Coherence Time and Doppler Spectrum of V2V Channel with Moving Scatterer Based on Autocorrelation Function

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Abstract —Vehicular Ad Hoc Network (VANET) technology allows vehicles to communicate with each other in mobile conditions. Modeling the channel by observing the movement of the vehicle as the transmitter, the receiver and the surrounding moving objects has been done and generates a large Doppler Shift. This modeling affects the Coherence Time value that determines the duration of the channel to not change at a certain time period. In this paper, the Coherence Time value was obtained through the autocorrelation of complex envelope V2V channel modeling. Furthermore, for various speeds of the transmitter, receiver, and scatterer, the Coherence Time values were validated using the equation on the correlation limit value that had been determined by the auto-correlation results. In addition, the obtained Doppler Spectrum values were validated through the inverse Fourier Transform process of the V2V channel complex autocorrelation function. Coherence Time value at the limit of autocorrelation function> 0.5 that was used on the wireless communication system channel had a slight difference with the results of V2V channel validation that generated a limit of autocorrelation function <0.5 at the same Coherence Time value. Meanwhile, the value of Coherence Time from the Geometric Mean results had a limit of the autocorrelation function at the position around of the first minimum value that approached zero.

Index Terms—V2V, moving scatterer, coherence time, auto-correlation function, doppler spectrum

I. Introduction

Channel modeling in wireless communication technology has been developed with regard to the communication environment. One of the wireless communication technologies applied to the vehicle to vehicle (V2V) communication has different characteristics with wireless communication systems in general. The unique characteristics of vehicular channels include the height of the transmitting and receiving antennas compared to cellular-based communication systems. The working frequency of cellular-based communication systems operates mostly in the range of 5.9 GHz, while cellular-based communication systems operate at a frequency of 700 - 2100 MHz [1]. In addition, the movement of vehicles in vehicular communication systems that have relatively greater speeds than users of cellular-based communication systems will produce a much greater Doppler Shift.

Some channel models developed for vehicular-based communications accommodate transmitting and receiving vehicles movements as well as the surrounding scatterers within a static circle radius [2]. Meanwhile, another channel modeling regulates the movement of the transmitting and receiving vehicles, and it accommodates a large number of scatterer movements in a random direction [3]. Each channel modeling produces a different Doppler Shift. The type of channel modeling that accommodates scatterer movements produces relatively large Doppler Shift compared to the first modeling. The generated Doppler Shift is a combination of Doppler Shift on the transmitter, transmitter to the scatterer, scatterer to the receiver, and Doppler Shift on the receiver.

Variations in the speed of the transmitter, receiver, and scatterer that move on the channel modeling have been validated using the autocorrelation and the spectral density parameters [4]. The speed of the transmitting vehicle can be constant, exponential, and random with uniform distribution is validated by using the autocorrelation parameter. Likewise, the speed of the scatterer around the transmitter and receiver divided into two Gaussian distributed groups, then they are combined with the Gaussian Mixture method to obtain the validation of autocorrelation parameters and power spectral density. The next research plan stated in [4] is the investigation of the Coherence Time parameter and the effect of moving scatterer distribution in a specific area. This indicates the importance of the Coherence Time parameter and the effect of the moving scatterer on V2V channel modeling.

The Coherence Time parameter is generated from the movement of vehicle or scatterers on vehicular channel models. The movement raises Doppler Shift which ultimately affects the duration of Coherence Time. The definition and formula of Coherence Time parameters on the condition of wireless communication systems have been established in previous studies [5]. In this study, the value of Coherence Time was determined at the limit of the correlation function of 0.5. Another research set the definition of Coherence Time by decreasing the formula from the combined Geometric Mean of two previous Coherence Time definitions [6]. In vehicular based channel modeling, the validation of Coherence Time

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parameters that accommodates the transmitter, receiver and scatterer movements has not been done.

Determining the value of Coherence Time and Doppler Spread on V2V channels has been carried out on rural and highway environments using real measurement methods in the city of Pittsburgh. The measured spectrum results are compared to the double ring model with the used Coherence Time parameter has the correlation function limits of 0.5 and 0.9. Doppler Spread from this study was obtained from measurement results without taking into account the moving scatterer [7].

