Extracting Clutter Metrics From Mobile Propagation Measurements in the 1755-1780 MHz Band

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***Abstract*—This paper discusses mobile propagation measurement campaigns in San Diego, CA; Denver, CO; and Washington, D.C. These measurements were made to inform possible clutter models in the 1755-1780 MHz band. This band was recently auctioned and will now be the first spectrum sharing band opened to both broadband wireless carriers and federal agencies. Clutter in this case is defined as the excess loss due to attenuation from buildings and vegetation, above either free-space path losses or terrain attenuation. Attenuation due to terrain was modelled using the irregular terrain model (ITM).**

***Index Terms*—attenuation, clutter metrics, ITM, mobile propagation**

I. INTRODUCTION

In July 2012, the Commerce Spectrum Management Advisory Committee (CSMAC) began a series of working group meetings between federal agencies and commercial wireless operators to investigate the feasibility of sharing spectrum between commercial and federal systems [1]. For these meetings, the International Telecommunication Union Recommendation ITU-R P.528 was used to predict user equipment (UE) aggregate emission power levels into federal systems [2]. This method predicts basic transmission loss from 125-15,500 MHz for aeronautical and satellite services using a set of curves derived from the IF-77 propagation model [3]. The sets of curves generated in the Recommendation used a smooth Earth (terrain parameter $\Delta h = 0$) approximation and Earth radius factor of $k = 4/3$ to compensate for excessive ray bending. The IF-77 curves also used average ground soil parameters ($\varepsilon_r = 15.0$, $\sigma = 0.005$ Siemens/m), isotropic antennas, and long-term fading statistics for a continental temperature climate. A two-ray geometric optics calculation was used to account for interference between the direct-ray from the antenna and the ground-reflected ray along the path. In this simplified method, no attenuation effects from terrain, or from buildings and vegetation (i.e. clutter) were included. These simplified assumptions led to proposing large coordination distances needed to protect federal systems from interference by commercial user equipment (UE).

As a follow-on to these meetings, commercial wireless carriers conducted several flight tests over the Washington D.C./Norfolk, VA area to understand the effect of clutter on a transmitted continuous-wave (CW) signal. Along one of the flight paths, a transmitter with an output power of 40 dBm was placed on the ground and the receiver was located on the belly of the aircraft. Institute for Telecommunication Sciences (ITS) engineers were able to show that the measured received power could be modelled when the terrain effects, antenna patterns of both the ground and the airborne antennas, and a simple clutter model [4] were considered. This final result is shown in Fig. 1. The green trace was the measured basic transmission gain, the blue trace includes modelled terrain attenuation, the red trace the antenna gains, and the purple trace includes modelled terrain attenuation, the antenna gains, and the clutter model.

This analysis gave us the idea to pursue a clutter measurement research program at ITS. In fiscal year (FY) 2015, we pursued a joint research program through the Center for Advanced Communications (CAC) with the National Institute of Standards and Technology (NIST) to characterize the uncertainties of our newly-developed measurement system. The report of the results of that joint research program is in review and is expected to be published in 2016.

At this time we are engaged with the Defense Spectrum Office (DSO) via the Spectrum Sharing Test and Demonstration (SST&D) Program to make propagation measurements in various cities to inform clutter metrics and to begin to inform a clutter model. This report discusses a small sampling of the many measurements made in each area. We will discuss the measurement system and post-processing techniques in Section II, and the measured data for San Diego,

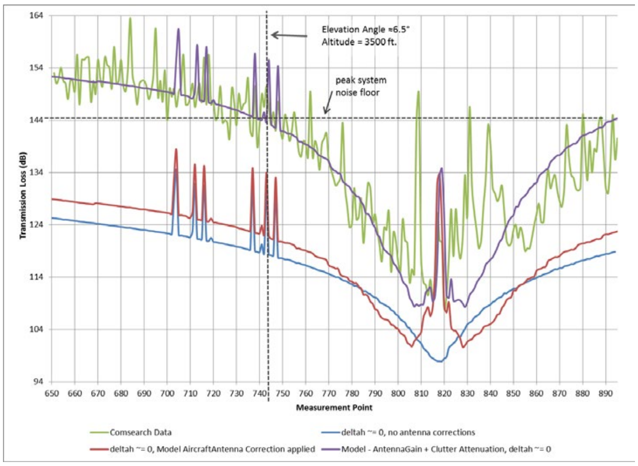

Fig 1. Graph showing measured basic transmission gain (green trace) and the contribution from each additional improvement to the model.

