Figure 8.2.3

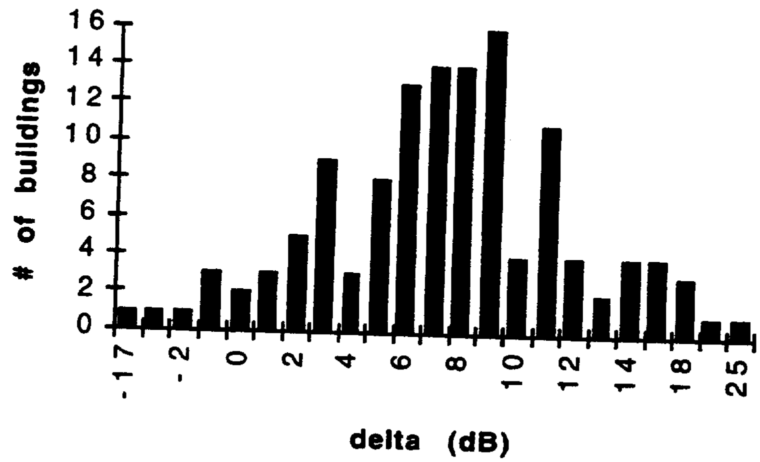
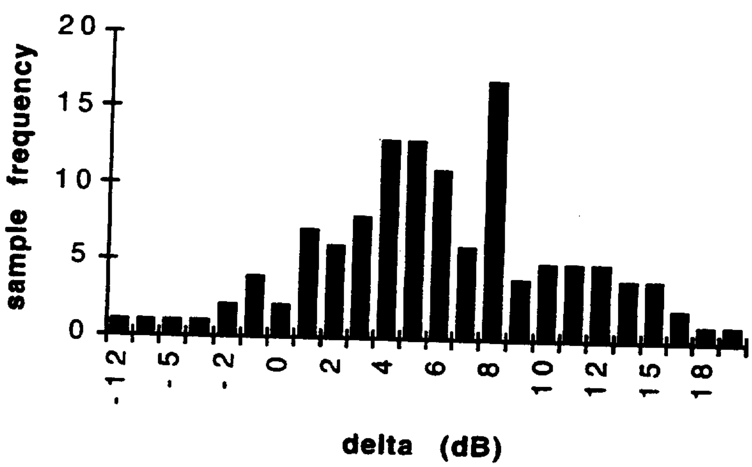


Figure 8.2.4



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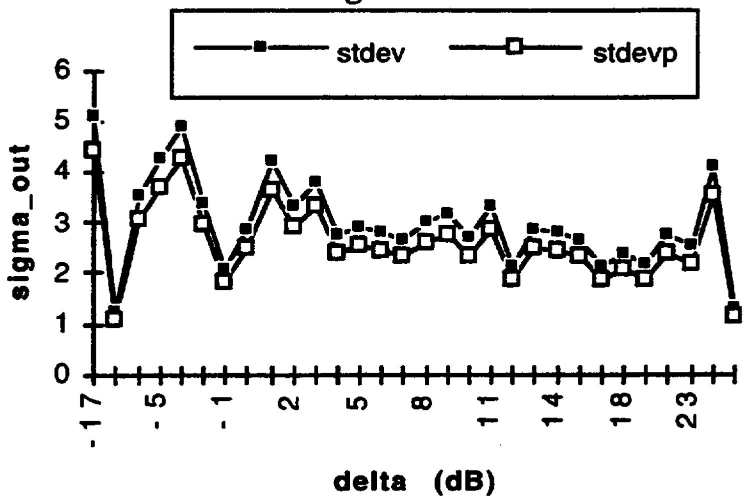


Figure 8.2.6

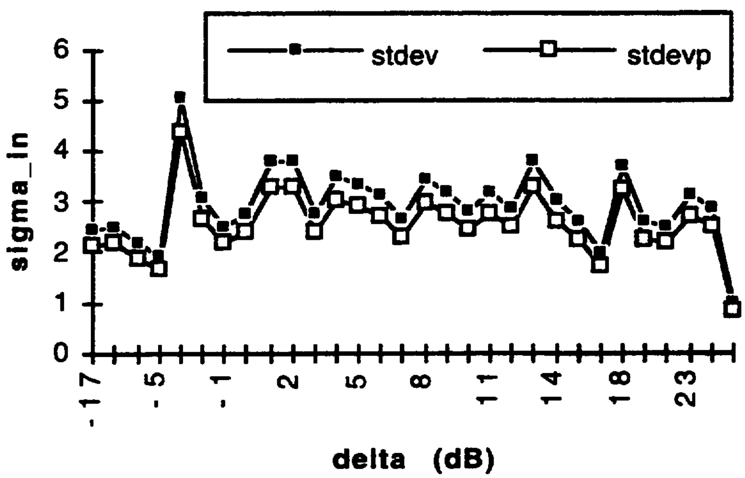
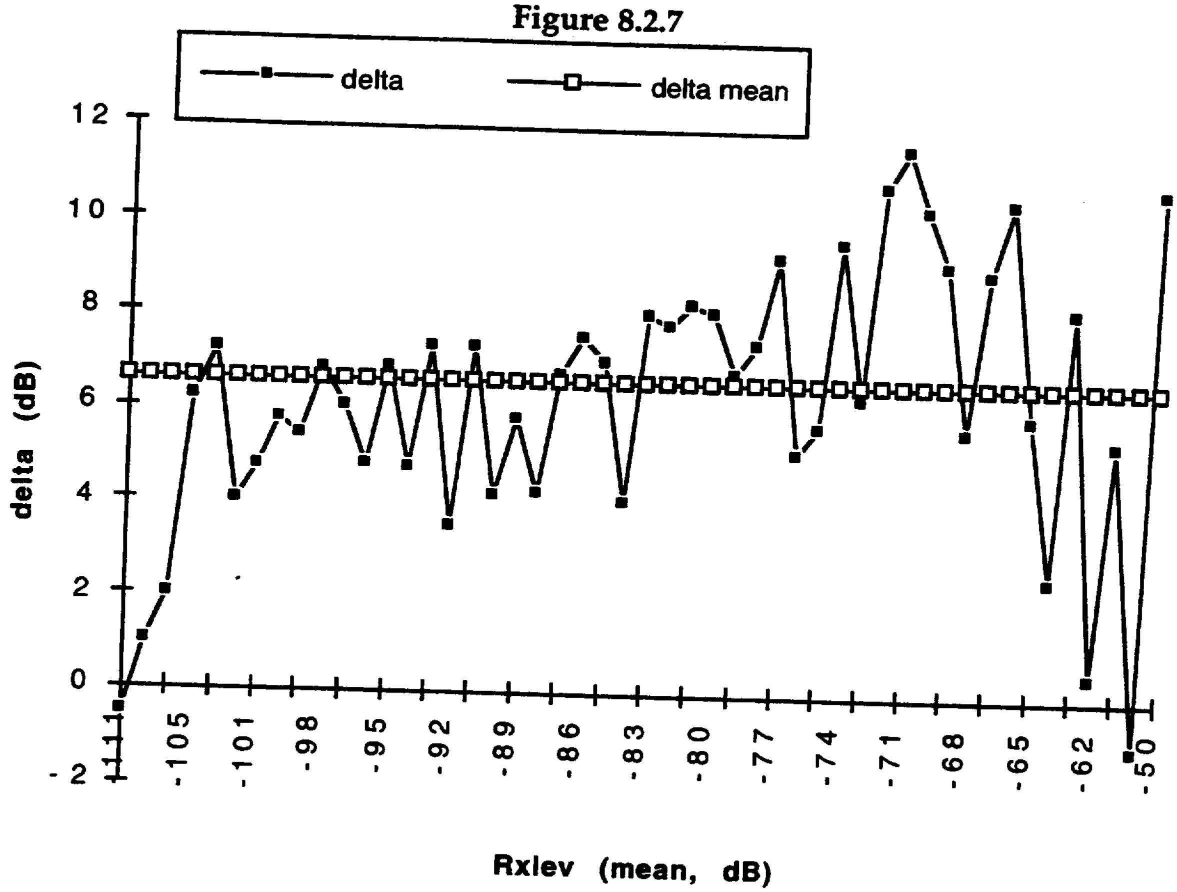
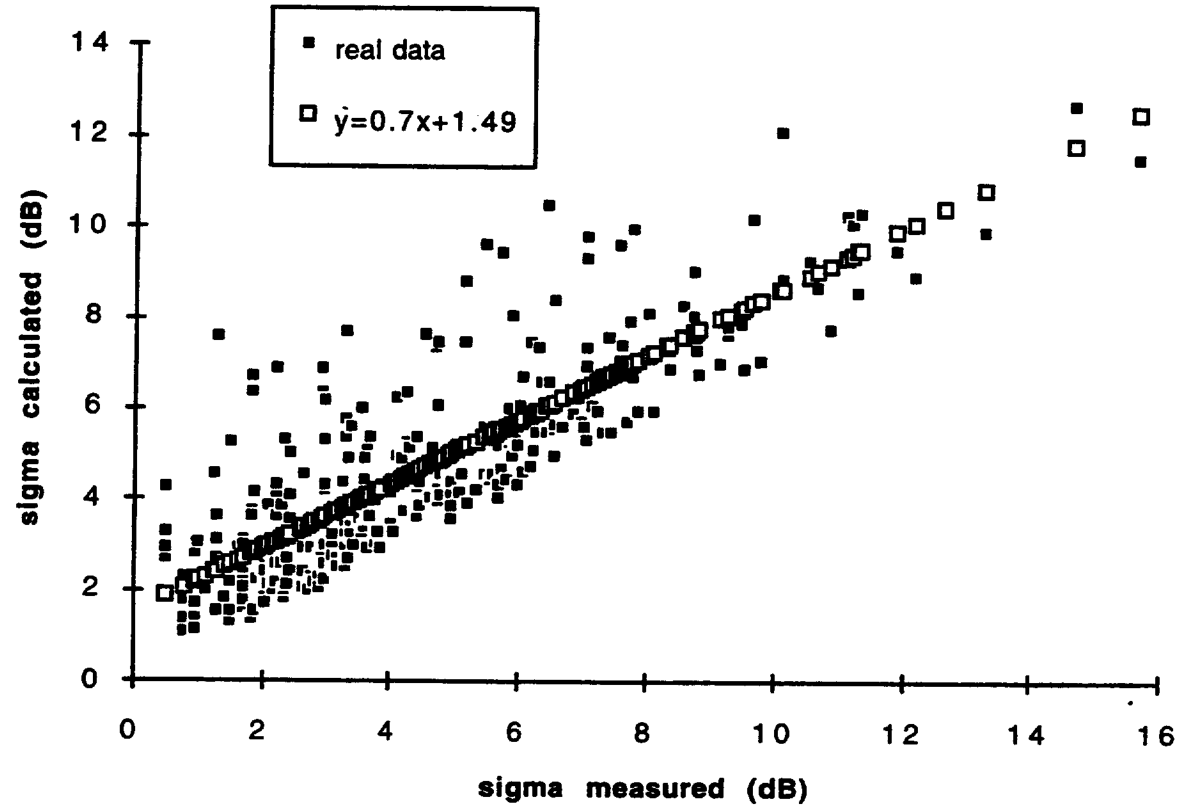


Figure 8.2.7



delta
delta mean
12
10
8
6
4
2
0
-2
delta (dB)
-111
-105
-101
-98
-95
-92
-89
-86
-83
-80
-77
-74
-71
-68
-65
-62
-50
Rxlev (mean, dB)

Figure 8.2.8


real data
y=0.7x+1.49
14
12
10
8
6
4
2
0
sigma calculated (dB)
0
2
4
6
8
10
12
14
16
sigma measured (dB)

8.3 Data Discussion

8.3.1 Δ versus number of samples

The indoor and outdoor RSS were averaged for each building, and the penetration loss Δ is calculated as:

$$\Delta = RSS_{out,\ ave} - RSS_{in,\ ave}$$

All Δ's were rounded to integer digit (for example: 3.49 was rounded to 3; 3.51 was rounded to 4). Then the frequency of the samples with the identical Δ was counted, and the result is shown on Figure 8.2.1. This, in fact, is a discrete, un-normalized probability density function f(Δ), with the following parameters:

m_Δ	σ_Δ
6.6	5.2

Table 8.3.1.1: Total data from 341 buildings gave a lognormal distribution characterized by the mean (m_Δ) and standard variation (σ_Δ), in dB

The measured density function is clearly lognormal. In order to check if the distribution is really Lognormal, we counted the percentage of samples contained in $m^+/-\sigma$, $m^+/-2\sigma$ and $m^+/-3\sigma$ windows. We found that 73% of the samples are in the $m^+/-\sigma$ window, which is off from what we expect for the lognormal distribution by 7.4%. However, $m^+/-2\sigma$ and $m^+/-3\sigma$ windows contain 95% and 99% of the samples, which is in accordance with the lognormal distribution.

From Figure 8.2.1 we can see that some buildings had negative Δ (penetration loss), which effectively amounts to a penetration gain. This is due to the fact that the buildings in question had the outdoor measurement points shadowed by the building, whereas the indoor measurement points were closer to the BTS that the handset was registered to, and also right next to the window that was illuminated by the BTS. The distribution of these samples fits well into the Lognormal distribution, as seen from Figure 8.2.1.

8.3.2 Building penetration loss versus sample percentage

After the probability density function f(Δ) is determined (4.1.1) the next step is to integrate f(Δ) to obtain the cumulative distribution function F(Δ). The result is shown in Figure 8.2.2. The cumulative distribution function represents the percentage of samples (data points) that have measured building penetration loss less than (or equal to) a given Δ. For example, we can read from the grahandsets that 90% of the buildings had penetration loss of 12 dB or less. From the calculated m_{Δ} (4.1.1) we see that 50% of the buildings had penetration loss of 6.6 dB or less.

8.3.3 Building penetration loss versus the type of the building

Figure 8.2.1 gives the building penetration loss density function for all buildings accessed, regardless of structure or height. However, most of the buildings accessed had either big shopping windows (in downtown pedestrian mall), or were brick buildings with normal size windows. Most were single story buildings. Although we had data for concrete/steel, as well as multiple (up to 4) story buildings, there were not enough of them to form a meaningful statistics. Therefore, only the statistics for large window buildings and small window brick buildings is presented.

Figure 8.2.3 shows the probability density function f(Δ) for the small window brick buildings. The mean and the standard deviation in this case are (for the total of 121 buildings):

$m_{b\Delta}$	$\sigma_{b\Delta}$
8.0	4.4

Table 8.3.3.1: First wall loss for 121 small window brick buildings, lognormal distribution, in dB

To check if we had enough samples to claim a lognormal distribution, we calculated the percentage of the buildings that fall within $m+/-\sigma$, $m+/-2\sigma$ and $m+/-3\sigma$ area. We had 72% for $m+/-\sigma$, 96% for $m+/-2\sigma$, and 99% for $m+/-3\sigma$. This proves that we had enough representative samples to claim Lognormal distribution in this case.

Figure 8.2.4 shows the probability density function for the buildings with large windows, regardless of their structure. Since the indoor data has been taken right next to the front entrance door which is usually facing the street, and because the shopping windows are also facing the street, we expect the mean to be lower than for that for the brick buildings with small windows. The mean and the standard deviation are (for the total of 128 buildings):

$m_{w\Delta}$	$\sigma_{w\Delta}$
5.96	4.92

Table 8.3.3.2: First wall loss for 128 buildings with large windows, lognormal distribution in dB

Again, we checked to see if we had enough samples to claim a lognormal distribution. The total of 68.5% of the samples were found to be within $m^+/-\sigma$ boundary, 95% within $m^+/-2\sigma$ and 99% within $m^+/-3\sigma$. Therefore, we had enough representative samples to claim lognormal distribution.

It can be concluded that the large window buildings regardless of the type of the material, typically have 2 dB less building penetration attenuation than the brick buildings with small windows. This holds true for the buildings not taller than 4 stores.

8.3.4 Building penetration loss versus the indoor and outdoor σ

In Section 8.1 we described the methodology for collecting the data samples. The question that we need to address is how big of an error we had made by making an assumption that averaging out 4 consecutive directional spatial measurements would give us a good estimate of the indoor (or outdoor) mean power level. The way to estimate this error is to compare two different standard deviations, σ (stdev) and σ_P (stdevp) obtained from 4 indoor and 4 outdoor directional spatial measurements for the each building. σ is calculated assuming that 4 readings are just a sample of all possible outcome of the measured power level. σ_p is calculated based on the assumption that 4 measurements are the only possible outcome of the measured data. If we had taken an infinite number of directional measurements, σ and σ_p would have been identical. The difference between σ and σ_p tells us the error in the standard deviation, made by taking finite number of power level readings, and consequently indicates if the number of points was large enough to give us a reliable mean power level. The comparison between σ and σ_p is given in Figure 8.2.5 for outdoor data points and in Figure 8.2.6 for indoor data points. σ and σ_p differ by 13.4% for both indoor and outdoor data. It would be preferable if this error is lower than 10%, so for the future trials we should consider taking 5 instead of 4 directional power readings. Taking more directional power readings would increase accuracy, but would be more time consuming, taking into effect that the relatively large number (in this case close to 350) of data points is needed to have statistically reliable data.

8.3.5 Building penetration loss versus the average power level

Figure 8.2.7 shows the building penetration loss as a function of the average power level. It can be noted that for small values of the average power level (Rxlev < -104), penetration loss (Δ) is much smaller than the mean (m_Δ) calculated in 8.2.1 (m_Δ=6.6 dB). This is because at very low level the handset reads its noise threshold, reducing the activated Δ. For Rxlev < -64 dB the penetration loss is grouped around its mean value. However, for Rxlev > -64 dB we see sudden oscillation in Δ. These are due to the fact that we didn't have enough data points for Rxlev > -64 dB to establish a reliable statistics for Δ. Therefore, the region of the interest is -104 < Rxlev < -64, and it should be noted that the relatively remarkable variation of Δ around its mean value is due to the fact that the standard deviation (σ_Δ=5.2 dB) is relatively large in comparison to the mean value m_Δ.

8.3.6 σ_Δ calculated versus σ_Δ measured

Based on measured indoor and outdoor power levels (4 spatial directional measurements each), standard deviation σ_{in} and σ_{out} can be calculated. σ_{in} and σ_{out} are calculated for each building, as defined in section 8.2.4. Since indoor and outdoor measurements for each building are independent, we can calculate σ_Δ if σ_{in} and σ_{out} are known as:

$$\sigma^2_{\Delta calc} = \sigma^2_{in} + \sigma^2_{out}$$

Another way to obtain σ_Δ is directly from the measured indoor and outdoor power level, $\sigma_{\Delta meas}$. First we calculate the difference Δ_1, Δ_2, Δ_3, and Δ_4 for each pair (indoor-outdoor) of measured power levels for a given building. Then $\sigma_{\Delta meas}$ is calculated for these Δ's, following the procedure outlined in 8.2.4. $\sigma_{\Delta calc}$ and $\sigma_{\Delta meas}$ would have been the same for each building if had taken infinite number of indoor and outdoor power level readings for each building. If we were to make a scattered x-y plot of such (ideal) data, we would have all the points to be on y=x curve. However, since we had a finite number of the sample points taken, we expect to see somewhat different scattered x-y plot, with points not necessarily lying along y=x curve. The scattered plot for $\sigma_{\Delta calc}$ versus $\sigma_{\Delta meas}$ is given on Figure 8.2.8. It is not readily seen how much the data deviates from the ideal case. To evaluate the overall error, the linear curve fitting using the least squares method was performed. It was found that the linear curve that fits data the best is y = 0.7x + 1.49. As outlined in previous sections, the agreement between theoretical and empirical results would have been better if we had taken more sample points for each building, but would have been more time consuming also, and would have increased the cost of the whole test trial.

8.4 Summary

The testing methodology adopted for PCS 1900 Building Penetration Measurements was described. The measured data were presented and interpreted. It was concluded that enough data points (buildings) have been included in the testing so that we could claim Lognormal density function distribution for certain types of buildings. It was shown that in the light urban and suburban areas the mean building penetration loss is m_{Δ}=6.6 dB, with standard deviation σ_{Δ}=5.2 dB. The buildings with large shopping windows have the mean building penetration loss $m_{w\Delta}$=5.96 dB, with standard deviation $\sigma_{w\Delta}$=4.92 dB. The brick buildings with small windows have the mean standard deviation $m_{b\Delta}$=8.0 dB, with standard deviation $\sigma_{b\Delta}$=4.14 dB. It can be concluded that the buildings with large windows have 2 dB less building penetration attenuation than the buildings with small or regular size windows.

APPENDIX A: STATEMENT OF INDEPENDENT OBSERVER.

The Institute For Telecommunication Sciences (ITS), the research and engineering arm of the National Telecommunications and Information Administration (NTIA), was asked by the JTC to function as the independent observer of the JTC technology field trails. Michael G. Laflin, of ITS, was the primary observer for this field trial.

The first technology to undergo field testing is that promoted by Technology Ad Hoc Group 5.

This role as independent observer involved reviewing test procedures and observing the test execution. This role also involved significant direct participation in the data collection, storage, and analysis. In so doing ITS is qualified to comment on the conduct and results of the TAG 5 technology field trail.

It is the opinion of Mr. Laflin that the testing was conducted honestly and within the guidelines of the test plan for this field trial. After all is said and done there is always mo data and additional analysis that one would like to have seen collected and performed to maximize the usefulness of a test such as this. Having said that though, the independent observer believes that the final product, this report, reflects adequately the results from this test.

ITS wishes to thank all of the participants for their hard work and patients in completing the first JTC technology field trial.

APPENDIX B: STATEMENT OF MANUFACTURERS.

MOTOROLA

Motorola extends its thanks to all participants in this very successful field test. Special thanks is extended to U S WEST for providing the Boulder Industry Test Bed (BITB) and their very capable technical staff. Additional thanks to the Institute for Telecommunication Sciences (ITS) and Northern Telecom for their contributions, as well as all other TAG 5 members who assisted with funding of the testing.

Motorola is pleased to have been part of the TAG 5 field test. As the first technology to complete field testing as required by the Joint Technical Committee (JTC), PCS1900 (based on the GSM technology) has laid much of the groundwork for other technologies to follow. At the same time, the efficiency, and comprehensiveness of the tests have set a high standard by which others will be compared.

Motorola wishes to caution the reader from drawing conclusions about certain aspects of system performance described in this report. The emphasis of the testing was on air interface aspects of PCS1900. Fundamental aspects of radio system performance such as coverage, interference immunity and voice quality were the focus of the test plan. This focused scope, combined with a limited time frame, did not permit any system parameter optimization to take place. As a consequence, inter-BSC functionality (such as handover) did not perform with the efficiency and reliability which has become the norm in mature GSM systems world wide.

Other advanced features available with PCS1900, such as Slow Frequency Hopping (SFH), and advanced frequency re-use schemes, were also outside the scope of the JTC test plan. These and other features are deserving of consideration when assessing the performance of the PCS1900 air interface.

Certainly one of the most significant results of this field tests was an intrinsic test of inter-operability between multiple manufacturers. Only a months time was required to assemble a system comprised of a switch and base stations from multiple vendors, providing seamless handovers to mobiles from multiple vendors. The success of this venture is a testimony to the open architecture of PCS1900.

The results of this field test will hopefully serve as a valuable source of information to the PCS industry. Motorola is happy to have been a part of this cooperative effort.

Northern Telecom, Inc.

Northern Telecom would like to acknowledge all the participants for their contributions towards the success of this PCS1900 field test technology trial, the first technology to be tested as required by the JTC. This includes the contributions from all TAG 5 members, Motorola and the staff and facilities of USWest for the use of the Boulder Industry Test Bed (BITB) and the Institute for Telecommunications Sciences (ITS).

The robustness and maturity of the GSM based technology is evidenced when two separate manufacturers, in a very short time frame, builds a seamless operational network within a metropolitan area. PCS1900 was the first technology to be tested, and as such encountered some non-technology dependent testing difficulties. Future tests with other technologies will draw on this experience base with enhanced testing procedures providing more exacting outcomes.

