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Enhancing the Non-Geometric Stochastic Model for Vehicle-to-Vehicle Channels Outside of the WSSUS

Dr C.RAJASELVAM[1], LALLAM VASU[2]

Abstract:

For V2V channels that don't rely on wide-sense stationarity and uncorrelated scattering (non-WSSUS), a new non-geometrical stochastic model (NGSM) is developed. This model effectively extends the existing NGSM to incorporate the line-of-sight (Loss) component; it is based on a regular NGSM and uses a more precise way to re-create the realistic properties of V2V channels. Doppler power spectrum density (PSD), power delay profile (PDP), and tap correlation coefficient matrix are only a few of the statistical properties of the proposed model that are simulated and compared with those of the current NGSM in a variety of situations. We have shown that our theoretical deductions are true, and the simulation results back up this claim.

Keywords:

automobile-to-automobile, non-WSSUS channels, non-geometric stochastic model, line-of-sight (Loss) component, statistical features.

Introduction

Intelligent transportation systems (ITS) use vehicle-to-vehicle (V2V) communication to increase productivity, reduce accidents, and open the door to new uses for the road [1]. V2V communication is a promising new form of communication, but it is hindered by a lack of study and a lack of standards. To aid in the study and development of V2V communication systems, researchers have focused heavily on channel modelling [2, 3]. Many types of V2V channel models have been discussed in [4, 5]; they include deterministic models, such as the geometry-based deterministic model (GBDM) [6, 7], and stochastic models, such as the non-geometrical stochastic model (NGSM) [7, 8]. (GBSM). The GBDM is totally deterministically characterised by the V2V physical channel characteristics, but its computing complexity grows as precision demands rise. Stochastic models are presently commonly utilised in V2V channel modelling because they provide a better compromise between accuracy and complexity than GB DM. Several GBSMs were suggested by the authors in [9]–[15]. These models modelled the propagation environment by using a reduced ray tracing technique and the equivalent scatterer notion.

The GBSM is more involved than the NGSM, but it is readily flexible enough to be used in a wide variety of situations. Without making any assumptions about the underlying geometry, the NGSM determines the V2V channel's physical properties. Two typical wideband NGSMs using the tapped delay line (TDL) construction have been suggested in the literature [7], [8]. Standardized by IEEE 802. 11p, the wideband NGSM created in [7] is a typical channel model. The Loss component is accounted for in the NGSM shown in [7], which also has a wide variety of Doppler spectra at various delays. In particular, for the scenario with low vehicular traffic density, the Loss component is commonly present owing to the short distance of V2V communication (VTD).

Assistant professor1,2
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
P.B.R.VISVODAYA INSTITUTE OF TECHNOLOGY & SCIENCE
S.P.S.R NELLORE DIST, A.P , INDIA , KAVALI-524201

The model makes use of Rician fading to detect the existence of a Loss component. In addition, the NGSM [7] assumes that each tap has several, indistinguishable sub paths, and that Doppler spectra take on a variety of forms depending on delay, such as a flat shape, a round shape, the standard 3 dB shape, or the classic 6 dB shape. Although the Rician fading is used in the NGSM [7], this assumption of wide sense stationary uncorrelated scattering (WSSUS) prevents it from accurately simulating the extreme fading seen in V2V channels.

Modelling Non-WSSUS Vehicle-to-Vehicle Communications Channels

Here, we first go through the constriction phases of the NGSM in [8] and show that forcing a uniformly distributed tap phase is not acceptable. Next, a new, enhanced NGSM with a non-standard tap phase distribution is presented.

Old-School NGSM

consisting of a Regular Phase Distribution Present NGSM [8] has three elements that narrow it down: modelling without WSS, modelling outside the US, and modelling with extreme fading. In this part, we will quickly outline the model's constraint steps and show that imposing a uniform phase distribution on the NGSM is unrealistically restrictive.

