Communications Availability: Estimation Studies at AMSC

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ABSTRACT

This paper presents the results of L-band communications availability work performed to date. Results include a L-band Communications Availability Estimate Model and field propagation trials using an INMARSAT-M terminal. AMSC's primary concern centers on availability of voice communications intelligibility, with secondary concerns for circuit-switched data and fax. The model estimates for representative terrain/vegetation areas are applied to the contiguous US for overall L-band communications availability estimates.

Introduction

The AMSC Mobile Satellite (MSAT) program uses Mobile Terminal (MT) receive and transmit frequency ranges of 1525-1559 MHz and 1626.5 - 1660.5 MHz, respectively. These ranges lie within the portion of RF spectrum commonly referred to as "L-Band." Unfortunately, vegetation, especially deciduous and coniferous trees, and terrain present significant obstacles to L-Band signals in a land mobile environment. The amount of signal degradation depends significantly upon tree height, tree density, road backoff from trees, terrain gradient, and tree placement with respect to terrain.

In order to adequately estimate operational end-user voice quality and overall MSAT availability, AMSC launched a program to model the effects of terrain and vegetation on MSAT L-band communications. Within this effort, an internal propagation estimation tool was produced along with a methodology of applying averaged point-wise propagation estimates to the contiguous US.

This paper provides an overview of the L-band propagation estimation model and the methodology that applies the model predictions to the contiguous US. Additionally, this paper presents limited initial results with accompanying assumptions and parameter values.

2.0 Communications Availability Model

Numerous sources have empirically documented the effects of terrain and vegetation on Radio Frequency (RF) L-Band propagation. Different authors (Ref. Goldhirsh, Vogel, Stutzman, etc.) have developed L-band propagation estimation models based on varying premises and parameters. The empirical models provide sufficient representation of the expected propagation losses produced by vegetation, but only for adequately described routes. The term adequate does not imply detailed, but merely described with more parameters than can easily be gathered for long routes over diverse sections of the US. AMSC faces this larger task of predicting L-Band propagation degradation due to vegetation and terrain for the contiguous U.S. The models developed to date cannot be easily combined and tailored to such a large task with minimal data. As such, AMSC elected to develop an internal Communications Availability Model that produced results specifically designed to the project needs.

2.1 Communications Availability Model Overview

Since AMSC required large scale and statistical L-band communication availability estimates, a basis for a model was very important. Essential requirements include: electronic data availability for terrain and vegetation; an existing model framework; flexibility in design and future enhancements; and minimal development time and effort. The Satellite Communications Availability Simulation Model (AMSIM) was developed for this purpose. Major features and capabilities of AMSIM include:

- USGS Electronic Topographic Data
- USGS Land Use/Land Cover Electronic Data
- US Census Bureau TIGER File Data Processing
- Full Compliment of dBase features
- User Friendly Man-Machine Interface

LDMap, a product providing integrated data base and mapping capabilities, was modified to process U.S. Geologic Survey (USGS) electronic 7.5° quadrature topographic maps. 7.5° topographic maps were selected for their 30 meter resolution. To further customize LDMap the base program was augmented to process electronic USGS Land-Use/Land-Cover (L-series) data maps. The L-series maps contain vegetation information across the US. The vegetation information is contained in complex polygons with the predominate vegetation type (if any) listed within the polygon.

Types include deciduous trees, coniferous trees, mixed trees, grasslands, tree covered and non-tree covered wetlands, etc. No information is provided on the vegetation densities, species, or heights. Even with these limitations the L-series maps provide the best data on vegetation across the US in a consistent format.

2.2 AMSIM Basic Operation

Operation of AMSIM requires scanning the area of interest on paper topographic map copy into the computer to use as a display. Electronic terrain data must also be loaded from tape/disk and registered with the scanned image. The registration process provides information to AMSIM necessary to plot on the map image at the correct geographic coordinates.

Once the maps are input and registered, the user selects a route of interest using a point & click interface. Parameters selected for the propagation model are input and stored in a database file. The model then predicts the L-band communications availability for equally spaced points along the defined route. The model calculates the availability estimate using the user defined parameters. These parameters include:

- Tree heights (varies for type and elevation angle range)
- Tree Backoff from road
- MT RF Link Margin
- RF Absorption per meter of tree foliage
- Antenna height above roadway.