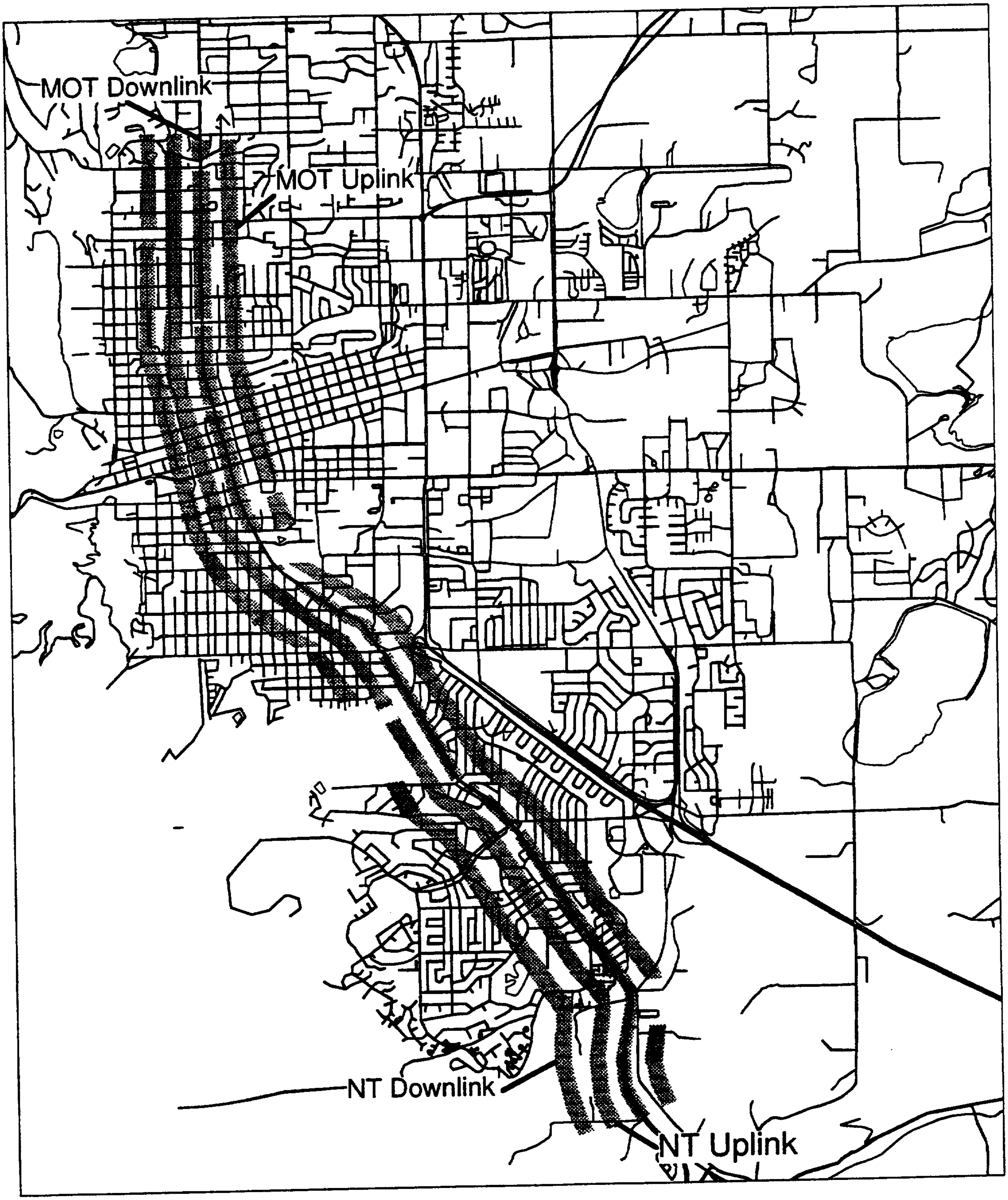
With the time constraints, it was not possible to perform a thorough evaluation on many of the PCS1900/GSM technology features (short message, quality control with DTX, frequency hopping, power stepping, handover deltas, etc,). Handovers performed correctly for the environment they were set for, but to ensure inter BSC handovers in extremely weak areas where no overlap was predicted to occur, deltas and margins were set to values which are not representative of an optimized system.

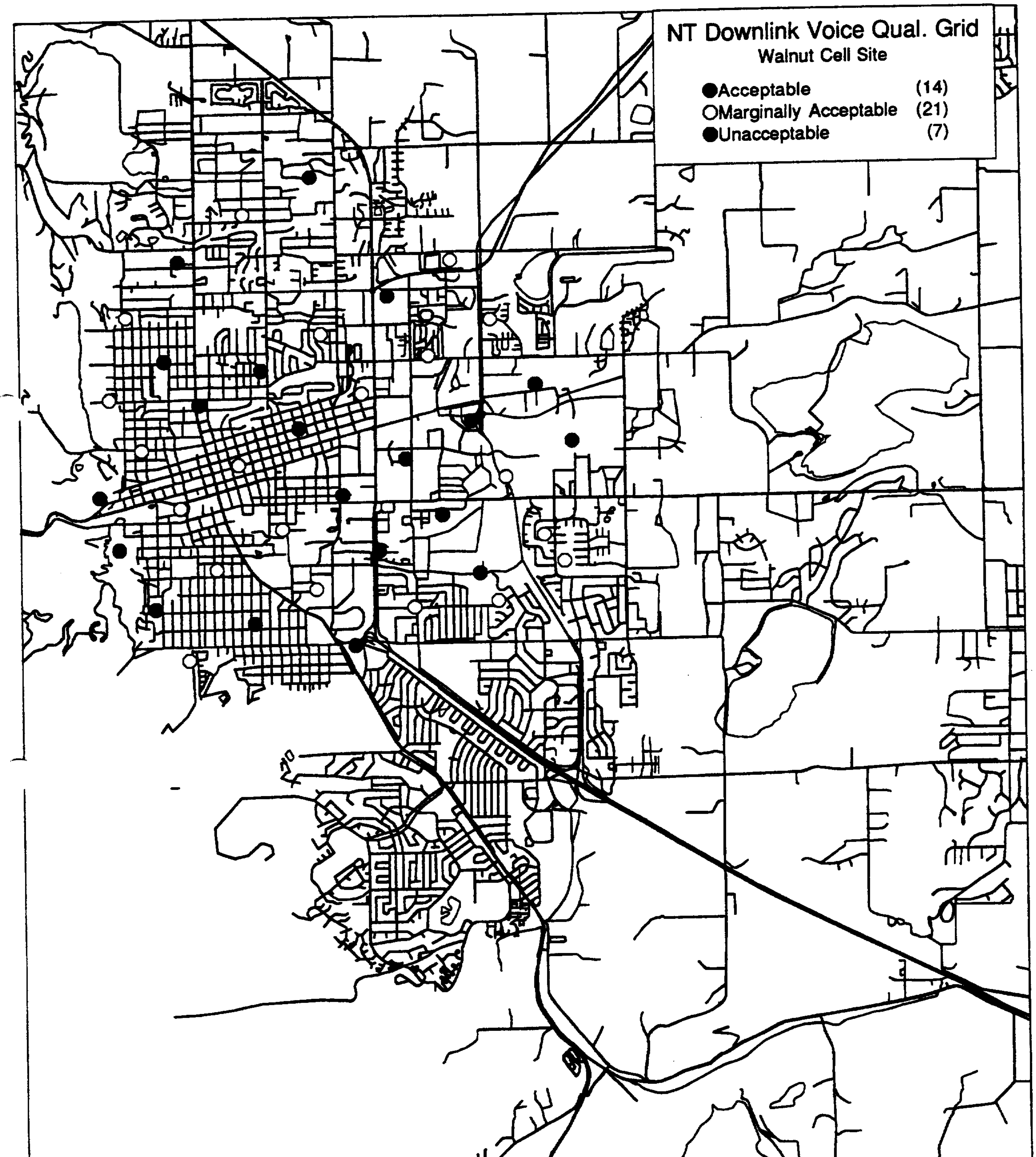
One would expect that MOS scoring should have a direct correlation with RXLEV and/or RXQUAL and additional analysis must be performed to identify the cause, while recognizi that the system was not optimized for voice quality (e.g. no Echo Cancellers were deployed towards the PSTN although the BTS / BSC distance was over 700 miles.) Caution must also be placed on the use of building penetration deltas given the limited time for testing.

Northern Telecom is pleased to have assisted in the demonstration of PCS 1900, towards the goal of rapid introduction of the technology into the industry. We trust that these results will be found useful by others in the PCS industry.

APPENDIX C: COVERAGE PLOTS.

PCS1900 Handoff
30 mph

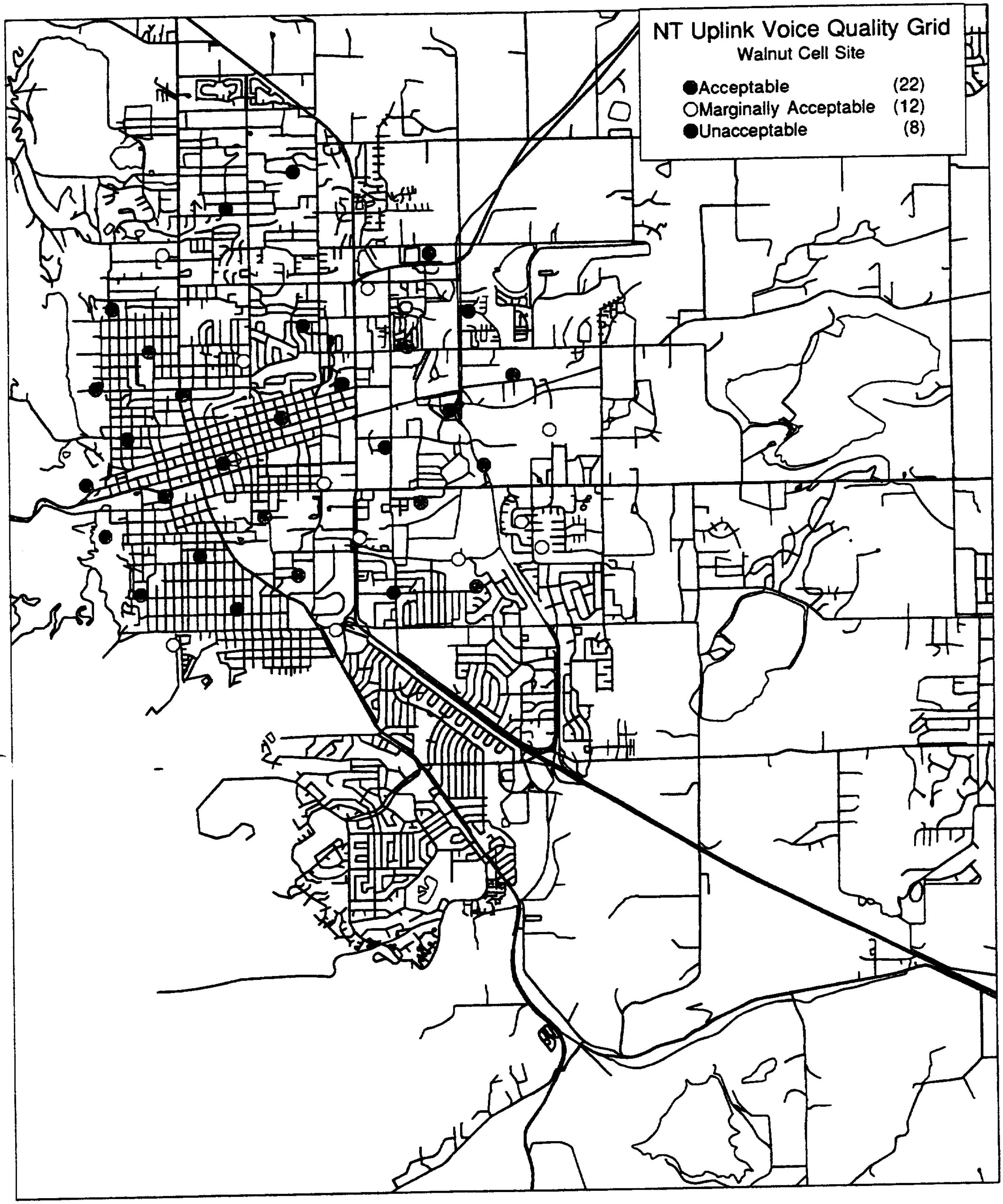


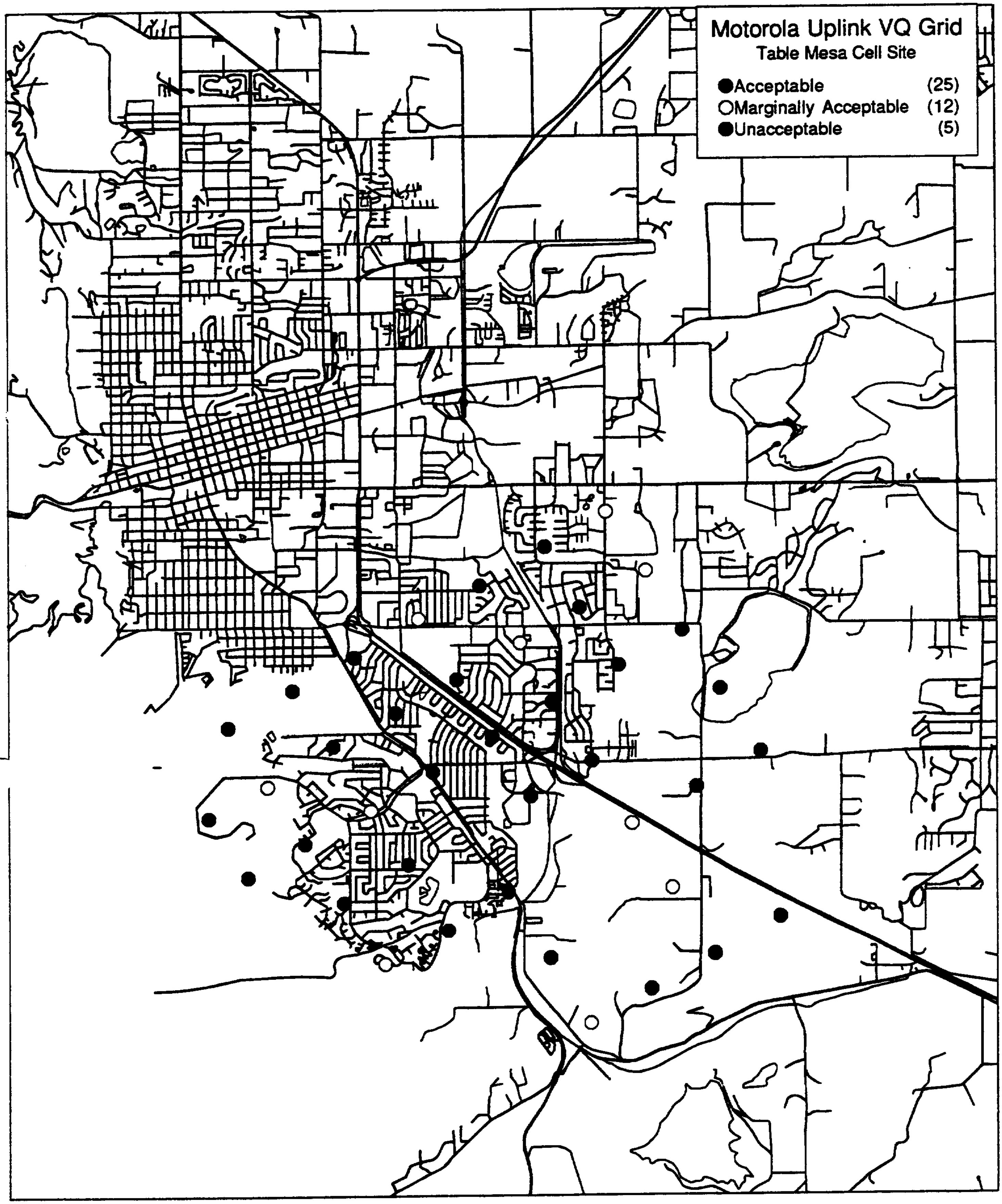

NT Downlink Voice Qual. Grid
Walnut Cell Site
●Acceptable (14)
○Marginally Acceptable (21)
●Unacceptable (7)

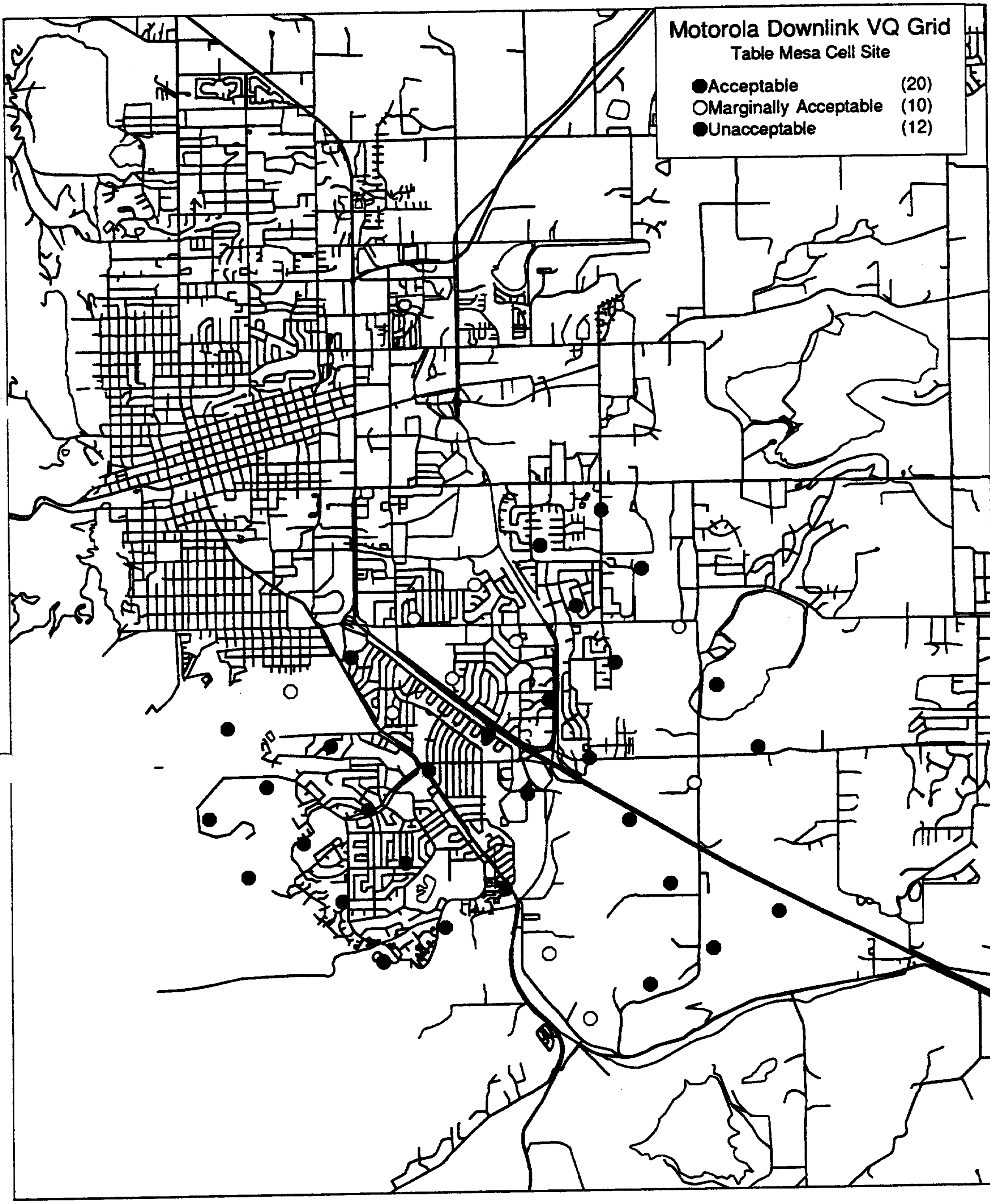
ENCLOSURE

PHP Field Trial

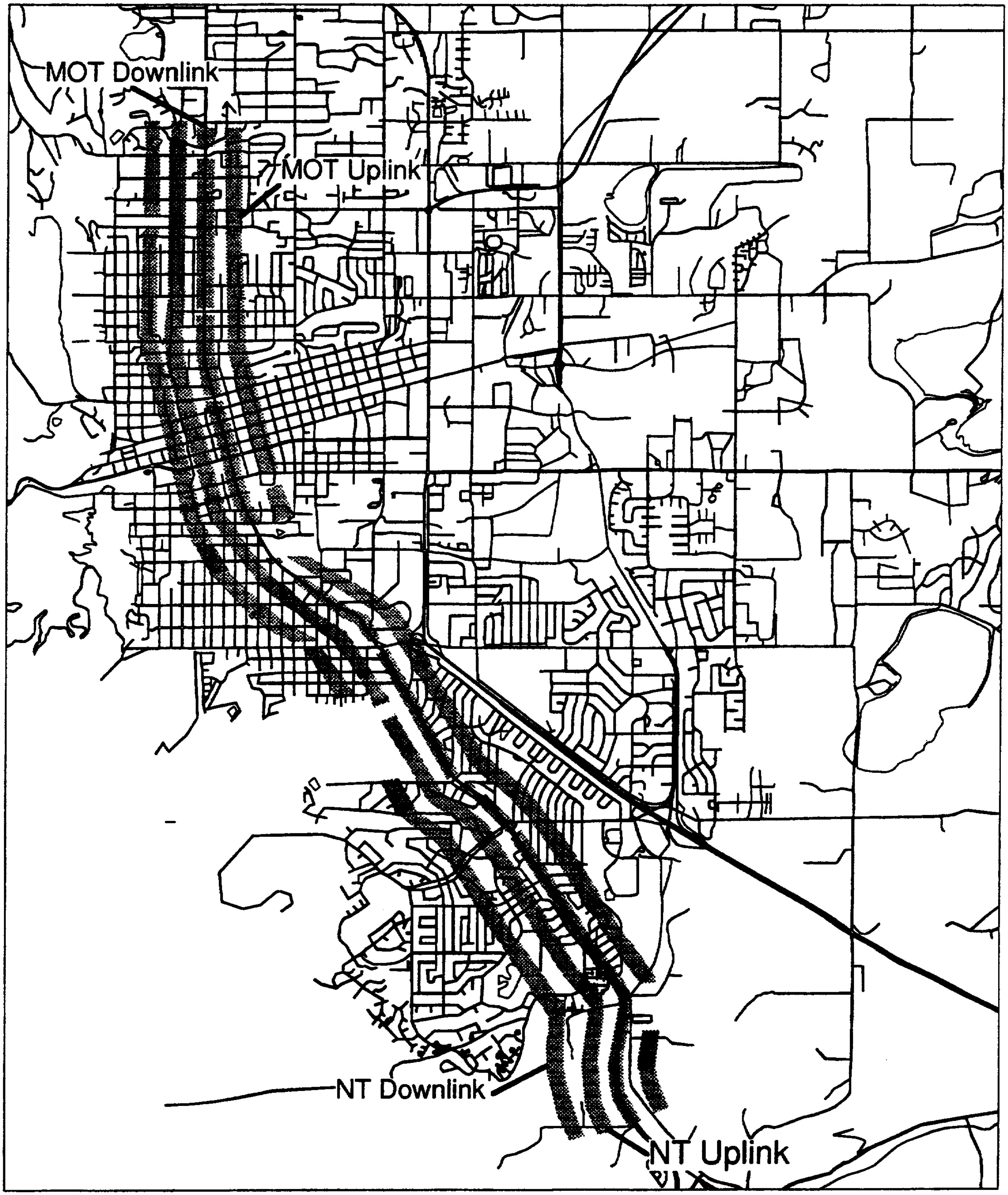
Test Summary Report

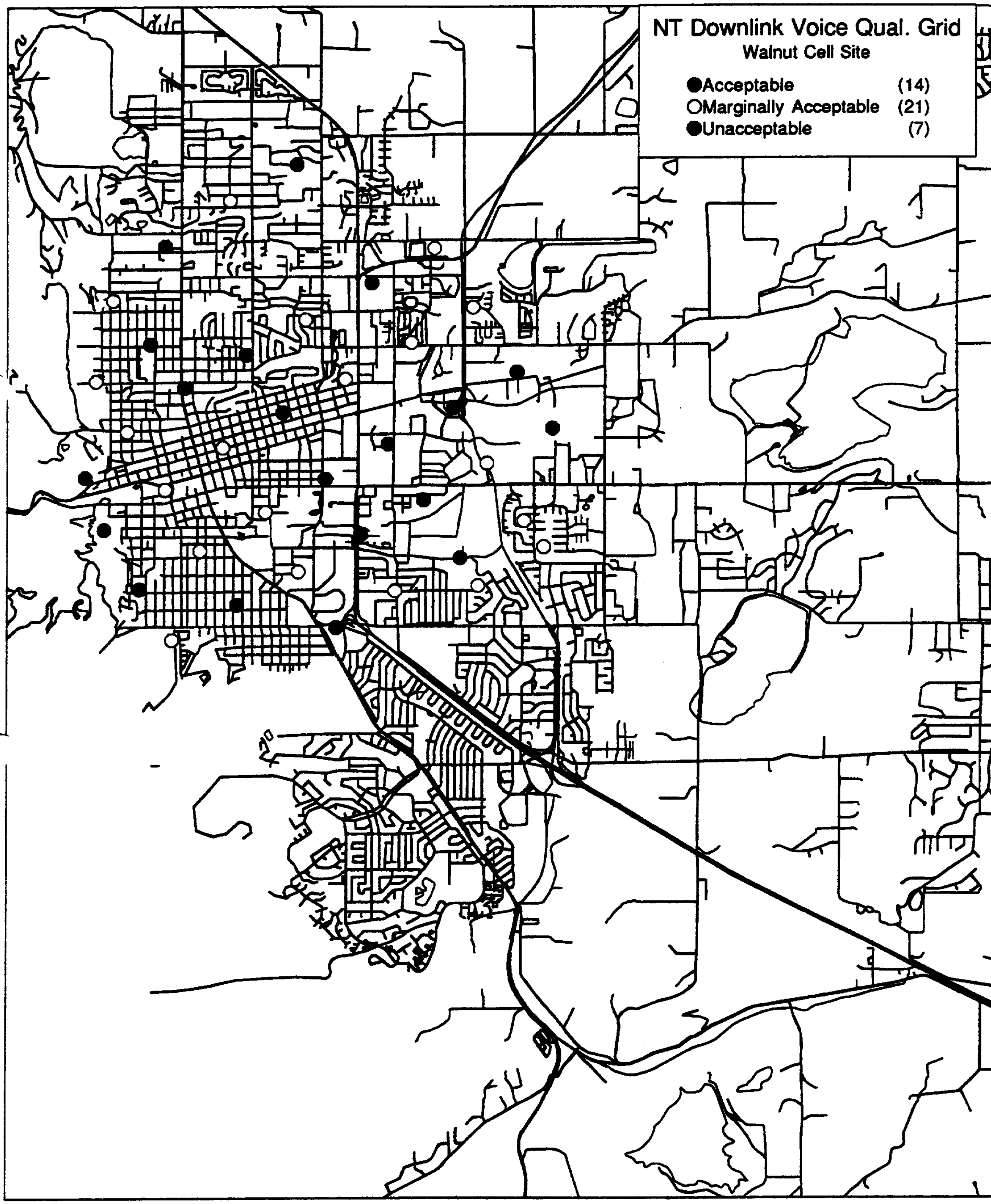

NT Uplink Voice Quality Grid
Walnut Cell Site
Acceptable (22)
Marginally Acceptable (12)
Unacceptable (8)


