Southwestern Bell
Technology Resources

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June 17, 1994

Dr. Thomas P. Stanley, Chief Engineer
Federal Communications Commission
2025 M Street, NW
Washington, DC 20554

Re: Southwestern Bell Technology Resources, Inc.
Call Sign KM2XBI
File Number: 3037-EX-PL-92
Quarterly Progress Report Number Eight

Dear Dr. Stanley:

In accordance with the Federal Rules and Regulations Part 5, Section 5.204(b), attached please find the eighth quarterly progress report for Southwestern Bell Technology Resources, Inc. in connection with our personal/wireless communications testbed in St. Louis, Missouri.

The main objective in our St. Louis testbed is to verify performance of the emerging wireless communications systems and technologies prior to integration into one of Southwestern Bell Corporation's business units. Attached we are reporting our progress and test results in the areas of wireless local loop and personal communications systems.

Please direct any inquiries to me at 314-529-7567.

Sincerely,

D. Walter for John Moore

John A. Moore
Director, Wireless Communications

Attachment

FCC Quarterly Progress Report Number Eight (8) in Connection with Personal/Wireless Communications Testbeds in St. Louis, Missouri

Conducted by Southwestern Bell Technology Resources, Inc.

June 17, 1994

Authorized by FCC Experimental License
Call Sign KM2XBI, File Number 3037-EX-PL-92

1.0 Introduction

The tests reported here were conducted in St. Louis, Mo., under the experimental license granted to Southwestern Bell Technology Resources, Inc. (TRI) . The efforts reported here include progress in the Wireless Local Loop experimental testbed, and propagation in the 2 GHz frequency region for macrocellular applications, during the period from March 19, 1994 through June 17, 1994.

2.0 Wireless Local Loop Progress

This section of the report will describe two independent studies performed in support of the Wireless Local Loop (WLL) program at Southwestern Bell. Later this summer, a technical testbed will be deployed in west St. Louis County wherein 25 Southwestern Bell Telephone Company (SWBT) employees will begin receiving telephone service via a low power radio system based on the Bellcore-specified Wireless Access Communications System (WACS)[1]. In order to better understand the testbed environment, and thus the environment in which such a system will eventually be deployed, we conducted the following studies: (1) propagation effects of foliage at 2 GHz in the suburban residential environment, and (2) delay spread and path loss characteristics of the suburban residential environment. These tests shall be referred to as the foliage effects study and the delay spread study, respectively, throughout the remainder of this report.

2.1 The Testbed Environment

These two tests were conducted in the same area of St. Louis County. A map of the testbed area is shown in Figure 2.1-1 below.

In the figure, the triangles represent radio port locations, the nominal radio coverage of the wireless local loop system is shown for each radio port, and the dots represent potential test participants.

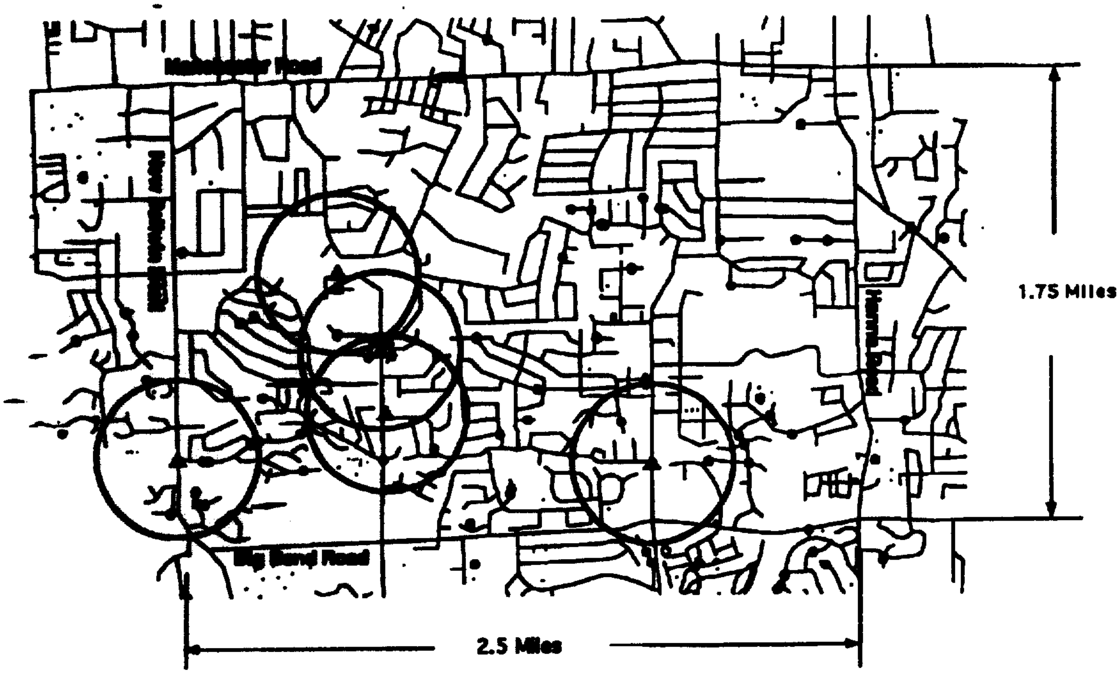

Figure 2.1-1 Testbed location with radio port sites and coverage

The testbed is an open residential area populated with typical one and two story homes, apartment buildings, small shopping complexes, schools, and churches. Few buildings exceed three stories. The area is typified by rolling hills, with some areas having rather abrupt elevation variations. Large trees are scattered throughout the test bed, and some areas are heavily wooded. The homes are typically of frame construction with decorative brick, and/or composition or vinyl siding. The telephone and/or electric plant in most of the testbed is aerial; the radio ports will be mounted on the utility poles at heights ranging from 4.6 to 6.0 meters (15 to 20 feet) above the ground. Although the selected radio port sites are placed at elevated terrain locations, the direct propagation path between the radio port and the test site was often obstructed by trees, a hillside, and/or other homes. Under these conditions, excess path loss will be dominated by shadowing induced by terrain, foliage, and human made obstructions. Delay spread will also be due to scattering from hills and nearby homes. Figure 2.1-2 is a photograph of a typical location within the testbed area.

Figure 2.1-2 A picture of a typical location and foliage in the WLL testbed

2.2 Foliage Effects Study

The purpose of this study is to understand and characterize the effects that foliage will have on the propagation of radio signals at 2 GHz in the suburban residential environment. Unlike macrocellular deployments, in this application, not only are the subscriber radios down in the foliage, but so is the radio port. Thus, the RF path through the foliage can be quite long.

The first phase of this test was conducted before leaves began to appear on the trees; the second phase will be conducted this summer where identical tests will be run with full foliage. The path loss values will be compared between these two measurement cycles to determine the impact that foliage has on signal attenuation. This study is being conducted as a collaborative effort between TRI and Motorola.

The measurement system consisted of a van with GPS reference equipment and transmitting equipment(herein referred to as the fixed equipment), and a portable cart with a receiver system, differential GPS equipment and a PC for data recording (referred to as the portable equipment).

Specifically, the fixed equipment consisted of:

- an RF signal generator operating at 1947.5 MHz,
- an RF amplifier,
- a 3 dBd transmit antenna ,
- a differential GPS reference station, and
- a UHF data modem.

