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Geometrical channel model for vehicle-to-vehicle systems

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ABSTRACT

In ITS impairments tend to be more severe as, in some scenarios, transmitter–receiver relative motion is larger than in cellular systems. This renders in larger Doppler shifts. Also, the scattering scenarios changes continuously and dispersers and reflector tend to lay along traffic roads. In this paper, Doppler shift is characterized in an ITS environment for line of sight and randomly located scatterers. Impact of vehicle speed and lane separation and transmitter–receiver distances are considered in terms of the overall Doppler probability density function (pdf) mixture. Asymmetric behavior with respect to mobile speed is also reported. Doppler spread for a scenario of several scatterers is introduced and shown to be in close agreement to real measurements.

1. Introduction

Doppler shift impairs wireless communications and it arises when relative separation of a transmitter–receiver pair changes. Doppler depends on relative motion, and is also affected by reflection and scattering phenomena that renders in time and frequency spreads that depend on the environment. In future environments such as the Intelligent Transportation Systems (ITS), it will be important to establish inter-vehicular and vehicle to infrastructure communications. These impairments are both present in fixed to vehicle (F2V) and vehicle-to-vehicle (V2V) systems. Although F2V environments have been characterized, see [1,2], V2V conditions are different as both transmitter and receiver antennas are placed near ground level and are subject to motion leading to more pronounced Doppler shifts. Measurements and impulse responses have been suggested for the Doppler [3,4]. Shadowing and scattering features are different, since in V2V reflected paths tend to be shorter and scatters tend to lay in the vicinity of the mobile location due, for instance, to the proximity of other vehicles or lateral road signs. This demands further characterization of the V2V channel. In [5], real measurements of a road lane scenario are obtained with the objective of measuring the Doppler spread. This paper presents a characterization of Doppler shift caused by movement of vehicles and interacting objects of the environment that create the Doppler spread of V2V systems. Due to multiple impairments and difficulties in keeping an accurate control of the propagation conditions, a statistical characterization and simulation of the road environment is conducted. We show that our model characterizes the road lane scenario and it has accuracy with respect to real measurements. After a description of the scenario, we characterize the Doppler shift for a typical environment using vehicle conditions as speeds, separation and lateral scatterer location. Doppler shift probability density function (pdf) and mixtures are presented for the line of sight and scattering scenarios.

2. Line of sight scenario

Propagation scenarios in ITS environments change as lane widths, surrounding infrastructure, speed, and vehicle heights do. In Fig. 1, on different parallel lanes, two vehicles move in opposite directions at speeds v_A and v_B, respectively. Doppler in the line of sight path is given by

$$\Delta = f_0 \frac{v_A + v_B}{c} \cdot \frac{l}{\sqrt{\delta_2^2 + l^2}}, \tag{1}$$

where f_0 is the communication frequency, δ_2 is the lane spacing, l is the vehicle separation and c is the speed of light. Doppler shift is a location dependent phenomenon along the traveled line. The maximum traveled line $l_{\max}$ or maximum separation to achieve communication [6] is a function of the transmitted power and receiver sensitivity.

Vehicle location changes continually, and actual V2V separation is unknown. However, for constant speeds [4] separation changes linearly with time and at given observation instants it can be

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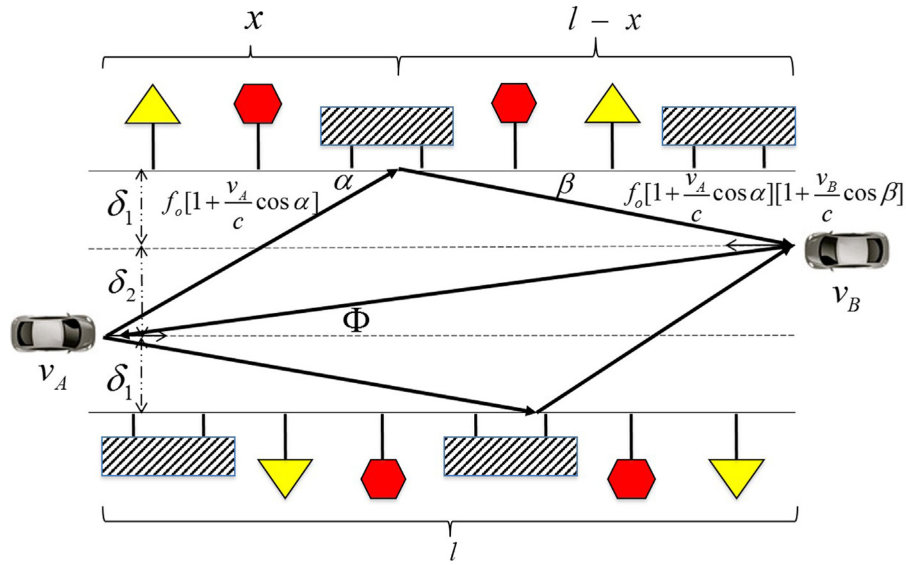

