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A general altitude-dependent path loss model for UAV-to-ground millimeter-wave communications

Key words: Path loss; UAV-to-ground channel; Millimeter-wave (mmWave) communication channel; Ray-tracing; Altitude-dependent

Qiuming ZHU

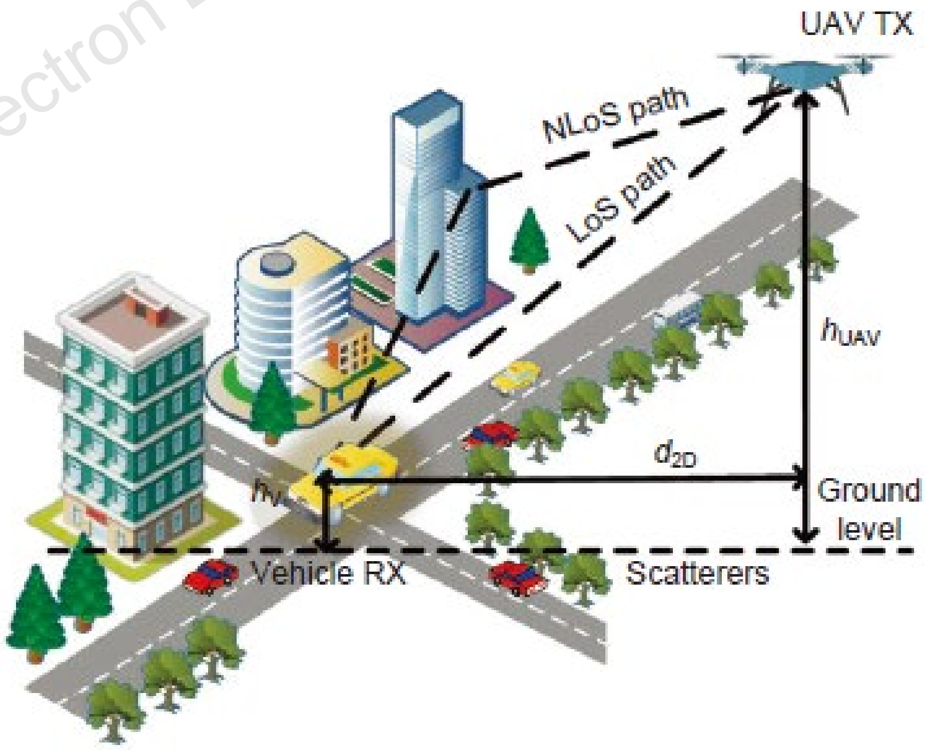
E-mail: zhuqiuming@nuaa.edu.cn

ORCID: https://orcid.org/0000-0002-4995-5970

Motivation

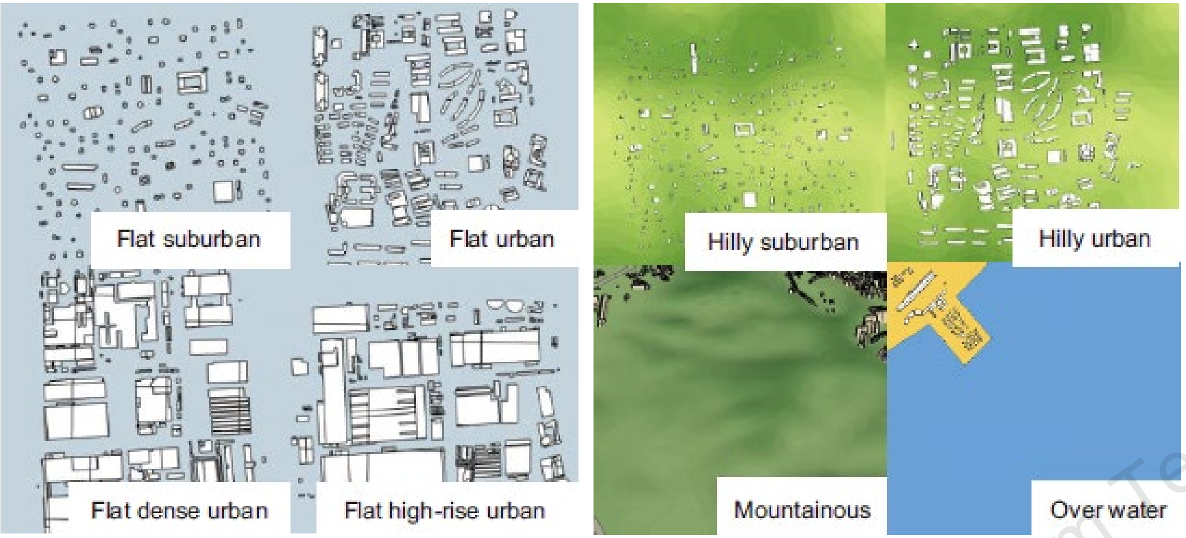
- A general parametric path loss (PL) model for air-to ground (A2G) mmWave channels is proposed. The new model considers not only the effects of scenario, distance, and frequency, but also the height factor. Moreover, the model consists of three cases, i.e., LoS, reflection, and diffraction, which can greatly improve the prediction accuracy.
- A deterministic PL prediction algorithm based on the digital map and RT technique is developed.
- To obtain proper parameters for the proposed PL model, numerous simulations are conducted by applying the map-based method to different specific scenarios with different UAV heights.