The portable equipment consisted of :

- an RF receiver operating at 1947.5 MHz,
- a 0 dBi receive antenna,
- a differential GPS mobile station,
- a UHF data modem, and
- a laptop computer acting as a controller and data logging device.

The portable measurement receiver system was calibrated in the lab prior to field measurements by injecting a - 40 dBm signal at 1947.5 MHz through a step attenuator into the base of the receive antenna and then recording the signal strength samples at 2 dB and 3 dB steps as the power was decreased to -130 dBm. The calibration procedure was performed under software control and resulted in a calibration table which was used in the data collection process.

The transmitter (signal generator/RF amplifier) was adjusted to provide +23 dBm into the base of the transmit antenna at a frequency of 1947.5 MHz, and the transmit antenna was raised on a mast to a height of 5.5 meters (18 feet) above the ground. The antenna for the GPS reference station was placed on a fixed, identifiable landmark (e.g. a street sign) for repeatability. The correction data from the GPS reference receiver was transmitted via a UHF data modem for use by the receiver system. A picture of the typical transmitter site configuration is shown in Figure 2.2-1.

Figure 2.2-1 Transmit site equipment van and mast

A differential GPS system was used to obtain accurate position data for the measurements. The GPS receivers and associated UHF data modems allow the location subsystem to operate in the differential mode, providing 3 foot RMS location accuracy by eliminating the error due to Selective Availability. The differential correction signal is sent, using the RTCM SC-104 format, at a one second update rate.

The signal strength data was collected by moving the measurement cart at a nearly constant speed along sidewalks in the residential testbed area. During measurement, the receiver takes Received Signal Strength (RSS) measurements every 9 milliseconds (msec) and averages these samples over a 150 msec window. The averaged RSS data, along with corrected differential GPS information was recorded in the laptop PC once per second. In addition, markers were inserted in the data at specific, identifiable, and repeatable locations for future comparison. These locations typically included street intersections and home locations. The data was stored for later post processing. The receiver system is shown in Figure 2.2-2.

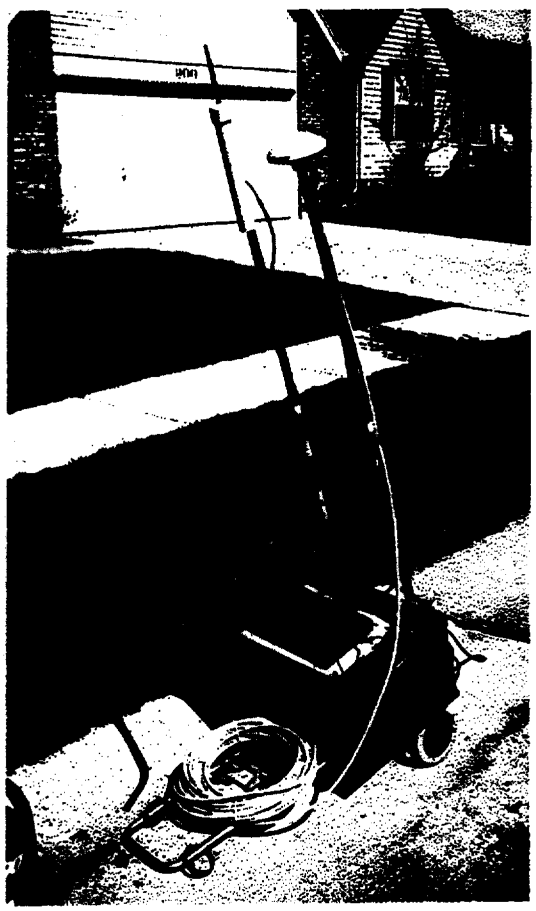

Figure 2.2-2 Portable receiver and data logging system

A sample of the processed output for one measurement route is shown in Figure 2.2-3. The dots in the figure represent the RSS value of every fifth sample in the data file. Thus, each point shows a 5 second interval, corresponding to a distance of 7.5 to 9 meters (25 to 30 feet). In addition to moving along the sidewalks, we also moved the cart completely around selected homes in the area. These can be seen as roughly circular deviations from the straight path. The color (shading) of each dot indicates the received signal strength in 10 dB increments. In general, the lighter shades indicate higher signal strength. As indicated in the plot, all test locations within about 300 meters (1000 feet) of the transmitter received sufficient signal strength to permit service via the WLL system (based on the specified link budget). Note that the values in this figure show received signal strength, not path loss. The measurements will be repeated this summer under full foliage conditions, and the results will be compared to the winter measurements. This will allow us to characterize the effects of foliage on the 2 GHz RF signal in this type of environment. The results of this comparison will be presented in the next quarterly report.