Tree backoff refers to the distance from the center of the lane closest to the tree vegetation to the start of the tree line. RF absorption per meter depends upon the type of tree and the density. Please refer to Section 4.1 for a complete description of the simulation parameter set.

Given an arbitrary area, the availability for routes may differ greatly. A selected route may align with the satellite azimuth, may be shadowed by a ridge line, etc. To minimize the variability in route selection from one area to the next, a generic route pattern, contained in Figure 2-1, was generated. The generic pattern attempts to remove route biases that may be present due to satellite, terrain , and/or vegetation location.

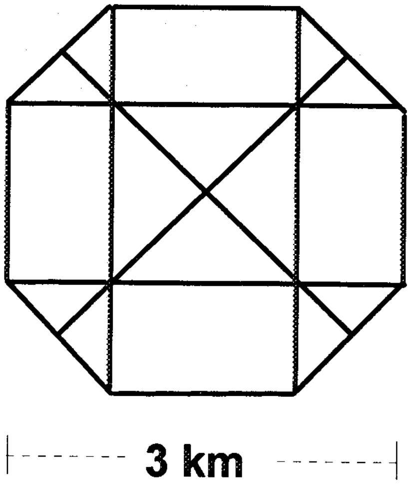


Figure 2-1 Generic Route Pattern

3.0 Availability Estimate Methodology

3.1 Detailed Overview

The US contains extremely diverse terrain and vegetation combinations. Applying the communications availability estimation model to the entire US requires large amounts of time and a significant investment in electronic and paper maps. The contiguous US was divided into 0.5° x 0.5° areas: a size selected to capture regional terrain and vegetation features while maintaining a manageable number of areas. Each area was categorized based upon three features: terrain, tree vegetation cover, and elevation angle. Five types of terrain and five types of tree vegetation density were selected. Three elevation angle ranges were selected. Combined, these attributes produce 75 possible overall terrain/vegetation/elevation angle choices to describe each of the 0.5° x 0.5° areas.

The five terrain categories are: 1) Flat; 2) Rolling; 3) Hilly; 4) Rugged; and 5) Mountainous. Table 3-1 details each terrain category.

Terrain Category	Definition	Examples
Flat	Little or no terrain gradient; gentle sloping terrain	Great Plains Florida
Rolling	Minor terrain gradient; low rolling hills	Central Maryland Central Carolinas
Hilly	Moderate terrain gradient; clustered large hills	Central Pennsylvania
Rugged	Large terrain gradient; clustered large hills/mountains	Upstate New York Ranges of California
Mountainous	Severe terrain gradient; mountain range peaks	Olympia Mountains Rocky Mountains

Table 3-1 Terrain Category Definitions

Similarly, the five tree vegetation categories are: 1) Clear; 2) Light; 3) Moderate; 4) Heavy; and 5) Dense. Table 3-2 present definitions of each tree vegetation category.

Vegetation Category	Definition
Clear	Tree Coverage < 10% of area
Light	Tree Coverage >10% & < 25% of area
Moderate	Tree Coverage >25% & <50% of area
Heavy	Tree Coverage >50% & <80% of area
Dense	Tree Coverage >80% of area

Table 3-2 Tree Vegetation Category Definition

3.2 Terrain Characterization

Terrain characterization of the 0.5° x 0.5° areas began with the 1:1,000,000 Map of the World series. These maps contain topographic information using color tinting and contour lines. For this project, all map reference materials were obtained from the US Geologic Survey (USGS) Cartographic Library in Reston, Virginia.

The main point in characterizing the terrain is to look at the gradient of the terrain vice the elevation. Parts of the Great Plains have somewhat high altitudes but are relatively flat. Selecting the proper characterization requires a subjective interpretation of the terrain guidelines applied to the terrain at hand. Some individual areas may not be characterized correctly; however, the error should only be one category level. Moreover, the statistical nature of the model and the number of 0.5° x 0.5° areas (appr. 2000) renders minor characterization errors statistically insignificant.

