A GIS Broadcast Coverage Prediction Model for Transmitted FM Radio Waves in Peru

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Introduction

The goal of this project was to develop a radio broadcast coverage prediction model using a Geographic Information System (GIS). Applied to transmitted Frequency Modulated (FM) radio waves in the mountains in Peru, this study demonstrated a method for incorporating geographic spatial components. Developing the GIS coverage prediction model required an understanding of three spatial relationships. First, the level of transmitted power in relation to distance traveled by a radio wave. Second, the power and distance traveled by the radio wave in relation to changes in elevation. Third the interactive behaviour of a propagating radio wave with surface terrain, particularly the rugged mountainous terrain in Peru. Spatial relationships were calculated using the Longley-Rice Irregular Terrain Model (ITM) and spatially assessed using Environmental Systems Research Institute's (ESRI) ArcGIS 9.1.

Radio Waves

Radio waves are a form of electromagnetic (EM) radiation and are studied as part of EM Theory, which describes how electric and magnetic fields oscillate together, at perpendicular angles, to emit energy in the form of waves. An EM wave is characterized by amplitude and wavelength in relation to time or distance. Wavelength and frequency are inversely related, as wavelength decreases and the distance between wave crests gets smaller, the frequency of waves cycles increase.

A continuous wave is a succession of wave cycles with a constant amplitude and frequency. Continuous waves are commonly modified, a process known as modulation, to act as carrier waves for information (NIMA, n.d.). Radio waves transfer sound as a signal via modified carrier waves, from a transmitting (Tx) antenna to a receiving (Rx) antenna. An Rx antenna demodulates the signal by removing the modulating wave and converting it back to its original form (NIMA, n.d.). In Frequency Modulation (FM) the frequency of the carrier wave is modified. FM radio waves are within the Very High Frequency (VHF) band and range from 88 – 108 MHz. This numeric range corresponds to the frequency and the number of cycles of the modified carrier wave.

Radio Wave Propagation, Field Strength and Path Loss

Propagation refers to a wave in motion and is used to describe the traveling process of a radio wave. Propagation models predict *how* a radio wave travels between Tx and Rx antennas, focusing specifically on how a path is influenced by obstructions along the way. Field strength refers to the power of the signal carried by a radio wave.

Field strength prediction of a propagating radio wave introduced the spatial component of distance that related to a factor of path loss, explained in terms of free space propagation. Theories of free space conceptualize the distance a radio wave travels. As long as there are no objects to influence the radio wave, theoretically the wave will continue on forever.

Path loss refers to the amount of power loss associated with a radio wave as it travels outward from the transmitting antenna. As distance increases from a transmitting antenna, path loss increases, while field strength decreases.

Depending on the type of receiver, a minimum field strength, the power of a radio wave, is required in order for radio waves to be distinguished as sound. As a radio wave travels away from a transmission tower, a certain amount of path loss is associated with the field strength of the wave. In general, increasing the distance traveled will increase the associated path loss. This project quantified the relationship between power and distance by determining path loss values for propagating radio waves.

Project Components

Study Area

Working in conjunction with the Mapping the Media Technical Team at the University of Calgary, this project was applied to mountainous areas in Peru. The Peru Mountain District spans roughly 1750 kilometers north to south and up to 450 kilometers east to west, covering an area of 346,820 kilometers squared. This project focused on the mountainous terrain in Peru, which was found to have minimum elevation values of 136 meters above sea level and maximum values of 6,687 meters above sea level (SRTM, 2002). Landuse in the mountains consists mostly of shrublands, 32%, grasslands, 32%, and tundra, 17% (DIVA-GIS, 2006). Landuse characteristics were not applied in the Peru GIS prediction model and are provided here for area description purposes only.

Data

Data used to complete the Peru GIS prediction model are listed in Table 1. For efficiency in time and scale the developed methodology was applied to one FM radio station in the Mountain District. The Panamericana FM station has 20 transmission towers located throughout the Mountain District. Transmission power was not available for 4 of the 20 locations, resulting in 16 studied antenna locations.

