol. Thus, the resultant data in an OFDM symbol is:

$$s'_{m,n} = \begin{cases} p_n & n = 0, 1, \cdots, D-1 \\ s_{m,n+N-16} & n = D, D+1, \cdots, D+L-2 \\ s_{m,n-16} & n = D+L-1, \cdots, D+L+N-2 \end{cases} \tag{2}$$

where $D = 16 - L + 1$ with L corresponds to the length of multipath fading channel and $D + L + N - 1 = 80$ (length of one OFDM symbol).

$s'_{m,n}$ are serially fed to a D/A converter and the resultant signal $s(t)$ is transmitted. The transmitted signal is passed through a time-varying multipath fading channel and is corrupted by white Gaussian noise. The A/D converter at the receiver converts this noisy analog information back into serial digital information which is denoted by $r'_{m,n}$ as:

$$\begin{aligned} r'_{m,n} = &\{c_0, c_1, \cdots, c_{D-1}, r_{m,N-L+1}, r_{m,N-L+2}, \cdots, \\ & r_{m,N-1}, r_{m,0}, \cdots, r_{m,N-1}\} \end{aligned} \tag{3}$$

The last N time domain samples of $r'_{m,n}$ are fed to the discrete Fourier transform (DFT) block. The resultant output in the frequency domain is denoted as $\hat{r}_{m,k}$ where $k = 0, 1, \cdots, N-1$. We utilize the first *D* time domain symbols of $r'_{m,n}$ for channel estimation. A detailed explanation on channel estimation is provided in Section III. The estimated channel tap coefficients are denoted as $\tilde{h}_0, \tilde{h}_1, \cdots, \tilde{h}_{L-1}$ and the *N*-point DFT of the estimated channel tap coefficients are denoted as $\hat{h}_{m,k} = DFT_N\left(\tilde{h}_0, \tilde{h}_1, \cdots, \tilde{h}_{L-1}, 0, 0, \cdots, 0\right)$. Zero forcing channel equalization algorithm is used to estimate the transmitted frequency domain OFDM symbol as below [12]:

$$\tilde{s}_{m,k} = \hat{r}_{m,k}/\hat{h}_{m,k} \quad \text{for} \quad k = 0, 1, \cdots, N-1. \tag{4}$$

III. DECISION DIRECTED CHANNEL ESTIMATION

In the case of rapid time-varying channel, channel coefficients change within the OFDM frame. A robust channel estimation algorithm should be able to track this channel. For the case of V2V communication, the channel delay spread is observed to be in between 400ns to 800ns (corresponding to 4 to 8-tap channel) [13]. This implies that a CP of length 7 (*L*-1 where *L* is the length of channel) will suffice to counter ISI. Thus, GI has an additional space of 9 samples. In this paper, we utilize this additional space for channel estimation by inserting a pseudo-random sequence in the GI of every OFDM symbol. Since we have a short PRS for channel estimation, we propose decision directed (DD) channel algorithm that is explained below.

The first *D* received time domain samples of $r'_{m,n}$ after A/D conversion denoted in (3) can be written as

$$\mathbf{c} = \mathbf{Qh} + \mathbf{e} \tag{5}$$

where $\mathbf{c} = \left[c_0, c_1, \cdots, c_{D-1}\right]^T$,

$$\mathbf{Q} = \begin{bmatrix} p_0 & s_{m-1,N-1} & \cdots & s_{m-1,N-L+2} & s_{m-1,N-L+1} \\ p_1 & p_0 & \ddots & \vdots & \vdots \\ p_2 & p_1 & \ddots & p_0 & s_{m-1,N-1} \\ \vdots & \vdots & \ddots & \vdots & p_0 \\ \vdots & \vdots & \ddots & p_{D-L} & \vdots \\ p_{D-1} & p_{D-2} & \cdots & p_{D-(L-1)} & p_{D-L} \end{bmatrix}_{D\times L} \tag{6}$$

