Condition of Constant Frequency of RICIAN Channel Variation Achieved During Inter-Vehicular Communication

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***Abstract*—VANETs (Vehicular Ad-Hoc Networks) usually utilize the double-ring model in estimating the channel effects. Our proposal exploits the double-ring model in presence of line of sight (LOS) components to observe the complex envelope of the received Frequency of Variation in Channel (FVC) effect. The effect is observed in presence of a Rician faded channel. Constant variation in FVC is a requisite condition for every vehicle communicating with another vehicle as variation in FVC is not only an unwanted effect but also responsible to generate a time-variant condition. This paper suggests several factors that are responsible for achieving a constant level of FVC by taking different possibilities of vehicle velocities relative to another vehicle during inter-vehicular communication. As a result, new techniques can be thought of to compensate the effect of FVC for inter-vehicular communication.**

Keywords-VANETs; V2V Communication; Channel Variatio; Fading

I. INTRODUCTION

In V2I (Vehicle-to-Infrastructure) communication, the scattered model is different than that of V2V (Vehicle-to-Vehicle) communication. V2I uses the Single-Ring scattered model whereas V2V communication uses the Double-Ring scattered model. It is observed that the Double-Ring scattered model is more complicated than Single-Ring scattered model. [1] Shows the phenomena of a ring of scatterers around a transmitting antenna which serve as basis for the proposed idea in this paper. V2V communication exploits several channel models including Sum-of-Sinusoid, Discrete-Line spectrum and Inverse Fast Fourier Transform (IFFT) techniques [7]. The channel model presented in this paper uses the Sum-of-Sinusoid technique. In V2V communication, the active vehicle (one which initiates communication and transmits information) communicates with the passive vehicle (one which accepts to receive information from an active vehicle) under the Rician-Faded channel environment and estimates the complex envelope of the channel that changes according to some frequency. The change of the channel envelope under a certain frequency is termed FVC (Frequency of variation in channel). It is worth noting that the FVC effect is not constant if at-least one node is under motion and the case is more severe in V2V communication as both the active and passive vehicles are in motion. It can be noted that variation in FVC cannot be compensated by guiding the vehicles to move at certain velocity. This paper shows the possible scenarios at which the FVC is said to have achieved some constant/ stable level. This concept can certainly aid in compensation of FVC variation in future research efforts.

II. RICIAN FADED CHANNEL CHARACTERISTICS

Two important parameters for defining the Rician faded channel are *K* (Rician-Factor) and ρ (Total Power). *K* is defined to be the ratio of LOS (Line of Sight) power components (γ) to the scattered power components (δ) whereas ρ is defined to be the total power summation from LOS power components and the scattered power components as shown in (1).

$$\rho = \gamma + 2\delta \tag{1}$$

Where δ and γ are defined in (2) and (3) respectively.

$$\delta = \frac{\rho}{2(1+K)} \tag{2}$$

$$\gamma = \frac{K}{(1+K)}\rho \tag{3}$$

If $f(t)$ represents the Rician-faded channel for V2I communication w.r.t time, then (4) best defines the relation.

$$f(t) = \frac{2(K+1)t}{\rho}\exp\left(-K - \left(\frac{(K+1)t^2}{\rho}\right)\right) I_0\left(2\sqrt{\frac{K(K+1)}{\rho}}\,t\right) \tag{4}$$

where I_0 is the zero$^{\text{th}}$-order Bessel function of the first kind.

It must be noted that that *K* does not aid in compensating the effect of variation in FVC. It is the auto-correlation function of the complex Rician channel the magnitude of which is contingent upon *K*.

Let us take the case of V2V communication for which the scatterers are assumed to have a uniform distribution. Let v_1 and v_2 be the velocities of active and passive vehicles respectively. Similarly f_1 and f_2 be the maximum Doppler frequencies due to motion of active and passive vehicles respectively. *M* is assumed to be the number of independent channel paths at the active vehicle's end whereas *N* be the number of independent channel paths at the passive vehicle's

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end. [1] and [3] defines the amplitude of normalized complex envelope of Rician-faded channel as shown in (5).

$$g(t) = \sqrt{\frac{1}{\mathrm{AB}}} \sum_{a=1}^{\infty} \sum_{b=1}^{\infty} e^{j\,(2\pi f_1 t \cos \alpha_a + 2\pi f_2 t \cos \beta_b + \varphi)} \quad (5)$$

