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# Angular beta distribution for 3D vehicle-to-vehicle channel modeling

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## HIGHLIGHTS

- An innovative angular Beta distribution is proposed for the elevation AoA of the multipath components to account for the non-isotropic scattering. It is a parametric distribution with two shape parameters and has flexibility to model a lot of different scattering environments including isotropic scattering as special case.
- The closed-form expressions of the corresponding time correlation functions are derived and simulated.
- The modeled Doppler power spectral density (D-PSD) is compared with the available measured data. The close agreements between the modeled and measured D-PSD curves confirm the utility of the proposed angular Beta distribution.
- The results would provide useful insight on the modeling for V2V communications in different scenarios.

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## ABSTRACT

The 3D non-isotropic multipath scattering and dynamic communication environment make Vehicle-to-Vehicle (V2V) channel modeling particularly challenging. In this paper, an innovative angular Beta distribution is proposed for the elevation angle of arrival of the multipath components to account for the non-isotropic scattering. It is a parametric distribution with two shape parameters and has flexibility to model a lot of different scattering environments including the isotropic scattering as a special case. Furthermore, the closed-form expressions of the corresponding time correlation functions are derived and simulated. Finally, the modeled Doppler power spectral density (D-PSD) is compared with the available measured data. The close agreements between the modeled and measured D-PSD curves confirm the utility of the proposed angular Beta distribution.



## 1. Introduction

Vehicle-to-Vehicle (V2V) communication is one of the basic elements that make up Internet of Vehicles (IoVs) [1,2] which can bring significant societal benefit and commercial value to the automobile transportation [3,4]. Its performance is directly constrained by the signal propagation environment. An appropriate channel model is of great significance to the design and performance enhancement of V2V communication systems [5]. However, V2V communication is characterized by the 3D non-isotropic multipath scattering and a dynamic environment due to the movement of the transceiver and scatterers. These characteristics make V2V channel modeling particularly challenging.

The moving scatterers are unavoidable in V2V communications. Moving foliage, walking pedestrians and passing vehicles are only a few examples of scatterers in motion [6]. Many V2V channel models have been proposed in various ways considering the moving scatterers. A non-stationary multiple-input-multiple-output (MIMO) V2V channel model was derived from the geometrical street model, and the impact of fixed and moving scatterers on the correlation function was studied in [7]. A single-input-single-output (SISO) V2V channel model was proposed in which the local scatterers can move with random velocities in random directions, and the corresponding autocorrelation functions and power spectral density were derived in [8] and [9]. A 3D fixed scattering and 2D moving scattering narrowband reference channel model that includes stationary and moving scatterers was proposed, and the corresponding space–time correlation function (ST-CF) and Doppler power spectral density (D-PSD) were derived in [10]. The work in [10] was extended to wideband channels in [11]. An extension of spatial channel model for V2V channel in roadside scattering environment was investigated under the idealized assumption of isotropic scattering in [12], and general expressions of the most important statistical properties such as angular power density and autocorrelation function were derived. The isotropic scattering mentioned above means that the outgoing direction of

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scattered electromagnetic waves appears with equal probability in each spatial direction. A non-stationary geometry-based scattering model for street wideband MIMO V2V fading channel was proposed in [13], and it is assumed that the static and mobile scatterers were uniformly distributed on time-varying ellipses and time-varying segment of the road, respectively. A geometry-based stochastic scattering model (GBSSM) for wideband MIMO V2V channels was proposed in [14], and the proposed GBSSM with cross-polarized antennas combined 3D two-cylinders to model the stationary scatterers and 2D multi-rings to imitate the moving scatterers. A generic statistical characterization of the V2V SISO channel was presented, and the 3D isotropic moving scattering was considered in [15]. The analytical expression of the temporal autocorrelation function of 3D non-stationary multipath scattering channel was derived in the presence of moving scatterers in [16]. A 3D propagation model that includes line-of-sight, single bounced and multiple bounced rays for narrowband MIMO V2V multipath fading channels was developed, and the corresponding ST-CFs, time correlation functions (T-CFs), space correlation functions (S-CFs) and D-PSD were analytically investigated and numerically simulated in terms of various factors in [17]. A 3D V2V MIMO channel model in different roadway scenarios with moving scatterers was developed, and the corresponding ST-CF and D-PSD were analytically investigated in [18].

Most of the previously reported moving scattering models have assumed that the moving scattering is isotropic or the angle of arrival (AoA) is characterized by uniform, quadratic, Gaussian, Laplacian, von Mises or cosine distributions. Note that V2V channels usually exhibit non-isotropic scattering except in cases of high vehicular traffic density [19]. The outgoing direction of scattered electromagnetic waves appears with a certain probability in a specific spatial direction in the non-isotropic scattering scenario. Furthermore, the closed-form expression can intuitively reflect the relationship between various parameters, and it can be used not only for quantitative calculation but also for qualitative analysis. However, all the mentioned distributions fail to provide closed-form expression of the T-CF for 3D non-isotropic scattering. To determine the closed-form solution of the T-CF, an innovative angular Beta distribution is proposed to characterize the elevation angle of AoA in this paper. Beta distribution is a distribution with two shape parameters and limited support range which gives it the flexibility to model a lot of different scattering environments. It was used to optimize the array geometry of multiple antenna systems for direction-of-arrival estimation in [20]. Since the application scenario in [20] is quite different from this paper, an angular Beta distribution with additional scale and shift operation is needed for V2V channel modeling.