3.3 Vegetation Characterization

Vegetation characterization of the 0.5° x 0.5° areas used the Land Use/Land Coverage map series for the US. These maps contain complex polygons defining areas of similar vegetation. Area tree vegetation characterization was performed manually from these maps.

Manual area tree vegetation characterization consisted of three steps. First, the area was physically partitioned on the map. Second, the portions of the area with tree vegetation were visually 'integrated' to estimate the percent of the area with tree vegetation. For this model, no distinction was made for the percentage of each tree type within the area, only total tree coverage. Third, the percentage of tree coverage determined the tree vegetation category to apply to the area. Due to the nature of the percentage tree coverage estimation, the conservative approach desired for the simulation results dictated that a bias be applied towards the more heavily treed categories. Also note that for urban areas, the tree cover may be very light but man-made obstructions dominate. As such, the tree vegetation estimates may produce optimistic results for urban areas.

3.4 Representative Area Selection and Communication Availability Model Integration

A representative area was selected for each of the fifteen terrain/elevation angle types. The areas were selected based on geographic diversity, terrain type, and elevation angle. Tree Vegetation was added via five 'standardized' overlays. The standardized overlays contained deciduous, coniferous, and mixed trees in equal proportions. A small percentage (5%) of the Heavy and Dense overlays were dedicated to Wetland trees.

The simulations performed produced consistent results, exhibiting a general decrease in estimated availability as the terrain roughness increased and as the tree vegetation cover increased.

4.0 Availability Analysis Results, Interpretation, and Limitations

4.1 Parameter Set Description

A complete model of the communications availability of the contiguous US requires many variables. In order to maintain a tractable model, many parameters were fixed in generating this particular set of results. The parameter set for this set of simulations is given below in Table 4-1. An attempt was made to select conservative values for all simulation parameters. **Interpretation of the availability results must include a review of the model parameter values. Variations of these parameters may greatly change the resultant communications availability estimates.** Man-made obstructions (overpasses, bridges, buildings, etc.) were not modeled. Availability estimates may not apply to primarily urban areas.

Parameter	Value
Deciduous Tree Height	30°-40° - 50' 40°-50° - 40' 50°-60° - 40'
Coniferous Tree Height	30°-40° - 50' 40°-50° - 30' 50°-60° - 30'
Mixed Tree Height	30°-40° - 50' 40°-50° - 30' 50°-60° - 30'
Wetland Tree Height	30°-40° - 30' 40°-50° - 30' 50°-60° - 25'
RF absorption per meter (L-Band) for Tree Foliage	Absorption - 0.5dB/Meter
Road Type	Interstate/Primary Routes
Tree Backoff from Roadway	20'
Link Margin with Minimal Acceptable CODEC Performance	Margin - 6 dB, Voice only (Assumes AWGN Channel)
MT Antenna Height Above Roadway	Height - 0'

Table 4-1 Availability Estimation Parameter Set

4.1.1 Tree Height

The USGS Land Use map series contains information regarding tree coverage. The maps divide the tree information into 4 broad categories: Deciduous, Coniferous, Mixed, and Wetland. The maps provide no information regarding tree species, height or density. Due to this lack of detailed information, tree heights were selected for the broad categories based on elevation angle. The position of the satellite and the elevation angle ranges selected essentially divide the US into thirds, running North-South. The tree heights were selected for the top, middle, and bottom thirds of the US, assuming 'typical' species within the tree type. Unfortunately, tree heights vary significantly between species even within the same type. Moreover, tree height is major factor in the availability estimate. Thus, proper operation of the availability models requires accurate and consistent tree height information. Although this can be done for individual simulations for know routes and areas, accurate tree height information over large areas proves difficult. To reemphasize, the communications availability model results apply in the aggregate: care must be exercised in applying the model results to specific routes.

4.1.2 Vegetation Absorption

The tree species sets the density of leaves and branches and the thickness of the branches. At L-band, tree leaves and branches readily absorb RF energy. Thus, the total absorption along a path through the tree vegetation is determined by the absorption per tree and the number of tree along the path. Using data from [1] and a generic tree to tree density, an average absorption of 0.5 dB/Vegetation-Meter was selected. The model calculates and applies this absorption for communications paths through tree vegetation. As with tree height, the simulation results for heavily treed areas depend significantly on the selected tree vegetation absorption per meter.