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CA; Denver, CO; and Washington, D.C, in Section III.

II. MEASUREMENT SYSTEM

A. Equipment & Setup

The measurement system is composed of a transmitting side and a receiving side. The equipment used in the transmitting system consists of a signal generator, a rubidium oscillator, a power amplifier, and an omni-directional antenna. This equipment is usually housed in a building or in our Radio Spectrum Measurement System (RSMS-4) measurement vehicle. The equipment used on the receiving side of the measurement system is placed in our measurement vehicle, typically a green cargo van outfitted with equipment racks. The receiving system consists of a vector signal analyzer (VSA), a spectrum analyzer (SA), a power meter, a power divider, a rubidium oscillator, an omni-directional antenna, and a computer to store the data. The SA is equipped with a Global Positioning System (GPS) receiver to record latitude and longitude during data collection. The GPS antenna is connected to an SA port and is placed on the roof of our vehicle [5]. Fig. 2 shows the transmitting truck and the receiving van.

The transmitting truck has a mast which is raised to a full mast height of approximately 10 m above ground level (AGL). As the signal is transmitted into the environment, the receiving antenna on the van captures the signal, which is then split and measured by both the SA and the VSA. There is a time lag between the VSA and SA due to the lag in start times between the two instruments. The VSA has a larger dynamic range than the SA, however it does not contain an internal GPS receiver and so the SA data is used to align the GPS signals with the VSA data. This alignment is discussed in the next section.

B. Post-Processing

The SA data is processed separately from the VSA data and then the two are aligned as discussed in the following paragraphs. The SA data for each sweep is stored as log magnitude in a Matlab® event data structure and the GPS data is stored in a separate Matlab® event structure in the same file. The measured data for a single sweep is shown in Fig. 3. To process the SA data, the log magnitude is converted to watts and multiplied by 100 to account for the impedance. The mean value for all points in the linear power sweep is computed and is then assigned to the GPS time stamp for this sweep. In Fig. 3 the red X shows the mean value of the sweep as -101.3 dBm. This is done for every sweep in the file. The mean power for each sweep is then used along with the latitude and longitude to calculate the basic path loss and the free-space path loss at that point.

Fig. 2. Transmitting truck and receiving van overlooking downtown Denver.

The VSA raw I-Q parameters are written to a Matlab® file. Data saved into this file includes the sampling time, the frequency information, and the complex I-Q data pairs. During this processing step, the magnitude of the raw I-Q data measured by the VSA is smoothed over a 500 ms window to approximate a 40 wavelength driving distance [6], [7]. Fig. 4 shows the smoothed, windowed average power compared to the raw data. The raw data is shown by the blue trace and the smoothed power is shown by the red trace. The smoothed power is then time-shifted to align the VSA and SA data. A linear regression model is then used to minimize the residuals between the two data sets. The aligned data is displayed by plotting the SA power in dBm on the x-axis and the VSA power in dBm on the y-axis as shown in Fig. 5. The curvature at points below approximately -115 dBm is because the SA system noise floor is higher than the VSA system noise floor.

The alignment of the VSA power and the SA power vs. the elapsed time in seconds is shown in Fig. 6. The GPS time stamp from the SA mean power is then attached to the first data point of the VSA average smoothed power data series. This data is then saved and used in the Longley-Rice/Irregular Terrain Model (ITM) which will be discussed in the next section.