Table 1 Data Specifications

Data	Layer/Attribute	Source
Antenna	Antenna Coordinate Locations	Ministry of Transport and Communication, 2005
	Antenna Frequencies	Ministry of Transport and Communication, 2005
	Antenna Power	Ministry of Transport and Communication, 2005
Administrative	South America Political Boundaries	Ministry of Transport and Communication, 2005
	Peru Political Boundary	Ministry of Transport and Communication, 2005
	Land Districts	National Institute Geography, 2004
	Digital Elevation Model	Satellite Radar Topography Mission, 2002
Terrain	Digital Elevation Model	Satellite Radar Topography Mission, 2002

Data Pre-Processing

Additional attribute data was required for this application. Field calculations were applied to generate the Effective Isotropic Radiated Power (EIRP). The EIRP was calculated by adding the power with the antenna gain. Cable loss and receiver gain values were not provided and not incorporated in the EIRP calculation. Seamless elevation data was available in 3 arc seconds of latitude and longitude from the Satellite Radar Topography Mission (SRTM) website. Focal statistics were applied to the raster elevation layer in order to assign values to the NoData pixels.

Assumptions and Limitations

Altitude values were provided with antenna attributes. It was unknown as to whether these values represented ground elevation, antenna height or both ground elevation with an incorporated antenna height. This project used the extracted SRTM elevation values as ground elevation and predicted coverage areas based on Tx antenna heights of 100 meters. This project was limited by not knowing the exact location or parameters of Rx antennae. In order to predict where a reception could be received, a Rx antenna height of 1 meter above the ground was assumed based on a hand-held radio or a radio placed on a desk or table. This project did not account for the difference between outdoor and indoor reception. Receiver sensitivity was assumed to be 6 micro volts which convert to approximately to -91 dBm (Purdy, Pers. Comm. 2006).

Methodology

NITA's ITM program and ESRI's ArcGIS 9.0 provided the software capability to develop the Peru GIS prediction model. The Longley-Rice method was implemented to generate path loss in relation to increased distances from Tx antennae. The Longley-Rice method was developed as a computerized model to predict transmission loss over irregular terrain. ITM models were generated for each of the sixteen Tx antenna towers and area parameters were chosen based on representation for the conditions in the Peru Mountains. Input, Environmental, Statistical and Tabulation parameters were set using the ITM Area Prediction Mode Graphic User Interface. Values listed in Table 2 represent the path loss values used to define the maximum distance coverage areas.

Table 2 Antenna Path Loss Distances to -91 dBm

Antenna ID	EIRP (dBm)	ERP (dBm)	Required Path Loss	Confidence Interval Distances (Km)		
				90%	50%	10%
1	76.4	-91	167.4	38	50	70
2	77.4	-91	168.4	36	50	70
3	73.4	-91	164.4	35	45	68
4	52.2	-91	143.2	17	27	32
5	73.4	-91	164.4	32	45	65
6	70.4	-91	161.4	31	41	60
7	70.4	-91	161.4	33	42	66
8	70.4	-91	161.4	31	43	61
9	55.4	-91	146.4	19	28	38
10	79.4	-91	170.4	42	60	82
11	70.4	-91	161.4	32	42	61
12	49.2	-91	140.2	12	22	32
13	71.6	-91	162.6	34	47	63
14	79.4	-91	170.4	42	60	82
15	74.6	-91	165.6	40	51	74
16	74.9	-91	165.9	38	50	70

Acquired broadcast coverage distances were spatially mapped in reference to the Peru project data. Proximity tools from ArcToolBox were applied to generate multiple buffer rings for different confidence level distances from each Tx antenna. The spatially modeled confidence distances provided insight into understanding the relationship between transmission power, frequency and path loss. Lower power resulted in shorter distances traveled by the radio signal. Lower power also corresponded with shorter distances for each confidence level. The various confidence interval lengths directly correspond to the frequency and wavelength of the signal. Lower frequencies have longer wavelength which increase chances of reception. Lower frequencies can travel around interfering objects compared to higher frequencies because higher frequencies travel along straighter paths.

Broadcast coverage areas were further refined by analyzing the surface terrain in relation to the location and height of each Tx antenna. A viewshed was generated for each antenna within the maximum distance range defined by the ITM program. A viewshed provided a better understanding of surrounding terrain heights in relation to the height of the Tx antenna towers.

