Doppler Spectra in Non-Stationary Vehicle-to-Vehicle Communication Channels

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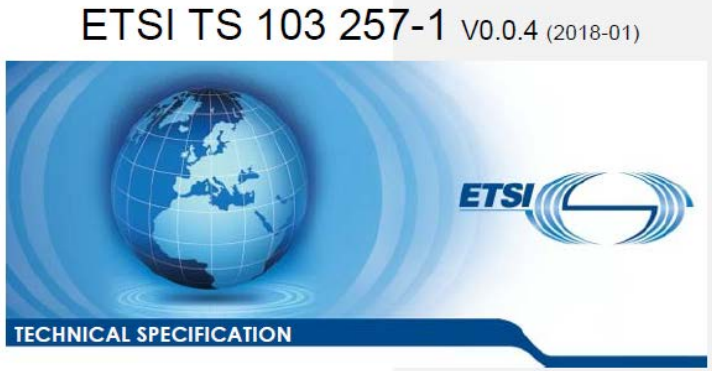
Current Standardization Activities on Channel Models

- Path loss models
  - Free space path loss
  - Two-ray ground reflection model
  - Path loss for V2V channels obstructed by vehicles: Vehicles-as-obstacles
- Shadow fading models
  - Single link shadow fading for V2V and V2I communications
  - Multilink shadow fading for V2V communications
- Small-scale fading models
  - Acosta-Marum channel model
  - Channel models from the ETSI Plugtests™ 2013
- Framework for geometry-based stochastic channel modelling (GBSCM)
- Geometry-based deterministic channel modelling (GBDCM)

