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USWEST

Elridge A. Stafford
Executive Director-
Federal Regulatory

July 3, 1996

Mr. H. John Morgan
Office of Engineering and Technology
Experimental Licensing Branch
2000 M Street, N.W., Room 230
Washington, D.C. 20554

RE: U S WEST Communication, Inc.
PCS Experimental License for Boulder, CO
Call Sign KK2XCC
File Numbers: 2148-EX-PL-91, 3306-EX-ML-92,
3630-EX-ML-93, 3630-EX-R-93, 4064, EX-ML-93,
4506-EX-ML-94, 4970-EX-MR-95
Seventeenth Quarterly Report

Dear Mr. Morgan:

Enclosed please find U S WEST Communications' (USWC) seventeenth quarterly report addressing the above referenced authorization for PCS field trials in Boulder, Colorado. Also enclosed are the final two Boulder Industry Test Bed (BITB) test reports submitted to the Joint Technical Committee (JTC) which address the TAG-3 and TAG-7 technology field testing. These results were summarized in USWC's fifteenth quarterly report dated December 1, 1995, and are the final two technologies tested under the auspices of the JTC at the BITB prior to its cessation.

Should you have any questions or require additional information, please call me.

Sincerely,

Elridge A. Stafford

Enclosures

U S WEST Communications, Inc.

Field Testing

Quarterly Process Report, Boulder, Colorado
FCC Experimental License
KK2XCC

July 3, 1996

Submitted to:

Federal Communications Commission
Experimental Licensing Branch
2000 M Street, N.W., Room 230
Washington, DC 20554

Prepared By:

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Introduction

This second quarter, 1996 quarterly report summarizes the field testing activities and accomplishments as conducted by U S WEST Communications, Inc. in Boulder, Colorado under FCC Experimental License KK2XCC. This reports covers activities during the period April 4, 1996 through July 3, 1996. During this period, activities begun in the previous quarter were continued for the purposes of antenna polarization testing, CDMA performance and verification testing, and operational trials.

Polarization Testing

The polarization testing begun last quarter was continued and refined. Faulty data from last quarter forced a repeat of the data collection.

Preliminary conclusions indicate that the car top antenna/receiver performed the best in terms of mean RSSI (received signal strength indicator) and standard deviation. The next best was the antenna inside the vehicle receiving vertical linear. The third best was the antenna receiving RHCP (right hand circular polarization). The antenna/receiver with the slant 45 polarization was rated last among the four.

There were enough uncertainties with the test data that reliable conclusions cannot be drawn at this time. Conclusions cannot be finalized without further testing.

J-STD-008 CDMA Testing

CDMA field testing was continued using the same equipment configuration as previously reported. The testing is now progressing from the design and engineering phase to the operational testing phase.

We have six base stations operating in the metropolitan Boulder area. The following additional tests are currently being conducted to evaluate operational performance:

- Call origination
- Audio quality
- System access monitor software involving software developers
- System loading
- System hand-off parameters

User Handset Summary

Tests with prototype handsets have begun. Employee volunteers are currently utilizing the system on a very limited basis to assess the basic service performance. We have not yet obtained a sufficient number of handsets to test engineering assumptions concerning system capacity and capabilities, but expect to acquire additional handsets for this evaluation. As soon as additional handsets are available, the scope and number of test participants will be expanded in order to obtain sufficient feedback to validate the design in areas of hand-offs and peak loading capabilities.

Early indications are that the coverage as designed is consistent with customer desired usage. In addition, the quality of the communications channels seems comparable to basic wireline grade local service. As more units are deployed, we should obtain data that will assist in evaluating loading impacts on switching capabilities and system control.

Future Plans

Ongoing and future plans call for more and improved coverage tests, polarization trials and adjustments to operating parameters. Much of the early tests must be verified so that changes and redesign can be validated. This should result in improved system performance and a better engineering model for future deployment.

Planned changes for future polarization tests include the following:

- Collection of all samples mode data and analysis of the "fast fading" characteristics of the three polarizations.
- Use of antennas with the same (90 degree) horizontal beam width. This test cannot be conducted until such antennas are available.
- Use of two identical vertical linear antennas on the uplink to compare dual polarized antenna's diversity to spatial diversity.
- Adjustments to the selected drive route. This is a minor issue, but a more selective route pattern could improve the reliability of the data.

Early results have been very valuable, but we still need to improve the level of confidence in test results as we evolve to operation testing and increase load on the system. Lessons learned here will be useful in optimizing designs for future working systems. It is our goal to utilize the spectrum as effectively as possible and to provide the highest level of service to our customers.

Atlanta, GA

JTC(AIR)/96.05.02-048

STANDARDS PROJECT: Joint Technical Committee on Wireless Access

TITLE: Test Report For The TAG 3 Technology Field Testing At The BITB

ABSTRACT: This technology field test was performed at the US WEST Advanced Technologies (USWAT) Boulder Industry Test Bed (BITB), located in Boulder, Colorado, in cooperation with the Joint Technical Committee on Wireless Access (JTC). The Technology Ad Hoc Group (TAG) 3, Personal Access Communications System (PACS) technology is one of several technologies being standardized within the JTC. All technologies being standardized in the JTC are required to submit to testing at the BITB. High tier systems each use the same cell sites and cell site antennas. Low tier systems each use the same microcell sites and cell site antennas. The cell site layout, antenna type, and antenna orientation are given and do not vary from technology to technology. TAG 3 testing was carried out at the BITB from October 1, 1995 Through October 31, 1995. A visitor day was held on October 27, 1995.

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1. Introduction

This technology field test was performed at the US WEST Advanced Technologies (USWAT) Boulder Industry Test Bed (BITB), located in Boulder, Colorado, in cooperation with the Joint Technical Committee on Wireless Access (JTC). The Technology Ad Hoc Group 3 (TAG 3) Personal Access Communication System (PACS) technology is one of several technologies being standardized within the JTC. All technologies being standardized in the JTC are required to submit to testing at the BITB. High tier systems each use the same cell sites and cell site antennas. Low tier systems each use the same microcell sites and cell site antennas. The cell site layout, antenna type, and antenna orientation are given and do not vary from technology test to technology test. TAG 3 testing was carried out at the BITB from October 1, 1995 through October 31, 1995. A visitor day was held on October 27, 1995.

The field tests examined coverage and voice quality under quasi-stationary conditions. This report describes the test plan, method, and results for the technology field trial conducted by TAG 3. The technology tested was the native PCS designed PACS standard. Radio Port Control Units (RPCU) and Radio Ports (RP) were supplied by NEC. Subscriber Units (SU) were supplied by Motorola and Panasonic. The Institute For Telecommunication Sciences (ITS), the research and engineering arm of The National Telecommunications and Information Administration (NTIA), acted as the independent observer for this field test.

The testing was carried out, by TAG 3, in fulfillment of the JTC requirement that field testing be carried out within six months of the draft standard being submitted to Committee T1 and the Telecommunications Industry Association (TIA) for ballot. This requirement is identified in JTC document JTC(AIR)/94.08.04-459R2, the JTC living list JTC(AIR)/94.10.31-003R6, and finally in the Test Plan Administration Guide JTC(AIR)/94.09.23-707.

2. BITB and Testing Overview

2.1 BITB System Configuration

A block diagram of the BITB test configuration is given in Figure 2.1. TAG 3 testing utilized 4 low tier sites in the Boulder downtown area and 3 low tier sites in south Boulder that were used in high speed handoff testing. The RPs mounted at each site utilized receive antenna diversity. The downtown sites used 6 dBi omnidirectional antennas and the high speed sites used 9 dBi shaped pattern antennas.

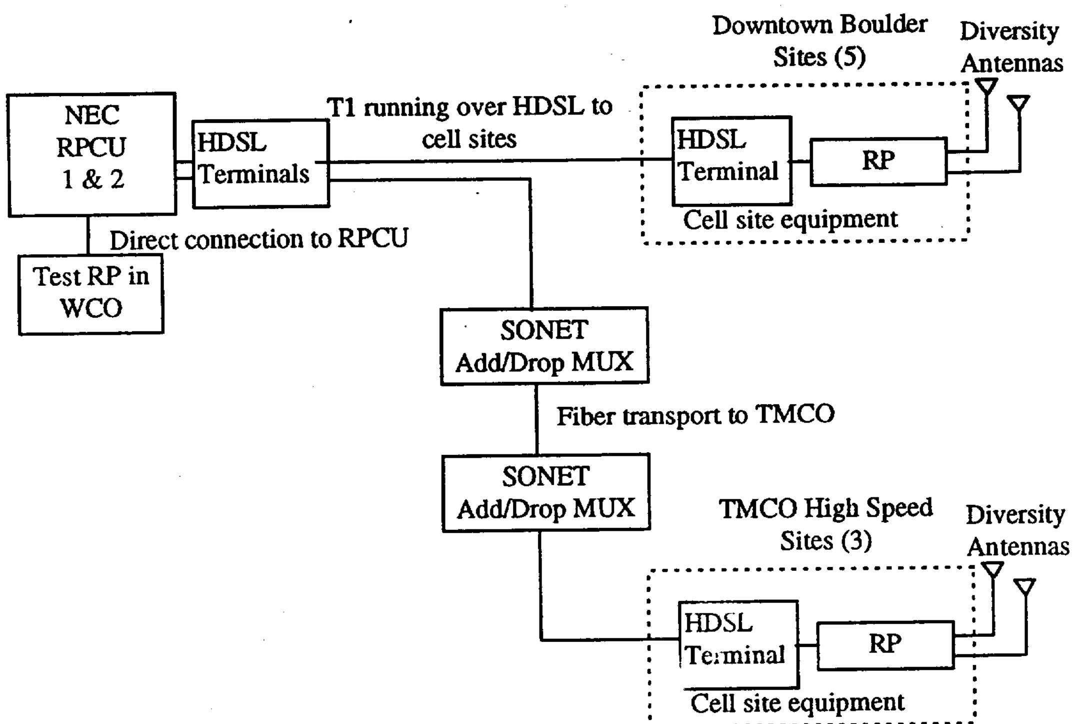

Figure 2.1 BITB configuration for PACS

The general configuration of the cell sites is as follows:

- Site 1 - located at the intersection of Pearl Street and Broadway.
- Site 3 - located at the intersection of Pearl Street and 15th Street.
- Site 9 - located on 13th Street halfway between Pine Street and Mapleton Street
- Site 11 - Located on 16th Street halfway between Pine Street and Mapleton Street
- Site 17 - (high speed handoff site) located at Hanover Street and Broadway
- Site 19 - (high speed handoff site) located on the Table Mesa Central Office at Grinnel Street and Broadway
- Site 18 - (high speed handoff site) located at Chambers Street and Broadway

The configuration of the cell sites in the BITB has been established prior to the trial for consistency throughout JTC testing. The TAG manufacturers must use the facilities supplied and are not allowed to alter cell location, or testbed equipment outside of what is required for power and telecommunications connectivity.

2.2 TAG 3 System Configuration

NEC supplied the RPC which was located in the Walnut Street Central Office (WCO). The RPCUs were connected to the RP s via T1. U S WEST provided ISDN BRI interfaces to the Nortel DMS100 switch which also is at the WCO. This switch is used only for test purposes and as such there was no connection to the PSTN or any other outside available lines.