Motorola Uplink VQ Grid
Table Mesa Cell Site
Acceptable (25)
Marginally Acceptable (12)
Unacceptable (5)


Motorola Downlink VQ Grid
Table Mesa Cell Site
Acceptable (20)
Marginally Acceptable (10)
Unacceptable (12)

PCS1900 Handoff
30 mph

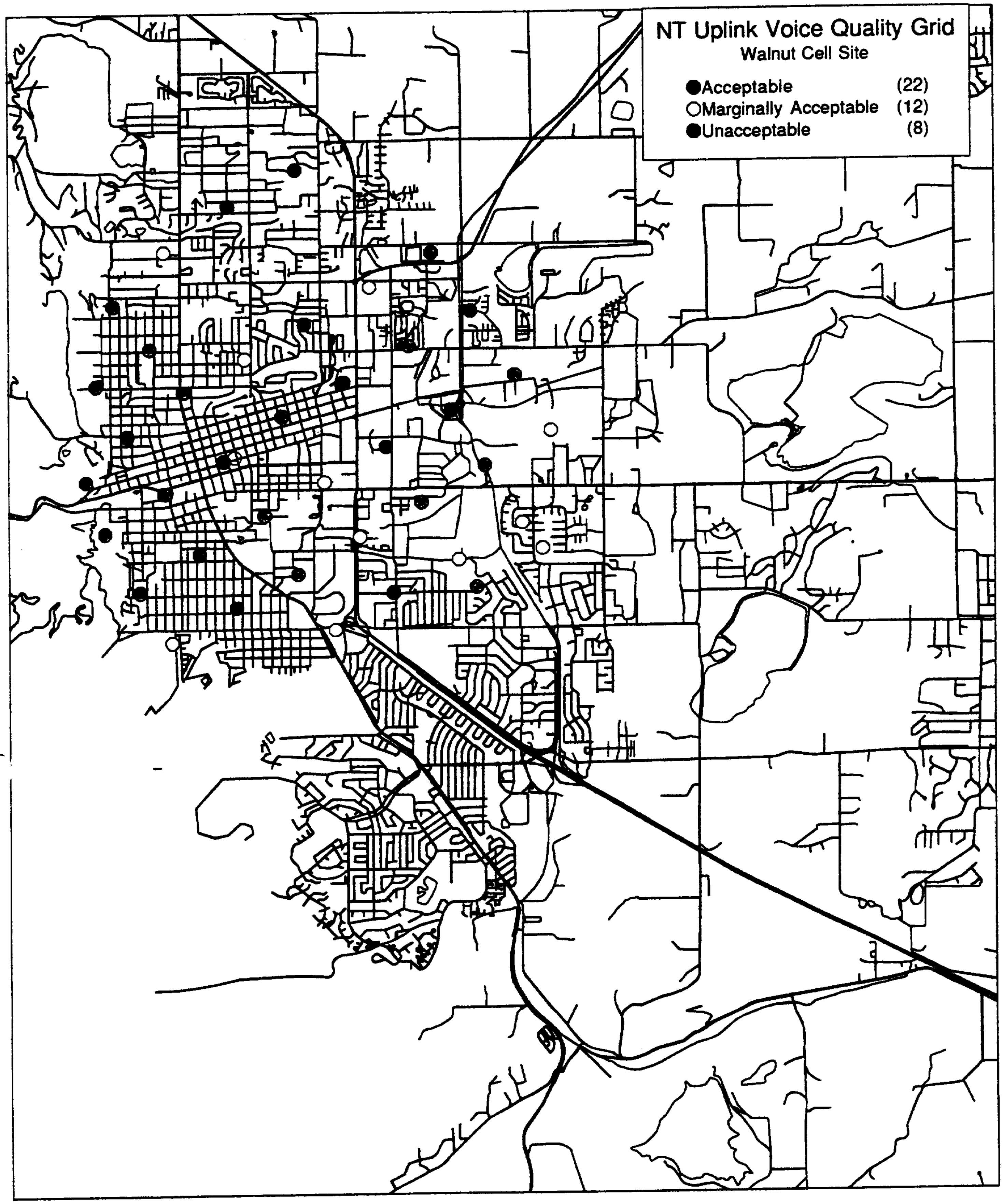


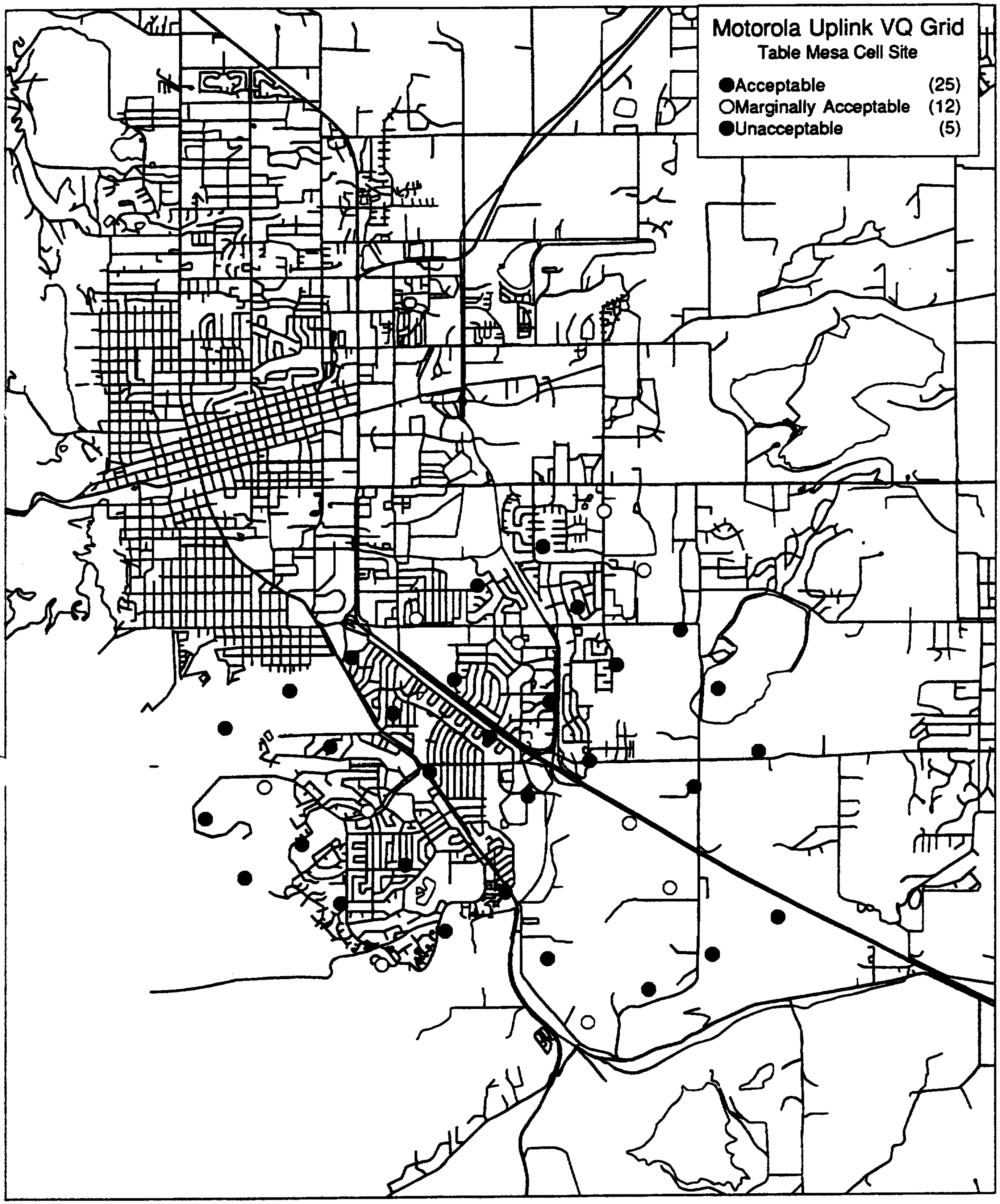

NT Downlink Voice Qual. Grid
Walnut Cell Site
Acceptable (14)
Marginally Acceptable (21)
Unacceptable (7)

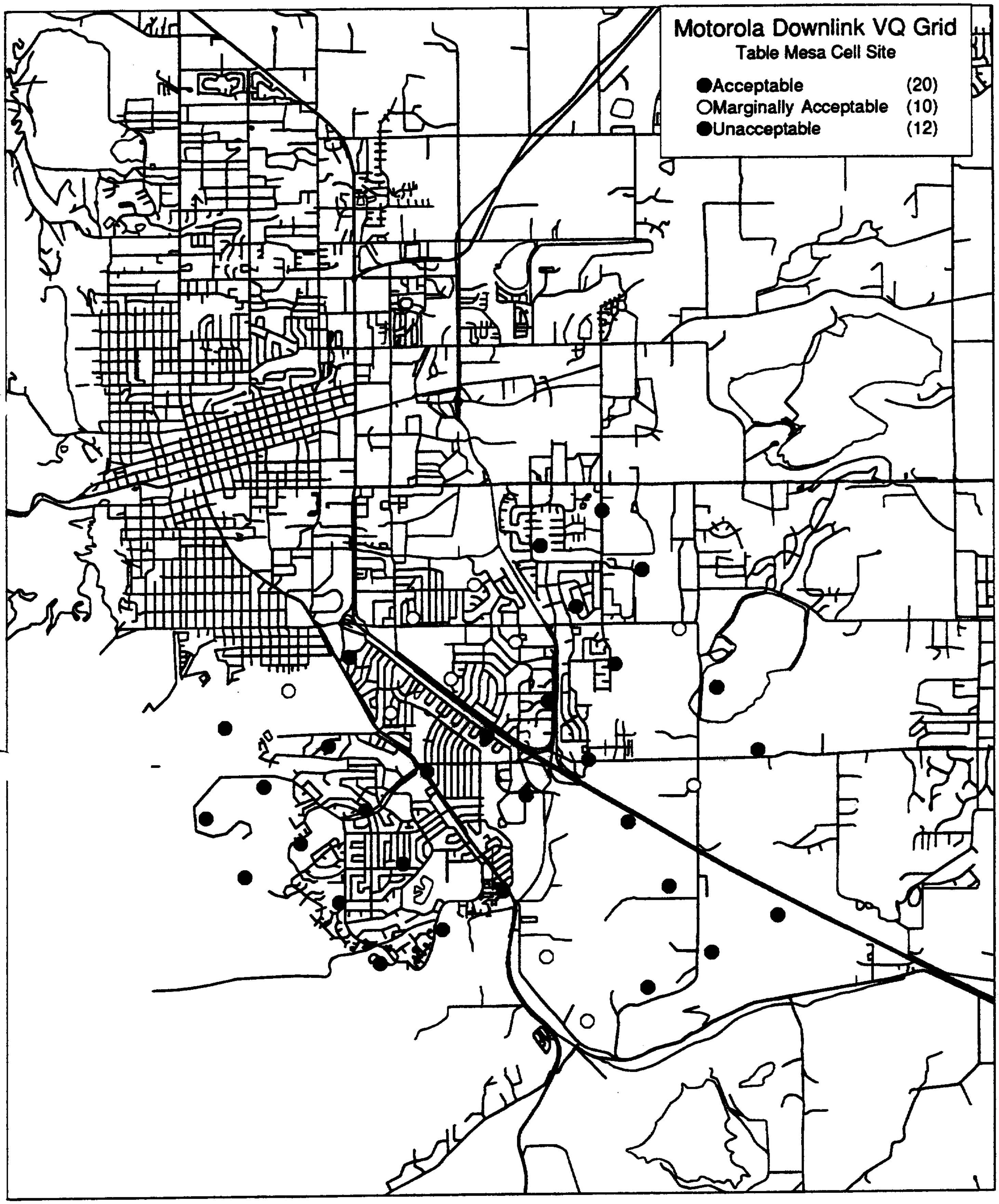
ENCLOSURE

PHP Field Trial

Test Summary Report


NT Uplink Voice Quality Grid
Walnut Cell Site
●Acceptable (22)
○Marginally Acceptable (12)
●Unacceptable (8)


Motorola Uplink VQ Grid
Table Mesa Cell Site
Acceptable (25)
Marginally Acceptable (12)
Unacceptable (5)



Motorola Downlink VQ Grid
Table Mesa Cell Site
●Acceptable (20)
○Marginally Acceptable (10)
●Unacceptable (12)

PHS BITB Field Trial Test Summary Report

DOC NUMBER: JTC(AIR)/94.10.31-732 R1

Prepared By
U S WEST Technologies, Inc.
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Abstract:
Personal Handiphone Service (PHS) is a personal communications service (PCS) product that has become the Japanese PCS standard and it is acknowledged as one of the candidate systems for the unlicensed band operation here in the United States. The Joint Technical Committee (JTC) is currently active in developing standards for PCS in the U. S. The JTC has consolidated the PHS and a derivative of Bellcore's Wireless Access Communication System (WACS-8) standards proposals into a single standard called Personal Access Communication System (PACS). PACS is a candidate system for the licensed band operation in the U.S. Panasonic, NEC, and Hitachi, with support from NTT have teamed up to introduce PHS into the United States, where PHS performance has not yet been demonstrated. The PHS systems tested has several common components with PACS, such as radio transmitter, radio receiver, vocoder and physical configuration.
U S West Technologies and the trio jointly tested the system in the Boulder Industry Test Bed (BITB). Testing included outdoor base station coverage measurements, outdoor coverage measurements with varying antenna heights, indoor wireless PBX coverage measurements, indoor user trial, voice quality assessment (indoor and outdoor), and home-base station service performance. This document outlines the results of the PHS voice quality assessment and user trials.

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Document Distribution:	U S West Technologies PCS Team, Joint Technical Committee

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Second Draft - Submitted to PHS Manufacturers on 11/15/94
Final Draft - Completed 1/4/95

1. INTRODUCTION

The Personal Handiphone System (PHS) was trialed in the Boulder Industry Testbed from August 31, 1994 to October 14, 1994. This trial was a cooperative effort between Hitachi, NEC, Panasonic and U S WEST Technologies. The pupose of the trial was to measure performance and coverage of PHS in and indoor PBX environment, an outdoor environment, and to get user feedback on home systems.

2. OUTDOOR SYSTEM PERFORMANCE

This section describes the performance of the PHS outdoor system as trialed in the Boulder Industry Testbed (BITB). The outdoor testing was performed between 9/7/94 and 10/7/94 using 9 outdoor sites in the BITB. Six of the base stations installed were manufactured by NEC and 3 were manufactured by Panasonic.

Each base station was connected to the NEC Network Adapter using 2 BRI connections. The Network Adapter (NA) handled call setup, registration, handover, and disconnect. The interface between the NA and the base stations utilized 3 B channels and a single D channel from the 2 BRI circuits. The NA was located in the BITB lab and 3280 28th Street in Boulder, CO. The BRI circuits were transported via BRI Terminal Extenter (BRITE) cards to the Boulder Central Office where they were cross-connected to the wire pairs feeding the base station sites. Each base station enclosure contained a base station unit, 2 NT1 interfaces and power supplies and associated cabling. Two 6 dBi antennas were used at all sites. Power output was nominally 160 mW for each base station. Measured power output of each base station is given in Appendix B. SU power output was always displayed at 80 mW on the oudoors SUs.

Interface to the central office switch was performed via PRI to a Northern Telecom DMS100 Class 5 switch located in the BITB switching lab at the Boulder Central Office. This switch allows outgoing calls to the PSTN but does not allow incoming calls to be delivered to subscriber circuits on the DMS100. Figure A shows the network configuration supporting the outdoor system.

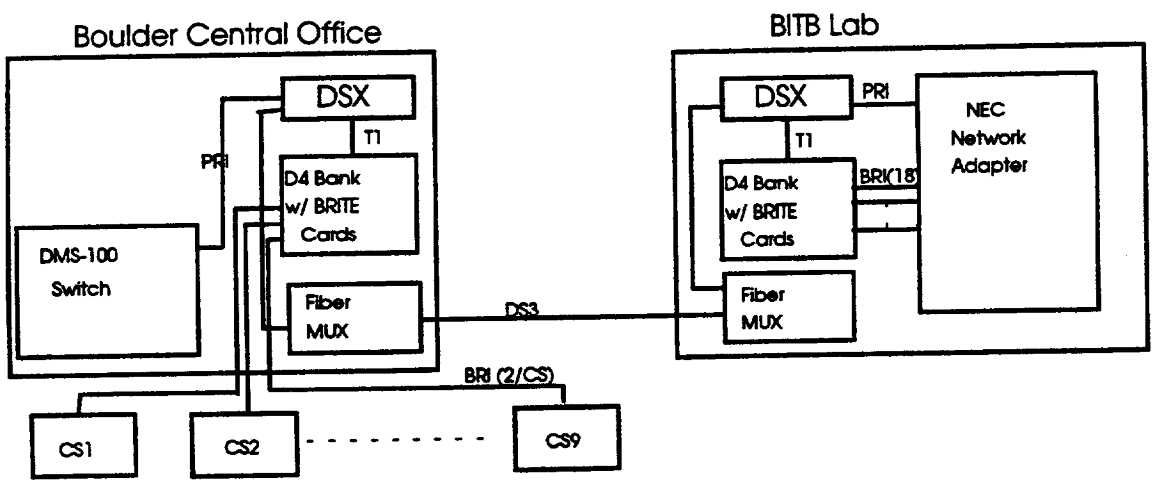


Figure A.
Outdoor System Configuration

Data was collected using Panasonic engineering handsets and Panasonic regular handsets and also Hitachi regular handsets and Hitachi engineering handsets. All handsets were capable of measuring RSS and FER. Radio link measurements were collected on the downlink only, except for some voice quality measurements collected on the uplink. All RSS me*asurements presented here are in dBμV as read off the handset display. The dBμV is a power scale conversion based on 0 dBμV equals -113 dBm for a 50 ohm system. Therefore dBm can be derived simply by subtracting 113 from each dBμV value.

2.1. Coverage Analysis

2.1.1. Description of Propagation Environment

The 9 sites chosen for the PHS trial included areas ranging from light urban to mostly suburban. The outdoor mall area that is characterized as light urban has a large number of trees. The more suburban area to the east of the mall has heavy trees and dense foliage. The mall buildings are predominantly brick 2 or 3 story structures. Most blocks have alleys that were also checked for coverage.

2.1.2. Data Collection Methodology

Coverage data was recorded as the received signal strength (RSS) and frame error rate (FER) at approximately 800 locations in the downtown Boulder area. Data was recorded manually from the RSS & FER readout on the handset display. At each location four readings were taken, each facing a different direction. This gave sove local spatial averaging over an area 1 meter in radius. All data presented here was collected with the traffic channel in use unless otherwise specified. FER was not collected at all locations. Early data collection simply gathered data and recorded handover from base stations, no attempt was made at that time to cover single base stations in all directions. Later analysis of the data showed that this would provide insufficient results. Further data was collected in order to analyze the complete coverage of all base stations. This gave an indication of areas of handoff hysteresis. Two sites, site #1 and site #13 were used to collect data with all other sites inactive, so that coverage could be determined in the absence of handover.

2.1.3. Overall Range

True line of sight (LOS) range was difficult to determine in the BITB. Most areas contain at least some foliage contributing to overall path loss. The best coverage measured using standard antenna mounting on traffic signal yardarms occurrs going north on Broadway Street from Cell Site 1. The measurements presented here were determined using the ruler tool in MapInfo™. From the base station location to the farthest measurement taken at above 24 dBμV (actual RSS value 25 dBμV) measures at 489 meters. A range of 510 meters was measured with an RSS of 23 dBμV. The call was still active at this point although was dropped before the next data point to the north (30 meters farther) was reached. In the heavily foliated areas to the east and west of cell site one, along the outdoor mall the range measures 220 meters with an RSS of 28 dBμV to the east and 272 meters with an RSS of 26 dBμV to the west. These are LOS measurements, with no large structure blockage. The environment for these measurements is two and three story mostly connected brick buildings to the east and west and varying from two and three story brick buildings 2 blocks north and south to residential areas farther north.

Measurements taken at site 13 represent a more suberban setting with one and two story homes and moderate to dense foliage. Overall the coverage in this area maintained a more circular pattern as opposed to the more linear appearance of the cell site 1 coverage. This is even more pronounced in the elevated antenna height measurements. A range of 390 meters was measured to the west of site 13 at an RSS of 25.5 dBμV. The longest distance measured at this sight while the call was still active was at a

ACKNOWLEDGMENTS

The authors would like to thank the many engineers from Hitachi, NEC, Panasonic and U S WEST who helped in installation, maintanence, and data collection during the trial. We would also like to thank Mike Barrick for generously donating the use of the Anritsu Wiltron analyzer used in making base station power measurements.

distance of 420 meters with an RSS of 23.25 dBµV. To the south, although not directly down a street, a range of 390 meters was measured at an RSS of 24.5 dBµV. On the main street going south of site 13 the range was measrured at 329 meters at an RSS of 27.5 dBµV. Note the structures that occurr in the signal path due to the bend in the road contribute significantly to the decreased range at this point. A range of 340 meters is measured to the east with an RSS of 24 dBµV. On the north an RSS of 25.25 dBµ V was measured at a distance of 235 meters.

For the combined measurements of sites 1 and 13, averaging the north, south, east and west ranges for the farthest point above 24 dBµV in each direction gives a value of 320 meters with an antenna height of 21'. Note that this is not entirely LOS coverage, but is coverage in conditions typical of those found in the BITB. In mose cases, propagation down alleys was very good, and was better in the more urban mall area than in the residential area to the east of the mall. Figure 1 and 2 for single cell coverage by sites 1 and 13 respectively, show the slight difference in propagation environments between the light urban mall and the more suburban area. Site 13 has a more circular coverage pattern, while site 1 tends to extend north and south down the street.

Figure 3 depicts the best RSS measured at each point with all 9 stations active. The figure does not show overlaps in coverage; that will be covered in the handover section. This does show that the signal strength was good at most point not on the periphery of the coverage area. Some areas of poor coverage exist in alleys and building shadows on the south side of the trial area.

2.1.4. Boundary Behavior

Voice quality and call origination capability remained consistent as long as the handset measured 30dbµV or greater. However, the FER increased significantly below 30dbµV. At the edge of coverage areas call quality dropped quickly from an acceptable range (>30dBµV) to unacceptable within a 10 meter span. When link quality dropped significantly, an active call was usually disconnected before the user could return to a known good quality zone. Perhaps a longer timeout here would be appropriate. Note that in a fully deployed environment, handover would be the usual option, and this would not normally be a problem.

2.1.5. Effect of Antenna Height on Coverage

A telescoping mast was used to measure coverage variation with antenna height at 24', 34', and 44'. In each case RSS and FER measurements were taken near the coverage boundaries until the call was dropped. Coverage to the east of site 13 down a tree lined street increased by approximately 45 meters for each 10 antenna height increment. However, to the west the coverage decreased slightly in going from 24' to 34' but increased by nearly 100 meters going to 44'. Coverage not directly aligned with a street was significantly affected in each case.

The best range of the outdoor trial was measured at the 44' antenna height down the street to the west of site 13. An RSS of 25 dBµV was achieved at a distance of 540 meters. At 44' an estimated 95% coverage within a 300m radius was achieved, with the exception being a few building shadows. Antenna height data collection was concentrated towards the edge of the coverage area as depicted in figures 4, 5, and 6. The normal antenna height for this location is 21' as shown in the single base station coverage data of Figure 2.

2.1.6. Building Penetration Study

Along the outdoor mall area 32 in building measurements were taken to determine whether or not quality of service (QOS) was significantly affected by building loss. Since no data collection points on the maps corresponded to in building locations, this data has not been correlated with the rest of the coverage data.

On average a 17.9dB drop was seen in RSS readings inside of buildings vs. immediately in front of the building. The standard deviation was 9.5 dB. As would be expected the call dropped if this loss caused the RSS to go below about 22 dBµV. When the RSS was strong enough to maintain the call, their seemed to be generally pleasing quality of service. However, to insure coverage inside all buildings would require much closer base station spacing than we are currently using.

The data collected in the building penatration study is depicted in figures 30 and 31.

2.2. Handover Analysis

Handover in the PHS system is based on a combination of RSS and FER. If the FER remains 0 or below a threshold level (exact value not specified) then the handover is triggered when the RSS reaches a level of 24 dBµV. When this occurs the handset will search for a BS that has a measured RSS of 33 dBµV or higher. Approximately 1 second of silence takes place during the handover execution. On the outdoor system, degradation in voice quality was usually apparent before the handover was initiated. The silence period was less objectionable than the voice quality degradation, as in normal usage it would sometimes go unnoticed as during silence in conversation.

Analysis of handover data shows that the average handover trigger measured occurs at 21.9 dBµV with a median value of 23, close the preset trigger value. Figure 7 shows handover contours of the 9 cell sites. There are locations where it is possible to handover to more that one base station. There are a few cases, most notably handover from cell site 1 to site 2 or 9 where handover to one cell is made immediately followed by handover to a different cell. Clearly, multiple handovers in a short time span may seriously affect quality of service. Proper cell planning may alleviate this problem.

2.3. High Speed Mobility Testing

The system was tested at speeds up to 50 mph between 3 base stations. Two of the base station, #48 and #49 used shaped pattern antennas with 8 dBi gain along the driven road, as opposed to the 6 dBi omnidirectional antennas used elsewhere. The third, site 47 used a 6 dBi omnidirectional antenna. Assessment of voice quality and the affect of handover at high speed were made. The test range was largely line of sight, there were few large scatterers, and there was no other call traffic or interference. Figure 8 shows a typical 50 mph run including handover time. RSS values are labeled along the bottom of the voice sample. There was some differences in FER collected between the 2 handsets used in the vehicle. One handset showed significantly higher FER at RSS values above 30 dBµV, the other one did not show this tendency.