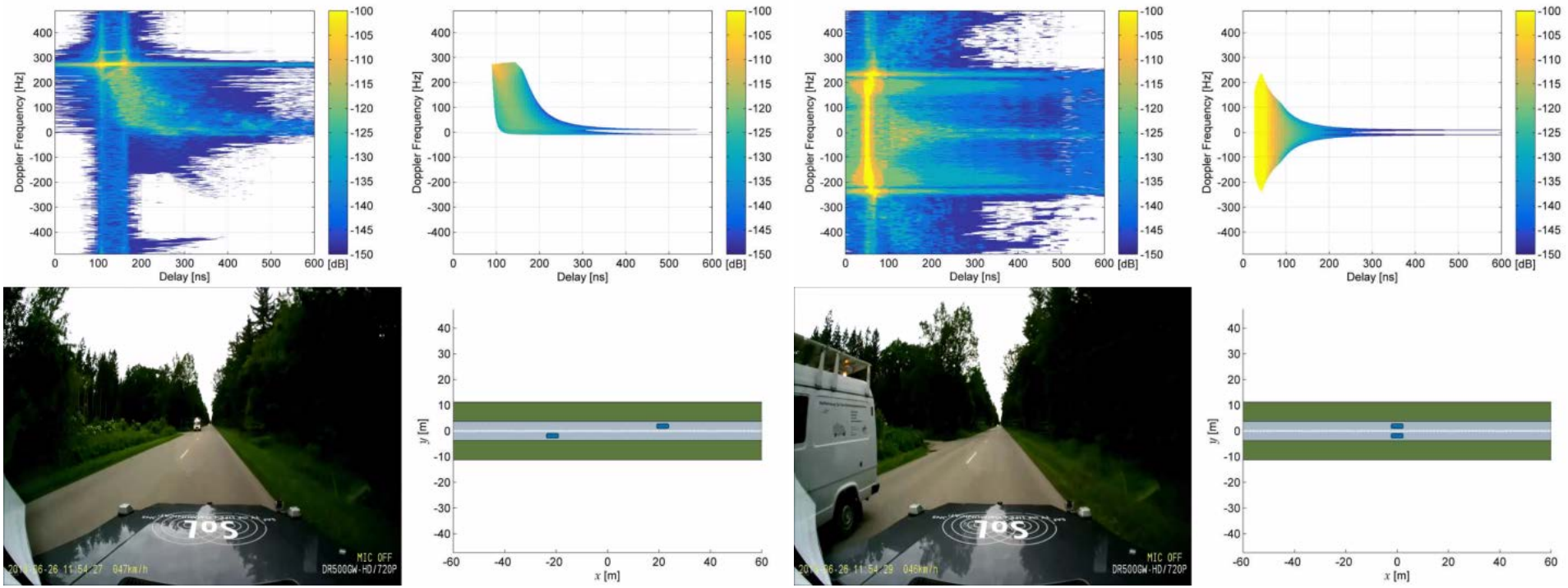


Vehicular channel
- highly time-variant
- correlated scatterers

Major Issues
- Wide Sense Stationary Uncorrelated Scatterers
- Computational complexity

Highly Time-Variant V2V Channel: Measurement Data vs. Theoretical Model

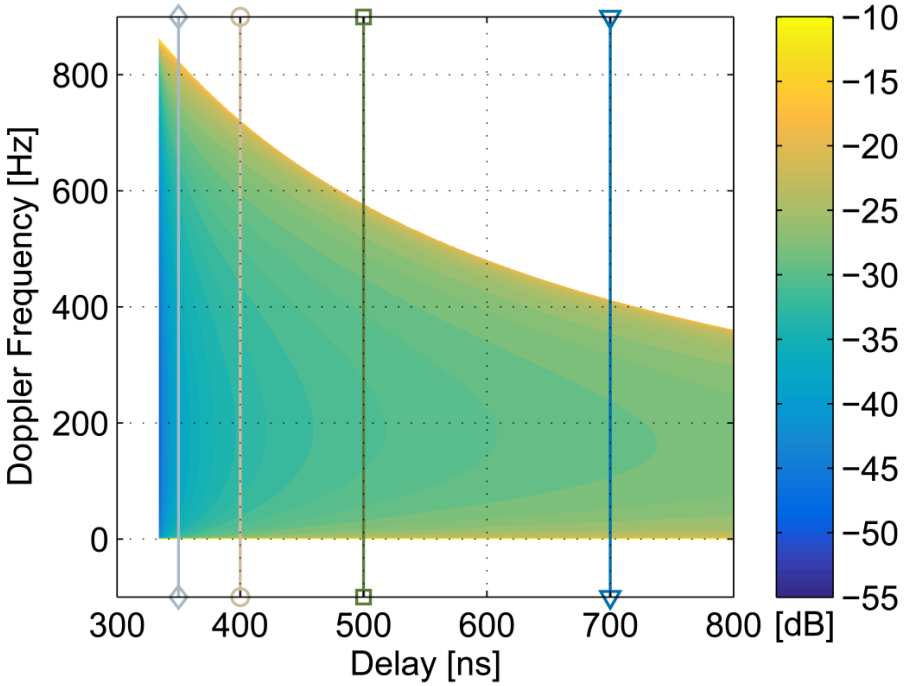
Tx and Rx driving in opposite directions.



