Determining Accurate Microwave Path Performance
Why a Detailed Path Survey Will Save Money

Executive Summary: An optimally performing microwave communication network begins with a properly conducted path survey that analyzes the microwave path's characteristics to identify and mitigate all potential signal obstructions. Ultimately, a detailed path survey can reduce outage time and save money on costly repair or reinstallation bills. As the demand for point-to-point microwave transmission technology increases, the need for a properly designed and installed network becomes imperative. This paper outlines the recommended methods used by Communication Infrastructure Corporation® for conducting a thorough path survey, as well as key items to consider when hiring a company to install your network.

Introduction

An optimally performing system begins with a properly conducted survey that analyzes a path's characteristics to identify and analyze all potential signal obstructions. Ultimately, such a detailed survey can reduce outage time and, therefore, improve customer satisfaction. More importantly, when emergency responders depend on uninterrupted service for communications, reduced outages can potentially mean the difference between life and death. Done right, a formal microwave path survey can also save money in the long run by reducing repair bills and the potential for costly reinstallation. Thus, for a relative fraction of the cost of a complete microwave installation, companies who spend a little extra up front for a thorough survey can significantly reduce the frequency of outages, save money in repair costs, and potentially save lives.

A Brief History

In its early stages, point-to-point microwave systems were used primarily for long-haul communications, such as long-distance telephone service. Later, utility companies began to adopt its use. Today, point-to-point microwave technology is favored for backhaul in conjunction with mobile phone service providers and private networks, as well as in public safety. Many smaller users, like schools and libraries, deploy microwave point-to-point systems as well.

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Microwave systems continue to evolve in application, capacity, assigned frequency bands, modulation schemes (and the latest adaptive modulation), and in multiple other enhancements and advances. The advent of microprocessor technology has also had a major impact, including many aspects of design engineering and implementation.

Short links do not necessarily need a path survey; establishing line-of-sight (LOS) might be sufficient. However, those with much longer paths require more detailed surveys, now possible with software and terrain databases that provide the necessary details for determining path characteristics. For example, specialized software now includes design elements like k-factors and Fresnel zone clearances. Additionally, terrain features (including photographic images of man-made structures) and climate zones are available via electronic databases with varying degrees of projection and detail.

Use of this specialized software and their associated databases is most applicable to microwave systems with relatively long paths and applications needing actual design elements beyond a simple determination of LOS.

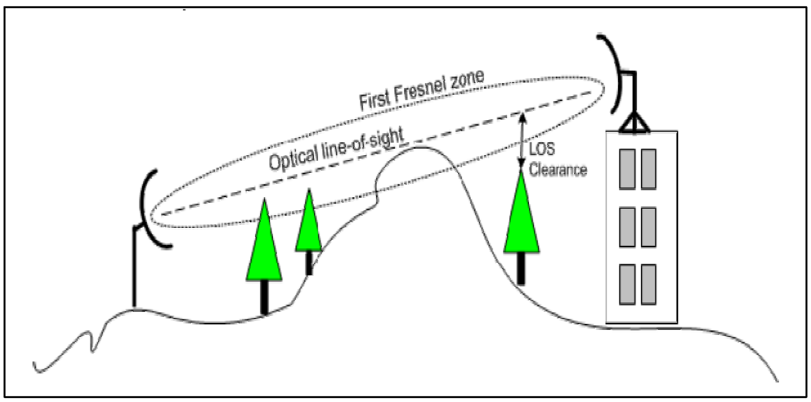
The Disadvantages of Visual Line-of-Sight Surveys

Some microwave systems have path lengths of only several blocks, or even shorter, while others transmit signals along paths tens of miles long. In many cases, the assigned frequency bands reflect both path length and also bandwidth requirements. For networks with relatively short path lengths, LOS can be easily determined via a simple visual method: Is the other end of the path visible or obstructed? If the distance between the points is too far, field technicians use binoculars and strobes or mirrors to send a light signal from one end of the path to the other. If the flashing light is detectable from the other end of the path, it constitutes a visual LOS, and the path is deemed acceptable. Visual assessments are okay for an initial feasibility study (and/or for very short paths) but not adequate for designing a microwave link to perform at maximum capability and for a long period of time. In particular, systems with longer paths require alternate methods of determining LOS and other path characteristics.