III. MEASUREMENT RESULTS

Measured results will be shown for three separate cities: San Diego, CA; Denver, CO; and Washington, D.C. For each city, we will show plots of measured basic transmission gain, and clutter statistics. We will also show how we extract clutter statistics from the measured data using the ITM terrain

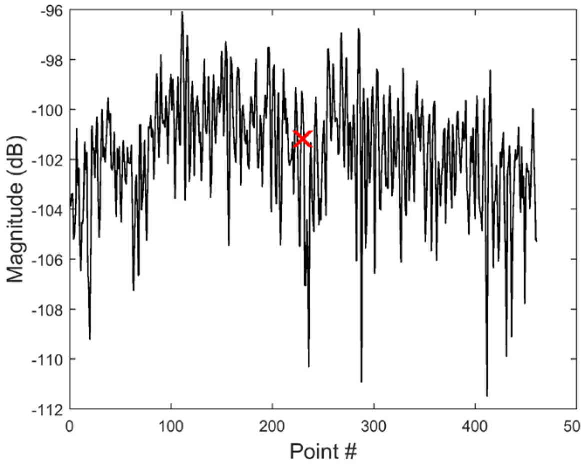

Fig. 3. Single sweep for SA data capture consisting of 461 points over a 500 ms sweep time.

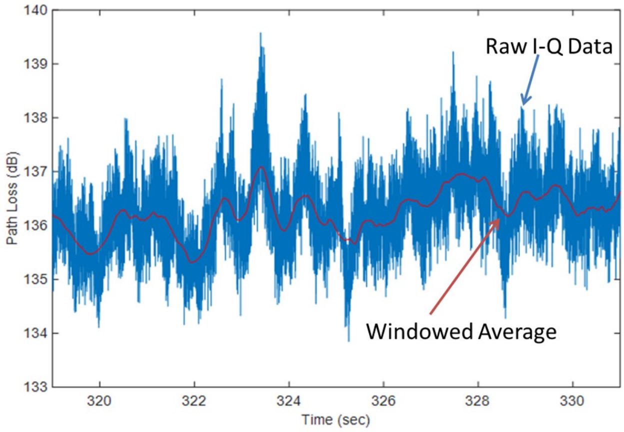

Fig. 4. Raw magnitude of I-Q data for VSA sweep (blue trace) vs. the smoothed, windowed average (red trace) for the VSA.

attenuation predictions and free-space path gain.

During each measurement campaign we tried to choose areas that were representative of urban, suburban, and, if possible, rural areas. Per our experimental special transmit authority (STA), to prevent interference to any current operations we scanned the frequency band of interest along each drive route and post-processed the scan to find a single open frequency on which to transmit our test signal.

A. San Diego, CA

We set up our transmitter in two locations, the Cabrillo National Monument maintenance facility (CNMMF) [8] on Point Loma and a parking lot on the Navy Point Loma submarine base ("sub-base"). The transmitting power was approximately 40 dBm. We drove two routes while in San Diego. The first route included the neighborhoods of Point Loma and La Jolla. The second drive route took us through the streets of downtown San Diego and the neighborhoods west of the city. Most of the testing in San Diego was completed at 3505.0 MHz for an internal project; however, we did complete a measurement along drive route 1 with the transmitter at the CNMMF at a frequency of 1760.0 MHz for comparison. Data will be shown for the measurements at 1760.0 MHz.

The elevation at the CNMMF is approximately 110 m above mean sea level (AMSL). The data shown in Fig. 7 is given in units of basic median transmission gain in decibels (dB). We use basic transmission gain which eliminates the system dependencies and makes it easier to reference our measurements to other measurements that may use a different system. The purple points show areas of lowest median basic transmission gain and the pink points show areas of highest median basic transmission gain. The regions where purple and blue points are located are areas that are shielded by the terrain. Pink and red points are located in line-of-sight regions or areas where hills are prominent. The transmitting location is shown by the black star with the red line.