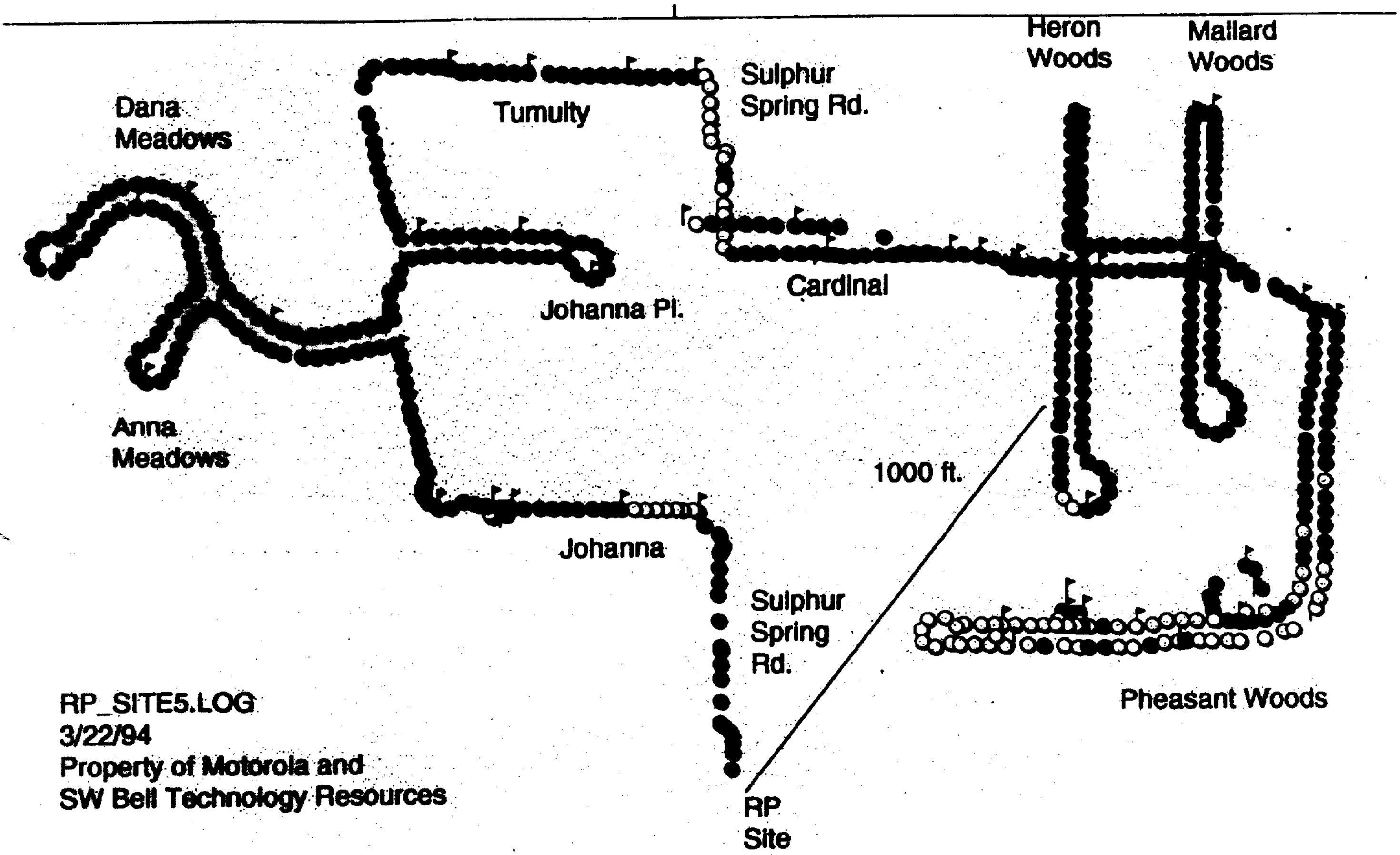

Figure 2.2-3 Sample signal strength results

2.3 Delay Spread Study

The purpose of this study was to characterize the RF delay spread in a suburban residential environment with low transmit power and low antenna heights. This study was a collaborative effort between Southwestern Bell Technology Resources and Bellcore.

Previous work conducted by Bellcore[2], at 850 MHz, in Red Bank, NJ showed a maximum rms delay spread of 660 nsec, with values less than 300 nsec when link range was less than 500 feet. The Bellcore WACS radio system[1] was specified with a channel data rate low enough to handle expected rms delay spread and still meet a 99% grade of service level in the local exchange environment. Since Southwestern Bell is interested in frequencies around 2 GHz, and given that the local environment in St. Louis is somewhat different than that in Red Bank, Southwestern Bell chose to test the delay spread environment to determine whether or not this would be an area of concern during equipment testing and eventual deployment.

During this investigation, a wideband radio transmitter was placed at a defined radio port location and the receiver was taken to each of the houses identified as participants in the wireless local loop testbed. The delay spread and path loss was determined at several locations in and around each test house. The following paragraphs will describe the experiment, the results which were obtained, and will then conclude with a brief discussion of the conclusions derived from this work.

2.3.1 Experiment Description

Details of the experimental setup to measure the impulse response of the radio propagation channel have been reported earlier[2]. Briefly, a 1.9 GHz carrier, bi-phase modulated by a 40 Mbit/s pseudonoise code, is broadcast by a transmitter. The signal suffers time-smear in the propagation channel and is then correlated at the receiver with an identical pseudonoise code, running 4 kbit/s slower. As the codes sweep past each other, the receiver traces out the power-delay profile of the channel, and its envelope is recorded.

The transmitting and receiving antennas were vertically-polarized, sleeve dipoles. For convenience, both the transmitter and the receiver were carried in vehicles. The transmitter was in a small van. The antenna was mounted on a telescoping mast and initially raised to a height of 5.5 meters (18 feet) above ground level. This was slightly below the height of the electric power lines in the area. For one base location, the antenna was also raised to 7.3 meters (24 feet) to compare the effect on the propagation. The sites of the base van location were very close to proposed base station sites for the wireless local loop testbed. The measurement transmitter output power was about 10 watts.

The time delay spread measurement receiver was in the cab of a pickup truck. Its antenna was connected using a 30 m low-loss flexible cable which enabled it to be moved to locations in and around the houses under test. Figure 2.3.1-1 shows a picture of the vehicles.

Figure 2.3.1-1 The measurement equipment at a test site.

At every measurement site, outside locations were chosen at the front, left, back, and right side of the house (facing the front of the house from outside). The hand-held receiver antenna was manually moved by a person standing at these locations, from top-to-bottom and side-to-side, in a raster fashion, over the full reach of the arm. This scanning helps to characterize the local area and prevent the measurement of a null in the pattern. At some houses, measurements were also made inside, at a few locations on the ground floor. Where possible, some measurements were also made on the 2nd floor and basement.

One hundred forty four (144) power-delay profiles were obtained at each location, 256 milliseconds apart, during the scanning. The 144 individual profiles were then power averaged at each time delay to calculate an averaged power-delay profile. After noise clipping, the area under the curve together with attenuator settings, gives the received power level, while the square root of its second central moment, the rms time delay spread, is the measure of channel dispersion that has a very significant effect on the error rate of a digital radio link[3] [4].

Six transmitter van sites were chosen around the area. Many receiver locations were used for each of the six transmitter sites. The maximum separation between the transmitter and receiver was about 915 m (3000 ft). A total of 218 averaged power delay profiles were obtained at 1.9 GHz.

2.3.2 Experimental Results

Note that, unless otherwise stated, all results following will be given for the 5.5 m (18 ft) transmitter antenna height.

Examples of averaged power-delay profiles at 1.9 GHz taken at two different sites are shown in Figure 2.3.2-1 and Figure 2.3.2-2. Each curve has been normalized to the peak power of a power-delay profile that would be received at that frequency at a hypothetical reference distance in free space. The relative power scale referenced to 0.3 m (1 foot) is shown at the left of the figure, while the scale for a 1 m reference distance is given at the right. This normalization removes the frequency dependent system parameters such as transmitted power, antenna gains, and path loss to the reference distance. The two profiles are examples of the widely different data obtained at different sites. Note that in figure 2.3.2-1, the received peak power is quite low, and the delay spread is very long. In figure 2.3.2-2, the received peak power is 20 dB higher, and the delay spread is rather small.

