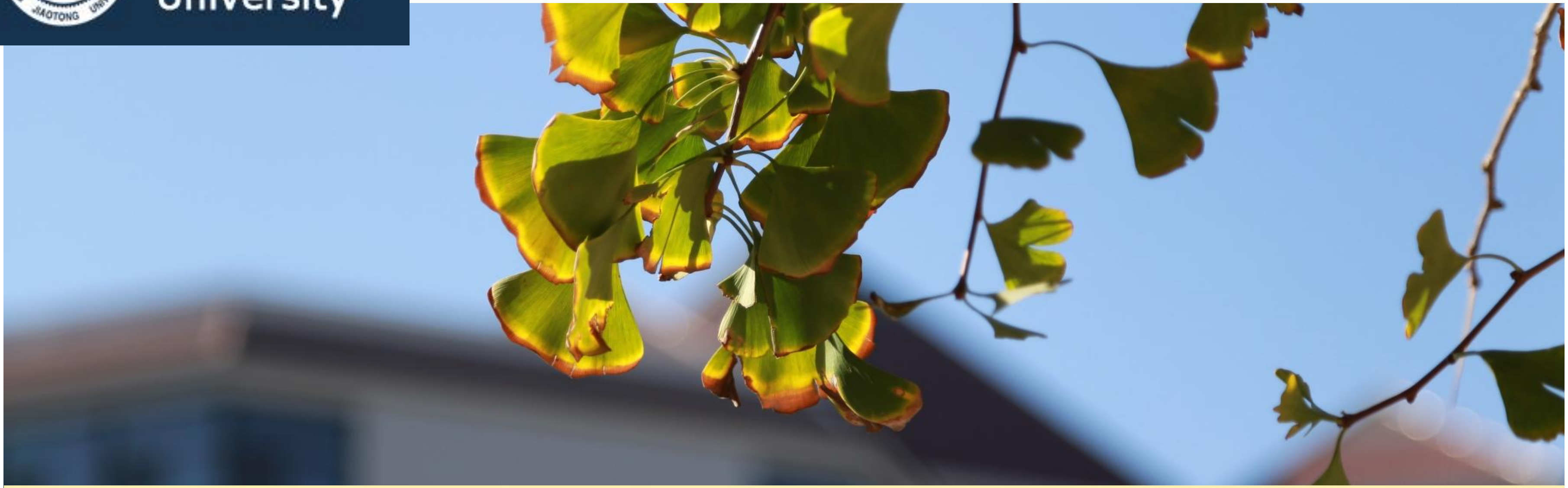
Beijing Jiaotong University

Wireless & Mobile Communication for Rail Transportation (WiMiRT)



# Obstructed Vehicle-to-Vehicle Channel Modeling for Intelligent Vehicular Communications

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# Outline

1. Motivation
2. Integrating V2V small-scale structures into ray-tracing simulator
3. Realistic V2V ray-tracing simulator for intelligent connected vehicles
4. Ray-tracing simulations on obstructed V2V channels
5. Channel characterization
6. Verification with QuaDRiGa
7. Conclusion

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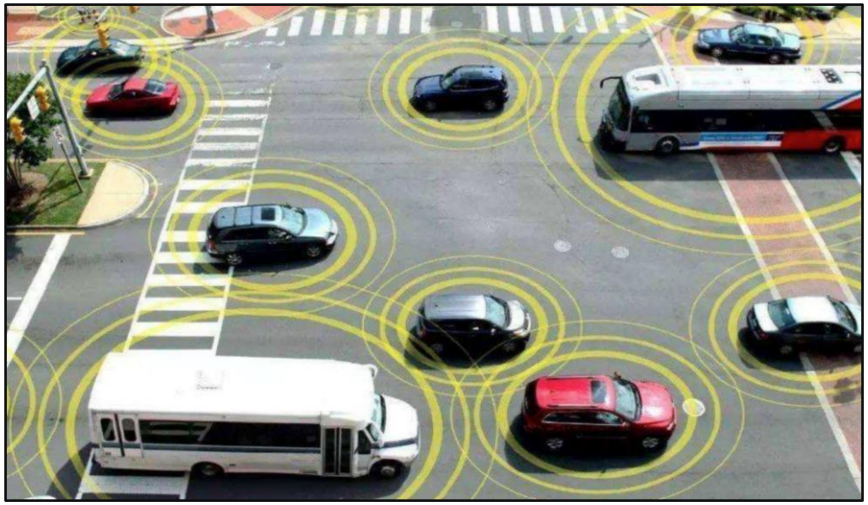
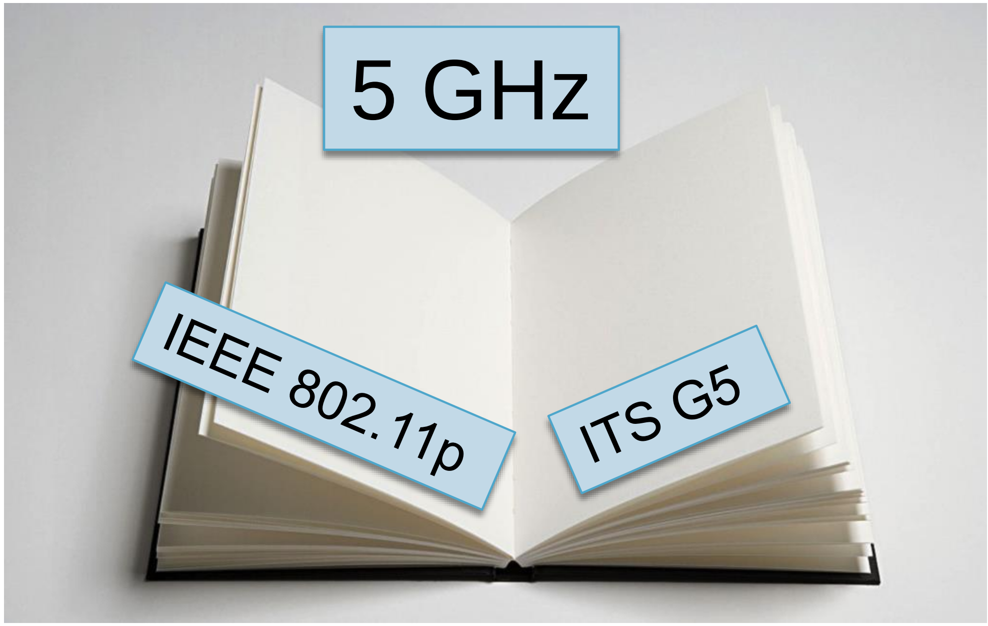
# Motivation