2.2.1 TAG 3 Cell Site Component

Each cell site contained a single NEC RP. T1 was delivered to the cell sites through high speed digital subscriber loop (HDSL) circuits. The nominal height of all downtown sites was 24' above street level. The antennas used in the high speed handoff test were also at 24' above street level, two of them being mounted on utility poles and one on the south corner of the Table Mesa Central Office (TMCO).

2.2.2 TAG 3 Mobile System Components

SUs were supplied by Motorola and Panasonic. Differential GPS was used to locate the SUs and data was collected on 1 second intervals. SUs employed receive diversity.

3. Calibration

Calibration and verification of the main parameters was performed on both the SUs and the RPs, used in this field trial.

3.1 Radio Port Calibration

The RPs used in the field trial were supplied by NEC, as stated in the previous sections.

The equipment used to verify the calibration was:

> Anritsu MS 8604 A - Digital Mobile Radio Transmitter Tester. (100 Hz - 8.5 GHz.) w/ Option 16 (PACS).
> Anritsu MG 3670 B - Digital Modulation Signal Generator. (300 KHz - 2.25 MHz.). w/ MG 0303 B (Burst Card) MG 0307 A (PACS Card)

The procedure followed to verify the transmission parameters, i.e.: transmitted power, frequency accuracy, modulation accuracy, and occupied bandwidth, consisted basically in the connection of the transmission tester to the output of the RP under test, start transmission, and monitor the values averaging then over enough samples to have a representative value. Should be noted that the output power at the RP is constant. For this test a real link must be established between the RP under test and the radio port controller unit (RPCU).

Previous to the monitoring of the values, cable and couplers loss measures were taken for all the devices used in the test configuration.

To measure receiver parameters, a similar procedure was followed. In this case however, the Anritsu signal generator was used as the signal source. and the measures RSSI values were recorded on a PC.

Although the RP is provided with diversity reception, it does not allow the intentional selection of a diversity branch. The RP is normally operating on diversity branch. Thus an accurate calibration on branch 2 is not possible and all calibrations were done in branch 1.

The following parameters were recorded for all the units:

Frequency accuracy:	Nominal and Delta frequency were averaged over 500 samples.
Transmitted Power:	dBm averaged over 20 samples.
Modulation accuracy:	RMS vector error averaged over 500 samples.
Occupied Bandwidth:	(99% PWR) KHz. averaged over 100 samples.
RSSI	Reported value vs. measured input RF power.

All parameters measured were within specification. In particular reported RSS error was less than 1 dB over the operating range of the RP. Calibration data for the RPs is shown in tables 3-1 through 3-15.

3.2 Subscriber Units Calibration:

The SUs used in this field trial were supplied by Motorola and Panasonic.

The procedure followed for the calibrations of these units were the same as those used for the radio ports, but in this case, the SU has a variable output power. The values recorded for the transmission part were measured with the maximum output power according to the manufacturer specifications.

In RSS calibration it should be noted that the diversity in this system is enabled, and the values measured as RSS are always reported on the strongest path.

For the calibration of all the SUs, the following parameters were recorded:

F :	Nominal frequency. MHz. (500)
ΔF :	Frequency deviation. KHz. (500)
Tx :	Transmitted power . dBm. (20)
RMS V E :	Modulation accuracy. RMS Vector error %. (500)
Occ BW:	Occupied Bandwidth . KHz. (100)
RSSI	Reported value vs. measured RF power input

The figures between parenthesis show the number of samples averaged to obtain the values.

The equipment used to check the calibration was:

Anritsu MS 8604 A - Digital Mobile Radio Transmitter Tester. (100 Hz - 8.5 GHz.) w/ Option 16 (PACS).

Anritsu MG 3670 B - Digital Modulation Signal Generator. (300 KHz - 2.25 MHZ.). w/ MG 0303 B (Burst Card) MG 0307 A (PACS Card)

Anritsu MD1616A - PACS Signaling tester (PACS RPCU)

3.2.1 Panasonic SUs Calibration

Tables 3-16 through 3-24 show the calibration parameters for all the Panasonic SUs used in this field trial.

Should be noted that in this case the RSSI reported was expressed directly in dBm.

3.2.2 Motorola SUs Calibration

Tables 3-25 through 3-32 show the calibration parameters for all the Motorola SUs used in this field trial.

In this case the RSS reported needed to be calculated with reference to the RSSI value obtained for -100 dBm as input. The conversion formula could be expressed as:

$$RSS = -100 + 0.8(RSSI - RSSI(100))$$

where

RSS: Received signal strength in dBm

RSSI: Received signal strength indicator

RSSI(100): RSSI obtained at the calibration process when -100 dBm was injected.

The 0.8 factor was used because one unit increment in hexadecimal (the RSSI readout value) from the A/D converter was equivalent to a 0.8 dB increment in input power.

The test configuration was as shown in figure 3.1. The total loss between A and B is -21.8 dB.

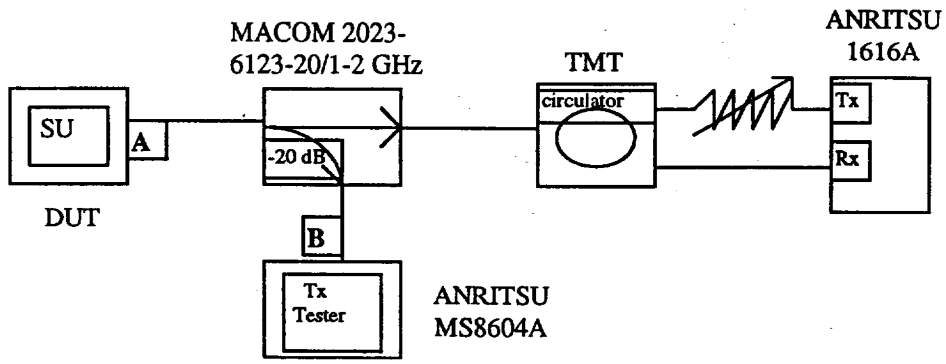

Figure 3.1 Calibration test configuration

Table 3-1 RF parameters for RP 39

Freq. Acc. :	F = 1970 MHz. ΔF = 1.97 KHz.
Mod Acc.:	RMS vector = 11.11%
Tx Power:	29.0 dBm
Occ. BW.:	256 KHz.

Table 3-2 RSS calibration table for RP 39

RSSI INPUT dBm	RSSI REPORT hex	RSSI REPORT dBm	INPUT - REPORT dB
-45	47	-57	12
-50	46	-58	8
-55	45	-59	4
-60	42	-62	2
-65			
-70	38	-72	2
-75			
-80	2D	-83	3
-85			
-90	24	-92	2
-95			
-100	1A	-102	2
-105			
-110	11	-111	1
-115			
-120	O2	-126	6

Table 3-3 RF parameters for RP 24

Freq. Acc. :	F = 1970 MHz., ΔF = 2.386 KHz.
Mod Acc.:	RMS vector = 4.4%
Tx Power:	28.6 dBm
Occ. BW.:	270 KHz.

Table 3-4 RSS calibration table for RP 24

RSSI INPUT dBm	RSSI REPORT hex	RSSI REPORT dBm	INPUT - REPORT dB
-45	4A	-54	9
-50	49	-55	5
-55	48	-56	1
-60	43	-61	1
-65	3E	-66	1
-70	38	-72	2
-75	34	-76	1
-80	2E	-82	2
-85	29	-87	2
-90	25	-91	1
-95	20	-96	1
-100	1B	-101	1
-105	16	-106	1
-110	12	-110	0
-115	OD	-115	0
-120	O7	-121	1

Table 3-5 RF parameters for RP 38

Freq. Acc. :	F = 1970 MHz. ΔF = 2.095 KHz.
Mod Acc.:	RMS vector = 3.95%
Tx Power:	28.5 dBm
Occ. BW.:	260 KHz.

Table 3-6 Calibration table for RP 38

RSSI INPUT dBm	RSSI REPORT hex	RSSI REPORT dBm	INPUT - REPORT dB
-45	4E	-50	5
-50	4A	-54	4
-55	4A	-54	-1
-60	43	-61	1
-65	3E	-66	1
-70	39	-71	1
-75	33	-77	2
-80	2F	-81	1
-85	2A	-86	1
-90	25	-91	1
-95	21	-95	0

-100	1B	-101	1
-105	17	-105	0
-110	10	-112	2
-115	OC	-116	1
-120	O5	-123	3

Table 3-7 RF parameters for RP 36

Freq. Acc. :	F = 1970 MHz. ΔF = 2.025 KHz.
Mod Acc.:	RMS vector = 4.39%
Tx Power:	27.8 dBm
Occ. BW.:	269 KHz.

Table 3-8 RSS calibration table for RP 36

RSSI INPUT dBm	RSSI REPORT hex	RSSI REPORT dBm	INPUT - REPORT dB
-45	52	-46	1
-50	4E	-50	0
-55	4B	-53	-2
-60	44	-60	0
-65	3F	-65	0
-70	39	-71	1
-75	35	-75	0
-80	2F	-81	1
-85	2A	-86	1
-90	25	-91	1
-95	20	-96	1
-100	1B	-101	1
-105	16	-106	1
-110	11	-111	1
-115	OB	-117	2
-120	O7	-121	1

Table 3-9 RF parameters for RP 23

Freq. Acc. :	F = 1970 MHz. ΔF = 1.911 KHz.
Mod Acc.:	RMS vector = 4.58%
Tx Power:	28.5 dBm
Occ. BW.:	266 KHz.

Table 3-10 RSS calibration table for RP 23

RSSI INPUT dBm	RSSI REPORT hex	RSSI REPORT dBm	INPUT - REPORT dB
-45	4F	-49	4
-50	4E	-50	0
-55	4A	-54	-1
-60	44	-60	0
-65	3E	-66	1

-70	39	-71	1
-75	34	-76	1
-80	2E	-82	2
-85	29	-87	2
-90	25	-91	1
-95	20	-96	1
-100	1B	-101	1
-105	16	-106	1
-110	11	-111	1
-115	O9	-119	4
-120	OO	-128	8

Table 3-11 RF parameters for RP 26

Freq. Acc. :	F = 1970 MHz. ΔF = 2.131 KHz.
Mod Acc.:	RMS vector = 3.57%
Tx Power:	28.5 dBm
Occ. BW.:	256 KHz.

Table 3-12 RSS calibration table for RP 26

RSSI INPUT dBm	RSSI REPORT hex	RSSI REPORT dBm	INPUT - REPORT dB
-45	48	-56	11
-50	48	-56	6
-55	45	-59	4
-60	43	-61	1
-65	3D	-67	2
-70	38	-72	2
-75	33	-77	2
-80	2E	-82	2
-85	29	-87	2
-90	25	-91	1
-95	20	-96	1
-100	1A	-102	2
-105	15	-107	2
-110	OF	-113	3
-115	O7	-121	6
-120	O3	-125	5

Table 3-13 RF parameters for RP 25

Freq. Acc. :	F = 1970 MHz. ΔF = 2.172 KHz.
Mod Acc.:	RMS vector = 3.76%
Tx Power:	28.4 dBm
Occ. BW.:	258 KHz.

Table 3-14 RSS calibration table for RP 25

RSSI INPUT dBm	RSSI REPORT hex	RSSI REPORT dBm	INPUT - REPORT dB
-45	50	-48	3
-50	49	-55	5
-55	48	-56	1
-60	44	-60	0
-65	3F	-65	0
-70	3B	-69	-1
-75	35	-75	0
-80	30	-80	0
-85	2C	-84	-1
-90	27	-89	-1
-95	22	-94	-1
-100	1B	-101	1
-105	18	-104	-1
-110	12	-110	0
-115	OD	-115	0
-120	O4	-125	5

Table 3-15 RF parameters for Panasonic SU 5

F :	1890.000 MHz.
ΔF:	0.004 KHz.
Tx:	22.96 dBm.
RMS V E :	7.07 %
Occ BW :	250 KHz.

