IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 5 Issue 3, March 2018
ISSN (Online) 2348 – 7968
www.ijiset.com

Analytical Estimation of Doppler Shift in Vehicular Ad Hoc Networks for Enhanced Detection in Accident Avoidance Campaigns

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Abstract

Road accidents are a global public health hazard. The concept of Vehicular Ad Hoc Networks (VANETs) enables implementation of wireless communication technologies to realize safety in vehicular environment in response to growing concerns of road accident injuries. Preliminary research findings indicate that majority of vehicular accidents involve non-impaired drivers who, if alerted of the impeding danger, would avoid such crashes. Solutions have been proposed in collision avoidance through cooperative safety applications supported in vehicle-to-vehicle and vehicle-to-infrastructure communications. While the existing protocols relying on pilot carriers adequately address the fixed and low mobility scenarios, high vehicular mobility is perturbed by Doppler shift which renders the existing protocols ineffective by degrading the received signal quality. In this paper a method based on analytical techniques is developed to enhance signal detection by yielding more accurate Doppler shift estimates. Numerical results indicate that the proposed method outperforms the methods based on existing algorithms.

Keywords: *Doppler Shift; Estimation; MIMO; OFDM; Safety.*

1. Introduction

Safety in vehicular ad hoc networks (VANETs) is a key element implemented in vehicle-to-vehicle (V2V) and vehicle-to- infrastructure (V2I) communication [1]. VANETs promise to revolutionize road transport through integration of Intelligent Transportation System (ITS) where safety occupies a significant position [2]. ITS aims to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and smarter use of transport networks.

Passive safety systems like the airbag, the safety seat belt, and the Anti-Lock Braking System already exist and help to decrease intensity of accident fatalities but have proved inadequate with time. Active systems such as emergence messaging and collision avoidance imbedded in vehicular communications have been proposed to warn drivers in advance and form an active area of research [3] [4]. The supporting technology imbedded in wireless communication is based on the IEEE 802.11 protocol [5].

Motivated by the possibility to reduce the number of accidents, avoid potentially dangerous traffic situations and improve user mobility comfort, the US Federal Communication Commission (FCC) allocated 75 MHz frequency band at 5.9 GHz, designated Dedicated Short Range Communication (DSRC), to cover the entire ITS applications [6].

The first amendment to the IEEE 802.11 protocol, the IEEE 802.11a, introduced orthogonal frequency division multiplexing (OFDM) to address the increased demand for high bit rates on the 20 MHz bandwidth in WiFi fixed and portable devices. OFDM transforms a broadband frequency-selective channel into parallel narrowband overlapping frequency-flat sub channels where the sinc-shaped spectra exhibit zero crossings at all the remaining sub carriers, thereby constituting an orthogonal set. Since each subcarrier could be modulated independently, OFDM created low data rate parallel channel links with reduced BER by splitting the high data rate single-carrier channel [8].

The second amendment creating IEEE 802.11p halved the bandwidth which tremendously changed the physical layer parameters to adapt to the high mobility conditions encountered in vehicular networks. In fact, the standard is designated Wireless Access in Vehicular Environment (WAVE) in upper layers of the protocol [9]. The increased symbol size combined with the guard interval makes OFDM robust to multipath fading by removing Inter-symbol Interference (ISI) and introducing diversity [10].

Further, the standard incorporates multi-antenna operation at both the transmitter and the receiver, called multiple input multiple output (MIMO) technique [11]. The two most important advantages of a MIMO system are (i) a significant increase of both the system's capacity and

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spectral efficiency, where the capacity of the link increases linearly with the minimum of the number of transmitter or receiver antennas and (ii) dramatic reduction of the effects of fading due to the increased diversity, particularly in a rich multipath environment [12]. For these reasons MIMO-OFDM has been proposed for use in vehicular networks as a spatial multiplexing technology [13].

Despite these benefits OFDM suffers a setback arising from high sensitivity to Doppler shift. The particular problem arises when the receiver is moving towards the source. The received frequency is increased whereas if it is moving away from the source the received frequency is decreased [14]. This effect, called Doppler Effect, causes a frequency offset with the local oscillator, the Doppler shift, and it is one of the major sources of increased BER experienced in a vehicular channel.

