A Street Reference Model of MIMO Vehicle-to-Vehicle Fading Channel

Chen Wei [1,2]
[1]School of Information Engineering
Wuhan University of Technology
WuHan, Hubei
P.R.China, 430070
greatchen@whut.edu.cn

He Zhiyi
School of Information Engineering
Wuhan University of Technology
Wuhan, Hubei
P.R. China, 430070
hezhiyi@whut.edu.cn

Yao Tianren[2]
[2]Department of Electronic Engineering
Huazhong University of Science and Technology, Wuhan, Hubei
P.R.China, 430074
tryao@mail.hust.edu.cn

***Abstract*—In future, cars will form a network with other cars and roadside data systems to exchange information that alerts the driver on traffic congestion, road conditions, and accidents. It is expected that vehicle-to-vehicle communication systems will play an important role in intelligent transportation systems. MIMO systems employ multiple transmit and multiple receive antennas, combined with the opportunities opened by large vehicle surfaces on which multielement antennas can be placed, makes MIMO techniques very attractive for vehicle-to-vehicle communications. In this paper, we propose an original street model for MIMO vehicle-to-vehicle fading channels, derived from this model, the analysis of statistical properties of transmit and the receive correlation functions is given, and some numerical results for the special case of isotropic scattering are presented. Our procedure provides also an important framework for studying the channel capacity of MIMO vehicle-to-vehicle channels, channel coding and wireless intelligent transportation systems planning.**

Keywords-Mobile communication, Intelligent transportation, MIMO channel, Mobile-to-mobile channel,; Vehicle-to-vehicle street model

I. INTRODUCTION

MIMO systems employ multiple transmit and multiple receive antennas. The profit from using several antennas on transmit and the receive side is that not only the system performance can be improved, but also the capacity can be increased in comparison to SISO communication systems. This fact, combined with the opportunities opened by large vehicle surfaces on which multielement antennas can be placed, makes MIMO techniques very attractive for car-to-car (C2C) communications, also called vehicle-to-vehicle (V2V) communications. The communication between vehicles can be considered as a kind of mobile-to-mobile (M2M) communication. In future, cars will form a network with other cars and roadside data systems to exchange information that alerts the driver on traffic congestion, road conditions, and accidents. It is expected that V2V communication systems will play an important role in various fields including ad hoc networks and intelligent transportation systems, where the communication links must be extremely reliable. To cope with problems faced within the development and performance investigation of future MIMO V2V communication systems, a solid knowledge of the underlying multi-path fading channel characteristics is essential.

In this paper, we propose an original street model for MIMO V2V fading channels. The scattering environment around the transmitter and receiver is modeled here by the geometrical two-ring scattering model with a diffracting street corner, which is used as a starting point for the derivation of a proper reference model.

The rest of this paper is structured as follows. In Section2, we present the street model for a wireless transmission link between two mobile vehicles. In Section 3, we show how a reference model for the path gains can be derived from the geometrical model and provide general expressions for transmit and the receive correlation functions. Section 4 presents some numerical results for the special case of isotropic scattering. In Section 5, we finally draw the conclusions.

II. DOUBLE RAYLEIGH STREET MODEL

In this section, we present a street model for the narrowband MIMO V2V channel in Fig.1. In such propagation scenario, the line-of-sight (LOS) is more likely to be obstructed by buildings and obstacles between the transmitter and the receiver, such propagation conditions generally occur between mobile cars in urban areas. For reasons of brevity, we restrict our considerations on a 2 x 2 antenna configuration, meaning that both the transmitter and the receiver are equipped with only two omnidirectional antennas. Such an elementary antenna configuration can be used to construct many other types of 2-D multielement antenna arrays, including uniform linear arrays, hexagonal arrays, and circular antenna arrays.

Fig.1 shows the V2V propagation scenario, where the double scattering phenomenon occurs. The multi-antennas placed on the surface of two cars, which surrounded by one ring of scatterers respectively, for both the cars are moving, the street corner effectively functions as a multiplier for the double Rayleigh processes. A discussion and generalization of the double-Rayleigh propagation model is presented by J.B. Andersen et al. [1]. The proposed multiple Rayleigh propagation mechanism assumes two or more independent Rayleigh fading processes generated by independent groups of scatterers around the two mobile terminals. The resulting

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transfer function corresponds to a weighted sum of independent single, double, triple- etc. Rayleigh processes with propagation via diffracting wedges, such as street corners in urban micro cells. If both the transmitter and receiver are moving, the street corner effectively functions as a multiplier for the double Rayleigh processes [2].