Non-WSS

Modelling The quantity and intensity of multipath components fluctuate regularly because of factors including unexpected traffic and variations in the size, location, and velocity of scatterers. The NGSM in [8] uses the "birth and death" process with persistence process Zak (t) = 0, 1 in the V2V channel model to represent the non-WSS characteristic, where tap "off" signifies below the 25-dB threshold from the main tap.

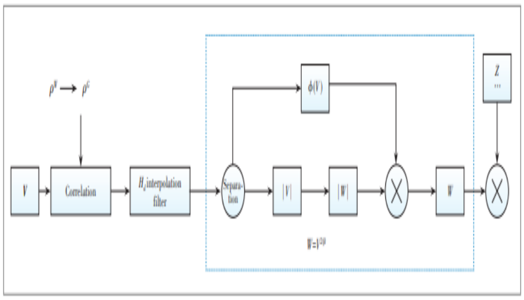
In order to reduce the number of taps to just those with non-negligible energy [8, such thresholding approaches [19]-[21] are often utilised in the literature. Furthermore, first-order two-state Markov chains may characterise the on/off process's state transition process, and the transition (TS) matrix and the steady-state (SS) matrix [8] can be provided by

$$TS = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} \qquad SS = \begin{bmatrix} P_0 \\ P_1 \end{bmatrix},$$

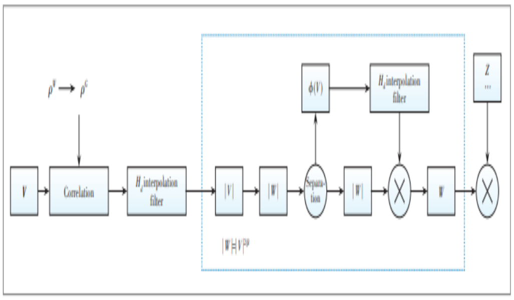
where each element Pij in matrix TS is defined as the probability- ty of going from state I to state, and each SS element Py gives the "steady-state probability "associated with the jet state. Then, the channel impulse repulse (CIR) of the NGSM in [8] can be expressed as

$$h(t,\tau) = \sum_{k=1}^{N} z_k(t) c_k(t) \delta(\tau - \tau_k) \times \exp\left\{ j2\pi \left[f_{D,k}(t - \tau_k) - f_c \cdot \tau_k \right] \right\},$$

Improved NGSM with Non-Uniform Phase Distribution In this section, an improved NGSM with non-uniformly dis- tributed tap phase is proposed, which is based on the existing NGSM [8]. The process to develop the improved model also consists of three parts: non-WSS modelling, non-US modelling, and severe fading modelling. However, the proposed model me- ploys a more accurate method to represent the characteristics of V2V channels, which extends the NGSM [8] to have the bail- it to include the Loss component. As can be seen from the above analysis, Loss component can- not be included in the NGSM [8]. This is because the tap phase is directly gained from the separation from Gaussian stop- chiastic process and follows a uniform distribution in the inter- Val [- π,π], which causes the absence of the Loss component. Thus, the uniformly distributed tap phase must be changed. Specifically, in the Weibull stochastic process, the amplitude and the phase of complex Gaussian stochastic variables are both transformed with complex exponentiation 2/β, and then the complex Gaussian stochastic variables are separated into the amplitude part and the phase part since the amplitude and phase of the complex stochastic variables are independent on each other. As a result of the above transformation, β affects equivalently the amplitude part and the phase part. Cones- quaintly, the tap amplitude follows the Weibull distribution and the tap phase follows non-uniform distribution. Above all, the constriction steps of the improved mode are shown in Fig. 3. With β being increased, the resulting tap phase concentrates within a smaller phase range, as expected. Consequently, an impulse at zero occurs as β → ∞. Also, when β = 2, a unit-



▲ ***Figure 2. The constriction steps of the NGSM [8] (V is an independent and identical complex Gaussian stochastic variable, and Z is a post-operation such as a persistence process).***



