Building Mesh Networks with Line-of-Sight and Viewshed Analysis

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Abstract

As high-quality broadband connectivity improves, community members from low income neighbourhoods are the first victims to suffer from digital injustice. Low-income communities constantly suffer from key services that otherwise could help a community progress. One of these services is the lack of resources to pay for an Internet service. In today's world, Internet accessibility has become a necessity. No online access often impedes the personal and economic growth of individuals. Not to forget, it might even be difficult to have their voices heard on many political and social topics. Many communities have made the decision to stop depending on corporations and take matters into their hands by owning their own Internet wireless network infrastructure. Mesh networks are believed to help close the digital divide of low-income communities by increasing broadband accessibility. To facilitate the effort of communities to build their own broadband infrastructure, this project explores the power of geospatial technologies applications to identify suitable urban areas to install affordable equipment were nodes communicate with each other without obstruction. In urban settings, trees and buildings are major constraints to expanding a broadband ecosystem which otherwise delays the process of installing antennas. In this project, I suggest that a line-of-sight and viewshed analysis of the Hilltop Neighbourhood will identify suitable areas for the installation of access points to build a robust and stable wireless connection. By rethinking and establishing a workflow around a line-of-sight and viewshed analysis from lidar imagery, the trials and errors of nodes installation will be cut back, and more families can be serviced with affordable Internet access. By predicting areas where Internet connectivity is reachable, might allow organizations to improve site planning and continue fighting back against the digital divide created by the constant competition among Internet Service Providers (ISP).

1. Introduction

In 1996, the Telecommunications Act, was the first significant attempt from the United States to free up the telecommunication market and allow telecommunication companies to compete in this industry. The new regulations on internet access affected telephone services by allowing competition among companies and lowered internet service prices for Americans. The rapid evolution of the communication industry raised many concerns about internet service. The online "world" was quickly evolving, making it difficult to strictly regulate broadband services for Americans. In recent years, there have been many discussions that the internet should be considered a form of utility. A utility system in which it is considered a human right that everybody should have equal access to. According to the Telecommunications Act of 1996 “the Internet and other interactive computer services offer a forum for a true diversity of political discourse, unique opportunities for cultural development, and myriad avenues for intellectual activity.” Even more important, the American population has grown a strong dependence on ISPs, accustomed to overcharging families for their broadband services.

As a result, more and more organizations and communities have started building their own local broadband network. A local broadband network would allow community members to deploy their own antennas and join the network of the community be connecting to their neighbor’s antennas. This system in which everyone’s antennas connect to each other allows for an exchange of bandwidth in which the inclusion of more nodes could mean faster internet bandwidth at an affordable price. This study attempts the use of Environmental Systems Research Institude (ESRI) three dimensional scenes as a tool to continue exploring geospatial technologies in the telecommunications industry.

Geospatial technologies could play a significant role in the design and implementation of equitable internet access for everybody. Specifically, geographic information system (GIS) have become a very popular industry for its ability to effectively and accurately to tie attribute data to spatial locations. As a result, from the Telecommunications Act of 1996 and the National Infrastructure initiative, telecommunications must provide sufficient access to urban and rural communities (MapInfo, 1997, 11). GIS can serve as a tool by using their data to provide population density analysis, map current facilities, and network expansion site planning. There are many costly extensions that create radio frequency propagation models, analyze communication networks, and choose location sites (Carstenen, 2001). Nonetheless, these types of extensions can be very costly and might even be more than what is needed for local community networks.

This project focuses on understanding the influence of a viewshed and line-of-sight analysis to facilitate the planning and installation of antennas that act as nodes on a mesh network. At the same time, how to account for landscape surface object and manmade infrastructure that act as local obstructions within urban areas. Finally, can analysis with lidar imagery help communities close the digital divide gap and be cost effective for organizations building mesh networks within urban areas? How can exploratory analysis of the landscape be created and used to limit field site planning?