It should be noted that the PHS system was not originally intended for use at vehicular speeds. However, test results and user perception are generally favorable at the speeds used in the trial. Overall, under the conditions tested, high speed vehicular mobility has little effect on voice quality. However, the sites used for this test were as far apart as possible and handover still occurred only 30 seconds into the test very near site #48. A 1 to 2 second gap in voice every 30 seconds may affect service quality during a long conversation, however, multiple handoffs were not testable during this trial..

3. PHS INDOOR PBX TESTING

3.1. Introduction

This section is a report on the Indoor Personal Handiphone Services (PHS) testing that was being conducted as a part of PHS test trial from August 23 1994 to October 11 1994 at U S WEST Advanced Technology building at 4001 Discovery Drive in Boulder, Colorado. This building is a three story office building, with large open spaces of modular offices, separated by composition walls with metal studs and a large 3 story atrium area. The indoor test period was August 23, 1994 to October 11, 1994. The indoor testing consisted of three components:

- Single cell coverage testing
- Testing of coverage of the whole building
- Handover testing

This section gives a description of the testing methodology, presents the measured data obtained during the testing and gives some additional subjective comments based on tester's feedback.

3.2. Test approach

3.2.1. System Components

The wireless PBX was installed at USWT building in the PCS lab area in suite 160. The total of 12 indoor base stations were used in the indoor test trial. Ten base stations were fed by 1 twisted pair that carried voice and signaling traffic and also supplied power to the base station. Two out of twelve base stations were fed by 75 Ohm coax cable. Each base station has been assigned the unique identification number (ID) and they were located throughout the building. The locations were chosen in empirical manner, with the goal to ensure a good radio coverage in the entire building. The listing of base station's ID numbers and locations appear in appendix A. USWT used 14 Personal Handsets (PS) manufactured by Panasonic. Each was capable of operating in three different modes: indoor, outdoor and intercom (handset to handset).

3.2.2. Personal Handsets

There were two types of Personal Stations (PS) used in the indoor trial, both of them manufactured by Panasonic. Regular handsets had the handover capability and were capable of giving RSS and base station ID readings on the display. Engineering handsets that were used for the indoor measurements did not support a handover, but were capable of giving FER readings in addition to RSS and base station ID readings. Engineering handsets had an audio output as well, which allowed us to have Voice Sample (VS) recording for the purpose of determining the Voice Quality (VQ). USWT had only two Engineering PS at its disposal, and they were used for the coverage of the single base station. In addition to this, they were used for about 10% of the time for the testing of the coverage of the whole building, when all 12 base stations were transmitting. However, since Engineering PS do not support handover, they were used only in the areas where the measured signal was at least 6 dB above the handover threshold for the coverage of the whole building. Only regular PS were used for handover testing. Only downlink data has been collected for all indoor measurements. RSS and FER readings are averaged over 1 second and shown on the PS display at the same rate.

3.3. Data Collection and Analysis

3.3.1. Handover Testing

Handover threshold was set up by Panasonic to be 24 dBμV corresponding to -89 dBm. Handing off would take place if the received signal strength (RSS) from registered base station goes below the threshold, providing that there exists a signal from another base station that is at least 36 dBμV strong. If no signal with such strength could be received by PS, handover would not take place. It was brought to our attention by manufacturer (Panasonic) that at the time the call is being established PS searches for all active BS that can be detected by PS's receiver. The PS makes a list of available base stations that have RSS greater than 36 dBμV in descending order. That list is to be used if the RSS from the base station which the PS originally registered to ever drops below the threshold. If that happens, PS searches the list, from the top down, trying to find listed base station that still has RSS greater than 36 dB. If such base station can be found, the handover would occur. It is important to underline the fact that PS simply chooses the first base station on the list that has RSS that meet the handover criteria. However, it is not certain if the handover list is updated after the handover takes place.

Cell handovers has been conducted between all cells, both on the same floor and between floors. It has been observed by the testers that cell handovers were repeatable. Repeated handover testing showed that the exact location of each handover is accurate within 10 feet. Handover spots for each base station were collected by walking away from the base station at which the call had originated, until the handover occurred. Each time the exact location of the handover was noted, as well as a path that had been crossed before handover has taken place. The testers have observed that handovers occurred as soon as RSS dropped below 24 dBμV. During the handover the communication was blocked for approximately 1 second. No clicks or pops or other noise has been otherwise observed during the handover. Link quality right before the handover has been judged to be acceptable. Only occasional clicks or pops would be heard before the handover which did not affect communication between testers significantly. All handovers occurred at walking speed.

As a result of handover data collection, the handover contours are presented. The contours are interpolated by simply connecting the handover points. If a handover was not observed in a certain suite, then the outer boundaries of the suite (outer walls) were taken to be part of a handover contour. Although all the handover points between different floors have been collected, only the handover points that were collected at the same floor level are presented here in order to simplify the data presentation. For example, although the base station located at second floor had a handover points at all three floors, only handover points taken at the second floor are taken into consideration in the report. To further facilitate the reading of the contours, no indication was given to which particular base station the call was handed off. The net results are handover contours given for all base stations at each floor on Figures 9, 10 and 11. It should be noted that the handover contours have been interpolated through west side outdoor patio area on the first floor. Although no handover measurements have been taken there, it is reasonable to assume that the signal would propagate there in a manner that interpolation suggest, since it is open area surrounded by large windows rather than walls or other solid objects. Only regular handsets were used in handover testing.

3.3.2. Full Coverage Testing

The full coverage testing had a goal to examine the radio coverage in the whole building when all 12 base stations were transmitting. The location of the base stations was determined in an empirical way, with the goal to ensure a good radio coverage in entire building. The axial symmetry of the first and third floor made the process of choosing the location easier, and it was successfully completed after one iteration. The data collected is downlink only. Since about 90% of the data has been collected using regular handsets that do not have FER reading, FER data is not represented for the full coverage measurements. Each floor plan had a grid with nodes being 10 feet apart. The measurements were taken at grid nodes, except for some inaccessible areas (closed offices, labs with the limited access etc.). Inaccessible areas were left blank on the maps. The readings were stationary, and at each point 4 consecutive measurements were taken, having PS oriented in 4 different directions (north, south, east, west). The readings are then averaged, the base station's ID identified, and the results entered in the database. Averaging out the readings was necessary in order to minimize the effect of spatial fades on measurements. It should be noted that all the readings were made with the handset being at least 1 feet away from the tester's head, which means that head loss has not been taken into account.

Two set of results are presented for the full coverage testing. Figures 12, 13, and 14 represent the measured RSS inside the building, and at the west side patio. The tester's subjective impression was that the coverage was excellent, except for a small area at the northeast side of the building of the first floor. That area is hard to cover, because it houses a huge power generators that cause attenuation and interference. Figures 15, 16 and 17 show BS IDs for the points at which RSS had been taken for Figures 12, 13 and 14. It can be seen that the open areas (lobbies, corridors) had registered signals from several base stations from different floors. This is especially pronounced for the first floor (Figure 15), but is present for the second floor as well (Figure 16).

3.3.3. Single Cell Coverage

Single cell coverage testing was done by measuring the radio coverage of the base station # 54 (suite #290, second floor) as all other base stations were shut down. As explained in 3.2., the data has been collected at pre-defined nodal points, in stationary manner, with spatial data averaging. Only engineering PS were used, which allowed USWT testers to collect FER, RSS and record VS at the same time. The data were collected at all three floors starting at the location closest to the base station (on the first at third floor those were the locations right under/below the base station), and moving away from it until the call was dropped. It has been noticed that the calls were usually dropped once the RSS was below 15 dBµV. The call drop was associated with high pitch beeping tone that indicated low RSS. After the beeping tone started, the call would be dropped within 5 seconds, unless PS was moved to an area with stronger signal. As noted in 3.2. all measurements were made with handset at least 1 feet away from testers head. Although FER and RSS show up simultaneously on the display, we tend to believe that FER readings lagged RSS readings by 1 second. It is common knowledge that after passing certain RSS threshold, FER increases dramatically even for a slight drop in RSS. The RSS threshold after this phenomenon is observed for PHS is approximately 25-26 dBµV, based on our experience during test trial. Hence, every FER reading that is taken while RSS is less then 25 dBµV should be greater than 0%. However, three consecutive RSS readings of 25, 19 and 26 dBµV would give FER of 0%, 0% and 11%. Clearly, RSS reading of 19 dBµV should have FER of 11% associated with it, not 0%. Since 11% reading showed up in the third reading (they are given every second), we believe that the inaccurate readings are due to lagging of FER readings by 1 second. After a while, testers learned to overcome this difficulty, but since FER changes rapidly once the RSS gets in 15-19 dBµV range, the FER data were difficult to collect, and is inherently less accurate than RSS data.

RSS data for the single cell coverage is given on figures 18, 19 and 20. It can be seen that the suite where BS was located had excellent coverage (dark green), and that the coverage in the suites adjacent to suite #290 was good to acceptable (bright green and yellow). The locations on the third floor that are right above the base station, and on the first floor, at the open area and right below the base station had excellent to good coverage. All green areas (dark and light) on the map are above 35 dBμV, and represent the areas where a call from the other base station could be handed over to base station #54. These ratings are purely subjective, represent testers opinion, and are made to make readings and understanding of the measured data easier.

In order to establish the relation between RSS and FER, the RSS and FER data collected throughout the building is plotted on the Figure 21, and is given as scattered plot. The data is then curve fitted using Table Curve 2D software package. It should be once again repeated that the method of collecting RSS and FER rate (especially the latter) had very limited accuracy, given the manual nature of data collecting, and the time lag between the FER and RSS screen display. As an example, it can be seen on scattered plot in Figure 21 that 2 identical FER readings of 30% give two significantly different RSS readings: 17 dBμV and 23 dBμV. Conversely, RSS reading of 19 dBμV gives FER in a range from 4 - 57 %. For the future trial the testers strongly recommend a user interface that would automatically collect, average and store data in the file, so that the human imperfection be minimized at data collection stage of the trial test.

4. VOICE QUALITY ASSESSMENT METHODOLOGY

Voice quality (VQ) assessment was performed on recorded voice data taken as part of the outdoor, indoor, adn high speed testing. This section describes the VQ assessment methodology and presents VQ results.

4.1. Subjects

Thirty-one subjects were recruited from the Boulder area to participate. Three groups of eight subjects and one group of seven subjects were presented with 40 PHS voice samples. Each group listened to a unique set of samples, and everyone within a group listened to the same samples. Each of the following age ranges were represented within the subject pool: 18-25 yrs, 25-35 yrs, 35-50 yrs, and over 50 yrs. Subjects consisted of an equal number of males and females. Subjects were cordless but non-cellular phone users. Subjects were paid $35.00 for their participation or they chose to defer receipt of payment to an organization of their choice.

4.2. Schedule and Resources

Testing occurred on October 15 and 16, 1994, at U S West Technologies, Boulder, CO. Each testing session lasted approximately two hours.

4.3. Methodology

Subjects first filled out a consent form and a demographic survey. The experimenter then read procedural instructions to them. After instructions were read by the experimenter participants were shown how to use the computer and mouse (when necessary). For training, subjects were presented with two practice samples of voice segments. After each one, they were given a chance to use the computer to respond to the sample.

During the actual study, subjects were given 40 voice segments to which they responded. Each segment consisted of 20 Harvard sentences, phonetically-balanced sentences designed to represent all English sounds. Ten sentences were spoken by a male and were presented first 50% of the time, ten were spoken by a female. The order of presentation of male vs. female samples was varied. Each voice segment was taken at a different location and distance from a base station, and represents either uplink or downlink transmission from or to the PHS handset. Each was taken in different propagation environments: light urban, residential or indoor. The order of presentation of each voice segment were randomized. A total of 160 samples were presented.

Subjects answered the following questions after each segment using the computer: How would you rate the overall QUALITY of the sound? (on a 5-point scale: Excellent, Good, Fair, Poor, Bad); How annoying are any ADDITIONAL sounds you may hear? (on a 5-point scale); and Would this be ACCEPTABLE as portable service? (Acceptable or Not Acceptable)

After all segments were presented, subjects filled out a post-trial questionnaire and a receipt of payment form.

4.4. Data Collection and Analysis

4.4.1. Data Collection

The computer application recorded subjects' responses to each voice segment. Voice segments were collected at different locations away from a base station, in different propagation environments, and measured on the uplink or downlink (see Test Plan for PHS Field Testing by Jim Corliss). In each condition, Frame Error Rate (FER) and Received Signal Strength (dB) data were collected simultaneously with the voice segments.

4.4.2. Data Analysis

Voice quality ratings from question one were averaged in order to obtain Mean Opinion Scores (MOSs). Figures 22 and 23 shows a comparison of MOSs against two objective measures: received signal strength (dB) and Frame Error Rate. MOSs show a large variance in scores at an RSS below 45 dBμV and a FER below 20%. FER and RSS do not appear to be accurate predictors of MOSs, according to Figures 22 and 23.

It is important to note that the highest MOS for a given sample was 4.375, on the 5 point scale, with 5 being excellent, even for those samples which had RSS readings near 66 dBμV. Although an MOS of 5.00 is rare, it appears the lower MOSs are related to additional sounds. Subjects consistently rated additional sounds on average between 2 (slightly annoying) and 3 (annoying), which may have impacted total MOS. Future steps should be taken to reduce the amount of background noise introduced during recording.

Responses to question three: Would this be ACCEPTABLE as portable service? were transformed into a 3-point scale of acceptability: Definitely acceptable (more than 70% of subjects rated the sample acceptable), Marginally acceptable (30 to 70% rated it acceptable), and Not acceptable (below 30% of subjects rated it acceptable). RSS and FER were analyzed based on this 3-point scale. When the service was definitely acceptable (>70% rated a sample acceptable) RSS ranged from 24 dBμV to 66 dBμV with a mean of 41 dB. When the service was marginally acceptable RSS ranged from 21 dBμV to 60 dBμV with a mean of 30 dB. When the service was unacceptable RSS ranged from 10 dBμV to 40 dBμV with a mean of 23 dB. (see figure 24) Definitely acceptable coverage corresponded to an average FER of 1.2%, with FER ranging from 0 to 25%. Marginally acceptable coverage corresponded to an average FER of 3.3%, with FER ranging from 0 - 21%. Unacceptable coverage corresponded to an average FER of 14%, with FER ranging from 0 - 90% (see Figure 25)

Voice segments were also analyzed utilizing the expert listener methodology before the results of panels of listeners were analyzed. This system utilizes a 3-point scale of acceptability: Definitely acceptable (or "Green"), Marginally acceptable ("Yellow"), and Unacceptable ("Red"). The expert listener, Michelle Owens, was trained, prior to PHS testing, to emulate the responses of panels of listeners to question three: Would this be ACCEPTABLE as portable service?

Figure 26 compares the PHS expert listener ratings with subjects' MOSs. When the expert listener rated samples "Red", MOSs measured between 1.0 and 3.25 and averaged 1.7. When the expert listener rated samples "Yellow", MOSs measured between 2.1 and 4.25 and averaged 3.4. When the expert listener rated samples "Green", MOSs measured between 2.1 and 4.25 and averaged 3.8. A more interesting comparison is expert listener ratings vs. Subjects' acceptability ratings. As mentioned above, the expert listener (EL) methodology was designed to match results of subjects' acceptability ratings. Figure 27 shows this comparison. Of the samples rated "Red" by the EL, the mean % acceptability was 10%. This mean falls within the proposed range of 0-30% acceptable that the EL was striving to achieve. Of the sample rated "Green" by the EL, the mean % acceptability was 90%. This falls within the proposed 70-100% range of acceptability. Of the samples rated "Yellow" by the EL, however, the mean % acceptability did not fall within the proposed 30-70% range. Instead the mean was 80%. In other words, the EL rated several samples as "yellow", while the panel of listener's considered them, on average, to be "green". This implies that the EL "graded harder" than the panel of listeners in the green-yellow range. Although the EL made finer distinctions in the green-yellow range, if PHS were deployed, this would ensure that most customers would consider a green-yellow level of service to be acceptable. It is better that the EL rated samples with a finer distinction than grade them "easier", or with less distinction than a panel of listeners.

EL ratings were compared with the objective measure. RSS ranged from 10-38 dBμV at an EL rating of "Red" and averaged 23dB. RSS ranged from 24-64 dBμV at an EL rating of "Yellow" and averaged 32 dB. RSS ranged from 28-66 dBμV at an EL rating of "Green" and averaged 45 dBμV (see Figure 28). The mean RSSs for the green and yellow categories of the EL rating scheme are slightly higher than the RSSs for the "green" and "yellow" categories of the % acceptability method. This implies that the EL "graded harder" than the panel in the green-yellow range, as does the EL vs. % acceptability comparison (see Figure 27).

The mean FER in the red EL category was 13% (as opposed to 14% in the FER vs. Acceptability comparison). The mean FER in the yellow category of EL ratings was 2% (vs. 3.3%). The mean FER in the red category was 0.3% (vs. 1.2%). (see Figure 29). The categories represent lower FERs in the EL rating scheme vs. the % acceptability method.

4.5. Indoor and Home User Trials

4.5.1. Subjects

Twenty users within U S West Technologies volunteered to use the Panasonic PHS handsets that were connected to the indoor PBX. Seven different volunteers used Panasonic and Hitachi home base stations.

4.5.2. Schedule and Resources

Indoor users agreed to use the handset in place of their desk phones whenever possible for one week. Home users replaced their home phones for one week.

4.5.3. Methodology

Volunteers were given a handset, charger, (home users were also given home base stations), and instruction manual. Users were briefed on the basic operation of the handset and were asked to fill out a pre-trial questionnaire. They were also given a tally sheet were asked to keep track of the number of calls made and received, number of calls with poor quality sound, and the number of dropped calls experienced. Michelle Owens provided a help desk for any questions or problems throughout the week. After one week, users returned the equipment and filled out a post-trial questionnaire.

4.5.4. Data Analysis

When asked to rate the overall indoor service, indoor users rated the service 3.83 (on a 5-point scale) on average. This 5 point scale is an overall rating of the users perception of the service; it is not a representation of the MOS used for voice quality measurements. 83% of users rated the service as acceptable. When asked to rate the quality of sound typically heard from the handset, users rated the quality 3.86. Home users rated the service between 4.13 and 4.60. 100% of users rated home service as acceptable. Several indoor users expressed dissatisfaction in the 1-second silence during a handover.

Conclusions:

- Responses to the home and indoor user trials were very favorable. Many agree that the fidelity of sound captured by the PHS system comes close to wireline service. Many also agree that improvements should be made so that poor quality service is not handled using muting (as is the case during handovers). A one-second period of silence during handover is generally considered unacceptable by the survey respondents listening to continuous voice samples, however, testers in the outdoor and indoor environments considered it less objectionable during normal conversation.
- Given these data, RSS and FER do not appear to be accurate predictors of MOS voice quality ratings when averaged over 1 second.
- Steps should be taken to reduce any background noise introduced during recording in order to improve MOS as an indicator of performance.
- The EL ratings may or may not be an accurate predictor of % acceptability or MOS. It is difficult to determine without further analysis. It does appear that the EL "graded" samples on a harder scale than the panels of listeners. It is better that the EL rated samples with a finer distinction than grade them "easier", or with less distinction, than a panel of listeners. One problem with the EL methodology is that an EL may shift in his/her ratings unknowingly over

time away from % acceptability measures of panels of listeners and more towards the engineering measures.

APPENDIX A. INDOOR BASE STATION LOCATIONS

Base station ID	Suite #	Note
4.5.4.1.	190	
4.5.4.2.	North of PCS lab	
4.5.4.3.	South of PCS lab	
6C	PCS lab	Coax
5C	120	
4.5.4.4.	Southeast lobby	Coax
4.5.4.5.	290	
4.5.4.6.	270	
4.5.4.7.	2110	
4C	250	
4.5.4.8.	390	
4.5.4.9.	320	

APPENDIX B. OUTDOOR BASE STATION POWER OUTPUT.

This information is provided through the courtesy of Mike Barrick of Anritsu Corporation.

S/N	Mnfr.	Cell Site	Power Output
310	Panasonic	Site 12 (moved to 48 for high speed trial)	22.23 dBm
309	Panasonic	Site 11	21.68 dBm
306	Panasonic	Site 3	21.57 dBm
117	NEC	Site 9	21.53 dBm
104	NEC	Site 1	21.15 dBm
114	NEC	Site 2	21.76 dBm
111	NEC	Site 8	21.82 dBm
116	NEC	Site 13 (moved to 47 for high speed trial)	21.76 dBm
107	NEC	Site 16 (moved to 49 for high speed trial)	21.48 dBm

This shows 30 dBμV and 24 dBμV contours for cell site 1 with all other cells inactive. The north to south coverage was basically LOS with very few large blockages. East to west coverage is concentrated on the pedestrian mall and is heavily foliated.

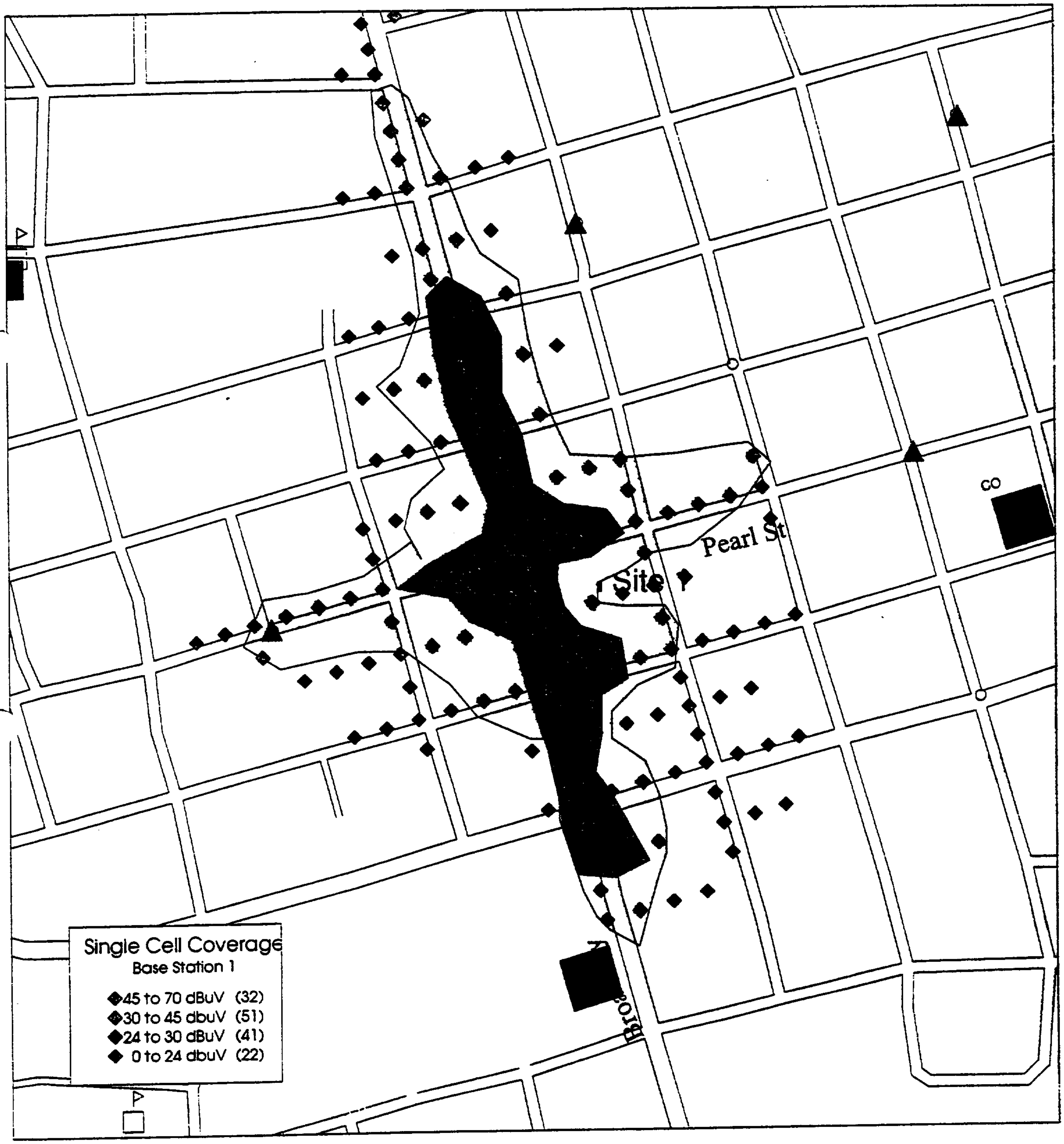


Figure 1.
RSS Coverage for Single Base Station 1

This shows 30 dBμV and 24 dBμV contours for cell site 13 with all other cells inactive. This area is mainly residential, with many trees and 2 story houses. The north side coverage is impeded by a hill.