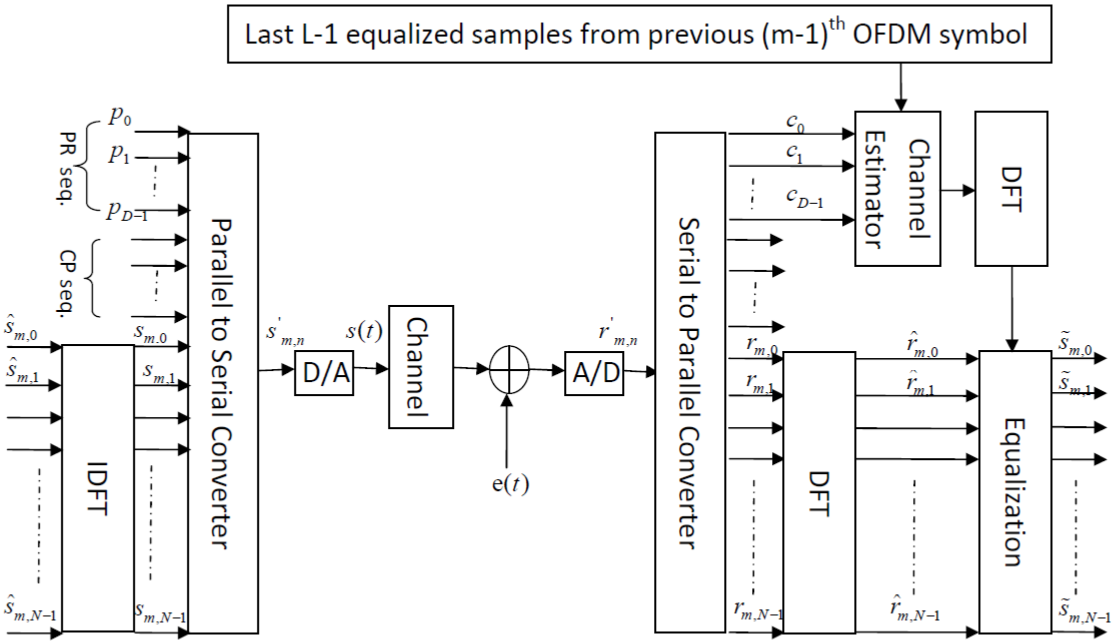

Fig. 1: Proposed PRwCP OFDM Transceiver Structure

$s_{m-1,N-1}$ is the $(N-1)^{th}$ sample of the $(m-1)^{th}$ OFDM symbol and **e** is the vector of complex baseband additive white Gaussian noise (AWGN) that is assumed to be uncorrelated with the channel. Please note that the first $L-1$ rows of matrix $\mathbf{Q}$ contain the last $L-1$ data samples of the previous OFDM symbol. Since these data samples of the previous OFDM symbol have already been estimated, the use of the estimated symbols in the channel estimate during the current OFDM symbol makes the scheme decision-directed. It is quite obvious that channel estimate will be erroneous in the absence of decision-directed scheme.

With the availability of the PR training sequence and the estimates of $\{\tilde{s}_{m-1,N-1}, \tilde{s}_{m-1,N-2}, \cdots, \tilde{s}_{m-1,N-L+1}\}$ from the previous OFDM symbol, the matrix $\mathbf{Q}$ is estimated as $\tilde{\mathbf{Q}}$ at the receiver end during the GI of the current OFDM symbol. Least squares solution of (5) minimizes the risk, R, or the cost function given as below:

$$R = (\mathbf{c} - \mathbf{Q}\mathbf{h})^H (\mathbf{c} - \mathbf{Q}\mathbf{h}) \tag{7}$$

Solution of (5) under minimum risk R is easily seen to be [14]:

$$\tilde{\mathbf{h}} = \left(\tilde{\mathbf{Q}}^H \tilde{\mathbf{Q}}\right)^{-1} \tilde{\mathbf{Q}}^H \mathbf{c} \tag{8}$$

where $\tilde{\mathbf{h}} = [\tilde{h}_0, \tilde{h}_1, \cdots, \tilde{h}_{L-1}]^T$ is the estimated channel in the current OFDM symbol. This proposed solution of channel estimation is labeled as PRwCP decision directed time-domain least squares estimation (PRwCP TDLSE w/DD). The proposed channel tracking scheme is illustrated with block diagram in Fig. 2.