2. Literature Review

2.1 Background on Broadband

According to the Federal Communications Commissions (FCC), broadband is defined as high-speed Internet access, other than dialups, that allow users to connect to the Internet backbone and related services (Industry Canada, 2001). Many low-income communities lack the luxury of high-speed Internet access or online access at all. Therefore, mesh networks have become an outlet for these communities to gain access to high speed internet without depending on service providers. Even though mesh networks have not taken off, they tend to be more reliable than your regular Internet service connected to a few centralized access points governed by ISP. In this paper, mesh network refers specifically to a local neighbourhood network topology in which nodes, computers and devices, connect directly to as many nodes as possible to deliver fast Internet data. Nodes can be considered as antennas and routers with a dynamic connection allowing neighbours to share Internet connections. These networks have been considered to have more advantages over wired connections. In moments where a network is broken, it holds the ability to reconfigure itself according to the availability and proximity of bandwidth and storage (DeFilippi, 2014). Once a mesh network infrastructure is established, they can continue to grow by anybody that is willing to install a wireless router on their rooftop or windows, allowing routers to pass the signal around.

Besides the many efforts of past administrations in the United States to expand broadband, as of today 2% of Americans remain with no access to the Internet and roughly 20% of Americans are not online (Scola, 2015). In the last few years, communities are beginning to come together to figure out a way to create an Internet network infrastructure that will fit the contours of their neighbourhood at an affordable price. Communities that have adopted this model have helped people come from off the grid to apply for jobs and connect with people more often. Kansas City is a great example where a great portion of the population was left off the grid by a major company, Google Inc. In 2012, their citywide Google fiber project left 17% of the community members without internet access when fiber was installed only for those that could afford to pay for an upgrade. As a result, KC Freedom Network, a community-owned wireless internet co-op that installs and maintains a grassroots mesh network, was created to support those affected by the ISPs monopoly.

For decades, scholars have been examining the innumerable ways in which geospatial technologies can impact and narrow the digital divide gap by understanding the interaction between humans and the space around them. The internet services have not been used within the geospatial field as much as other industries. This research looks to explore visibility studies to improve the planning of mesh Internet network infrastructures. In Garnero's reading (2015) emphasizes that visibility studies, referring to rural and forest landscape analysis, are usually based on terrain representation and require some level of simplification in order to take vegetation and other obstacles that affect visibility into account. The same logic would apply to mesh networks on urban areas, as vegetation and building obstructions affect the connectivity of antennas on a mesh network. Specifically, the use of Digital Elevation Models (DEMs) for three-dimensional GIS (3D GIS) has become a conduit for enabling investigations into landscape visibility within urban environments (Stewart, 2019).

2.2 Approach to Viewshed and Line-of-Sight Analysis

Case studies have come to a consensus that a geospatial approach is a powerful way to assess a wide variety of issues extending from environmental, governmental, and economic issues (Jones, 2009). Geospatial technologies can play an important role in the deployment, planning and system design of wireless broadband networks. In order to study a wireless signal propagation model within an urban neighbourhood it is recommended to consider a methodology that considers both topology, environmental, and infrastructure factors (Garnero et al, 2013). A viewshed analysis is a function of GIS that determines which areas within a surface raster are visible from a vantage point of view. A line-of-sight will determine the visibility of sight lines over obstructions ("clutter") in the landscape between two points. Therefore, these models will determine areas and location points that can help nodes interact dynamically with each other without any obstruction between them.

In a mesh network, nodes communicate with each other in a line-of-sight beaming signal from one node to another. A line-of-sight would, ideally, facilitate the installation of access points by determining obstruction between them. There is no consensus on a single approach for broadband planning and network development. The many variables and sources of data to create an Internet network infrastructure are a challenge that needs to be addressed and researched further (Cai, 2002). Specifically, vegetation and utility infrastructure are a real challenge for field crews installing access points. There is not a streamline process established that helps communities determine areas of complex Internet connectivity. Given the many variables in urban areas, a line-of-sight and viewshed analysis approach is one of the most straightforward tools within the field of geospatial technologies to identify the most suitable locations to create and/ or expand a mesh network (Sawada, 2006). This work tries to consider more realistic factors that become local obstruction in the development of a robust and reliable broadband network (Jones, 2009) and that do not solely depend on human vision (Garnero et al, 2013).

2.3 Analysis Parameters

Line-of-sight models are often used to determine what can be seen from a vantage point in the landscape. One of the first requirements for a line-of-sight and viewshed analysis is a three dimensional surface of the landscape. For most visibility studies buildings, vegetation, and soil surface characteristics play a crucial role in the results of an analysis. On this project, I am moving beyond the standard binary approach of terrain modeling and utilizing local physical variables such as infrastructure and environmental variables that might influence the outcome of the modeling analysis. The installation of antennas on building rooftops, particularly in dense urban areas, is a promising solution to building affordable, equitable, and fast mesh networks. However, several factors impact the time and availability for installation of antennas and gateways on the rooftop of buildings. It is imminent to account for localized features on the landscape, such as trees and urban infrastructure that have a substantial impact on the distribution of signal between nodes. From Anderson’s case study (2003), there are four main environmental categories to consider during wireless signals propagation models: topography, building/structures, land use/land cover, and atmospheric conditions.

