Propagation Analysis of a 900 MHz Short Path Spread Spectrum Centralized Traffic Signal Control System

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Abstract

This paper reports the propagation analysis and the modeling of a 900 MHz short path spread spectrum centralized traffic signal control system. The traffic signal controls at intersections in the City of Denton, Texas are examined. Eleven sites are constructed and signal strengths from the study sites are monitored. Analysis is performed for the large city, urban, small city, semi-rural, and rural forms of the Okumura-Hata model. The statistic data analysis shows that Okumura-Hata's Suburban and Semi-rural models can be used to predict signal strength for the City of Denton's 900 MHz spread spectrum traffic signal control system.

1. Introduction

Many cities' traffic departments are using dial-up connections to communicate with various traffic control signals throughout cites [1]. The major drawback of the dial-up connection is its slow data transfer speed. It can take up to several minutes to download information from a single controller. One possible solution to the dilemma is to implement centralized control of traffic signals using microwave point-to-point spread spectrum digital radio links. A significant issue in planning and implementing a radio system is signal strength and its fluctuations at each system receive point. Therefore, accurate prediction of the propagation environment's effect on the signal is essential in the development and design of a communications system. Conventionally, point-to-point microwave link propagation analysis is performed using Longley-Rice modeling [2, 3]. Longley-Rice requires a digital terrain database. Links modeled using Longley-Rice usually traverse open (rural) terrain and are longer than the links to be used by the cities, thus not suitable for modeling in a city environment. This study investigates alternate propagation models in an effort to determine a model which is better suited for use in digital radio applications over developed (urban or suburban) terrain where link distances are short, less than 6 km. Specifically, the Okumura-Hata [4] radio propagation model will be studied to determine if it accurately predicts received signal strength in 900 MHz spread spectrum radio applications. The study focuses on problems associated with configuring and monitoring traffic signal controls at intersections in the City of Denton, Texas. The City currently employs leased telephone lines to communicate with traffic signal controllers. Because of the ongoing expense and the slow data transfer the City of Denton plans to install a master signal controller to improve traffic signal control that will be linked via radio from a central location to a signal controller at each designated intersection. The traffic signal control system will operate using frequency hopping spread spectrum (FHSS) radios under Part 15 of the Federal Communications Commission (FCC) regulations in the 900 MHz Industrial, Medical, Scientific (ISM) frequency band [5]. This study is undertaken to provide the City of Denton with a method of predicting link performance prior to constructing a specific link using computer modeling methods that have proven to be accurate when compared to measured data. The prediction modeling developed in this study could also be adopted by other similar sized cities.

When designing a radio system, a link budget must be prepared which contains all radio frequency (RF) system gains and losses. System gains are transmitter output power, transmit antenna gain, and receiving antenna gain. Antenna gain is typically specified in dB relative to an isotropic radiator (dBi) or to a half-wave (λ/2) dipole (dBd). Losses in the link budget are transmission line loss, connector losses and any losses associated with filters, diplexers, attenuators or other devices that may be present in the system. Propagation path loss is also in the link budget, and this is the one parameter over which the system designer has the least control, as path loss is dependant on various terrain factors. A link budget calculation sums the gains and losses in dB such that:

$$P_R = P_T - L_T + G_T - A_P + G_R - L_R \tag{1}$$

where

P_R = Received power

P_T = Transmitter output power

L_T = Losses between transmitter and antenna

G_T = Transmit antenna gain

G_R = Receive antenna gain

L_R = Losses between receive antenna and receiver

A_P = Propagation path loss

This study focuses on A_P , signal strength losses in RF propagation, and its effects on the system being implemented by the City of Denton Traffic Department. Propagation analysis is affected by many environmental factors including terrain morphology, vegetation density, building height and density, open areas, and water surfaces [6].

2. Using the **Okumura-Hata** Model in Prediction Radio Frequency Propagation

The Okumura-Hata radio propagation model is computerized formulation of Okumura's 1960's empirical graphical path loss prediction produced by Hata in 1980 [4, 11]. The model is valid for frequency ranges from 150 MHz to 1500 MHz. The model presented the urban area propagation loss as a standard formula and supplied correction equations for application to other situations. The model, which first predicts the free space path loss and then adds a correction factor whose value depends on the type of propagation environment, is summarized in Table 1 [4, 7]:

