Improving Millimeter-Wave Channel Models with Site-Specific Geometric Features

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Motivation

- The increasing demand of mobile users is exhausting the currently available spectrum below 6 GHz for mobile telecommunications.
- Millimeter waves (mm-waves) have become the most promising candidate among higher frequencies that are underutilized for enlarging the usable radio spectrum in future wireless networks.
- Mm-waves are sensitive to location-specific blockages.
- The challenge is understanding the propagation characteristics of mm-wave signals and accordingly predicting the channel state information as needed, so that the high mobility requirements of future wireless networks can be addressed in real time.

Mm-Wave Propagation Measurements for Suburban Environments[a]

- An intensive measurement campaign has been carried out at the United States Naval Academy in Annapolis, Maryland.
- The transmitter (TX) was installed at a height of 90 feet (27.4 m) to emulate a microcell deployment.
- A custom-designed broadband sliding correlator channel sounder was used as the receiver (RX) to record propagation data.

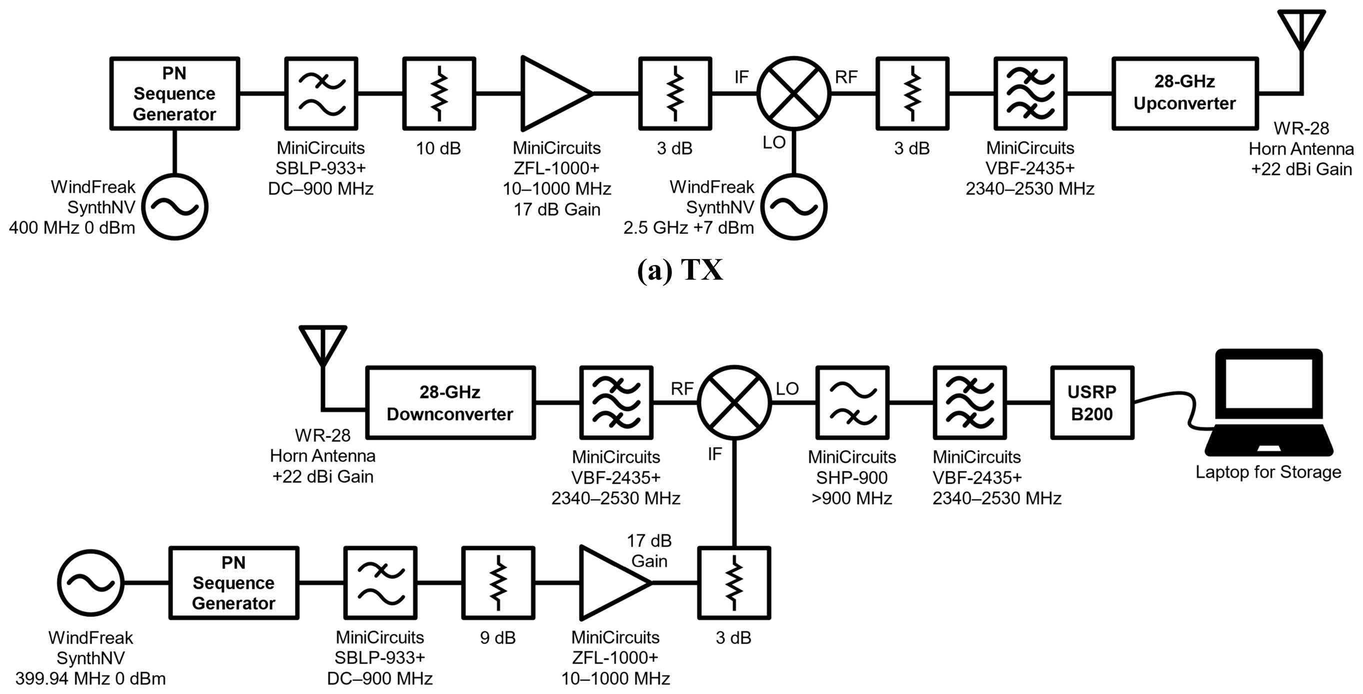


Fig. 1. Block diagrams for the 28-GHz broadband sliding correlator channel sounder. Model numbers are labeled for some commercially available parts.