Fig. 1. Geographical description of a typical highway.

assumed a uniform random variable L in $[-l_{\max}, l_{\max}]$, Then, for $k = f_0(v_A + v_B)/c$, (1) becomes a function of L, $\Delta = g(L)$, with pdf

$$f_\Delta(z) = \frac{\delta_2 k^2}{l_{\max}(k^2 - z^2)^{3/2}}, \quad |z| \le \frac{l_{\max} k}{\sqrt{\delta_2^2 + l^2}}. \tag{2}$$

3. Fixed scatterer scenario

In a road environment, scatterers as side road traffic signs cause multipath phenomena. Scatterers are distributed along lines parallel to road lanes. We consider that a scatterer is located δ_1 units away from a road lane, see Fig. 1, and at distances x and $l - x$ from vehicles A and B, respectively. Define $h_1(x) = (v_A x)/([c\sqrt{x^2 + (\delta_1 + \delta_2)^2}])$ and $h_2(x) = (v_B(l - x))/([c\sqrt{(l - x)^2 + \delta_1^2}])$, then Doppler shift associated to this scatterer is

$$\Delta = f_0[h_1(x) + h_2(x) + h_1(x)h_2(x)]. \tag{3}$$

For a given vehicle separation $L = l$, the scatterer location x is assumed uniformly distributed in [0,l]. Note that, there is an associated Doppler shift conditional pdf $f_{\Delta|L}(z|l)$ for each separation l. Yet, (3) is not monotonic on x and precise calculation of $f_\Delta(z)$ is cumbersome. Thus, $f_\Delta(z) = \int_0^{l_{\max}} f_{\Delta|L}(z|l) f_L(l)dl$ is obtained by simulation for different scenarios. It can be seen that the same Doppler shift can be experienced for different locations and separations of vehicles and scatterers, Fig. 2(a), where iso-Doppler lines are shown on an (x, δ_1)-plane.

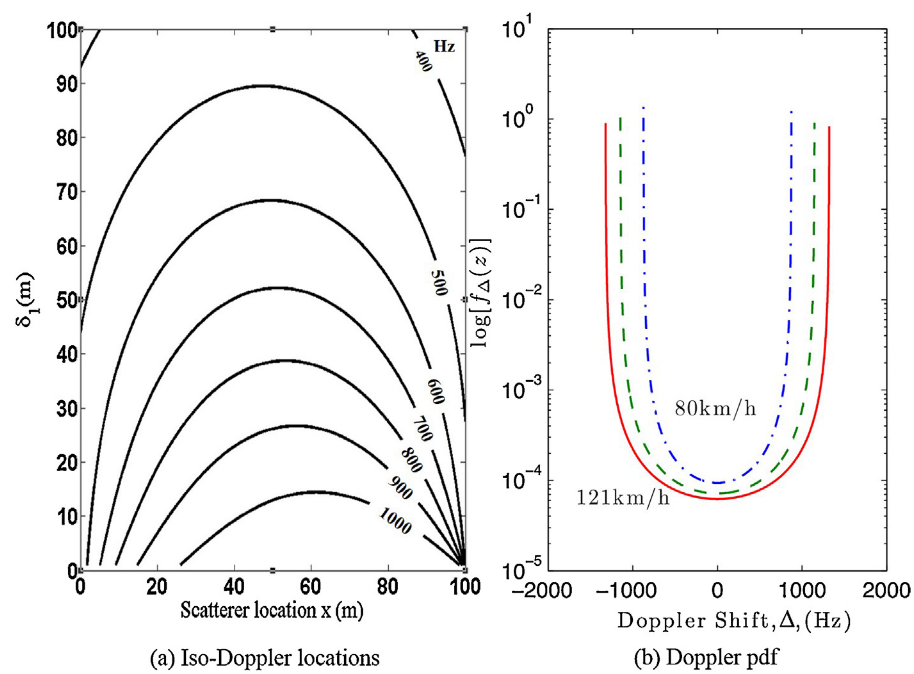

Fig. 2. Line of sight Doppler shift for typical values of vehicle speeds and separations [6].