Frequency dispersion across adjacent subcarriers leads to power leakage which breaks orthogonality among the subcarriers and causes increased BER arising from Inter-carrier Interference (ICI) [15]. This effect is especially experienced in high mobility conditions where Doppler shift is predominant [16].

The vehicular channel has been investigated for multipath fading, shadowing and Doppler shift in [17] [18] [19] [20] [21] [22]. In all cases under reference, the channel matrix was modelled with time-invariant coefficients obtained by means of pilot carriers, suitable for portable and low mobility nodes, to estimate Doppler shift. In high mobility conditions, the algorithms fail to estimate the correct Doppler shift values thus, causing errors in the detection of the received signal due to the residual effects.

The proposed method models a channel matrix with time-variant coefficients analytically obtained as exponential functions of time with better Doppler shift estimation capability in high node mobility scenarios. Numerical results indicate that the proposed method performs better than the existing methods in estimating Doppler shift in high vehicular mobility conditions.

To the best of my knowledge no algorithm utilizing a channel matrix with analytically obtained time-variant exponential coefficients for estimating Doppler shift has been published in the recent literature.

The rest of the paper is arranged as follow. Section II is the system model; Section III is Doppler shift estimation; Section IV is numerical results; while Section V is the conclusion.

2. System Model

Figure 1 is a model based on a spatial multiplexed transceiver system where the challenges of frequency-selectivity of the channel caused by Doppler shift (DS) are confronted to emulate a vehicular channel.

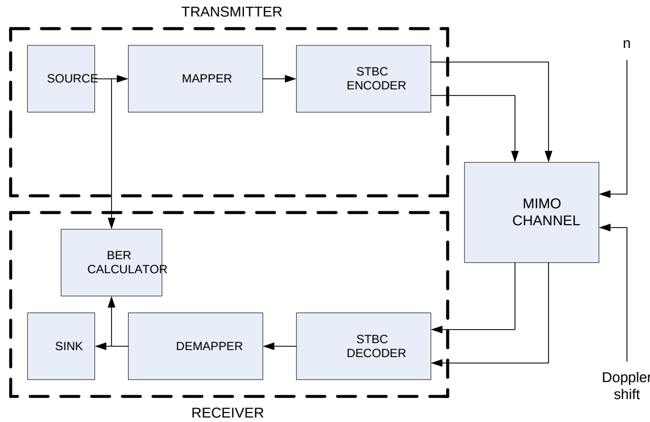

Fig. 1: Transceiver system with MIMO channel in high speed vehicular environment

Consider a system with transmit antennas and receive antennas linked with a MIMO channel such that

$$y = Hx + n \tag{1}$$

where $x = \left[x_1 x_2 \ldots x_{N_T} \right]^T$ and $y = \left[y_1 y_2 \ldots y_{N_R} \right]^T$ are transmit and receive signals with x_i and y_j denoting transmit signal from i-th transmit antenna (i=1,2,...,N_T) and receive signal at j-th receive antenna (j=1,2,...,N_R), respectively, with elements considered to be zero-mean independent and identically distributed (i.i.d.) Gaussian variables. H is an $\left(N_R \times N_T \right)$ matrix with complex exponential elements h_{ij} while the noise vector $n = \left[n_1 n_2 \ldots n_R \right]^T$ is assumed to have zero-mean and variance σ_n^2 at receive antenna j. The symbol $[.]^T$ denotes vector transpose.

Each link between a pair of transmit and receive antennas can be regarded as an $L-$tap Finite Impulse Response (FIR) filter. Moreover, the channel is assumed time variant (TV) over the transmission of one OFDM symbol as a result of fading caused by DS. Hence, a time-domain channel matrix for the lth tap is expressed as:

$$H^l(k)=\begin{bmatrix} h^l_{1,1}(k) & h^l_{1,2}(k) & \cdots & h^l_{1,N_r}(k) \\ h^l_{2,1}(k) & h^l_{2.2}(k) & \cdots & h^l_{2,N_r}(k) \\ \vdots & \vdots & \ddots & \vdots \\ h^l_{N_r,1}(k) & h^l_{N_r,2}(k) & \cdots & h^l_{N_r,N_t}(k) \end{bmatrix}_{N_r\times N_t} \tag{2}$$

where $h^l_{N_r,N_t}(k)$ stands for the TV channel impulse response (CIR) between the *j*th (*j*=1…N$_r$) receive antenna and the *i*th (*i*=1…N$_t$) transmit antenna of the lth (*l*=1…L) tap during the *e*th(*e*=1…E) OFDM symbol.