Table 3-16 RSS calibration table for Panasonic SU 5

RSSI INPUT dBm	RSSI OUTPUT dBm	INPUT - OUTPUT dB
-45	-48	3
-50	-52	2
-55	-58	3
-60	-62	2
-65	-66	1
-70	-71	1
-75	-77	2
-80	-81	1
-85	-84	-1
-90	-89	-1
-95	-95	0
-100	-101	1
-105	-106	1
-110	-111	1
-115	-115	0
-120	-117	-3

Table 3-17 RF parameters for Panasonic SU 1

F :	1890.000 MHz.
ΔF:	0.138 KHz.
Tx:	22.81 dBm.
RMS V E :	6.44 %
Occ BW :	253 KHz.

Table 3-18 RSS calibration table for Panasonic SU 1

RSSI INPUT dBm	RSSI OUTPUT dBm	INPUT - OUTPUT dB
-45	-43	-2
-50	-49	-1
-55	-54	-1
-60	-60	0
-65	-65	0
-70	-69	-1
-75	-73	-2
-80	-79	-1
-85	-83	-2
-90	-88	-2
-95	-95	0
-100	-101	1
-105	-103	-2
-110	-106	-4
-115	-106	-9
-120	-107	-13

Table 3-19 RF parameters for Panasonic SU 10

F :	1890.000 MHz.
ΔF:	0.089 KHz.
Tx:	23.03 dBm.
RMS V E :	6.00 %
Occ BW :	250 KHz.

Table 3-20 RSS calibration data for Panasonic SU 10

RSSI INPUT dBm	RSSI OUTPUT dBm	INPUT - OUTPUT dB
-45	-49	4
-50	-50	0
-55	-54	-1
-60	-60	0
-65	-65	0
-70	-69	-1
-75	-74	-1
-80	-78	-2
-85	-83	-2
-90	-87	-3
-95	-94	-1
-100	-99	-1

-105	-102	-3
-110	-109	-1
-115	-110	-5
-120	-115	-5

Table 3-21 RF parameters for Panasonic SU 8

F :	1892.400 MHz.
ΔF:	0.069 KHz.
Tx:	22.40 dBm.
RMS V E :	7.78 %
Occ BW :	251 KHz.

Table 3-22 RSS calibration data for Panasonic SU 8

RSSI INPUT dBm	RSSI OUTPUT dBm readings	1dB loss	INPUT - OUTPUT dB including loss
-45	-43	-44	-1
-50	-50	-51	1
-55	-55	-56	1
-60	-60	-61	1
-65	-65	-66	1
-70	-68	-69	-1
-75	-72	-73	-2
-80	-77	-78	-2
-85	-81	-82	-3
-90	-85	-86	-4
-95	-90	-91	-4
-100	-95	-96	-4
-105	-100	-101	-4
-110	-104	-105	-5
-115	-107	-108	-7
-120	-108	-109	-11

Table 3-23 RF parameters for Panasonic SU 15

F :	1890.000 MHz.
ΔF:	0.036 KHz.
Tx:	22.93 dBm.
RMS V E :	6.24 %
Occ BW :	252 KHz.

Table 3-24 RSS calibration data for Panasonic SU 15

RSSI INPUT dBm	RSSI OUTPUT dBm	INPUT - OUTPUT dB
-45	-45	0
-50	-50	0
-55	-54	-1
-60	-58	-2

-65	-64	-1
-70	-68	-2
-75	-73	-2
-80	-79	-1
-85	-85	0
-90	-92	2
-95	-97	2
-100	-102	2
-105	-114	9
-110	-123	13
-115	-122	7
-120	-119	-1

Table 3-25 RF parameters for Motorola SU 9/15

F :	1892.400 MHz.
ΔF:	0.445 KHz.
Tx:	23.25 dBm.
RMS V E :	6.77 %
Occ BW :	254 KHz.

Table 3-26 RSS calibration data for Motorola SU 9/15

RSSI INPUT dBm	RSSI REPORT dec.	RSSI OUTPUT dBm	INPUT - OUTPUT dB
-40	105	-47.2	7.2
-45	103	-48.8	3.8
-50	100	-51.2	1.2
-55	95	-55.2	0.2
-60	89	-60	0
-65	83	-64.8	-0.2
-70	78	-68.8	-1.2
-75	71	-74.4	-0.6
-80	65	-79.2	-0.8
-85	58	-84.8	-0.2
-90	52	-89.6	-0.4
-95	46	-94.4	-0.6
-100	39	-100	0
-103	35	-103.2	0.2
-105	33	-104.8	-0.2

Table 3-27 RF parameters for Motorola SU 6/8

F :	1892.400 MHz.
ΔF:	0.689 KHz.
Tx:	22.60 dBm.
RMS V E :	6.56 %
Occ BW :	247 KHz.

Table 3-28 RSS calibration data for Motorola SU 6/8

RSSI INPUT dBm	RSSI REPORT dec.	RSSI OUTPUT dBm	INPUT - OUTPUT dB
-40	103	-44.8	4.8
-45	100	-47.2	2.2
-50	96	-50.4	0.4
-55	91	-54.4	-0.6
-60	85	-59.2	-0.8
-65	79	-64	-1
-70	73	-68.8	-1.2
-75	67	-73.6	-1.4
-80	60	-79.2	-0.8
-85	54	-84	-1
-90	47	-89.6	-0.4
-95	41	-94.4	-0.6
-100	34	-100	0
-103	31	-102.4	-0.6
-105	28	-104.8	-0.2

Table 3-29 RF parameters for Motorola SU 7/11

F :	1892.400 MHz.
ΔF:	0.835 KHz.
Tx:	22.78 dBm.
RMS V E :	10.90 %
Occ BW :	252 KHz.

Table 3-30 RSS calibration data for Motorola SU 7/11

RSSI INPUT dBm	RSSI REPORT dec.	RSSI OUTPUT dBm	INPUT - OUTPUT dB
-40	101	-44.8	4.8
-45	98	-47.2	2.2
-50	94	-50.4	0.4
-55	89	-54.4	-0.6
-60	83	-59.2	-0.8
-65	76	-64.8	-0.2
-70	71	-68.8	-1.2
-75	65	-73.6	-1.4
-80	58	-79.2	-0.8
-85	51	-84.8	-0.2
-90	45	-89.6	-0.4
-95	39	-94.4	-0.6
-100	32	-100	0
-103	28	-103.2	0.2
-105	26	-104.8	-0.2

Table 3-31 RF parameters fro Motorola SU 10/12

F :	1892.400 MHz.
ΔF:	-1.947 KHz.
Tx:	23.35 dBm.
RMS V E :	8.37 %
Occ BW :	253 KHz.

Table 3-32 RSS calibration data for Motorola SU 10/12

RSSI INPUT dBm	RSSI REPORT dec.	RSSI OUTPUT dBm	INPUT - OUTPUT dB
-40	109	-44	4
-45	106	-46.4	1.4
-50	102	-49.6	-0.4
-55	97	-53.6	-1.4
-60	91	-58.4	-1.6
-65	85	-63.2	-1.8
-70	79	-68	-2
-75	72	-73.6	-1.4
-80	65	-79.2	-0.8
-85	59	-84	-1
-90	53	-88.8	-1.2
-95	46	-94.4	-0.6
-100	39	-100	0
-103	36	-102.4	-0.6
-105	33	-104.8	-0.2

4. COVERAGE TESTING

Note: The high and low tier cell site locations and the RP site antennas and their orientation are given as part of the BITB. The individual TAGs have no latitude in cell location or in the antenna configuration. For some technologies the cell layout may not be optimal.

4.1 Coverage Methodology

The physical configuration of the cell sites was that given in section 2. The RP power was set to 0.8 watts (29 dBm). Each downtown Radio Port had 6 dBi omni antenna attached to it, so the nominal ERIP was 35 dBm (3.16 W). The SU test cart was configured with the SU station under test placed on the flat top inside the cart with its antenna mounted on the wooden pole, attached to a side of the cart. GPS was mounted on a side of the cart, next to the antenna mounting structure. Routes were chosen such that they ran radially outward from the RP sites. Where time permitted, routes were run that filled in the coverage area around the RPs. For isolated cell testing a single RP site was activated. For combined coverage handoff was allowed between the active RPs. Only one SU call at a time was initiated for isolated and combined RP coverage. For isolated RP coverage Motorola's SU was used; for combined RP coverage Panasonic' SU was used. Tables 4.1-2. list the parameters logged for each run. All data listed were averaged per one second . For each drive route a call was initiated at the beginning of the route, and the SU and RP logging was activated. At the end of the route the data logging was stopped and the log files saved. Items logged at the SU station include all SU station statistics along with GPS location, velocity, and time. Items logged at the RP site include all RP site statistics, along with GPS time.

Data structure for SU and RP logs are shown in Tables 4.1-2.

Table 4.1 Data logged at SU for each run

Column	Data Logged
A	Time and date (GPS)
B	Latitude
C	Longitude
D	Serving channel Receive Signal Strength Indicator (RSSI)
E	SU count of errored frames per second (WERI)
F	Serving channel number
G	Active Time Slot No.
H	SU transmit power

Table 4.2 Data logged on RP site for each coverage run

Column	Data Logged
A	Time and date (GPS)
B	Latitude
C	Longitude
D	RP site number
E	RP site transmit power
F	Active time slot number
G	RP site Receive Signal Strength Indicator (RSSI)
H	RP Site Quality Indicator (QI)
I	RP site count of errored frames per second (WERI)

Note: Conversion from Receive Signal Strength Indicator (RSSI) to Receive Signal Strength (RSS) was done using the following conversion equation (Motorola SU only) :

RSS (dBm) = -100 + 0.8*(RSSI - 39)

This conversion equation was determined using the calibration data for the SU used in coverage testing.

Number of errored frames per second (WERI) is converted to Word Error Rate (WER %) according to the following equation (the 400 is due to the fact that there are 400 frames per second):

WER (%) = WERI/400 * 100%

4.1.1 Isolated Cell Coverage

Isolated cell coverage testing was conducted on four separate RPs located in downtown Boulder. They are labeled as RP Site 1 (located at the intersection of Pearl street and Broadway), RP Site 3 (at a corner of Pearl and 15th street), RP Site 9 (on 13th street, midway between Pine and Mapleton street), and RP Site 11 (on 16th street, midway between Pine and Mapleton street). The choice for cell sites' numbering was made at a time when low tier BITB cell site planning was made (1993); low tier BITB has a total of 47 cell sites. The RP that had its coverage tested was active; the other ones were turned off. All RPs had omnidirectional antennas.

The coverage for each site was measured by pushing the SU cart on the radial routes away from the site at a pedestrian speed, and filling in between radials, as time permitted. A call was initiated close to the RP site, then the test cart was pushed along one of the radial routes. The point at which the call was dropped was the end of coverage for the chosen route. For all test runs, SU and GPS data were logged both at the SU and at the active RP site. The SU and RP site data were later collocated into one file, using a GPS time to collocate each data point.