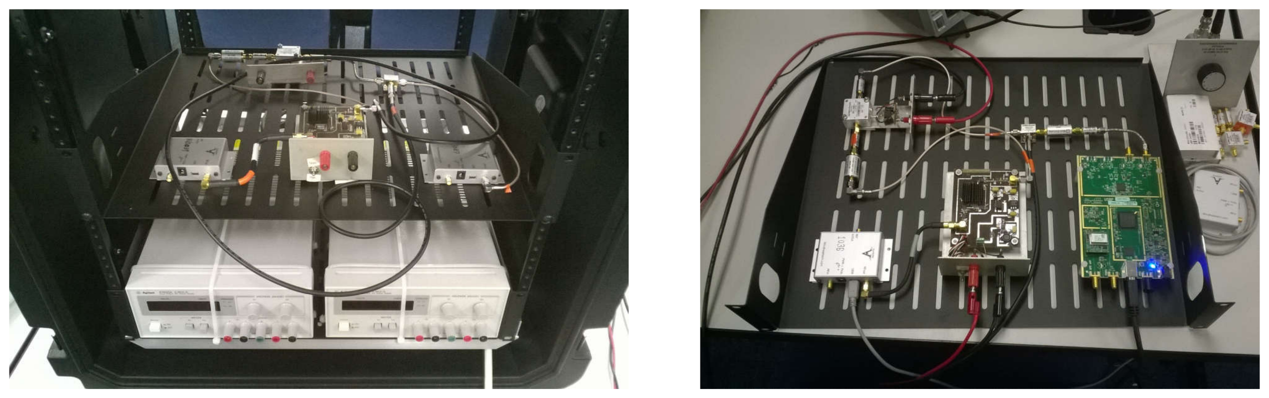


Fig. 2. Photos of the custom-designed spread-spectrum channel sounder. Components are fixed on shelves for portability and the TX is further more enclosed into a rack case for extra protection during the deployment.

- More than 5000 power delay profiles at 50 individual sites and on two pedestrian paths over distances from 80 m to 1000 m were obtained.

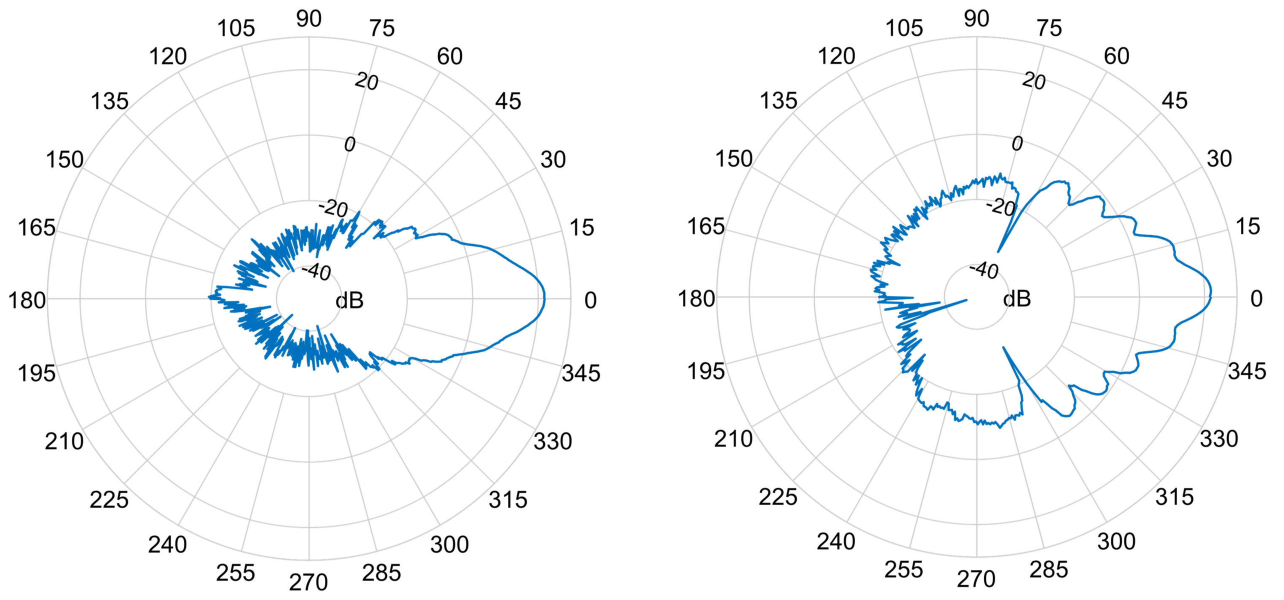
TABLE I
BROADBAND SLIDING CORRELATOR CHANNEL SOUNDER SPECIFICATIONS

Carrier Frequency	28 GHz
Chip Sequence Length	2047
RF Bandwidth (First Null)	800 MHz
TX Chip Rate	400 Mcps
Temporal Resolution	2.5 ns
RX Chip Rate	399.94 Mcps
TX Power	23 dBm
TX/RX Antenna Gain	22 dBi
Measured TX/RX Azimuth HPBW	10.1°
Measured TX/RX Elevation HPBW	11.5°
Maximum Measurable Path Loss	182 dB

[a] More details on the measurement setup can be found in: Y. Zhang, *et al.*, "28-ghz channel measurements and modeling for suburban environments," Department of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana, Tech. Rep. TR-ECE-17-07, November 2017.