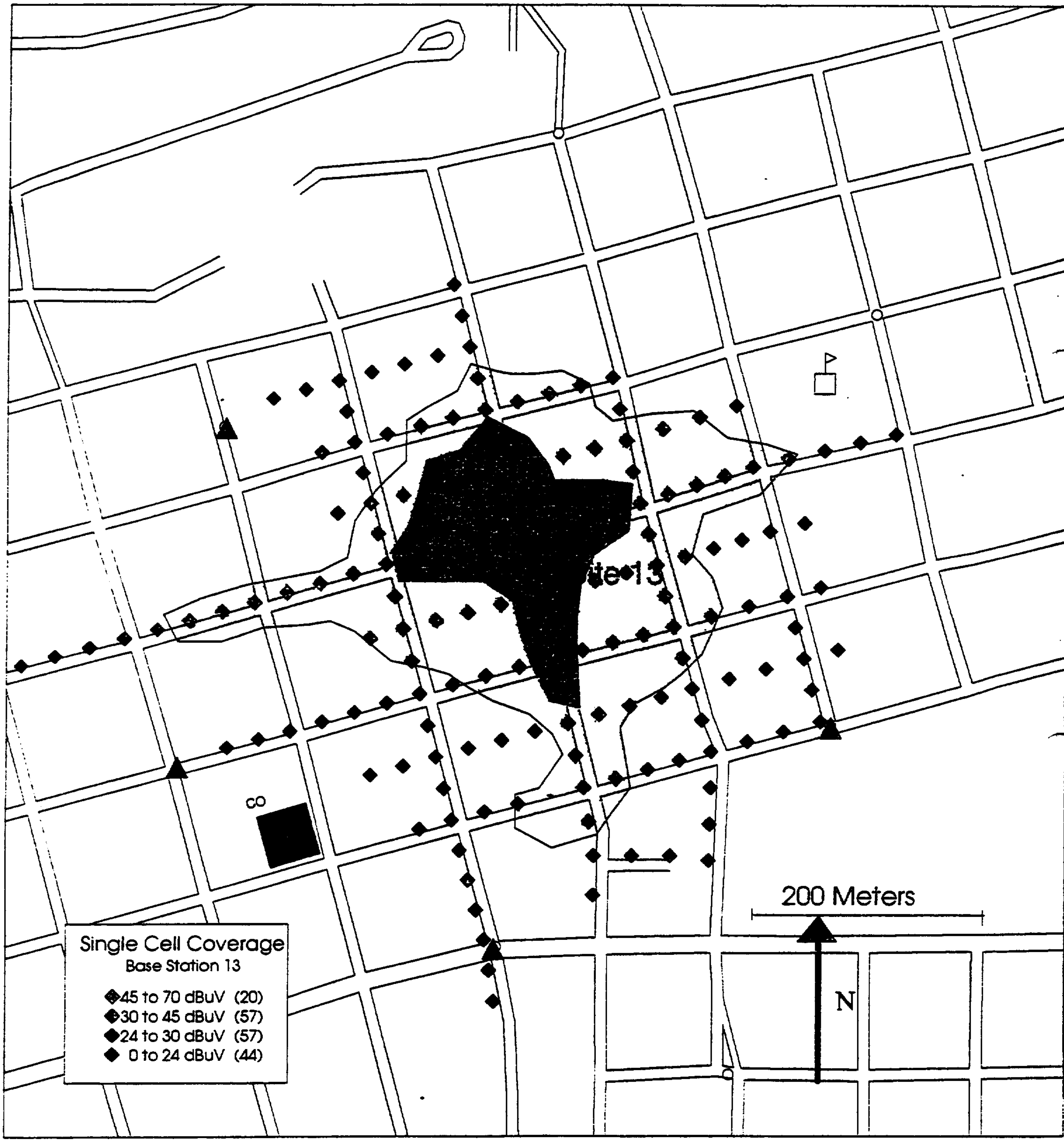


Figure 2.
RSS Coverage for Single Base Station 13

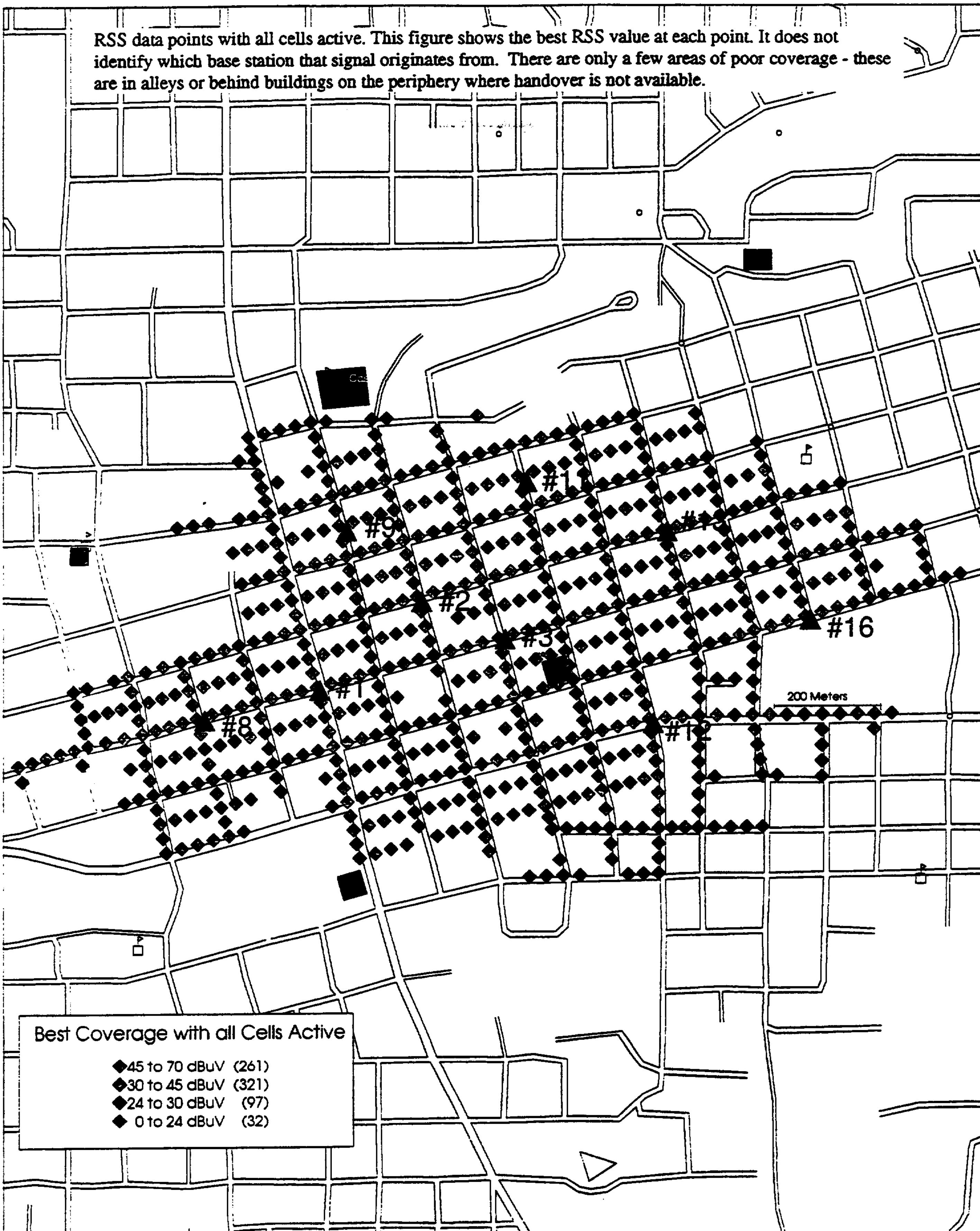


Figure 3.

RSS Coverage with All Stations Active

The longer coverage range east and west with 24 foot antenna height is due to antenna orientation and fewer obstacles. This antenna height is 3 feet higher than the normal antenna at this location. Contour is for 24 dBμV. Data collection concentrated on the coverage edge.

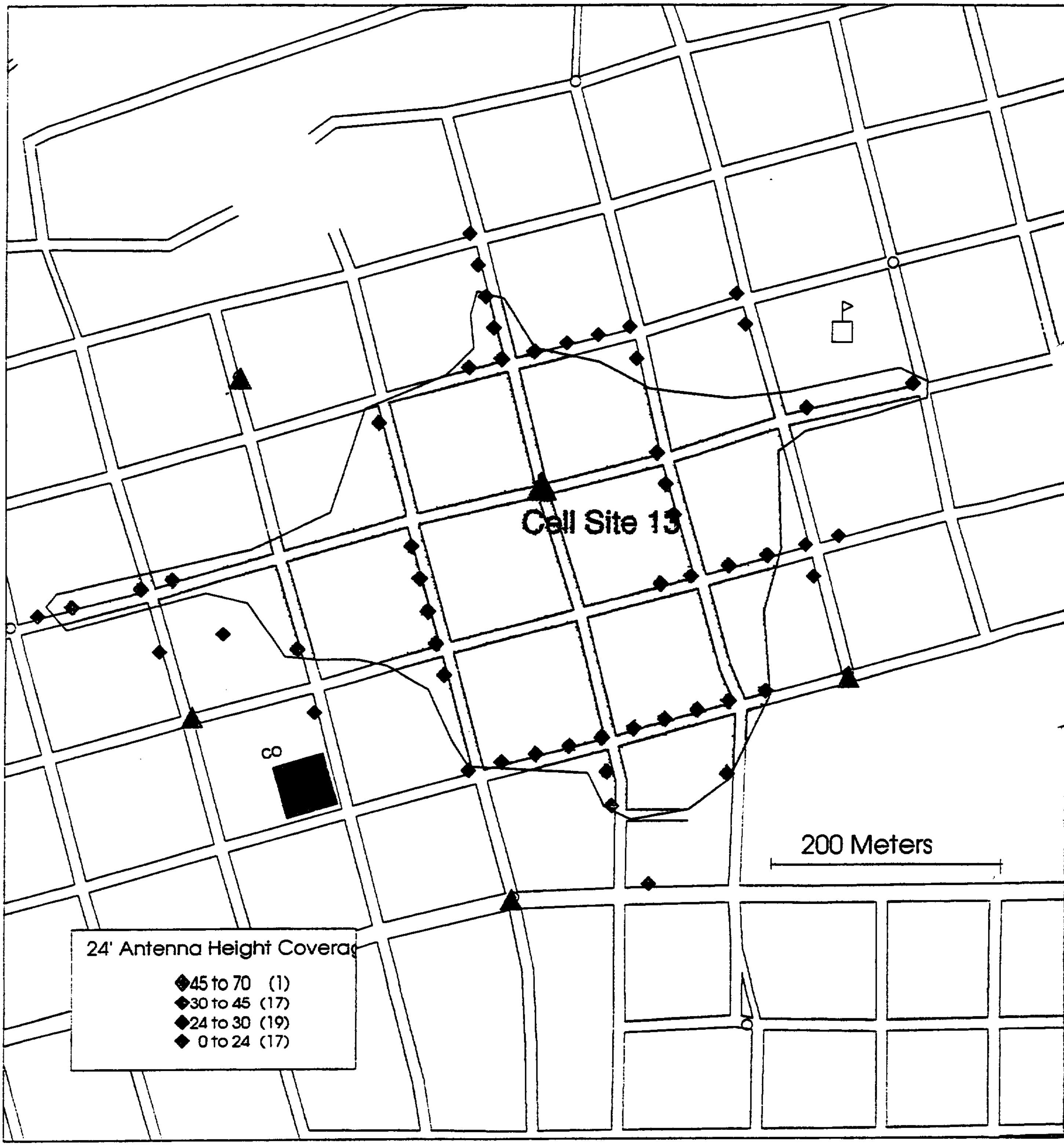


Figure 4
Coverage with Antenna at 24 feet

Note that as height increases, the coverage area assumes a much more radially oriented structure. At 34 feet, coverage to the northwest increased significantly. East-west coverage down the street was inceerased only slightly.

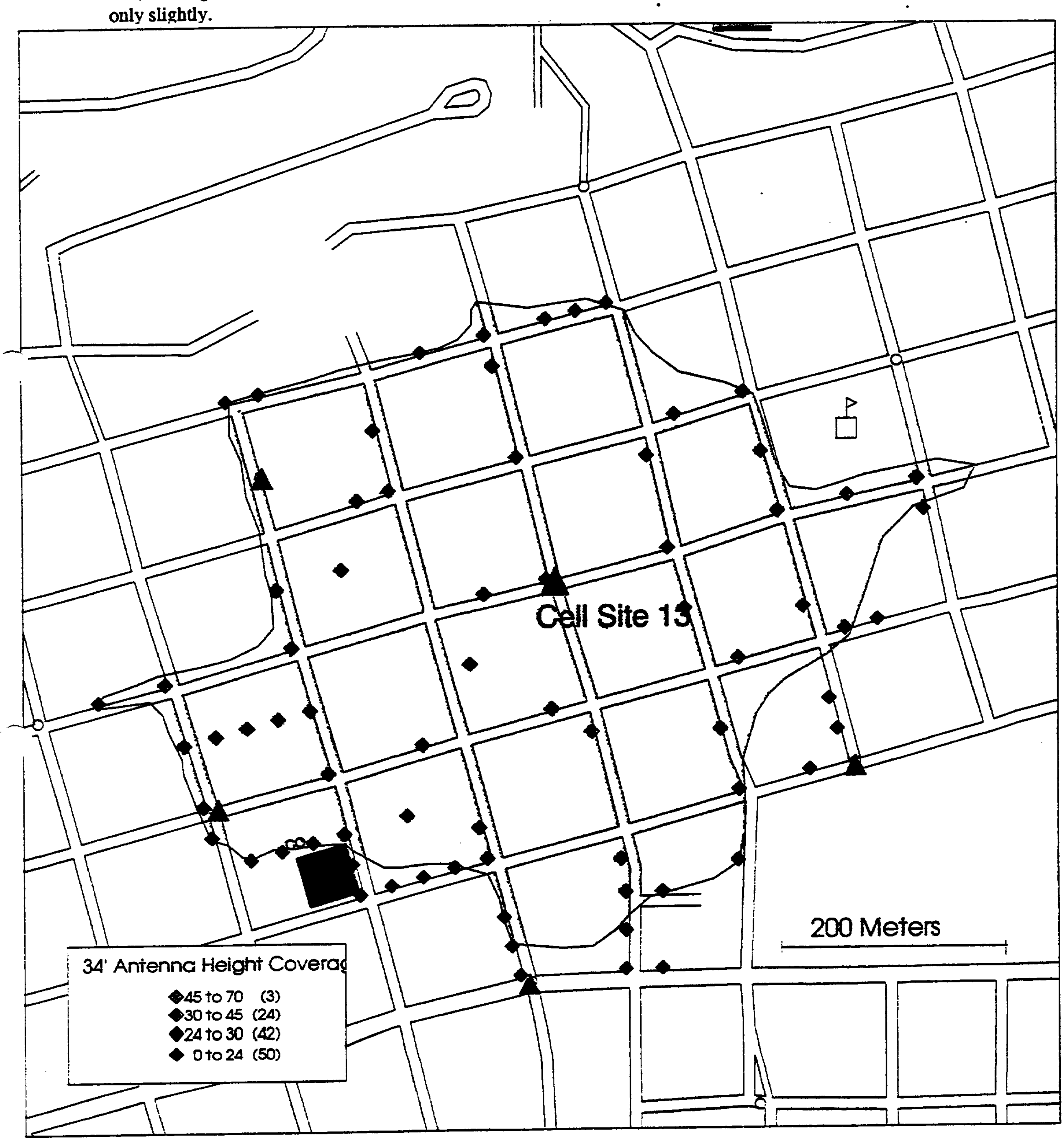


Figure 5.
Coverage with Antenna at 34 feet

At 44 feet acceptable coverage is achieved within a 300 meter radius of the base station. To the north the signal did not propagate over the hill. East-west coverage was also markedly increased at this height.

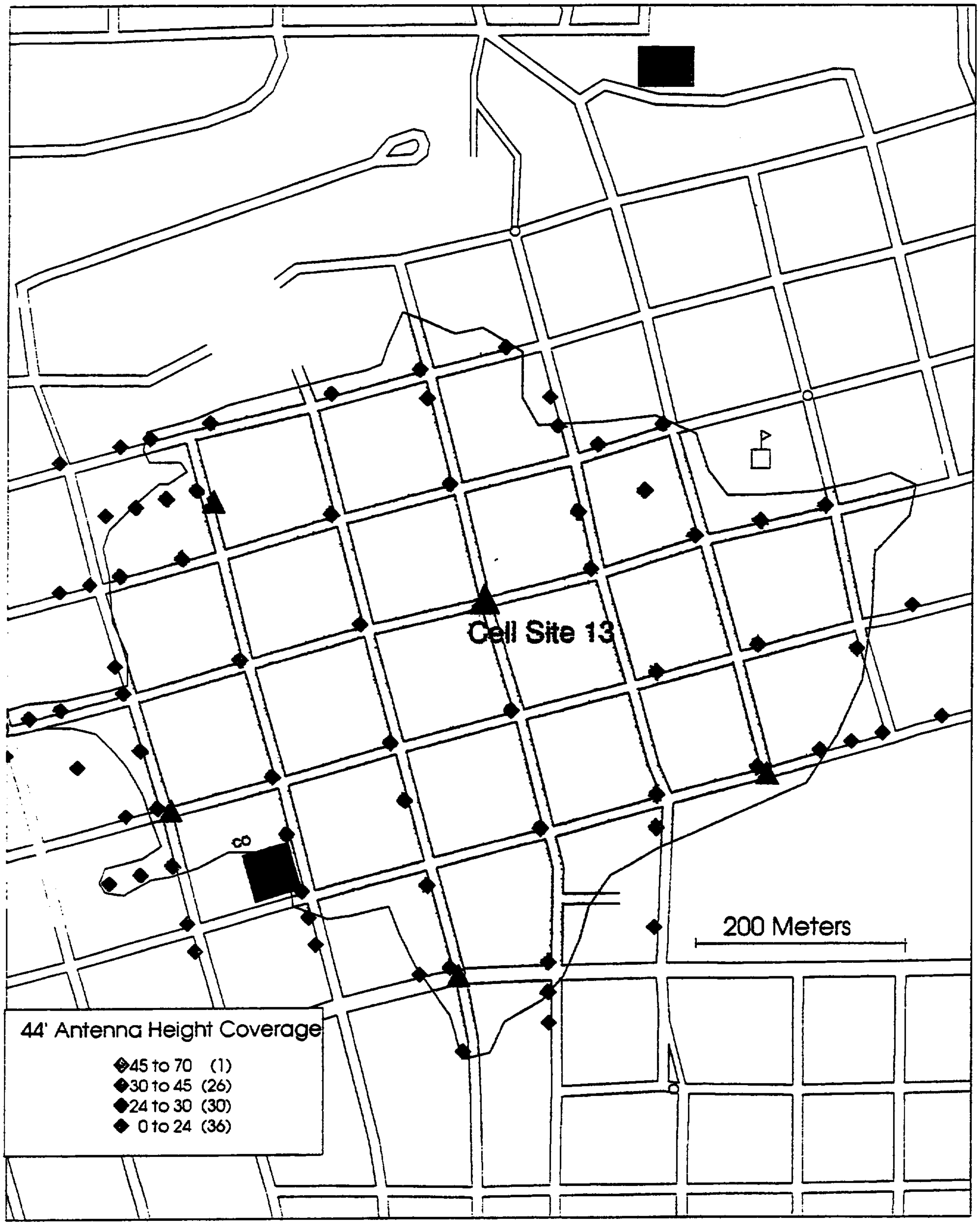


Figure 6.
Coverage with Antenna at 44 feet

Handover points. this shows all measured handover points between different base stations. As can be seen there are several handover scenarios for any given path taken between base stations. Handover is also dependent on how many calls are currently active on a given base station.

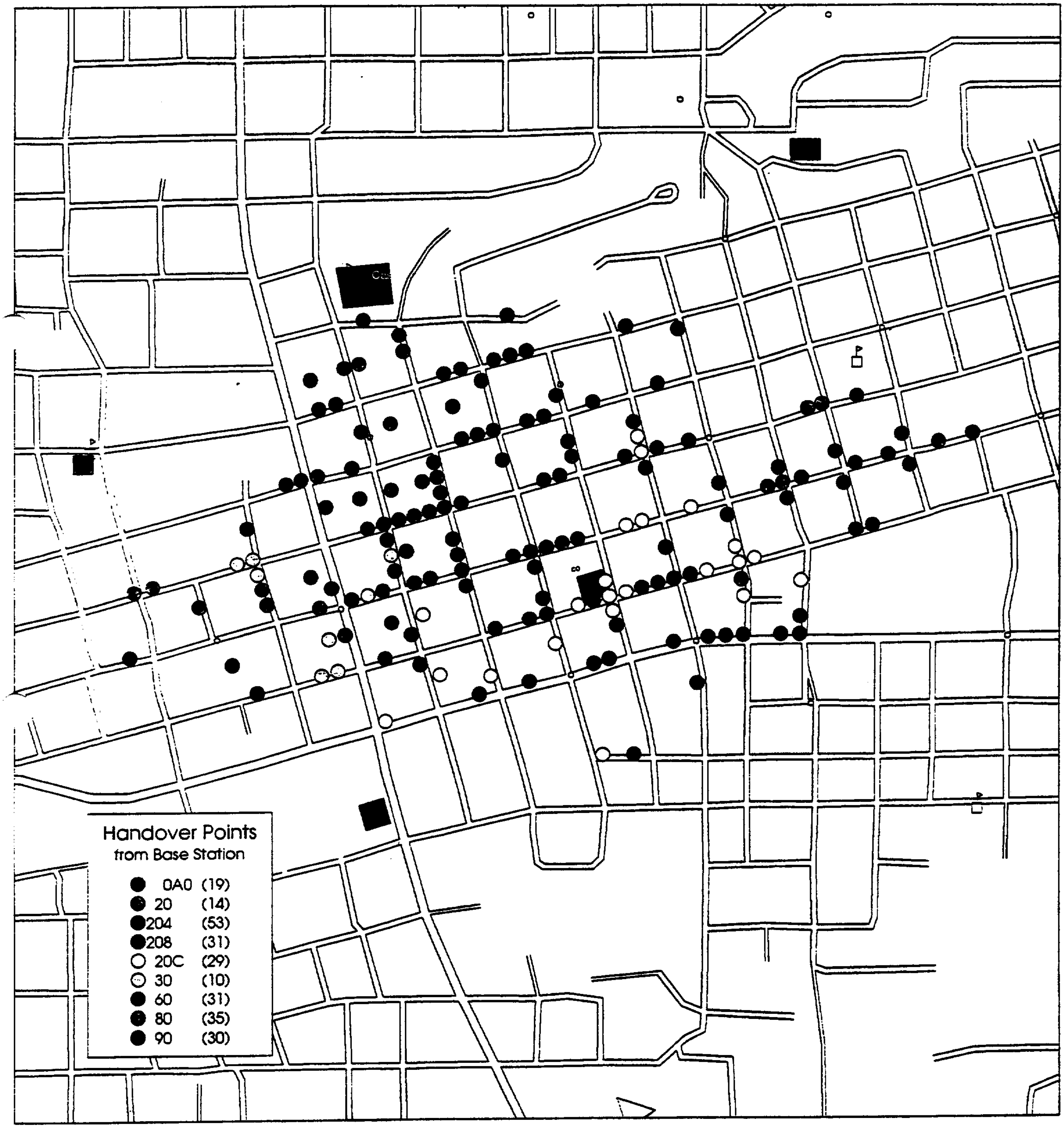


Figure 7.
Handover Points

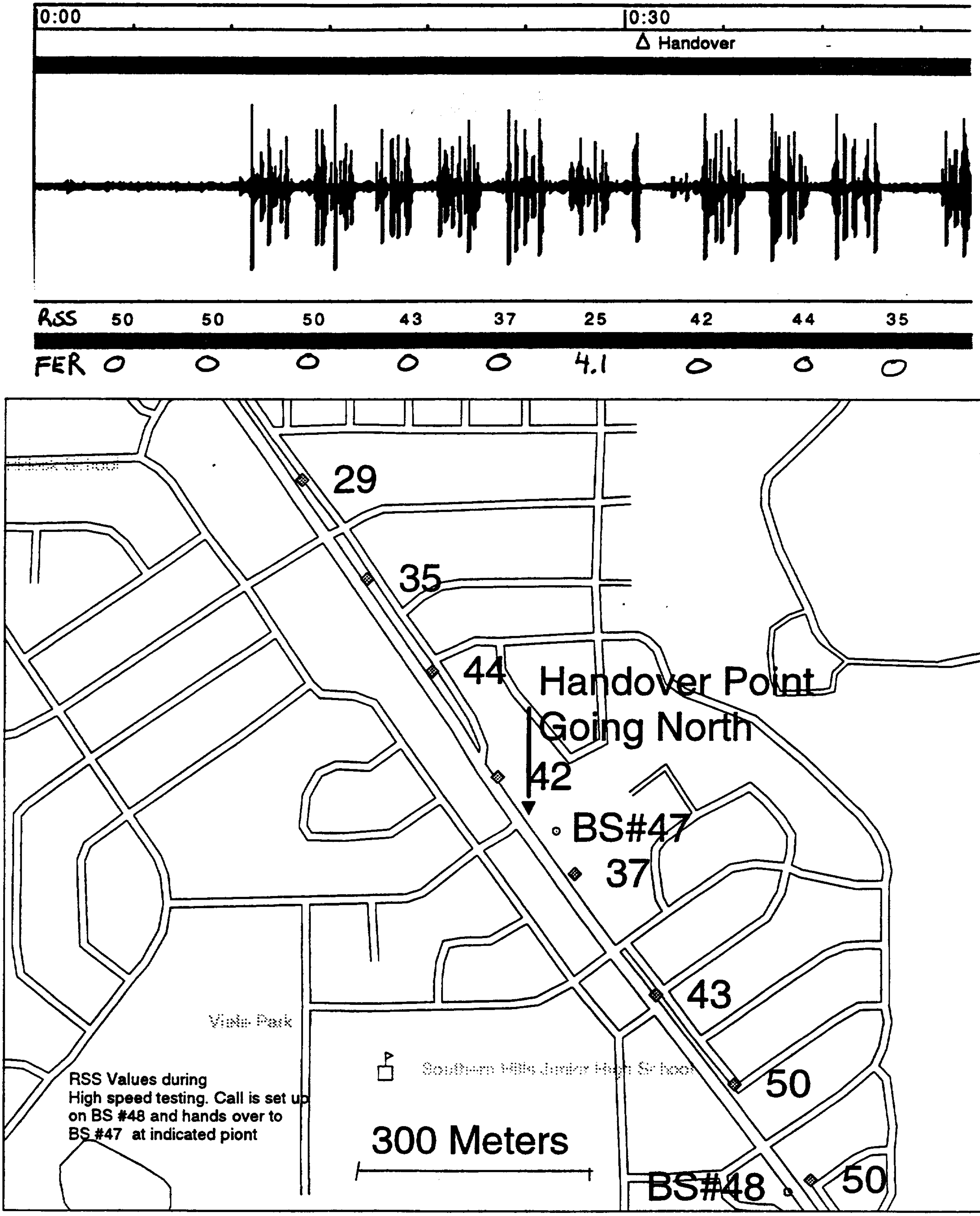


Figure 8.
High Speed voice sample data at 50 MPH.