Table 1. Okumura-Hata Radio Propagation Model Summary

Urban areas	$L_u(dB) = 69.55 + 26.16\log_{10} f - 13.82 1\log_{10} h_t - A(h_r) + (44.9 - 6.55\log_{10} h_t)\log_{10} d$ For medium or small cities $A(h_r)(dB) = (1.1\log_{10} f - 0.7)h_r - (1.56\log_{10} f - 0.8)$ For large cities: $A(h_r)(dB) = 8.29\log_{10}(1.54h_r) - 1.1$ if f ≤ 200 MHz $A(h_r)(dB) = 3.2\log_{10}(11.75h_r) - 4.97$ if f>200 MHz
Suburban areas	$L_{su}(dB) = L_u - 2\left(\log_{10}(\frac{f}{28})\right)^2 - 5.4$
Quasi-open rural areas	$L_{rqo}(dB) = L_u - 4.78(\log_{10} f)^2 + 18.33\log_{10} f - 35.94$
Rural areas	$L_{ra}(dB) = L_u - 4.78(\log_{10} f)^2 + 18.33\log_{10} f - 40.94$
where f = frequency in MHz (150 < f < 1,500 MHz), h_t = transmit antenna height in meters (30 m < h_t <200m) h_r = receive antenna height in meters (1 m < h_r <10 m) d = path distance in kilometers (1 km < d < 20 km)	

The model should give a reasonably accurate prediction of path propagation, and is easy to implement in modern computer spreadsheets. When used by its self, the Okumura-Hata model does not require a digital terrain database. Without examining terrain, it could be possible to analyze a propagation path that is obstructed and the analyses show the path viable, when in fact, the path is partially or completely blocked. Terrain data or topographic maps typically do not provide information on buildings that may lie in the propagation path. Therefore, it is recommended that, in addition to terrain data analysis, someone familiar with the general area physically examine the propagation path. New building construction is one thing that system operators have absolutely no control over and is a concern for all fixed microwave radio system operators. It is possible for a new building to partially or completely block a previously valid propagation path. If this occurs, the system operator has no choice but to redesign the path in question through the use of reflector panels, active or passive repeaters, or alternate routes.

3. Experimental Results

The following parameters are considered in designing the research for this study: data necessary to complete the study, data collection, and data analysis. Necessary data include received signal strength, transmitter power output, antenna gain, transmission line losses, and path distance. Data collection is performed using software supplied by the radio manufacturer. This software is capable of querying the radio at each site and recording current operating parameters such as transmitter power output and received signal strength. Data is recorded in an Excel spreadsheet compatible format, and is easily imported to Excel for statistical analysis.

The traffic signal control system will transmit from the Traffic Department's Texas Street facility in Denton, Texas to a tower repeater located at the power plant on Spencer Road (Spencer Tower), also in Denton, Texas. Spencer Tower will transmit to the individual controllers at designated intersections. The system diagram is shown in Figure 1 [5]. During this study eleven sites along Loop 288 in Denton, Texas are constructed and one set of received signal strength data are recorded for each site. Table 2 summarizes all parameters for each study site. Signal strengths from the various study sites are monitored using InSite 6i™ Radio Management Software provided by the Microwave Data Systems, Inc. [8]. This software has specific provisions for monitoring signal quality parameters from remote sites at a central location. Logging of parameters with output to disk is provided in the software. Monitoring features of the MDS 9810 radio, as recorded by the InSite 6i™ software, are used to test system performance. The data consists of one set of measured value per site for the eleven sites.