4.1.1.1 RP Site 1 (Pearl & Broadway)

For the RP Site 1 isolated cell coverage testing the other RP sites was turned off. For all the test routes, calls were originated prior to start of the route, approximately one half block away from the RP site, and the SU and RP side data logging begun.

4.1.1.2 RP Site 3 (15th street, between Pearl and Spruce street)

The coverage test for the RP Site 3 was conducted in a similar manner to that used for the RP Site 1.

4.1.1.3 RP Site 9 (13th between Pine and Mapleton street)

The coverage test for the RP Site 9 was conducted in a similar manner to that used for the RP Site 1.

4.1.1.4 RP Site 11 (16th between Pine and Mapleton street)

The coverage test for the RP Site 11 was conducted in a similar manner to that used for the RP Site 1.

4.2 Isolated Cell Coverage Data and Discussion

Data was collected at SUs and at the active RP site including GPS. The data from the different sources was then collated with respect to time, and combined to provide a file with location, speed, and information about the radio link as listed in Table 4.1. All parameters were averaged over one second.

The reader is referred to Appendix A for the resulting coverage plots. Each is labeled according to the section to which it corresponds. Also found in Appendix A is a topographic map of the Boulder vicinity. This is labeled as Map 4.2.

4.2.1 RP Site 1

Coverage plots for the RP Site 1 isolated coverage test are as follows (in Appendix A):

Map 4.2.1.1 SU Rx coverage plot (1 inch= 0.18 miles)
Map 4.2.1.2 SU average WER % coverage plot (1 inch= 0.18 miles)
Map 4.2.1.3 Uplink Rx coverage plot (1 inch= 0.18 miles)
Map 4.2.1.4 Uplink WER % coverage plot (1 inch= 0.18 miles)

RP Site 1 is indicated as a star in the center of the Maps 4.2.1.1-4.2.1.4. To obtain a rough estimate of the coverage region, we assume that downlink received signal strength of -90 dBm or higher is desired. In that case, the coverage boundaries are approximately 0.41 miles north-northwest, 0.35 miles west-southwest, and 0.57 miles south-southeast. The RP Site 1 is located at a intersection of Pearl street and Broadway, which is in the middle of a pedestrian mall. Pedestrian mall is located at Pearl street, between the 11th and 15th street, in a light suburban environment, with a heavy foliage at the time of TAG 3 testing (October). Due to high volume of foliage, GPS data was inaccurate on Pearl street, east of RP Site 1. Hence, although we collected the radio coverage data in that area, it could not be represented on a coverage map, due to GPS inaccuracy. A careful examination of coverage maps gives an impression that the coverage data was 'shifted' for about half a block to the west-southwest direction. This is due to the fact that the GPS accuracy was within 150 feet, which is about half a block. Due to the shadowing effect, the RSS level varies significantly along the RP Site 1 routes, crossing the -90 dBm level several times before finally dropping below -90 dBm for good. The above stated distance, however, is measured from RP Site 1 to the first area on the route where the RSS drops below -90 dBm. We note that that the RP Site 1 had a greater coverage along Broadway (State Highway 93) than along Pearl street, due to the lesser volume of foliage along Broadway.

The log distance vs. SU RSS (Downlink RSS) is shown on Figure 4.2.1.1 The data included in this figure is the overall data for this cell, excluding the points for which RSS was less than -101 dBm. Those points were excluded because -101 dBm is the threshold level for the SU receiver for normal system operation. The large variation in RSS level is mostly due to different propagation environments along Broadway and Pearl street, and shadowing in a light urban environment. Note that relatively strong signals (~ -85 to -88 dBm) exists relatively far away from the cell (~0.63 miles). Those signals were recorded along Broadway, and had clear line of sight with the RP Site 1.

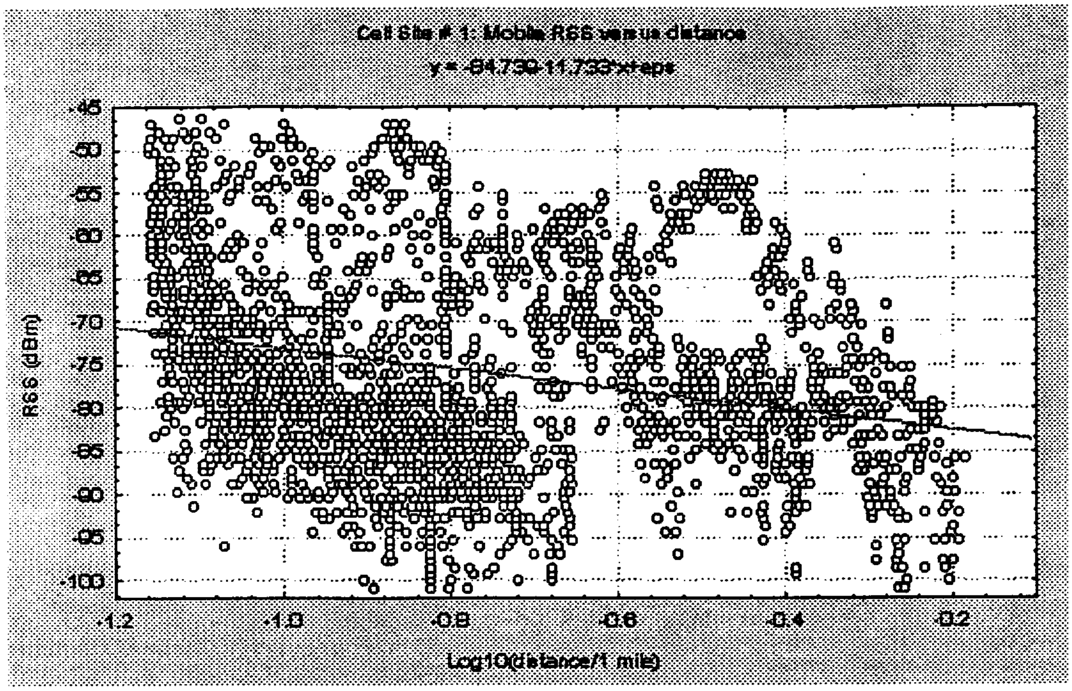

Figure 4.2.1.1. Received power versus $\log_{10}$(distance/1 mile).

Figure 4.2.1.2 shows the SU RSS histogram. Again, points at which RSS was less than -101 dBm were excluded. The mean is -75.9 dBm, and the standard deviation is 12.95 dB.

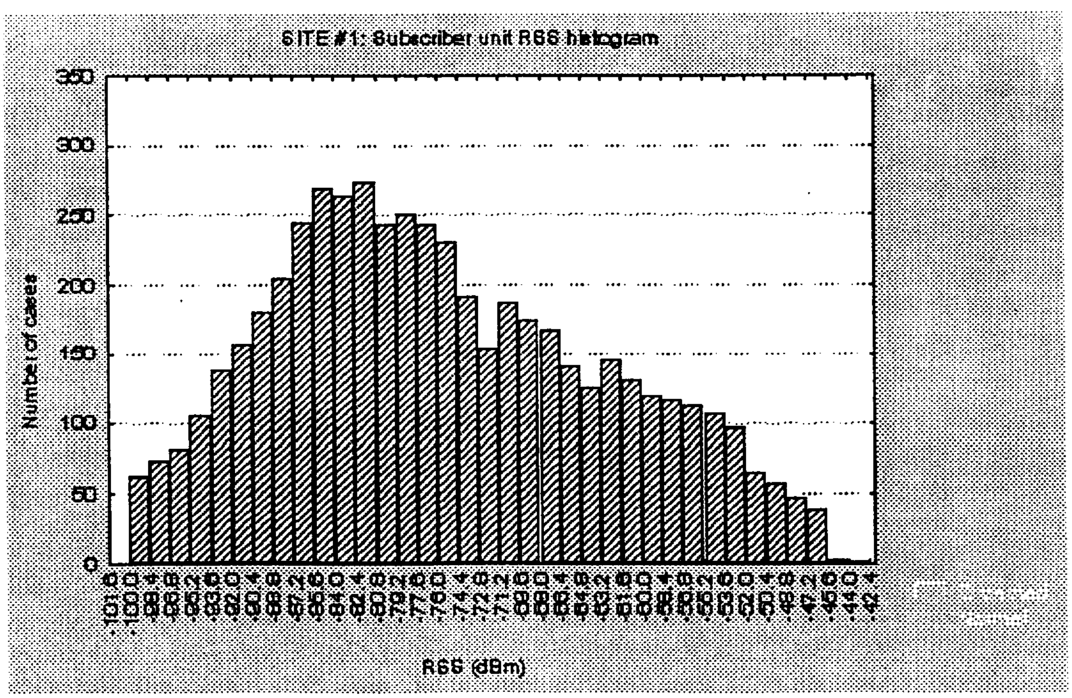

Figure 4.2.1.2. SU received power histogram .

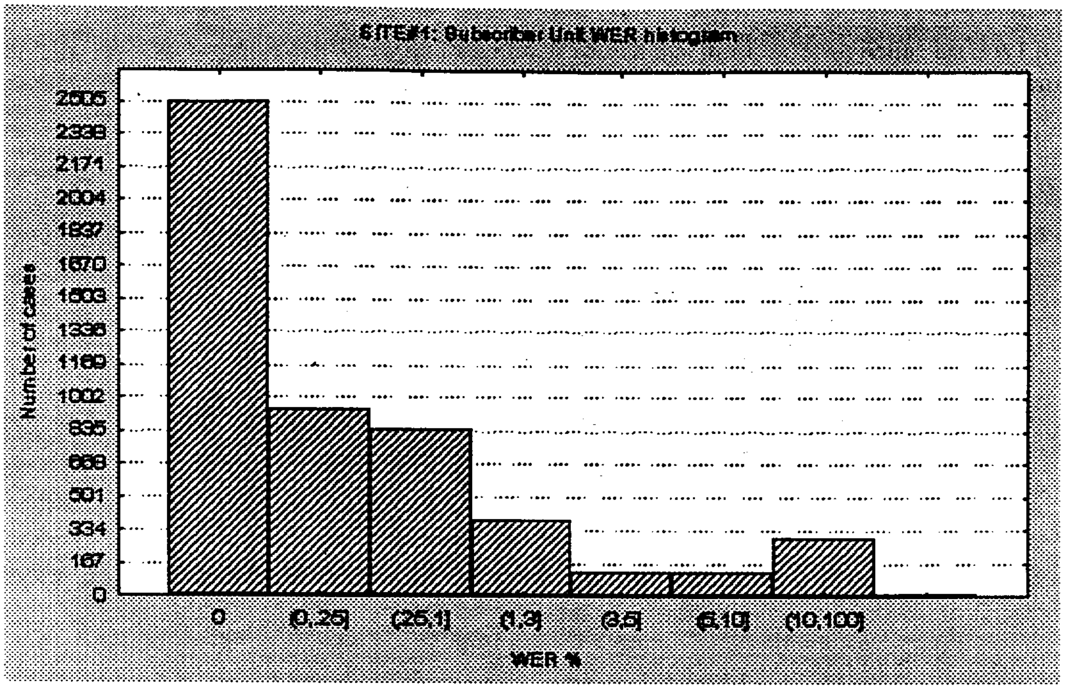

Figure 4.2.1.3. SU received WER % histogram

Figure 4.2.1.3 is an SU received WER % histogram. It is seen that most (~75 %) points have WER < 1%. This is due to the fact that WER % increases rapidly as RSS approaches threshold level (-101 dBm) at the edge of coverage area.