Third Floor Handoff Contours

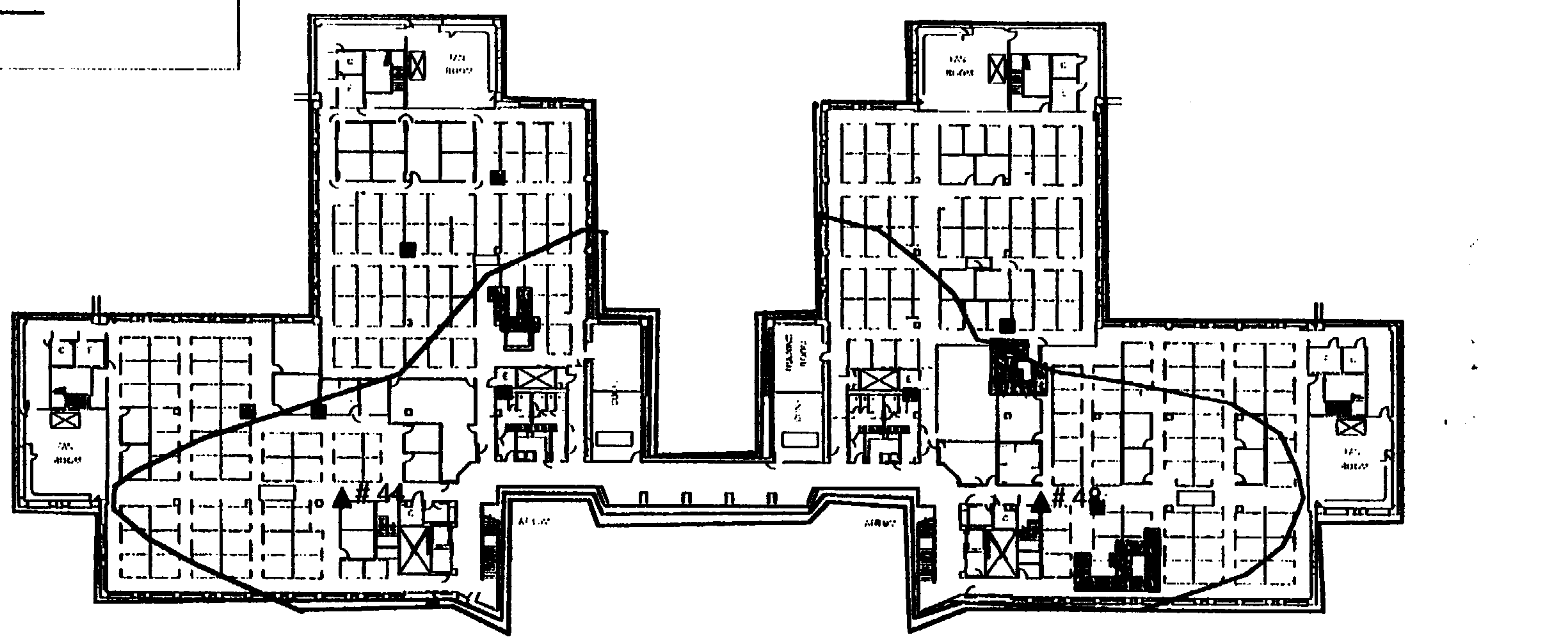
Base St. #48

———

Base St. #44

———

Figures 9, 10, and 11 show the indoor handover contours on each individual floor. Although handovers occured between base stations on different floors, they are not shown in these figures. Note that the contours have been interpolated to show continuity.



USWEST TECHNOLOGIES

THIRD FLOOR PLAN

Figure 9.

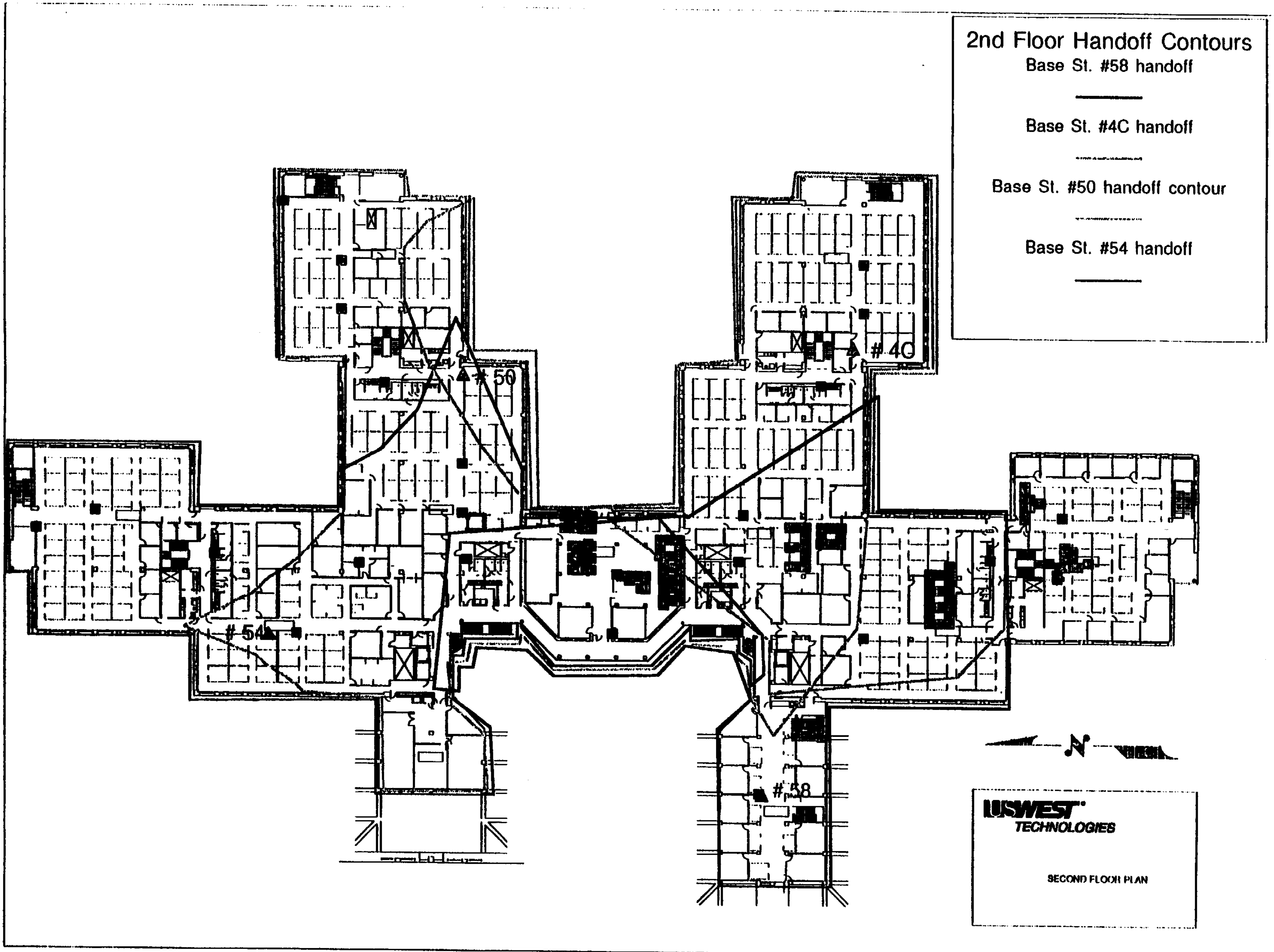
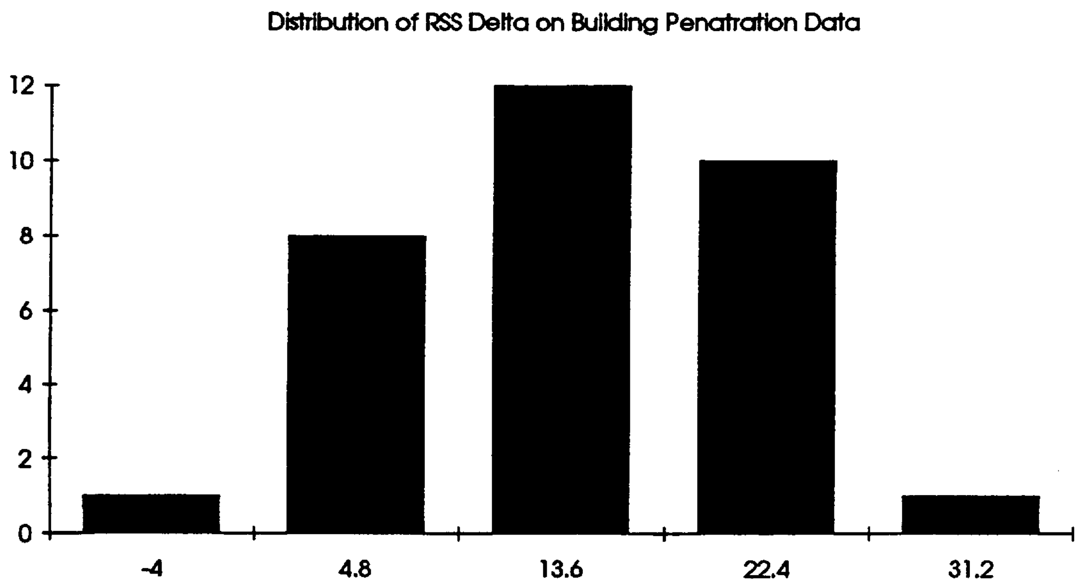

2nd Floor Handoff Contours
Base St. #58 handoff
Base St. #4C handoff
Base St. #50 handoff contour
Base St. #54 handoff
4C
50
54
58
N
USWEST
TECHNOLOGIES
SECOND FLOOR PLAN

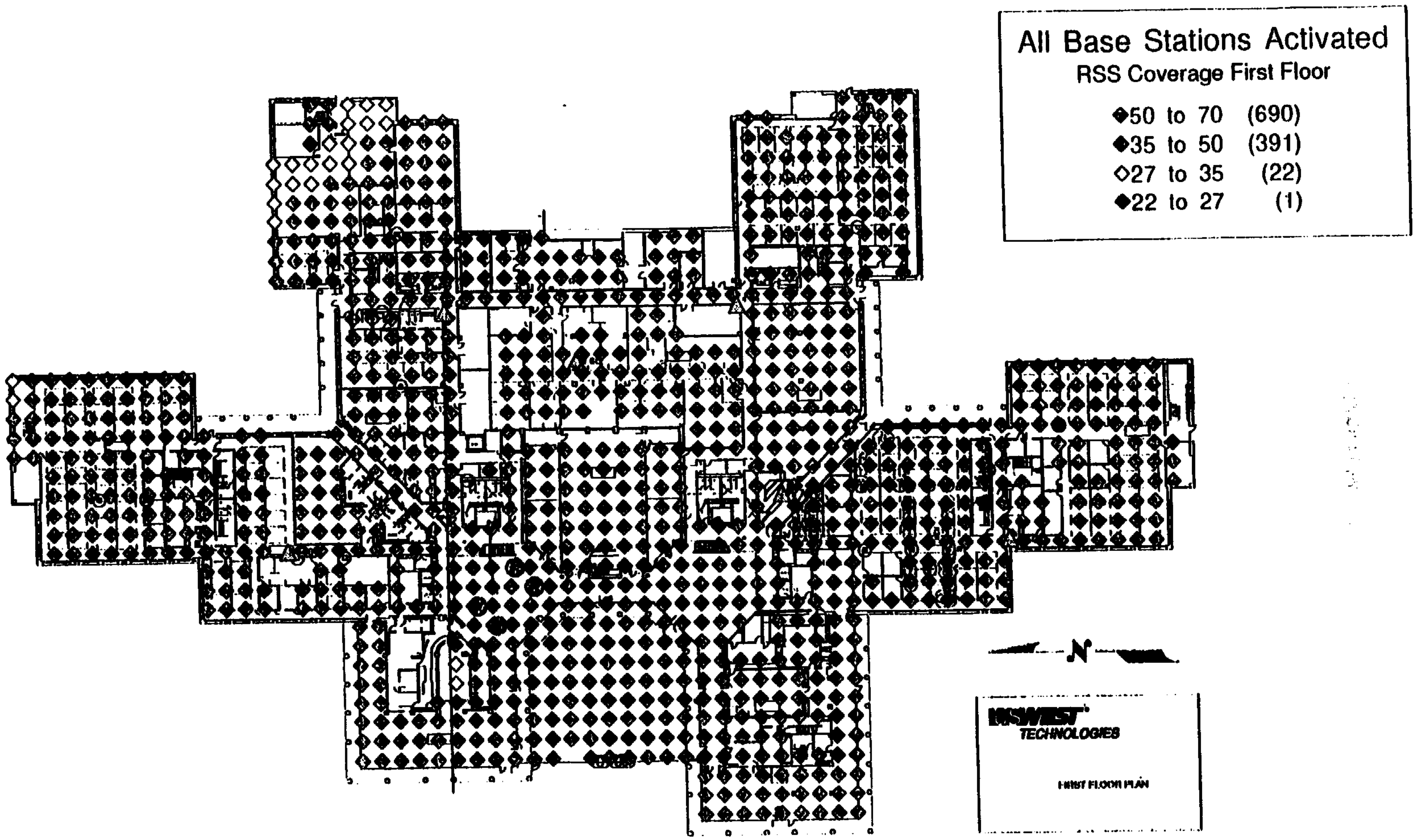
Figure 10.



This chart presents a histogram of the cumlative distribution of the RSS delta between outdoor and indoor measurements. It forms normal distribution with the following statistical description:

Mean	17.875
Standard Error	1.687089257
Median	18
Mode	5
Standard Deviation	9.543618033
Variance	91.08064516
Kurtosis	-0.074112597
Skewness	-0.121648878
Range	44
Minimum	-4
Maximum	40
Sum	572
Count	32

Figure 31.



Figures 12, 13, and 14 represent the measured RSS inside the building, and at the west side patio. The tester's subjective impression was that the coverage was excellent, except for a small area at the northeast side of the building of the first floor. That area is hard to cover, because it houses a huge power generators that cause attenuation and interference.

Figure 12.

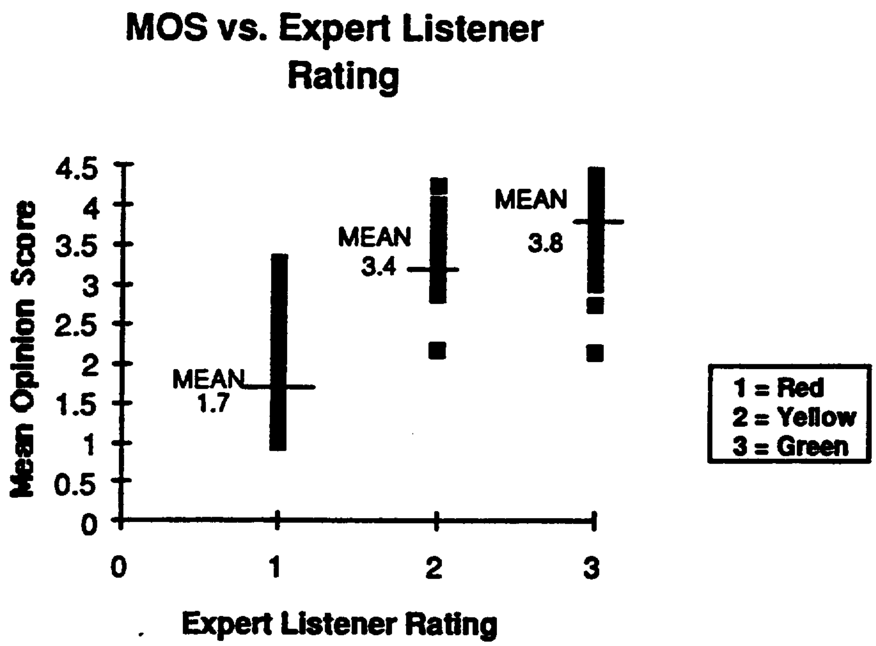


Figure 26

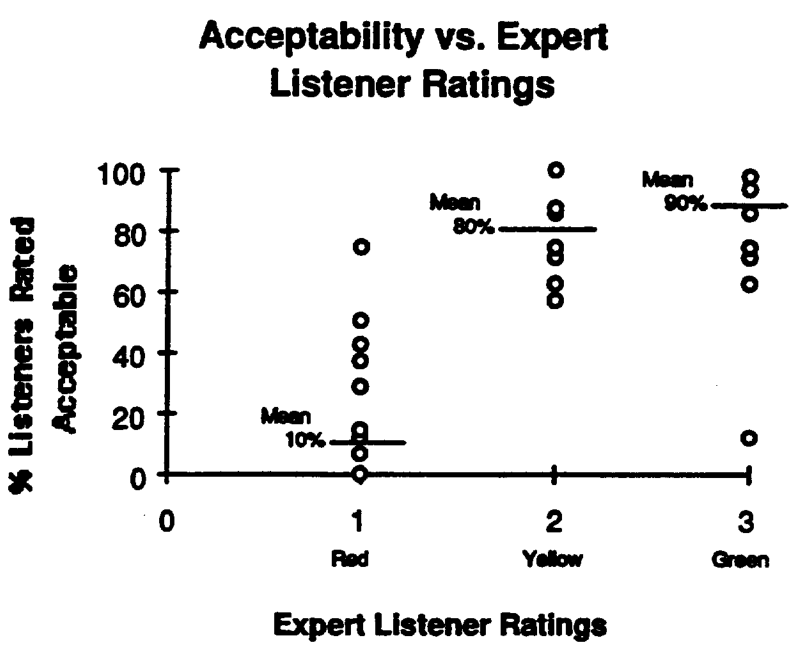


Figure 27.a

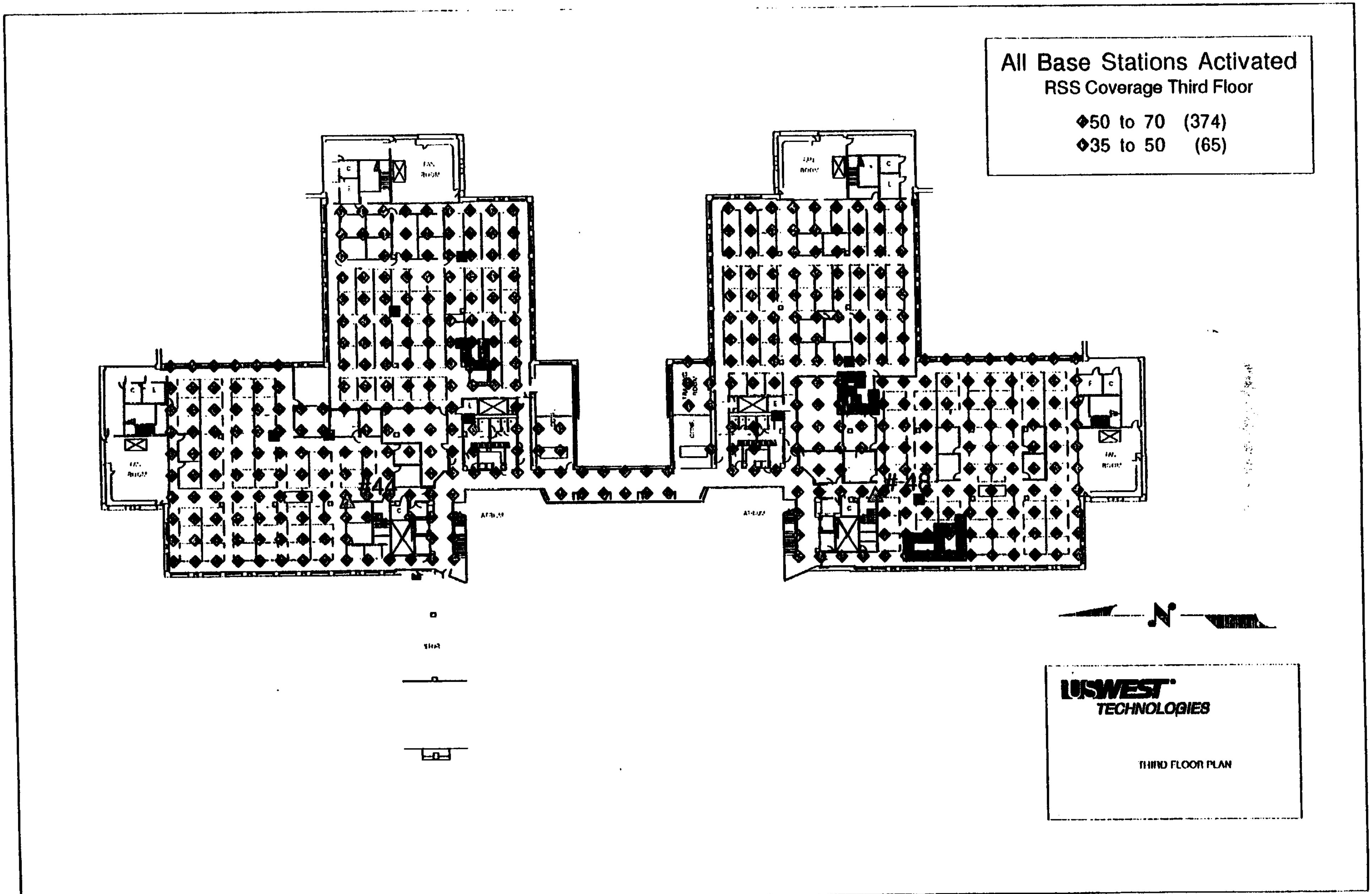

All Base Stations Activated
RSS Coverage Third Floor
50 to 70 (374)
35 to 50 (65)
#44
#48
USWEST TECHNOLOGIES
THIRD FLOOR PLAN

Figure 14.