Double Rayleigh distribution is used to model multi-path fading in M2M communication scenarios and provides a better fit to experimental data in such scenarios compared to the conventional Rayleigh channel model [3].

The general form of the narrow-band impulse response of the multiple scattering radio channel [1] is

$$H=C_0+C_1+C_2+C_3+\ldots=w_0e^{j\phi}+w_1H_1+w_2H_2H_3+w_3H_4H_5H_6+\ldots \quad (1)$$

where the first term models the LOS component (a Rice term C_0) with constant magnitude w_0 and uniformly distributed ϕ over [0, 2 π). The mixture weights { w_n } are deterministic real valued constants. The H_i ($i=1,2,3,\ldots$) are assumed to be independent circularly symmetric Gaussian zero-mean complex random variables with unit variance. In this paper, we focus on the interesting special case of second-order scattering, i.e., $w_n=0$ for all n > 2:

$$H=C_0+C_1+C_2=w_0e^{j\phi}+w_1H_1+w_2H_2H_3 \quad (2)$$

In this street model, there is no LOS component, and double-Rayleigh distributed amplitude results as the special case of (2) where $w_0=w_1=0$

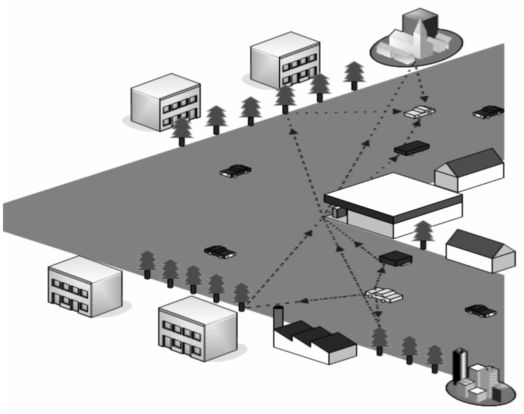

Figure 1 The V2V Propagation Scenarios

For easy to derive the reference model, we give the geometrical model in fig.2 instead of the street model shown in fig.1.

III. Reference Model

A. Derivation of The Reference Model

In this section, we derive the reference model for the MIMO V2V channel. The starting point is the geometrical two-ring model with a diffracting street corner shown in Fig. 2, from which we observe that the m th homogeneous plane wave emitted from the first antenna element A_T^1 of the transmitter travels over the local scatterers S_T^m , corner and S_R^n before impinging on the first antenna element A_R^1 of the receiver. At first, it is assumed that all waves reaching the receiver antenna array are equal in power, and then it is assumed that the numbers of local scatterers, M and N , around the transmitter and receiver are infinite i.e.. $M\to\infty, N\to\infty$. As can be seen from Fig. 2, angles β_T and β_R describe the orientation of the transmitter's antenna array and the receiver's antenna array, respectively, relative to the x-axis. Similarly, the transmitter and the receiver are moving with speeds v_T and v_R in directions described by angles α_T and α_R , respectively. The symbols ϕ_T^m and ϕ_R^n denote the angles of departure (AOD) and the angles of arrival (AOA), respectively. The antenna spacing at the transmitter and the receiver are denoted by δ_T and δ_R, respectively. Since the antenna spacing δ_T and δ_R are generally small in comparison with the radii R_T and R_R, it can be assumed that the inequality $\max\{\delta_T,\delta_R\}<<\min\{R_T,R_R\}$ holds.

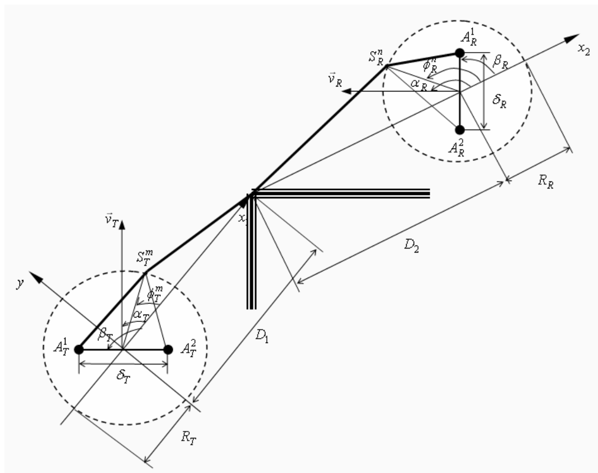

Figure 2 Geometrical Two-ring Model with a Diffracting Street Corner

Consequently, the time-space received faded envelope can be written as:

