Examination of 1.7 GHz Measured Propagation Loss for Free-Space/Clutter Paths in Salt Lake City

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***Abstract*—In June 2018, ITS performed mobile clutter measurements in Salt Lake City, UT at 1.7 GHz. This measurement campaign was designed for path geometries with larger take-off angles by placing the transmitter in the hills of the nearby mountains. The resulting measurement dataset contains a large percentage of paths that would traditionally be considered line-of-sight (LOS), in that the terminals have an unobstructed view of each other. We present this LOS data and explore what a LOS path implies within a cluttered environment. We integrate high-resolution lidar data into our analysis showing that traditional assumptions of LOS links need further descriptors to clarify the frame of reference. Finally, we present how lidar data can be incorporated into modeling activities to support improved prediction methods and understanding of the expected clutter losses for such geometries.**

***Index Terms*—Propagation, Clutter, Lidar**

I. Introduction

Line-of-sight propagation, in which terminals have an unobstructed view of each other, is typically modeled using overly simplistic assumptions. With the exception of very short paths in which near-field effects come into play, many clutter models either rely on free space constructions to predict basic transmission loss, or are constructed without differentiating between line-of-sight and non-line-of-sight paths.

The Okumura-Hata model [1] [2], as well as its various derivations and extensions [3] [4] [5], all rely heavily on an empirical approach in which measurement data—both line-of-sight and non-line-of-sight paths—are combined. Accounting for the distribution of LOS and NLOS paths is accomplished through the use of location variability. However, such statistics rely on the assumption that the modeled environment contains geometrical statistics similar to those of the underlying empirical data, something that can be difficult to validate and review, as underlying data for both the measurements and the environment might not be readily available.

Clutter models that take a more site-specific approach attempt to utilize specific clutter information along the path to incorporate diffraction-based effects. In [6], the geometry of the terminal's clutter horizon is required, with the option to use local data if available or default values if such detailed information is unknown. In [7], additional site-specific information regarding clutter along the path is utilized, often with simplifying geometrical assumptions regarding building spacing, widths, and heights. However, these models generally focus on the vertical plane, so that two terminals having an unobstructed view of each other relative to the clutter result in clutter losses at or approaching free space.

Fig. 1. View from transmitter site, looking south towards downtown Salt Lake City, UT. The paths from the transmitter site to the measurement area have first Fresnel zone clearance of the terrain located in the foreground.

Upon examination of measurement and environmental data, it becomes clear that the definition of "line-of-sight" itself needs to be refined for clutter modeling. Engineers traditionally consider LOS paths to be as described in the first paragraph: terminals that have an unobstructed view of each other. At times, considerations of paths in which the first Fresnel zone is partially obstructed are presented, but these approaches assume an ideal, perfectly absorbing, horizontal knife-edge to account for the diffraction effects [6].

In this paper, we present clutter measurement results for free-space/clutter path geometries where the transmitter is at a distance and well above the clutter. The measured data contain a relatively high number of line-of-sight paths. We analyze the measured losses and look at causes of observed losses. We discuss and present how incorporating high-resolution data in the analysis of the measurement results can lead to an improved understanding of line-of-sight paths and more precise modeling techniques.

II. Measurement Campaign

ITS performed a measurement campaign in June 2018 to capture clutter loss measurements in urban and suburban environments for larger takeoff angles at mid-band frequencies. Salt Lake City, UT, was chosen as a measurement site because the city encompasses accessible mountains to the north where a transmitter could be placed, allowing elevated takeoff angles from the receiver system to the transmitter. The benefits of such free-space/clutter path geometries include an increased number of line-of-sight paths, as clutter presents as a strictly end-point phenomenon; thus, the absence of clutter in the receivers' immediate foreground generally results in unobstructed propagation between the antennas.