1. Certain Signal Disruptors Are Missed

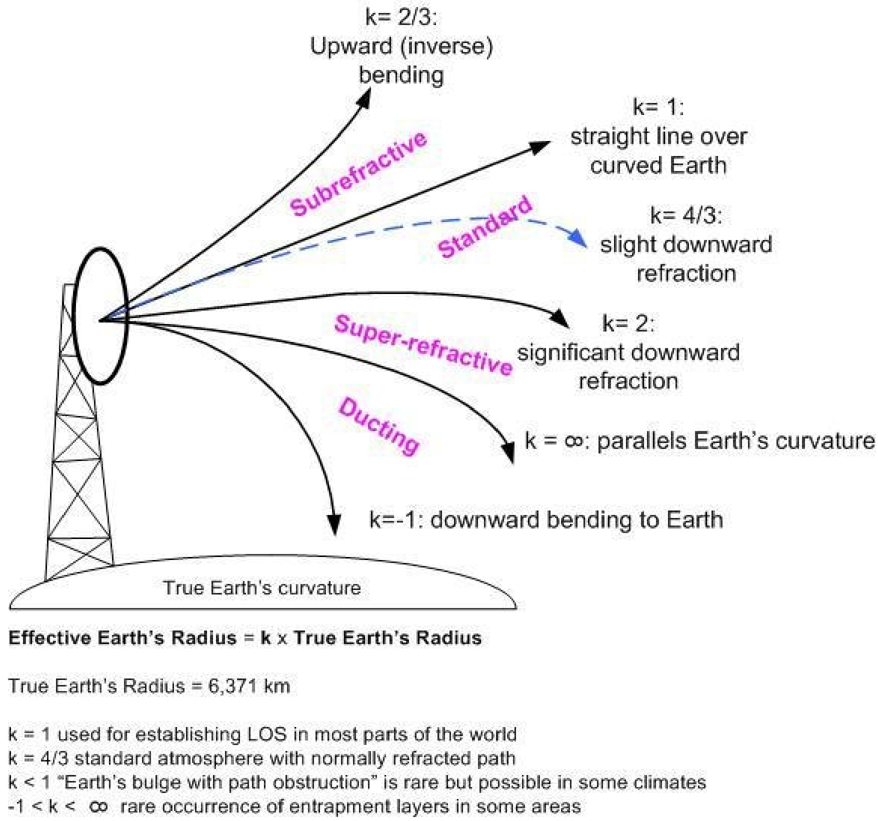
Trees, terrain, buildings, and other structures all have the potential to cause propagation anomalies; that is, they disrupt or deflect microwave signals to distort and scatter them. Yet even if such physical barriers are noted in a visual LOS survey, their actual affects cannot properly be accounted for without a more thorough survey. For example, if the Fresnel zone clearance is not calculated, a tree that appears out of the way in a visual survey could actually cause diffraction losses, increasing outage time. (See Figure 1) In microwave communications, a Fresnel zone is one of a theoretically infinite number of concentric ellipsoids forming the radiation pattern between a transmitter and receiver. Each zone has a specific volume; the largest zone (called F1) is widest at the midway point between the transmitter and receiver.

__Figure 1:__ A visual LOS survey cannot predict which physical features have the potential to create propagation anomalies.



Less obvious barriers to microwave signals include the Earth's curvature (k-factor) and atmospheric conditions, which differ over geographic areas and change locally throughout the year. In coastal areas, for example, changes in atmospheric density due to temperature inversions, rain storms, and normal diurnal fluctuations can vary the Earth's effective curvature from 4/3 to 0.5. During the year, a typical microwave path might experience a change in clearance by 20 feet or more. As atmospheric fluctuations cause the beam to bend, the signal strength can easily vary by 20 to 30 dBm. (See Figure 2) In order to account for these fluctuations, the engineer must carefully calculate the Fresnel zone clearance based on the likely range of k-factors for the region where the microwave path is to be built. Thus, Fresnel zone clearance cannot be determined through a visual LOS survey.

Figure 2: *K factors describe the effective Earth radius, e.g., the radius of a hypothetical Earth for which the distance to the radio horizon in straight-line propagation is the same as for the actual Earth with a uniform vertical gradient of atmospheric refractive index.*



Visual surveys can cost more in the long run and the potential for outages is much higher than for detailed path surveys.

2. The Potential For Outages Increases

Skimping on path design details in favor of a visual LOS survey—whether using mirrors, spot lights, balloons, or simply climbing the tower and looking with binoculars—will likely result in a significant number of blocked paths. Again, the full effect of physical obstructions and atmospheric effects cannot be taken into account visually. Fresnel zones must be determined. If propagation anomalies go unaddressed, outages persist. Even when the problems are addressed, companies still must suffer some down time in order to fix them.

