V2V Channel Performance on VANET Technology with OFDM and Moving Scatterer’s Influence

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Abstract. The channel modeling in VANET technology has been developed by involving various factors, i.e., propagation, scatterer, traffic density, and their environments. One of them is the V2V channel that involves moving scatterer. This modeling has not been yet incorporated in with OFDM. Hence the performance is still unknown. This paper used a V2V channel influenced by moving scatterer and combined with OFDM. Two vehicles were modeled as transmitter and receiver, while 8 scatterers moved at constant speed. Model’s gain channel was convoluted with OFDM and modulated with QPSK. Fast moving vehicle yielded Doppler effects which impacted Coherence Time and number of symbols in one OFDM frame. Higher Doppler effects as a result of faster vehicle, lowered Coherence Time made the number of correlated symbols in one frame was decreasing. Simulation showed at speed of 10 – 20 m/s, the decreasing of Coherence Time and number of correlated symbols was the most significant and noticeable. As the Coherence Time decreased up to 50% whilst some correlated symbols decreased up to 75%. The number of moving scatterer used greatly affected SNR value where the increase in the number of moving scatterer doubled from 4 to 8 resulted in a decrease in SNR value up to 6 dB at the speed of 40 m/s.

1. Introduction
The wireless communication system has been widely implemented in various popular technology in our daily life. Satellite communication system, cellular system, Bluetooth technology, and vehicular communication are amongst the implementation of a wireless communication system. In a vehicular communication system, vehicle movement as a transmitter, receiver, and scatterer around yields frequency shifting. This phenomenon is known as a Doppler effect that causes frequency shifted from its desired. This frequency shift is called Doppler Shift. This research (1) stated that higher carrier frequency and vehicle speed yields bigger Doppler Shift.

The vehicular communication channel modeling has been widely developed and adapted to communication scopes that are being used. This model produces communication system parameters that each of them varies. A correlated double ring consist of transmitter and receiver surrounded by scatterer that did not move and used on the vehicular channel was analyzed using autocorrelation function (ACF) and probability density function (pdf) (2). Another research (3), the scatterer that located inside transmitter and receiver circle were designed moving. The Doppler Shift of the transmitter, receiver, and moving scatterer was analyzed using ACF.

In the other research (4), the positions of moving scatterer were randomly generated and distributed. This channel has resulted bigger Doppler Shift because the Doppler frequency being used was mathematically combined from Doppler frequency of transmitter, receiver, and scatterer. A higher
number of moving scatterer yielded bigger Doppler frequency. This model was measured by using ACF, then second order statistic was added as additional performance calculation (5). The V2V channel model that accommodated scatterer movement was modeled in 3-dimensional form by adding MIMO diversity technology and adopted in an urban environment (6). Research that utilizes V2V channel with moving scatterer combined with OFDM multicarrier measured the power spectral density in receiver side as a result of vehicles movement (7).

Vehicle to vehicle communication system that used IEEE 802.11p standard is known as Vehicular Ad-hoc Network (VANET) (1). VANET requires OFDM as a multicarrier technique and uses carrier frequency 5.85 GHz and 70 MHz bandwidth. The OFDM multicarrier is merged with a channel modeling and added with noises. The research that used the modeling, discussed channel estimation on OFDM based on time variant propagation channel. The channel characteristic being modeled yielded great delay and Doppler spread by using Geometry Based Stochastic Model (8). In the structure of OFDM frame consisting of Short Training Symbol, Long Training Symbol, Signal Guide, and Data Symbol amount of data can be contained in one frame, highly depend on Coherence Time it produces (9).

This is our second research that used V2V channel with moving scatterer combined with OFDM multicarrier. Differ from previous research that combined moving scatterer V2V channel with OFDM, the output of channel gain on V2V channel and IFFT on the OFDM transmitter were combined and added with Gaussian noise (AWGN). The parameter we used to measure the quality of V2V channel was Signal to Noise Ratio and number of correlated OFDM symbols as an effect of vehicle movement. Number of correlated symbols were analyzed by using ACF to have a deep understanding of what Coherence Time value that the symbols were still able to correlate.

The next sections of this paper will be divided as follows. Section II discusses research method, Section III presents the results and analysis, and Section IV presents the conclusions.

2. Research Methods
2.1. Modeling V2V Channel in the presence of Moving Scatterers
The V2V channel model used in this paper refers to figure Figure 1. It was assumed that the transmitter (Tx) moved with direction and speed $V_T$ while receiver (Rx) moved with direction and speed $V_R$. Transmitter and receiver are vehicles. Tx moves with angle $\alpha_T^v$ and Rx moves with an angle $\alpha_R^v$ toward the same horizontal plane.