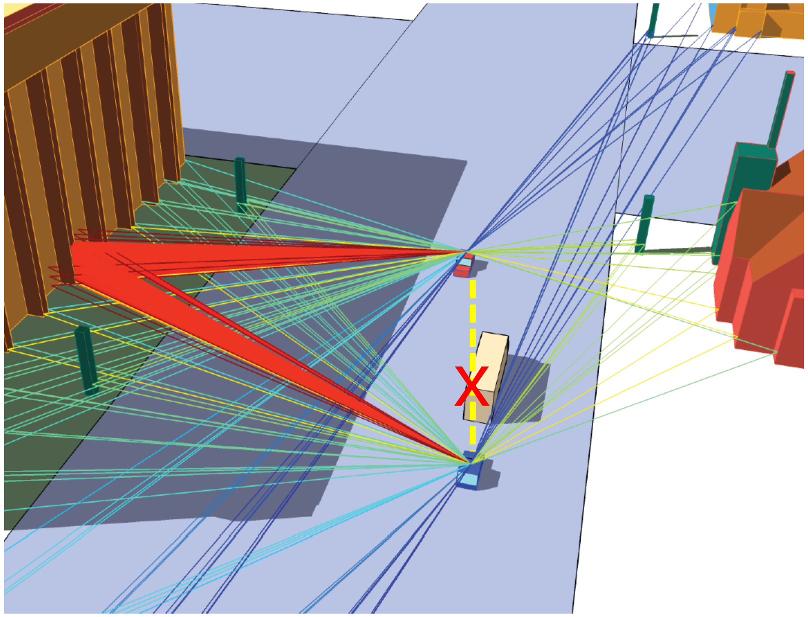


- The vision of **intelligent connected vehicles** requires a **seamless low-latency** and **ultra-reliable** vehicle-to-vehicle (V2V) communication network.
- Hence, V2V communications have drawn considerable attention and made remarkable progress in recent years.

# Motivation

For the frequency band, 5 GHz is of importance because two V2V communications standards – IEEE 802.11p and ITS G5 – have been proposed for this band.