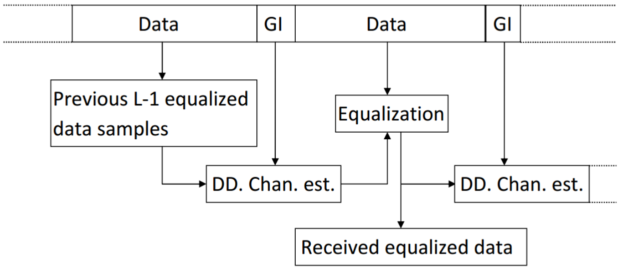

Fig. 2: Block Diagram of the Proposed Channel Estimation Method

IV. SIMULATION RESULTS

In this section, we present the simulation results to validate the effectiveness of a proposed channel estimation scheme. We simulated data communications via IEEE 802.11p standard for two wireless channel models (as shown in Table-I) of DSRC [13]. We used tapped delay line model for generating channel taps with the desired power spectrum profile. We generated each tap after 100ns delay. Maximum channel delay spread is 700ns for the 8-tap channel model and 400ns for the 5-tap channel model, respectively.

In order to assess the uncoded performance of the proposed channel estimation scheme, no error correction codes were used in simulations. In this section, we compare the performance of PRwZP TDLSE and its variants [9] and the proposed PRwCP TDLSE w/DD scheme with reference to bit error rate (BER) versus energy per bit to noise power spectral density (E_b/N_0). Perfect timing synchronisation is assumed at the receiver end. Simulation are carried out via the transmission of 100 OFDM frames over 500 channel realizations and 200 noise realizations. The number of OFDM symbols per frame is 10 and the data is modulated via quadrature phase shift keying (QPSK). Results are generated for slow fading and fast fading scenarios with channel coherence times of 120μs (equal to 15 OFDM symbol duration) and 24μs (equal to 3 OFDM symbol duration), respectively. Fig.3 & Fig.4 show the simulation results for channel model-1 (8-tap) under both slow and fast fading scenarios where the channel coherence times

Table II: Parameters of vehicular channel models

Tap	Time (ns)	**Channel-1** Suburban street (120 km/h)	**Channel-2** Expressway (140 km/h)
1	0	0.0 dB, Rician, K = 3.3 dB	0.0 dB, Rician, K =−5.3 dB
2	100	−9.3 dB, Rayleigh	−9.3 dB, Rayleigh
3	200	−14.0 dB, Rayleigh	−20.3 dB, Rayleigh
4	300	−18.0 dB, Rayleigh	−21.3 dB, Rayleigh
5	400	−19.4 dB, Rayleigh	−28.8 dB, Rayleigh
6	500	−24.9 dB, Rayleigh	0
7	600	−27.5 dB, Rayleigh	0
8	700	−29.8 dB, Rayleigh	0

K = ratio of the specular to diffuse component power of the received signal

are 120μs and 24μs, respectively. Similarly, Fig.5 & Fig.6 show the simulation results for channel model-2 (5-tap) under both slow and fast fading scenarios. From these figures, the following observations are in order:

1) The proposed PRwCP TDLSE w/DD scheme works better than the existing schemes that utilize GI for channel estimation in both the slow and fast fading channel scenarios.
2) Number of channel taps affects the performance of the proposed scheme (Fig.3 vs. Fig.5) and (Fig.4 vs. Fig.6). For the 5-tap channel model, BER obtained is close to that with perfect channel state information (CSI). Thus, maximum excess delay spread of the channel impacts the performance of the proposed system.
3) Performance of TDLSE scheme are similar for both 120μs and 24μs, because this scheme estimates channel at the beginning of every OFDM symbol.
4) In the case of fast fading scenario, the existing PRwZP TDLSE with OLA is not able to overcome this problem leading to higher BER (refer to Fig.4 and Fig.6). Moreover, the performance of OLA based scheme is degraded as compared to simple TDLSE (Fig.3 vs. 4 and Fig.5 vs. 6). Thus, OLA based schemes cannot be used for fast fading scenarios.
5) Smoothing based techniques will fail when the channel varies within the smoothing window (as is apparent from Figs.4 and 6). Also, large smoothing windows may be undesirable in real-time operations because it requires data storage up to the duration of the smoothing window for channel estimation.