3. Visual Surveys Can Cost More

Though the hourly labor rate may be higher to perform a detailed microwave path survey, the overall cost outlay is less than for labor required for a visual LOS survey. (See Table 1) Further, the guessing game of visual spotting can lead to building excessive clearance, which increases costs (extra transmission line and tower rental fees) and the potential for outages (higher potential for reflections, multipath distortion, and radio frequency interference). At best, companies must invest more money later for the more detailed survey and reinstall the system. At worst, systems can completely fail.

Visual LOS Survey		Formal Survey	
Estimated Effort (Hours/Path)	17.25	**Estimated Effort (Hours/Path)**	3.3
Number of Persons Required 2 tower climbers 2 ground crew (per OSHA) 1 project coordinator	5	**Number of Persons Required** 0 tower climbers 0 ground crew 1 path surveyor	1
Effective Project Duration (Hrs) 3 average per path 10% poor weather factor	3.45	**Effective Project Duration (Hrs)** 3 average per path 10% poor weather factor	3.3
Average Hourly Labor Rate	$75	**Average Hourly Labor Rate**	$95
Total Labor Cost Per Path	**$1,293.75**	**Total Labor Cost Per Path**	**$313.50**

__Table 1:__ If each of the five people on the flash team were path surveyors, the time required to survey a system could be cut by a factor of 4 to 5, saving both time and money.(Costs are based on 2007 figures.)

The Benefits of a Detailed Microwave Path Survey

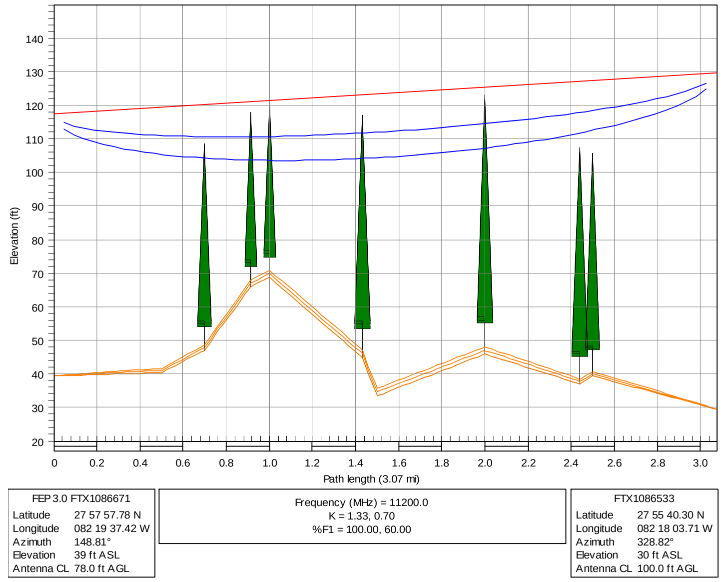
As mentioned earlier, systems with relatively short path lengths may get away with a simple visual analysis to determine line-of-sight. But most systems require more detailed surveys, which specialized software and databases make possible. For optimum performance of a microwave network, the Earth's curvature (k-factor), Fresnel zone clearances, terrain features, and climate conditions are all factors that can most easily be taken into consideration when surveying.

1. Detailed Surveys Can Uncover Most Propagation Anomalies

Specialized databases and software enable detailed surveys to be conducted more easily.

Microwave beams require additional height—above what a visual LOS survey can account for—to clear the largest Fresnel zone (F1). For example, at a beam's midpath, the diameter of the F1 zone for a 10-mile link at 11GHz is 34.5 feet. The same path for visible light (using the flash survey method) of around 5 THz is about 0.5 feet. Although you might be able to clearly see a visible light grazing above the tree canopy, the microwave beam would be 17 feet into the trees and thus diffracted. (See Figure 3) While it is true that obstructions must penetrate into the F1 zone by 56.7% or more before diffraction losses occur, it is wise to keep the F1 zone as clear of obstacles as possible in order to maximize signal strength. In addition, due to tree growth, this path could be completely obstructed within one or two years.

Figure 3: ***The first Fresnel zone should be kept at least around 60% clear of any obstructions, including trees whose growth can penetrate the F1 zone within just a year or two.***



2. The Potential For Outages Decreases

Because a detailed path survey systematically accounts for all possible obstructions, including geographical features, manmade structures, and changing atmospheric conditions, companies who invest in them experience fewer outages. If a system is properly installed to begin with, the need for down-time to make repairs decreases.

3. Detailed Surveys Cost Less

A thorough path survey can cost less than 1% of the total system installation and yet is the foundation for establishing a strong reliable link with minimal down-time. In the long run, such detailed surveys reduce the likelihood of costly repair or re-installation bills, increase the system's reliability, and make for customer satisfaction. With today's plethora of consumer options and special offers, dissatisfied customers can easily take their business elsewhere. Thus, optimal reliability from a microwave network goes a long way in maintaining customer satisfaction and business retention.