4.1.3 Tree Backoff

Tree backoff refers to the distance from the center of the roadway lane closest to the trees to the tree vegetation. For purposes of this parameter set, only Interstate and primary routes were considered. Typically, highway designers and State transportation departments maintain a tree backoff for Interstate and Primary roads. To maintain a conservative approach, 20 feet was selected for the tree backoff. Note, if a vehicle is on the side of the road closest to the satellite, then there is a 20 foot backoff; however, if the vehicle were on the other side of the road (or in another lane), then the backoff greatly increases. Because of this, the availability estimates are the average of the simulation results for the 'bad side' and the 'good side'. Simulations of the 'bad side' use a 20 foot backoff. Simulations of the 'good side' use a 50 foot backoff. The significance of tree backoff depends on the tree heights and the elevation angle. Simulations results for treed areas with tall trees and elevation angles of 30°-40° are the most affected by tree backoff variations.

4.1.4 RF Link Margin

The RF link margin refers to additional link power available above the minimum power necessary to maintain the link performance at or above a specified level. For purposes of this parameter set, a 6 dB link margin was selected corresponding to a AWGN channel. The selected margin does not include beam illumination variation -- edge of beam gain considered in all cases.

4.1.5 MT Antenna Height

The MT antenna was assumed to be on the roadway surface. Typical passenger vehicle installations provide an antenna height of 3-4 feet. Installations for trucks give the antenna a height of 7+ feet. The higher the antenna, the better the performance through roadside tree foliage. Thus an antenna height of 0 feet provides for a conservative availability estimate with respect to antenna height.

4.2 Results

The Communications Availability estimate model was used on the representative terrain areas detailed in Section 3. Table 4-2 contains the results for these Representative areas. Note that the general results are favorable. However, the overall results of the modeling exercise are proprietary. The results for Maryland, Kansas, and California are provided in Table 4-3 as examples.

The overall L-band Communications availability estimate for each state cannot be directly applied on a per call basis. For instance, a call of infinite duration that traversed the entire state could expect an overall availability for the duration of that equal to the estimated availability for that state. However, calls of anticipated duration (1 - 2 minutes) within certain terrain and vegetation combinations with a low elevation angle may experience a much smaller availability for the duration of the call. In fact, the link may degrade so significantly that the call is dropped. Conversely, a call of anticipated duration for most terrain and vegetation combinations will have an availability approaching 100%. For example, a call from a MT located in the Great Plains will likely have an availability approaching 100%.

The design of the voice CODEC removes or reduces intelligibility loss due to small signal dropouts produced by tree trunks, telephone poles, etc, while producing natural sounding voice. As such, the actual communications availability for voice communications may be higher than the estimated values.

		30-40	40-50	50-60	Elevation (deg)
Terrain	Vegetation	Voice Avail Avg	Voice Avail Avg	Voice Avail Avg	
Flat	Clear	100	100	100	
Flat	Light	98.5	100	100	
Flat	Moderate	94	100	100	
Flat	Heavy	93.5	100	100	
Flat	Dense	91.5	100	100	
Rolling	Clear	99.5	100	100	
Rolling	Light	97.5	100	100	
Rolling	Moderate	92	99.5	100	
Rolling	Heavy	89.5	99.5	100	
Rolling	Dense	87	99	100	
Hilly	Clear	98.5	100	100	
Hilly	Light	97.5	99.5	100	
Hilly	Moderate	95.5	99	100	
Hilly	Heavy	91.5	99	100	
Hilly	Dense	90.5	98	100	
Rugged	Clear	99	99	100	
Rugged	Light	96.5	99	100	
Rugged	Moderate	90.5	98	100	
Rugged	Heavy	86	98	100	
Rugged	Dense	84	97.5	100	
Mountainous	Clear	98.5	99.5	100	
Mountainous	Light	94.5	99	100	
Mountainous	Moderate	87	98	99.5	
Mountainous	Heavy	84	97.5	99.5	
Mountainous	Dense	77.5	97	99	

Figure 4-2
Representative Area Communications Availability Estimates

State	Estimated Voice Availability
California	95.6 %
Kansas	100 %
Maryland	94.9 %

Figure 4-3
Communications Availability Estimate Examples

4.3 Model Validation and Verification

The AMSIM propagation estimation model has undergone limited field validation; however, additional validation and verification is necessary for high confidence in the model outputs. Validation and verification will continue with appropriate model adjustments, as necessary.

