# Intermediate Frequency Level GPS Multipath/NLOS Simulator based on Vector Tracking and Ray Tracing

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# Motivation

- What we have done in **2019** regarding Multipath/non-line-of-sight (NLOS) research

**GNSS Multipath/NLOS Evaluation Platform**

Xu B, Hsu L-T (2019) **Open-source MATLAB code for GPS vector tracking on a software defined receiver**. *GPS Solut. 23:46*

GNSS Multipath/NLOS **Classification**

Xu B, Jia Q, Luo Y, Hsu L-T (2019) **Intelligent GPS L1 LOS/Multipath/NLOS Classifiers Based on Correlator-, RINEX- and NMEA-Level Measurements**. *Remote Sens. 11, 1851*)

Sun R, Hsu L-T, Xue D, Zhang G (2019) **GPS Signal Reception Classification Using Adaptive Neuro-Fuzzy Inference System**. *J. Navigation 72: 685*)

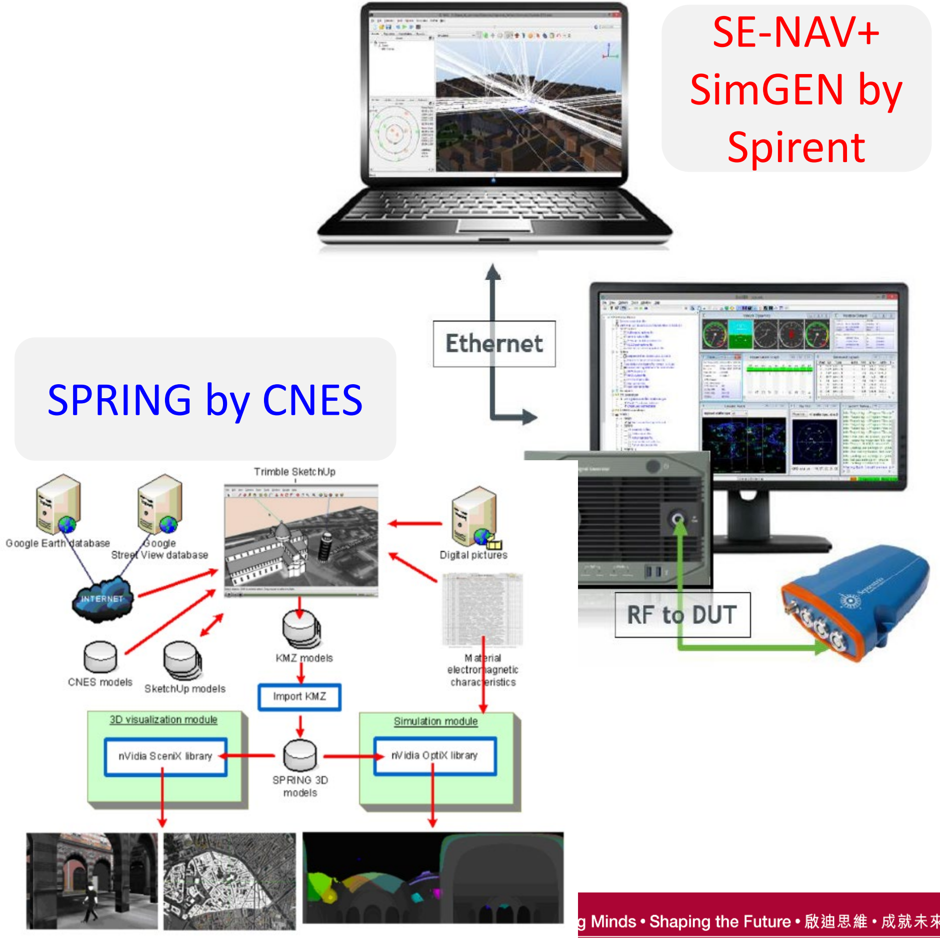
**GNSS Multipath/NLOS Correction**

Xu B, Jia Q, Hsu L-T (2019) **Vector Tracking Loop-Based GNSS NLOS Detection and Correction: Algorithm Design and Performance Analysis**. *IEEE Trans. Instrum. Meas*. DOI: 10.1109/TIM.2019.2950578)

**We need large-scale, realistic, and controllable Multipath data!**

# Motivation

- Generating signal parameters (power, delay, Doppler and ephemeris) from scratch is really a systematic and complex work!
- How to simulate multipath signal in a low-cost and flexible way?
- Is it possible to do a software-based simulator based on existing low-cost resources?



# Multipath simulator categories

I.

Tracking simulators

Geometrical simulators

Polarimetric simulators

Categories identified by Nievinski and Larson (2014), focusing on the generation of parameters of reflected signals, e.g., **reflection power**, **delay**, **phase**, **Doppler**

**Nievinski and Larson, An open source GPS multipath simulator in Matlab/Octave, *GPS Solut.* (2014) 18:473–481.**

II.