The transmitter was placed at (40.807196, -111.881283) located north of downtown Salt Lake City. The transmitter antenna was placed atop a telescoping mast and raised to 19.4 meters above the ground. A continuous wave (CW) signal was broadcast at 1773 MHz. Fig. 1 shows the view looking south from the transmitter site towards the city, with the downtown urban core located in the foreground. The difference in elevation between the transmitter site and the plain containing Salt Lake City and its surrounding developments was approximately 575 meters.

The receiver system was a mobile channel sounder as described in [8]. The measurement van drove three drive routes over three consecutive days. The Urban Route focused on the Salt Lake City downtown urban core. The South Route consisted of longer paths through areas that would be described as suburban and/or dense suburban. The Subwest Route consisted primarily of suburban areas. Fig. 2 shows the three measurement drive routes relative to Salt Lake City and the placement of the transmitter.

Measurement data were acquired and processed according to best practices [9]. Fast fading was removed from the measurement samples in post-processing to arrive at a local mean representing basic transmission loss. This basic transmission loss information was then used in the subsequent analysis and modeling work. Summary statistics of path geometry parameters are presented in Table I.

III. Environmental Information

The recent availability of high-resolution lidar datasets allows researchers to perform detailed site-specific analysis of clutter measurements. Whereas previous researchers were limited to coarse generalizations of clutter classifications, such as urban, suburban, and rural, airborne-collected lidar information allows site- and path-specific geometrical information.

TABLE I
SUMMARY STATISTICS REGARDING MEASUREMENT GEOMETRIES.

	Min	Max	Mean	St Dev
Path Distance (km)	2.30	12.50	5.99	2.61
Elevation Angle (deg)	2.56	9.86	6.16	1.95
Clutter Height above Receiver (m)	0	126.93	5.39	6.45

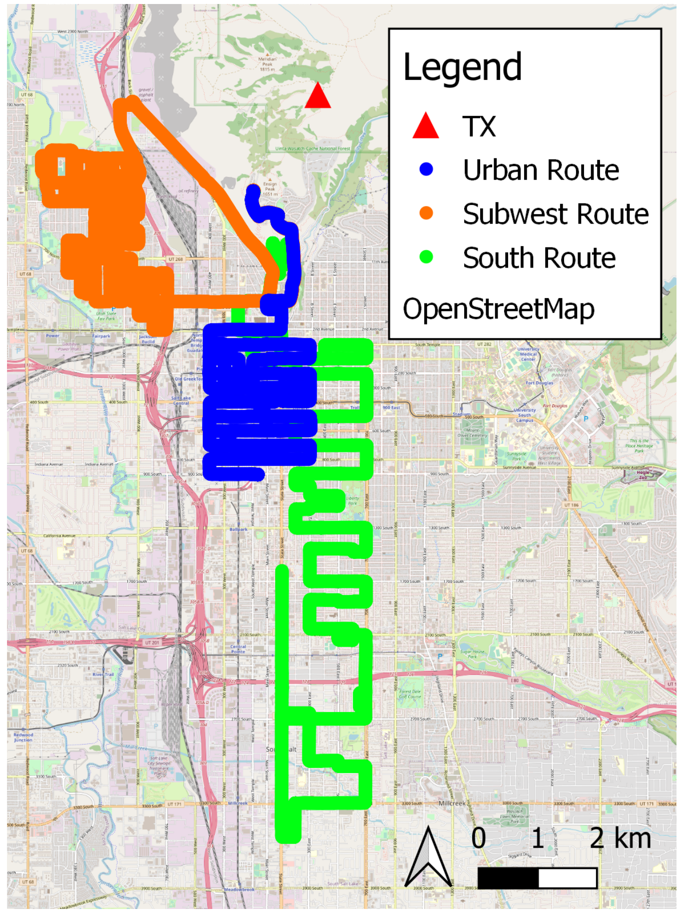

Fig. 2. Map of the three Salt Lake City, UT, clutter measurement drive routes. Base map and data from OpenStreetMap and OpenStreetMap Foundation, www.openstreetmap.org/copyright

The State of Utah's Automated Geographic Reference Center (Utah AGRC) commissioned an airborne lidar acquisition along the Wasatch Front, which includes Salt Lake City. This data acquisition was performed in 2013 and the resulting point cloud data subsequently made freely accessible to the public.