t_1 approaching each other

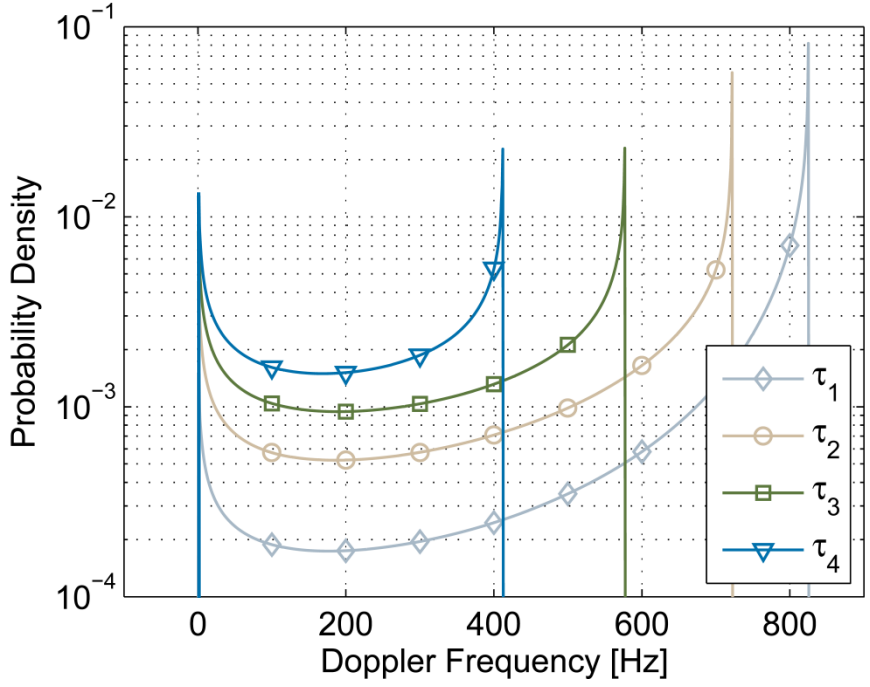
t_2 crossing each other

V2V-Channel: Driving in Opposite Directions



$f_c = 5.2$ GHz

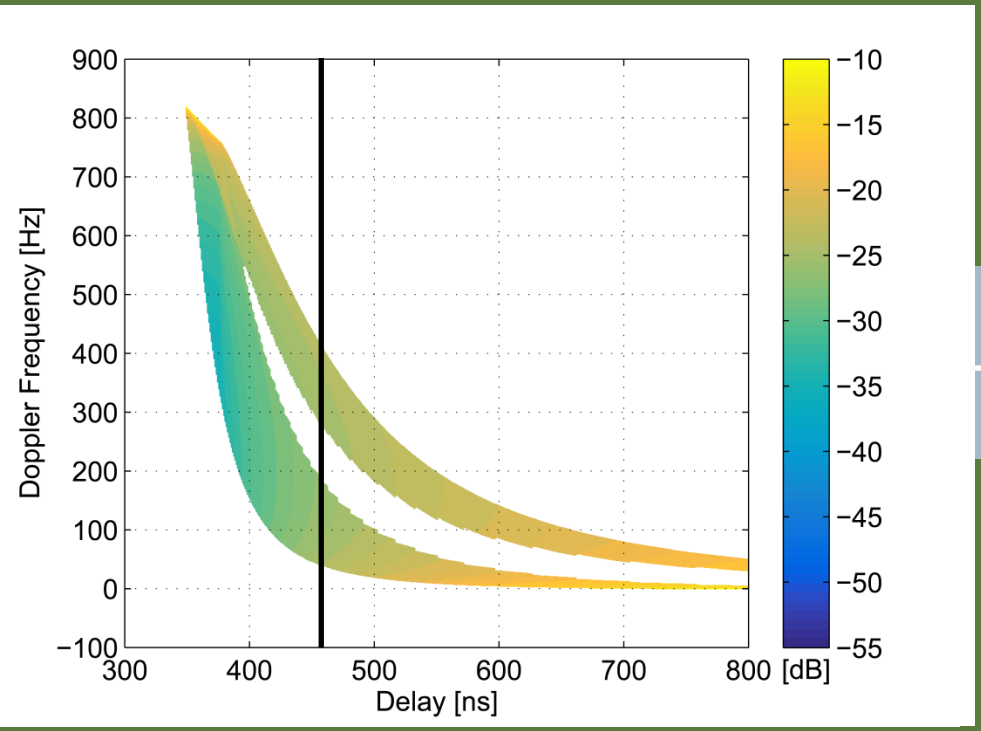
90 km/h

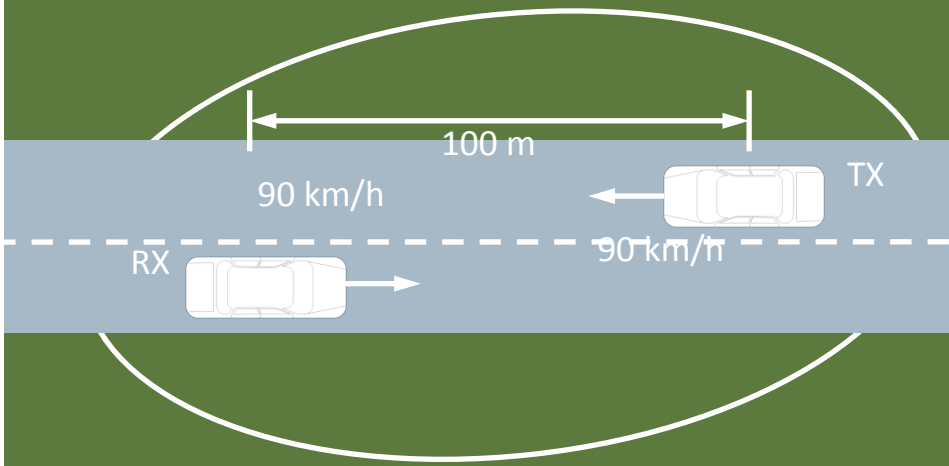


90 km/h

Doppler spectrum depends
on delay, velocity vectors, and Tx-Rx distance

V2V-Channel: Influence of Finite Scattering Areas