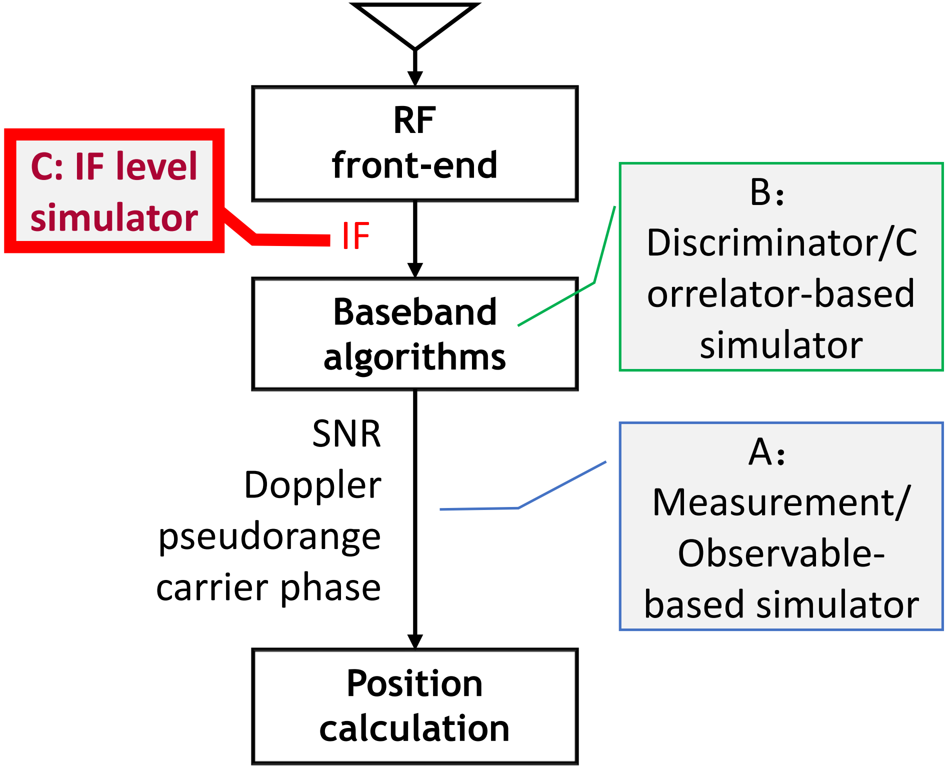
Deterministic or Statistic?

Land Mobile Multipath Channel Model

DLR Institut für Kommunikation und Navigation

Lehner A, Steingaß A, Schubert F, **A location and movement dependent GNSS multipath error model for pedestrian applications,** *ATTI Journal dell'Istituto Italiano di Navigazione* (189), pp. 108-119, ISSN 1120-6977, Italien Institute of Navigation I.I.N., Rome, Italy, 2009.

# Our category and objective




Our objective of multipath simulator:

1. Intermediate frequency level
2. Low-cost (based on existing recourses)
3. Deterministic

# Our solution

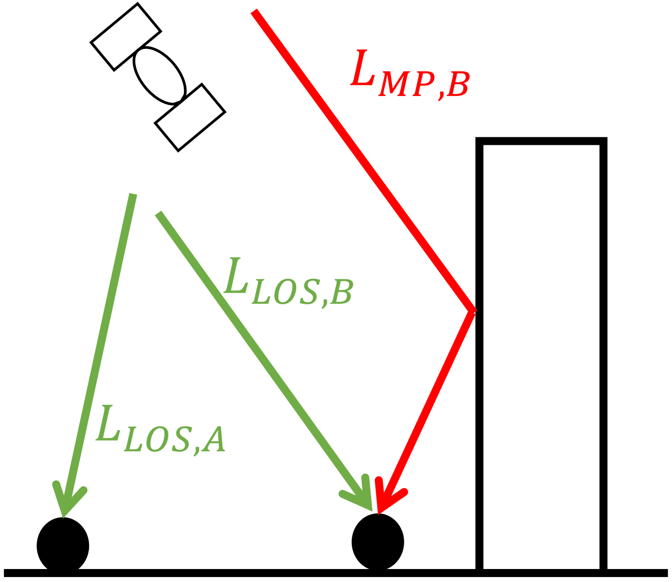

1. Collect real GNSS signal at Point A (open-sky)

2. Process IF signal using Vector Tracking-based SDR

3. Ray tracing at Point B based on ephemeris at defined epochs. Outputs include the delay, Doppler, phase, incident angle, etc.

4. Simulate IF signal at B considering the relative distance between A and B, the additional path delay of MP/NLOS, carrier phase change and power attenuation.

# Convert signal parameters from A to B – LOS




Point A
Open-sky

Point B
Urban

$$s_A(t) = s_{LOS,A}(t) = A \cdot c(t-\tau_0) \cdot \cos(2\pi(f_{IF} + f_d)\,t + \theta_0)$$

$$s_B(t) = s_{LOS,B}(t) + \sum_i s_{MP,i}(t)$$
$$= A \cdot c(t-\tau_0-\Delta\tau) \cdot \cos\big(2\pi\big(f_{IF} + f_d + \Delta f_{d,LOS}\big)t + \theta_0 + \Delta\theta\big) + \sum_i s_{MP,i}(t)$$

$$\Delta\tau = \big(L_{LOS,B} - L_{LOS,A}\big)/\lambda_{CA} + \varphi_w$$
$$\Delta\theta = \big(L_{LOS,B} - L_{LOS,A}\big)/\lambda_{L1} + \varphi_w$$
$$\Delta f_{d,LOS} = \big(\vec{v_s} \cdot \overrightarrow{h_{LOS,A}} - (\vec{v_s} - \vec{v_{r,B}}) \cdot \overrightarrow{h_{LOS,B}}\big)/\lambda_{L1}$$

**Parameter conversion**

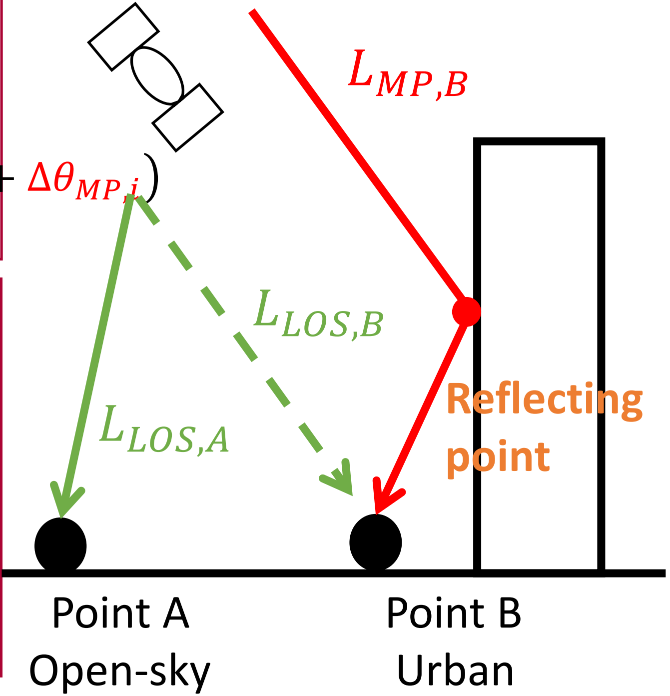
# Convert signal parameters from A to B – Reflected signal

$$s_B(t) = s_{LOS,B}(t) + \sum_i s_{MP,i}(t)$$

$$= s_{LOS,B}(t) + \sum_i \alpha_i A \cdot c(t - \tau_0 - \Delta\tau_i) \cdot \cos(2\pi(f_{IF} + f_d + \Delta f_{d,MP,i})t + \theta_0 + \Delta\theta_{MP,i})$$