Not many scholars have dove into atmospheric and/or meteorological conditions as variables for a wireless propagation model because these weather variables are considered to have minimal effect on broadband network signals (Jones, 2009,35), unless the modelling is focused strictly on visibility analysis. According to Jones, there are many other categories that can be considered for a propagation model like earth’s curvature and antenna power gain which would affect the transmittal of signal among antennas through space. These categories tend to fall within a more mathematical model approach that will not be addressed in this study. The focus of this study is to find a workflow in which geospatial technologies can continue to be utilized as a cost and time effective tool for communities in the process of building their own wireless broadband network.

3. Intervention

For the intervention of this project a methodology was developed to extract landscape and manmade features from urban areas with publicly available lidar point cloud data. Two scenarios were created on the neighbourhood of Hilltop in the City of Tacoma. This neighbourhood is home to organizations working to expand reliable, fast, and cheap local community wireless mesh networks. The urban locality of the area allows for fast installation of antennas on the roof of community members to be able to connect to the antenna of their neighbours and together create a relay node to form the community Internet network. The locality of the area also serves as a great exploratory site to understand the powerful tools of geospatial technologies in the telecommunication industry. The basis of this project was to develop a series of three dimensional scenarios from point cloud or LAS data aimed at analysing the landscape and propose different routes or areas of antenna connectivity among community members. Landscape features and manmade features were extracted and visualized in three dimensional local scenes. The analysis was able to identify areas with a high vegetation index to define areas that might be affected with lack of bandwidth and cause the signal frequency to bounce back. Using GIS software this project is to analyse potential obstruction free areas aimed at increasing site planning and to bring affordable Internet network to families in the local communities. Using key vantage points will provide a varied look from around the area to determined impacts of possible future expansion of an Internet mesh network from given elevation points.

4. Methodology

The methodology that was developed in this research is quantitative and applied in nature. A line-of-sight and viewshed analysis model was created to construct a workflow that could be adopted, utilized, and further developed by organizations to analyze the landscape and identify suitable locations for the installation of community network equipment. This research will be focused on the Hilltop Neighbourhood area within the City of Tacoma. The neighbourhood has adopted a mesh network infrastructure managed by the Tacoma Cooperative Network. The Tacoma Cooperative Network provides community access to fast, reliable, secure, and inexpensive internet to Hilltop Neighbourhood. This is a great location to develop a model for its urban locality and the amount of spatial public available data of the area. The research will unfold in three different phases: data gathering and set up, development and analysis, and visualization and distribution of results.

4.1 Data Gathering

This project was completed using Esri ArcPro to develop two dimensional and three dimensional local scenes for analysis. A geodatabase (Table 1) was developed for this project with original LAS data, vector feature layers and analysis of geoprocessing outputs. Data was primarily sourced from the City of Tacoma GIS Analysis and Data Services (GADS) Portal.

Table 1. Project geodatabase schema.

Feature Type	Feature Name	Source	Feature Year	Purpose
LAS	LAS Dataset	Tacoma Water	2018	Data Analysis
Polygon	Buildings	City of Tacoma	2015	Basemap
Polygon	Hilltop Boundary	City of Tacoma	2015	Basemap
Raster	Hilltop DEM	Created	2020	Elevation
Polygons	Extruded Buildings	Created	2020	Analysis
LAS	Extruded Vegetation	Created	2020	Analysis
Raster	Vegetation Index	Created	2020	Analysis
Point	Vantage Points	Created	2020	Analysis
Point	Target Points	Created	2020	Analysis
Polyline	Line of Sight	Created	2020	Analysis

4.2 LAS Data

Lidar data was acquired in the form of point cloud data also known as LAS file. LAS data is a file format of point cloud data designed to provide data in its native format, statistics, and details of area coverage across a specific area. The lidar was processed to create a digital surface model (DEM) of the area from ground points to serve as the base elevation for this project. The LAS point cloud data from the City of Tacoma was tailored to the landscape following ASPRS Classification standards. This classification included Unclassified, Ground, Noise, Water, and Bridge points. The absence of vegetation and building point cloud classification on the original LAS data required post processing to be able to accurately extract vegetation and building features to account for obstruction variables in the analysis.