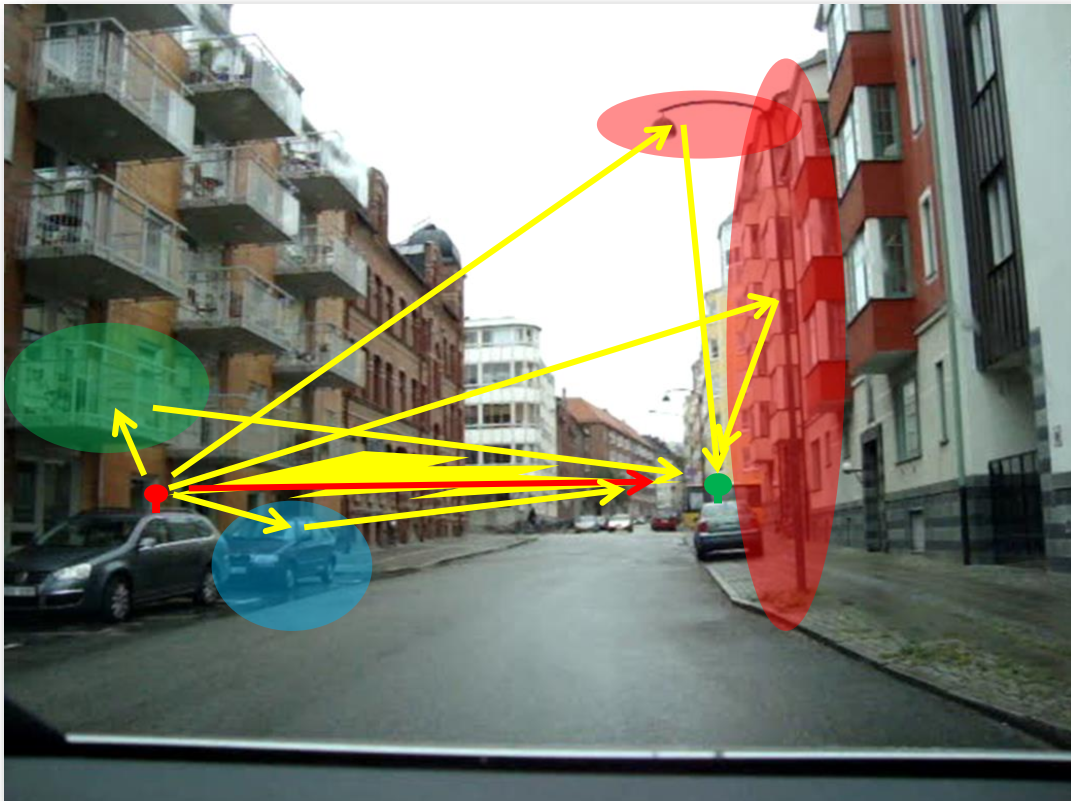



In order to address the challenges in intelligent vehicular communications, it is of importance to investigate the V2V channel characteristics in the 5 GHz band especially in the most challenging conditions, such as when shadowing induced by vehicles obstructs the line-of-sight (LOS) between transmitter (Tx) and receiver (Rx) of two communicating vehicles.

# Motivation

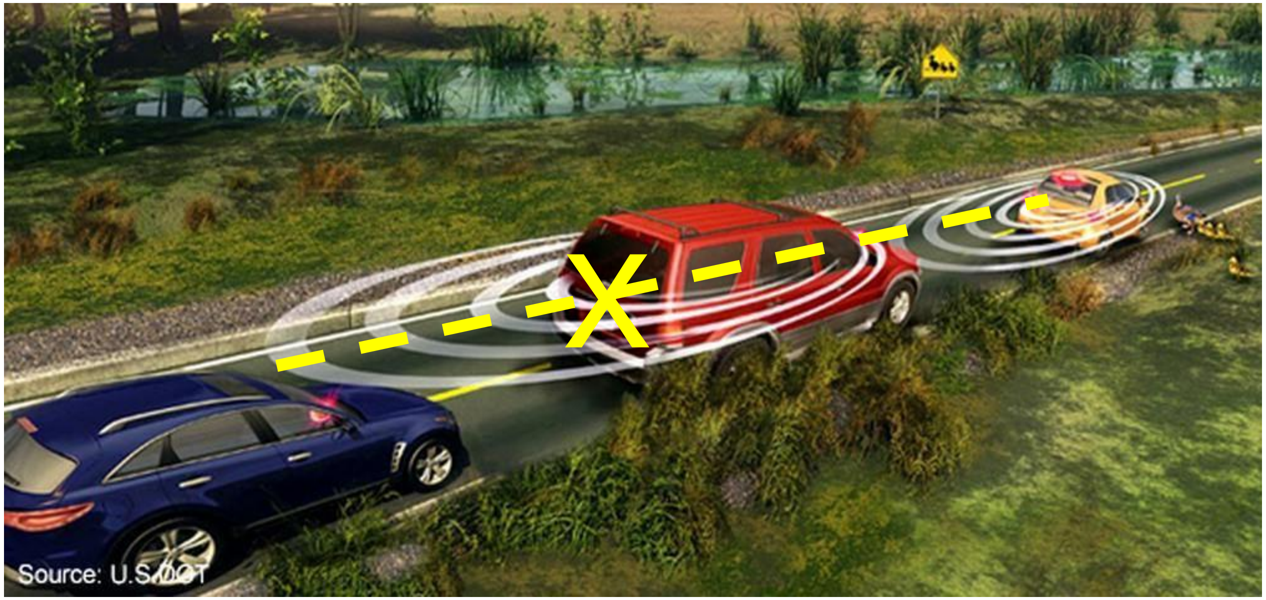
To model V2V channels realistically, the influence of the main objects in the environment must be considered.



- The small-scale structures such as traffic signs and lamppost are the most important scatterers in a traffic congestion situation.
- Thus, ray-tracing tools have to take into account multi-paths from both large-scale and small-scale structures.

# Motivation

Another particular significant topic is how to incorporate the dynamic shadowing effect of the vehicular obstruction.




Only when incorporating the obstructing vehicle effects via V2V channel measurements, extensive RT simulations for such obstructed V2V channels can be used to evaluate candidate intelligent vehicular communication schemes in challenging conditions.