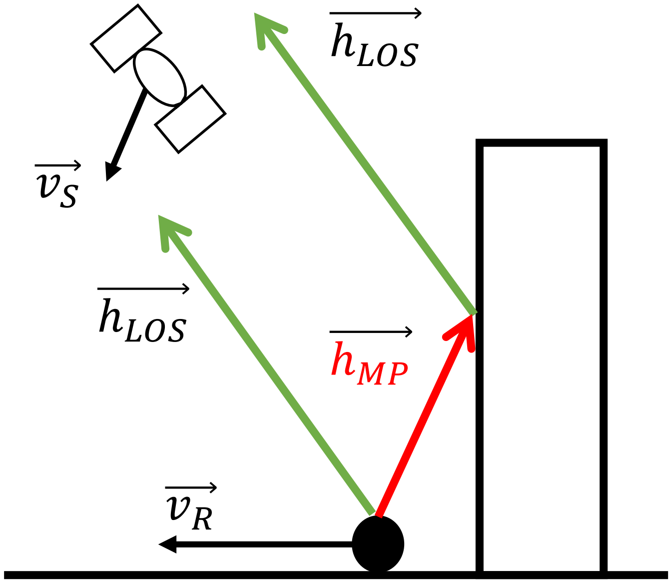
$$\Delta\tau_i = \frac{L_{MP,B} - L_{LOS,A}}{\lambda_{CA}} \qquad \Delta\theta_{MP,i} = \frac{L_{MP,B} - L_{LOS,A}}{\lambda_{L1}}$$

$\alpha = \rho F \eta_a$,
- $\rho$ – **reflection coefficient**
- $F$ – polarization efficiency
- $\eta_a$ – user antenna gain ratio between the LOS and reflected signal




Lau and Cross, Development and testing of a new ray-tracing approach to GNSS carrier-phase multipath modelling, *J Geod* (2007) 81:713–732.

# How to calculate Doppler shift on reflected signal?



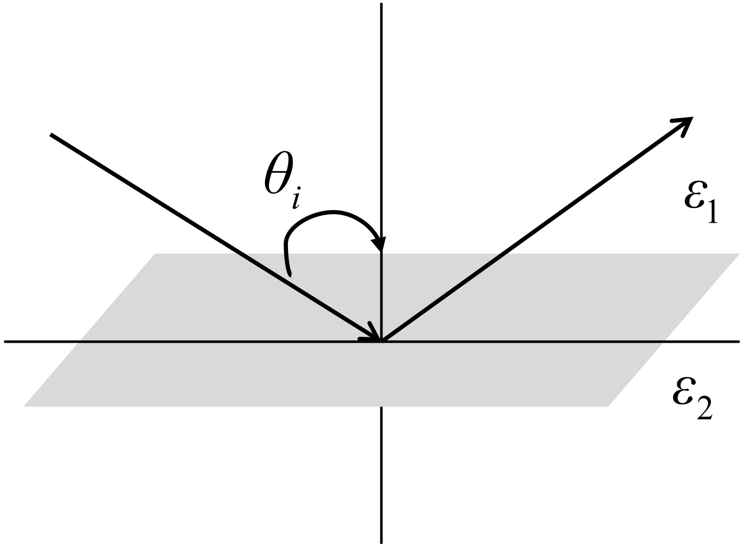

$$f_{d,LOS} = (\overrightarrow{v_S} \cdot \overrightarrow{h_{LOS}} - \overrightarrow{v_R} \cdot \overrightarrow{h_{LOS}})/\lambda$$

$$f_{d,MP} = (\overrightarrow{v_S} \cdot \overrightarrow{h_{LOS}} - \overrightarrow{v_R} \cdot \overrightarrow{h_{MP}})/\lambda$$

$$\Delta f_{d,MP,i} = f_{d,MP} - f_{d,LOS}$$
$$= (\overrightarrow{v_R} \cdot \overrightarrow{h_{LOS}} - \overrightarrow{v_R} \cdot \overrightarrow{h_{MP}})/\lambda$$
$$\in [(\overrightarrow{v_R} \cdot \overrightarrow{h_{LOS}} - |\overrightarrow{v_R}|)/\lambda \quad (\overrightarrow{v_R} \cdot \overrightarrow{h_{LOS}} + |\overrightarrow{v_R}|)/\lambda]$$

**Xie and Petovello, Measuring GNSS Multipath Distributions in Urban Canyon Environments, *IEEE Trans. Instrum. Meas.* (2015) 64:366–377.**