Despite all these considerations, Coherence Time of V2V channel with moving scatterers has not been validated at any research before. Thus, in this work, we validated the formula of Coherence Time at two autocorrelation limits with the result of Autocorrelation Function of complex envelope V2V with moving scatterer. Furthermore, using the Fourier Transform function from the Autocorrelation, Doppler Spectrum parameters are obtained to validate the Doppler Spread formula that has been determined in previous studies [8].

The next sections of this paper will be presented as follows. Section II discusses the research method and the channel modeling characteristics using the V2V Channel with moving scatterers, the Coherence Time and Doppler Spread. Meanwhile, Section III presents the results and analysis and Section IV presents the conclusions.

II. Research Method

The V2V channel modeling in this study refers to Fig. 1. T_x vehicle moves with V_T direction while the R_X vehicle moves with V_R direction. The T_x vehicle moves with α_v^T angle and the R_X vehicle moves with α_v^R angle to the same horizontal line.

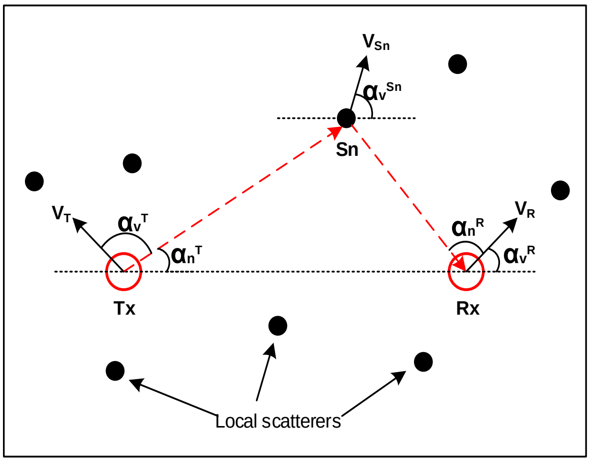

Fig. 1. V2V channel model

The scatterers are placed around the transmitter and receiver vehicles with random locations. These scatterers move at the same v_{S_n} speed for a number of Sn scatterers with directions that are also considered random. The direction of the moving scatterers is denoted by the $\alpha_v^{S_n}$ angle. To avoid high attenuation values, the scatterer that is located far away is ignored. The wave is only considered to propagate from the transmitter vehicle with the α_n^T Angle of Departure (AoD) that is received on the receiving vehicle at the α_n^R Angle of Arrival (AoA) after reflected by the S_n scatterers that move around the area. The channel gain value from the modeling is obtained by using the following formula.

$$\mu(t)=\sum_{n=1}^{N} c_n e^{j(2\pi f_n+\theta_n)} \tag{1}$$

Complex Envelope in Equation (1) is a complex stochastic process that is the sum of all scattering components. The value of c_n is defined as the damping factor of the scatterer object S_n reflection and the f_n value is the Doppler Shift value as a result of the combined movement of the transmitting, receiving, and scatterer components. The amount of the Doppler Shift value is defined as follows.

$$f_n = f_n^T + f_n^{TS} + f_n^{SR} + f_n^R \tag{2}$$

The parameter denoted as f_n^T is the Doppler Effect caused by transmitter movement. The parameter f_n^{TS} is the parameter caused by a transmitted signal that hit n-th moving scatterers. The parameter f_n^{SR} is the effects of scatterers that move and bounce signals towards the receiver. The parameter f_n^R is the Doppler that caused by receiver movement. All four of Doppler Shift components are defined as follows.

$$f_n^T = f_0 \frac{v_T}{c_0}\cos\left(\alpha_v^T-\alpha_n^T\right) \tag{3}$$

$$\begin{aligned} f_n^{TS} &= \left(f_0+f_n^T\right)\frac{v_{S_n}}{c_0}\cos\left(\pi+\alpha_n^T+\alpha_v^{S_n}\right) \\ &\approx -f_0\frac{v_{S_n}}{c_0}\cos\left(\alpha_n^T+\alpha_v^{S_n}\right) \end{aligned} \tag{4}$$

$$\begin{aligned} f_n^{SR} &= \left(f_0+f_n^{TS}\right)\frac{v_{S_n}}{c_0}\cos\left(\pi+\alpha_v^{S_n}-\alpha_n^R\right) \\ &\approx -f_0\frac{v_{S_n}}{c_0}\cos\left(\alpha_v^{S_n}-\alpha_n^R\right) \end{aligned} \tag{5}$$

$$\begin{aligned} f_n^R &= \left(f_0+f_n^{SR}\right)\frac{v_R}{c_0}\cos\left(\alpha_v^R-\alpha_n^R\right) \\ &\approx f_0\frac{v_R}{c_0}\cos\left(\alpha_v^R-\alpha_n^R\right) \end{aligned} \tag{6}$$