# Motivation

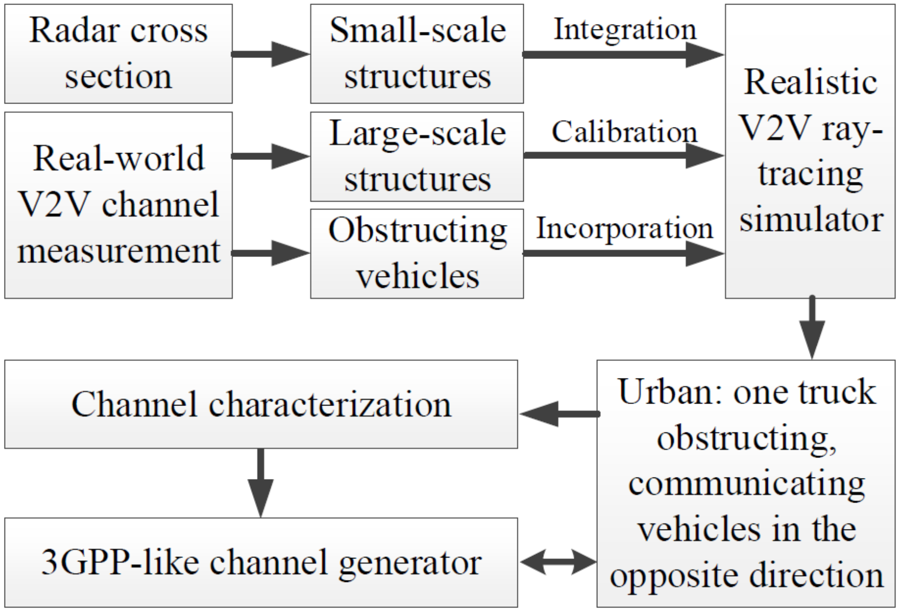
- In this paper, we stochastically model the obstructed V2V channels in the 5-GHz band through measurement-validated RT simulations in terms of:
  - Path loss (PL)
  - Shadow fading (SF)
  - Delay dispersion

- For the latter, we provide root-mean-square (RMS) delay spread (DS) results.

- We also provide small-scale fading Rician K-factor (KF), spatial information in terms of:
  - Azimuth angular spread of arrival/departure (ASA/ASD)
  - Elevation angular spread of arrival/departure (ESA/ESD)
  - Cross-polarization ratio (XPR)
  - The cross-correlations among several parameters

# Motivation

Workflow of obstructed V2V channel modeling for intelligent vehicular communications




1. The radar cross sections of the small-scale structures are integrated into RT tools through a general framework.
2. We calibrate the EM and scattering parameters of the large-scale structures through measurements.
3. The shadowing effects of the obstructing vehicles are incorporated in the RT tool.
4. After this integration and calibration, extensive RT simulations are conducted.
5. Based on the RT results, the target channel is characterized and input into and verified by the 3GPP-like quasi deterministic radio channel generator (QuaDRiGa).

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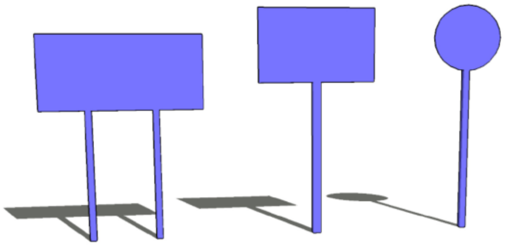
# Integrating V2V small-scale structures into RT simulator

- The most relevant propagation mechanism of the small-scale structures in V2V environments is not reflection, but scattering.
- In RT tools, the electric field intensity of the ray scattered from the small-scale structure can be expressed as:

$$|\mathbf{E}_s| = \frac{\lambda}{\sqrt{4\pi}} \sqrt{G_{Tx} G_{Rx}} \cdot \frac{1}{4\pi r_1 r_2} \cdot \sqrt{\sigma_{SCS}} \cdot |\mathbf{E}_0|$$

The radar cross section of the small-scale structure, which is a measure of how much electromagnetic energy is scattered from an object.

- The small-scale structures can be integrated into V2V RT simulators through modeling their radar cross section with a framework detailed in our recent publication [A].
- Through this framework, we integrate three types of typical traffic signs into an in-house developed RT simulator.



[A] K. Guan, B. Ai, M. L. Nicol´as, R. Geise, A. Moller, Z. Zhong, and T. K¨urner, "On the influence of scattering from traffic signs in vehicle-to-x communications," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 8, pp. 5835–5849, Aug. 2016.

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# High-Performance Ray-Tracing Platform -- CloudRT

## Ray-tracing methodology

3D environment modeling and antenna modeling

Parameter configuration for frequency, propagation mechanisms, snapshot, etc.

Ray optical method

$$h(\tau,t)=\sum_{k=1}^{N(t)} a_k(t)\cdot e^{j(2\pi f\tau_k(t)+\varphi_k(t))}\cdot\delta(\tau-\tau_k(t))$$

**Accurate method:**

- Image theory

**Accelerating techniques:**

- Space division
- Back face cut (BFC)
- Multi-core computing
- High-performance platform

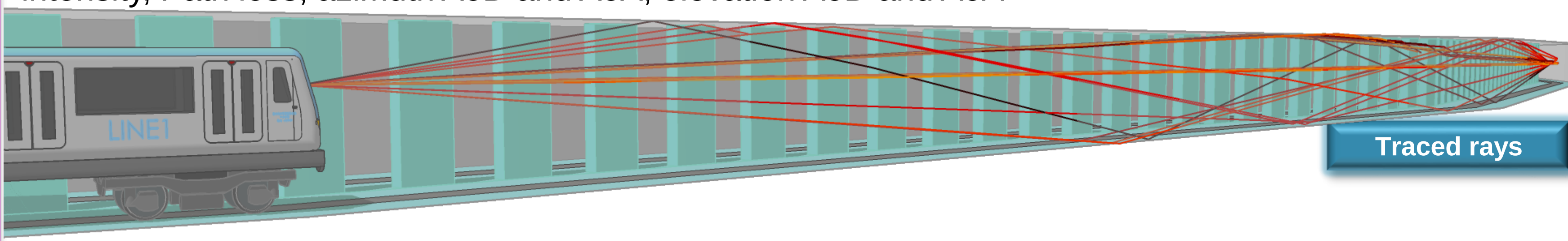
J. Nuckelt, et al., "Deterministic and stochastic channel models implemented in a physical layer simulator for Car-to-X communications," 2010 Advances in Radio Science, 2010.