# Reflection coefficient calculation




Fresnel Reflection model

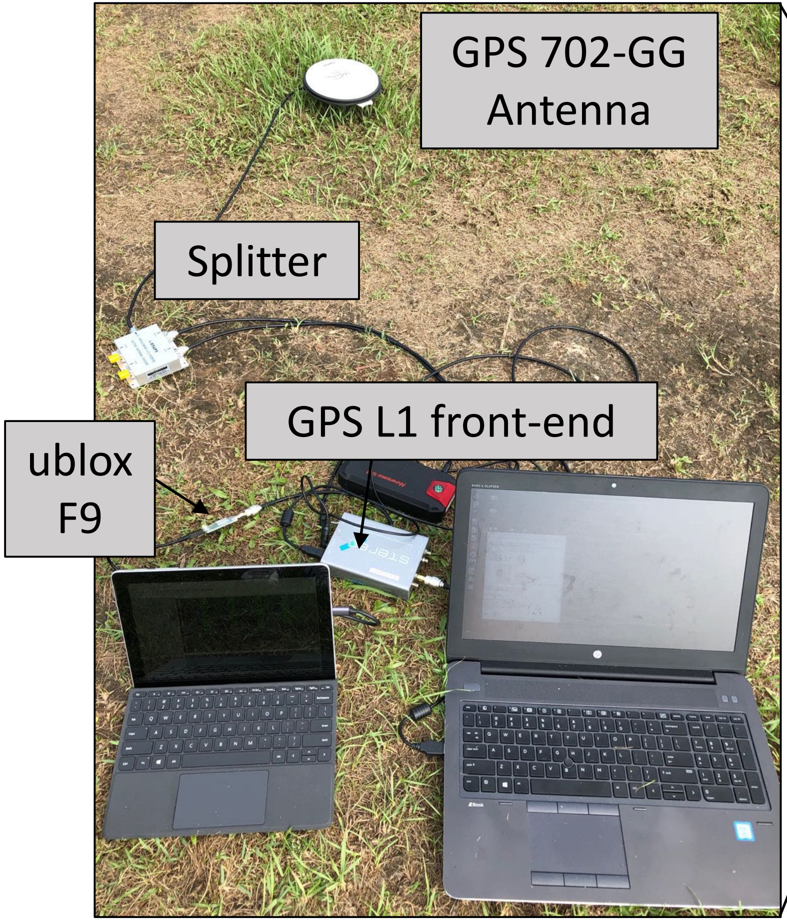
$$\rho_{\perp} = \frac{\varepsilon_2/\varepsilon_1 \cdot \cos\theta_i - \sqrt{\varepsilon_2/\varepsilon_1 - \sin^2\theta_i}}{\varepsilon_2/\varepsilon_1 \cdot \cos\theta_i + \sqrt{\varepsilon_2/\varepsilon_1 - \sin^2\theta_i}}$$

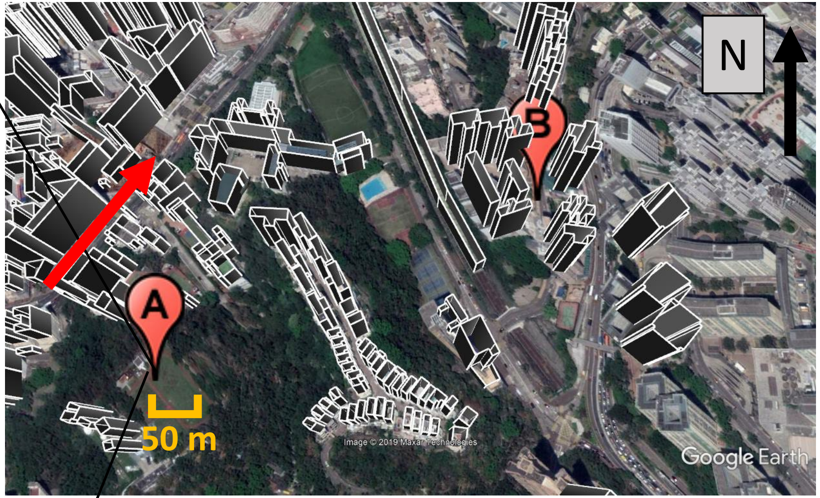
$$\rho_{\parallel} = \frac{\cos\theta_i - \sqrt{\varepsilon_2/\varepsilon_1 - \sin^2\theta_i}}{\cos\theta_i + \sqrt{\varepsilon_2/\varepsilon_1 - \sin^2\theta_i}}$$

$$\rho = \frac{1}{2}\left(\rho_{\perp} - \rho_{\parallel}\right)$$

**Suzuki, T. and Kubo, N., GNSS Positioning with Multipath Simulation using 3D Surface Model in Urban Canyon, ION GNSS 2012, Nashville, TN**