This dataset was captured at Quality Level 1 (QL1), allowing the generation of a 0.5 meter resolution Digital Terrain Model (DTM) and Digital Surface Model (DSM). As the name suggests, the DTM represents the bare earth terrain, and is processed using ground-return lidar pulses. The DSM is generated using techniques to accurately represent the clutter as defined in Recommendation ITU-R P.2108, namely, "objects, such as buildings or vegetation, which are on the surface of the Earth but not actually terrain" [6]. This represents the traditional definition of clutter used in propagation modeling and analysis.

IV. Measurement Data Classification

Data from the three measurement routes were aggregated into a single measurement dataset for analysis. To remove location bias, where certain locations are over-represented in the data, locations containing multiple measurement points, such as stationary locations at traffic signals or roadways traversed

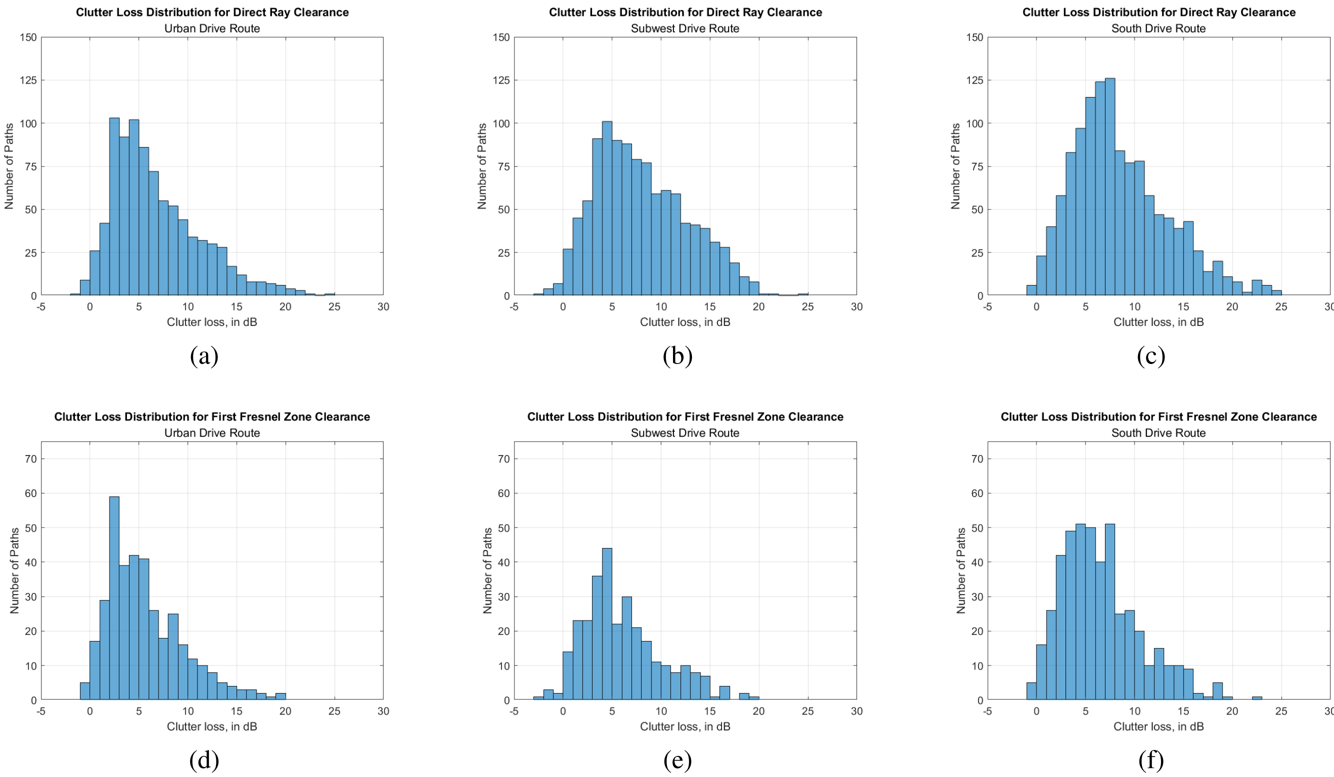

Fig. 3. Distribution of measured clutter loss for paths containing direct ray clearance for measurement routes (a) Urban, (b) Subwest, and (c) South. Distribution of measured clutter loss for paths containing first Fresnel zone clearance for measurement routes (d) Urban, (e) Subwest, and (f) South.

multiple times, are averaged in both basic transmission loss and location to result in a single derived datapoint.

In order to clearly quantify clutter losses, only measurement paths that exhibited full first Fresnel terrain clearance were used. This allows clutter loss to be defined simply as the measured loss in excess of free space, as presented in (1), since atmospheric losses are negligible at 1,773 MHz and no other loss mechanisms are present in the radio path. The resulting dataset consists of 12,290 points.

$$L_{clut} = L_{meas} - L_{fs} \tag{1}$$