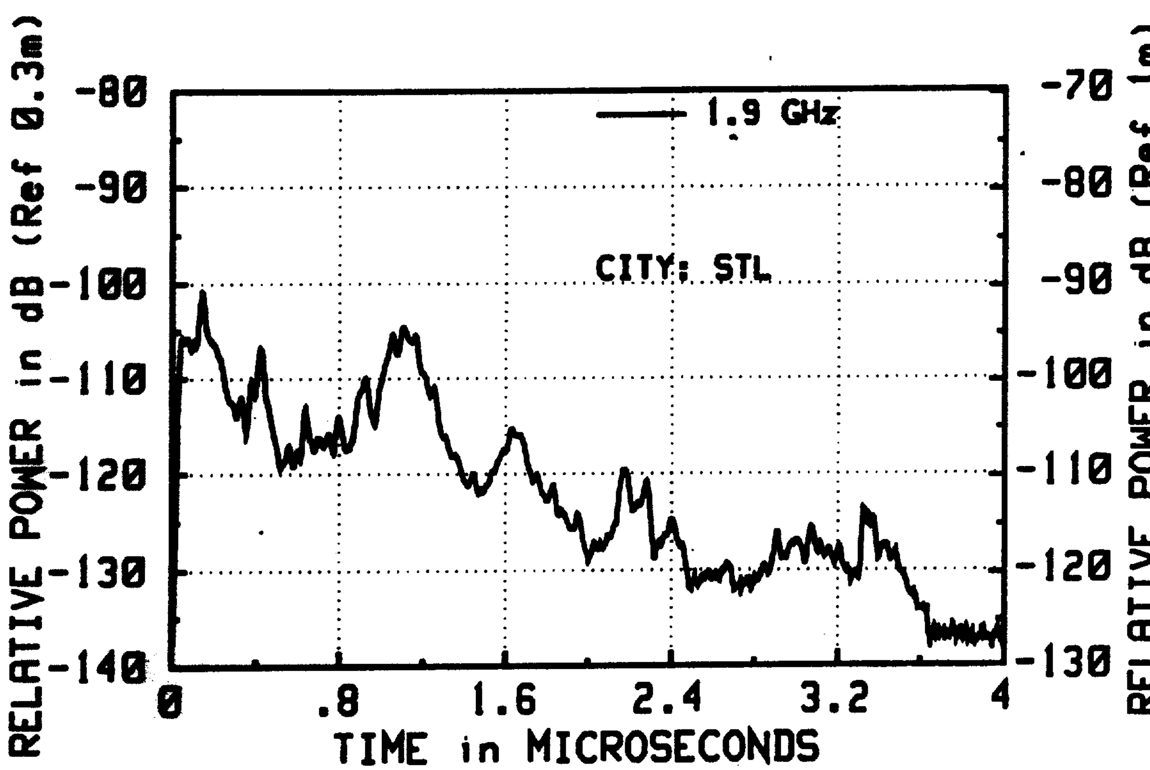

Figure 2.3.2-1 Averaged power-delay profile with largest rms time delay spread measured.

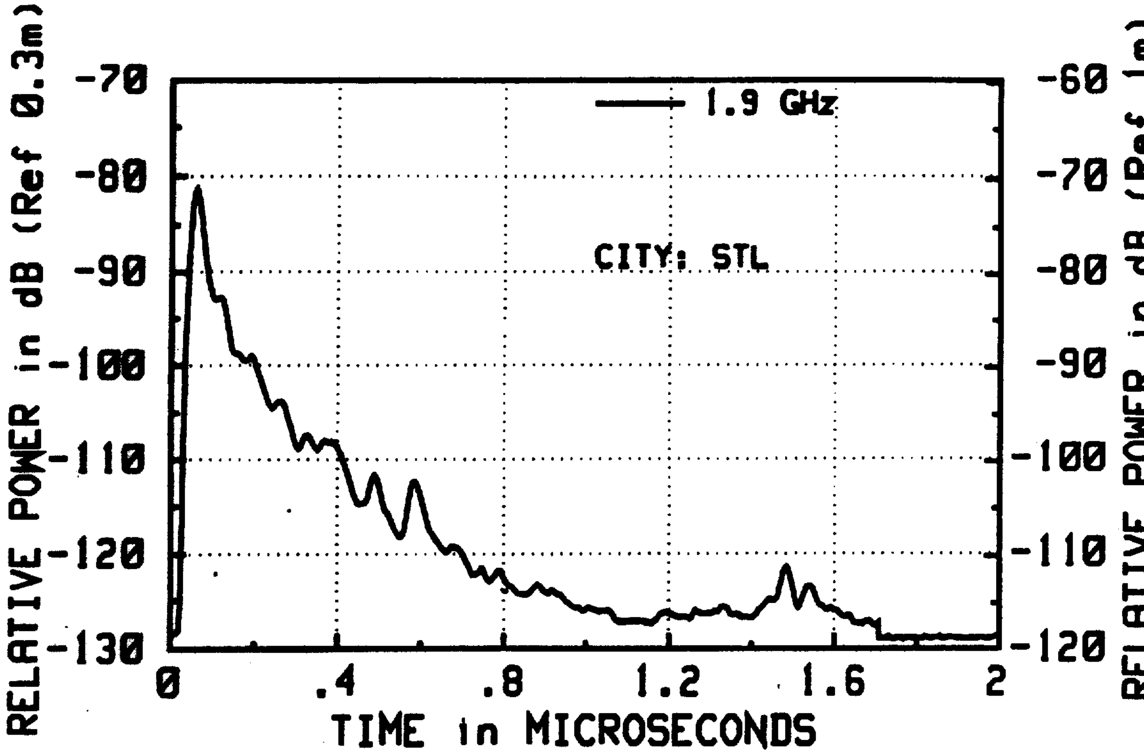

Figure 2.3.2-2 A typical averaged power-delay profile.

Figure 2.3.2-3 shows the cumulative distributions of rms time delay spread measured for the data. The solid curve shows the results at 1.9 GHz for all the data. The dotted curve shows the distribution when receiver distances were less than 600 m from the transmitter. Similarly, the short and long dashed lines are for distances less than 300 m and 150 m respectively. The maximum rms delay spreads were 566, 566, 354, and 158 nanoseconds (ns), respectively. The largest rms time delay spread (found in the profile shown in Figure 2.3.2-1) was measured at a house only 400 meters (1300 ft) from the transmitter. For comparison, the rms delay spread of the profile shown in Figure 2.3.2-2 is only 66 ns, at a separation of 225 m (740 ft).

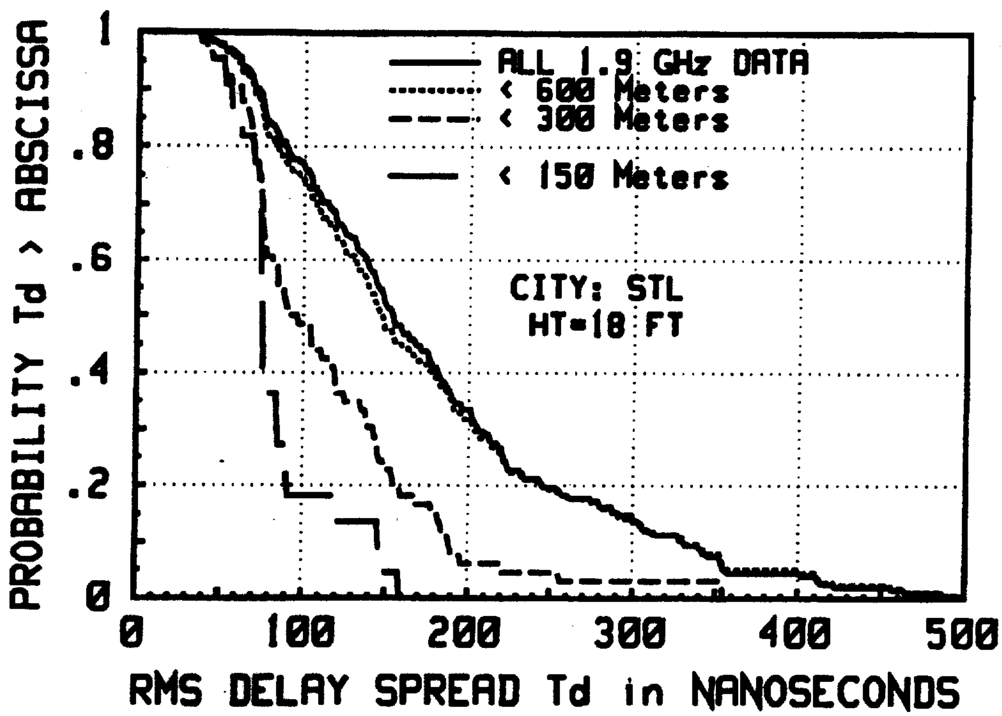

Figure 2.3.2-3 Cumulative distributions of rms time delay spread, by cell radius, for the data at 1.9 GHz.