$$h_{11}(\vec{r}_R)=\left\{\lim_{M\to\infty}\left(\sum_{m=1}^{M}E_m\exp[-j(KD_m-\vec{k}_T^m\cdot\vec{r}_T-\theta_m)]\right)\right\}\cdot \quad (3)$$
$$\left\{\lim_{N\to\infty}\left(\sum_{n=1}^{N}E_n\exp[-j(KD_n+\vec{k}_R\cdot\vec{r}_R-\theta_n)]\right)\right\}$$

In our model, we assume that each scatterer S_T^m on the ring around the transmitter introduces an infinitesimal constant gain $E_m=1/\sqrt{M}$ and a random phase shift θ_m . Analogously, on the receiver side, each scatterer S_R^n introduces a constant gain $E_n = 1/\sqrt{N}$ and a random phase shift θ_n. The phase shifts θ_m and θ_n are assumed to be independent, identically distributed (i.i.d). random variables with a uniform distribution over the interval [0, 2π).

Furthermore, the symbol K denotes the free-space wave number, which is related to the wavelength λ via $K = 2\pi/\lambda$. Symbol D_m is the length of the distance which a plane wave travels from A_T^1 to corner via the scatterers S_T^m and D_n is the length of the distance which a plane wave travels from corner to A_R^1 via the scatterers S_R^n. Then, D_m and D_n can be written as

$$\begin{cases} D_m \approx R_T - 0.5\delta_T \cos(\beta_T - \phi_T^m) + D_1 - R_T \cos\phi_T^m \\ D_n \approx R_R - 0.5\delta_R \cos(\beta_R - \phi_R^n) + D_2 + R_R \cos\phi_R^n \end{cases} \qquad (4)$$

In (3), $\vec{k}_T^m$ is the wave vector pointing in the propagation direction of the m th transmitted plane wave, and $\vec{r}_T$ denotes the spatial translation vector of the transmitter. Analogously, $\vec{k}_R^n$ is the wave vector pointing in the propagation direction of the n th received plane wave and $\vec{r}_R$ denotes the spatial translation vector of the receiver. The phase changes $\vec{k}_T^m \cdot \vec{r}_T$ and $\vec{k}_R^n \cdot \vec{r}_R$ can be expressed as

$$\begin{cases} \vec{k}_T^m \cdot \vec{r}_T = 2\pi f_{T\max} \cos(\phi_T^m - \alpha_T)t \\ \vec{k}_R^n \cdot \vec{r}_R = -2\pi f_{R\max} \cos(\phi_R^n - \alpha_R)t \end{cases}. \qquad (5)$$

Where $f_{T\max} = v_T/\lambda$ and $f_{R\max} = v_R/\lambda$ are the maximum Doppler frequency caused by the movement of the transmitter and receiver, respectively.

One can show that the diffuse component $h_{22}(t)$ of the link from A_T^2 - corner- A_R^2 can be obtained from (3) by replacing

$$\begin{cases} D'_m \approx R_T + 0.5\delta_T \cos(\beta_T - \phi_T^m) + D_1 - R_T \cos\phi_T^m \\ D'_n \approx R_R + 0.5\delta_R \cos(\beta_R - \phi_R^n) + D_2 + R_R \cos\phi_R^n \end{cases} \qquad (6)$$

Similarly, the diffuse components $h_{12}(t)$ and $h_{21}(t)$ can directly be obtained from (3) by performing the substitutions D_m to D'_m, and D_n to D'_n, respectively. The four diffuse components $h_{ij}(t)$ ($i, j = 1,2$) of the A_T^j - corner- A_R^i link can be combined to the stochastic channel matrix

$$H(t) = \begin{pmatrix} h_{11}(t) & h_{12}(t) \\ h_{21}(t) & h_{22}(t) \end{pmatrix} \qquad (7)$$

which describes completely the reference model of the proposed MIMO V2V frequency-nonselective Rayleigh fading channel.