A. Filtering Line-of-Sight Paths

The datapoints are classified as either line-of-sight (LOS) or non-line-of-sight (NLOS). We use the traditional definition of line-of-sight as previously described, namely, that the terminals have an unobstructed view of each other.

Consider the filtered LOS measurement results shown in Fig. 3, and detailed in Tables II and III. Subfigures (a)-(c) present measured LOS clutter losses along three different measurement routes in Salt Lake City, UT in which paths have direct-ray clearance relative to the terrain and clutter. Subfigures (d)-(f) present measured LOS clutter losses along the same three routes for paths that have first Fresnel zone clearance relative to terrain and clutter. It is clear that low-loss, free-space methods can significantly underestimate the impact of clutter on signal strength.

B. Dataset Aggregation

The measurement routes occurred in varied environments, from the downtown urban core of Salt Lake City to the suburban surroundings to an industrial area to the West. The data presented in Tables II and III show that when filtered using the geometrical definition of LOS clearance, the three different measurement routes show similar clutter loss characteristics. In addition, the filtering criteria of direct ray LOS and first Fresnel zone LOS provides little advantage, as again, similar clutter loss statistics are present across both the filtering criteria and the measurement routes. For these

TABLE II
CLUTTER LOSS STATISTICS FOR DIRECT RAY CLEARANCE PATHS.

	Count	Mean (dB)	Median (dB)	St Dev (dB)
Urban	875	6.80	5.69	4.51
Subwest	1,066	7.98	7.27	4.66
South	1,242	8.50	7.57	4.83

TABLE III
CLUTTER LOSS STATISTICS FOR FIRST FRESNEL ZONE CLEARANCE PATHS.

	Count	Mean (dB)	Median (dB)	St Dev (dB)
Urban	367	5.63	4.85	3.90
Subwest	298	6.05	5.11	4.06
South	465	6.54	5.90	4.04