These results should be compared to earlier measurements at 850 MHz in residential areas in New Jersey, reported earlier. In that study, on inside-to-outside paths, the maximum rms delay spread was 420 ns[5]. In Red Bank, New Jersey, a small city with low building heights and different (flatter) topography, reported previously[6], the maximum rms delay spread for all data was 660 ns. RMS delay spread was under 300 ns only when the transmitter-receiver distance was restricted to under 150 meters. The base antenna height was 8.2 m (27 ft) in all these cases.

As a further point of comparison, measurements made in Brooklyn, New York[7], showed overall maximum rms delay spread at 1.9 GHz of 233 ns, and maximum rms delay spreads of 194 ns, 194 ns and 103 ns, respectively when the transmitter-receiver distances limited to < 600m, < 450 m, and < 75 m, respectively at a base antenna height of 6.1 m (20 ft).

Figure 2.3.2-4 shows the cumulative rms time delay spread distributions for only those residences where both inside and outside measurements were made. The solid curve is for outside data (33 data points) and the dotted curve is for inside data (38 data points). The cumulative distributions are very similar, with only one outlyer. This is reasonable since the scattering within the houses themselves would introduce only small differential delays.

The overall profile would have been determined by the outside scatterers, especially if the intervening walls were relatively leaky so as to not block a direct ray.

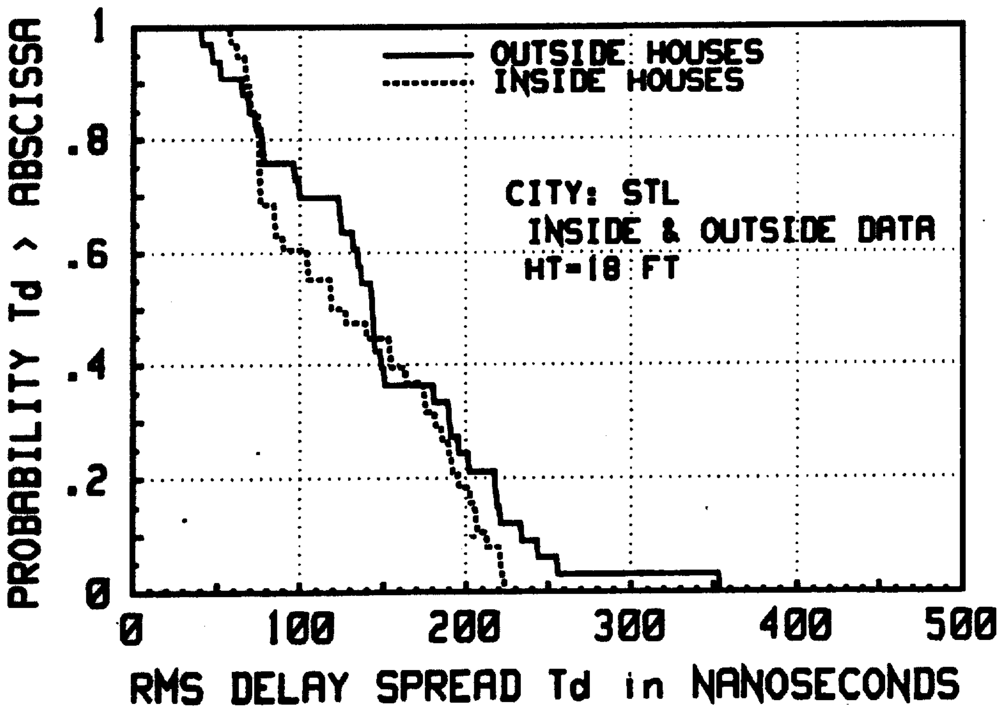

Figure 2.3.2-4 Cumulative distributions of rms time delay spread, measured outside selected houses (solid line) and inside the same houses (dotted line).

Figure 2.3.2-5 shows the scatter plot of the delay spread data for the two different transmitter antenna heights. The data at 7.3 m (24 ft) is plotted against the corresponding points for 5.5 m (18 ft) transmitter height. Due to the limitations of the available telescoping mast, greater height differences could not be explored. The 13 data points are at base site 4. The full regression line to the data had a slope of 0.96 with a correlation coefficient of 0.955. Therefore, a regression line with slope 1.0 was fitted to the data and is shown in the figure. Its correlation coefficient is 0.954, fully justifying this approach. Its intercept is -15 ns and the standard deviation is 24 ns. Hence, the 5.5 m (18 ft) antenna height data had an average of 15 ns greater rms time delay spread than the 7.3 m (24 ft) data. However, the number of data points is small and the standard deviation of the data is quite large.

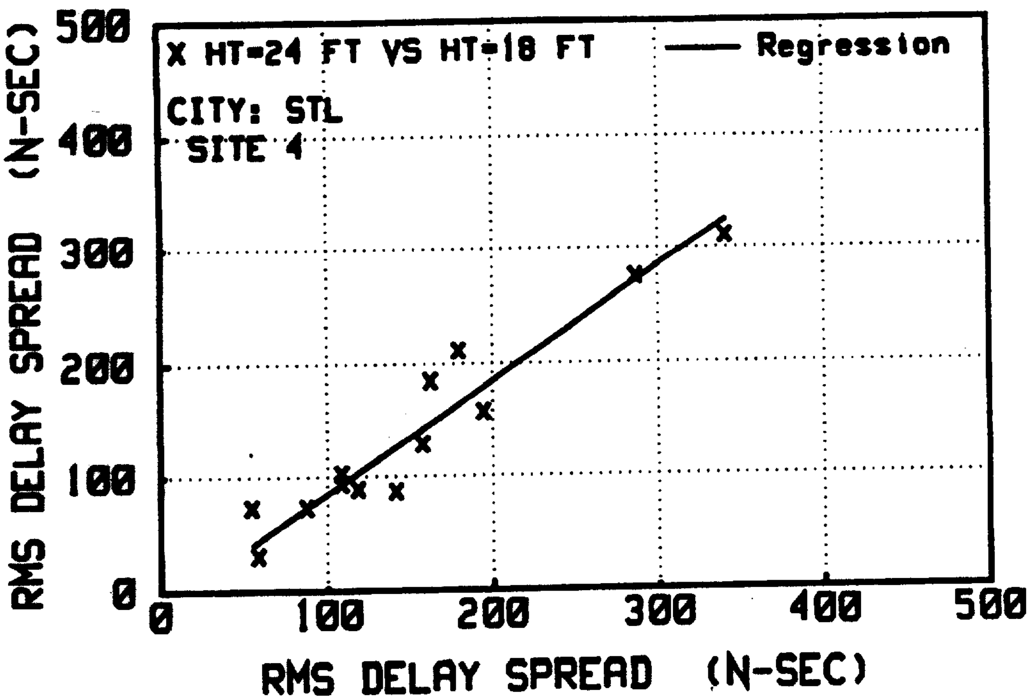

Figure 2.3.2-5 Scatter plot of rms time delay spread, measured at one base location, for transmitter antenna height of 7.3 m (24 ft) against the corresponding values at f 5.5 m (18 ft). The unity slope regression line is also shown.