Figure 4.2.1.4 is Base Station 1 Rx histogram. Points that had signal level less than -118 dBm were excluded from the histogram. The mean is -91.24 dBm, and the standard deviation is 11.28 dB.

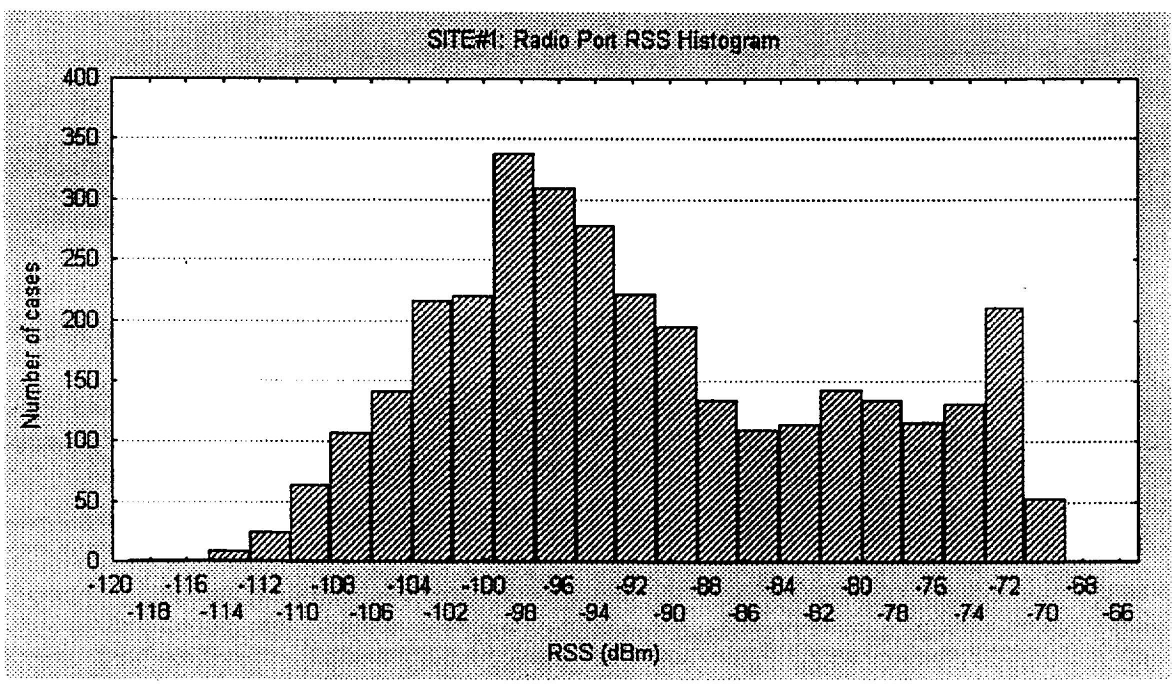

Figure 4.2.1.4. Base Station 1 received signal histogram

Figure 4.2.1.5 is base Station 1 WER % histogram. Again, we see that most of the data points (~65%) had WER < 3%.

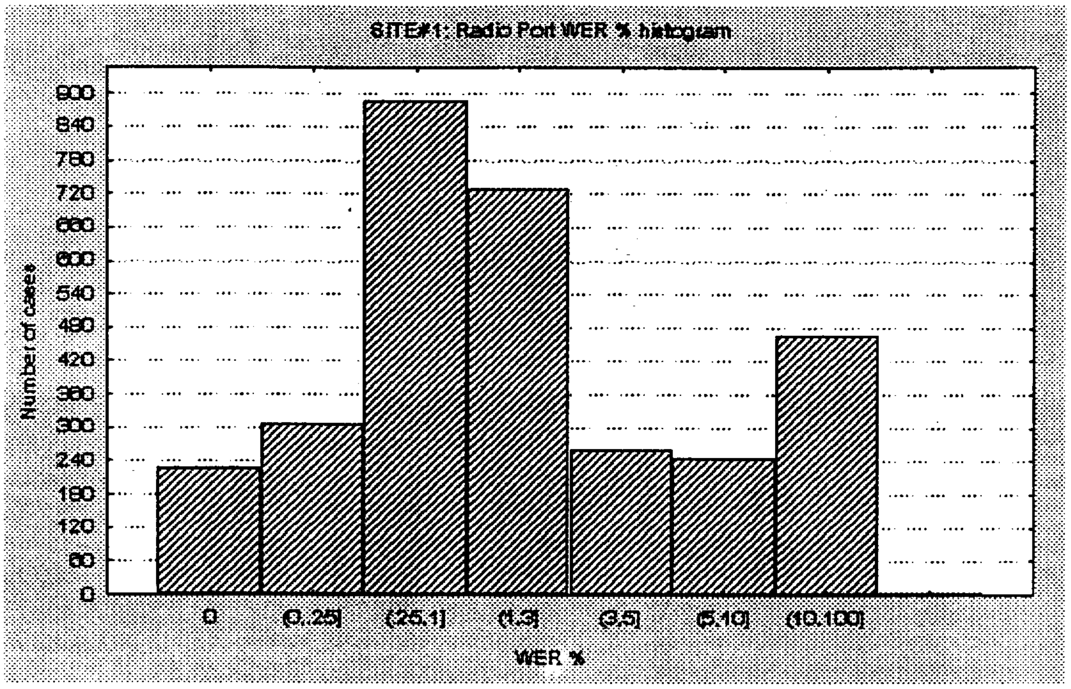

Figure 4.2.1.5. Base Station 1 WER % histogram

4.2.2 RP Site 3

Coverage plots for the RP Site 3 isolated coverage test are as follows (in Appendix A):

Map 4.2.2.1 SU Rx coverage plot (1 inch= 0.12 miles)
Map 4.2.2.2 SU average WER % coverage plot (1 inch= 0.12 miles)
Map 4.2.2.3 Uplink Rx coverage plot (1 inch= 0.12 miles)
Map 4.2.2.4 Uplink WER % coverage plot (1 inch= 0.12 miles)

RP Site 3 is indicated as a star in the center of the Maps 4.2.2.1-4.2.2.4. To obtain a rough estimate of the coverage region, we assume that downlink received signal strength of -90 dBm or higher is desired. In that case, the coverage boundaries are approximately 0.138 miles north-northwest, 0.26 miles West-Southwest, and 0.36 miles south-southwest. The RP Site 3 is located at the corner of 15th and Pearl street. As it was the case with RP Site 1, we see that the coverage data was 'shifted' for about half a block to the West-Southwest direction. This is due to the fact that the GPS accuracy was within 150 feet, which is about half a block. Due to the shadowing effect, the RSS level varies significantly along the RP Site 1 routes, crossing the -90 dBm level several times before finally dropping below -90 dBm for good. The above stated distance, however, is measured from RP Site 3 to the first area on the route where the RSS drops below -90 dBm. We note that the RP Site 3 had a greater coverage along 15th street than along Pearl street, due to the clear line of sight along 15th street.

The log distance vs. SU RSS (Downlink RSS) is shown on Figure 4.2.2.1 The data included in this figure is the overall data for this cell, excluding the points for which RSS was less than -101 dBm. Those points were excluded because -101 dBm is the threshold level for the SU receiver for normal system operation. The large variation in RSS level is mostly due to due the fact that the base station was mounted on a light pole in the middle of the street, which made shadowing more pronounced. Note that relatively strong signals (~-65 dBm) exists relatively far away from the cell (~1.37 miles). Those signals were recorded along 15th street, where the SU had a clear line of sight with RP Site 3.

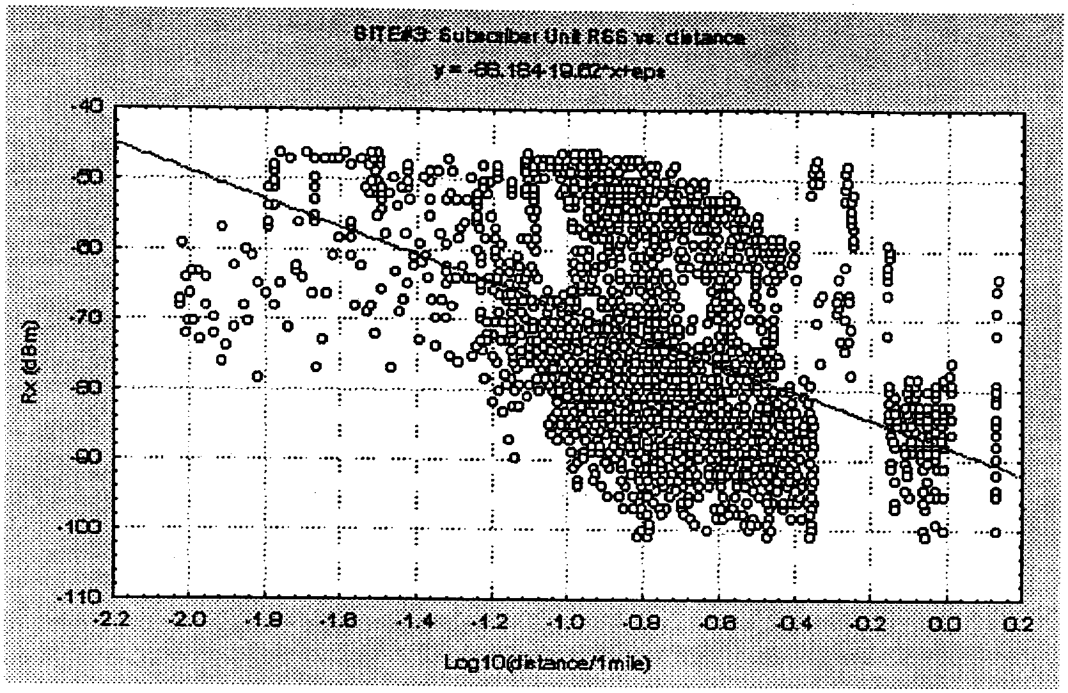

Figure 4.2.2.1. Received power versus $\log_{10}$(distance/1 mile).

Figure 4.2.2.2 shows the SU RSS histogram. Again, points at which RSS was less than -101 dBm were excluded. The mean is -74 dBm, and the standard deviation is 15.81 dB.

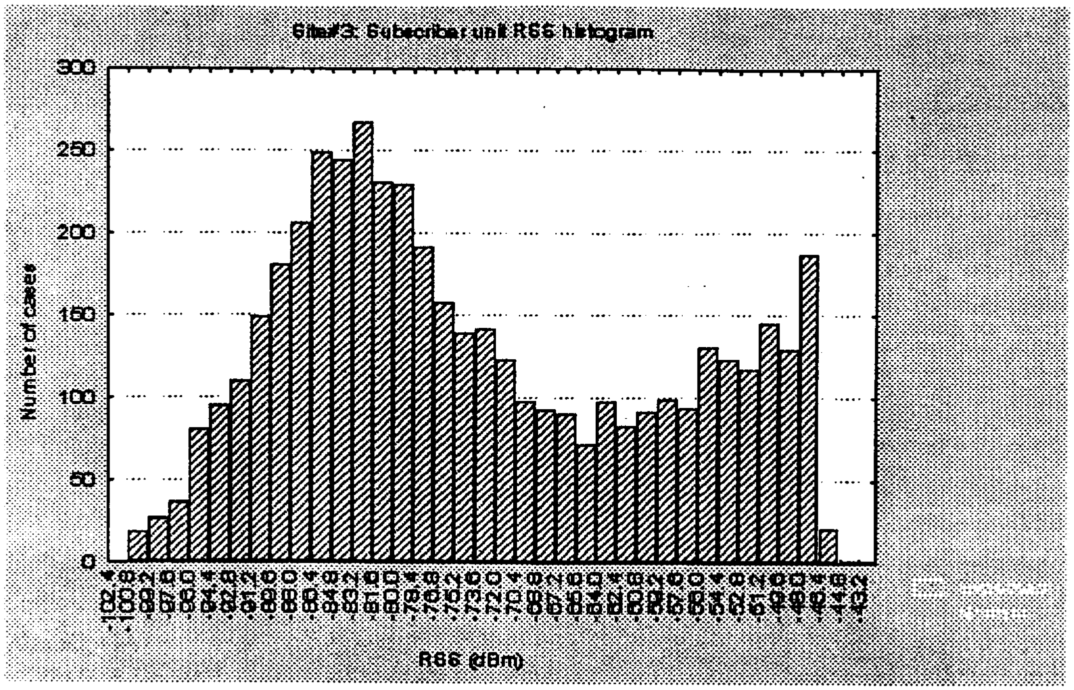

Figure 4.2.2.2. SU received power histogram .