# High-Performance Ray-Tracing Platform -- CloudRT

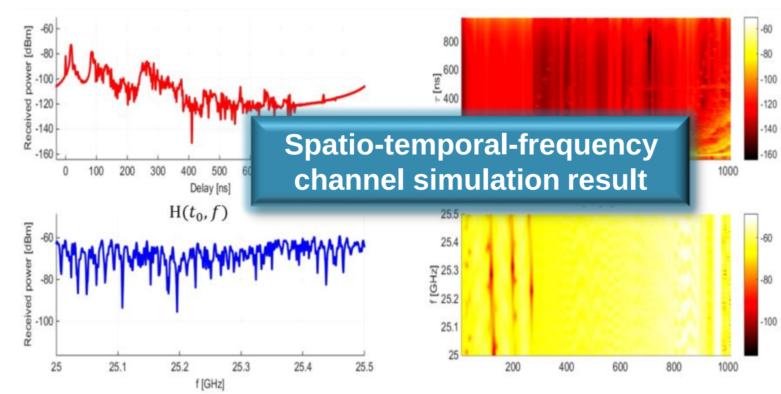
## Output of ray-tracing simulation platform

### Parameters are record for each ray, including:

Types (Directed, reflected, scattered, diffracted), Reflection order, Time of arrival, Distance, Field intensity, Path loss, azimuth AoD and AoA, elevation AoD and AoA




| Many channel characteristics can be calculated | |
|---|---|
| Loss and fading | Received power |
| | Rician K-factor |
| Power delay profile | RMS delay spread |
| Angular power spectrum | RMS angular spread |
| Doppler spectrum | RMS Doppler spread / mean Doppler shift |
| Time-varying property | Coherence time |
| Polarization | Cross-correlation coefficient |
| | Cross polarization discrimination (XPD) |
| | Co-polarization power ratio (CPR) |



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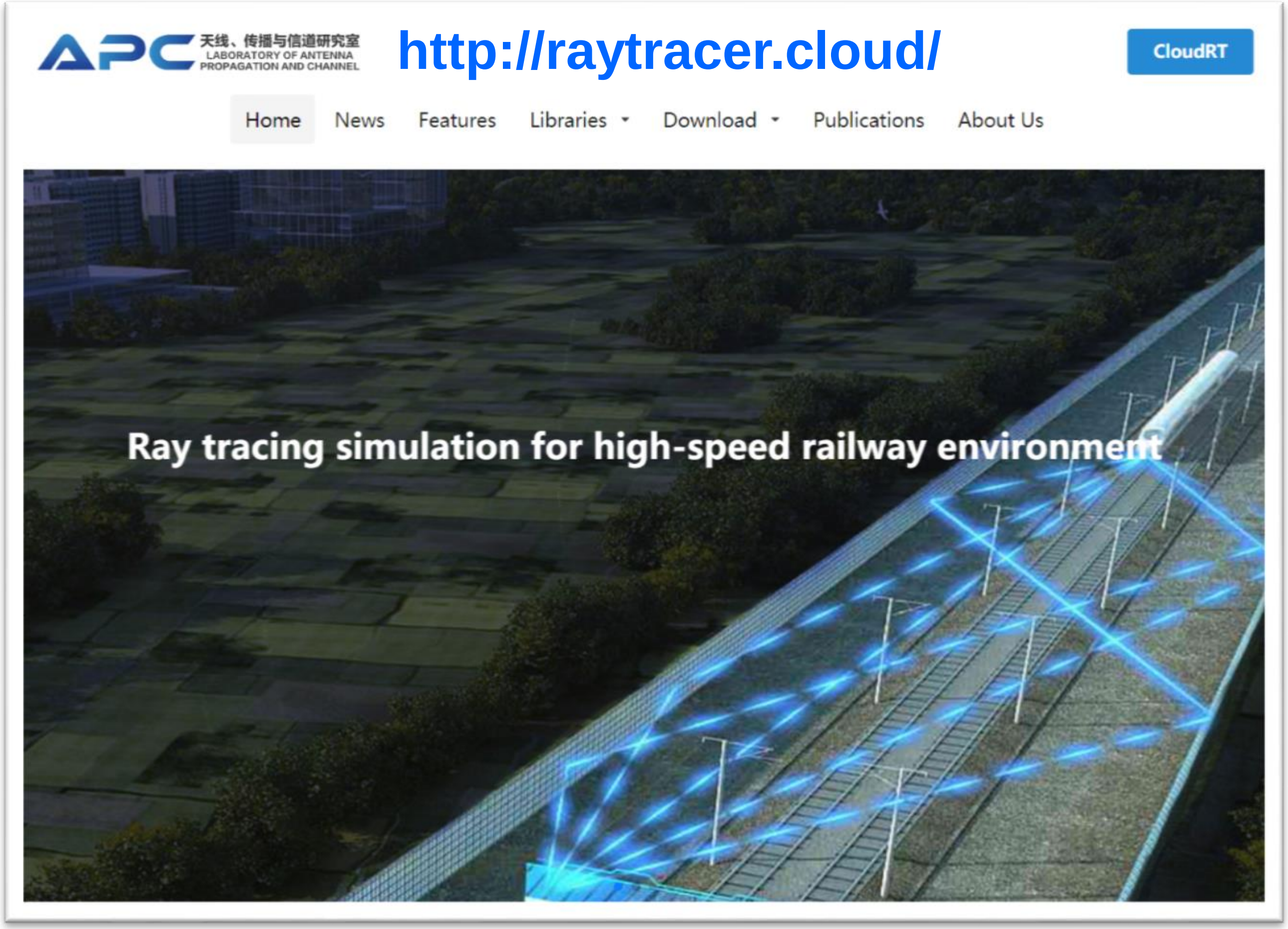
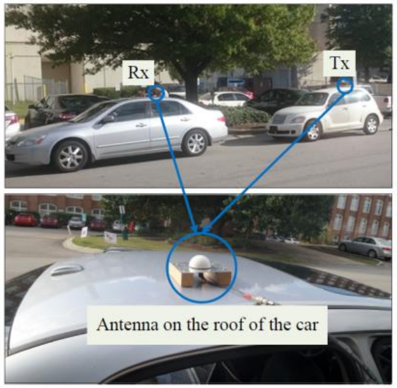