UAV-aided A2G mmWave communication link



PL prediction

3D scattering scenario reconstruction

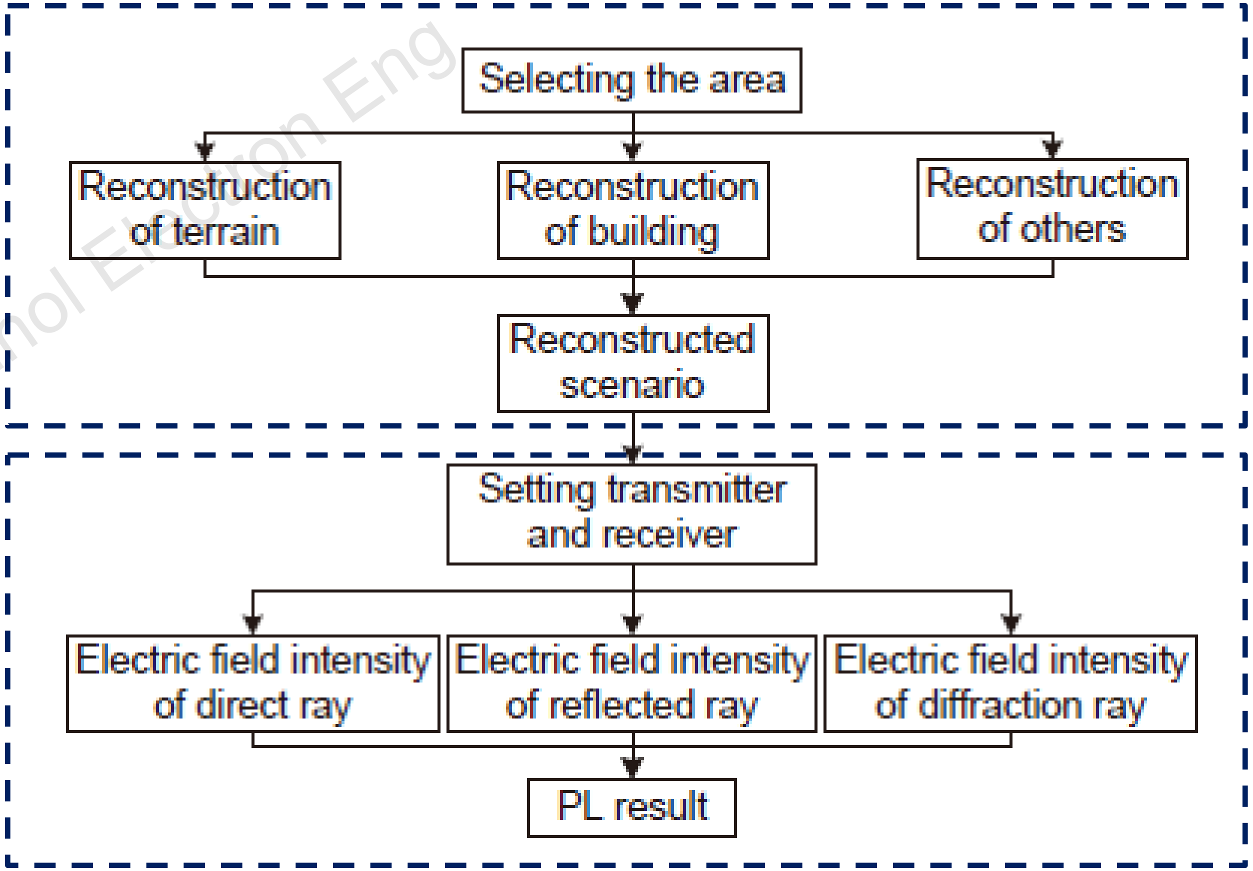


RT technique

Direct ray: $E_{\mathrm{LoS}} = E_0 \cdot \mathrm{e}^{-\mathrm{j}kd}/d$

Reflection ray: $E_{\mathrm{R}} = E_0 R \mathrm{e}^{-\mathrm{j}k(s_1+s_2)}/(s_1+s_2)$

Diffraction ray: $E_{\mathrm{D}} = \frac{E_0}{s_1} D \sqrt{\frac{s_1}{s_2(s_1+s_2)}} \mathrm{e}^{-\mathrm{j}k(s_1+s_2)}$



New latitude-dependent mmWave PL model

CI PL model: $L^{\mathrm{CI}}(f_c, d)\ [\mathrm{dB}] = 32.4 + 20\lg f_c + 10n\lg d + \chi_\sigma$

Data fitting

The proposed new latitude-dependent mmWave PL model takes the height factor into consideration based on the CI PL model, which makes it more suitable for A2G communication.

For 10 typical scenarios, we repeat the simulations to obtain enough data with different UAV heights. By fitting the data under different scenarios, we obtain the path loss exponent with different UAV heights and calculate the parameters of *A* and *B*.