Basic Transmission Loss Calculation

- Multiple procedures, including *received signal power calculation*, *RX calibration*, and *antenna pattern generation*, were taken into account for computing the basic transmission loss to ensure the measurement accuracy.



(a) Azimuth Plane Pattern (b) Elevation Plane Pattern

Fig. 3. Antenna pattern measurement results for the azimuth and elevation planes. The antenna beamwidths (10.1° azimuth HPBW and 11.5° elevation HPBW) were computed accordingly.

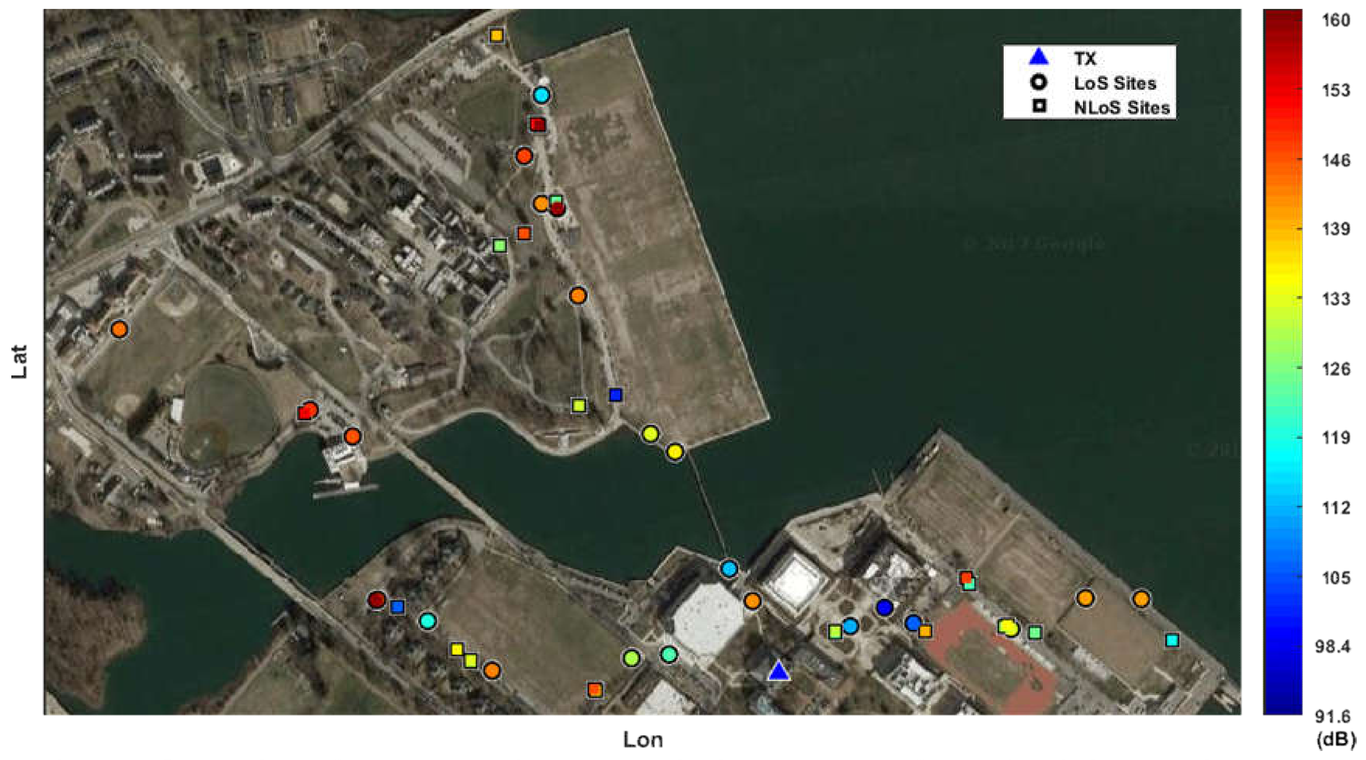


Fig. 4. Overview for the basic transmission losses of the individual sites. The geographic locations for the measurement sites are shown on a Google map of the USNA campus, with their corresponding worst-case basic transmission losses illustrated by color labels.