Next we consider received power levels. The average power which would be measured by a receiver over the scanning area for each transmitter and receiver position was calculated (as explained earlier) and normalized to the average power at 0.3 m (1 foot), and 1 m, respectively[2]. Note that the free space path loss referenced to isotropic antennas at 1 ft and 1 m are 27.7 and 38.0 dB, respectively at 1.9 GHz. Figure 2.3.2-6 shows the received relative power at 1.9 GHz plotted against logarithmic distance between the transmitter and receiver for all the 5.5 m data. The logarithmic regression line is also given. The distance exponent is -3.8 . The intercept at 300 meters (1000 ft), which is in the middle of the measurement range, will be called the Mid Range Intercept (MRI_300m)[8]. Its value is -79.0 dBr 1m (-89.3 dBr 1ft).

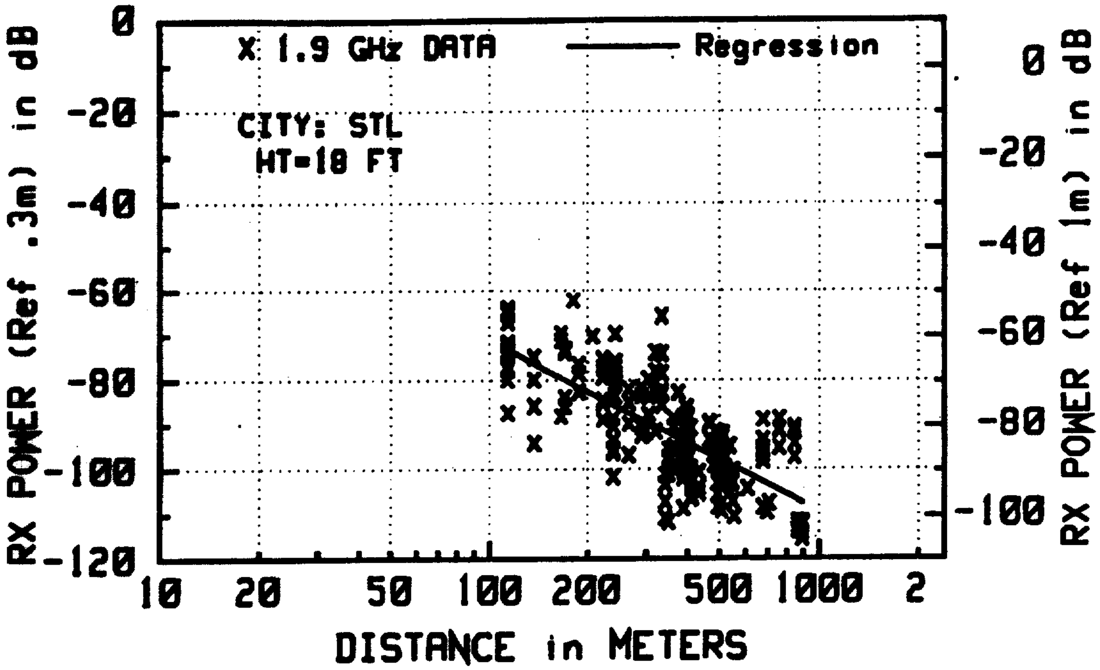

Figure 2.3.2-6 Scatter plot of received relative power with distance of all data, together with logarithmic regression model fit.

Figure 2.3.2-7 shows the comparison of relative received power levels outside (X symbols) and inside (O symbols) the houses with distance. The corresponding logarithmic regression lines (solid and dotted lines, respectively) are also shown. The distance exponent for outside data is -4.1, while the exponent for the locations inside the houses is -3.9 . Given the relatively small sample size (38 and 33 points, respectively), the slopes appear to be about the same. The intercepts at 300 meters are -76.3 dBr 1m (-86.6 dBr 1ft) for outside data, and -80.7 dBr 1m (-91.0 dBr 1ft) for inside data. The difference is 4.3 dB, which is the average attenuation through the houses. The standard deviation of the data was approximately 8 dB in each case. Multi-frequency CW measurements over outside-to-inside paths in residential environments in New Jersey[8] showed a Mid Range Intercept, MRI_300m, at 1.9 GHz, of -85.0 dBr 1m (-95.3 dBr 1ft) for summer data in mixture of vegetated and non-vegetated paths. The distance exponent was 4.8 and the standard deviation was 11.4 dB. In winter, the intercept was 2.5 dB higher. Hence, the present data appears to show slightly lower attenuation, overall.

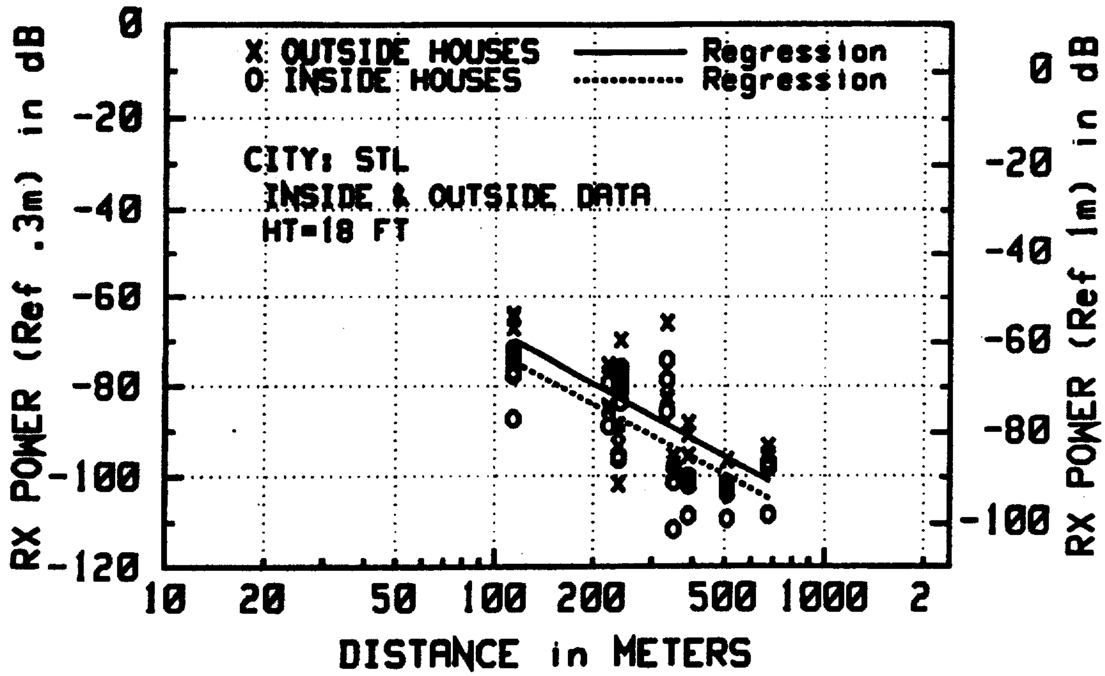

Figure 2.3.2-7 Scatter plot of received relative power with distance, and logarithmic regression lines, measured outside selected houses ("X" symbols, solid line) and inside the same houses ("O" symbols, dotted line).

When the basement data taken at five houses were removed from the inside data, the exponent changed to -3.7 and the average attenuation into the houses at 300 m reduced to 2.5 dB. The basement points, alone, are shown by the five lowest "O" symbols in Figure 2.3.2-7. The excess attenuation to the basements over the outside data regression line ranged from 8 to 21 dB, and averaged 17 dB at 300 meters.