It is to be noted that $g(t)$ is the amplitude of complex envelope of Rician-faded channel in case of V2V in-vehicle communication like $f(t)$ which is defined for V2I communication. α_a and β_b in (5) are the phase angles which are defined in (6) and (7) respectively.

$$\alpha_a = \frac{2a\pi - \pi + \theta_a}{4N} \quad (6)$$

$$\beta_b = \frac{2(2b\pi - \pi + \emptyset_b)}{4M} \quad (7)$$

Where φ and $\emptyset_b$ are the angles of arrival [2] and θ_a denote's a vector of angles of departure associated with scattering paths. f_1 and f_2 in (4) represent the maximum Doppler frequencies generated as a result of motion by active and passive vehicles respectively.

III. VECTORIAL REPRESENTATION AND DOUBLE RING MODEL

Let us consider an active and passive vehicle moving with velocities v_1 and v_2 respectively. Figure 1 represents the ring of scatterers around the above mentioned vehicles. These scatterers are assumed to be uniformly distributed around each vehicle.

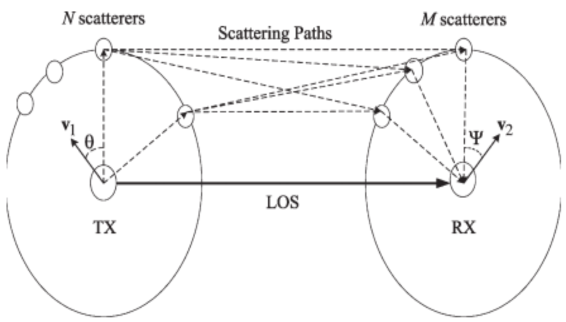

Figure 1. Double-Ring model with an LOS component around two communicating nodes [1].

The autocorrelation function of the received complex envelope in (8) is,

$$R_{uu}(\tau) = \frac{J_0(2\pi f_1 \tau)\, J_1(2\pi f_2 \tau)}{2} \quad (8)$$

Where J_0 (.) is the Bessel function of first kind with order zero. f_1 and f_2 are the maximum Doppler frequencies associated with active and passive vehicles respectively. Figure 2 shows the velocity vector v_3 as the resultant of v_1 and v_2.

Mathematically, the magnitude of relative velocity is defined in (9):

$$|v_3| = \sqrt{(|v_1| \cos \theta_{12} - |v_2|)^2 + (|v_1| \sin \theta_{12})^2} \quad (9)$$

Where $\theta_3 = \theta_1 + \theta_{13}$ and θ_{12} is the angle between vectors v_1 and v_2 (Figure 2). According to the law of cosines,

$$\theta_{13} = \cos^{-1}\left(\frac{|v_1|^2 + |v_3|^2 - |v_2|^2}{2|v_1||v_3|}\right) \quad (10)$$

We can derive LOS component from Figure 2 as:

$$\mathrm{LOS} = \sqrt{\mathrm{K}}\, e^{j\,(2\pi f_3 t \cos \theta_3 + \varphi)} \quad (11)$$

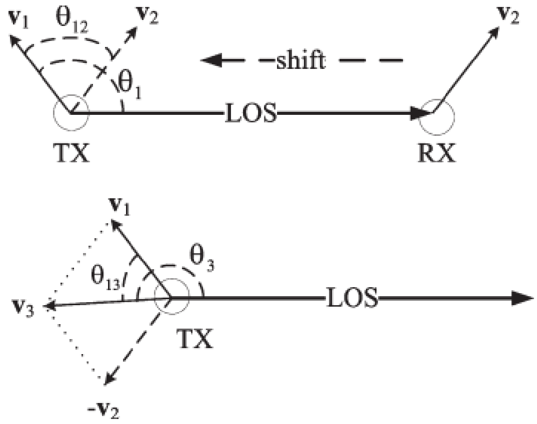

Figure 2. Graphical representation of the resultant velocity v_3 [1].

Figure 2 shows that the graphical representation and derivation of v_3 which is defined to be the relative velocity of active vehicle if the velocity of passive vehicle is set to zero.

IV. V2V BEHAVIORAL COMPARISON OF RICIAN AND RAYLEIGH FADED CHANNELS

The channel changes its behavior if either of the active and passive vehicles is moving. The variation in channel behavior is even more complex if both the vehicles (active and passive) are moving with the velocities v_1 and v_2 respectively. [1, 2] explains how a Rician-faded channel changes in sinusoidal fashion.