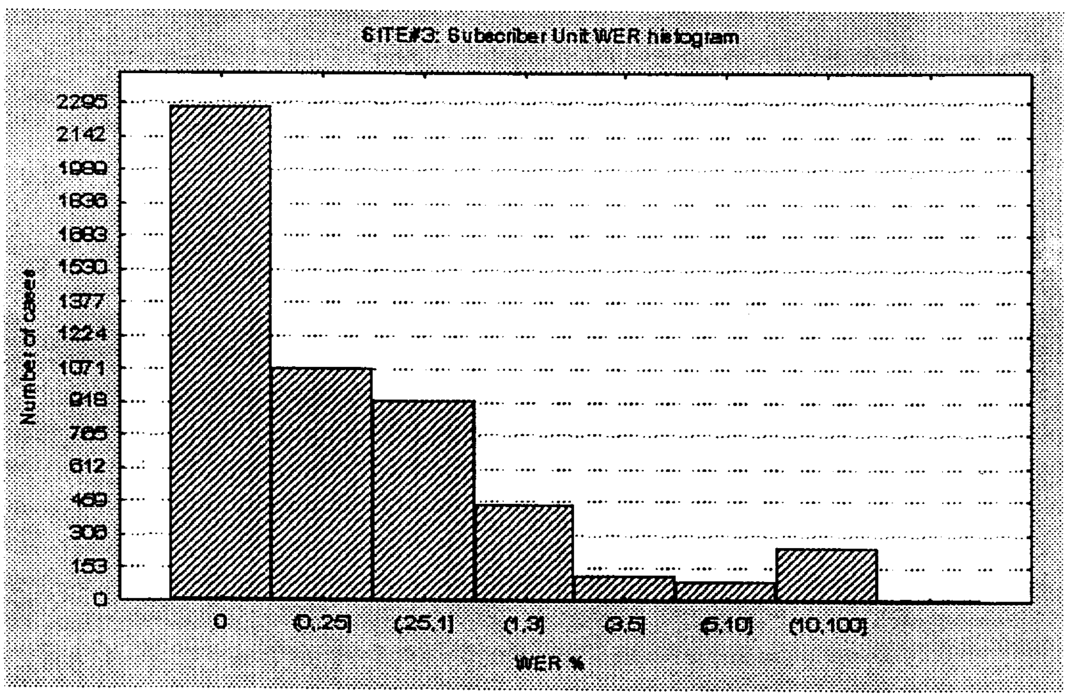

Figure 4.2.2.3. SU received WER % histogram

Figure 4.2.2.3 is an SU received WER % histogram. It is seen that most (~90 %) points have WER < 1%. This is due to the fact that WER % increases rapidly as RSS approaches threshold level (-101 dBm) at the edge of coverage area.

Figure 4.2.2.4 is Base Station 3 Rx histogram. Points that had signal level less than -118 dBm were excluded from the histogram. The mean is -86 dBm, and the standard deviation is 11.314 dB.

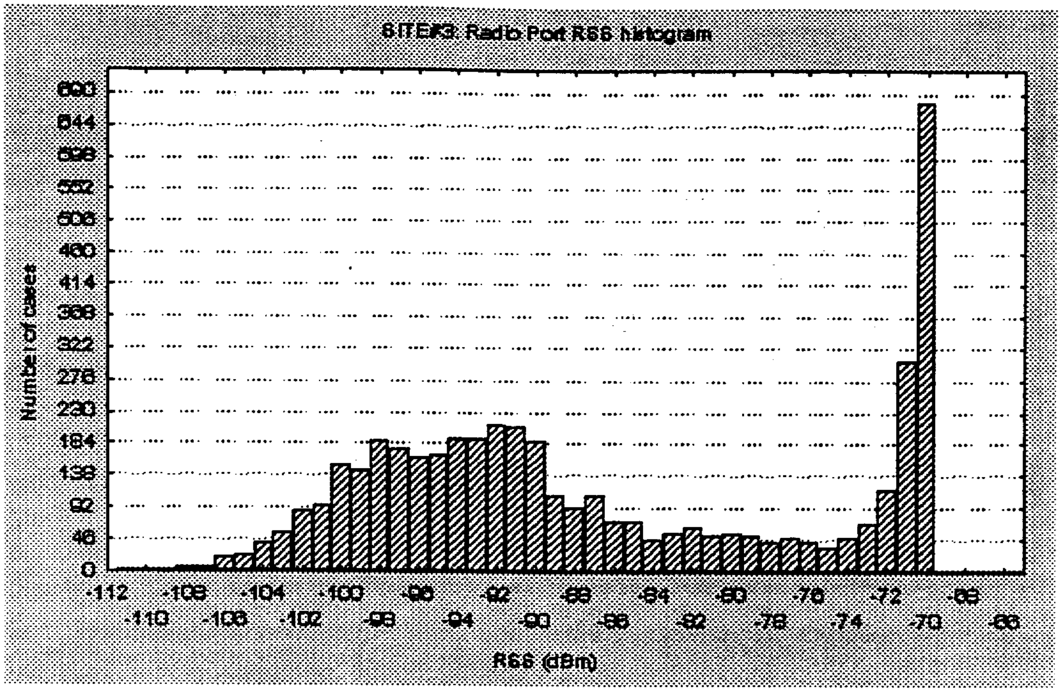

Figure 4.2.2.4. Base Station 3 received signal strength histogram

Figure 4.2.2.5 is base Station 1 WER % histogram. We see that most of the data (~70 %) points had WER < 3%.

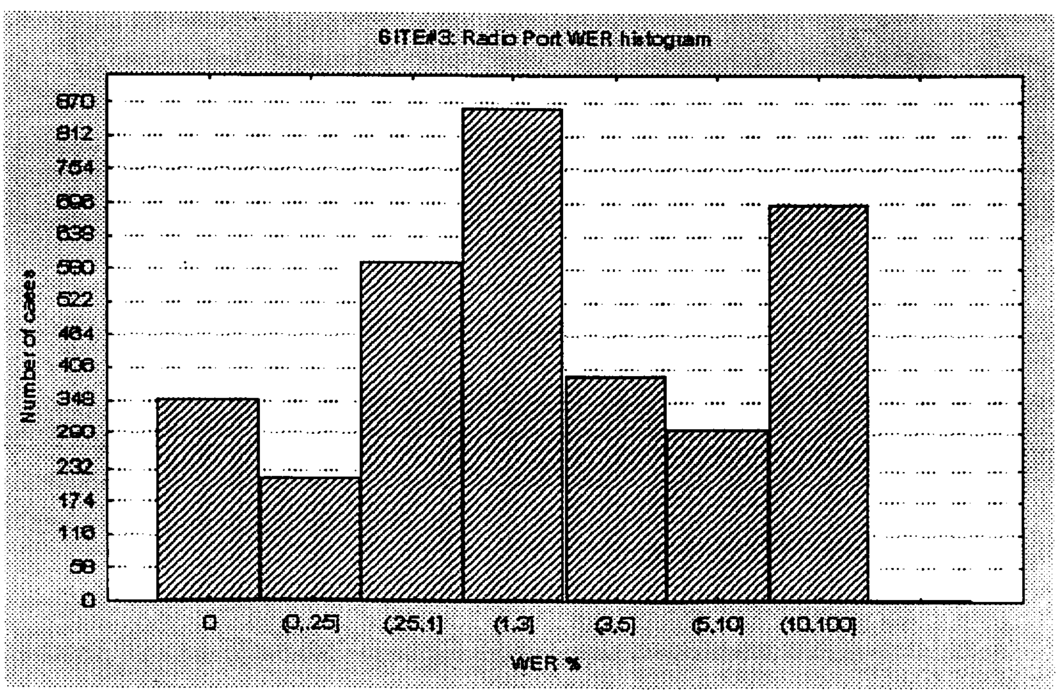

Figure 4.2.2.5. Base Station 3 WER % histogram

4.2.3 RP Site 9

Coverage plots for the RP Site 9 isolated coverage test are as follows (in Appendix A):

Map 4.2.3.1 SU Rx coverage plot (1 inch= 0.13 miles)
Map 4.2.3.2 SU average WER % coverage plot (1 inch= 0.13 miles)
Map 4.2.3.3 Uplink Rx coverage plot (1 inch= 0.13 miles)
Map 4.2.3.4 Uplink WER % coverage plot (1 inch= 0.13 miles)

RP Site 9 is indicated as a star in the center of the Maps 4.2.3.1-4.2.3.4. To obtain a rough estimate of the coverage region, we assume that downlink received signal strength of -90 dBm or higher is desired. In that case, the coverage boundaries are approximately 0.24 miles due north-northwest, 0.42 miles due West-Southwest, and 0.24 miles due West-Northwest. The RP Site 9 is located at 13th street, midway between Pine and Mapleton, in a mixed light urban/suburban environment. As it was seen from previous coverage maps, coverage data was 'shifted' for about half a block to the West-Southwest direction. This is due to the fact that the GPS accuracy was within 150 feet, which is about half a block. Due to the shadowing effect, the RSS level varies significantly along the RP Site 9 routes, crossing the -90 dBm level several times before finally dropping below -90 dBm for good. The above stated distance, however, is measured from RP Site 9 to the first area on the route where the RSS drops below -90 dBm. We note that that the RP Site 9 had a greater coverage along 13th street than along surrounding areas, due to the fact that SU was in clear line of sight on the routes along 13th street.

The log distance vs. SU RSS (Downlink RSS) is shown on Figure 4.2.3.1 The data included in this figure is the overall data for this cell, excluding the points for which RSS was less than -101 dBm. Those points were excluded because -101 dBm is the threshold level for the SU receiver for normal system operation. The large variation in RSS level is mostly due shadowing in a light urban environment, and the fact that base station was located on a lightpole, in the middle of the street. Note that relatively strong signals (~ -82 dBm) exists relatively far away from the cell (~0.45 miles). Those signals were recorded in the area that had clear line of sight with the RP Site 9.