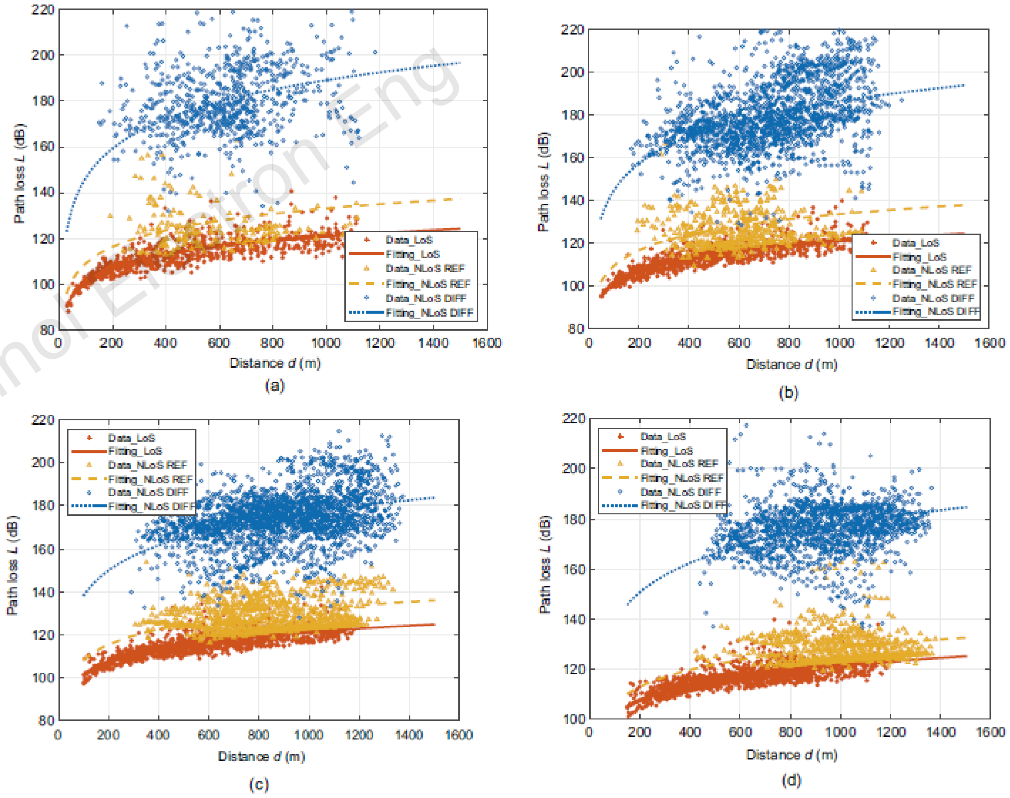
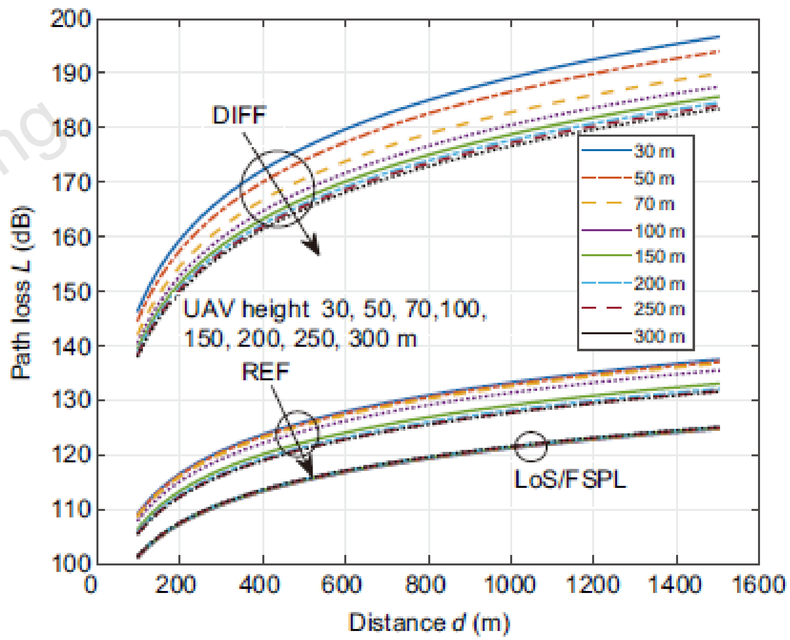


Fig. 6 Data fitting under the high-rise urban scenario with the UAV heights of 30 m (a), 50 m (b), 100 m (c), and 150 m (d)

New PL model: $L(f_c, d, h_{\mathrm{UAV}})\ [\mathrm{dB}] = 32.4 + 20\lg f_c + 10\left(A\cdot(h_{\mathrm{UAV}})^B\right)\lg d + \chi_\sigma$

New latitude-dependent mmWave PL model

The figure clearly shows that the LoS PL curves are almost the same as those of the FSPL model, since obstacles have no effect on the PL in the LoS case. The fitting curves with different UAV heights in the NLoS case are significantly different, which is not considered in previous PL models.