V. CONCLUSIONS

This paper presents a novel guard interval based PRwCP TDLSE decision directed channel estimation scheme that is efficient for both slow and fast fading scenarios of IEEE 802.11p wireless standard. The proposed scheme does not restrict the length of CP, but utilizes the redundant space in GI (other than that required for CP) for channel estimation. Thus, the proposed scheme is capable of combating ISI (as CP length is more than channel delay spread) as well as ICI (since it correctly estimates the fast fading channel). Neither there is any reduction of throughput as it does not involve midamble insertion. Moreover, it does not require channel estimation via preamble and hence, effective data rate can be increased via removal of preamble in the future standards. The proposed scheme can address higher wireless data rate challenge for 5G communication besides robust channel estimation for fast fading scenarios.

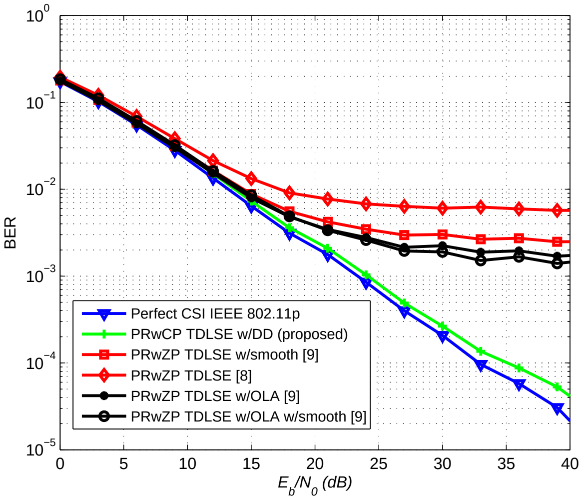

Fig. 3: BER vs. E_b/N_0, slow fading (coherence time 120μs), 8-tap channel model (Channel-1)

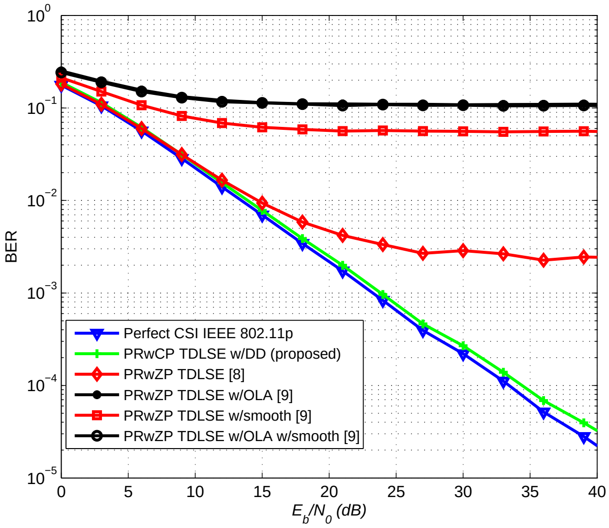

Fig. 4: BER vs. E_b/N_0, fast fading (coherence time 24μs), 8-tap channel model (Channel-1)

REFERENCES

[1] World health organization, "Global status report on road safety 2013," `http://www.who.int/violence_injury_prevention/road_safety_status/2013/en/`.

[2] F. Qu., F. Wang, and L. Yang, "Intelligent transportation spaces: Vehicles, traffic, communications, and beyond," *IEEE Commun. Mag.*, vol. 48, no. 11, pp. 136–142, Nov. 2010.

[3] C. F. Meck. et al., "Vehicular channel characterization and its implications for wireless system design and performance," *Proc. IEEE,* vol. 99, no. 7, pp. 1189–1212, July 2011.

[4] `http://www.ieee802.org/11/`.

[5] A. Paier et al., "Average downstream performance of measured IEEE 802.11p infrastructure-to-vehicle links," *Proc. IEEE ICC*, pp. 1–5, May 2010.