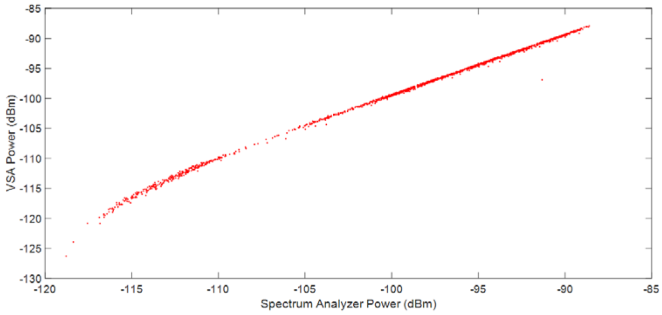

Fig. 5. Alignment of VSA Power and SA Power.

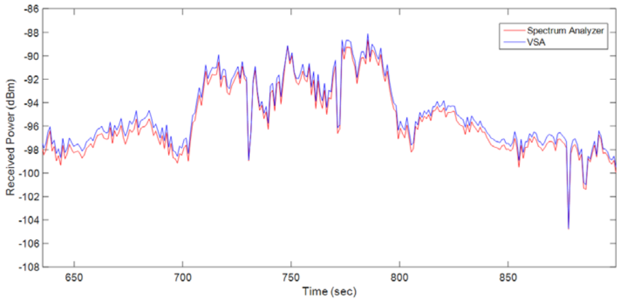

Fig. 6. Aligned VSA power and SA power vs elapsed time in seconds.

Fig. 8 shows a plot of the measured data (black x's), the ITM modelled median basic transmission gain (red circles (o)), and the free-space path gain (blue line (–)) as a function of elapsed time in seconds. The system noise floor for this measurement configuration was -165 dBm. Where the ITM model values are equal to the measured values, then ITM is predicting that all of the losses along this path are due to terrain diffraction. At places where the ITM model value is equal to the free-space transmission gain value, then ITM predicts that there is no terrain diffraction along this path. In this graph, there are places where the measured data, the modelled data, and the free-space data are all equal to the same value within some uncertainty. At these points, the receiving antenna has a direct line-of-sight back to the transmitting antenna. At places where the ITM model predicts free-space losses but the measured data is less than these values, then these losses are due to the attenuation around buildings and vegetation, or "clutter." These are referred to as clutter-only losses. These values are obtained by subtracting the measured data from the ITM modelled data. In places where the ITM modelled data is less than the free-space path gain, but greater than the measured data, then the path loss is a

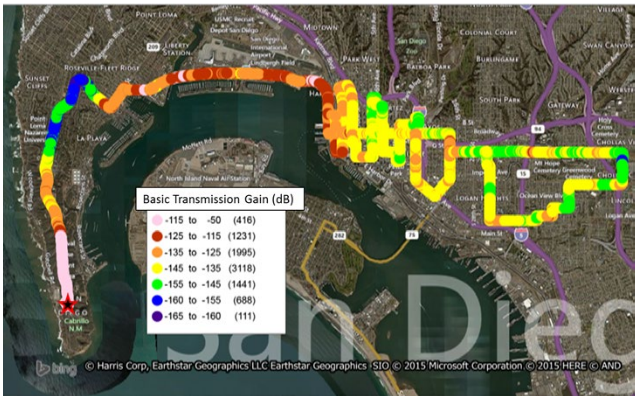

Fig. 7. Median basic transmission gain values along drive route 2 at a frequency of 1760 MHz.