The AMSIM model was verified by comparison of measured data with the output of the model for the same terrain/vegetation combinations. An INMARSAT Standard M terminal mounted in a truck was used to gather direct information on L-band propagation through vegetation. INMARSAT Standard M has a similar link margin to that simulated and uses a variation of the CODEC designed into the AMSC system. Because of this, the INMARSAT propagation results can be directly compared to the propagation model results.

The tests conducted used a tape recorded message (length 30 minutes) connected to a PSTN phone. The Standard-M phone dialed this phone number. An audio pick-up collected the recorded message as received by the Standard-M phone. The pick-up was fed into the audio port of a Video Cassette recorder which (approximately) recorded the Line-of-Site to the INMARSAT AORW or AORE satellite. Availability of a given route was taken as the amount of time that the recorded message was intelligible divided by the total length of the call. Experiment runs located in central Maryland, with sustained Standard-M terminal to PSTN phone connectivity, compared consistently with the model results for similar terrain, within the constraints of the experimental arrangement.

5.0 Conclusions

This task has produced useful and documentable results. The resultant Communications availability values indicate that AMSC's customers will enjoy 'on the average' acceptable or better voice quality over nearly the entire contiguous US.

6.0 References

[1] **Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results,** J. Goldhirsh and W. Vogel, NASA Reference Publication 1274, February 1992.

Communications Availability Studies at AMSC

- **AMSC's Mission:** Provide Mobile Telephony Service via Geo-synchronous Satellite and Low Cost Earth Terminals.
- **Issue:** Given Satellite & Mobile Earth Terminal (MT) design constraints, what is expected voice communications availability for U.S.?
- **Resolution:** Undertake task to determine communications availability throughout U.S.

Communications Availability Estimation Development

◆ **Restrictions:**

- Low Cost
- Minimal Information
- Marketing Department Applications

Communications Availability Estimation Development (cont.)

◆ Solution:

- Divide contiguous U.S. into $0.5^{\circ} \times 0.5^{\circ}$ area blocks;
- Categorize area blocks into terrain type and tree vegetation type;
- Select 'Representative Areas' for each terrain/vegetation combination and elevation angle range;
- Develop tool to estimate communication availability for each representative area; and
- Apply results for 'Representative Areas' to all area blocks.

Terrain/Vegetation Characterization

- Define terrain and vegetation categories.
- Use USGS 1:1,000,000 and L-series Land Use/Land Cover maps for terrain and vegetation information.
- Apply categories to $0.5^{\circ} \times 0.5^{\circ}$ areas.

Terrain Category Definitions

Terrain Category	Definition	Examples
Flat	Little or no Terrain Gradient; gentle sloping terrain	Great Plains Florida
Rolling	Minor Terrain Gradient; low rolling hills	Central Maryland Central Carolinas
Hilly	Moderate Terrain Gradient; large hills	Central Pennsylvania
Rugged	Large Terrain Gradient; clustered large hills/mountains	Upstate New York Ranges of California
Mountainous	Severe Terrain Gradient; mountain range peaks	Olympia Mountains Rocky Mountains

Tree Vegetation Category Definition

Vegetation Category	Definition
Clear	Tree Coverage < 10% of area
Light	Tree Coverage > 10% & < 25% of area
Moderate	Tree Coverage > 25% & < 50% of area
Heavy	Tree Coverage > 50% & < 80% of area
Dense	Tree Coverage > 80% of area

Terrain/Vegetation Characterization (cont.)