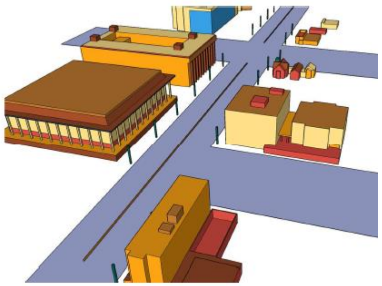

Danping He, Bo Ai, **<u>Ke Guan (corresponding author)</u>**, et al. "The Design and Applications of High-Performance Ray-Tracing Simulation Platform for 5G and Beyond Wireless Communications: A Tutorial," to appear, ***IEEE Communications Survey and Tutorial***, 2018.

## Realistic V2V RT simulator for intelligent connected vehicles

### RT calibration on large-scale structures







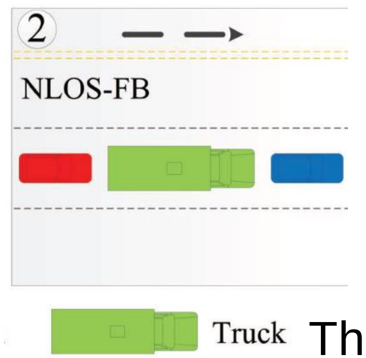
| | $\mu_{PL}$ [dB] | $\sigma_{PL}$ [dB] | $\mu_{DS}$ [ns] | $\sigma_{DS}$ [ns] |
|---|---|---|---|---|
| Measurement | 66.37 | 4.43 | 59.08 | 19.90 |
| Calibrated RT | 67.60 | 3.15 | 59.10 | 19.85 |

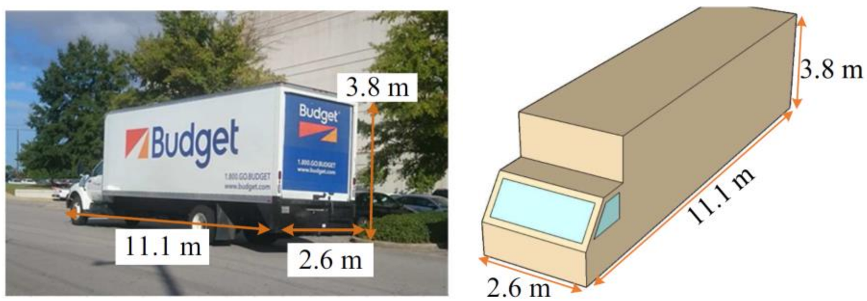
- The differences of the mean path loss are less than 1 dB
- The mean delay spread differences are less than 1 ns
- It indicates that the environment and the EM parameters of materials are correct.

| **Object Name** | $\varepsilon_r'$ | $\tan\delta$ | $S$ | $\alpha_R$ |
|---|---|---|---|---|
| Building (concrete A) | 3.50 | 0.02 | 1.00 | 5 |
| Building (glass) | 4.00 | 0.02 | 0.01 | 20 |
| Ground (concrete B) | 3.50 | 0.02 | 0.10 | 20 |
| Vehicle (metal) | 1.02 | 0.48 | 0.02 | 57 |