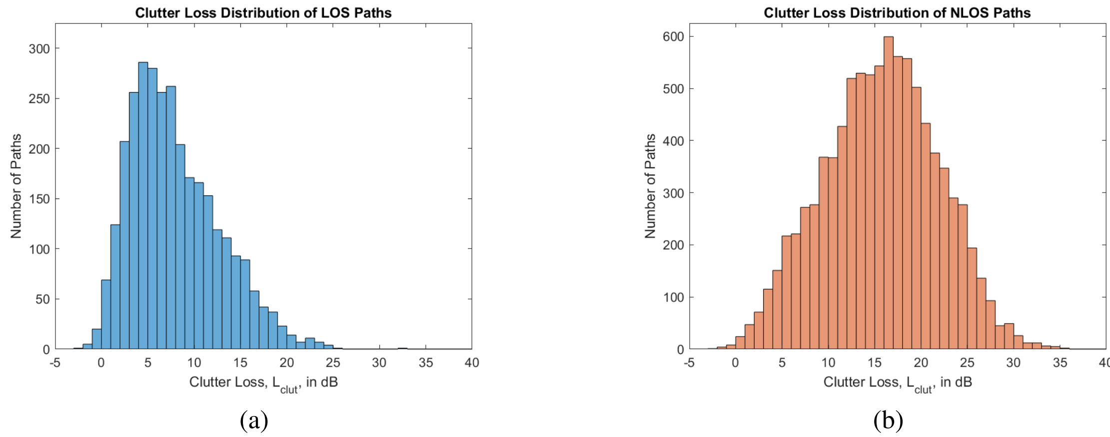

Fig. 4. Distribution of clutter loss (a) for line-of-sight (LOS) and (b) non-line-of-sight (NLOS) measurement data points.

reasons, we can combine all LOS paths into a single aggregate dataset for analysis.

The classification of the measurement data into LOS or NLOS points results in two distinctly different clutter loss distributions. Fig. 4 shows the distribution of clutter loss for LOS and NLOS points. Summary statistics for these distributions are presented in Table IV.

The NLOS paths present locations that, with the exception of some low-loss paths, generally contain sizable clutter losses ($L_{clut} > 10$ dB). The LOS data, however, contains a significant fraction of measurement points demonstrating clutter losses in excess of 10 dB. Considering a grazing ray to an ideal absorbing knife-edge diffraction solution results in 6 dB of loss, these high-low paths appear to demonstrate significantly higher losses than might be intuitively expected.

V. Line-of-Sight Path Analysis

The Salt Lake City measurement dataset resulted in approximately 25% of the paths being classified as LOS. These paths show no clutter obstruction along the ray path from transmitter to receiver, even when analyzed with clutter information extracted at a 0.5 meter resolution. In this scenario, a free space path loss model would dramatically under-predict the observed signal levels. Closer analysis, however, shows that deterministic methods are possible for the development of improved clutter loss models.

A. Vertical Edges

The first feature to look for in the measurement data are paths that contain vertical edges. In traditional terrain-based propagation models, vertical diffracting edges are generally ignored as terrain features change slowly relative to a Fresnel radius. In cluttered environments, however, vertical edges are commonplace, originating from such features as the sides of buildings. Furthermore, for this measurement data, the first Fresnel zone can be as large as 9 meters in radius, increasing the likelihood of path geometries in which clutter obstructs from the lateral direction, resulting in diffraction losses.

TABLE IV
Statistics of measured clutter loss values for for LOS and NLOS paths, in dB.

	Count	Mean (dB)	Median (dB)	St Dev (dB)	% of Total
LOS	3,080	7.99	7.10	4.94	25.06
NLOS	9,210	15.67	15.84	6.20	74.94
Total	12,290	13.75	13.73	6.78	100.00