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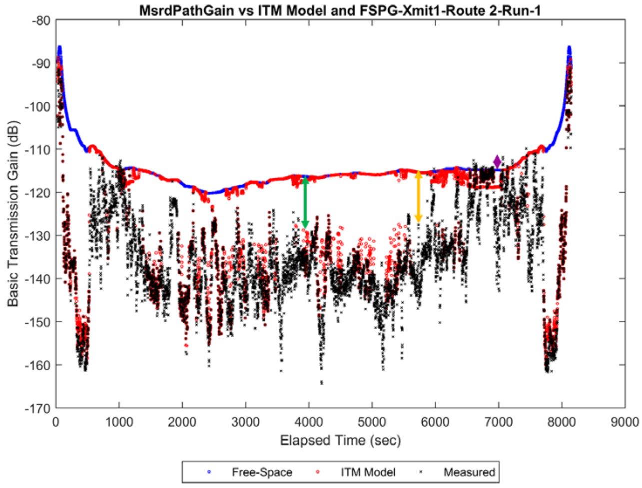

Fig. 8. Graph showing definitions of clutter (orange arrows) and terrain-diffraction (green arrows) losses and clutter gains (purple arrows) along route 2 in San Diego.

combination of terrain-diffraction losses and clutter losses. We will not show these terrain or clutter distributions in this report because these clutter statistics are dependent on the attenuation predicted by ITM and are therefore more uncertain. Fig. 9 shows the clutter-only loss probability distribution function (PDF) and cumulative distribution function (CDF). In this figure, the median value of clutter loss is approximately 20.7 ± 8.6 dB.

B. Denver, CO

ITS measured three routes in and near the downtown Denver urban area from three transmitting locations. The first transmitting location was 10–13 km away from the downtown Denver area and is named Hackberry Hill, the second transmitting location was 1–3 km from the downtown Denver area and is named Diamond Hill, and the third transmitting location was 1–5 km from the downtown Denver area on the rooftop of the Denver Museum of Nature and Science. Fig. 10 shows the three transmit locations and the three routes measured in this campaign. The area outlined in green is known as lower downtown and contains mostly low-rise buildings from approximately 4 m (13ft.) to 42 m (139 ft.) tall, outlined in purple is the high-rise urban area with building heights from 46 m (152 ft.) to 100 m (327 ft.), and outlined in pink is an area of residential buildings of one to two stories with many mature trees [9].

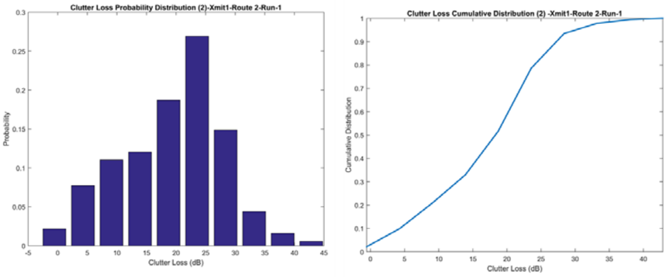

Fig. 9. Clutter-only loss PDF and CDF, respectively. This data was taken for the full drive route 2 at a transmitting frequency of 1760 MHz.

Fig. 10. This figure shows the three transmit locations (red circles) and three measurement routes on Google Earth®. The area outlined in green contains the low-rise downtown area buildings, the area outlined in purple contains the high-rise urban area buildings, and the area outlined in pink contains the area of residential buildings.

Fig. 11 shows a plot of measured basic transmission gain along the entire drive route with the transmitter at the farthest location. The elevation in this area was 1600 m AMSL. The transmitting frequency was 1761.5 MHz. The purple points show areas of lowest basic transmission gain values and the red points show areas of highest basic transmission gain values. The direction of the transmitter (white arrow) is also shown in this plot. Streets aligned with the direction of the transmitter will show higher basic transmission gain than streets not aligned with the direction of the transmitter. This is due to waveguiding effects down the aligned streets. Fig. 12 shows the clutter-only loss PDF and CDF. The median value for this clutter distribution is 22.2 ± 7.1 dB.