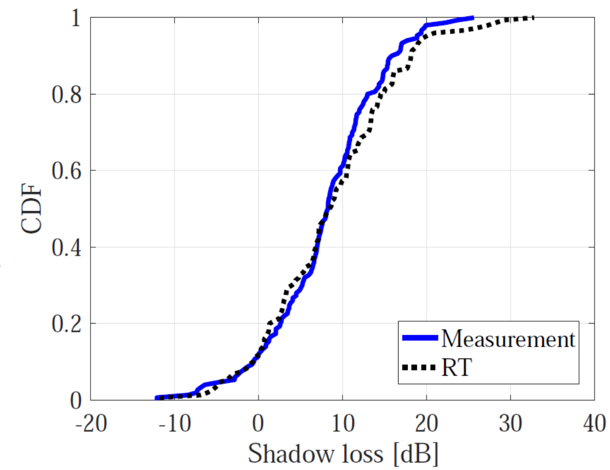
# Realistic V2V RT simulator for intelligent connected vehicles

## Incorporation of obstructing vehicle




The truck and its corresponding 3D model




Comparison of the shadowing of the truck

- The mean value of the shadowing attenuation for measurement and RT is 8.22 dB and 8.28 dB, respectively.
- The values of standard deviation are 6.96 dB and 7.15 dB, respectively.
- Thus, the RT agrees very well with the measurement without conducting any dedicated calibration of the car material.

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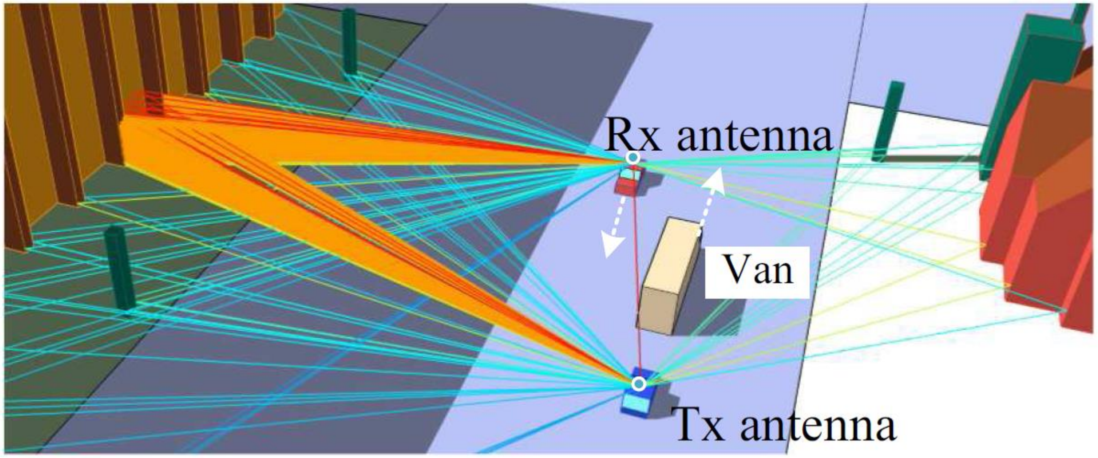
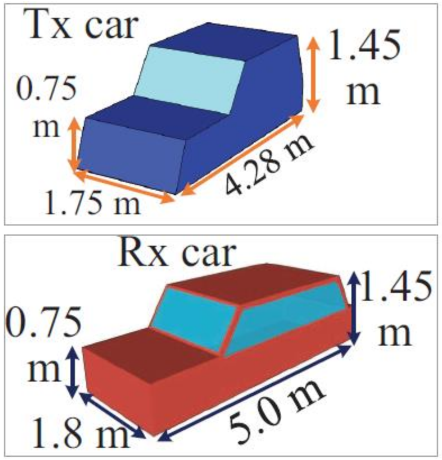
# Ray-tracing simulations on obstructed V2V channels




- The Tx and Rx in RT simulations are deployed on the roofs of oncoming cars driving in opposite directions in the urban environment.
- The starting distance between the Tx and Rx is 300 m.
- A truck is in front of the Tx car, and the distance between them is kept at 5 m. The vehicles move at the same speed, the moving step of each snapshot is 1 m.
- We perform 100 different simulations, in each of which, 5-10 traffic signs are randomly generated along the road sides.
- After the RT simulations, the statistical results of key channel parameters are obtained.

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# Channel characterization

## Channel parameters

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $A$ | 21.85 | $\mu_{ASD}$ $[\log_{10}([°])]$ | 0.92 |
| $B$ | 41.60 | $\sigma_{ASD}$ $[\log_{10}([°])]$ | 0.29 |
| $\sigma_{SF}$ [dB] | 6.70 | $\lambda_{ASD}$ [m] | 21.69 |
| $\lambda_{SF}$ [m] | 14.40 | $\mu_{ESD}$ $[\log_{10}([°])]$ | -0.11 |
| $\mu_{DS}$ $[\log_{10}([s])]$ | -7.30 | $\sigma_{ESD}$ $[\log_{10}([°])]$ | 0.55 |
| $\sigma_{DS}$ $[\log_{10}([s])]$ | 0.27 | $\lambda_{ESD}$ [m] | 26.15 |
| $\lambda_{DS}$ [m] | 14.40 | $\mu_{ASA}$ $[\log_{10}([°])]$ | 0.90 |
| $\mu_{KF}$ [dB] | -10.71 | $\sigma_{ASA}$ $[\log_{10}([°])]$ | 0.33 |
| $\sigma_{KF}$ [dB] | 9.19 | $\lambda_{ASA}$ [m] | 23.10 |
| $\lambda_{KF}$ [m] | 4.34 | $\mu_{ESA}$ $[\log_{10}([°])]$ | -0.03 |
| $r_{DS}$ | 2.33 | $\sigma_{ESA}$ $[\log_{10}([°])]$ | 0.45 |
| $\mu_{XPR}$ [dB] | 1.35 | $\lambda_{ESA}$ [m] | 35.20 |
| $\sigma_{XPR}$ [dB] | 5.45 | | |
| Per-cluster parameter | | | |
| Cluster number | 5 | SF [dB] | 6.91 |
| ASD [°] | 4.04 | ASA [°] | 3.66 |
| ESD [°] | 0.32 | ESA [°] | 0.34 |