4.3 Building Extraction

ArcPro local scene was utilized to visualize point cloud data in three dimensional scenes. The three-dimensional local scenes allow a 360 view of the Hilltop neighbourhood from a given point. From the remaining unclassified point cloud data, the "Classify Buildings" tool was used to classify points with a minimum of 6 feet and an area bigger than 60 square feet. Further classification of points was manually with the lidar interactive edit tool achieved after some quality control of the new las dataset output. The lidar interactive tool allowed to zoom in into areas where there might be errors to the classification of points. This allows reclassification of points to a different category from the ASPRS Classification standards. Once the unclassified point cloud data have been reclassified, a series of steps followed to convert the building classified points to three dimensional polygons. These included a series of steps:

1. Convert building points as a statistic raster. This assigned each cell of the raster with a statistical value represented by the building.
2. From a raster these cell values were converted to a polygon feature layer.
3. Some processing took place to smooth and regularize buildings footprint parts.
4. A multipatch derived from building's rooftops was created to model the buildings in a three dimensional form.

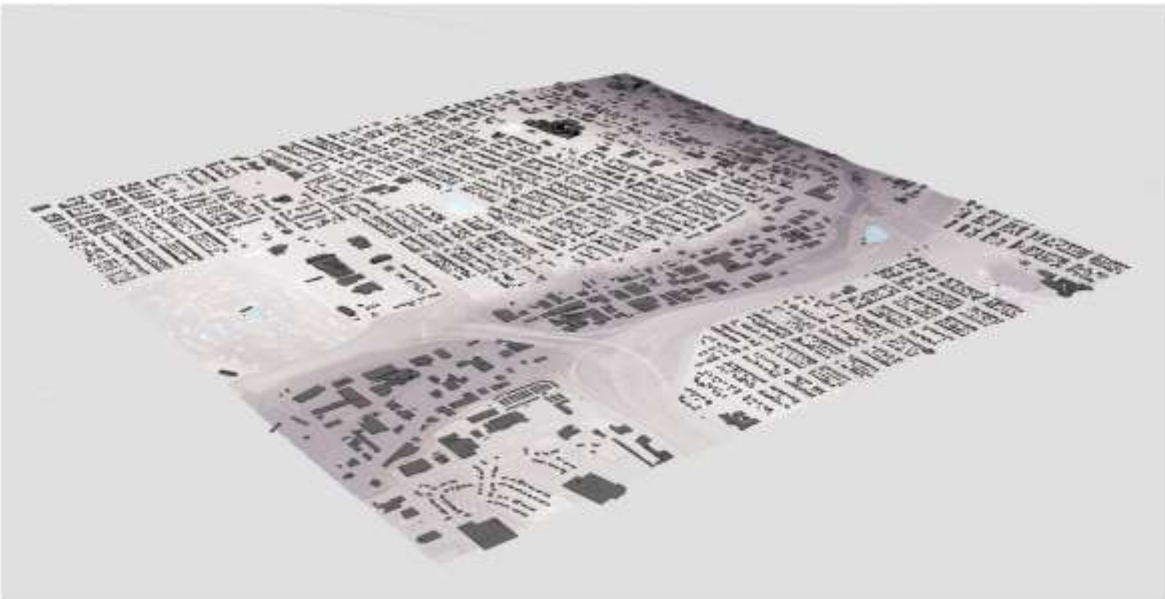

Figure 1. 3D representation of buildings with digital elevation model.

4.4 Vegetation Extraction

Acquiring vegetation data was considered however the study was not successful finding vegetation points. Vegetation boosts the capabilities of a line-of-sight analysis. Once building footprints and ground points were classified, vegetation was extracted from lidar first return points. Specifically, the "Classify LAS by Height" geoprocessing tool was used to define vegetation at the 3 (low vegetation), 4 (medium vegetation), 5 (high vegetation) class codes. The classification of vegetation points allows to analyse the landscape and identify areas with dense vegetation that may require further consideration when expanding a mesh network infrastructure. Refer to Figure 2 for a visualization of the vegetation raster generated of the Hilltop neighbourhood.

Figure 2. Hilltop Neighbourhood after vegetation extraction.