Theoretical Geometric-Stochastic Channel Model based on *Prolate Spheroidal Coordinate System*

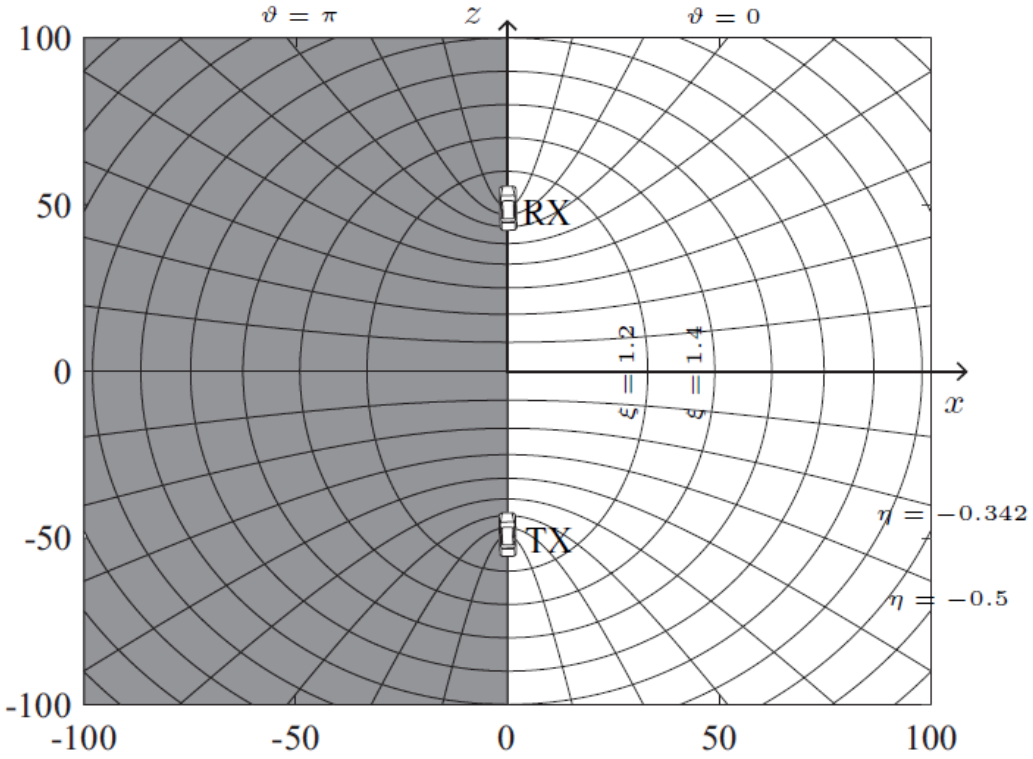
- Exploit symmetry of problem by using adequate coordinate system

- Separate coordinate ξ to describe constant delay resulting in ellipses

- Allows a delay-dependent description of the Doppler frequency

- No trigonometric functions

Algebraic analysis is possible!