The remainder of the paper is organized as follows. The definition of angular Beta distribution and its parameters setup process are described in Section 2. Section 3 derives the closed-form expression of T-CF of the received signal. Comparisons between the modeled D-PSD and measured data are provided in Section 4. Finally, Section 5 provides some concluding remarks.

## 2. Angular Beta distribution

The proposed angular Beta distribution for the elevation angle $\beta$ is

$$p_\beta(\beta) = \frac{(1+\sin\beta)^N(1-\sin\beta)^M}{P}, \beta \in [-\frac{\pi}{2}, \frac{\pi}{2}], \tag{1}$$

where $N, M$ are positive integers that control the mean and variance of $\beta$, $P$ is a normalized constant and can be written as

$$P = \sum_{n=0}^{N}\sum_{m=0}^{M} C_N^n C_M^m (-1)^m \sqrt{\pi}\frac{\Gamma(K+1/2)}{\Gamma(K+1)}, \tag{2}$$

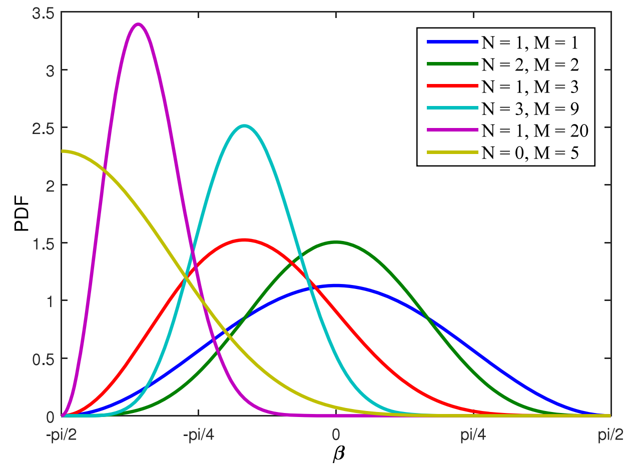


**Fig. 1.** PDF of angular Beta distribution in Cartesian coordinate. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

where $K = (n+m)/2$ is integer, and $\Gamma(\cdot)$ is gamma function. Eq. (2) only takes the sum of the terms that $n+m$ is even. The angular Beta distribution with the support range of $[-\pi/2, \pi/2]$ is the counterpart of the Beta distribution with the support range of [0, 1]. The incorporation of $\sin(\beta)$ is to guarantee the closed-form solution of the T-CF. Thus, the proposed distribution is named as angular Beta distribution. If $N = M = 0$, it equals uniform distribution. If $N = M$, it degrades to cosine distribution.

Fig. 1 shows the probability density function (PDF) of angular Beta distribution in Cartesian coordinate. The mean of angular Beta distribution could be any value within the support range. As long as the mean is determined, the variance could be tuned to meet the angle spread requirement of specific environments. Thus, angular Beta distribution shares the same advantages of the original Beta distribution, and it is quite suitable for modeling non-isotropic scattering with different means and widths in V2V communication scenarios.

Theoretically, the mean and variance of angular Beta distribution can be obtained, and then the parameters $N, M$ can be estimated by the usage of the method of moment. However, this involves solving an extremely complicated non-linear equation. Therefore, here we propose the following two curves for parameters setup. Fig. 2 shows the mean and half-beam width of angular Beta distribution. We use the half-beam width to approximate the variance, and the special case of $N = 0$ or $M = 0$ is considered separately. The parameters setup process works as follows: firstly, the appropriate ratio of $M_1/N_1$ is obtained according to the mean of elevation angle and the red curves in Fig. 2; secondly, the appropriate ratio of $M_2/N_2$ is obtained according to the angle spread requirement of elevation angle and the blue curves; finally, the parameters of angular Beta distribution are set to $(N, M) = (M_1/N_1, M_1M_2/N_1N_2)$. This is because the mean of angular Beta distribution is mainly determined by $M/N$, while the variance is determined by $M + N$. Referring to the mean and variance of original Beta distribution would make the meaning of this process clearer. For example, in some specific environments, the mean and angle spread of elevation angle of AoA are required to be zero and $\pi/4$. According to Fig. 2, $M_1/N_1$ and $M_2/N_2$ are about 1 and 3. The parameters of angular Beta distribution can be determined as $(N, M) = (3, 3)$. In general, angular Beta distribution is capable of modeling non-isotropic scattering and easy of parameters setup.