Figure 2.3.2-8 shows the scatter plot of the relative received power levels at 7.3 m (24 ft) base antenna height against the corresponding values at 5.5 m (18 ft), at site 4. The full regression line to this data had a slope of 1.08 , with a correlation of 0.967 . As before, a line with slope 1.00 was fitted to this data. Its correlation was 0.964, once again justifying this procedure, The intercept of this line was 3.4 dB, and the standard deviation was 3.2 dB. Previous measurements have suggested a height-squared signal increase in residential environments[10]. It would correspond to a 2.5 dB increase in this case. Although the number of data points is small (13), and the standard deviation is on the same order as the shift, the present results do not contradict this view.

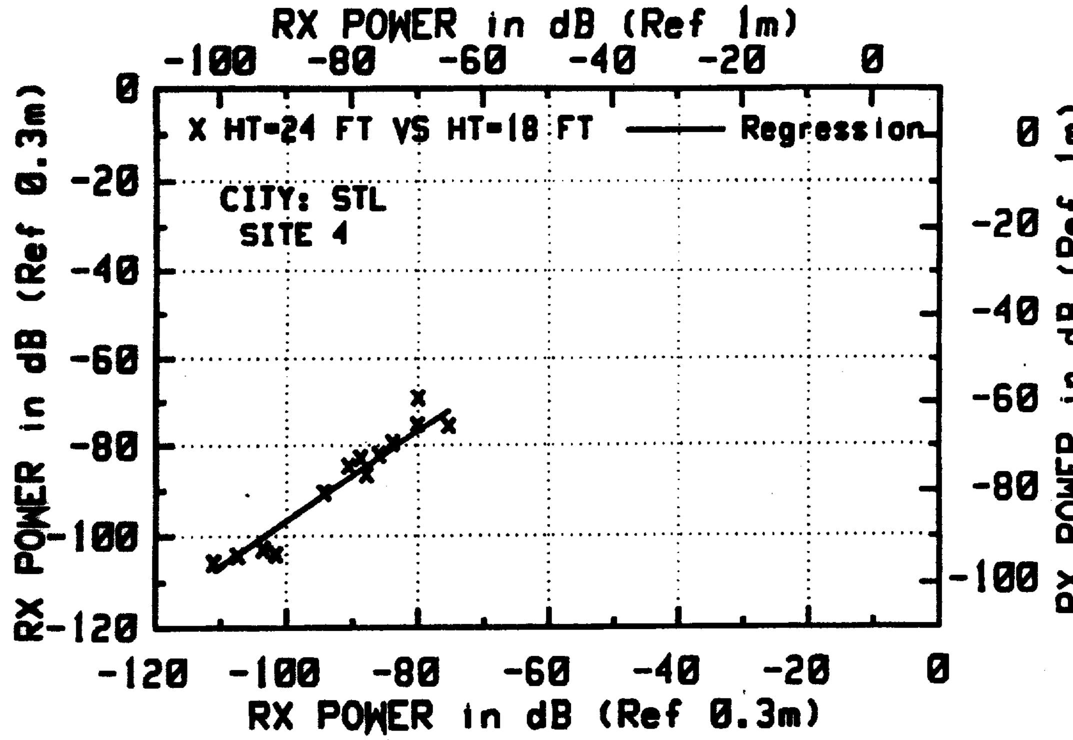

Figure 2.3.2-8 Scatter plot of received relative power, measured at one base location, for transmitter antenna height of 7.3 m (24 ft) against the corresponding values at 5.5 m (18 ft). The unity slope regression line is also shown.

The relationship between signal path loss and the logarithm of the rms time delay spread was first reported in [6]. Figure 2.3.2-9 shows such a plot for all the present data. The regression line is also shown. The slope indicates that the rms delay spread doubles for every 19 dB decrease in signal level (increase in path loss), which corresponds to a decade change in rms delay spread for every 63 dB change in path loss. This compares with 77 dB/decade of rms delay spread in Red Bank.

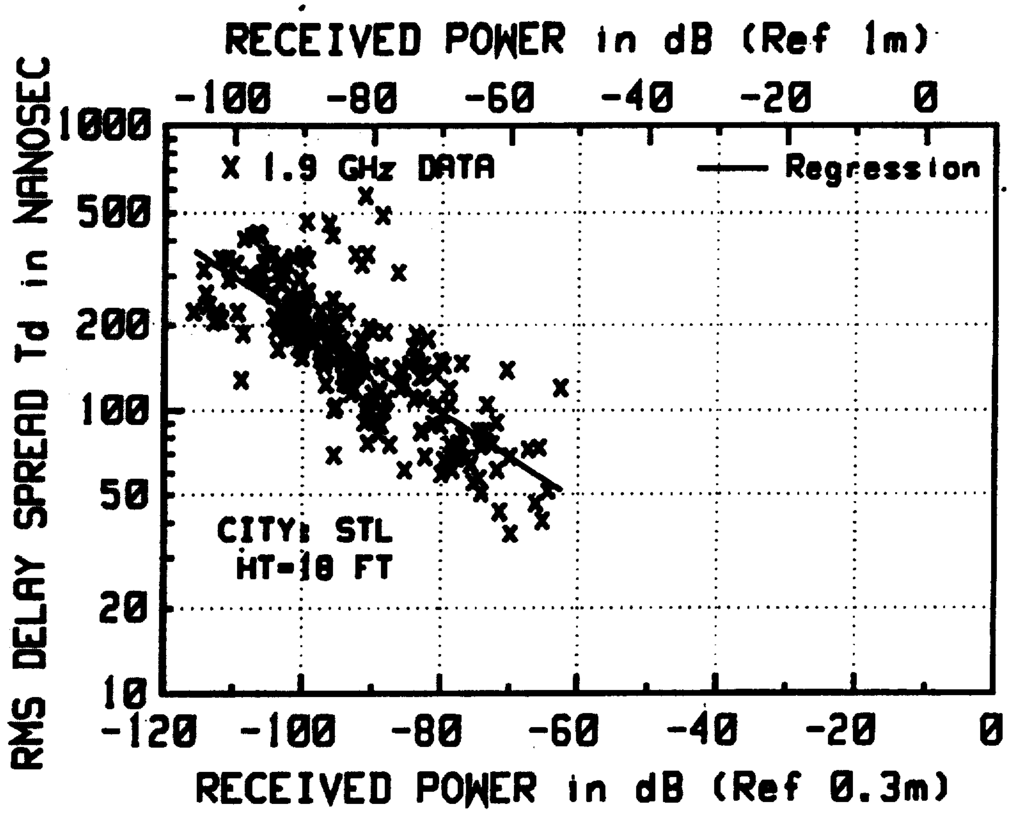

Figure 2.3.2-9 Scatter plot of rms time delay spread with received relative power for all the data; logarithmic scale, and regression line.

2.3.3 Discussion of Results

The range of rms time delay spreads encountered in this study is on the order of values measured in previous measurements in residential and urban environments for low antenna heights. The largest value of 566 ns is interesting because it was measured at a distance of only 400 m from the transmitter, where the relative path loss was about 81 dBr 1m. Using typical link budget analysis at this location for the WACS fixed wireless access communications system[11], it is estimated that the available small scale multipath fade margin here is 16 dB, which is adequate. The symbol rate for this system over the channel is 192 kBaud. At a word error ratio of 1%, the system should tolerate between 550 and 600 ns of rms time delay spread[12]. Hence this location will be a useful test of the design and quality of implementation of this and other such systems.