▲ ***Figure 3. The constriction steps of the improved model (V is an independent and identical complex Gaussian stochastic variable, and Z is a post-opera- action such as a persistence process)***

firmly distributed phase occurs, and the stochastic variables of the improved model can be expressed as

$$\widetilde{W}'_k = \tilde{V}_k^{2/\beta_k} = \left(\left|\tilde{V}_k\right| \cdot e^{j\tilde{\phi}_k}\right)^{2/\beta_k} = \left|\tilde{V}_k\right|^{2/\beta_k} e^{j\tilde{\phi}'_k},$$
$$\tilde{\phi}_k \in [-\pi, \pi], \tilde{\phi}'_k \in [-2\pi/\beta, 2\pi/\beta],$$

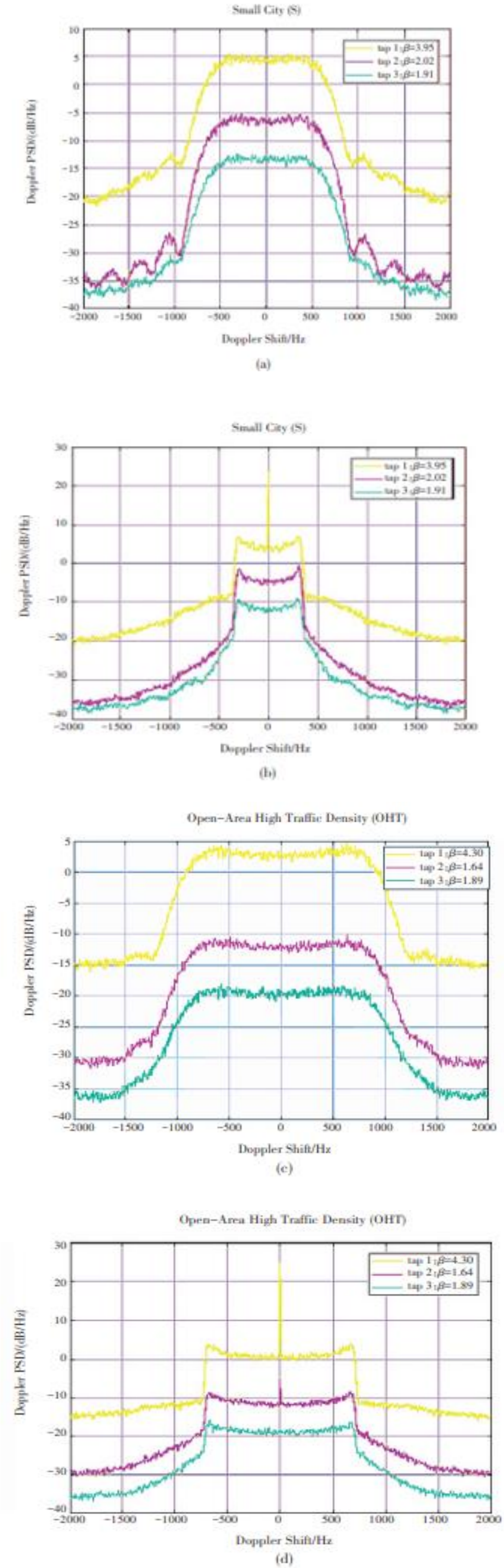
where the number of taps is assumed to be K and |Ṽ K |is the tap amplitude, which follows the Weibull distribution. ϕ̃ ' k is the tap phase of the improved model and follows the non-uniform distribution, which is a linear function of the uniformly diatribe-used phase. Specifically, the tap phase of the improved model can be given by

$$\tilde{\phi}'_k = \tilde{\phi}_k \cdot 2/\beta_k.$$

Similarly, the mean of the improved model can be calculated as

$$E(\tilde{W}'_k) = \frac{1}{2\pi}\int_{-2\pi/\beta_k}^{2\pi/\beta_k} \left|\tilde{V}_k\right|^{2/\beta_k} e^{j\tilde{\phi}'_k} d\tilde{\phi}'_k \Big|_{\beta>2} = \frac{\left|\tilde{V}_k\right|^{2/\beta_k}}{\pi}\left(1 - \cos\frac{4\pi}{\beta_k}\right) e^{j\frac{4\pi}{\beta_k}} \Big|_{\beta_k>2} \neq 0.$$