Model Verification and Comparison

- Existing models were verified with the measurement data.
- International Telecommunication Union (ITU) site-general model for propagation over rooftops for the line-of-sight (LoS) case:

$$PL(d,f) = 10\cdot\alpha\cdot\log_{10}(d) + \beta + 10\cdot\gamma\cdot\log_{10}(f) + N(0,\sigma)\,. \quad (1)$$

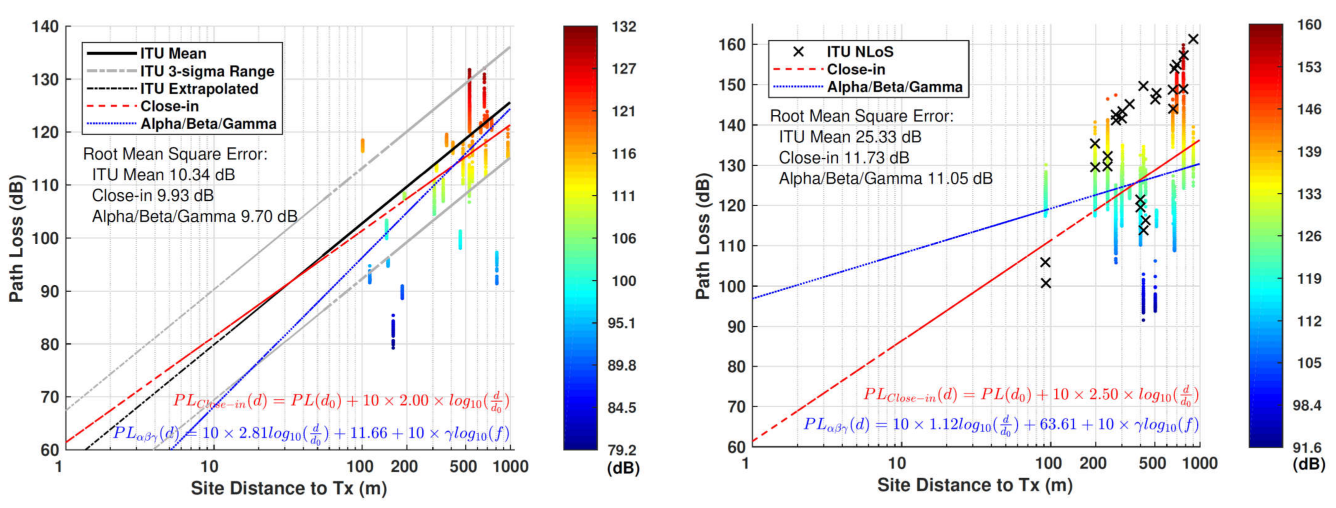
- Close-in (CI) free space reference distance path loss model:

$$PL(d) = PL_{FS}(d_0) + 10\cdot n\cdot\log_{10}\left(\frac{d}{d_0}\right), \quad (2)$$

$$PL_{FS}(d_0) = 20\cdot\log_{10}\left(\frac{4\pi d_0}{\lambda}\right). \quad (3)$$

- Alpha-beta-gamma (ABG) model:

$$PL(d) = 10\cdot\alpha\cdot\log_{10}(d) + \beta + 10\cdot\gamma\cdot\log_{10}(f). \quad (4)$$



(a) For the LoS Measurements (b) For the NLoS Measurements

Fig. 5. Model comparison for LoS and NLoS measurements. (a) In the LoS case, the ITU predictions agree reasonably well with our measurement results, as well with the reference models. (b) For NLoS sites, the ITU predictions show a trend of following the measurement results but with an overestimation.