If each component is added, then:

$$f_n = \frac{k_0}{2\pi}\begin{bmatrix} v_T\cos\left(\alpha_v^T-\alpha_n^T\right)-v_{S_n}+ \\ \left(\cos\left(\alpha_n^T-\alpha_v^{S_n}\right)+\cos\left(\alpha_v^{S_n}-\alpha_n^R\right)\right)+ \\ v_T\cos\left(\alpha_v^R-\alpha_n^R\right) \end{bmatrix} \tag{7}$$

with the parameter $k_0 = 2\pi \frac{f_0}{c_0}$ is a free space wave number.

To obtain the Autocorrelation Function (ACF) parameter from the Complex Envelope model used in this study, the following formula is applied.

$$r_{\mu\mu}(\tau) = \lim_{N\to\infty} \sum_{n=1}^{N} c_n^2 E\left\{e^{2\pi f_n \tau}\right\} \quad (8)$$

with $c_n = \sigma_0 \sqrt{2/N}$ and N is the number of scatterers around the transmitter and receiver area.

The Doppler Shift parameter in formula (7) is used to determine the value of Coherence Time which is defined as the duration where a channel does not change. The Coherence Time value is denoted as follows [6]:

$$\tau_C = \frac{1}{fn} \quad (9)$$

If the Coherence Time value has a correlation function limit > 0.5 then the value becomes:

$$\tau_{c1} = \frac{9}{16\pi f_n} \quad (10)$$

If the Geometric Mean function is applied from Equations (9) and (10), the Coherence Time value becomes:

$$\tau_{c2} = \frac{0.423}{f_n} \quad (11)$$

The correlation function limit of the Coherence Time value has not been defined in previous studies.

Meanwhile, the calculation of Doppler Spread value based on the Doppler Shift value from the V2V channel modeling used the following equation.

$$B_D = 2 f_n \quad (12)$$

Validation of Doppler Spread parameters was obtained from Doppler Spectrum with the Fourier Transform of the autocorrelation function formula (8) to yield:

$$S_c(\rho) = FFT(r_{\mu\mu}(\tau)) \quad (13)$$

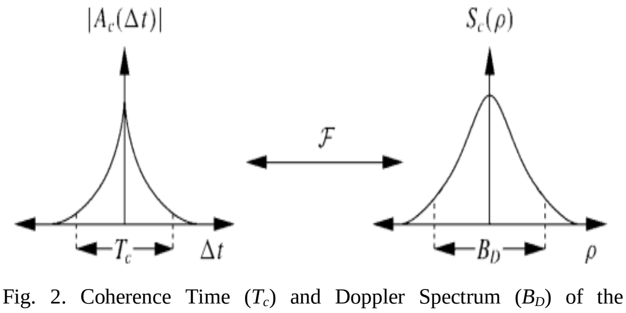

Fig. 2. Coherence Time (T_c) and Doppler Spectrum (B_D) of the Autocorrelation Function [8]

To validate the Coherence Time and Doppler Spread values from the Autocorrelation results, Fig. 2 is used as the reference. The coherence time parameter obtained from the calculation of the auto correlation function produces in Fig. 2. This is the real value of coherence time of the V2V channel.

Next, to determine the coherence time value in Fig. 2 it is used by determining the period length from the positive side to the negative side of the auto correlation value which is close to zero. This value is then compared with the calculation of the coherence time parameter obtained from formula (10), where the correlation function in theory is more than 0.5.

Furthermore, to validate the value of the doppler spectrum parameter, the results comparison between formula (12) and simulation result on Fig. 2 is used. Formula (12) is obtained from the total doppler frequency parameter (f_n) which is the total Doppler Shift from the sending, receiving and moving scatterer. This result is compared with the Fourier transformation process from the auto correlation function in formula (8).