In practice, when fixed wireless access services are fully implemented in the neighborhood, there will be other base stations which could also be used by this site. Then, the system could automatically choose a link to a base with less multipath in the channel.

The distance exponent of path loss is 3.8 for this data. Averages of measurements made in differing residential environments elsewhere, on outside-to-inside paths, estimate the average exponent to be 4.9 at 1.9 GHz. The Mid Range Intercept is also higher, by a few dB. Hence, these links are slightly less lossy. This may be partly due to the fact that the base stations in this study were selectively sited on local high ground to maximize coverage.

The average attenuation of 2.5 dB at 300 m into the first and second floors of houses, compared to the outside, is an interesting result. A figure of 6 dB is often discussed in the literature for wall attenuation. A study in a different part of the country showed a value of 3.8 dB at 815 MHz[9]. These two results are in rather good agreement and indicate that attenuation into a residential building might be less than typically assumed. However, the standard deviation was about 8 dB in the current data, so larger values should still be assumed when developing a link budget. The average attenuation into the basements of 17 dB for the present data compares well with 15.2 dB obtained in the 815 MHz study. Given the small number of data points, this data appears to be consistent.

The reduction in path loss at the higher base antenna height is consistent with more detailed residential measurements. However the apparent reduction in rms time delay spread is counter-intuitive. It is often thought that a higher base antenna would illuminate reflectors further away, and hence increase the delay spread. In this case, the higher antenna position was still quite low, and may have been just sufficient to clear the local roof line, allowing more direct energy to reach the receiver positions. Since the area had few large reflectors, the reflections would remain the same. These two effects would reduce the relative contribution of the delayed paths, reducing the rms delay spread. Inspection of the averaged power delay profiles for these data lends some credence to this hypothesis. This is a significant result for residential neighborhoods, and suggests the possibility, in residential neighborhoods, of using higher antenna heights for longer ranges where desired without incurring a large delay spread penalty. This hypothesis requires further study. Note that this would not likely be the case in an area where tall buildings were present.

3.0 Propagation of Radio Signals at 2 GHz in a Macrocellular Environment

In March, TRI performed a multi-frequency propagation study in the metropolitan St. Louis area. The study was conducted on behalf of Southwestern Bell Mobile Systems, Inc. (SBMS) in conjunction with the SBMS 2.1 GHz IS-54 TDMA trial in Dallas, Texas. A summary of the propagation study is provided herein. Refer to quarterly progress report filings associated with the Dallas trial[13] for more detailed information.

While 2 GHz propagation characteristics for microcellular scenarios (typical base station heights of less than 75 feet and coverage areas of less than 1 mile) have been studied[14] [15] extensively, limited published data is available on 2 GHz macrocellular scenarios. This study was undertaken to fill this need. Key objectives of the study were to:

- Characterize average propagation loss at 800 MHz, 1.9 GHz, and 2.1 GHz for macrocellular scenarios (base station antenna heights greater than 100 feet and coverage areas at or beyond one mile). In particular, the study addressed average propagation loss as a function of carrier frequency, base station antenna height, terrain, and environmental clutter.
- Compare measured data against "industry standard" propagation models and engineering practices. A further objective was to assess under what conditions existing design rules can be applied to 2 GHz wireless network deployment.

These objectives were met through a series of multi-frequency signal strength measurements done by TRI under this FCC experimental license. Signal strength data was collected and processed to permit direct comparison of 800 MHz and 2 GHz (either 1.9 GHz or 2.1 GHz) propagation. For data collection, a 2 GHz signal source was collocated with an existing 800 MHz signal beacon and data was collected from a van moving at approximately constant velocity. Simultaneous 800 MHz and 2 GHz signal strength measurements were acquired by a dual channel receiver system.

Two transmit locations within the St. Louis metropolitan area were used for the tests. Operational SBMS cell sites were chosen as transmit test locations to enable collocation of a 2 GHz source with an existing 800 MHz beacon (the forward control channel of the SBMS cell site). Specific transmit locations were selected to provide an adequate data sample for various terrain and urbanization conditions. Corresponding 2 GHz test frequencies and appropriate radiated power levels were determined from an interference coordination study. All 2 GHz signal transmissions were done on a non-interfering basis.

Measurement data was collected with a dual channel receiver system. Both receiver channels were based around a spectrum analyzer specially configured for narrow band signal strength measurements. To improve receiver performance, a custom RF preselector was placed between the receive antennas and the spectrum analyzers. The preselector contained a series of bandpass filters, ferrite isolators, and low noise amplifiers. Two omnidirectional vertically polarized antennas, covering the 850 to 900 MHz and 1850 to 2200 MHz frequency bands, were used for the measurements. Received signal strength readings were generated by sampling the spectrum analyzers' video signal with a multichannel, 12 bit analog-to-digital, data acquisition board mounted in a personal computer. All signal strength samples were logged on the hard disk of a PC along with two dimensional position information collected by Global Positioning System receiver. The entire measurement system was mounted in a customized commercial van.

More than 50 million signal strength samples were recorded in the two test locations. Data collection parameters (e.g., spectrum analyzer and data acquisition settings) were chosen to provide a complete characterization of instantaneous received signal strength as a function of receiver position. Drive routes were selected to provide an accurate measure of signal strength throughout the test location. Data was collected on interstates, major thoroughfares, and side streets under varying degrees of terrain, both flat and rolling terrain, and environmental clutter, including urban, suburban, and residential areas.

Signal strength data was processed to isolate both long term and short term signal fading. Long term fading data was used to compute average propagation loss. A statistical analysis of the data was then done to compare propagation characteristics at each test frequency. Some key findings of this analysis includes:

- The mean difference in average propagation loss between 800 MHz and 2 GHz is a function of terrain and urbanization conditions. Measurement data indicates that a 8 to 10 dB difference can be expected in urban areas and a 6 to 8 dB difference can be expected in residential areas. These values agree with theory, which would predict a 7 dB difference between the two frequencies.
- Average propagation loss at 800 MHz and 2 GHz appears to be correlated, suggesting that similar multipath scattering mechanisms (e.g., reflection, diffraction, diffuse scattering) exist at each frequency.
- The incremental difference in average propagation loss between 1.9 GHz and 2.1 GHz is small, typically less than 2 dB.
- For a vehicle traveling at a given speed, short term fading occurs approximately 2.5 times more frequently at 2 GHz than at 800 MHz. However, 2 GHz fading statistics, including the frequency, duration, and depth of fades, can be described using existing 800 MHz fast fading models when these models are scaled by the frequency difference.

The results indicate that designers of wireless networks need to carefully consider 2 GHz propagation factors in system design. Due to the 6 to 10 dB of additional propagation loss, the effective cell coverage area at 2 GHz will be less than at 800 MHz. For a given radio technology, more cells will be required to serve an area at 2 GHz than at 800 MHz. In some cases, appropriate countermeasures can be employed to improve coverage though these countermeasures will likely increase system cost and complexity. Ultimately, the coverage issue needs to be addressed within the system design.

While 2 GHz propagation poses challenges for a system designer, it is not a major impediment. The study findings support the use of existing wireless design methods for 2 GHz deployment. With appropriate modifications, existing propagation models and engineering practices can be employed for 2 GHz network planning.

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