Results

A GIS broadcast coverage prediction model was successfully implemented for 16 Tx antenna locations in the Peru Mountain District. With the application of an ITM program, distances from each Tx tower were defined based 90%, 50% and 10% service reception confidence levels. The size of the study was 346,820 kilometers squared. Without focusing on the difference between confidence distances, results showed that 16 transmission towers, at 100 meter heights above the ground, had a broadcast coverage of 4374 kilometers squared, about 1.3% of the area.

Spatial distribution of the predicted coverage areas was illustrated using various map scales (see Figure 1). Shown in red, the coverage areas were shaped by the topology of the mountains. This was obvious on map inset 2 in the lower left hand corner of Figure 1. Red coverage areas formed a branching structure representative of lower elevations in a valley. It was expected that broadcast coverage areas would adhere to the topology as a result of incorporating a viewshed analysis. Surface terrain elevations were the main requirement when generating viewsheds, which indirectly characterized the topology in the area.

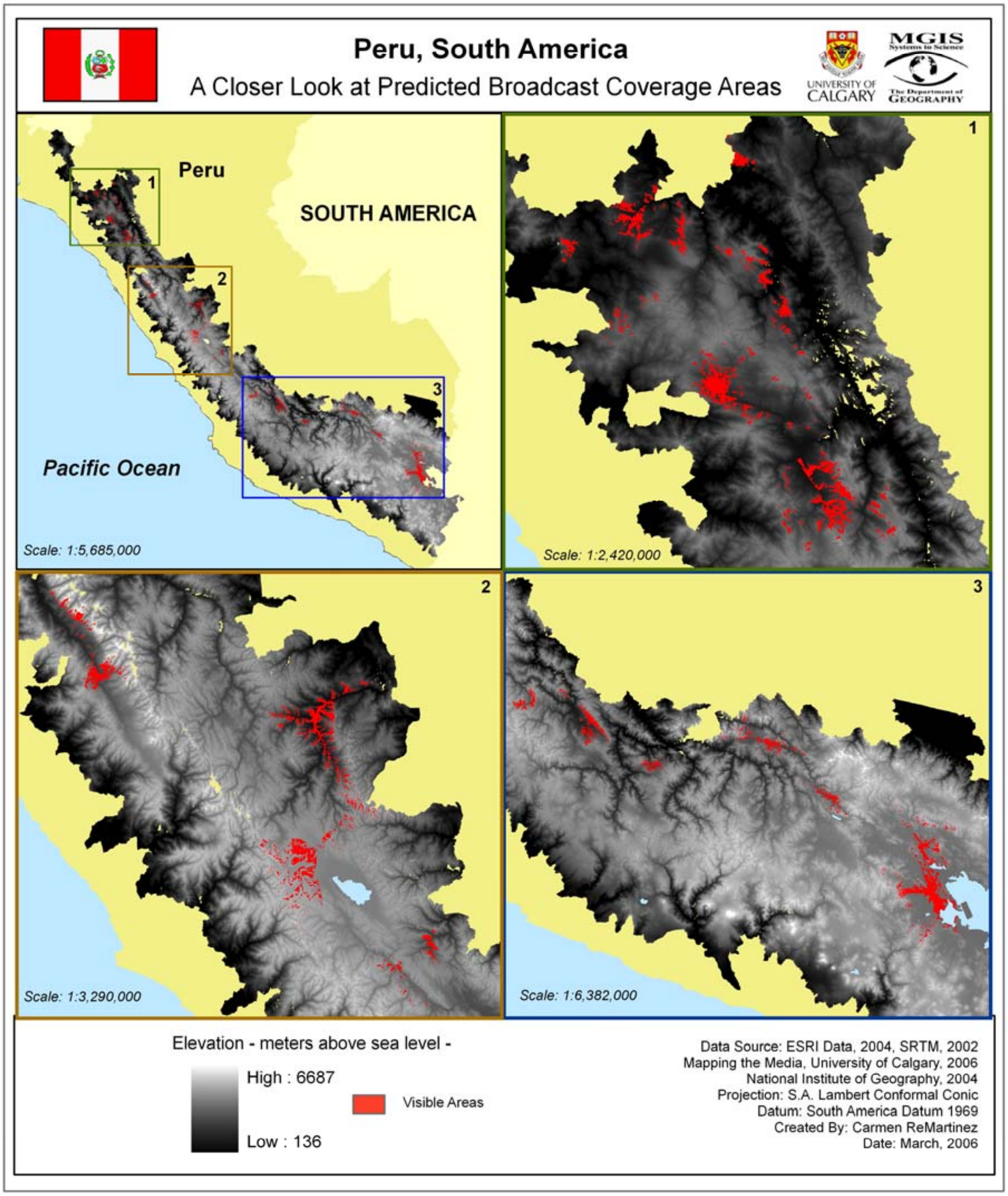

Figure 1 A Closer Look at Predicted Broadcast Coverage Areas

Discussion

Transmitted Power and Distance Relationship

The concern with implementing the ITM model program was verification. The ITM Model path loss results were assessed based on the free space curve. The free space propagation formula was applied in a GIS to generate free-space path loss over distance for a Tx antenna. A distance surface was generated from the antenna tower using the Euclidean distance tool. The algorithm was calculated in the raster calculator using the corresponding frequency value and the distance surface. A new raster surface was generated showing the increase in path loss away from each Tx tower. The ITM free space path loss curve was similar to the GIS generated free space model. Values were tested at various locations and compared with values on the ITM Model curve. These locations proved to have the same path loss values at the chosen distances. Overall the GIS model verified that the ITM model was implementing the equation properly.

Power, Distance and Elevation Relationship

The power, distance and elevation relationship was generated in the ITM model by incorporating the irregular terrain parameter. When verifying the free space path loss model in the GIS, mentioned above, it was discovered that the Euclidean distance would be inappropriate. Euclidean distances are the shortest path between two points. Generating a new gird layer, a straight line distance was measured between the antenna point feature to the center point location of each new grid cell. Using this tool was efficient in generating the gradual increase in distance from the antenna tower. The ESRI tool calculated the true Euclidean distance by acquiring the x and y directional line lengths and solving for the hypotenuse of the triangle. The Euclidean distance tool assumed a horizontal plane and does not account for vertical change when generating measured values, unlike the ITM model.