The scatterer positions were randomly distributed around Tx and Rx. The number of scatterers was represented with $S_n$ and all of them moved with the same speed $V_s$ with random directions. The directions of moving scatterer were notated with the angle $\alpha_s^v$. 

![Figure 1. Configuration of V2V Channel Model](image-url)
In order to avoid great attenuation, farthest scatterer was ignored. Signal was assumed to propagate from Tx with Angle of Departure (AoD) $\alpha_{n}^{T}$ then received by Rx with Angle of Arrival (AoA) $\alpha_{n}^{R}$ after being scattered by scatterer $S_{n}$ that moved around the circle. Channel gain value is calculated as follows:

$$\mu(t) = \sum_{n=1}^{N} c_{n} e^{j(2\pi f_{n} t + \theta_{n})}$$

(1)

The channel gain is a complex stochastic process as a summation of all scatterer components. Parameter $c_{n}$ is an attenuation factor as a result of scattering and value of $f_{n}$ is Doppler Shift. Doppler Shift can be calculated as follows:

$$f_{n} = f_{n}^{T} + f_{n}^{TS} + f_{n}^{SR} + f_{n}^{R}$$

(2)

The parameter denoted with $f_{n}^{T}$ is Doppler effects caused by transmitter movement. The parameter $f_{n}^{TS}$ is caused by a transmitted signal that hit $n$-th moving scatterers. The parameter $f_{n}^{SR}$ is the effects of scatterers that move and bounces signals towards the receiver. The parameter $f_{n}^{R}$ is the Doppler that caused by receiver movement. The formula to calculate $f_{n}$ involving these parameters is:

$$f_{n} = \frac{k_{0}}{2\pi} \left[ v_{r} \cos(\alpha_{n}^{T} - \alpha_{n}^{R}) - v_{s} + \left( \cos(\alpha_{n}^{T} - \alpha_{n}^{S}) + \cos(\alpha_{n}^{S} - \alpha_{n}^{R}) \right) + v_{r} \cos(\alpha_{n}^{R} - \alpha_{n}^{R}) \right]$$

(3)

with the parameter $k_{0} = 2\pi f_{0} c_{0}$ is a free space wave number. To calculate the ACF of the channel gain, below equation is used:

$$r_{\mu\mu}(\tau) = \lim_{N\to\infty} \sum_{n=1}^{N} c_{n}^{2} E\{ e^{2\pi f_{n} \tau} \}$$

(4)

with $c_{n} = \sigma_{n} \sqrt{2/N}$ and N is a number of scatterers around Tx and Rx.

2.2. Multicarrier OFDM

VANET technology uses OFDM multicarrier system with a bandwidth of 10 MHz. In this paper, a number of subcarriers used were 52 mapped into 64 points IFFT. There were 10000 symbols sent through with Eb/N0 30 dB. In this paper, we used BPSK modulation with an estimated channel has already been identified perfectly. IFFT output on transmitter side:

$$s(t) = \sum_{k=0}^{N-1} X_{k} \exp(-j2\pi k \Delta f t)$$

(5)

With $X_{k}$ is OFDM symbols, N is a number of scatterers i.e. 8 and $\Delta f$ represents Doppler frequency. In order to get combined output of OFDM with V2V channel, channel gain $\mu(t)$ is treated as a complex number $Z(t)$.

Parameter $x(t)$ is the real values and parameter $y(t)$ describes the imaginer values. The absolute value of complex envelope can be calculated as follows:

$$R(t) = |Z(t)| = \sqrt{x(t)^{2} + y(t)^{2}}$$

(6)

to calculate value of phase angle, following equation can be used:

$$\theta_{t} = \tan^{-1}\left(\frac{y(t)}{x(t)}\right)$$

(7)
to calculate the value of impulse response of the modeled channel, following equation is used

\[ h(t, \tau) = \sum_{k=1}^{N} R(t) \delta(t - \tau_k) e^{i \omega_k} \]

with \( N \) is equal to number of scatterer. The received signal is determined as a result of the convolution process between channel impulse response and \( s(t) \) as the output of IFFT OFDM as follows:

\[ G(t) = s(t) * h(t) + n(t) \]

Signal to Noise Ratio of received signal was calculated to measure the V2V channel performance over various velocities. Coherence time is defined as the time interval where the communication channel does not change and formulated as follows:

\[ T_C = \frac{9}{16\pi f_n} \]

with \( f_n \) is Doppler frequency.