46° – 45.5°	State = MT Terrain = F Veg = L El Ang = 36.8°	State = MT Terrain = F Veg = C El Ang = 36.9°
45.5° – 45°	State = MT Terrain = F Veg = M El Ang = 37.4°	State = MT Terrain = F Veg = L El Ang = 37.4°
45° – 44.5°	State = WY Terrain = R Veg = L El Ang = 37.9°	State = WY Terrain = R Veg = L El Ang = 38.0°

46° 45.5° 45° 44.5°

LATITUDE

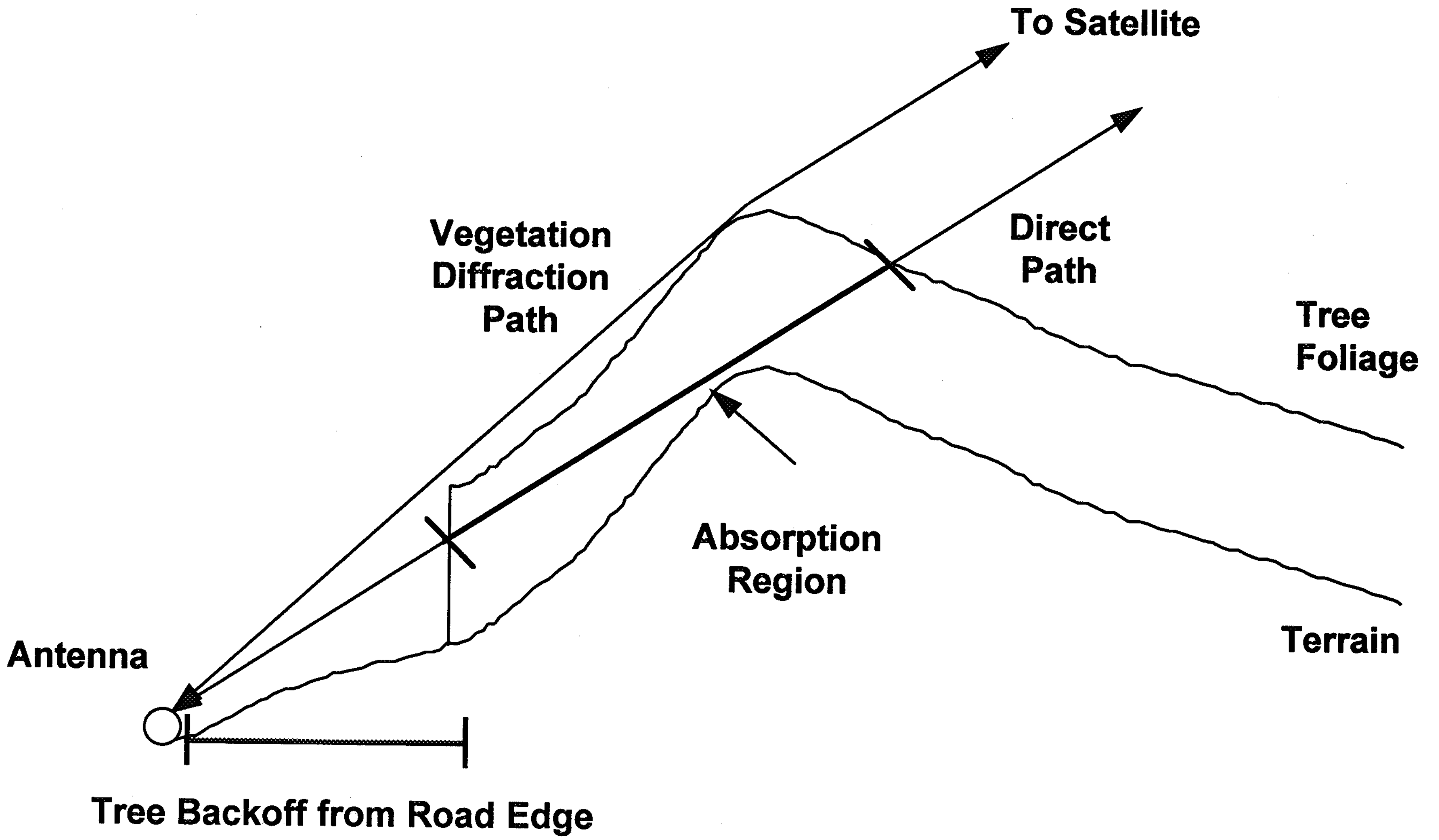
106° 105.5° 105°

LONGITUDE

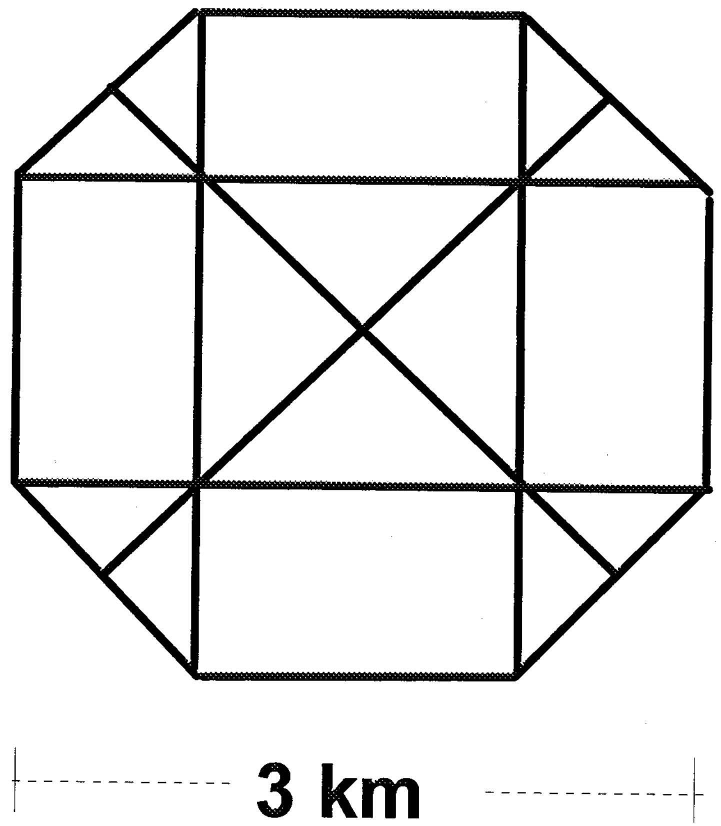
Communications Availability Model

- Considers 2 propagation paths.
- Uses USGS Electronic Topographic and L-Series Data.
- Bases availability estimate on ratio of route points with acceptable margin versus total points.
- Generic route pattern selected to reduce terrain, vegetation and elevation angle biases.

Propagation Paths



Generic Route Pattern



Result:

- Process and tool combined to form a communication availability estimate for contiguous U.S.

Results

Availability Estimation Parameter Set

Parameter	Value
Deciduous Tree Height	30° - 40° - 50’ 40° - 50° - 40’ 50° - 60° - 40’