III. Results and Discussion

The simulations in this paper were done by referring to Fig. 1. The specified carrier frequency was 5.9 GHz with a θn value of 5°. Vehicles as transmitters and receivers, moved at respective α_v^T and α_v^R angles in the same direction, with each angle was equal to 5°. There were eight scatterers that were assumed to be around transmitting and receiving vehicles with the same speed but random directions between 0 – 2π. Meanwhile, the sampling frequency to get the autocorrelation function was set at 1000 Hz.

The transmitting and receiving vehicles as well as the moving scatterers were divided into the low, medium, and high-speed categories. From each category, the Doppler Shift value of Equation (7) was used as a reference parameter to get the Coherence Time value in Equations (10) and (11). The results of the Coherence Time parameter obtained from Equations (10) and (11) were validated with the Autocorrelation value obtained from Equation (8). The Coherence Time values obtained from the graph of the autocorrelation function are shown in Fig. 2. The Coherence Time value at the correlation function limit was 0.5 measured from the Y = 0 coordinate point, with the X coordinate width is the autocorrelation function that was multiplied by two. The boundary of the correlation function for the Coherence Time parameter in Equation (11) was validated with the width of the X coordinate from the Y value that was closest to the equation.

Meanwhile, the Doppler Spread parameter was obtained from Doppler Shift results in Equation (7) which was validated with Fourier Transform results from Autocorrelation in Equation (13) as listed in Fig. 2. Doppler Spread values were measured from Y coordinate points at minimum values close to 0 as far as coordinates X multiplied by 2.

A. Low-speed Scenario

In the low-speed scenario, the assumption was that the speed of the transmitting and receiving vehicles was 50 m/s with the movement angles α_v^T and α_v^R in the same direction, with each value was equal to 5 º. Meanwhile, the speed of scatterers was 5 m/s with 8 pieces of them moving in a random direction. The results of this scenario are:

1) Coherence time

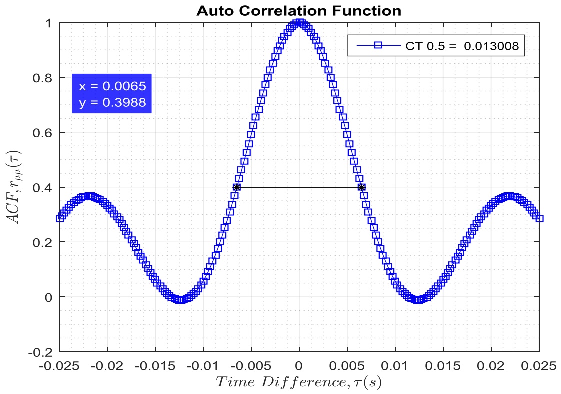

Fig. 3. Autocorrelation results in the 0.5 correlation function limit in the low-speed scenario

The Coherence Time value at the 0.5 correlation function limit using Equation (10) was 0.013. Meanwhile, as displayed in Fig. 3, at the position of the 0.3988 correlation function, the width of the coordinate X has a value of 0.0065, where if multiplied by 2 then the width of the coordinate was 0.013. This value had a difference of -0.000008 from the Coherence Time value based on Equation (10). At the Y point coordinate which was closer to 0.5, the X coordinate point value became smaller so that the correlation function limit of 0.5 was not the same as the calculated Coherence Time value. The Coherence Time value of the autocorrelation function compared with the calculated value was considered realized when the correlation function was <0.5.

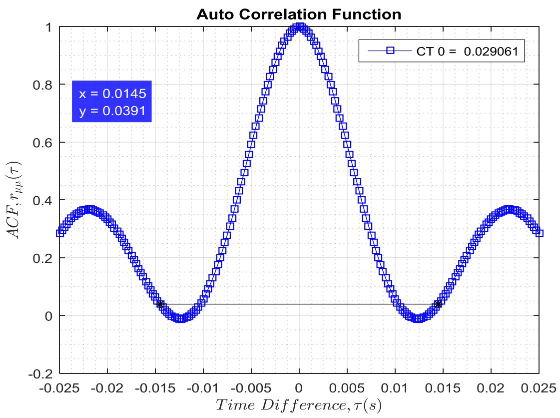

Fig. 4. Autocorrelation results in the second correlation function limit in the low-speed scenario

The results of Coherence Time calculation at the limit of the second correlation function using Equation (11) show that the Coherence Time value was 0.029061. This value was validated by finding the width of the X coordinate point with the same value as the Coherence Time result. This value was obtained at around the first minimum point of the autocorrelation function. At this point, the result was 0.00145, and when multiplied by 2, the result was 0.029. For this result, there was a difference in the Coherence Time value of 0.000061. (Fig. 4).