4.5 Line-of-Sight and Viewshed Analysis

After the three dimensional scene was constructed, an exploration of the Esri tools and analysis was conducted for a given areas. Exploration included utilizing multiple vantage points that represented an antenna at a given height and angle, modelling a line-of-sight and viewshed signal frequency. The viewshed analysis allowed to work with different vantage points in the neighbourhood and allowed to see where sightlines occur.

5. Discussion

The methodology developed illustrates the way GIS can be used to potentially show areas where antennas could be deployed with sufficient knowledge of the landscape study area. However, there are several caveats that need to be noted with regards to the use of the data and assumptions underlying this project. From the project design and operational perspective, the caveats are a guide to the informed used of the map, decision making, and it is intended to contribute further refinement of the methods used.

Once the data was process, GIS continued to be used to clarify additional questions related to this project and determine the validity of previous assumptions. For the first scenario, it has been assumed that an antenna, when placed, will be able to establish a link to the fiber optic-based backbone. Each scenario has been analyzed independently from the other considered locations. The extruded building heights and trees allowed the construction of three dimensional scenes, exploration of tools, and exploratory analysis of the landscape. Exploration of the landscape included utilizing a point designed as the observer (vantage) point in an interactive line-of-sight and viewshed analysis. The line-of-sight analysis (Figure 3) allowed the ability to work from these vantage points to analyze visibility to target points in a straight line of sight.

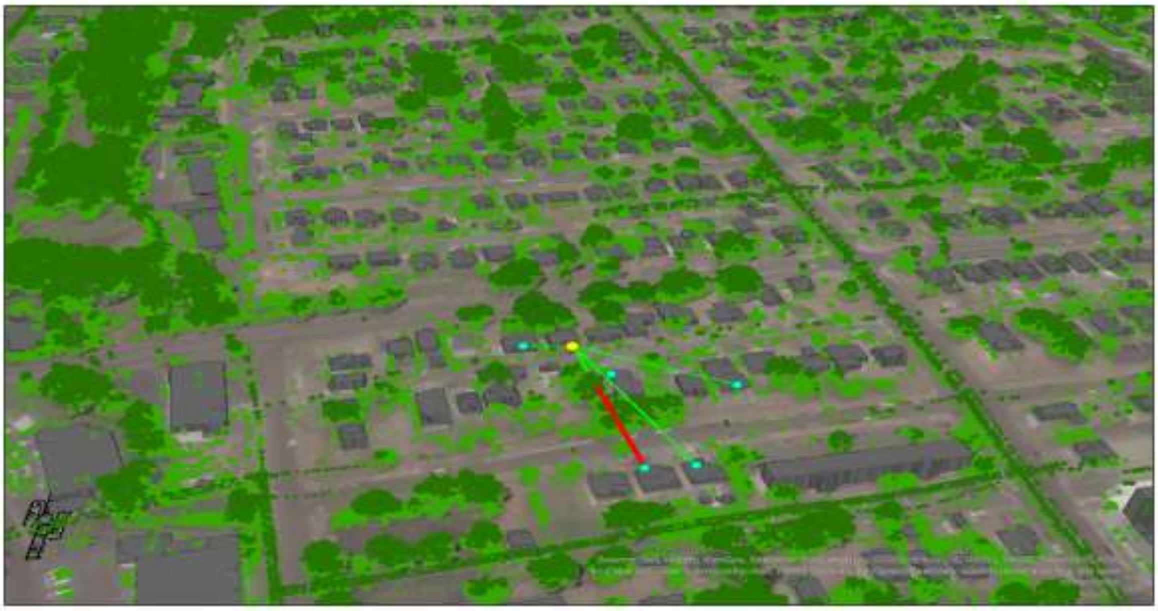

Figure 3. Hilltop Neighbourhood after vegetation extraction.

The viewshed analysis (Figure 4) allowed a 360-degree analysis of the landscape with inputs to define visible locations from the vantage point. The vantage point was chosen as there are considerations of installing an antenna at this location to expand a community wireless network. Based on the location of the vantage point: tilt, heading, distance, and angles were altered with the ArcPro 3D analyst tools. The viewshed analysis took into consideration building height and not vegetation. This project was able to extract vegetation as a raster and as a LAS file format. It is believed that the vegetation could be taken into consideration on this analysis if vegetation were to be converted as three dimensional vector points. The following figure visualizes the process and output of the methodology and analysis in three dimensional view from extruded building heights, vegetation, and ground data derived from acquired lidar data points. The viewshed analysis was created with a 45 vertical degree angle, 360 horizontal view, and 1,000 feet maximum viewshed distance. The conversion of this parameters into the viewshed analysis allows to see where there are obstructed sightlines from the vantage point based on building heights extruded in the three dimensional local scene.