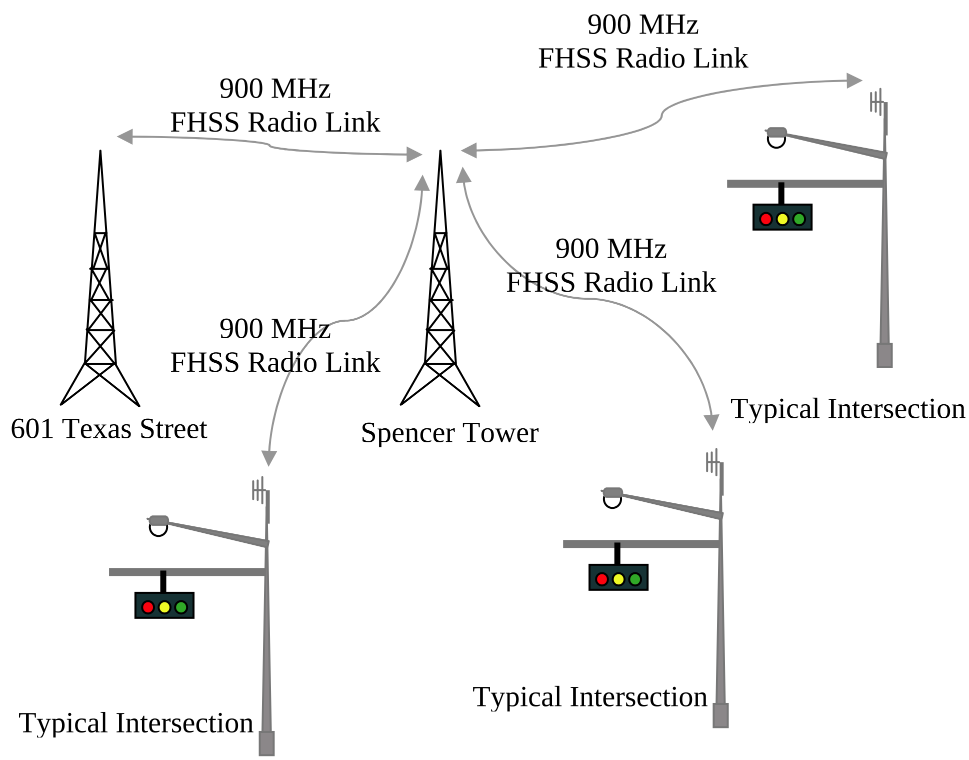

Figure 1. System diagram

Table 2. Site Parameter Summary

Spencer Tower to	Terrain	Path Length (km)	Antenna Centerline Height(m)	Antenna Gain (dBi)	Transmission Line Length in m (Cable Type)
Spencer Tower			33.5	12.15	36.6 (LMR1200)
Loop 288 at McKinney	Rural	2.2	9.1	9.15	18.3 (LMR 600)
Lillian Miller at Teasley Lane	Suburban	2.6	9.1	9.15	12.2 (LMR 600)
IH 35 at Lillian Miller	Urban	1.3	9.1	9.15	30.5 (LMR 600)
Teasley Lane at Ryan Road	Suburban	4.0	7.6	9.15	7.6 (LMR 600)
Lillian Miller at Southridge	Suburban	1.9	6.1	9.15	15.2 (LMR 600)
Lillian Miller at Southridge Village	Suburban	1.5	7.6	9.15	13.7 (LMR 600)
Loop 288 at Mall Entrance	Suburban	1.1	6.1	9.15	10.7 (LMR 600)
Loop 288 at Colorado	Suburban	1.0	9.1	9.15	10.7 (LMR 600)
Loop 288 at Brinker	Suburban	1.2	9.1	9.15	18.3 (LMR 600)
Teasley Lane at Hickory Creek	Suburban /Rural	5.7	8.5	9.15	12.2 (LMR 600)
Loop 288 at Spencer	Suburban	1.3	9.1	9.15	12.2 (LMR 600)

Propagation prediction models calculate the free space path loss, and usually do not contain system fixed gains and losses. The Okumura-Hata model is no exception. Received signal values obtained from InSite 6i™ do include fixed system gains and losses as well as the free space path loss. Therefore, the model must be adjusted to accommodate system fixed gains and losses.

Fixed gains in this system are transmitter output power, and transmit and receiving antenna gain. Fixed losses are antenna feed line loss and connector loss. All gains and losses are calculated in dB so as to facilitate calculating overall system performance. Antenna gains are given in manufacturer's data sheets and specific site data provided by CES Network Services, Inc. [9]. Transmission line losses are calculated from manufacturer's data where the loss is given as dB per unit length, usually 100 feet. Transmission line loss is frequency dependent; therefore, care must be taken in reading the data sheet to obtain the correct loss value. Connector losses are assumed to be 1.0 dB per connector; this value is given in the CES Network Services data sheet. All values for transmission line length, antenna gain, connector loss, and transmitter output power were extracted from CES Network Services documents.

As an example, the transmission line at Teasley Lane and Hickory Creek Blvd. is 40 feet of LMR 600 coax cable. Loss for this coax is 2.50 dB per 100 feet. The calculated transmission line loss is then calculated as

$$Attenuation_{dB} = \frac{(2.50)(40)}{100} = 1.0dB \quad (2)$$

There are two connectors with a loss of 1.0 *dB* each for a total of 2.0 *dB*, and one antenna gain of 7.0 *dBd* . The net gain for the system at Teasley Lane and Hickory Creek Blvd. is 4.0 *dB*. This value is added to the Okumura-Hata model predicted propagation loss, as is the gain from the Spencer Tower system. Note that the gain value for Spencer Tower also includes transmitter output power in *dB*. All gain/loss calculations were performed using standard Excel spreadsheet functions.