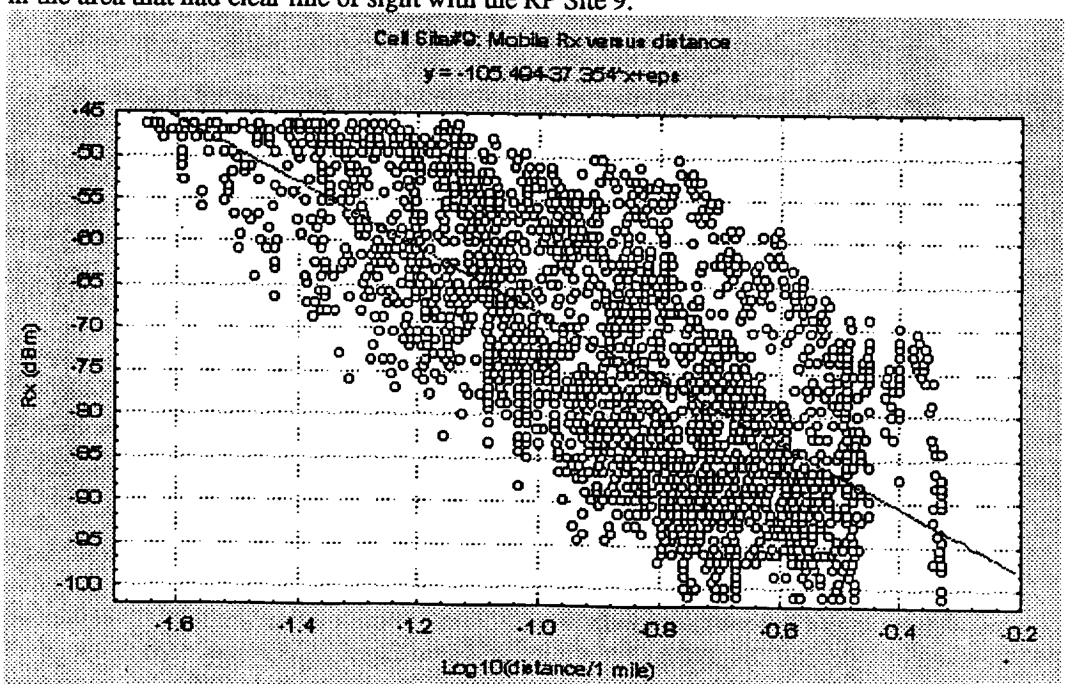

Figure 4.2.3.1. Received power versus $\log_{10}$(distance/1 mile).

Figure 4.2.3.2 shows the SU RSS histogram. Again, points at which RSS was less than -101 dBm were excluded. The mean is -73.4 dBm, and the standard deviation is 14.85 dB.

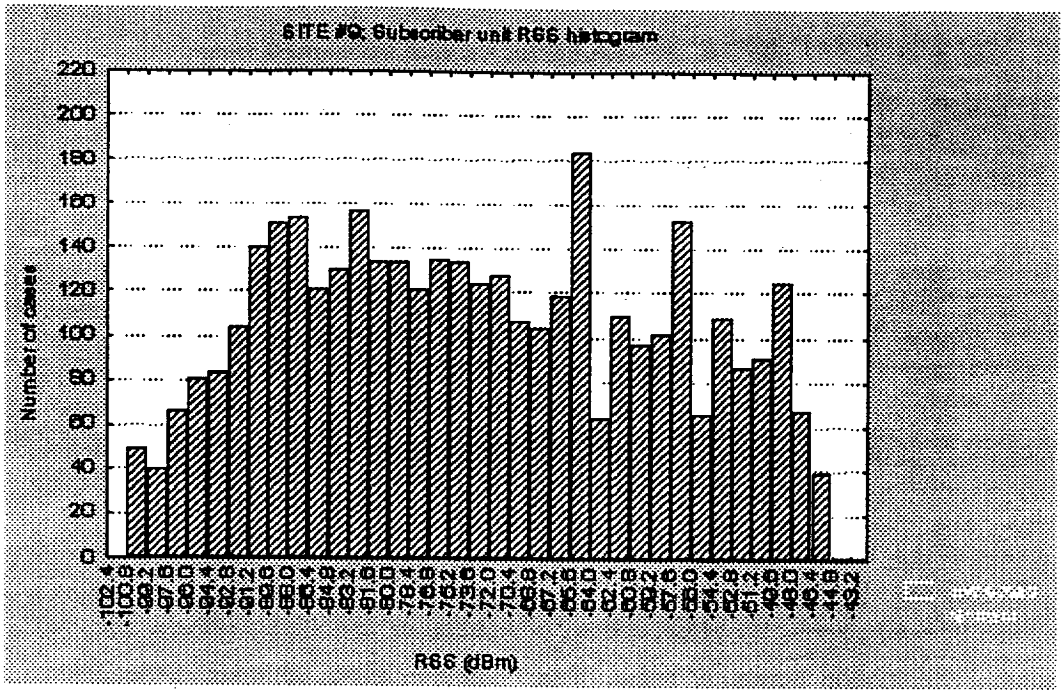

Figure 4.2.3.2. SU received power histogram .

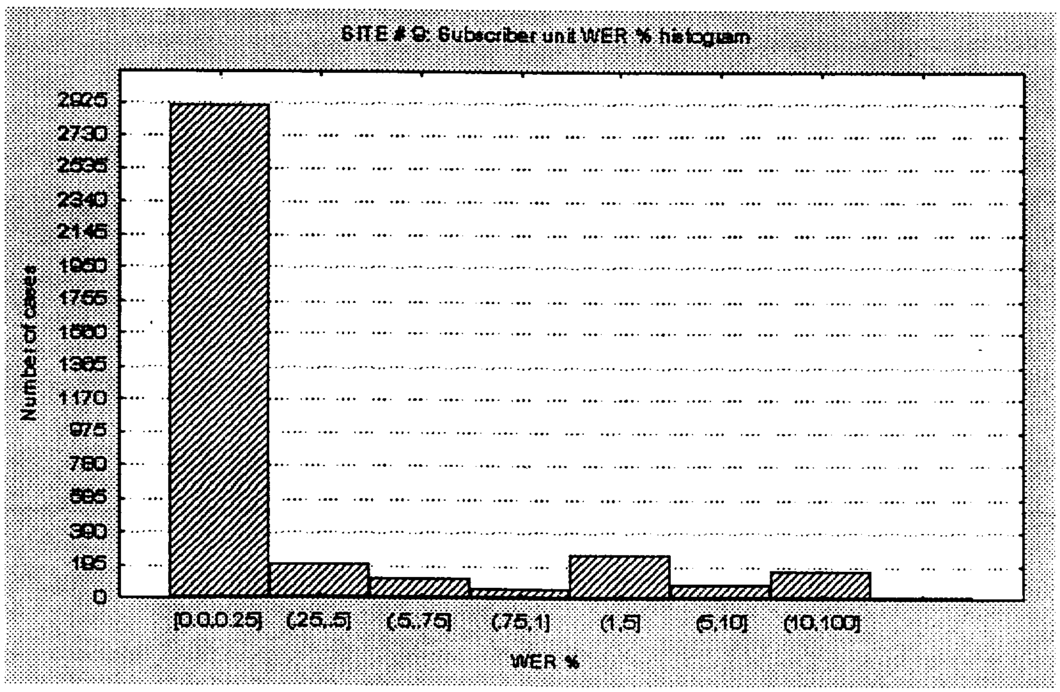

Figure 4.2.3.3. SU received WER % histogram

Figure 4.2.3.3 is an SU received WER % histogram. It is seen that most (~90 %) points have WER < 1%. This is due to the fact that WER % increases rapidly as RSS approaches threshold level (-101 dBm) at the edge of coverage area.

Figure 4.2.3.4 is Base Station 9 Rx histogram. Points that had signal level less than -118 dBm were excluded from the histogram. The mean is -91.24 dBm, and the standard deviation is 11.28 dB.

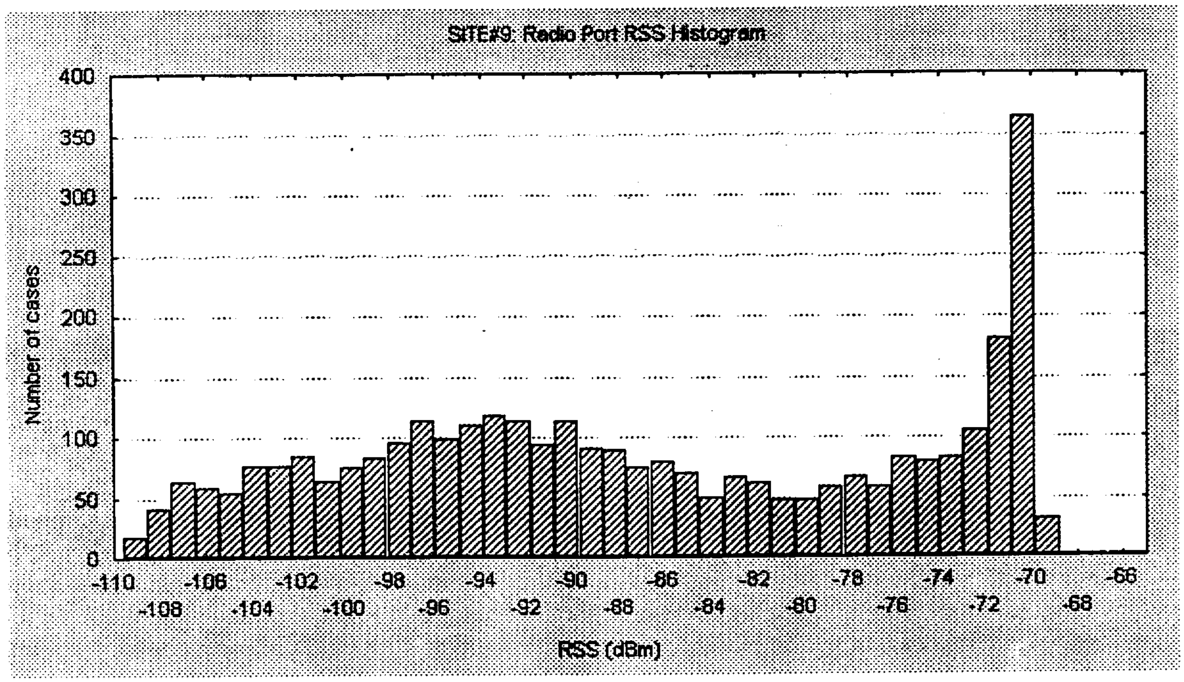

Figure 4.2.3.4. Base Station 9 received signal histogram

Figure 4.2.3.5 is base Station 9 WER % histogram. Again, we see that most of the data (~ 70%) points had WER < 3%.