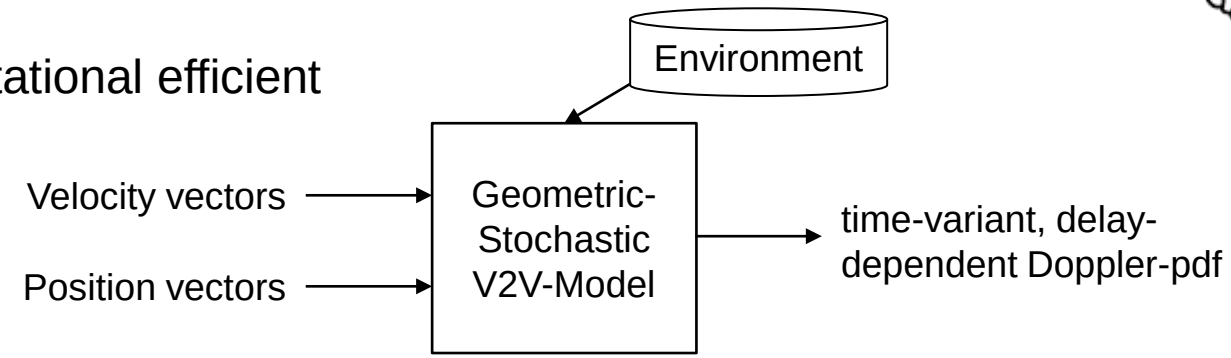


M. Walter, D. Shutin and A. Dammann, "**Algebraic Analysis of the Poles in the Doppler Spectrum for Vehicle-to-Vehicle Channels**," in *IEEE Wireless Communications Letters*, vol. PP, no. 99, pp. 1-1.

Theoretical Geometric-Stochastic Channel Model based on *Prolate Spheroidal Coordinate System*

- More realistic compared to (over-)simplifying models
  - time-variant (geometry-dependent) and delay-dependent Doppler spectrum
  - Resolve temporal and spatial correlation effects

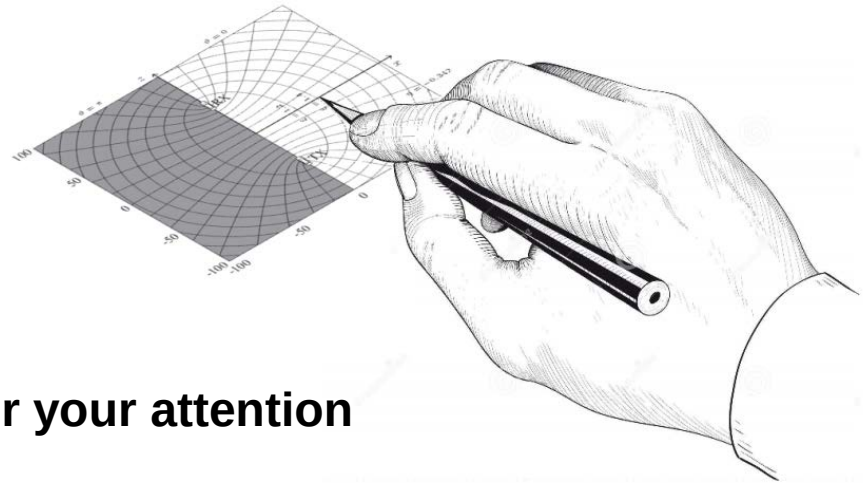
- Computational efficient



Easily applicable for
- PHY-layer simulation: TX-RX performance evaluation
- Enabling the enhancements of 802.11p
- Radio conformance testing: e.g. ETSI Plugtests
- Network Simulations