The channel correlation [1] is defined in (12):

$$R_{gg}(\tau) = \frac{J_0(2\pi f_1 \tau)\, J_1(2\pi f_2 \tau) + K\, e^{j(2\pi f_3 \tau \cos \theta_3)}}{1+K} \quad (12)$$

Figure 3 shows that the Rician channel changes its behavior in sinusoidal fashion if both the active and passive vehicles are moving.. It is shown that it is only amplitude of the complex channel envelope that keeps on changing with the varying value of *K*. The channel is not behaving in sinusoidal fashion if it is Rayleigh [5][9][10] (Rician Channel without LOS component), represented with the notation of *K*=0.

FVC is the number of repetitions in channel behavior. It is observed that for a Rician channel, the number of these repetitions is constant for different values of *K* and for different values of λ_3 where $\lambda_3 = \frac{v_3}{f_3}$. However, it is just the amplitude of channel envelope which directly depends upon *K* as shown in Figure 3 and Figure 4. Where f_3 is the maximum Doppler frequency caused due to v_3 as viewed in (9).

V. CONDITIONS FOR ACHIEVING CONSTANT FVC

There are certain set of velocities among moving vehicles at which one gets a condition of constant FVC. A passive vehicle while in motion might not avail time-invariant conditions due to variation in FVC. For the sake of elaborating the idea, let us consider an active vehicle named T_x and three passive vehicles termed as R_{x1}, R_{x2} and R_{x3}. In order to observe the condition of achieving constant FVC in all three passive vehicles, different initial conditions are considered. Initial negotiation between vehicles in inter-vehicular communication is discussed in [4][8].

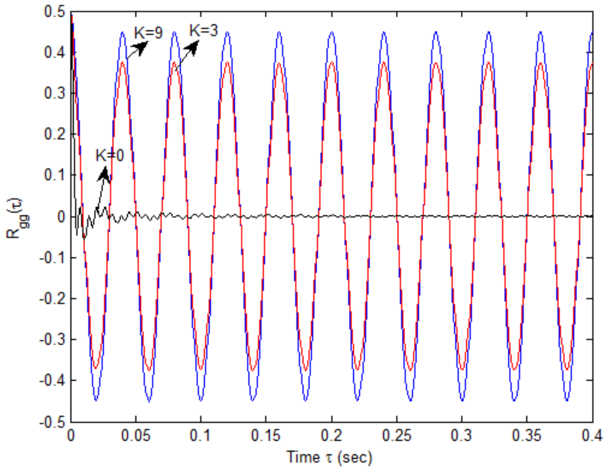

Figure 3. Variation in Channel Effect for different values of *K*

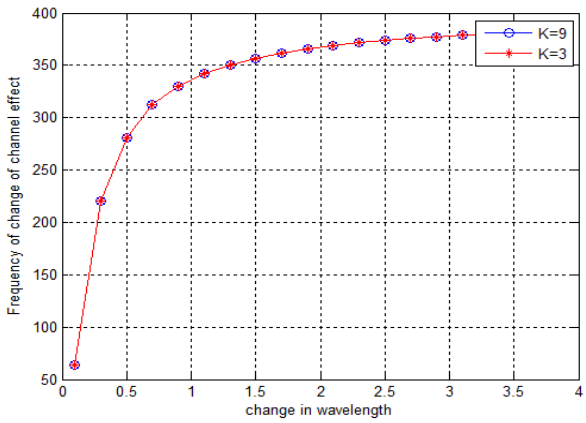

Figure 4. Frequency of complex envelope of channel correlation vs. Doppler wavelength for Rician fading channels.

A. *Active And Passive Vehicles Moving At Same Velocities*

Let the active vehicle T_x move at a certain velocity $V\angle\theta_{Tx}$ provided the initial distance be S_{Tx}. If we consider the passive vehicles R_{x1}, R_{x2} and R_{x3} to move at the same magnitude of velocity V with angles $\angle\theta_{Rx1}$, $\angle\theta_{Rx2}$ and $\angle\theta_{Rx3}$ and with the initial distance-gap of S_{Rx1}, S_{Rx2} and S_{Rx3}, then (13) defines a general expression for velocity as shown:

$$v(t) = S_i(t) + V\angle\theta_i \qquad (13)$$

Where i can be defined to be *Rx1*, *Rx2* or *Rx3* for passive vehicles and for active vehicles it is defined to be *Tx*.