2) Doppler spectrum

The result of the Doppler Shift calculation based on Equation (7) shows a value of 13.72 Hz so that it generated a Doppler Spread of 27.44 Hz as formulated in Equation (12). Meanwhile, the Doppler Spread value from Fig. 5 was 28.06 Hz so that there was a difference of 0.62 Hz.

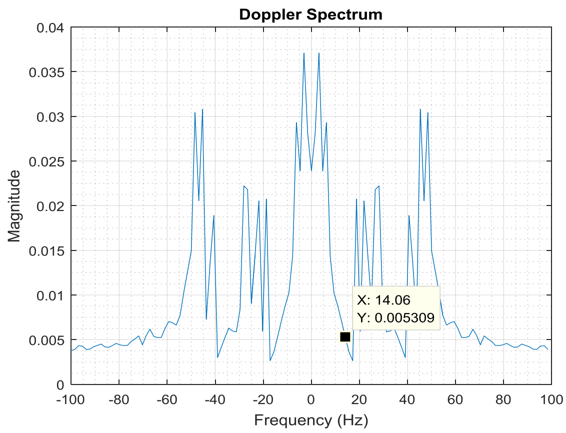

Fig. 5. The doppler spectrum of V2V channel in the low-speed scenario

B. Medium Speed Scenario

In the medium speed scenario, the velocity of the transmitter and receiver were set to 100 m/s while all other parameters were the same as the low-speed scenario.

1) Coherence time

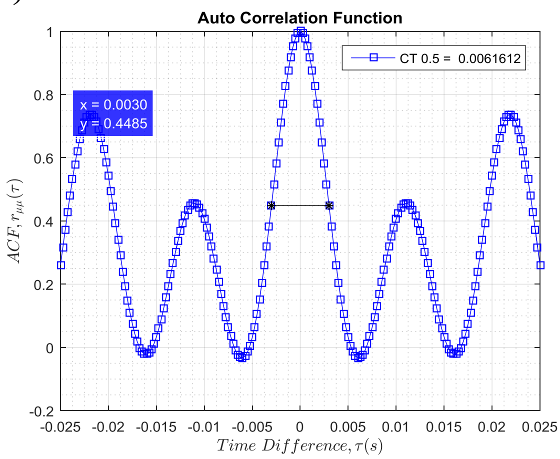

Fig. 6. Autocorrelation results in the 0.5 correlation function limit in the medium speed scenario

In the medium speed scenario, the Coherence Time value generated from Equation (10) was lower than the value obtained in the low-speed scenario. The Coherence Time in this scenario was 0.0061612 while as can be seen in Fig. 6, autocorrelation function generated a time duration width at the value Y = 0.4485 of 0.0030; thus, Coherence Time based on the duration of autocorrelation function time was 0.006 or there was a difference of - 0.0061612. The higher Y coordinate value that was more than 0.4485 tended to produce smaller time duration widths. Therefore, the same Coherence Time value was met when the autocorrelation function limit was <0.4485.

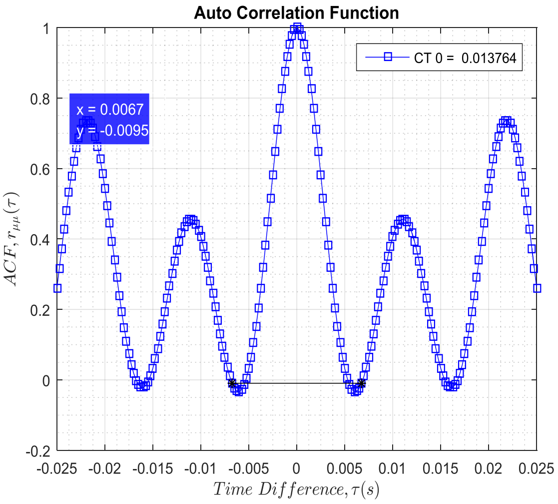

Fig. 7. Autocorrelation results in the second correlation function limit in the medium speed scenario