Fitting curves with different UAV heights

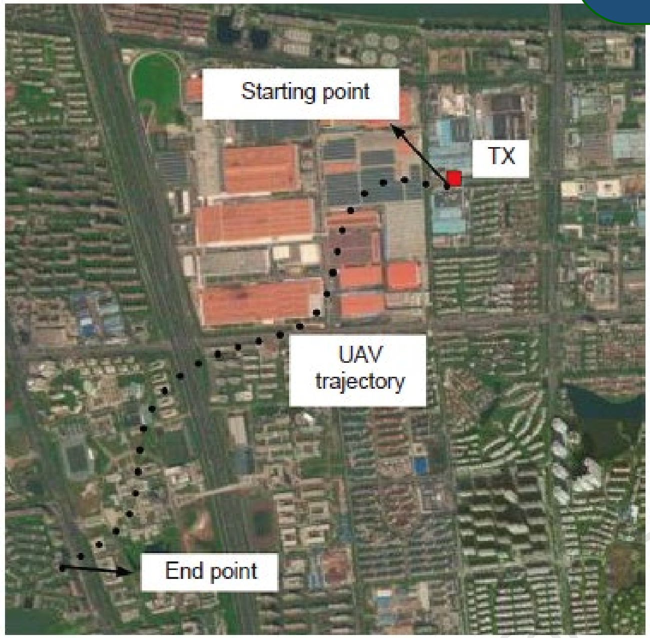
Table 1 Model parameters for different scenarios

Terrain	Scenario	A			B			σ (dB)		
		LoS	REF	DIFF	LoS	REF	DIFF	LoS	REF	DIFF
Flat	Suburban	2.000	2.406	3.649	0	−0.011 55	−0.047 34	2.24	3.13	6.49
	Urban	2.000	2.999	4.146	0	−0.069 58	−0.017 30	1.44	3.60	6.84
	Dense urban	2.000	2.772	5.619	0	−0.047 24	−0.074 43	1.91	3.53	6.65
	High-rise urban	2.000	2.611	4.921	0	−0.0269	−0.045 86	2.18	3.72	6.18
Hilly	Suburban	2.000	3.474	5.236	0	−0.068 46	−0.059 21	2.74	4.01	6.05
	Urban	2.000	3.052	4.203	0	−0.029 61	−0.018 91	2.32	4.32	6.90
Mountainous	Forest	2.000	–	–	0	–	–	3.44	–	–
	Vegetation	2.000	–	–	0	–	–	2.88	–	–
Over water	Fresh water	2.000	–	–	0	–	–	2.08	–	–
	Sea water	2.000	–	–	0	–	–	2.71	–	–

LoS: line-of-sight; REF: reflection; DIFF: diffraction

Comparison and validation

Simulations



Satellite view of simulation scenario

Table 2 Simulation parameters

Parameter	Value
Frequency	28 GHz
Bandwidth	500 MHz
Transmitting power	20 dBm
3GPP antenna type	Omnidirectional
UAV height	50, 300 m
Vehicle height	2 m

RT simulations were performed based on the digital map of Nanjing, China. The total trajectory is about 1660 m and the UAV position is sampled every 5 m, with a total of 332 sampling points. In the simulation, only six orders of reflection and one order of diffraction are considered.

Comparison and validation (Cont'd)