Figure 5 shows distance vs time characteristics of all the active and passive vehicles defined in (13). Let us assume the active vehicle to communicate with passive vehicles in the presence of Rician-faded channel. During the course of distance, the resultant wave-length λ_3 ($\lambda_3 = {}^{v_3}/_{f_3}$) changes its inherent value which makes the FVC to change abruptly in first place and then for a certain change in λ_3 the FVC maintains a series of consistency. The active vehicle sends an initial probe to the passive vehicle [6] which contains the information about its current speed and center frequency f_c. The passive vehicle after detecting the active vehicle sends acknowledgement by sending its own speed information. Based on the speed of both the vehicles, distance-gap and f_c the active vehicle decides to jump a value of resultant wavelength λ_3 for which there is some approximate consistency in FVC.

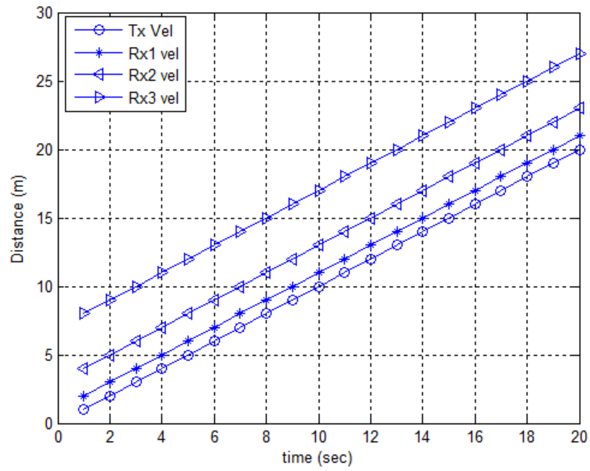

Figure 5. Slopes representing same set of velocities for three different receiver nodes.

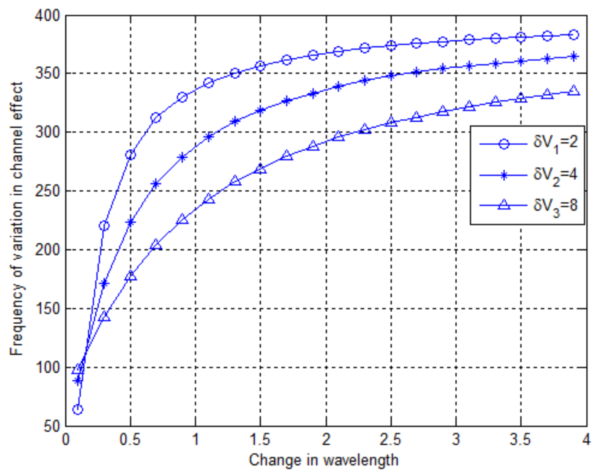

Figure 6. FVC vs $\nabla\lambda_3$ if the active and passive vehicles move at same velocities

Consider the following distance-gaps between active and passive vehicles:

- Distance-gap of 2 meters between the vehicles Tx and Rx1 characterized as $\delta V_1 = 2$m

- Distance-gap of 4 meters between the vehicles Tx and Rx2 characterized as $\delta V_2 = 4\text{m}$
- Distance-gap of 8 meters between the vehicles Tx and Rx3 characterized as $\delta V_3 = 8\text{m}$

A level of consistency in FVC might be achieved at the lower value of $\nabla\lambda_3$ which depends directly upon the initial distance-gap between active and passive vehicles. It is observed that $\nabla\lambda_3$ determines the effect of severity of variation in FVC. Figure 6 shows the effect of variation in FVC and for some higher range of $\nabla\lambda_3$ the effect of severity in FVC variation approaches zero. It is observed that a high level of consistency is possible if the initial distance gap between the vehicles is kept at a lower value.