Figure 4. Hilltop Neighbourhood after vegetation extraction.

5.1 Challenges

Lidar data proved to be a challenging task. The process of classifying point ground data from ground and unclassified points presents a challenge of itself. Given the classification of buildings and vegetation more time is required to explore other methods and tools to classify utilities and convert vegetation point cloud data into three dimensional points. Further use of wireless technologies require the consideration of antenna height, atmospheric scattering, frequency, vegetation, topography, manmade objects, and path. These factors need to be considered individually and collectively to create a site plan. While it is possible to integrate many of these factors into GIS there are limitations to GIS packages in conducting radio propagation analysis. While visibility analysis is great to explore it is also limited to understand signal strengths (M. Sawada, 2006).

Geospatial technologies can serve as an avenue to continue answering questions to create mesh network infrastructure. In this case, the technology exists to create exploratory scenes of the local landscape. Local three dimensional scenes allowed analysis of the landscape and the different variables that might impede the expansion of nodes within a wireless mesh network. The line-of-sight analysis proved to consider vegetation point cloud data. However, more time is needed to continue refinement the methodology to derive other obstruction objects and provide a well-rounded view of the project scope.

6. Conclusion

This paper began by establishing the importance of broadband connectivity and the challenges to equitable Internet access for underserved communities in urban and metropolitan areas. The beginning of this paper goes into comprehending the way affordable broadband can help community members to have access to more opportunities for personal and professional growth. Not only it will help community members with growth but to stay connected to a society invested in technological advances, providing them with a tool to have their voices heard in many political and social topics. Still to this day there are many organizations, communities, and businesses invested in finding solutions and affordable ways to equitable access to broadband Internet services.

This project specifically focused on finding ways that geographic information systems (GIS) can be used to purposely model line-of-sights and viewshed analysis for site planning and expansion of broadband internet access by measuring waves frequencies in a line-of-sight and viewshed analysis. In the second part of this paper, this study goes into exploring GIS as a tool to identify relevant obstructions in the process of developing more reliable, cost effective parameters for the deployment of antennas. GIS gathers and layers data to understand spatial patterns across a given area. This project discussed the way that a GIS approach in studies involving broadband connectivity in landscape surface analysis and planning can serve to analyze the landscape for obstructions.

The site area covered in this study was the Hilltop Neighborhood within the City of Tacoma. There are already organizations in the area modeling and deploying mesh networks for the local community. The acquisition of lidar data provided by the City of Tacoma (which is available through the Washington State Natural Resources Lidar Portal) allowed the creation of a digital elevation model (DEM) and extraction of surface and man-made features. The lidar data was acquired in the original LAS format also known as point cloud data. After further processing three dimensional scenarios were created to understand if the ways a viewshed analysis and line-of-sight could define a plan that predict future locations of mesh network nodes across the urban landscape.

Initial results of the analysis and methodology developed for the Hilltop Neighborhood indicates areas that could potentially be served with broadband wireless systems. In this study of line-of-sight and viewshed analysis, elevation data, building heights, vegetation were created as input layers for the project's analysis. From the results of the analysis it is hypothesized that the new data could be used as a predictive plan for areas that could receive signal sent from an emitting signal node at a line-of-sight frequency. The viewshed analysis and line-of-sight show general areas where signals can be received from a specific vantage point. Overall, the results of this project suggest that a GIS based analysis defines ways for rapid assessment of a particular area with minimal data and with the support of open source data. Moreover, vegetation feature extraction from point cloud data suggests the frequency's variance from line-of-sight activity and possible areas where a signal could possibly bounce back after encountering dense vegetation. This type of analysis could serve as a mean to develop initial site planning. This type of analysis could also be used to continue pushing for public policy initiatives to ensure the equal access to broadband Internet access and close the digital divide many communities face every day.

All this study is targeted at creating a GIS tool to help record, organize, and plan project sites at a more quick and affordable way for non-profit organizations to explore. Further research and refinement of methodology discussed in this paper should include a viewshed analysis for the study of the area using and comparing active network nodes for comparison. More research and refinement could be given to the viewshed analysis tool to determine whether the function can be altered to predict the frequency of different instruments.

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