C. Washington, D.C.

ITS measured at three separate transmitting locations around the Washington D.C. metropolitan area. The first transmitting location was in the Alexandria, VA, area and we

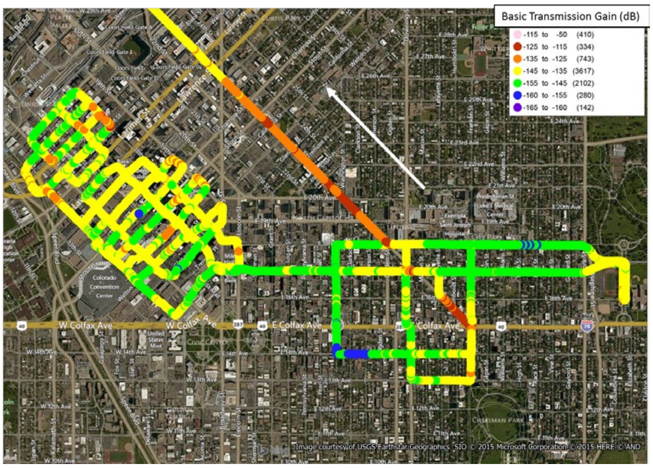

Fig. 11. Basic transmission gain values along the entire drive route in Denver, CO at a frequency of 1761.5 MHz.

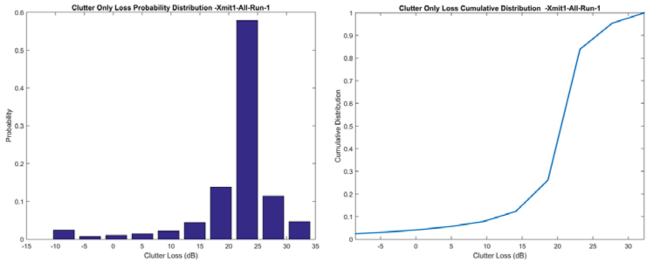

Fig. 12. Clutter-only loss PDF and CDF, respectively. This data was taken for the transmitter at Hackberry Hill, for the entire drive route at a transmitting frequency of 1761.5 MHz.

ran routes around this area. The second transmitting location was at the St. Elizabeth's Hospital Campus [10], and we ran drive routes into the downtown Washington, Arlington, and Suitland areas. The second transmitting location was 0.5-12 km from the downtown Washington area. The third transmitting location was at the Comsearch Government Systems (CGS) offices and we ran drive routes around the suburban/rural areas near Ashburn, VA. Fig. 13 shows all three transmitting locations, however, we will only show measured results from the St. Elizabeth transmitting location. The elevation at this transmitting location is approximately 40 m AMSL. The transmitting frequency was 1780.0 MHz.

Fig. 14 shows the measured basic transmission gain for all routes driven in the Washington, D.C. area. The first route was driven on the east side of Washington, the second route was driven from the Hoover Building to the west side of Washington, the third and fourth routes were driven around the Arlington-Suitland area, and the fifth route was driven near the National Cathedral [11]. The purple points show areas of lowest basic transmission gain and the red points show areas of highest basic transmission gain values. Fig. 15 shows the clutter-only losses PDF and CDF for the first route only. The median value for this clutter distribution is 27.8 ± 9.8 dB.

IV. CONCLUSION

This paper described the ITS propagation measurement system and post-processing of the measured data to extract clutter losses. We have described how to calculate basic transmission gain and have shown plots of clutter loss statistics for three cities at frequencies from 1755 to 1780 MHz. The three cities were San Diego, CA; Denver, CO; and Washington, D.C.

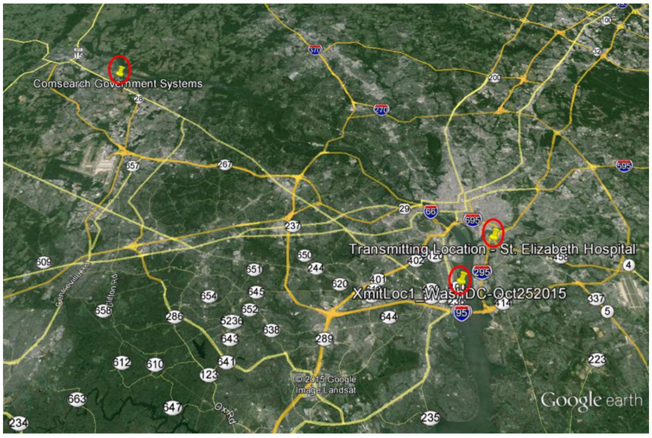

Fig. 13. Figure showing the location of the three transmit locations (red circles) with respect to the Washington, D.C., metropolitan area on a Google Earth® map.