For V2V channels that don't rely on wide-sense stationarity and uncorrelated scattering (non-WSSUS), a new non-geometrical stochastic model (NGSM) is developed. This model effectively extends the existing NGSM to incorporate the line-of-sight (Loss) component; it is based on a regular NGSM and uses a more precise way to re-create the realistic properties of V2V channels. Doppler power spectrum density (PSD), power delay profile (PDP), and tap correlation coefficient matrix are only a few of the statistical properties of the proposed model that are simulated and compared with those of the current NGSM in a variety of situations. We have shown that our theoretical deductions are true, and the simulation results back up this claim.



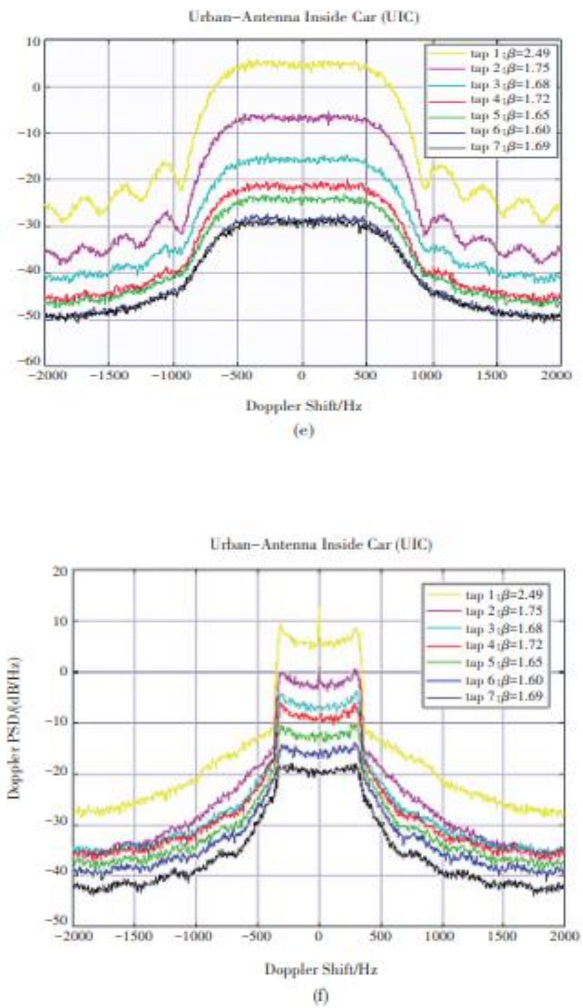


Figure 4. The Doppler PSD of different models for different scenarios. (a) Doppler PSD of the model in [8] for S scenario; (b) Doppler PSD of the mi- proved model for S scenario; (c) Doppler PSD of the model in [8] for OHT scenario; (d) Doppler PSD of the improved model for OHT scenario; (e) Dop- per PSD of the model in [8] for UIC scenario; (f) Doppler PSD of the improved model for UIC scenario;

Conclusions

Based on a traditional NGSM presented in [8], this work proposes a new NGSM for non-WSSUS V2V channels. In order to include the Loss component, the suggested NGSM uses a mechanism for generating phase that is not uniformly distributed in the Weibull distribution (NGSM [8]). The simulation results further show that the proposed model incorporates a dominating Loss component into the Doppler PSD, which directly identifies the existence of the Loss component, in contrast to the NGSM [8]. In addition, the suggested model's energy is more concentrated along the first route, as illustrated by the PDP comparison. As the suggested model more accurately describes the features of V2V channels, the simulation results confirm this.

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