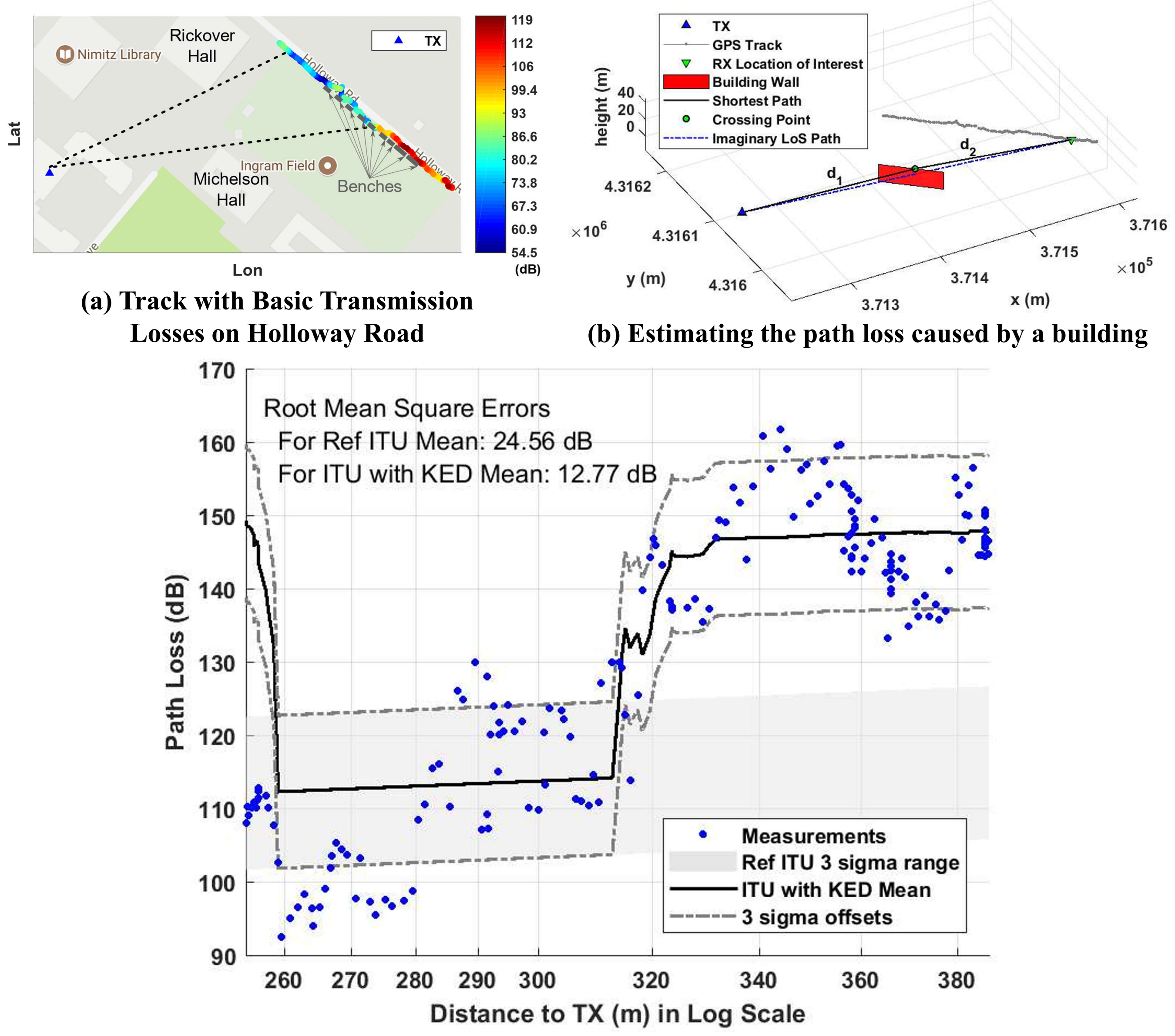
- The site-specific non-line-of-sight (NLoS) version of the ITU model was also considered when it is necessary.

TABLE II
KEY PARAMETERS FOR CHANNEL MODELS

Model	LoS					NLoS				
	n	α	β	γ	RMSE (dB)	n	α	β	γ	RMSE (dB)
ITU	N/A	2.29	28.6	1.96	10.34	N/A	N/A	N/A	N/A	25.33
Close-in	2.00	N/A	N/A	N/A	9.93	2.50	N/A	N/A	N/A	11.73
ABG	N/A	2.81	11.66	1.96	9.70	N/A	1.12	63.61	2.30	11.05

Channel Model Improvement with Site-Specific Geometric Features

- Blockages by buildings on the continuous track of Holloway Road were considered via the knife-edge diffraction (KED) model.
- A modest, but significant, overall improvement in propagation modeling accuracy was demonstrated for the LoS ITU model.



(a) Track with Basic Transmission Losses on Holloway Road (b) Estimating the path loss caused by a building (c) Path Loss for the Modified ITU Model

Fig. 6. Improving a statistical channel model by considering building blockages. (a) Path loss values on Holloway road illustrate the shadowing effect of buildings. (b) An illustration for computing the extra building blockage path loss via the KED model. (c) After being shifted by the diffraction losses, the ITU model closely follows the measurement results.

Conclusion

- Site-specific geometric information on buildings, when properly utilized, can help predict blockages.
- More investigation is needed for blockages caused by vegetations.

Future Works

- Acquire more mm-wave propagation measurements
- Combine traditional statistical models with side information, especially site-specific geometry features, to improve predictions on channel states
- Design and build a cloud-based multi-layer radio environment map database to support an agile software defined network architecture which is capable of adapting to varying network conditions for efficient and seamless network operations.

Acknowledgement

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