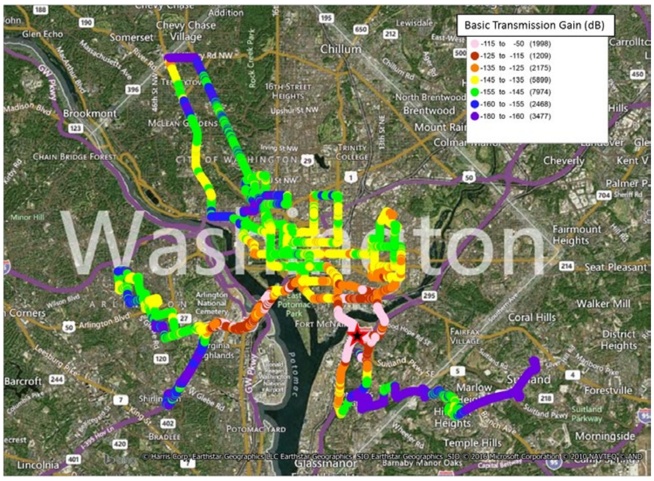

Fig. 14. Measured basic transmission gain (dB) for the five drive routes in and around the Washington D.C. area with the transmitting antenna located at the St. Elizabeth's Campus overlook.

We selected transmitting locations that offered a variety of elevation angles and at various azimuthal locations and distances around the city. An initial spectrum survey was conducted in each city prior to measurements to choose a CW transmitting frequency to avoid interference with operations in the band. Data taken in each city is given in Table I. Losses for route 1, with the transmitting antenna at St. Elizabeth's campus overlook, appear to give larger clutter loss values in Washington, D.C. We noticed that there are many narrow streets and many trees in the Washington area that contribute to the clutter losses. There are also many houses and building units that have no intervening space between them.

The downtown San Diego area appears to have larger open areas between buildings than either downtown Denver or the downtown Washington area. Current terrain models predict attenuation along a two-dimensional (2D) path. Future models need to understand the interaction between terrain and clutter in a three-dimensional (3D) environment. The land-use, land-cover (LULC) categories are currently being used to see if they can inform clutter models in a certain areas.

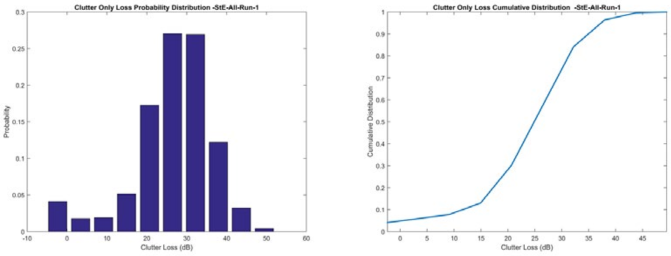

Figure 15. Clutter-only losses PDF and CDF, respectively. This data was taken for the St. Elizabeth overlook, for the first route, at a transmitting frequency of 1780.0 MHz.

TABLE I. DESCRIPTIVE STATISTICS FOR CLUTTER-ONLY FOR SELECTED ROUTES IN: SAN DIEGO, CA; DENVER, CO; WASHINGTON, D.C.

City	**Minimum (dB)**	**Maximum (dB)**	**Mean (dB)**	**Median (dB)**	**Standard Deviation (dB)**
San Diego, CA	-3.0	45.3	19.4	20.7	8.6
Denver, CO	-10.8	34.5	21.1	22.2	7.1
Washington, D.C.	-5.2	52.3	26.5	27.8	9.8

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