B. *The Space-time CCF of The Reference Model*

According to [4], the space-time cross-correlation function (CCF) between the two links A_T^1 - corner- A_R^1 and A_T^2 - corner- A_R^2 is defined as the correlation between the diffuse components $h_{11}(t)$ and $h^*{}_{22}(t)$, i.e.,

$$\rho_{11,22}(\delta_T, \delta_R, \tau) := E\left[h_{11}(t) h_{22}^*(t+\tau)\right] \qquad (8)$$

Here, the expectation operator applies on all random variables: phases { θ_m, θ_n }, AOD { ϕ_T^m } and AOA { ϕ_R^n }. Starting from (3) and making use of the fact that $h_{22}(t)$ can be obtained from $h_{11}(t)$ by performing the substitutions D_m to D'_m, and D_n to D'_n, we can express the 3-D space-time CCF as

$$\rho_{11,22}(\delta_T,\delta_R,\tau) = \lim_{\substack{M\to\infty \\ N\to\infty}} \frac{1}{MN} \left\{ \sum_{m=1}^{M} \exp[j(K\delta_T \cos(\beta_T - \phi_T^m) - 2\pi f_{T\max} \cos(\phi_T^m - \alpha_T)\tau] \right\} \cdot \left\{ \sum_{n=1}^{N} \exp[j(K\delta_R \cos(\beta_R - \phi_R^n) - 2\pi f_{R\max} \cos(\phi_R^n - \alpha_R)\tau] \right\} \qquad (9)$$

Hence, it follows from (9) that the 3-D space-time CCF of the reference model can be expressed as

$$\rho_{11,22}(\delta_T, \delta_R, \tau) = \rho(\delta_T, \tau) \cdot \rho(\delta_R, \tau) \qquad (10)$$

From (10), we observe that the 3-D space-time CCF $\rho_{11,22}(\delta_T, \delta_R, \tau)$ can be expressed as the product of the transmit correlation function $\rho(\delta_T, \tau)$ and the receive correlation function $\rho(\delta_R, \tau)$. Furthermore, we also observe that $\rho_{11,22}(\delta_T, \delta_R, \tau)$ is independent of the ring radii (R_T, R_R) and the distance (D_1, D_2) between the transmitter and the receiver.

The 2-D space CCF $\rho(\delta_T, \delta_R)$ defined as $\rho(\delta_T, \delta_R) := E\left[h_{11}(t) \cdot h_{22}^*(t)\right]$, equals the space-time CCF $\rho_{11,22}(\delta_T, \delta_R, \tau)$ at $\tau = 0$, i.e.,

$$\begin{aligned} \rho(\delta_T, \delta_R) &= \rho_{11,22}(\delta_T, \delta_R, 0) \\ &= \rho_T(\delta_T, 0) \cdot \rho_R(\delta_R, 0) \end{aligned} \qquad (11)$$

According to [5 , 6], the 3-D space-time CCF $\rho_{11,22}(\delta_T, \delta_R, \tau)$ can be written as:

$$\begin{aligned} \rho_{11,22}(\delta_T, \delta_R, \tau) &= \rho(\delta_T, \tau) \cdot \rho(\delta_R, \tau) \\ &= J_0\left(2\pi\sqrt{\left(\frac{\delta_T}{\lambda}\right)^2 + (f_{T\max}\tau)^2 - \frac{K\delta_T}{\pi} f_{T\max} \cos(\alpha_T - \beta_T)\tau}\right) \\ &\cdot J_0\left(2\pi\sqrt{\left(\frac{\delta_R}{\lambda}\right)^2 + (f_{R\max}\tau)^2 - \frac{K\delta_R}{\pi} f_{R\max} \cos(\alpha_R - \beta_R)\tau}\right) \end{aligned} \qquad (12)$$

where $J_0(\cdot)$ denotes the Bessel function of the first kind of order zero.

IV. NUMERICAL RESULTS

In this section, we present some numerical results for the special case of isotropic scattering.

The model parameters chosen as follows: the CCF for a scenario with the numbers of scatterers $M \to \infty, N \to \infty$. The antenna spaces are $\delta_T = \delta_R = \lambda/2$, and the tilt angles $\beta_T = 2\pi/3$, $\beta_R = \pi/3$. At the transmit side, the angle of motion is $\alpha_T = \pi/4$, while the receiver was moving in the direction determined by $\alpha_R = 3\pi/4$. Identical maximum Doppler frequencies of $f_{T\max} = f_{R\max} = 91Hz$ have been used, while the wavelength λ was set to $\lambda = 0.15m$.