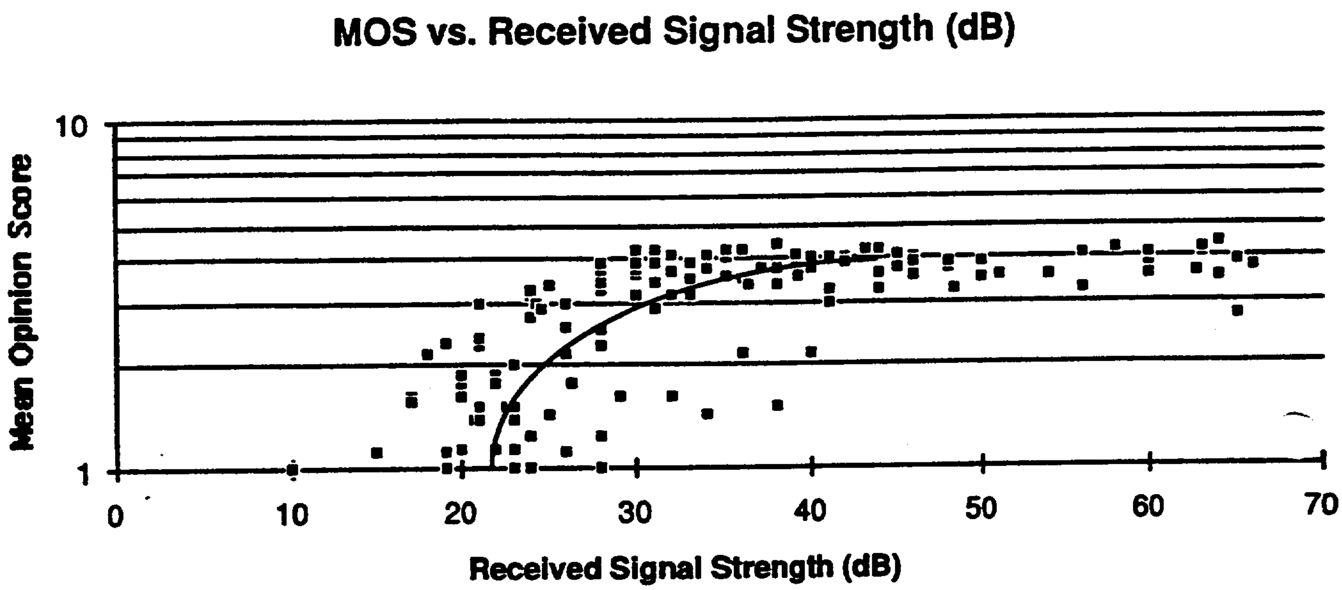


Figure 22

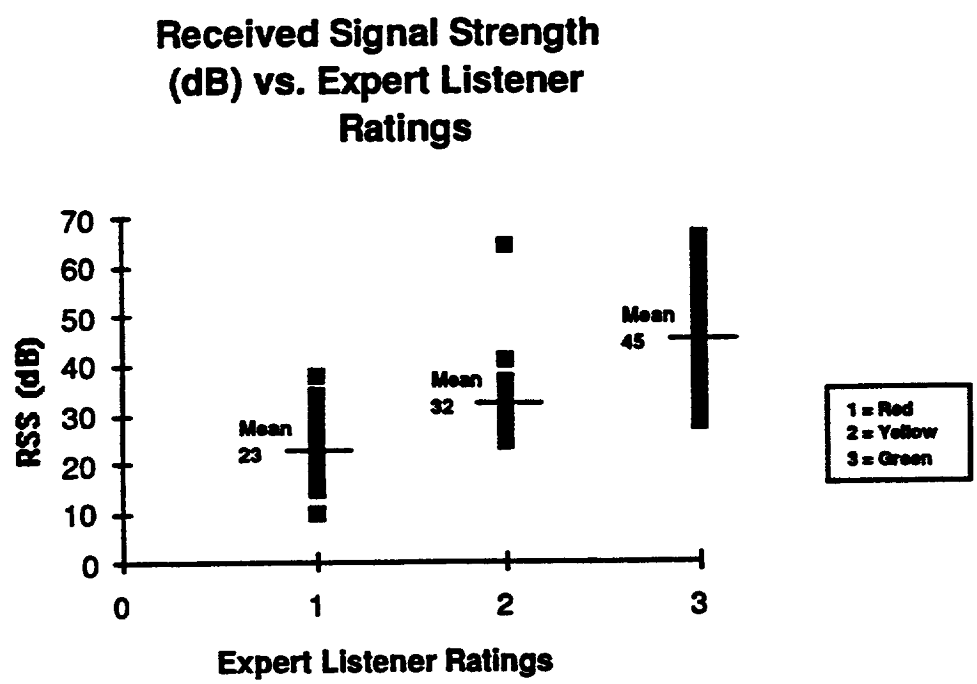


Figure 28

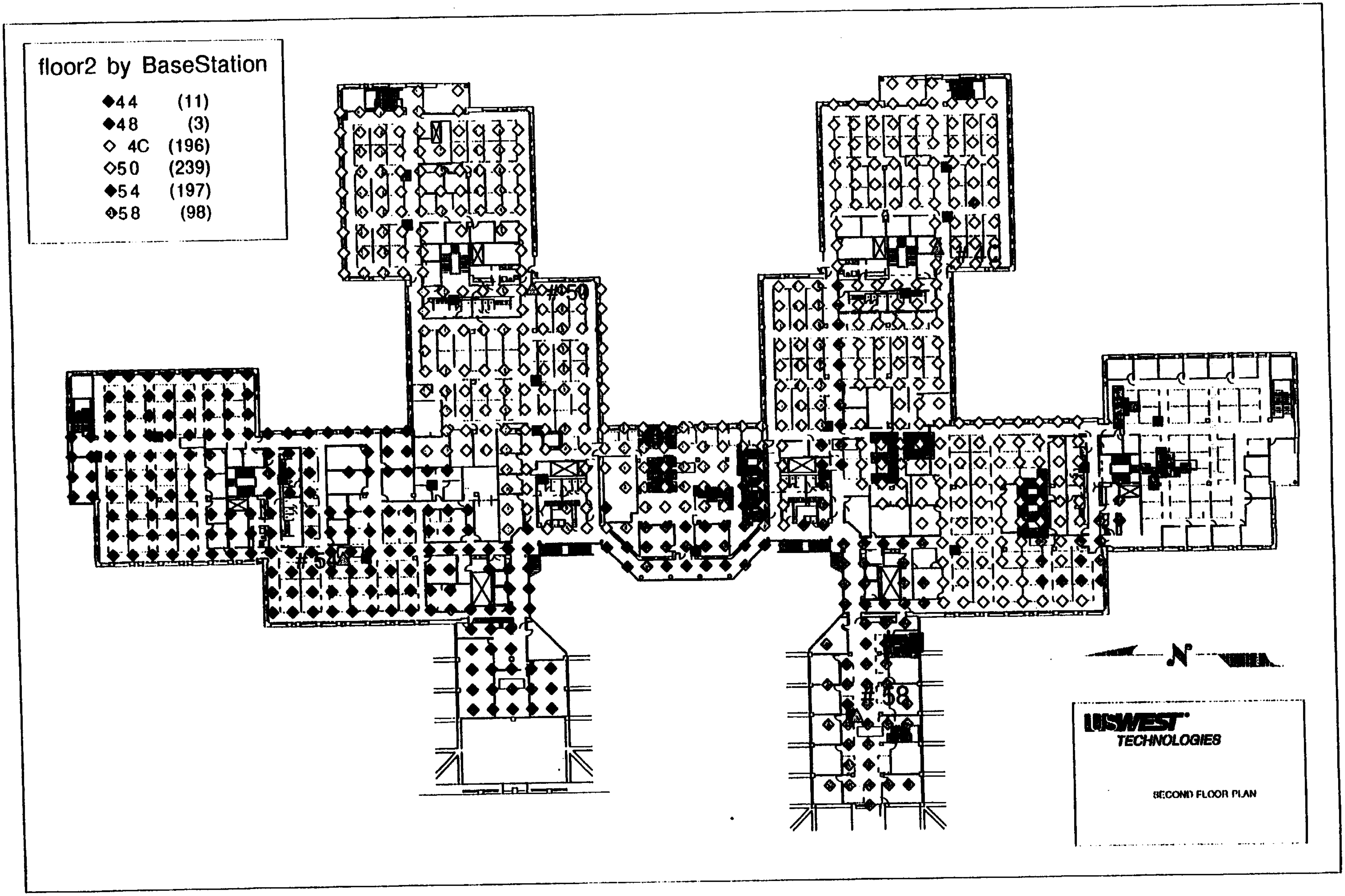

floor2 by BaseStation
44 (11)
48 (3)
4C (196)
50 (239)
54 (197)
58 (98)
#4C
#50
#54
#58
N
USWEST
TECHNOLOGIES
SECOND FLOOR PLAN

Figure 16.

Mean Opinion Score vs. Frame Error Rate

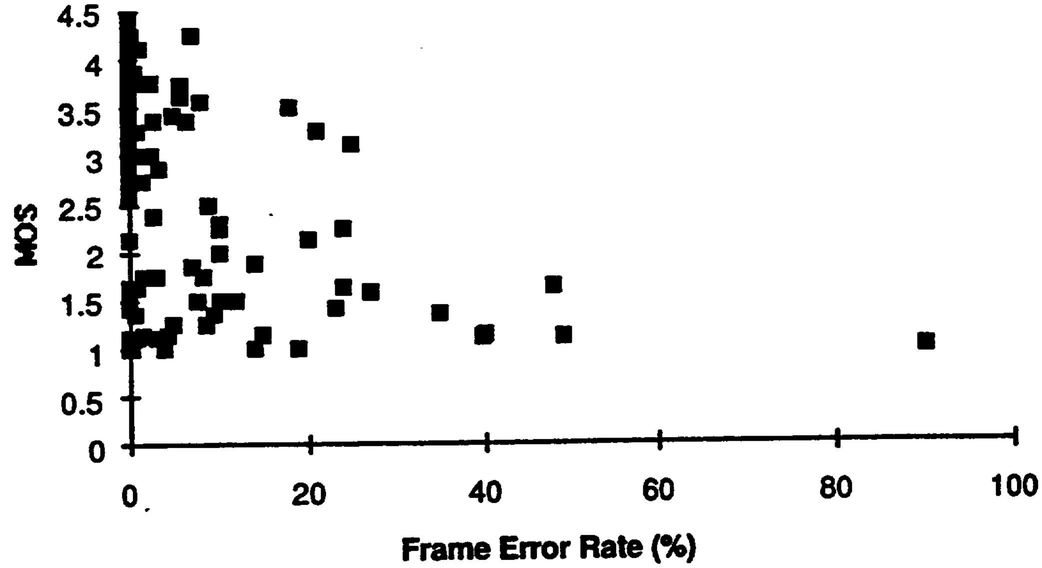


Figure 23

Frame Error Rate vs. Expert Listener Ratings

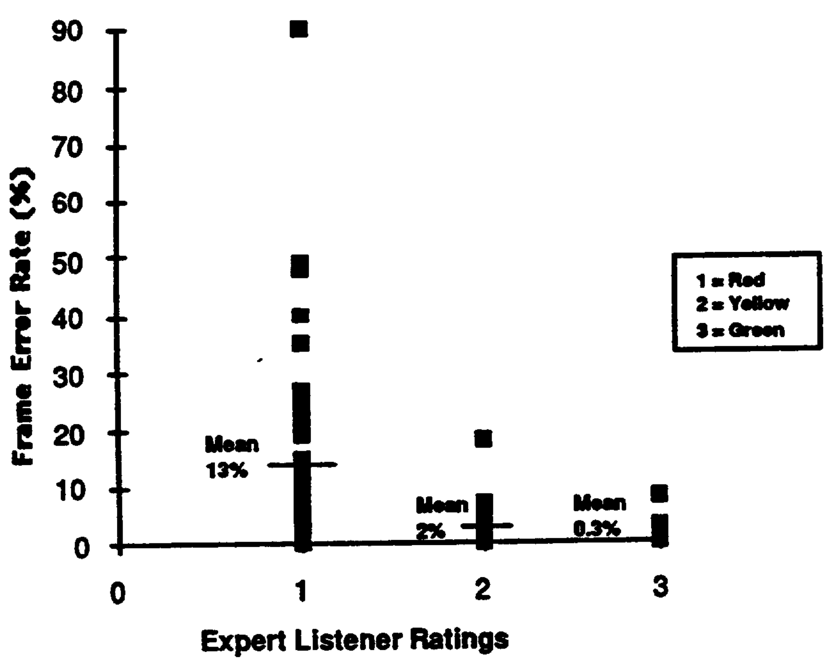


Figure 29

RSS data for the single cell coverage is given on figures 18, 19 and 20. It can be seen that the suite where BS was located had excellent coverage (dark green), and that the coverage in the suites adjacent to suite #290 was good to acceptable (bright green and yellow). The locations on the third floor that are right above the base station, and on the first floor, at the open area and right below the base station had excellent to good coverage.

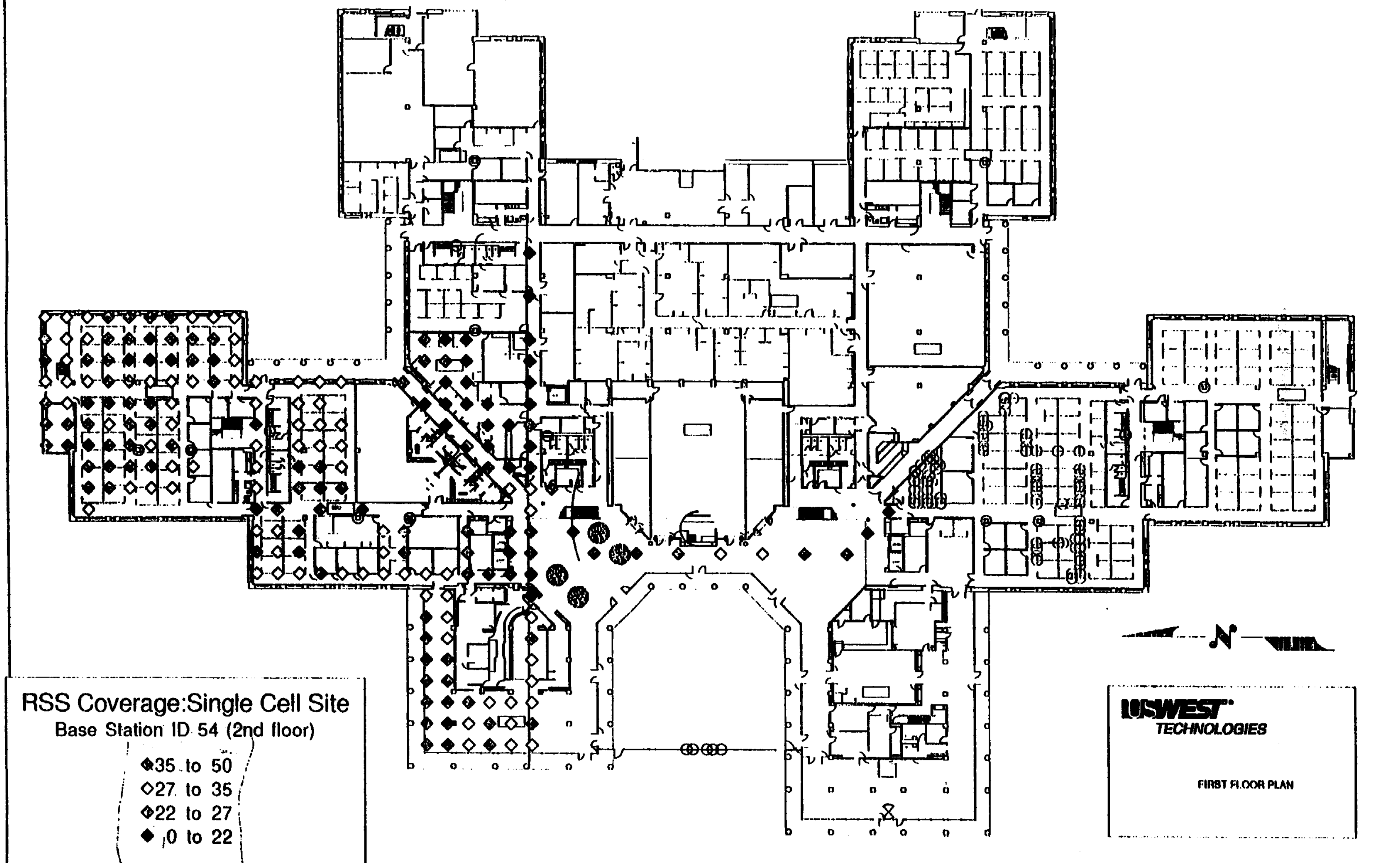
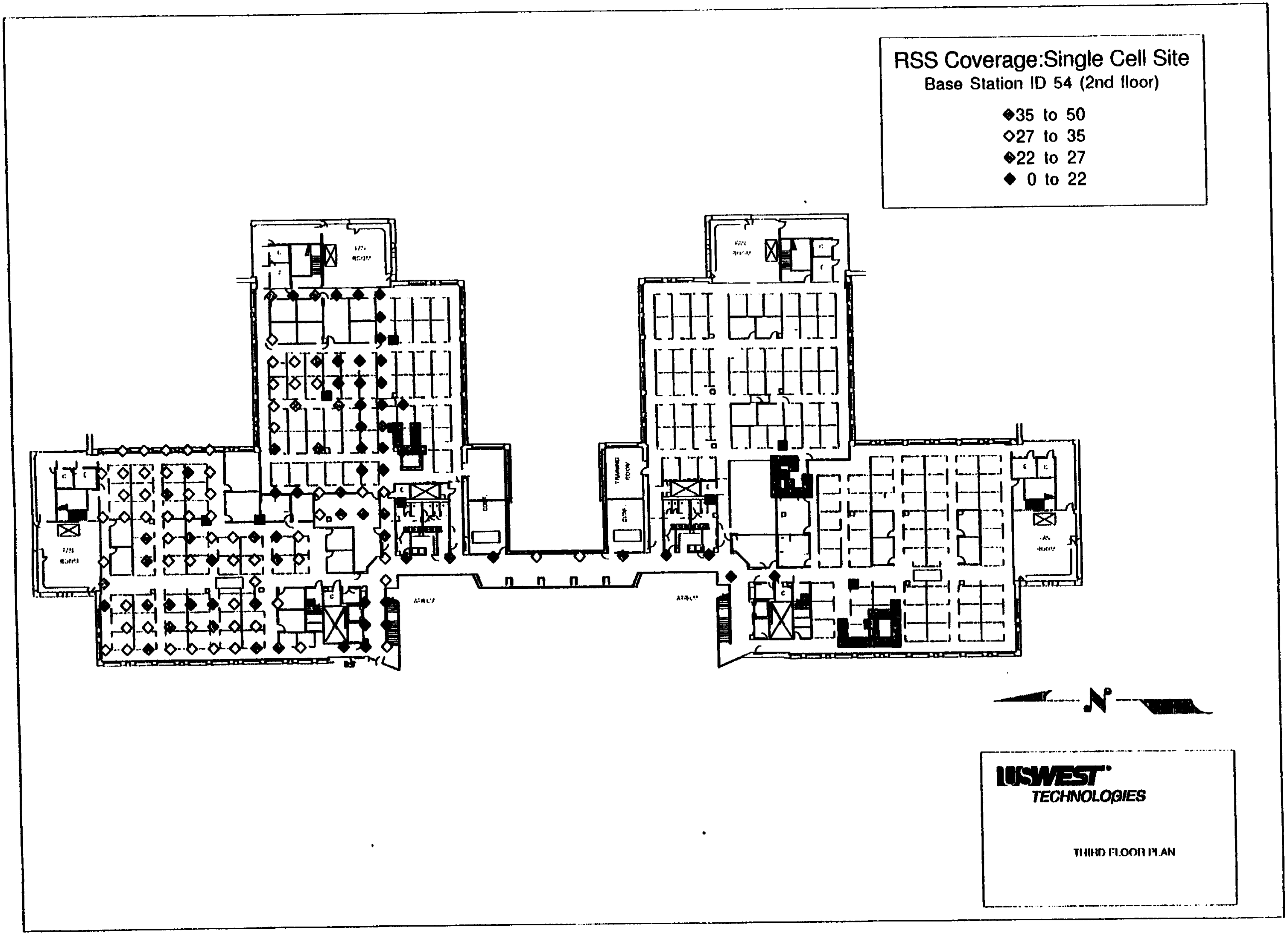
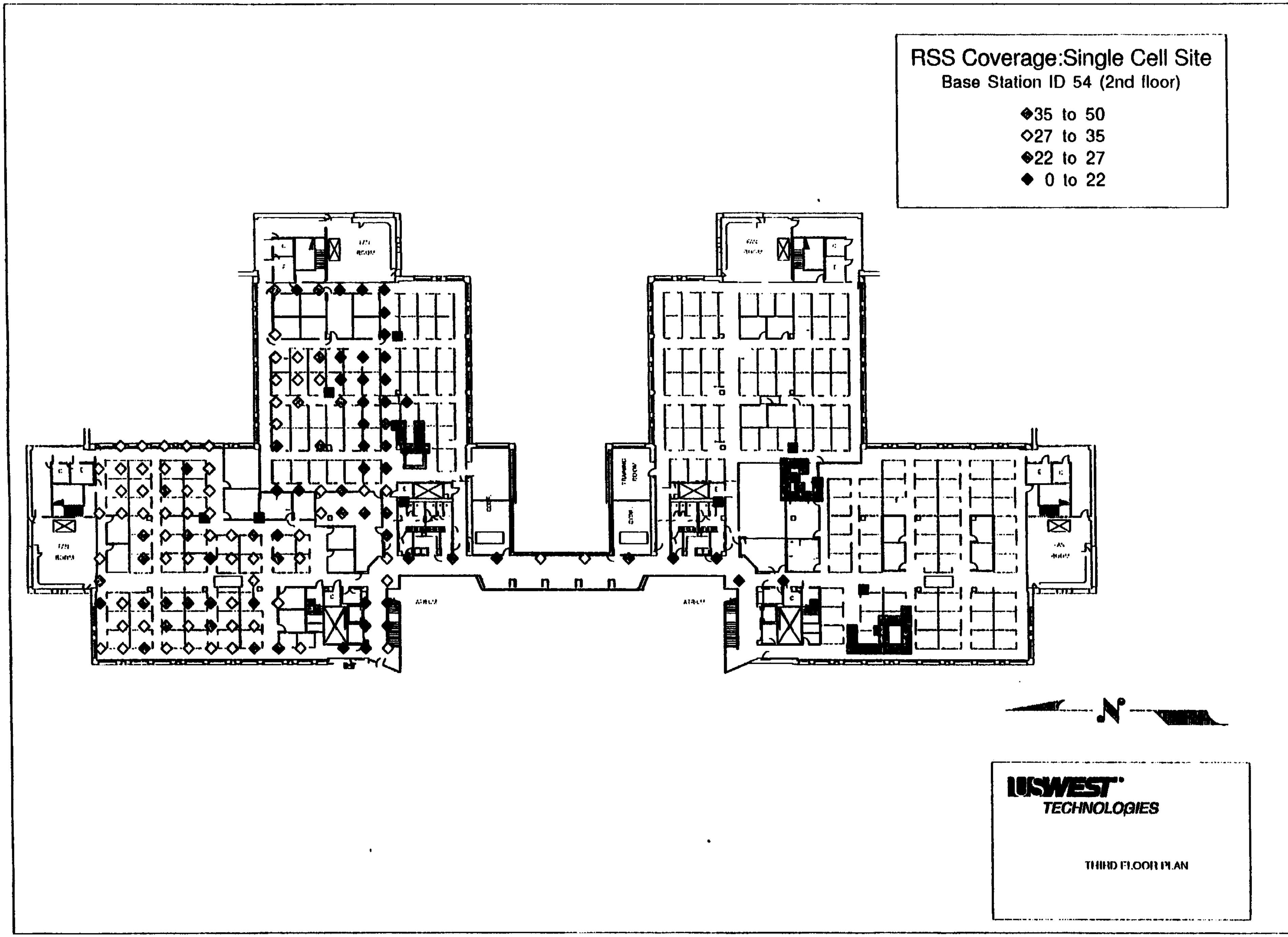


Figure 18.



RSS Coverage:Single Cell Site
Base Station ID 54 (2nd floor)
35 to 50
27 to 35
22 to 27
0 to 22
N
USWEST
TECHNOLOGIES
THIRD FLOOR PLAN

Figure 20.


RSS Coverage:Single Cell Site
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N
USWEST
TECHNOLOGIES
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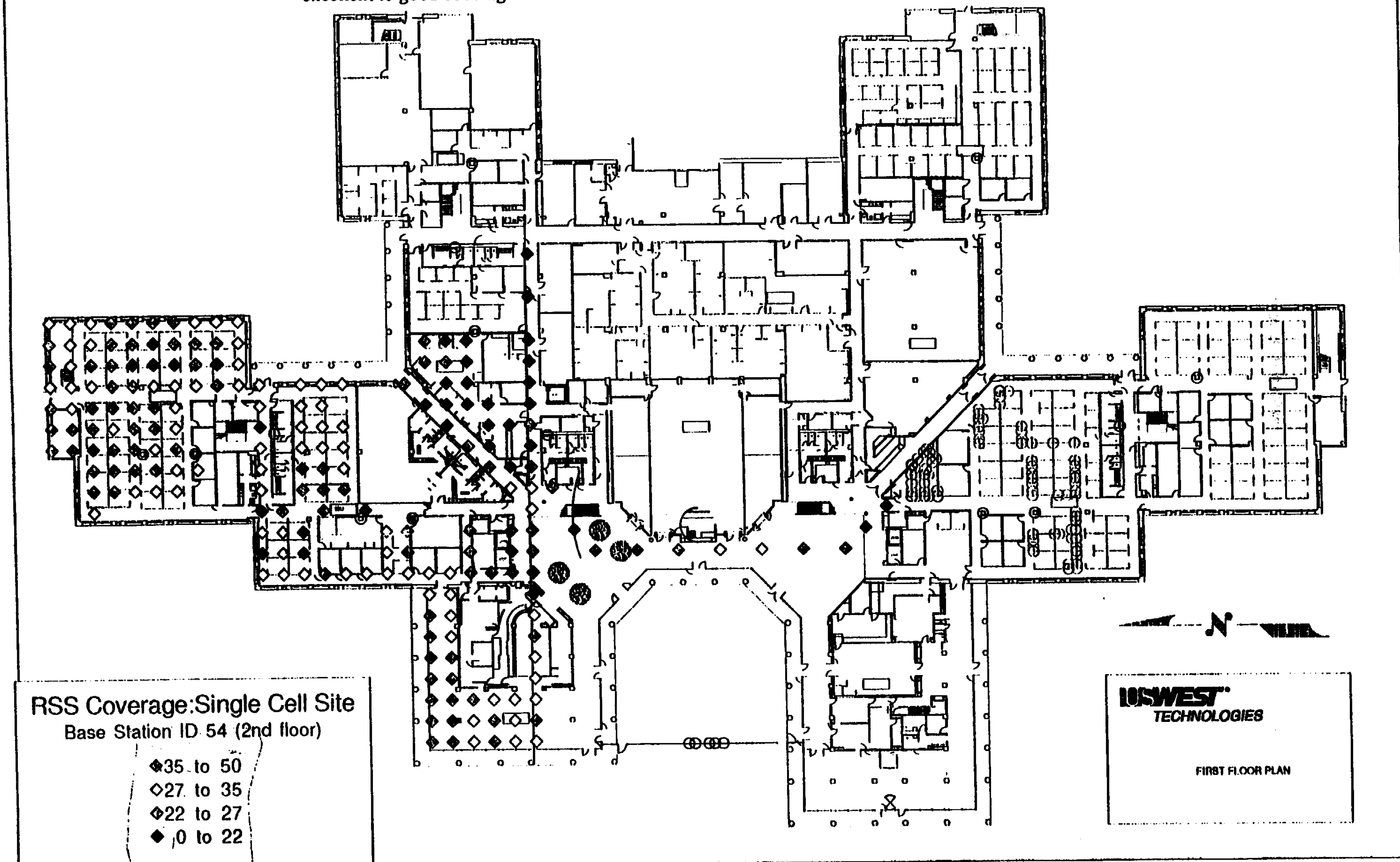