Propagating Radio Wave and Surface Terrain Relationship

Visibility analysis was implemented to refine the coverage distances to coverage areas. Discovered from previous works, it was clear that visibility did not define transmission coverage. A receiver, especially when using the VHF range, does not require a direct line-of sight from the Tx tower. It was assumed that if surrounding terrain elevations were greater than the height of the antenna, then the radio wave was stopped by a mountain. It is understood that waves diffract off the top of terrain features, but due to the complexities of this interactive behaviour, diffraction was not accounted for in this project. In a GIS, visibility analysis was implemented using the line-of-sight to delineate coverage areas.

Future Recommendations

Developing FM broadcast coverage areas was a challenge. With a geography background and focus in GIS it was easy to identify the relationships that existed between power, distance, elevation and terrain, but difficult to implement without access to appropriate electrical engineering resources. Each discipline has its own language. Acquiring the appropriate terminology and information to search for basic and broad propagation literature proved to be challenging. For future work, efficient access to basic electrical engineering resources is recommended to improve efficiency and time management to allow for a gradual versus steep learning curve. The relationship between two places can be defined in terms of distance and connectivity. With increasing communication technology more distant places, like the Mountains in Peru, can be made accessible through connections.

Conclusion

FM radio broadcast coverage areas were successfully predicted using the Longley-Rice propagation model and a viewshed spatial analysis. This project assessed and spatially modeled the relationship between power, distance, elevation and surface terrain. In general, the higher the transmission power, the further a radio wave will travel. It was shown that this relationship depended on two other factors, the frequency of the wave and the topology of the surrounding area. Results showed that two tower transmitting the same level of power did not have the same coverage areas because the frequencies were not similar. The higher the frequencies, the shorter the wavelength and the shorter the distance traveled by the radio wave.

References

DIVA-GIS (2006) Mapping and Analysis of Spatial Data. Retrieved on December 12, 2005 online http://www.cipotato.org/diva/data/DataServer.asp?AREA=PER&THEME=_msk_cov

NIMA. (n.d.) Chapter 10: Radio Waves. National Imagery and Mapping Agency. Retrieved on December 18th, 2005 online http://pollux.nss.nima.mil/NAV_PUBS/APN/Chapt-10.pdf

Purdy, I. (2006) Personal Communication on March 17, 2006. Telecommunications Technical Analyst, EnCana Corporation. Calgary, Alberta.

SRTM (2002). Satellite Radar Topography Mission