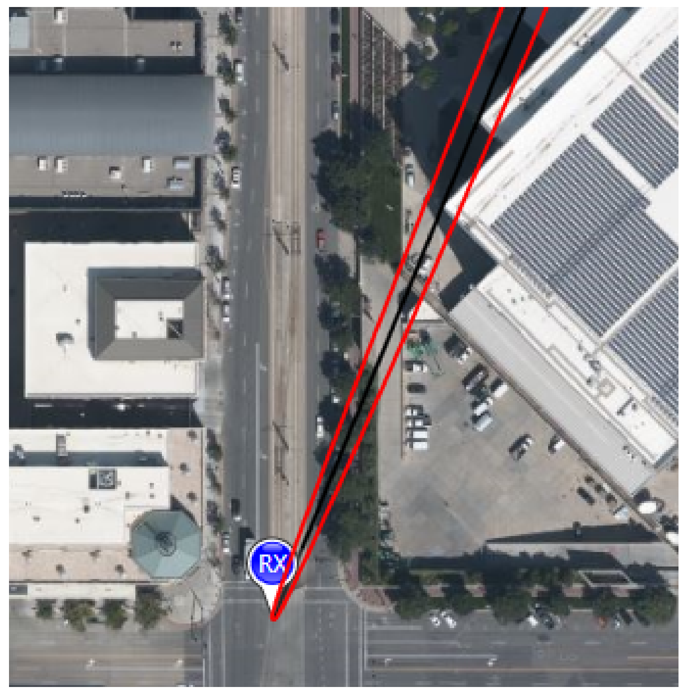

Fig. 5. A vertical grazing diffraction edge. The black line is the direct ray path and the red line is the first Fresnel zone. Bing Maps screenshot reprinted with permission from Microsoft Corporation.

An example of such a path is shown in Fig. 5. A large building presents a grazing vertical diffraction edge. The measured clutter loss for this path was 6.24 dB. The construction of a vertical knife-edge at the location of the clutter obstruction

(a) (b) (c)

Fig. 6. (a) Roadway sign causing diffraction losses in a LOS classified path. (b) Satellite view showing geometry of direct ray (black) and first Fresnel zone (red). (c) Horizontal profile from re-extracted lidar point cloud data. Bing Maps screenshots reprinted with permission from Microsoft Corporation.

results in a diffraction loss prediction of 6.01 dB.

B. Signage

Diffraction losses can occur not only due to traditional clutter obstructions such as buildings and trees, but also due to sign posts or billboards. The availability of high resolution lidar data allows finer objects to be identified. Consider the set of measurement points shown in Fig. 6(a). The measured clutter losses are shown in the map pins. The receiver is moving northward, through a region of high-clutter losses. Each of these measurement points is classified as a LOS path, and there are no building or vegetation obstructions within the first Fresnel zone.

However, the measured clutter losses were caused by diffraction. The diffraction obstruction was not a traditionally considered clutter obstruction, such as a building or tree, but was instead a roadside sign. Closer inspection of the lidar point cloud data clearly shows the presence of a large roadside sign, visible in Fig. 6(b). Inclusion of these obstructions within the DSM can support the construction of 2D diffraction screens for clutter loss predictions.

C. Metallic Screens

Not all deterministic losses are caused by purely diffraction-based effects. Consider the paths shown in Fig. 7. These measurement points measured clutter losses ranging from 3 to 7 dB. To the north of the measurement points is a large athletic field with no obvious diffracting obstruction present. A closer look shows that immediately next to the roadway is a tall mesh metal screen. The metallic nature of the screen interacts with the transmitted signal, incurring additional losses. In this case, a diffraction-based solution would be inappropriate. However, with such information provided by re-examination of the lidar point cloud data, model prediction methods could be improved to consider such effects.