How To Conduct a Detailed Microwave Path Survey

Accurate engineering of a point-to-point microwave path requires analysis of two critical primary aspects of the path design: a clear line of sight and potential propagation anomalies. Proper tools and the knowledge of how to use them are essential.

Locate the Tower Sites

To conduct a detailed microwave path survey, you must first geographically locate each of the transmitting and receiving sites. Unfortunately, historical records—like the FCC database—

and customer-provided information are often not accurate. A differential Global Positioning System (DGPS) provides sub-meter accuracy and is generally recommended to gather precise geographical coordinates. Until recently, a stand-alone GPS was accurate to only 300 feet (depending on the atmosphere) and did not have the precision level required to engineer a proper microwave path. Now the DGPS function can be performed by a single hand-held unit that receives the "differential" data over the air from ground stations operated by the FAA.

Detailed microwave path surveys include:

- *Accurately locating the tower sites.*
- *Plotting the tower sites and deriving an elevation profile.*
- *Traversing the path on the ground to identify potential obstacles.*
- *Determining the antenna heights and performing a reflection analysis.*

You can also use a theodolite for increased accuracy, but at nearly ten times the cost, it's hardly worth it. A typical 10-mile path can take up to two days to survey using a theodolite. Using modern equipment and techniques, a professional microwave path surveyor can frequently perform 3 to 5 average-length path surveys per day. The time it takes is a function of path length, terrain difficulty, access, and sometimes weather. Surveyor experience is also something to consider.

Plot the Sites and Map the Path Profile

Once the true coordinates of the tower sites are determined, plot them on a USGS topographic map then draw its great-circle route (the shortest path between two points on a sphere) between the two sites to derive the elevation profile from the topographic contour lines. While many tools can simulate the path using a topographic database, Pathloss 4.0™ has proved to be a most efficient and reliable software tool for profiling.

We recommend the terrain database Digitized Elevation Models (DEMs), available at different resolutions. The 3-second DEM provides a point for every 3 arc-seconds. The software, however, must interpolate all other points between those increments. For example, if a hill rises and falls somewhere between a given 3-arc-second grid pacing, the database will miss it, cropping off peaks to appear as flat. Inadequate resolution can result in blocked paths unless the critical points along the automated profiles are validated. The 1-arc-second DEM provides a slightly better resolution; however, keep in mind that in the central latitudes of the United States, 1 second of latitude is about 100 feet and 1 second of longitude is about 64 feet. Thus, in relatively flat areas like Colorado's eastern plains, low-resolution data could be sufficient. But in the mountainous western part of the state (where elevations can change drastically over short distances), using high-resolution data is essential and still requires critical point validations based on topographic maps. In some places, the most accurate readily available data are 1/3-arc-second DEMs.

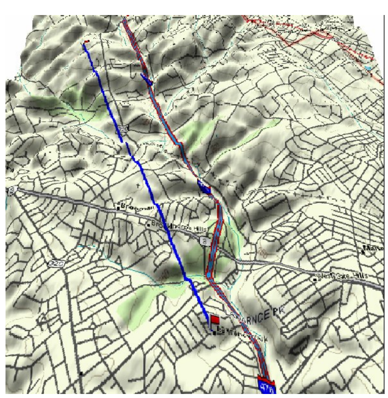


Figure 4: *USGS Map*

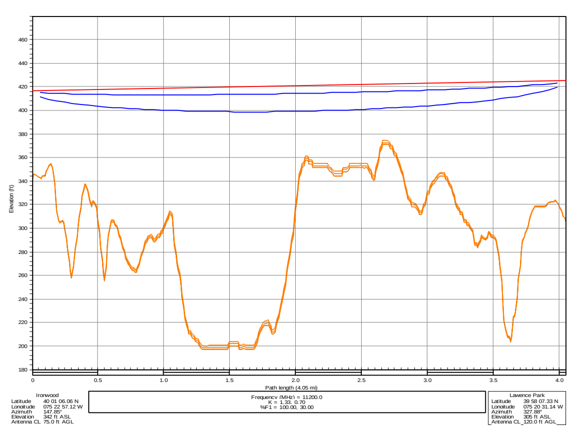


Figure 5: *Pathloss™ 4.0*

Locate All Potential Path Obstructions

Once the tower sites have been established and the path profile completed on a USGS topographic map, all path obstructions must be located and measured. To do this, the surveyor must physically traverse the path (usually by vehicle) with a DGPS to verify the route and document all potential obstacles, such as trees, buildings, water towers, power lines, and any other structures that can potentially interfere with the microwave signal. To measure the height of potential obstructions, use a laser range-finder with an accuracy of 3 inches. Pay careful attention to any construction taking place along the path, and allow a margin for vegetation growth, such as trees that will continue to gain height throughout the useful life of the microwave network. Typically, a 10-year growth factor is added to ensure a long-term, unobstructed path.