The results of Coherence Time values in this scenario based on Equation (11) show that the Coherence Time value was 0.013764. Validation of the Coherence Time value was done by looking for a value that was close to the result at the first minimum coordinate of the autocorrelation function. The coordinates were at Y = 0.0095 with the width of X coordinate = 0.0067. At this point, there was a difference in the Coherence Time value of - 0.000364. The Coherence Time value in this scenario was lower than the same correlation function at the low-speed scenario. The higher vehicle speed generates a greater Doppler Shift that consequently reduces the Coherence Time. (Fig. 7).

2) Doppler Spectrum

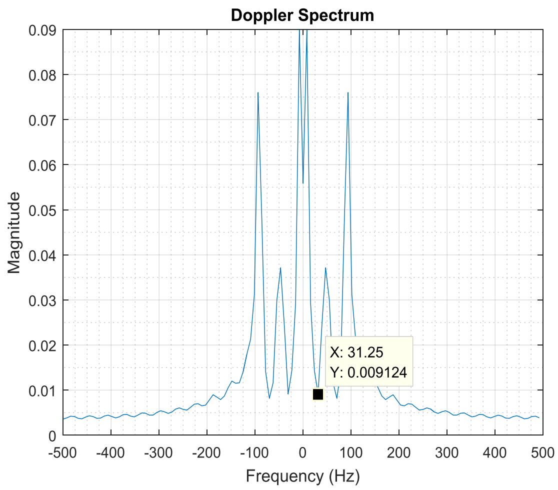

Fig. 8. The doppler spectrum of V2V channel in medium speed scenario

In this scenario, the Doppler Shift value generated from formula (7) was 29.25 Hz. Thus, the Doppler Spread value according to Equation (12) was 58.5 Hz. This value was higher than the value in the low-speed scenario. The validation results with the Doppler Shift position in Fig. 8 show a value of 31.25 so that the Doppler Spread generated from the Doppler Spectrum was 62.5 or there was a difference of 4 Hz from the calculation results.

C. High-speed Scenario

In the high-speed scenario, the velocity of the transmitting and receiving vehicles was 150 m/s while the speed of the moving scatterer was 5 m/s. All other parameters were the same as the previous scenarios.

1) Coherence time

Coherence Time in this scenario was smaller than the value in previous scenarios. For the 0.5 correlation function limit, the value of calculated Coherence Time was 0.0040366. Meanwhile, the Coherence Time results from autocorrelation graphs in Fig. 9 show that the Coherence Time was 0.004. Thus, there was a 0.0000366 difference from the calculation results. The same Coherence Time value was obtained for the correlation function <0.5 because as can be seen in Fig. 9, the graph of the autocorrelation function tended to widen at the limit of Y coordinate = 0.4901.

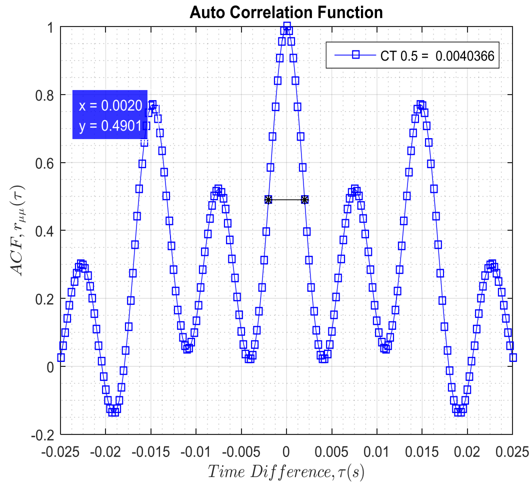

Fig. 9. Autocorrelation results in the 0.5 correlation function limit in the high-speed scenario