Due to Doppler spread arising from DS, the channel matrix coefficients vary dependent on the value of the Doppler spread. In our model, the channel is modelled with exponentially decaying path gains as a function of the DS. The time-domain matrix in Eq. (2) is Fourier-transformed to yield a frequency-domain channel matrix expressed as

$$H=\begin{pmatrix} h_{11}e^{-(f_c-f_d)^{-1}} & \dots & h_{1n}e^{-(f_c-f_d)^{-1}} \\ \vdots & \ddots & \vdots \\ h_{m1}e^{-(f_c-f_d)^{-1}} & \dots & h_{mn}e^{-(f_c-f_d)^{-1}} \end{pmatrix}, \tag{3}$$

where f_c is the carrier frequency and f_d is the DS given by

$$f_d=\frac{v}{c}f_c\cos\beta, \tag{4}$$

where v is speed of the vehicle, c is the speed of light and β is the angle of the signal arrival at the receive antenna. Substituting f_d in Eq. (3) using Eq. (4) at maximum DS ($\beta=0$), each coefficient in the channel matrix becomes

$$\begin{aligned}\hat{h}&=h_{mn}e^{-(f_c-f_d)^{-1}} \\ &=h_{mn}e^{-\left(1-\frac{v}{c}\right)^{-1}f_c^{-1}}\end{aligned}, \tag{5}$$

where the value in each case is dependent on the speed of the vehicle v. Normalizing Eq. (5) to $\exp\left(f_c^{-1}\right)$ the gains become

$\exp\left(f_c^{-1}\right)$ the gains become

$$h_N=h_0e^{-\left(1-\frac{v}{c}\right)^{-1}}, \tag{6}$$

where h_0 is a stationary gain. In the limits $v\to 0$, $h_Ne^{-\left(1-\frac{v}{c}\right)^{-1}}\to h_0e^{-1}$, constituting the well-known channel matrix with constant gains for the quasi-static channel. However, as $v\to c$, $h_Ne^{-\left(1-\frac{v}{c}\right)^{-1}}\to h_0e^{-\infty}=0$, implying that at extremely high vehicular speed the channel is extremely lossy so that it has no output $y(t)$ caused by extreme effects of mobility. In our model, v is scaled by a constant α to define the realistic channel gains expressed as $h_N=h_0e^{-\left(1-\frac{\alpha v}{c}\right)^{-1}}$.

Under the model, a critical speed, the High Speed (HS) is defined as the VANET speed beyond which estimation and compensation of DS will be performed. At HS the symbol time of the signal and the coherence time of the channel are equal, beyond which the channel becomes fast fading with consequences of signal distortion. Thus, it can be shown that at $T_s=T_c$ the critical speed

$$\begin{aligned}v_c&=\frac{c}{T_cf_c} \\ &=HS\end{aligned} \tag{7}$$

Given that different channel models have different coherence time, it follows that HSs of such channels will similarly vary for a given signal. For successful decoding to be realized in channels beyond HS position, estimation and compensation of DS is necessary.

3. Doppler Shift Estimation

The channel frequency response characteristics determine the effects of DS on the signal. Consider a signal with baseband B_s having symbol time $T_s = 1/B_s$ transmitted over the channel. Defining σ_τ as the RMS delay spread, [23] gives the expression of the channel coherence bandwidth as

$$B_c \approx \frac{1}{\sigma_\tau}. \tag{8}$$

Over this channel, frequency-selectivity is governed by signal bandwidth. Each path experiences a different amount of DS such that the total frequency dispersion in the received signal is Δ_f, the Doppler spread B_D. The reciprocal is the coherence time of the channel T_c, that is, $T_c = 1/B_D$. Recalling that when $T_s > T_c$, fast fading occurs [24], it becomes evident that high mobility will increase B_D and cause frequency-selectivity when T_c reduces to the level below T_s. Hence, the fading speed of the channel can also be measured by the Doppler spread. Conversely, DS is estimated as

$$B_D \approx \frac{1}{T_c}, \tag{9}$$

so that the rate of channel fading can estimate DS experienced in that channel. However, Eq. (9) does not provide the explicit amount of DS present sufficiently to enable compensation.