From (11) and (12), it follows that the 2-D space CCF $\rho(\delta_T, \delta_R)$ can be expressed as the product of two Bessel functions according to

$$\rho(\delta_T, \delta_R) == \rho_T(\delta_T, 0) \cdot \rho_R(\delta_R, 0) = J_0(2\pi\delta_T / \lambda) \cdot J_0(2\pi\delta_R / \lambda) \tag{13}$$

The shape of the 2-D space CCF $\rho(\delta_T, \delta_R)$ determined by (13) is illustrated in Fig. 3. Finally, Fig.4 shows the reference model transmit correlation function $\rho(\delta_T, \tau)$.

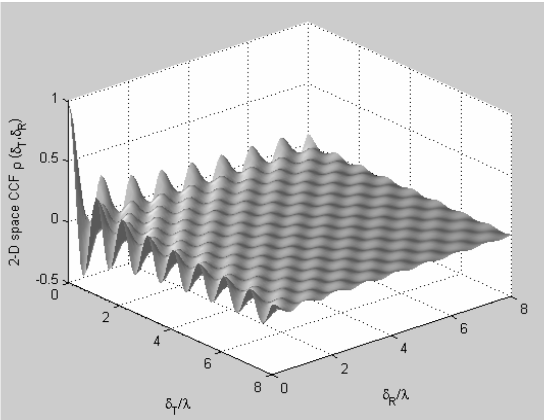

Figure 3 The normalized 2-D Space CCF of The 2×2 MIMO Vehicle-to-Vehicle Channel Model

V. CONCLUSIONS

In this paper, a street model for MIMO V2V fading channels is proposed. From this reference model, the space CCF and the space-time CCF are derived. The result shows that the complex faded envelope does neither depend on the distance between scatterers and antenna elements nor the distance between the transmitter and the receiver. Furthermore, the 3-D space-time CCF shows that placed antennas can have small correlations. Finally, some simulation results are presented to verify theoretical derivations. Our procedure provides also an important framework for studying the channel capacity of MIMO V2V channels, channel coding and wireless intelligent transportation systems planning.

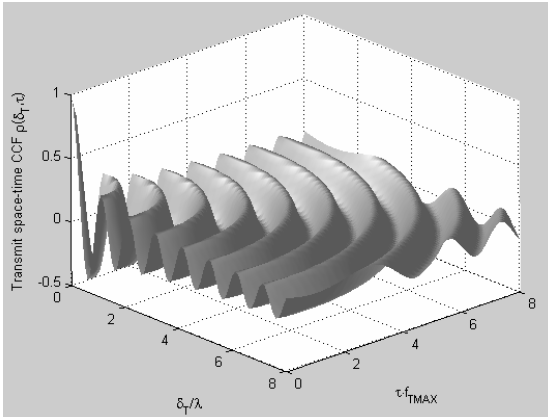

Figure 4 The normalized Transmit Space-time CCF of The 2×2 MIMO Vehicle-to-Vehicle Channel Model

REFERENCES

[1] J. B. Andersen, “Statistical distributions in mobile communications using multiple scattering,” in Proc. 27th URSI General Assembly, Maastricht, Netherlands, Aug. 2002.

[2] J. Salo, H. M. El-Sallabi, and P. Vainikainen, “Impact of double-Rayleigh fading on system performance,” in Proc. 1st International Symposium on Wireless Pervasive Computing, ISWPC’06, Phuket, Thailand, Jan. 2006.

[3] V. Erceg, S. J. Fortune, J. Ling, A. Rustako, and R. A. Valenzuela, “Comparisons of a computer-based propagation prediction tool with experimental data collected in urban microcellular environments,” IEEE J. Select. Areas Commun., vol. 15, no. 4, pp. 677–684, May 1997.

[4] A. Abdi. J. A. Barger. and MI. Kavei, "A parametric model for the distribution of the angle of arrival and the associated correlation function and power spectrum at the mobile station," IEEE Trans. I'ehm. Technol., vol. 51, no. 3, pp. 425---434, May 2002.

[5] M. P¨atzold, B. O. Hogstad, N. Youssef, and D. Kim, “A MIMO mobile-to-mobile channel model: Part I-the reference model,” Proc. IEEE PIMRC 05, Berlin, Germany, September 2005, vol. 1, pp. 573-578

[6] M. P¨atzold, Mobile Fading Channels. Chichester: John Wiley & Sons, 2002