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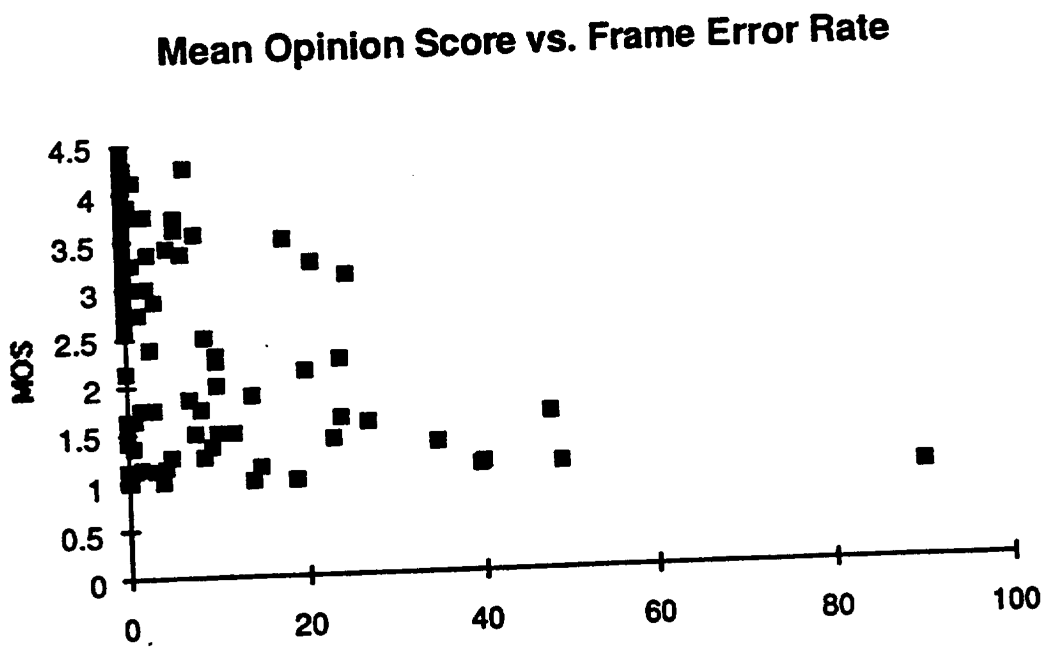


Figure 23

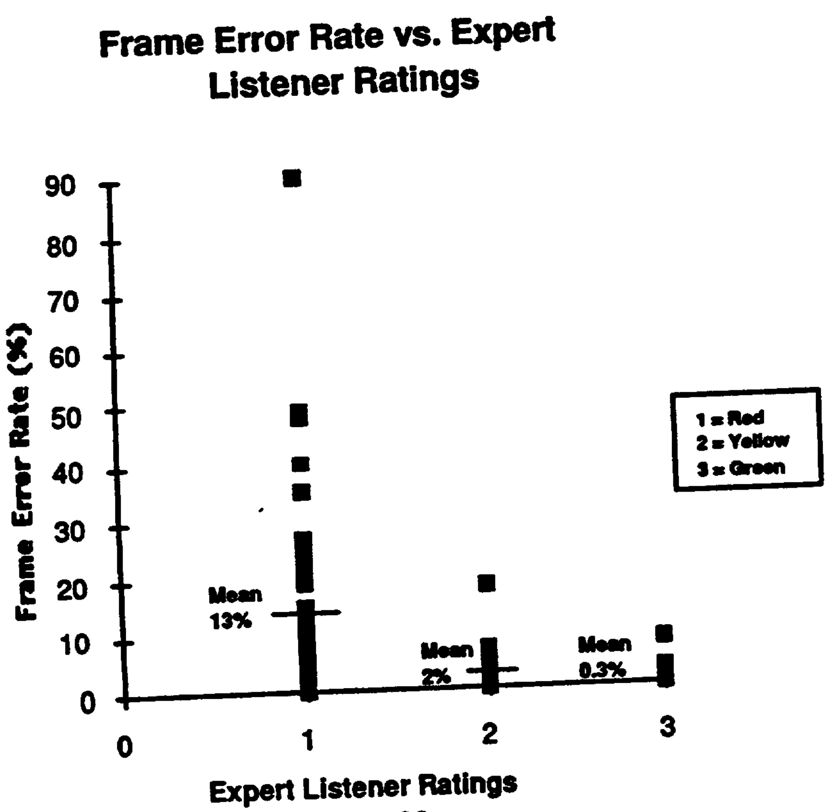
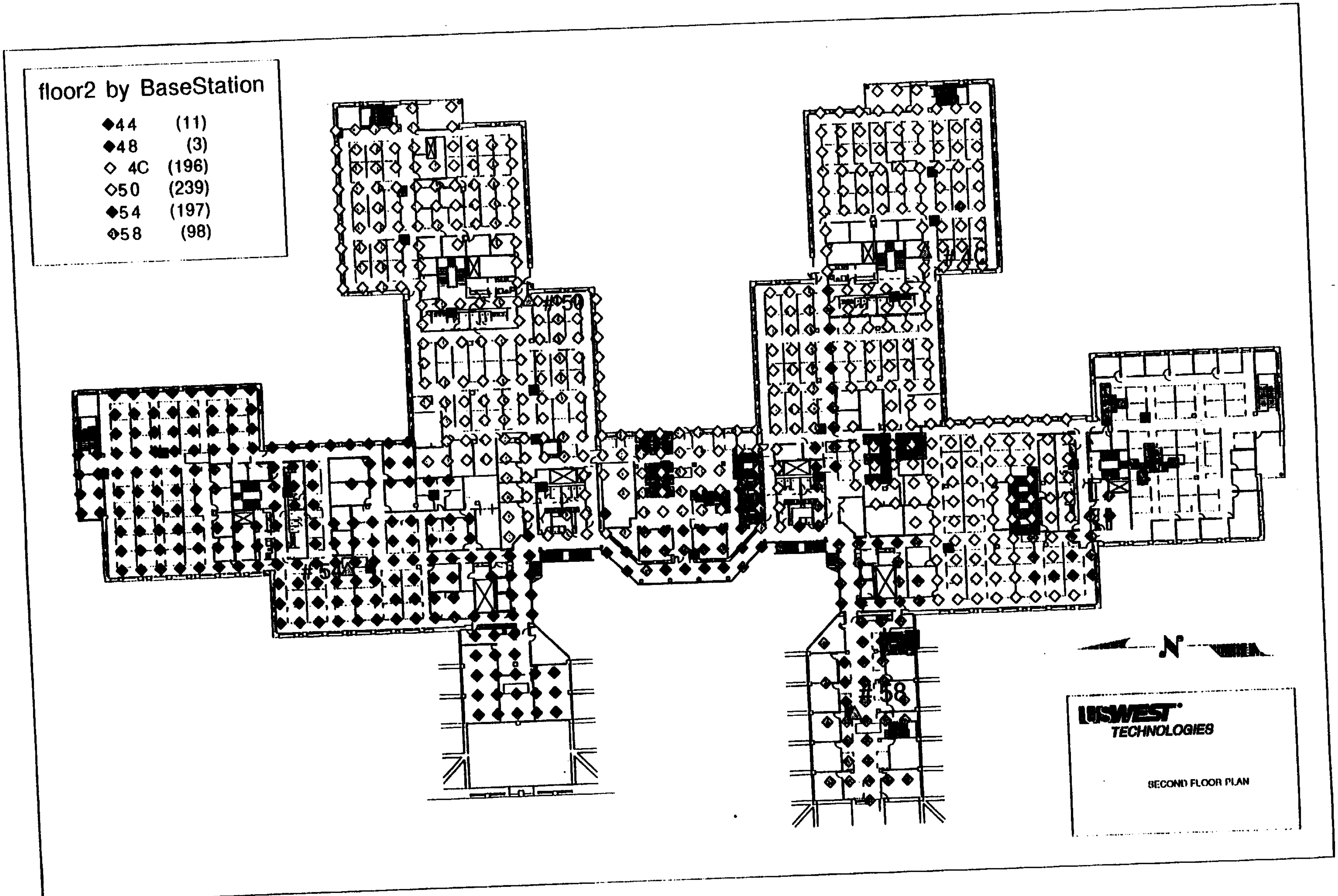


Figure 29



floor2 by BaseStation
◆44 (11)
◆48 (3)
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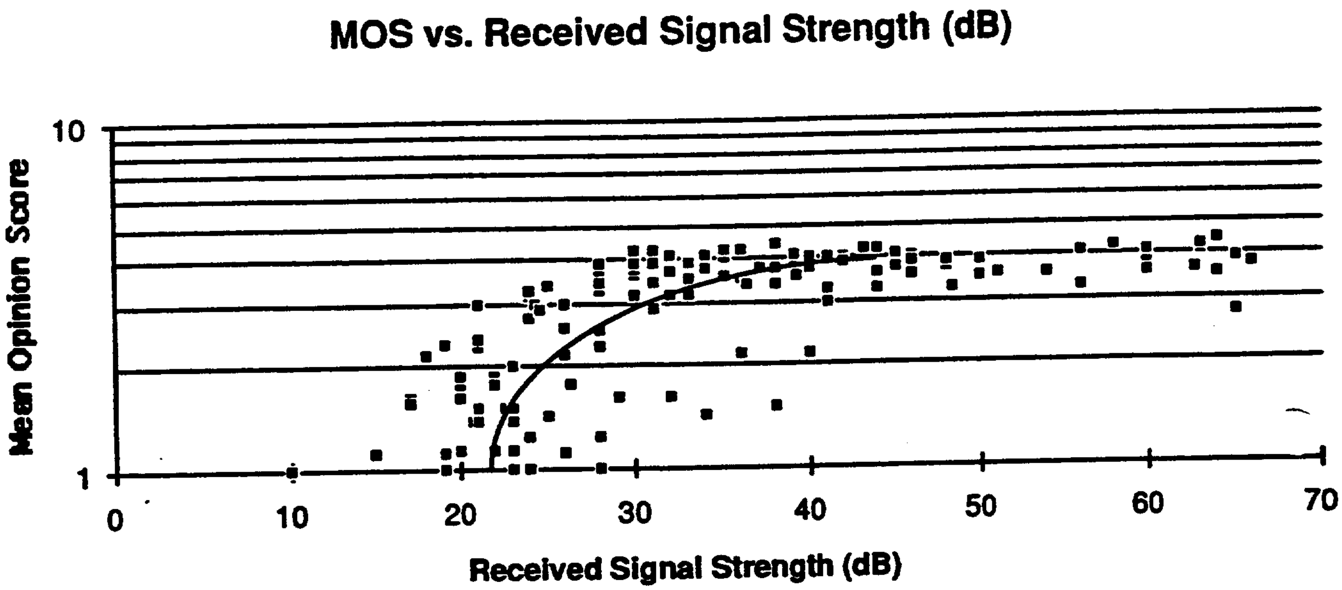


Figure 22

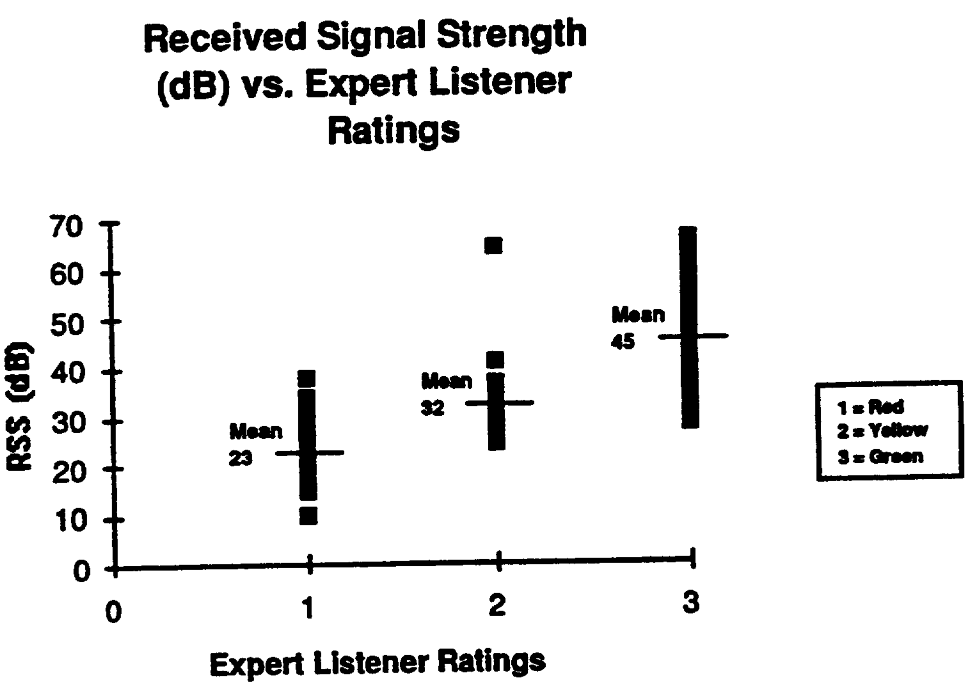
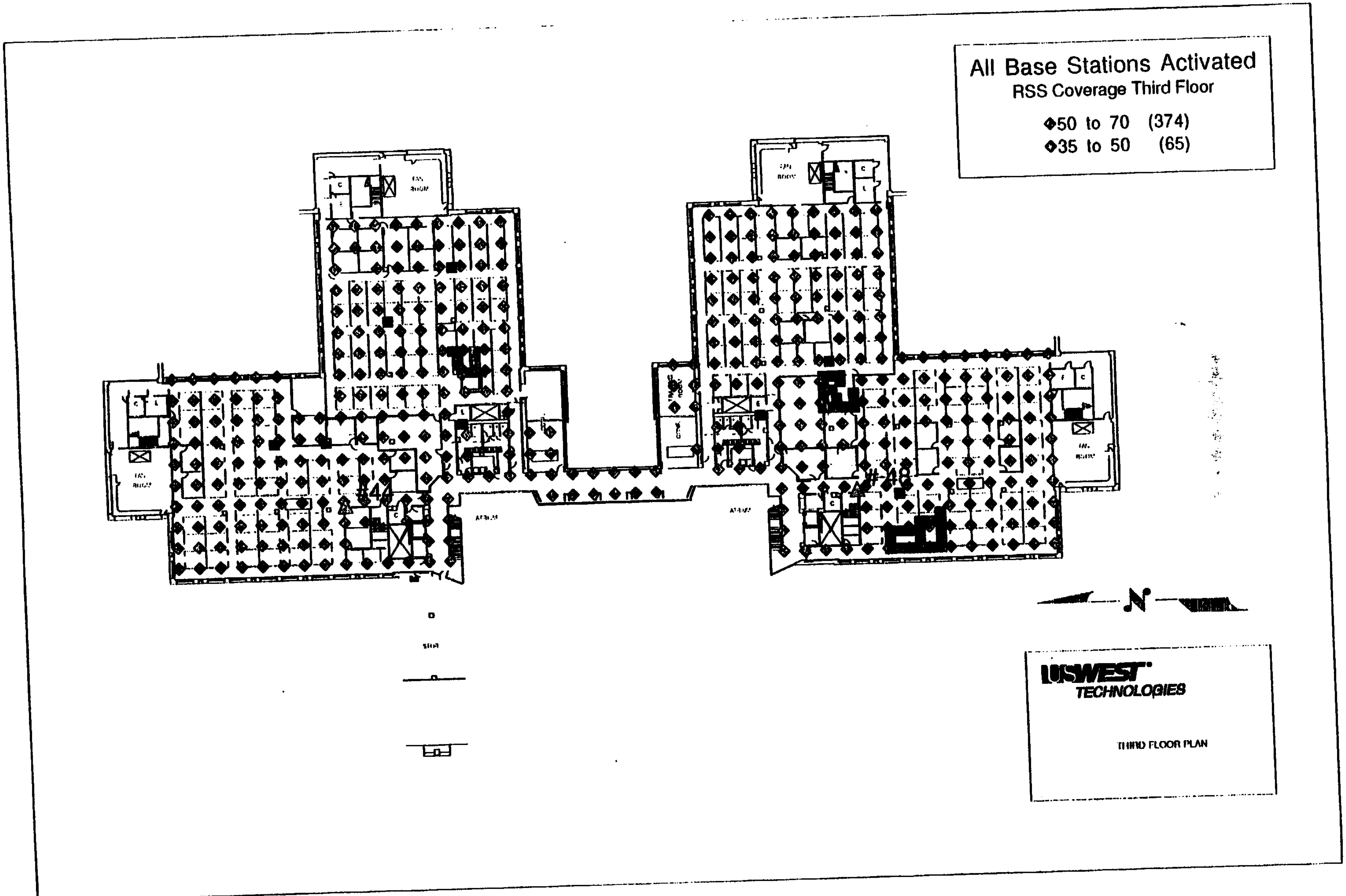


Figure 28



All Base Stations Activated
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#48
ATRIUM
ATRIUM
US WEST
TECHNOLOGIES
THIRD FLOOR PLAN

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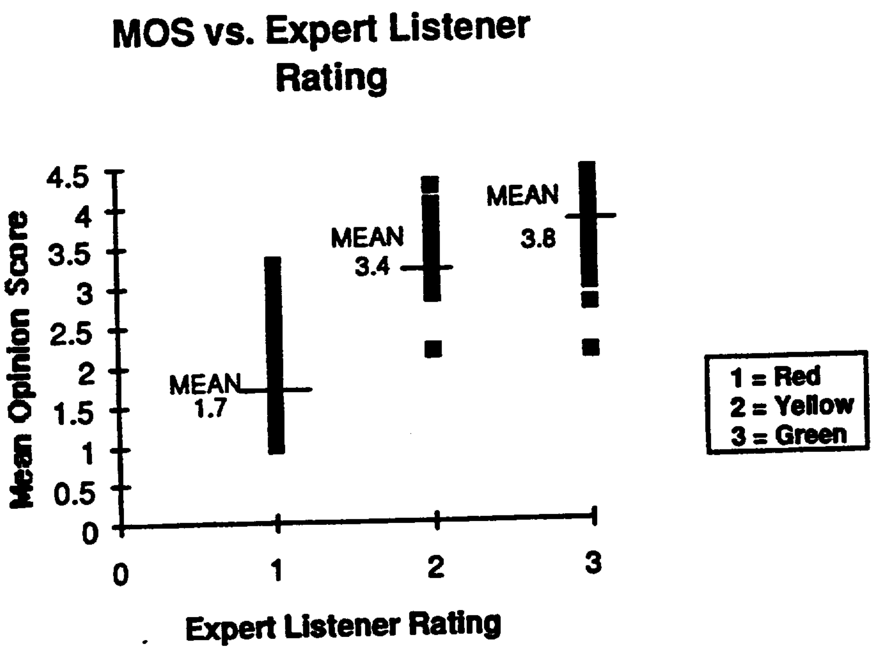


Figure 26

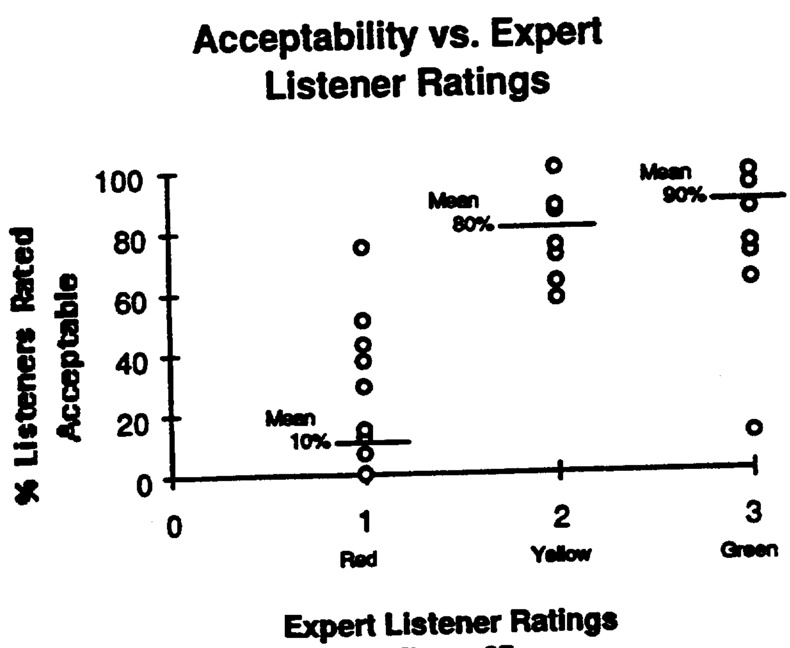
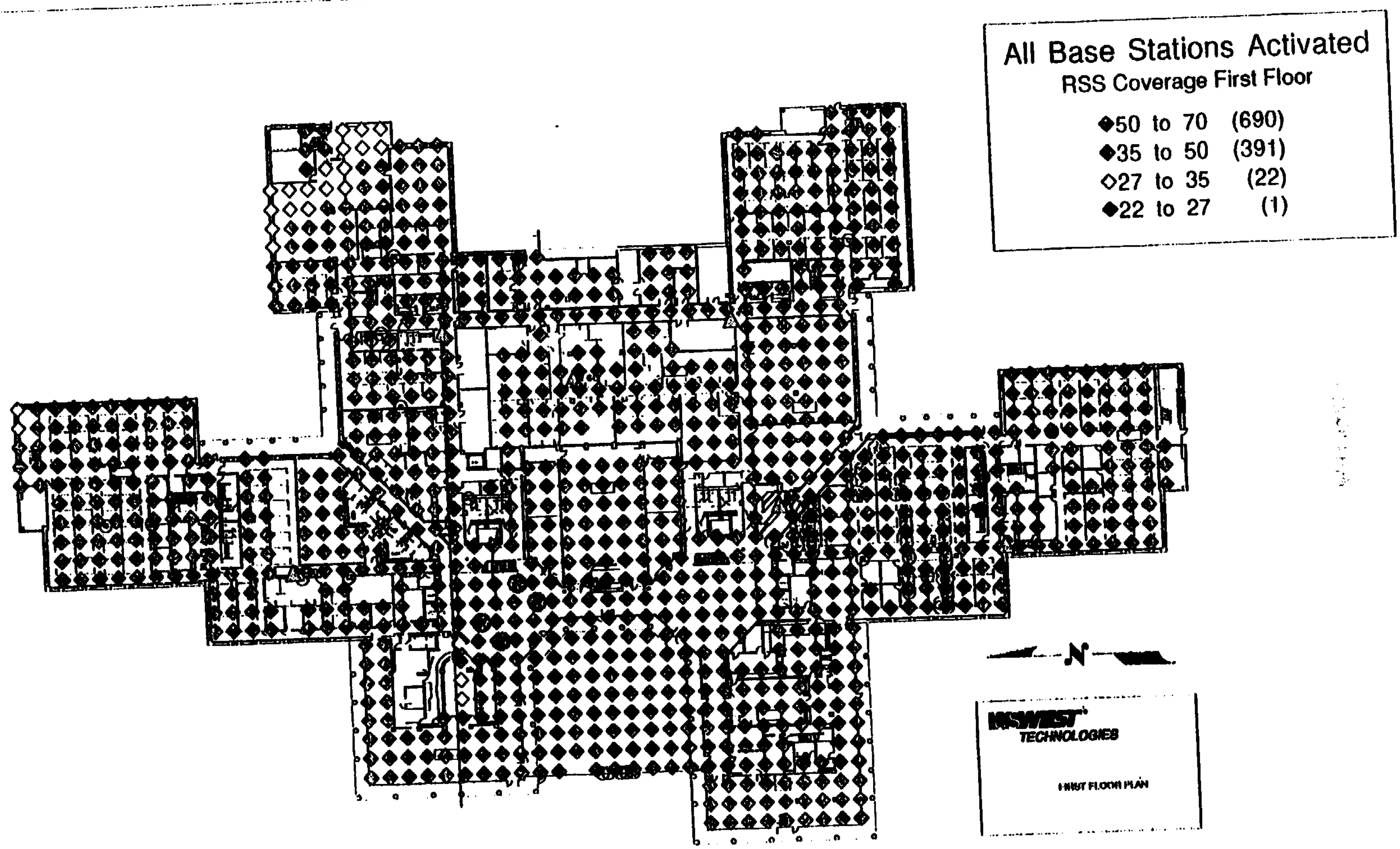


Figure 27.a



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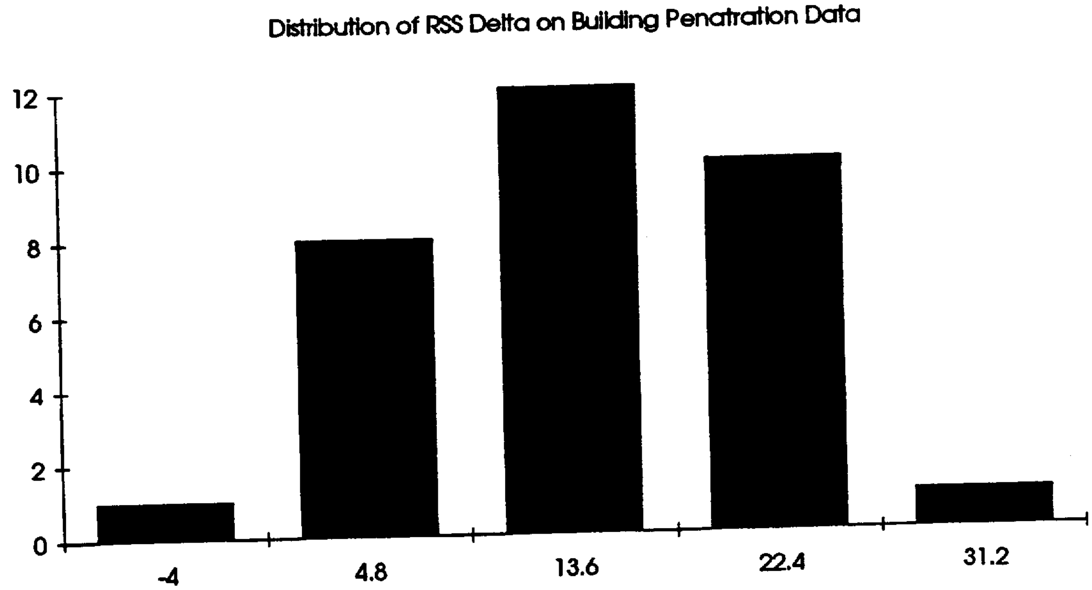

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