In frequency domain, at low vehicular speeds, B_D is low and as long as $B_D < B_c$, the channel is flat fading and the effect of DS is not experienced. However, as speed increases, B_D also increases according to Eq. (9). In the event that $B_D > B_c$, the signal will undergo fast fading and be filtered by the channel. This will generate the out-of-band interference that will reduce signal quality. Consequently, the DS-perturbed channel matrix in Eq. (3) becomes

$$H_D = e^{-\left(1-\frac{\alpha v}{c}\right)^{-1}} H, \tag{10}$$

as shown in Eq. (7), so that the amount of DS is estimated by the estimation matrix

$$\begin{aligned}\overleftrightarrow{H} &= H^{-1} H_D \\ &= e^{-\left(1-\frac{\alpha v}{c}\right)^{-1}} I_{N_r N_t}\end{aligned}. \tag{11}$$

The Doppler shift factor can be eliminated by compensation to enhance detection.

4. Numerical Results

Our model, proposed method (PM), was tested under the described conditions and the respective results are provided. Comparisons are made with existing models namely, Level-crossing Rate (LCR) and the uncompensated channel for validation.

For a given channel frequency response, frequency selectivity is governed by signal bandwidth. A channel with a hypothetical response was tested with a signal at 5.9 GHz in a range of velocity values for fading properties.

We validated our channel by testing the estimation performance using Eq. (11) followed by a compensation process. Then, we evaluated the performance of DS estimation in the simulation. The BER is the chosen metric for performance evaluation. The experiment is performed under two different normalized DS: 0.2 and 1.0 at 25 dB SNR, corresponding to DS of 334 Hz and 1632 Hz, at velocity of 30 km/h and 150 km/h (on-coming) in the Highway scenario of the vehicular channel model with carrier frequency at 5.9 GHz. The results are given in Figs. 2 – 4.

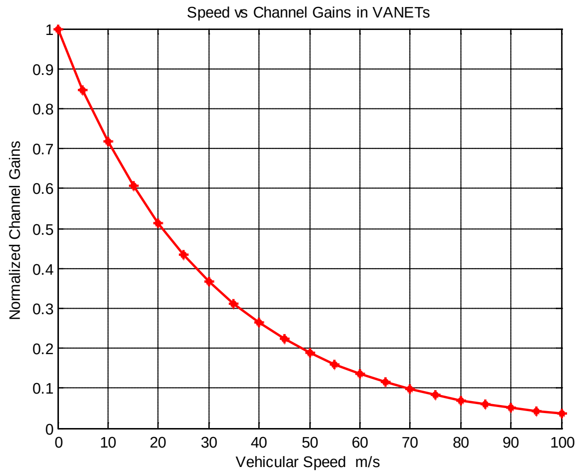

Fig. 2: Vehicle speed vs normalized channel gains

The channel gains in stationary conditions are consistent with the static and portable wireless systems. However, mobility induces DS which increases with vehicular speed as indicated in Fig. 2. At low values of DS corresponding to low and medium speeds distortion correction is done by channel equalization. However, DS exponentially reduces the channel gains so much in HS VANETs that distortion correction is only possible by channel estimation and compensation. The critical speed at which estimation commences varies with propagation scenarios. Typical scenarios classified based on environmental scattering features and associated vehicular velocities have variously been classified in the literature as: Highway; Rural; Suburban; and Urban whose propagation parameters are obtained in measurement campaigns.