Coherence Time will be used to decide a number of symbols that correlates in one OFDM frame. This can be calculated by using the formula:

\[ \gamma = \frac{T_C}{T_{OFDM}} = \frac{T_C}{8\mu s} \]

3. Result and Discussion

3.1. V2V channel performance based on Coherence Time and Symbol Correlation

V2V channel performance can be observed from values of Coherence Time parameter and number of symbols that still are able to correlate in one OFDM frame when various velocities of transmitter and receiver are applied. To be able to do this observation, simulation is conducted by giving certain ranges of speed to transmitter and receiver vehicles starting from 10 up to 200 m/s. A number of moving scatterer is 8 and their ranges of speed is 5 m/s with random directions. Transmitter and receiver are also assumed to move in random directions in the range of 0 - 2\( \pi \). The sampling frequency and carrier frequency are set to 1 kHz and 5.8 GHz consecutively. The system contains 64 points IFFT with 52 subcarriers which have 10000 symbols to be transmitted. Each of those symbols has 52-bit data. Energy bit to noise density ratio has been set to 30 dB to generate signal who carries data from a transmitter to receiver.

Simulation result shown by figure 4 states that at the speed of 10 – 20 m/s Coherence Time parameter is significantly decreasing up to 50%, but it slightly changes when the speed reaches 60 up to 200 m/s. It can be concluded that V2V channel can obtain optimum performance at the speed of 60 to 200 m/s because the Coherence Time decays in a very small step.

Coherence Time parameter that is getting smaller causes the channel to change faster. It causes the decrease in a number of symbols that still are able to correlate in the one-period interval. It brings consequence which is the system has to recheck current symbols to get perfect Channel State Information (CSI).

The way performance analysis conducted on V2V channel against a number of correlated symbols is similar to the way performance analysis part of V2V channel against Coherence Time conducted. The simulation result in figure 2 is compared to the ACF curve in figure 4 by validating time shifting on the range of Coherence Time against its correlation value. Figure 3 shows that in the speed range of 10 to 20 m/s, number of symbols that can correlate decreases up to 75% whereas in the range of 60 to 200 m/s the amount of decrease is insignificant. We may conclude that this range of speeds are valuable and recommended.

ACF curve in figure 4, the speed of the transmitter and receiver are set to 60 m/s. The directions of all objects are set to be random in the range of \(-\pi\) to \(\pi\). Carrier and sampling frequency are set to 5.8 GHz and 1 kHz consecutively with time shifting range is 1 second.
According to figure 2, transmitter and receiver that move with speed 60 m/s yields Coherence Time approximately 0.1 ms. If this result is mapped to figure 3 then it gives a number of symbols that still can correlate as much as 18 symbols in one frame. At the same point, figure 4 shows that autocorrelation value is close to 1 which approximately is 0.99. It concludes that at that point the number of symbols that can correlate between two consecutive OFDM frame is high.

3.2. Performance Analysis on V2V channel based on Signal to Noise Ratio
At this stage, the time shifting is set to 1 second, while the speed of the Tx and Rx are set to 40 m/s, and moving scatterer speed to 15 m/s. Similar to the previous condition, the angle of directions of all vehicles are set to be random in the range of $-\pi$ to $\pi$.

There are 2 scenarios used to compare the effects of a number of moving scatterer against SNR value. Firstly, a number of moving scatterer used is 4 that moving at the speed of 5 m/s. In figure 5, it can be
observed that when Tx and Rx move with speed 10 to 30 m/s they cause deteriorating on SNR value significantly. The SNR goes down around 0.7 dB but when their speeds are in the range of 30 to 40 m/s the decreasing of SNR values is insignificant.

The second scenario is carried out by changing the number of moving scatterer to 8. As can be seen in figure 6, SNR is decreasing significantly. At the speed of 10 m/s when a number of the scatterer is set to 8, SNR value decreases heavily compared to 4 scatterer which is approximately 6 dB. This is caused by in fact that a number of moving scatterer affects total Doppler Shift as stated in formula 2. At the speed of 0 – 30 m/s, the signal undergoes insignificant deteriorate on SNR value around 0.5 dB whereas in the range of 30 – 40 m/s it becomes more insignificantly decreasing.

4. Conclusion
In this paper, analysis on V2V channel performance based on moving scatterer combined with OFDM multicarrier against Coherence Time, Number of correlated symbols in one channel, and SNR has been explained. Transmitter and receiver movement at the speed range of 10 – 20 m/s has the most significant decrease of Coherence Time and number of correlated symbols. Coherence Time decreases up to 50 % whilst a number of symbols that can correlate with channel goes down to 75 %. It means that anticipation process i.e. estimation and detection process when the channel changes are required. Meanwhile, at the speed of 60 m/s, the position of ACF curve shows at that point the correlation value is high around 0.99 which nearly perfect. Also, number of moving scatterer involved highly affect SNR value. The number of scatterers doubled from 4 to 8 has raised the SNR decreasing into 6 db. It follows the fact that Doppler Shift will raise when a number of scatterers involved getting higher.

5. References
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