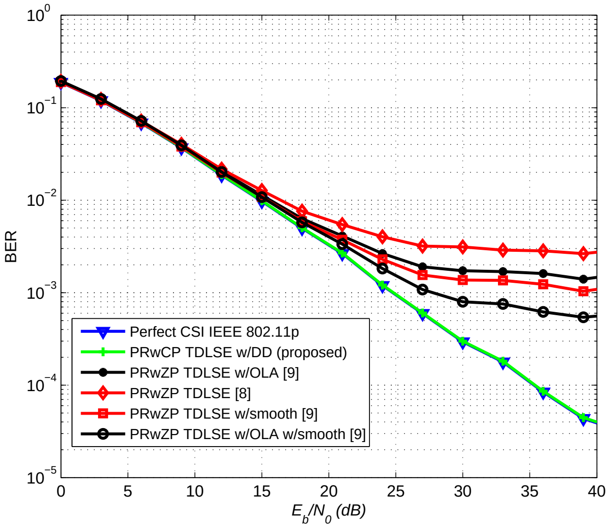

Fig. 5: BER vs. E_b/N_0, slow fading (coherence time 120μs), 5-tap channel model (Channel-2)

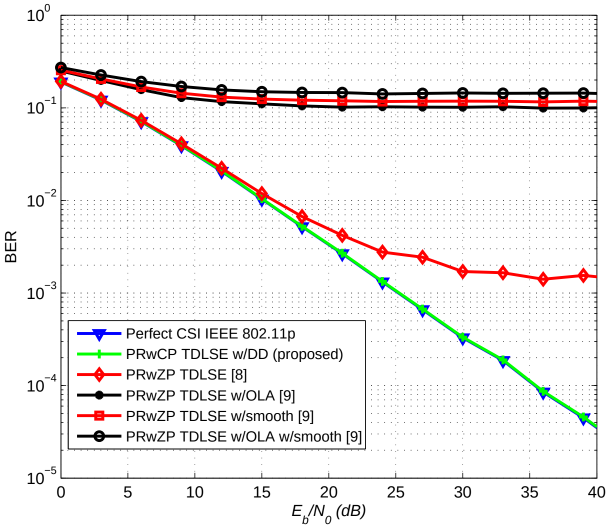

Fig. 6: BER vs. E_b/N_0, fast fading (coherence time 24μs), 5-tap channel model (Channel-2)

[6] H. A. Hamid, K. Tepe, and E. A. Raheem, “Performance of DSRC systems using conventional channel estimation at high velocities,” *Int. J. Electron. Commun. (AEU)*, vol. 61, no. 8, pp. 556–561, Sep. 2007.

[7] W. Cho et al., “Performance evaluation of V2V/V2I communications: the effect of midamble insertion,” *Proc. Wireless VITAE*, pp. 793–797, May 2009.

[8] C. S. Lin et al., “Performance evaluations of channel estimations in IEEE 802.11p environments,” *IEEE Int. conf. on ultra modern telecommunications (IUCMT)*, pp. 1–5, Oct. 2009.

[9] C. S. Lin et al., “Performance evaluations of channel estimations in IEEE 802.11p environments,” *Telecommunication Systems*, vol. 52 , no. 4, pp. 1731–1742, April 2013.

[10] A. Bourdux, H. Cappelle and A. Dejonghe, “Channel Tracking for Fast Time-varying Channels in IEEE802.11p Systems,” *IEEE Globecom*, pp. 1–6, Dec. 2011.

[11] S. Chen and J. Zhao, “The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication,” *IEEE Commun. Mag.*, vol. 52 , no. 5, pp. 36–43, May 2014.

[12] J. G. Proakis, *Digital Communications*. McGraw-Hill Inc., Third Edition, 1995.

[13] G. A. Marum and M. A. Ingram, “Six time and frequency selective empirical channel models for vehicular wireless LANs,” *IEEE Veh. Tech. Mag.*, vol. 2, no. 4, pp. 4–11, Dec. 2007.

[14] D. G. Manolakis, V. K. Ingle, and S. M. Kogan, *Statistical and Adaptive Signal Processing*. New York: McGraw-Hill Int. Editions, 2000.