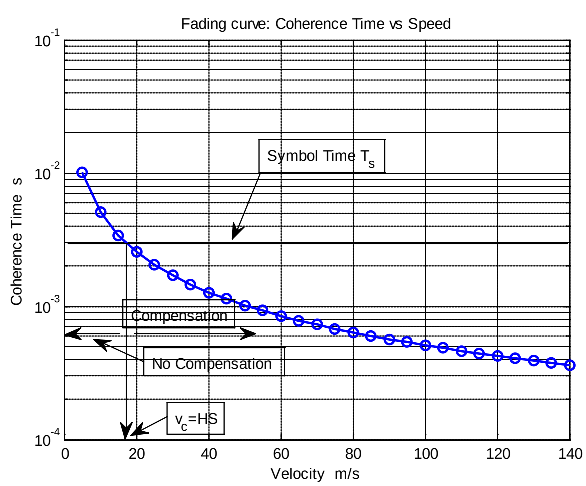

Fig. 3: Coherence time vs vehicular speed

Depending on the extent of the Doppler spread, the received signal undergoes fast or slow fading. For a transmission signal with symbol time $T_s = 3\times10^{-3}$, the critical speed v_c is defined as in Fig. 3. Up to a velocity of 18 m/s or 65 k/h the received signal undergoes slow fading and requires no compensation. The increasing velocity causes further reduction in coherence time, leading to fast fading. This condition requires compensation above the velocity of 65 km/h, which is defined as HS in this case.

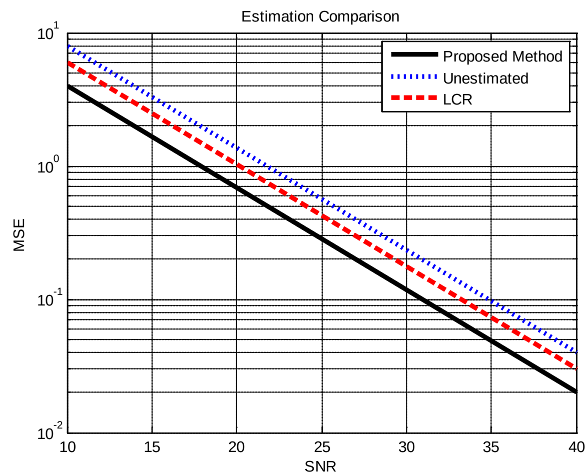

Fig. 4: Channel Estimator performance at different speeds

Different methods are compared for estimation performance in Fig. 4. The estimation error is improved in the Proposed method owing to the elimination of fading contributed by multi-path delay spread as a result of use of OFDM and cancellation of more accurately estimated Doppler noise achieved by the more effective analytical techniques.

5. Conclusions

The implemented analytical method yields numerically better Doppler shift estimates in high mobility vehicular channel that leads to superior signal detection performance in terms of BER compared to the existing methods based on pilot carriers. The method also simplifies the estimation process as it eliminates pilot carriers which are more complex to implement.

References

[1] US DOT, "Vehicle-to-vehicle safety application research plan," Connected Vehicle Research Program, October 2011

[2] WORLD HEALTH ORGANIZATION, "World report on road traffic injury prevention: summary", Geneva, 2004

[3] US DOT, "Centre for automotive research," Michigan Department of Transport, July, 2012

[4] F. NYONGESA, K. DJOUANI, T. OLWAL, AND Y. HAMAM, *"Doppler Shift Compensation Schemes in VANETs"*. Mobile Information Systems 2015, Vol.2015, 11 pages, Article ID 438159, http://dx.doi.org/10.1155/2015/438159.

[5] IEEE 2007. LAN/MAN Standards Committee: IEEE Standard for Information Technology – Telecommunication and Information Exchange Between Systems – Local and Metropolitan Area Networks – Specific Requirements; Part II: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. *IEEE Std 802.11-2007*.

[6] KENNEY, J. B. 2011. Dedicated Short-Range Communications (DSRC) Standards in the United States. *In: Proceedings of the IEEE.* Mountain View, CA, USA

[7] MA, J. M., ORLIK, V., ZHANG, J. & LI, G. Y. 2012. Reduced-Rate OFDM Transmission for Inter-Subchannel Interference Self-Cancellation over High-Mobility Fading Channels. *IEEE Transactions on Wireless Communications,* 11(6)**:**2013-2023.