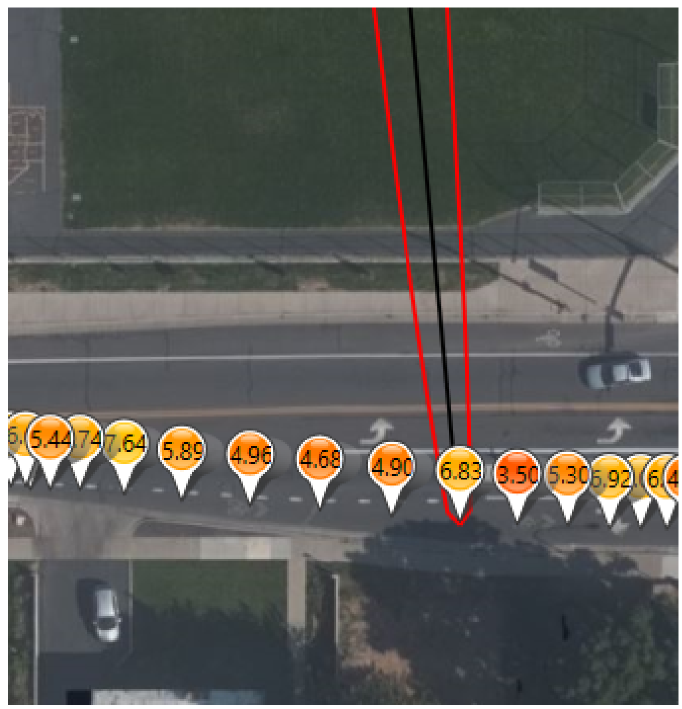

Fig. 7. Impact of metal screen on clutter loss for a traditionally defined line-of-sight path. The black line is the direct ray path and the red line is the first Fresnel zone. Bing Maps screenshot reprinted with permission from Microsoft Corporation.

VI. Summary and Future Work

This paper has shown that traditional definitions of line-of-sight paths can be insufficient for site-specific clutter models. Simple definitions, based around terminals having an unobstructed view of each other, require more information to understand the impact of the environment on the 3D ray path. Qualifiers such as direct-ray clearance and first Fresnel zone clearance can provide such context. This additional information can be used to develop improved clutter prediction methods, ones that combine high-resolution environmental data with underlying electromagnetic theory.

This paper also presents clutter measurement results at 1.7 GHz in Salt Lake City, UT, in which the transmitter was placed significantly above the measurement area, resulting in a high number of such "line-of-sight" measurements. The results show that the distributions of measured losses are non-Gaussian.

ITS is continuing work to develop a clutter model that relies on both statistical and data-driven techniques. Additional measurement campaigns containing geometries suitable for large numbers of LOS paths are being planned for the future. We observe in Tables II and III that the measured clutter loss for these LOS paths in the Urban Route (which is dominated by the downtown urban core) is lower and has a smaller standard deviation than the other measurement routes—an interesting observation that ITS plans to study further.

Lastly, ITS is pursuing analysis and modeling of the lidar datasets themselves. Investigations into spatial and environmental statistics of these datasets are examining how such metrics can be used to generalize empirical measurement data.

References

[1] Y. Okumura, E. Ohmori, T. Kawano, and K. Fukuda, "Field Strength and Its Variability in VHF and UHF Land-Mobile Radio Service," Review of the Electrical Communication Laboratory, Vol 16, No 9-10, 1968, pp. 825-873.

[2] M. Hata, "Empirical Formula for Propagation Loss in Land Mobile Radio Services," IEEE Transaction on Vehicular Technology, Vol 29, No 3, 1980, pp. 317-325.

[3] E. Drocella Jr., J. Richards, R. Sole, F. Najmy, A, Lundy, and P. McKenna. "3.5 GHz Exclusion Zone Analyses and Methodology," NTIA Technical Report TR-15-517, June 2015. https://its.ntia.gov/publications/details.aspx?pub=2805

[4] COST Action 231. "Digital Mobile Radio Towards Future Generation Systems, Final Report," Tech Report, European. 1999. Communities

[5] ITU-R, "Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 4 000 MHz," 2019.

[6] ITU-R, "Recommendation ITU-R P.2108-0: Prediction of clutter loss," 2017.

[7] J. Walfisch, H. Bertoni, "A theoretical model of UHF propagation in urban environments," IEEE Trans. Antennas and Propag. 36, 1788–1796 (1988)

[8] R. Johnk, C. Hammerschmidt, and I. Stange, "A High-Performance CW Mobile Channel Sounder," Proceedings of the 2017 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI). https://its.ntia.gov/publications/details.aspx?pub=3186

[9] C. Hammerschmidt, R. Johnk, P. McKenna, and C. Anderson, "Best Practices for Radio Propagation Measurements," NTIA Technical Memo TM-19-535, Nov. 2018. https://its.ntia.gov/publications/details.aspx?pub=3211