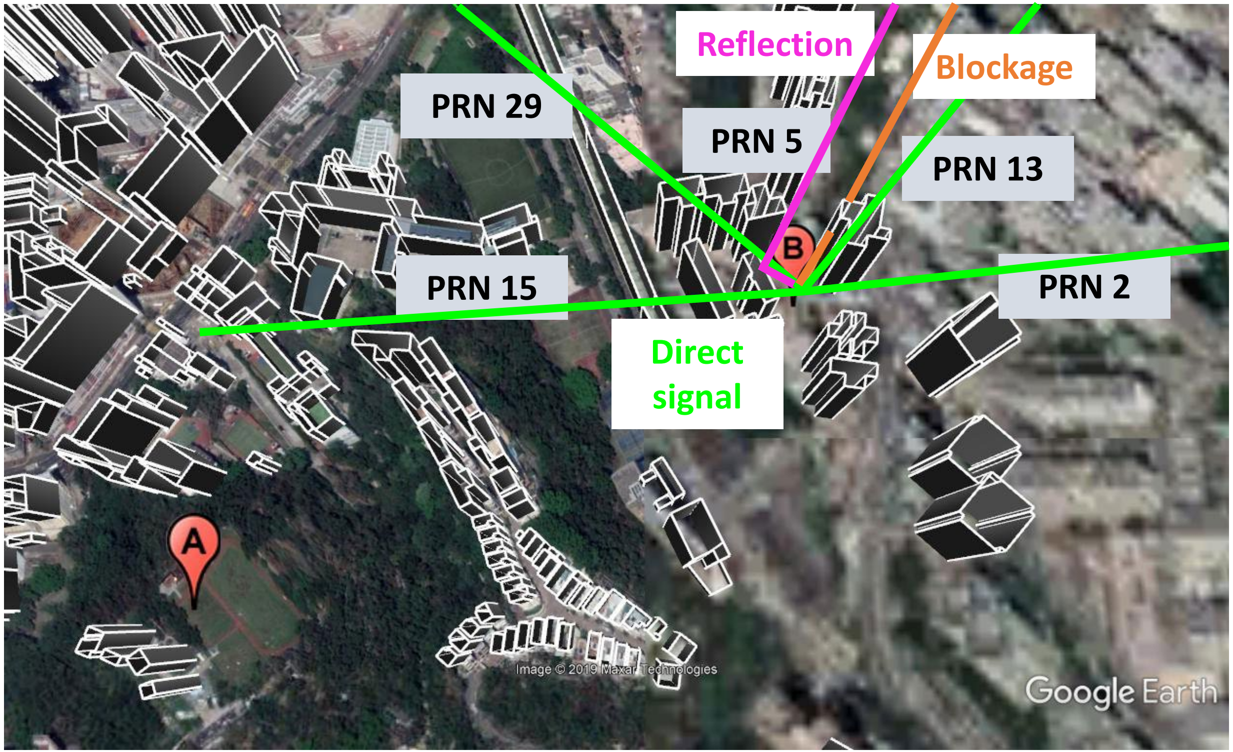
# Data Collection



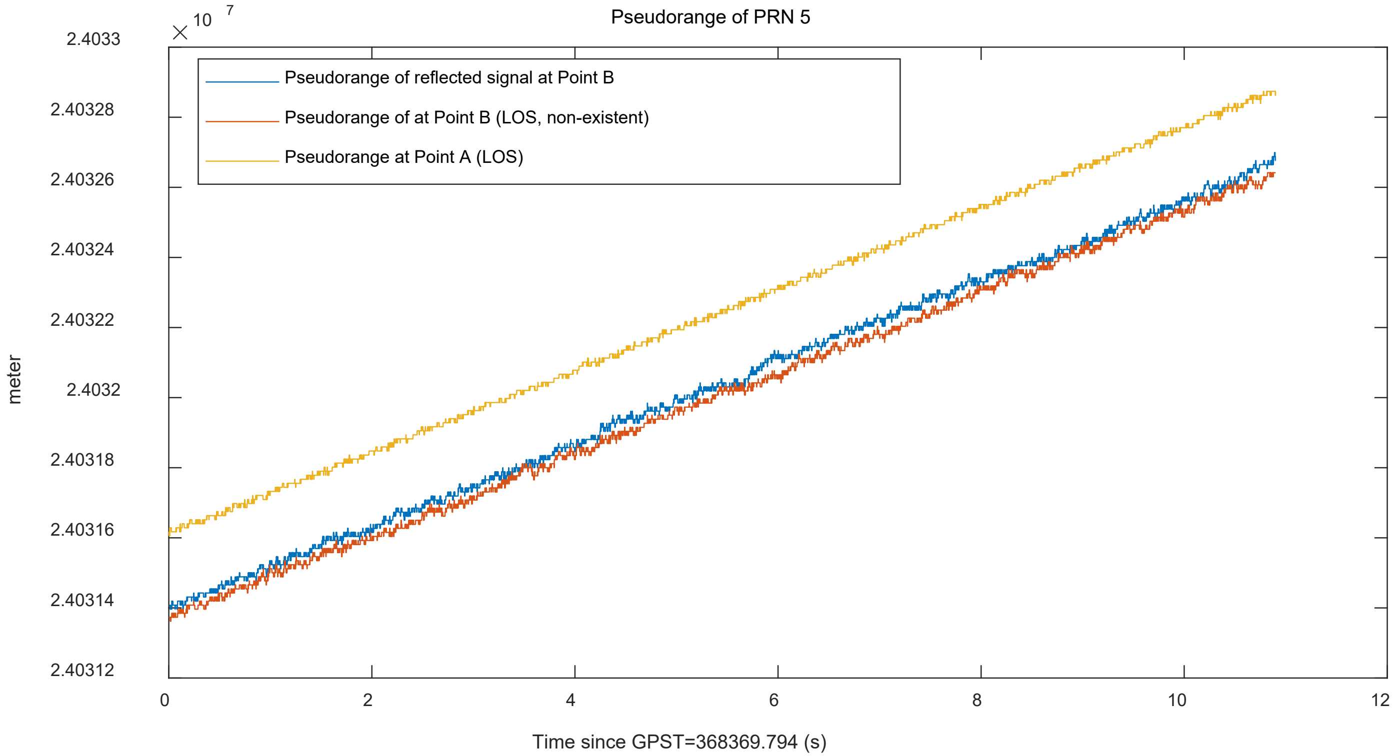




i. Collect real IF data in open-sky area
ii. Static
iii. Dynamic

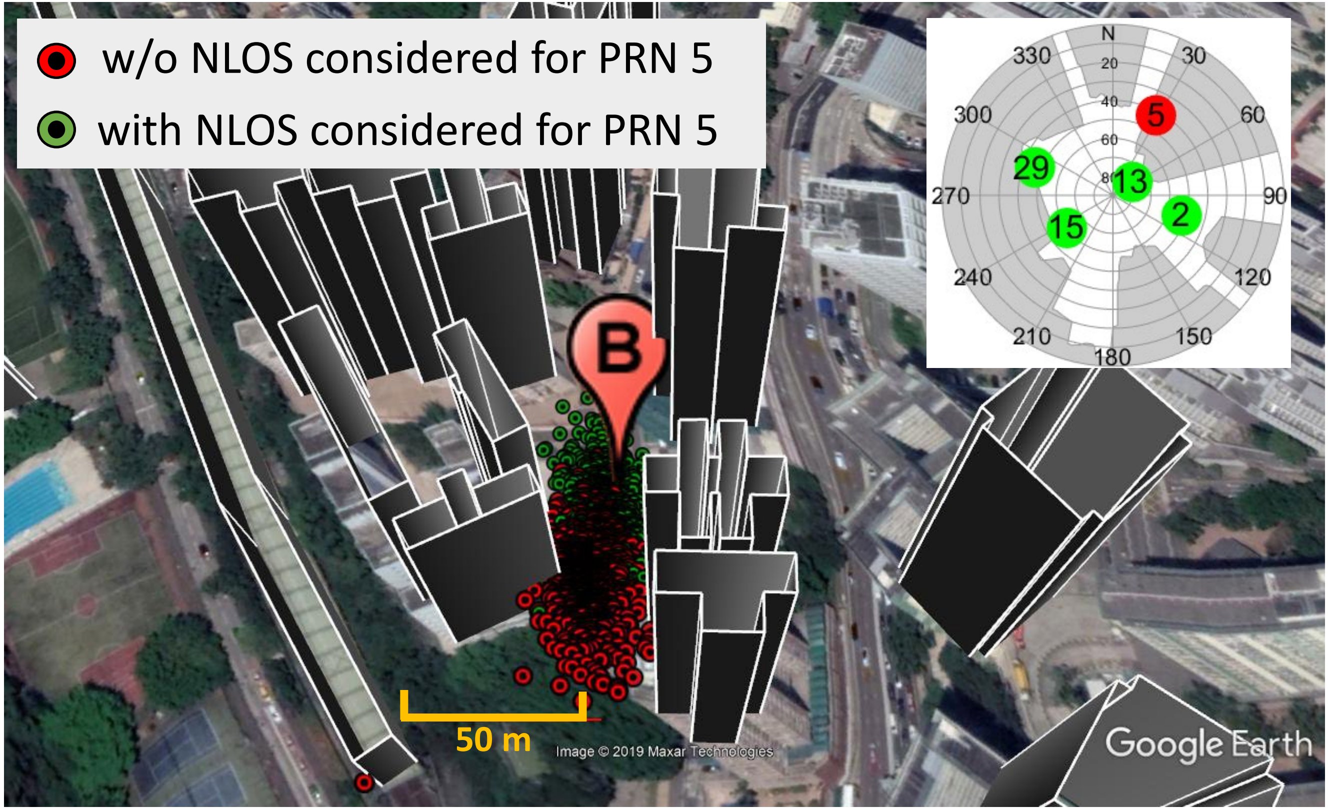
# Urban Data Simulation – Static



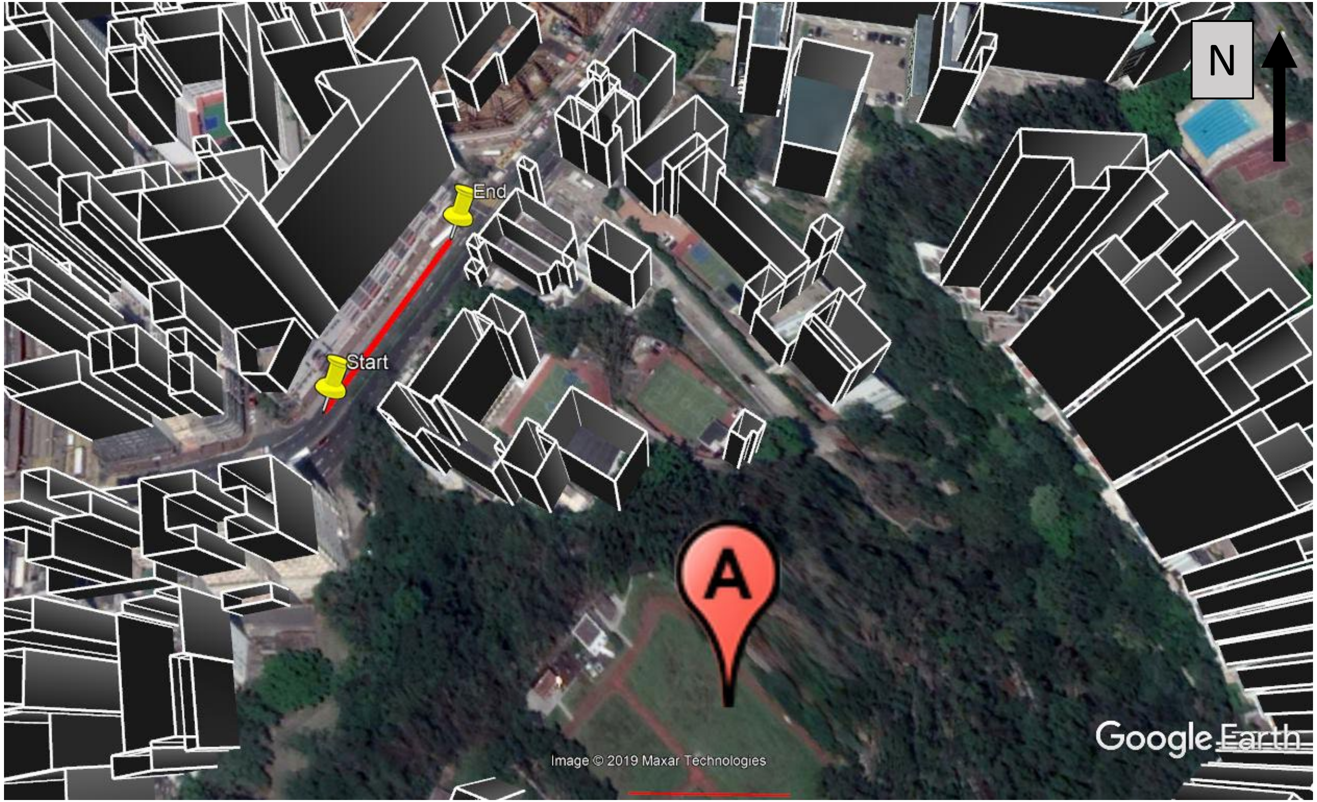
# Urban Data Simulation – Static



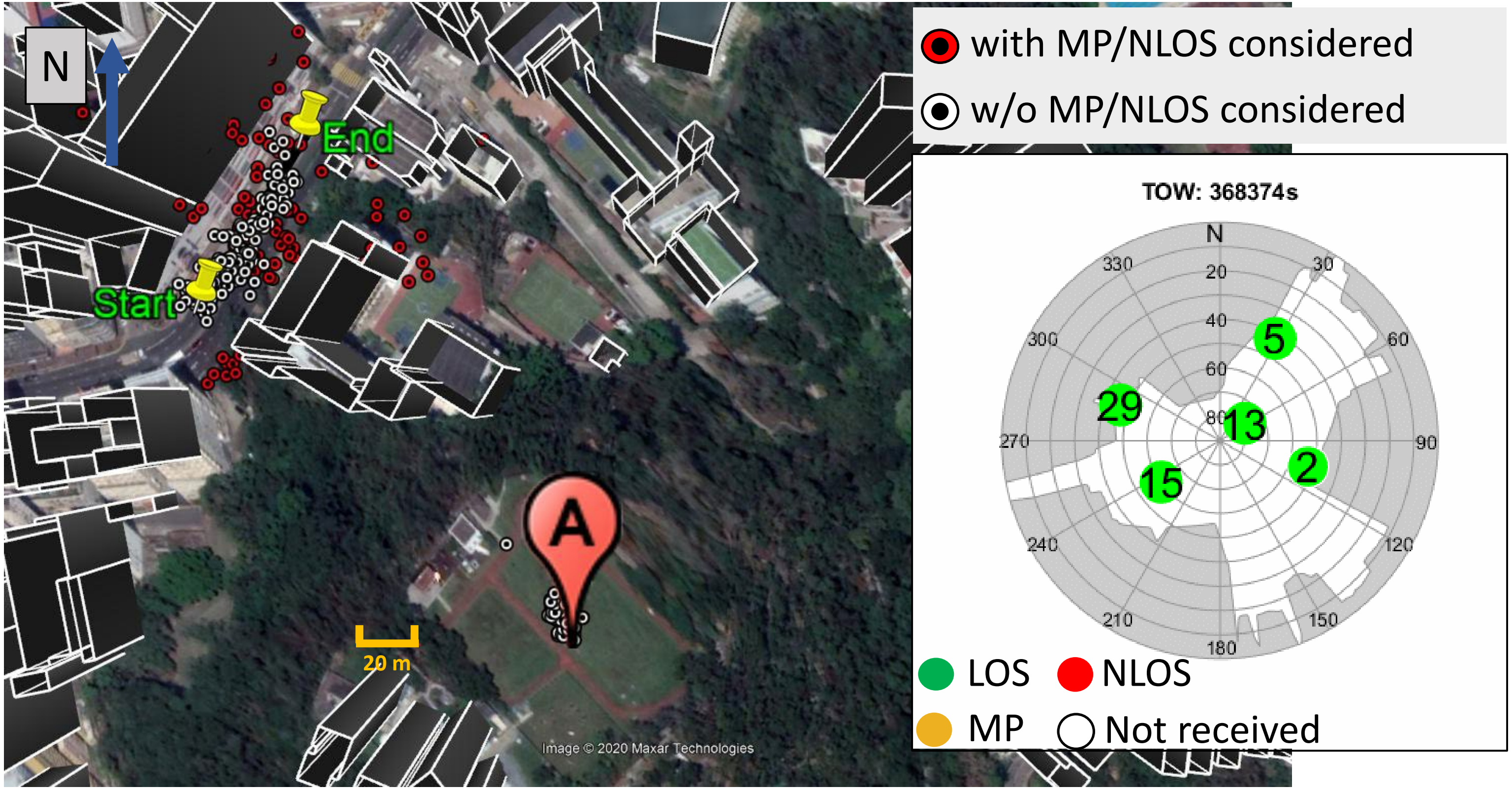