[8] COLERI, S., ERGEN, M., PUR, A. AND BAHAI, A. 2002. Channel Estimation Techniques Based on Pilot Arrangement in OFDM Systems. *IEEE Trans. on Broadcasting,* 48(3)**:**223-229

[9] LI, B., MIRHASHEMI, M. S., LAURENT, X. & GAO, J. 2010. Wireless Access for Vehicular Environments. *Telematics Communication Technologies and Vehicular Networks,* (205).

[10] AHN, M., SONG, C. & LEE, I. 2014. Diversity Analysis of Coded Spatial Multiplexing MIMO AF Relay Systems. *IEEE Transactions on Vehicular Technology,* 63(7)**:**3435-3439.

[11] STUBER, G. L., BARRY, J. R., MCCLAUGHLIN, S. W., LI, Y., INGRAM, M. A. & PRATT, T. 2004. Broadband MIMO-OFDM Wireless Communications. *In: Proc. of the IEEE.* Invited paper.

[12] HOLTER, B. 2001. On the Capacity of the MIMO Channel – A Tutorial Introduction. *Dept. Telecommunications, Norwegian University of Science and Technology, Stavenger, Norway, Tech.Rep*.

[13] EL-KEYI, A., ELBATT, T., BAI, F. & SARAYDAR, C. 2012. MIMO VANETS: Research Challenges and Opportunities. *In: IEEE Proc. Int. Conf. On Computing, Networking and Communications, Invited Position Paper Track.*

[14] SUR, S. N. & BERA, R. 2012. Doppler Shift Impact On The MIMO OFDM System In Vehicular Channel Condition. *Int. J. Info. Technology and Computer Science* 4**:**57-62.

[15] JEONG, H., KIM, D. & RYU, H. 2012. Doppler Spread and its Compensation by FDE and Turbo Code. *In: ICOIN 2012*.

[16] CHENG, X., YAO, W., WANG, C.-X., AI, B., STUBER, G. L., YUAN, D. & JIAO, B.-L. 2013. An Improved Parameter Computation Method for a MIMO V2V Rayleigh Fading Channel Simulator Under Non-Isotropic Scattering Enviroments. *IEEE Communication Letters,* 17(2)**:**265-268.

[17] MECKLENBRAUKER, C. F., MOLISCH, A. F., KAREDAL, J., TUFVESSON, F., PAIER, A., BERNADO, L., ZEMEN, T., KLEMP, O. & CZINK, N. 2011. Vehicular Channel Characterization and Its Implications for Wireless System Design and Performance. *In: Proceedings of the IEEE,* 99(7)**:**1189-1212.

[18] VANDENBERGHE, W., CAPPELLE, H., MOERMAN, I. & DEMEESTER, P. 2014. SDDV: scalable data dissemination in vehicular ad hoc networks. *EURASIP Journal on Wireless Communications and Networking,* 1(182).

[19] EICHLER, S. 2007. Performance Evaluation of the IEEE 802.11p WAVE communication standard. *In: Proc. of Vehicular Technology Conference***:**2199-2203.

[20] ALBARAZI, K., MOHAMMAD, U. & AL-HOLOU, N. 2011. Doppler Shift Impact on Vehicular Ad-hoc Networks *Canadian Journal on Multimedia and Wireless Networks,* 2(3)**:**46-56.

[21] TIAN, Q., ZHANG, Q., XIN, X. & HSU, D. 2012. Adaptive Doppler Frequency Shift Estimation for OFDM Systems. *In: International Conference on Wireless Communication and Signal Processing***:**1-5.

[22] SUR, S. N. & BERA, R. 2012. Doppler Shift Impact On The MIMO OFDM System In Vehicular Channel Condition. *Int. J. Info. Technology and Computer Science* 4**:**57-62.

[23] CHO, Y. S., KIM, J., YANG, W. Y. & KANG, C. 2010. *MIMO-OFDM Communications with MATLAB,* Asia, John Wiley and Sons.

[24] RAPPAPORT, T. S. 2002. *Wireless Communications - Principles and Practice,* Upper Saddle River, NJ, Prentice Hall.

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