4. Data Analysis

Data analysis is performed using standard statistical methods. Since the number of data points available was small, a two-sample analysis of the mean of measured and calculated data is used [10]. Analysis is carried out for the large city, urban, small city, semi-rural, and rural forms of the Okumura-Hata model in order to determine which provided the best fit to the measured data. Data from the eleven site readings is averaged to develop mean and standard deviation values for received signal strength. Model data, calculated using the Okumura-Hata radio propagation model from Table 1, for the same eleven sites is also averaged to arrive at mean and standard deviation values. Standard *t* tests are used to compare the mean of measured data and model data. Once the mean and standard deviation values are known, full analysis of received signal strength data is performed.

The sample mean $\bar{x}$ and the standard deviation s are calculated using equations 3 and 4:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (3)$$

$$s = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \quad (4)$$

where n is the number of samples.

Pooled standard deviation s_p is calculated using equation 5:

$$s_p = \sqrt{s_p{}^2} = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}} \quad (5)$$

where
n_1 = number of samples in the model
n_2 = number of measured data samples
s_1 and s_2 = the standard deviations for modeled and measured samples

The *t* test equation is given by:

$$t = \frac{\bar{x} - \mu}{\frac{s_p}{\sqrt{n}}} \quad (6)$$

where $\bar{x}$ is the modeled sample mean, and μ is the measured data mean.

A particular *t* distribution in the family of *t* distributions is indexed by its degrees of freedom (df). Degrees of freedom are the number of "free" choices of values in a given sample. For a two sample *t* test in our case, df = $n_1 + n_2 - 2 = 20$. For a confidence level of 95% ($\alpha = 0.05$), and 20 degrees of freedom, *t* is determined, using the equation 7 combined with a *t* test look up table [10], to be 2.086.

$$t\left(\frac{\alpha}{2}, 20\right) \quad (7)$$

Microsoft Excel was used to perform calculations using built-in functions. Calculated propagation path loss values for different forms of the Okumura-Hata model are treated in the same manner as measured data. The mean value, variance and standard deviation were found using Excel functions. Pooled variance s_p^2, and pooled deviation s_p, are calculated using Equation 5. Using these calculated values, the *t* statistic was determined using standard lookup. All statistical data is presented in Table 3.

From table 3 we conclude: For the Suburban model, designated X_{SBM}, and the Semi-Rural model, designated X_{SRM}, absolute *t* values are found to be 1.98 and 1.89 respectively which are smaller than the stated confidence level *t* value of 2.086. Therefore, the Suburban and the Semi-Rural of the Okumura-Hata models are suitable for predicting propagation loss for this study. All other variations of the Okumura-Hata model, (Rural, Large City, and Urban) failed to properly predict propagation losses because their absolute *t* values are found to be greater than the calculated 95% confidence level *t* value of 2.086.

Table 3. Data Values for Okumura-Hata Model Variations

	Measured Data (X_0)	Large City Model (X_{LM})	Urban Area Model (X_{UM})	Suburban Model (X_{SBM})	Semi-Rural Model (X_{SRM})	Rural Model (X_{RM})
Average Power (dBm)	-68.36	-97.97	-85.36	-75.33	-61.72	-56.72
Variance (s^2)	44.85	156.78	91.12	91.12	91.12	91.12
Standard Deviation (s)	6.70	12.52	9.55	9.55	9.55	9.55
Pooled Variance (s_p^2)	--	100.82	67.99	67.99	67.99	67.99
Pooled Deviation (s_p)	--	10.04	8.25	8.25	8.25	8.25
t value	2.086	-6.92	-4.83	-1.98	1.89	3.31

5. Conclusion

Data analysis shows that the Suburban or Semi-rural Okumura-Hata model can be successfully used to predict propagation for 900 MHz spread spectrum radio systems. The scope of this project is narrow and results are only valid in that narrow scope. Specifically, the propagation paths in this study are short, varying from approximately one kilometer to six kilometers in length. Terrain varied from virtually flat to large hills. Building density and height ranged from none through United States standard residential and business districts. Terrain variation and building density tend to create difficult propagation paths, while short paths tend to make propagation easily predictable.

Acknowledgement

Authors thank Dr. Robert Getty for discussions on data analysis using standard statistical methods.

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