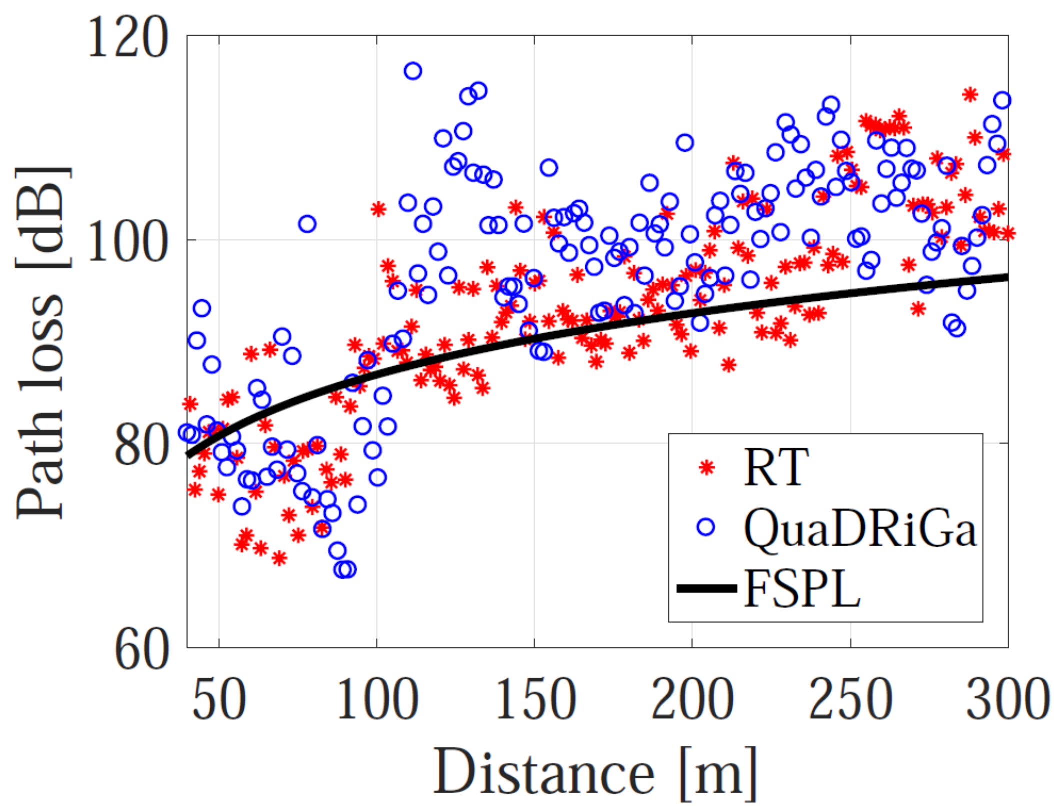
## Cross-correlation between key parameters

| | DS | KF | SF | ASD | ASA | ESD | ESA |
|---|---|---|---|---|---|---|---|
| DS | 1 | -0.57 | 0.35 | 0.63 | 0.66 | 0.65 | 0.67 |
| KF | | 1 | -0.54 | -0.62 | -0.69 | -0.90 | -0.89 |
| SF | | | 1 | 0.48 | 0.51 | 0.53 | 0.53 |
| ASD | | | | 1 | 0.99 | 0.65 | 0.65 |
| ASA | | | | | 1 | 0.72 | 0.73 |
| ESD | | | | | | 1 | 0.99 |
| ESA | | | | | | | 1 |

- The power relation of the MPCs changes faster than does the SF, DS and KF.
- The KF is negatively correlated with the other parameters.
- The correlation distances of the angular spreads are larger than those of the other parameters.
- The ASA and ASD, as well as the ESD and ESA are highly correlated.
- The XPR results indicate that substantial de-polarization takes place in this channel, and therefore, dual-polarized antenna configurations are recommended.

# Outline

# Verification with QuaDRiGa




Comparison of path loss and shadow fading between QuaDRiGa and RT

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# Conclusion

- Based on an in-house-developed realistic V2V RT simulator, obstructed V2V channels in the 5-GHz band were characterized and modeled.

- All the parameters are input into and verified to generally agree with those of the 3GPP-like channel generator (QuaDRiGa).

- Good agreement indicates that the two parameter tables presented in this paper and the obstructed V2V modeling can be incorporated into standard channel model families.

- The result of this study provides a baseline for system design and evaluation of intelligent vehicular communications in these challenging conditions.

# Thank you
# for your attention.

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