Determine the Antennae Heights

After all the identified obstructions are entered into Pathloss, you can precisely analyze the effects of varying k-factors to determine the minimum antenna center-line height needed to clear all obstructions. Once the minimal height combinations are determined, a reflection analysis can tell you whether or not the antennae heights can be optimized to avoid multipath distortions, e.g., potentially damaging reflection points off terrain, trees, bodies of water, buildings, or other obstructions. At this stage, you can also determine whether or not any multipath distortions can be mitigated, such as by varying antenna combination centerlines, using natural or man-made blockage, or using antenna space diversity techniques. For example, instead of building one antenna at each end, two antennas are placed at each end, usually vertically separated by 20 to 50 feet. These analyses are crucial in designing a microwave path for peak performance. Excessive beam clearance may well lead to an unnecessarily high transmission line, or wave guide costs, and tower space rental fees. It can also increase the potential for reflection and multipath problems. Antennas should be placed so as to clear the first Fresnel zone (F1), but block F2, F3, F4, and all subsequent zones from reaching the antennae and causing delayed signal degradation or out-of-phase signal cancellation.

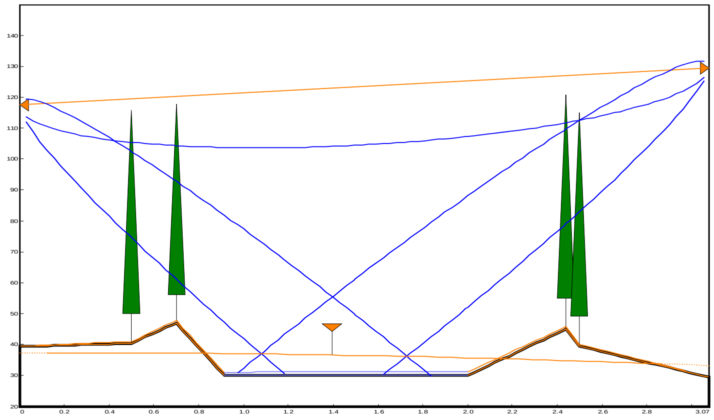


Figure 6: *A reflection analysis can determine whether or not antenna heights can be optimized to avoid multipath distortions.*

What to Look For When Choosing a Microwave Engineering Company

When hiring a company to design and install your microwave network, ask how they intend to survey the path. Will their survey account for all possible terrain features, man-made obstructions, trees (including future growth), and other potential blockages? Will they include terrain profiles, k-factors, and an analysis of potential blockages? Or will they simply use the flashing method to obtain a visual line-of-sight? To ensure your system is designed for optimum performance with the lowest possible chance for outages or system fluctuation, insist on a thorough survey to include a full detailed analysis of the microwave path. The surveyor should perform a physical path survey using industry accepted instruments, engineering methodology, and performance standards. A terrain profile should be mapped using the highest resolution possible of the Digitized Elevation Model (DEM) database or similar. It should also take into account the geographic and climatic features of the region in which the towers are to be located.

Though very short microwave paths can usually be engineered using line-of-sight survey methods, longer paths should be engineered using the detailed methods described in this paper.

At Communication Infrastructure Corporation®, we believe every single link of the microwave system should be properly surveyed and designed to ensure reliability and long life. If you have further questions about how your microwave system can be properly designed, installed, or optimized, we invite you to speak with one of our engineers.

Conclusion

Companies can spend tens to hundreds of thousands of dollars to build a single point-to-point microwave link, which includes engineering, equipment, and installation. Why cut corners by eliminating a cost-effective detailed path survey in favor of visually flashing the path? An optimally performing network needs a thorough path survey, and paying for one up front eliminates the need for potential costly repairs down the road. Not only do your customers depend on you for reliable service, but someone's life may very well depend on it.

About Communication Infrastructure Corporation®
CIC is a leading provider of infrastructure engineering and development services for the wireless telecommunications industry, specializing in the design and deployment of wireless backhaul solutions. We offer site development, microwave/RF engineering, installation, maintenance, and AWS relocation solutions for the efficient design and deployment of both large- and small-scale networks. Our expert team of 100+ professionals employs the latest appropriate technologies, the highest quality service, and the most up-to-date knowledge to meet the demands of wireless carriers. CIC can provide all of the services described in this paper.