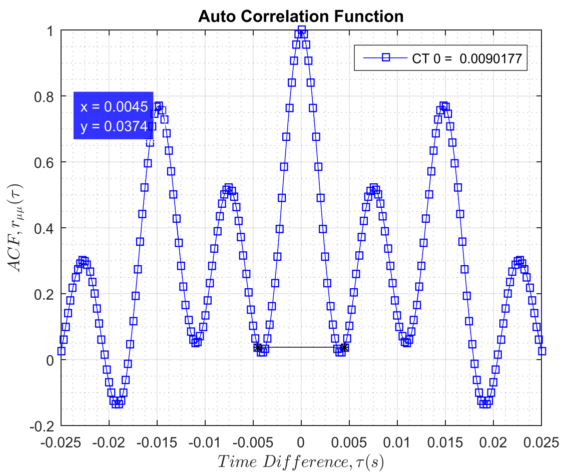

Fig. 10. Autocorrelation results in the second correlation function limit in the high-speed scenario

In the second Coherence Time definition, the obtained value was the lowest in all scenarios. The calculated Coherence Time was 0.0090177 while the value from the plot of the autocorrelation function in Fig. 10 shows a value of 0.009 or a difference of -0.0000177. This point was obtained at around the first minimum position of the autocorrelation function.

2) Doppler spectrum

The Doppler Shift generated in the high-speed scenario was the greatest in all scenarios, which was 44.35 Hz. This Doppler Shift generated a Doppler Spread of 88.70 Hz according to calculations in Equation (12). If validated using Doppler Spread from Fig. 11, the generated Doppler Spread was 87.50 Hz or there was a difference of 1.2 Hz from the calculated Doppler Spread.

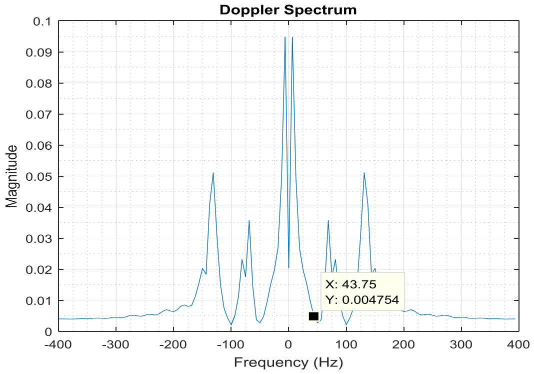

Fig. 11. The doppler spectrum of V2V channel in the high-speed scenario

IV. Conclusions

In this paper, we validated Doppler Spread and Coherence Time's of V2V Channel with moving scatterer based on Auto-correlation function. Three different scenarios of speed variation from vehicles as transmitter, receiver and moving scatterer have been discussed. We observed that Doppler Shift increases as the velocity of vehicles as transmitter, receiver and scatterer increases but the Coherence Time decreases.

The Coherence Time value at the autocorrelation function limit >0.5 used on the wireless communication system channel was different than the results of V2V channel validation that generated the autocorrelation function limit <0.5 at the same Coherence Time value.

The Coherence Time value of the Geometric Mean had a limit of the autocorrelation function at the position of the first minimum value approaching zero. Meanwhile, the Doppler Spreads generated from channel calculations had values similar to the width of the Doppler spectrum from the first minimum on the positive to negative.

References

[1] M. Boban and W. Viriyasitavat, "Channel models for vehicular communications," in *Vehicular Ad Hoc Networks Standards, Solutions, and Research*, 2015, pp. 1–544.

[2] W. Pamungkas, "Correlated double ring channel model at high speed environment in vehicle to vehicle communications," in *Proc. International Conference on Information and Communications Technology*, 2018, pp. 5–10.

[3] A. Borhani and M. Patzold, "Modeling of vehicle-to-vehicle channels in the presence of moving scatterers," *IEEE Transactions on Vehicular Technology*, 2013.

[4] A. Borhani and M. Patzold, "Correlation and spectral properties of vehicle-to-vehicle channels in the presence of moving scatterers," *IEEE Trans. Veh. Technol.*, vol. 62, no. 9, pp. 4228–4239, 2013.

[5] R. Steele and L. Hanzo, *Mobile Radio Communications*. Pentech Press Limited, 1992.

[6] T. Rappaport and S. B. O. (Firme), "Wireless communications: Principles and practice," 1996.

[7] L. Cheng, B. Henty, F. Bai, and D. D. Stancil, "Doppler spread and coherence time of rural and highway vehicle-to-vehicle channels at 5.9 GHz," in *Proc. IEEE GLOBECOM*, 2008, pp. 1–6.

[8] A. J. Goldsmith, *Wireless Communications*, no. 143. Cambridge University Press, 2005.

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