B. Active Vehicle moving at different Velocity than Passive Vehicle:

Active and passive vehicles may be moving at different velocities provided that they move constantly at same velocities. Let us now consider an active vehicle T_x to move at a certain velocity $V_{Tx}\angle\theta_{Tx}$ with the initial distance to be S. If we consider the passive vehicles R_{x1}, R_{x2} and R_{x3} moving at velocities $V_{Rx1}\angle\theta_{Rx1}$, $V_{Rx2}\angle\theta_{Rx2}$ and $V_{Rx3}\angle\theta_{Rx3}$ respectively and having the initial distance of S then a generalized expression in (14) shows the relationship among the mentioned variables.

$$v(t) = S(t) + V_i\angle\theta_i \qquad (14)$$

Where i can be defined to be *Rx1*, *Rx2* or *Rx3* for passive vehicles and for active vehicles it is defined as *Tx*.

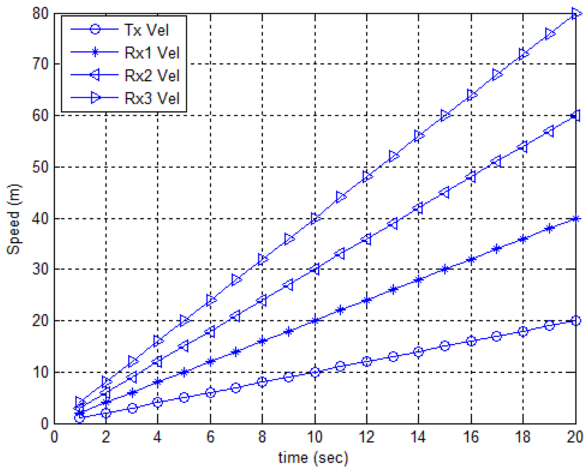

Figure 7. Slopes representing same set of velocities for three different receiver nodes

Figure 7 differentiates the characteristics of distance versus time for all the active and passive vehicles defined in (14) assuming the active vehicle to be communicating with passive vehicles in the presence of a Rician- faded channel.

Let us take an example of a passive vehicle moving at velocity X times the velocity of active vehicle where the value of X is 2, 3 and 4 for the vehicles R_{x1}, R_{x2} and R_{x3} respectively. The level of consistency in FVC in this case is more accurate than the previous one as the constant level of FVC always occurs at the lowest possible value of $\nabla\lambda_3$ as shown in figure 8. It is observed that the consistency is more accurate for higher value of X.

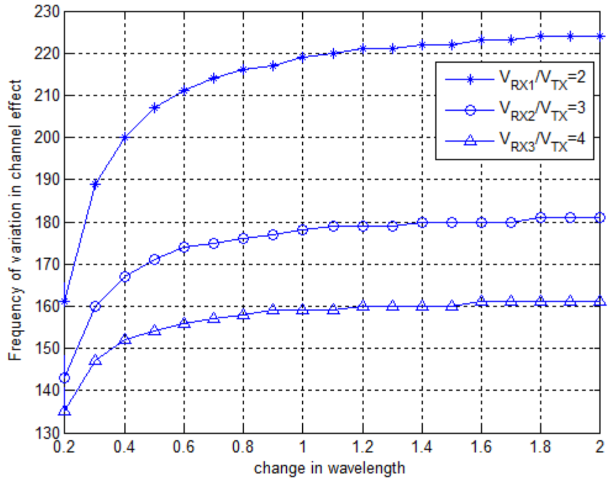

Figure 8. FVC vs $\nabla\lambda_3$ if the active and passive vehicles move at different velocity

VI. CONCLUSION AND FUTURE WORK

Different observations were recorded from different simulation results obtained using MATLAB. It was observed that for Rician channel, the number of repeated channel patterns is independent of K and for different values of change in λ_3 the amplitude of channel envelope is the only dependent variable which directly depends upon K. The effect of FVC w.r.t $\nabla\lambda_3$ was also observed in presence of Rician faded channel which determines the effect of severity of variation in FVC.

From different observations it was concluded that a high level of consistency in FVC is possible if active vehicle is moving at the same magnitude of velocity as that of passive vehicle and the initial distance gap between the vehicles is kept at a lower value. The only demerit of keeping the lower initial distance-gap is that the constant level of FVC is achieved for ample change in λ_3. Similarly it was concluded that for the active vehicle moving at different velocity to that of passive vehicle the consistency in FVC is relatively larger if compared to the previous case.

The active vehicle can play an important role in compensating the severity in variation of FVC by varying f_c which is part of the future work to be carried out in this area. An efficient compensating technique needs contemplation for which the present work in the paper plays an important role as a basic platform.

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