Coniferous Tree Height	30° - 40° - 50’ 40° - 50° - 30’ 50° - 60° - 30’
Mixed Tree Height	30° - 40° - 50’ 40° - 50° - 30’ 50° - 60° - 30’
Wetland Tree Height	30° - 40° - 30’ 40° - 50° - 30’ 50° - 60° - 25’
RF absorption per meter (L-Band) for Tree Foliage	Absorption - 0.5 dB/Meter
Road Type	Interstate/Primary Routes
Tree Backoff from Roadway	20’ and 50’
Link Margin with Minimal Acceptable CODEC Performance	Margin - 6dB, Voice Only (Assumes AWGN Channel)
MT Antenna Height Above Roadway	0’

Representative Area Communications Availability Estimates

Terrain	Vegetation	30-40 Voice Avail Avg	40-50 Voice Avail Avg	50-60 Voice Avail Avg
		Elevation (deg)		
Flat	Clear	100	100	100
Flat	Light	98.5	100	100
Flat	Moderate	94	100	100
Flat	Heavy	93.5	100	100
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Communications Availability Estimate Examples

State	Estimated Voice Availability
California	95.6 %
Kansas	100.0 %
Maryland	94.9 %

Conclusion: Significant majority of contiguous U.S. will, on the average, enjoy ‘acceptable’ or better voice quality on the AMSC MSAT System.