Comparison

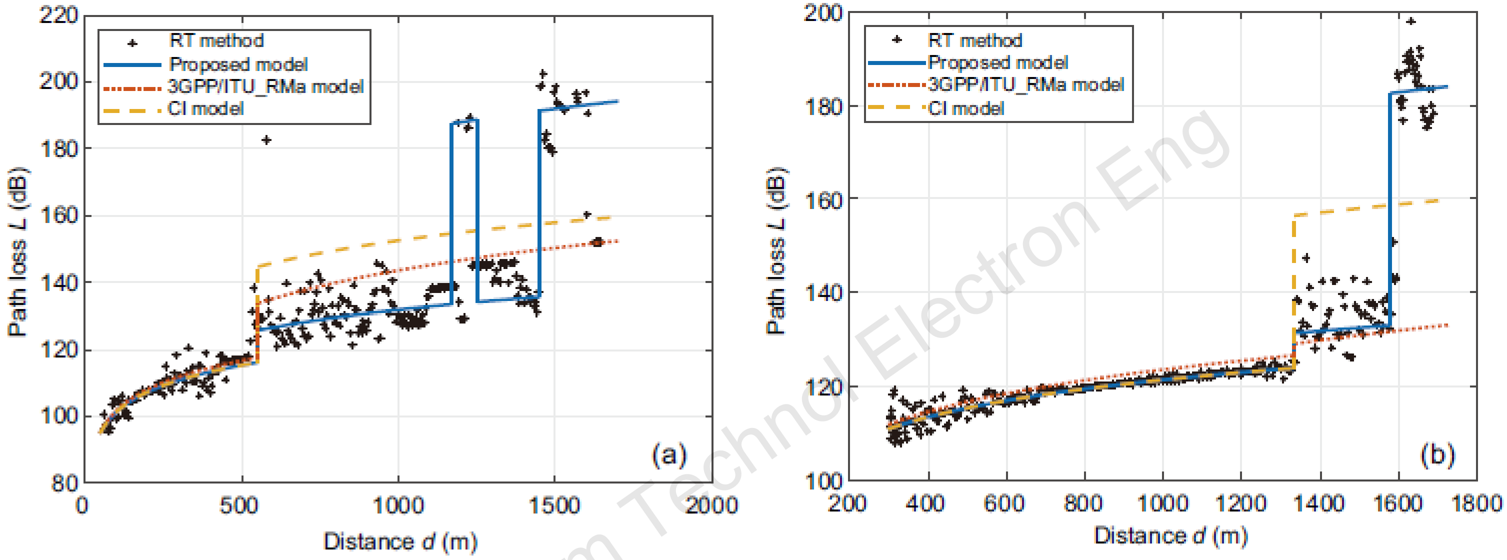


Fig. 9 Comparison of different PL models with the UAV heights of 50 m (a) and 300 m (b)

When the UAV height is 50 m, the three PL models have similar results for the LoS case. For the NLoS case, the 3GPP model may consider more the reflection but the CI model averages the effects of reflection and diffraction.

When the UAV comes to 300 m, the 3GPP model is no longer suitable, and the CI model lacks the impact of UAV height.

The proposed method has better performance than the other two models since it considers the effect of UAV height and propagation conditions.

Conclusions

- We proposed a general empirical PL model for A2G mmWave communications by considering the effects of environment, frequency, distance, and UAV height.
- A deterministic PL calculation algorithm based on the digital map and RT technique has been developed and a reconstruction method of 3D scattering scenario has also been presented to speed up the calculation.
- By fitting and analyzing numerous PL data, the optimized parameters of the proposed model for different scenarios have been given. The simulation results have shown that our proposed model better matches the RT method than other typical PL models for both low- and high-altitude cases.
- The new model is general and flexible to other A2G communication links by adjusting the model parameters according to the measurements or analytical data.

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Author profile

朱秋明，男，南京航空航天大学副教授，研究方向为电磁信号传播机理、无线信道测量建模应用以及通信装备智能化测试等。发表论文100多篇，中英文著作3部，PCT国际专利2项，中国发明专利40余项（转让4项），电子学会标准1项；主持参与国家自然科学基金重大科学仪器项目、国家自然科学基金重点项目、全军信息系统装备预研项目及省部级基金项目20余项，企业合作项目30余项；研究成果应用于航天5院、航天8院、中航612所、中电41所和中电54所等多家单位的面向航空/航天场景信道建模及通信装备测试，获得探月工程领导小组办公室感谢信，获国防科技发明二等奖1项、国防科技进步三等奖2项、江苏省科技进步三等奖1项。