# Urban Data Simulation – Static



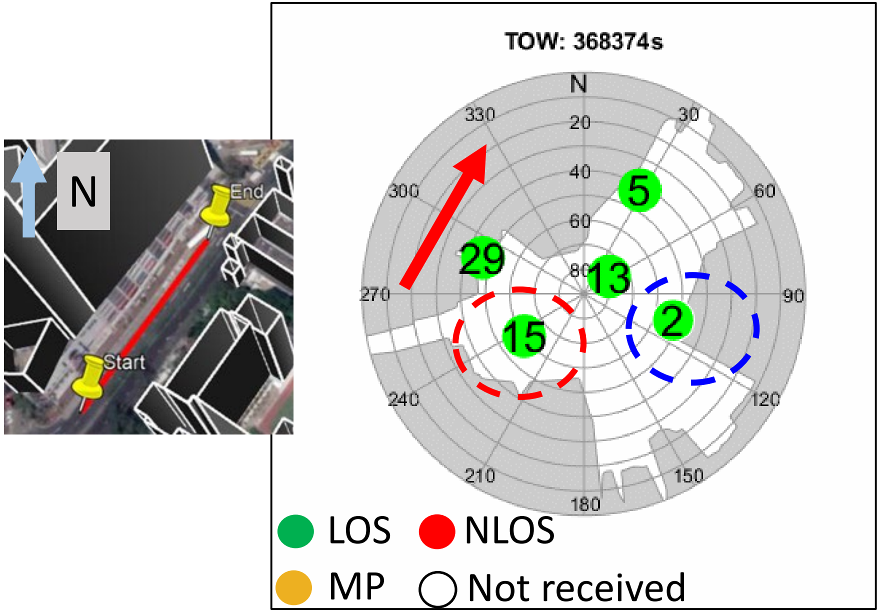
# Urban Data Simulation – Dynamic

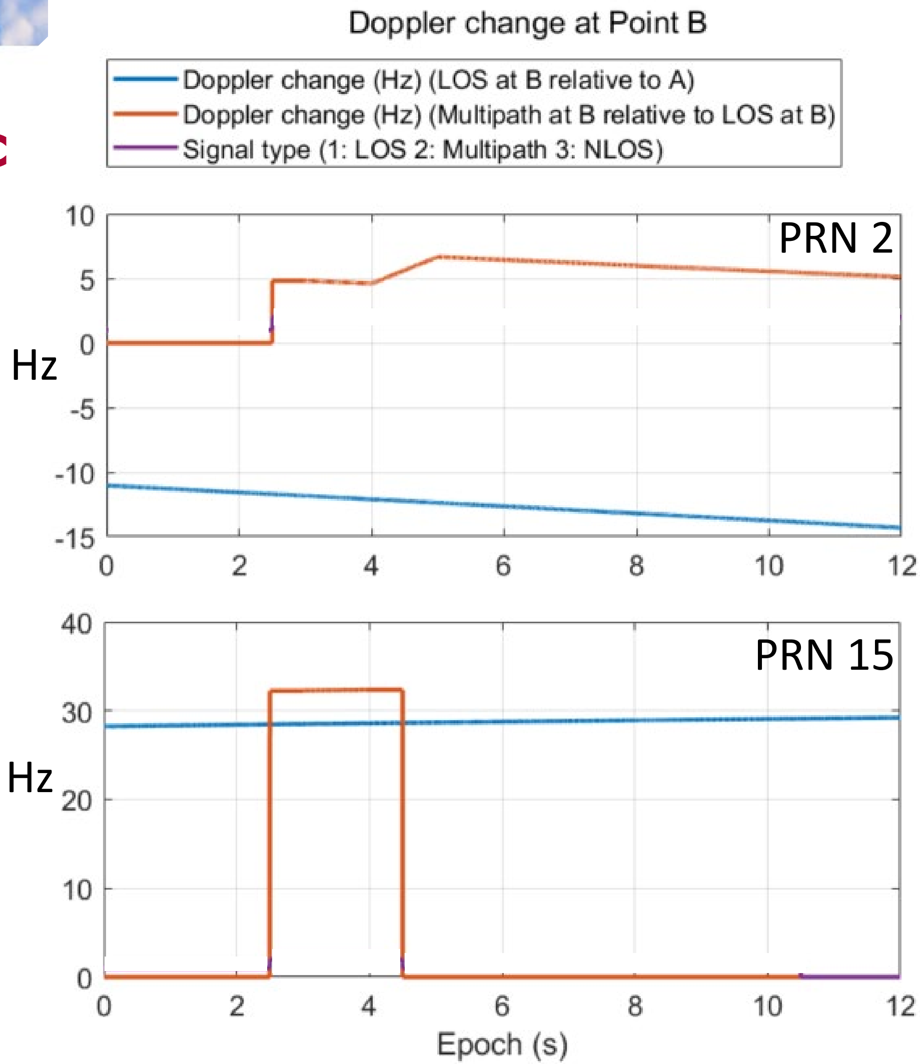


# Urban Data Simulation – Dynamic



# Urban Data Simulation – Dynamic

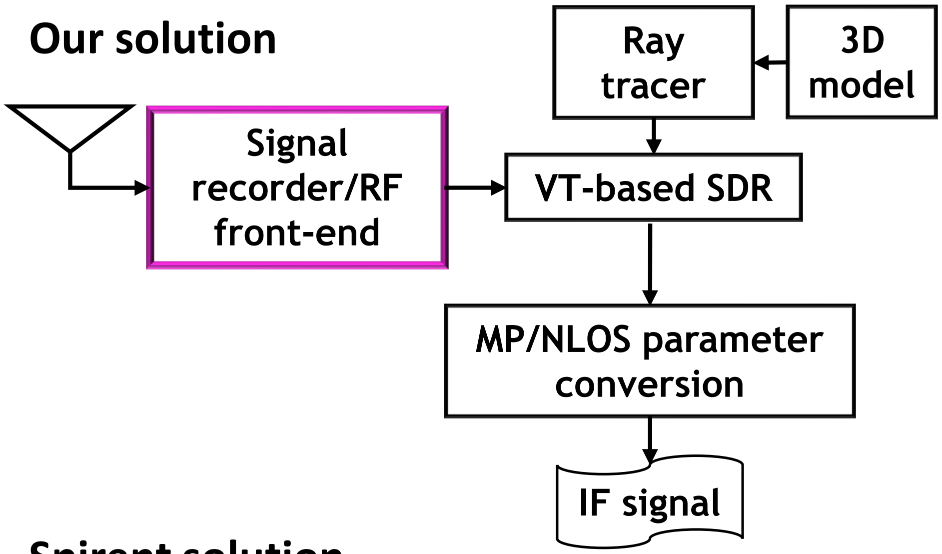


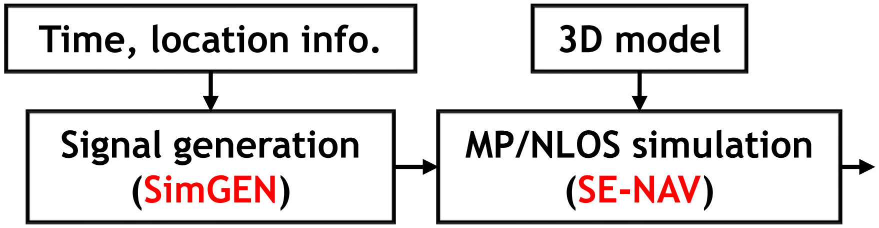

Xie and Petovello, Measuring GNSS Multipath Distributions in Urban Canyon Environments, *IEEE Trans. Instrum. Meas.* (2015) 64:366–377.

# Comparison with Spirent simulator

## Our solution




## Spirent solution




| | Spirent | Our |
|---|---|---|
| Hardware cost | High | Low (Signal recorder /RF front-end /IONSDR Metadata) |
| Software cost | High | Low (Parameter conversion) |
| Ray tracing | Yes | Yes (simplified) |
| Any time and location | Yes | No |

# Conclusion and Future Work

- We developed a flexible and low-cost IF-level multipath simulator by means of signal parameter conversion from open-sky to urban.
- Reflection coefficient calculation based on ray tracing

- Future works include consideration of multiple reflection and diffraction.
- The simulator is more feasible for academic research, but comparison with real data are also desired.

**Thank you for your attention!**