Summing up…

- Precise theoretical geometric-stochastic channel model for non-stationary vehicle-to-vehicle channels
  - ✓ very good match with measured V2V channel
- Applicable for simulations and (enhanced) performance evaluation
  - Software: tbd…



Thank you for your attention

Related Studies

- M. Walter, D. Shutin and U. C. Fiebig, "**Delay-Dependent Doppler Probability Density Functions for Vehicle-to-Vehicle Scatter Channels**," in *IEEE Transactions on Antennas and Propagation, vol. 62, no. 4, pp. 2238-2249, April 2014.*

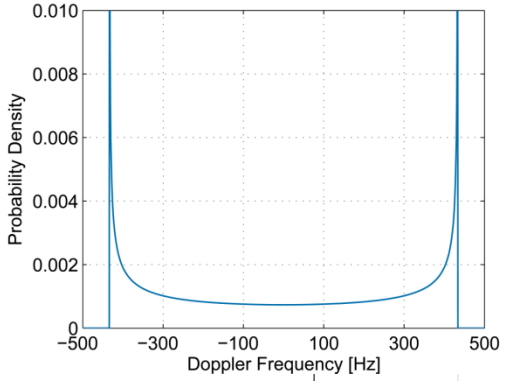
- M. Walter, D. Shutin and U. C. Fiebig, "**Prolate Spheroidal Coordinates for Modeling Mobile-to-Mobile Channels**," in *IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 155-158, 2015.*

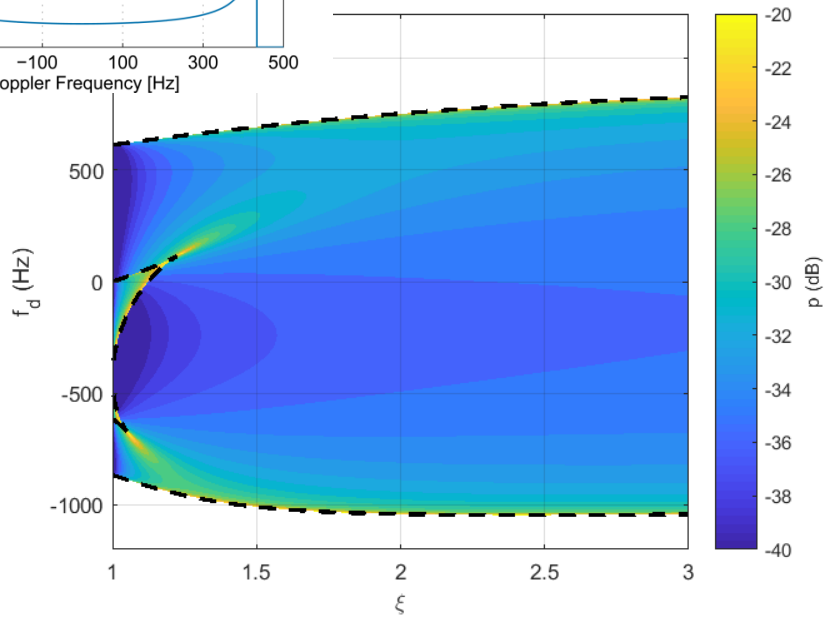
- M. Walter, D. Shutin and A. Dammann, "**Time-Variant Doppler PDFs and Characteristic Functions for the Vehicle-to-Vehicle Channel**," in *IEEE Transactions on Vehicular Technology, vol. 66, no. 12, pp. 10748-10763, Dec. 2017.*

- M. Walter, D. Shutin and A. Dammann, "**Algebraic Analysis of the Poles in the Doppler Spectrum for Vehicle-to-Vehicle Channels**," in *IEEE Wireless Communications Letters*, vol. PP, no. 99, pp. 1-1.

Algebraic Analysis of Poles in the Doppler Spectrum

- Poles determine the limiting frequencies of the spectrum
- Theorem: *In V2V channels the Doppler spectrum caused by single-bounce scattering can possess* ***up to six distinct real poles****.*
- Polynomial of degree 6 to resolve for the spectrum poles





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