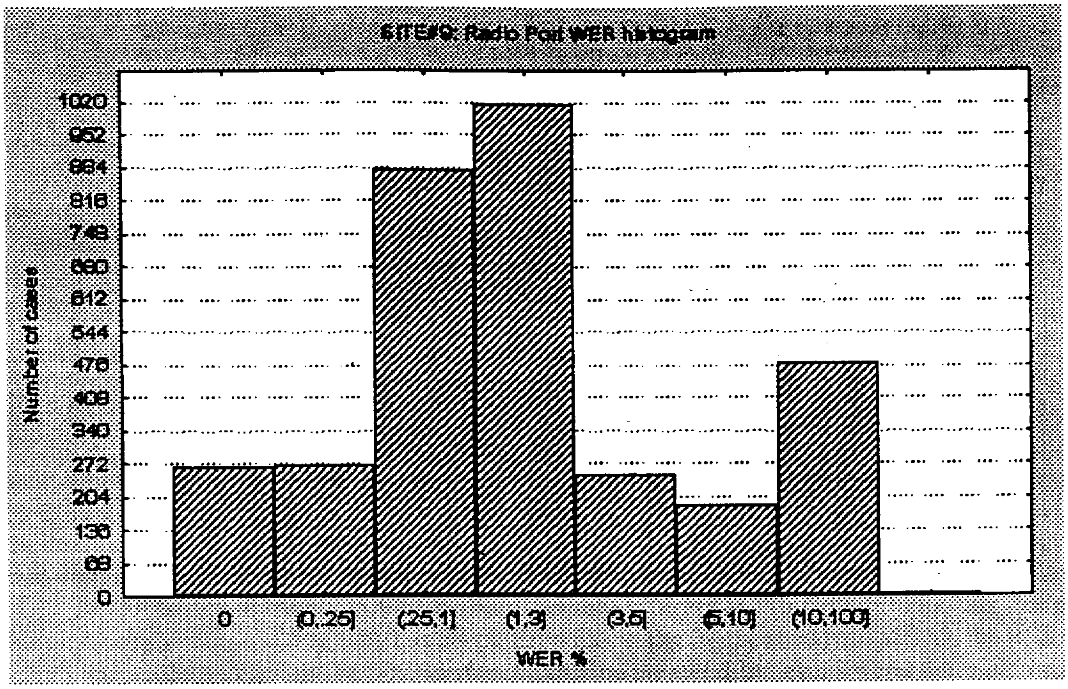

Figure 4.2.3.5. Base Station 9 WER % histogram

4.2.4 RP Site 11

Coverage plots for the RP Site 11 isolated coverage test are as follows (in Appendix A):

Map 4.2.4.1 SU Rx coverage plot (1 inch= 0.1 miles)
Map 4.2.4.2 SU average WER % coverage plot (1 inch= 0.1 miles)
Map 4.2.4.3 Uplink Rx coverage plot (1 inch= 0.1 miles)
Map 4.2.4.4 Uplink WER % coverage plot (1 inch= 0.1 miles)

RP Site 11 is indicated as a star in the center of the Maps 4.2.4.1-4.2.4.4. To obtain a rough estimate of the coverage region, we assume that downlink received signal strength of -90 dBm or higher is desired. In that case, the coverage boundaries are approximately 0.35 miles West-Southwest, 0.275 miles East-Northeast, and 0.475 miles south-southeast. The RP Site 11 is located at 16th street, midway between Pine and Mapleton, in a suburban environment. As it was seen from previous coverage maps, coverage data was 'shifted' for about half a block to the West-Southwest direction. This is due to the fact that the GPS accuracy was within 150 feet, which is about half a block. Due to the shadowing effect, the RSS level varies significantly along the RP Site 11 routes, crossing the -90 dBm level several times before finally dropping below -90 dBm for good. The above stated distance, however, is measured from RP Site 11 to the first area on the route where the RSS drops below -90 dBm. We note that that the RP Site 11 had a greater coverage along 16th street than along surrounding areas, due to the fact that SU was in clear line of sight on the routes along 16th street. There is a hill immediately North to the RP Site 11 that obstructed the coverage in that direction, so very few data was collected there.

The log distance vs. SU RSS (Downlink RSS) is shown on Figure 4.2.4.1 The data included in this figure is the overall data for this cell, excluding the points for which RSS was less than -101 dBm. Those points were excluded because -101 dBm is the threshold level for the SU receiver for normal system operation. The large variation in RSS level is mostly due to shadowing in a light urban environment.

Note that relatively strong signals (~ - 80 dBm) exists far away from the cell (~0.46 miles). Those signals were recorded in the area that had clear line of sight with the RP Site 11.

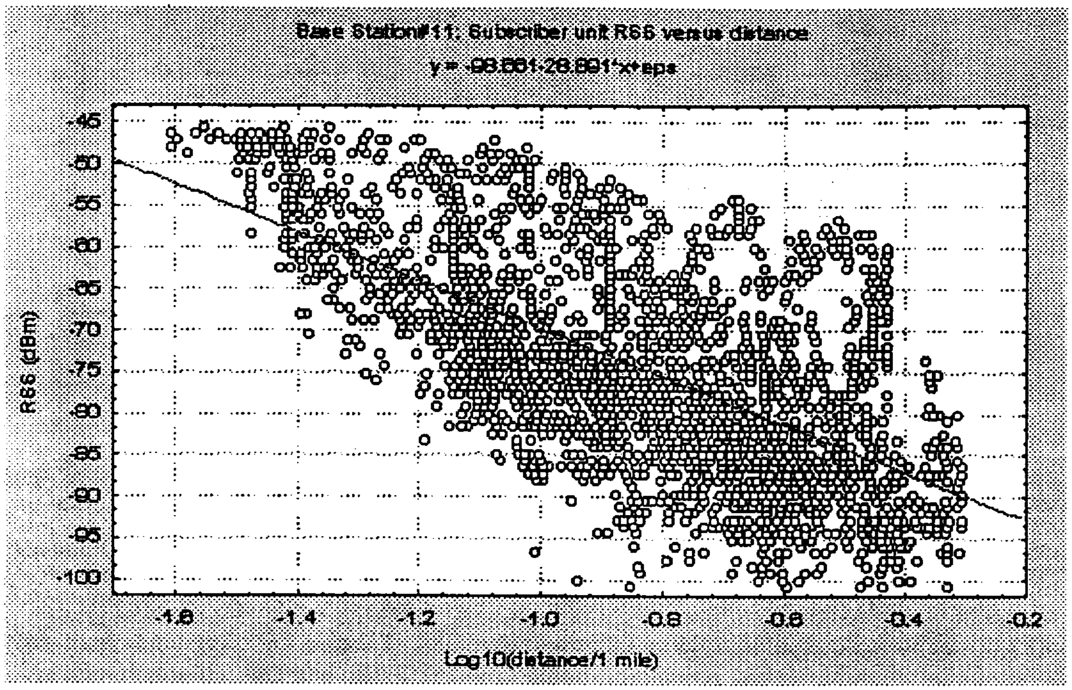

Figure 4.2.4.1. Received power versus $\log_{10}$(distance/1 mile).

Figure 4.2.4.2 shows the SU RSS histogram. Points at which RSS was less than -101 dBm were excluded. The mean is -74.14 dBm, and the standard deviation is 13.28 dB.

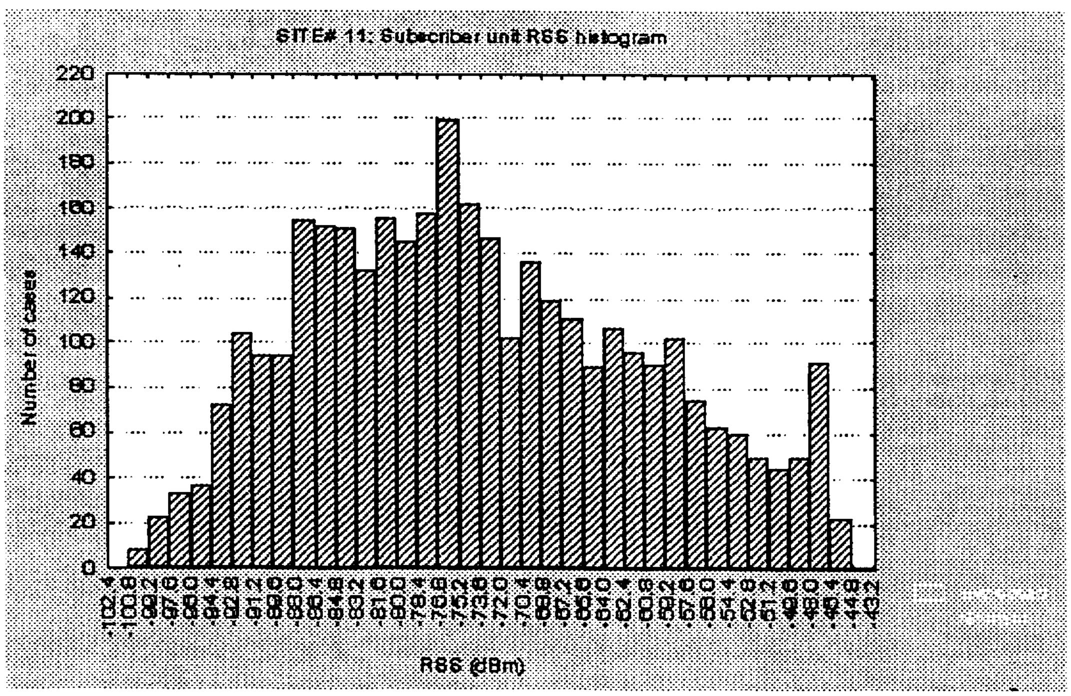

Figure 4.2.4.2. SU received power histogram .

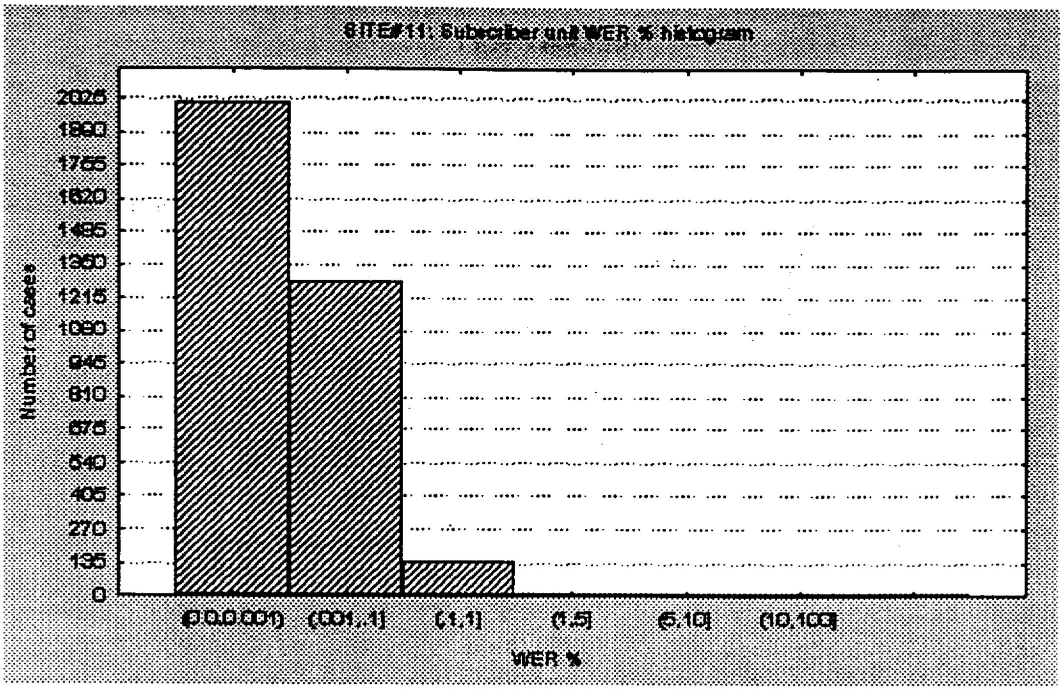

Figure 4.2.4.3. SU received WER % histogram

Figure 4.2.4.3 is an SU received WER % histogram. It is seen that most (~90 %) points have WER = 0%. This is due to the fact that WER % increases rapidly as RSS approaches threshold level (-101 dBm) at the edge of coverage area.

Figure 4.2.4.4 is RP Site 11 Rx histogram. Points that had signal level less than -118 dBm were excluded from the histogram. The mean is -88.79 dBm, and the standard deviation is 11.95 dB.

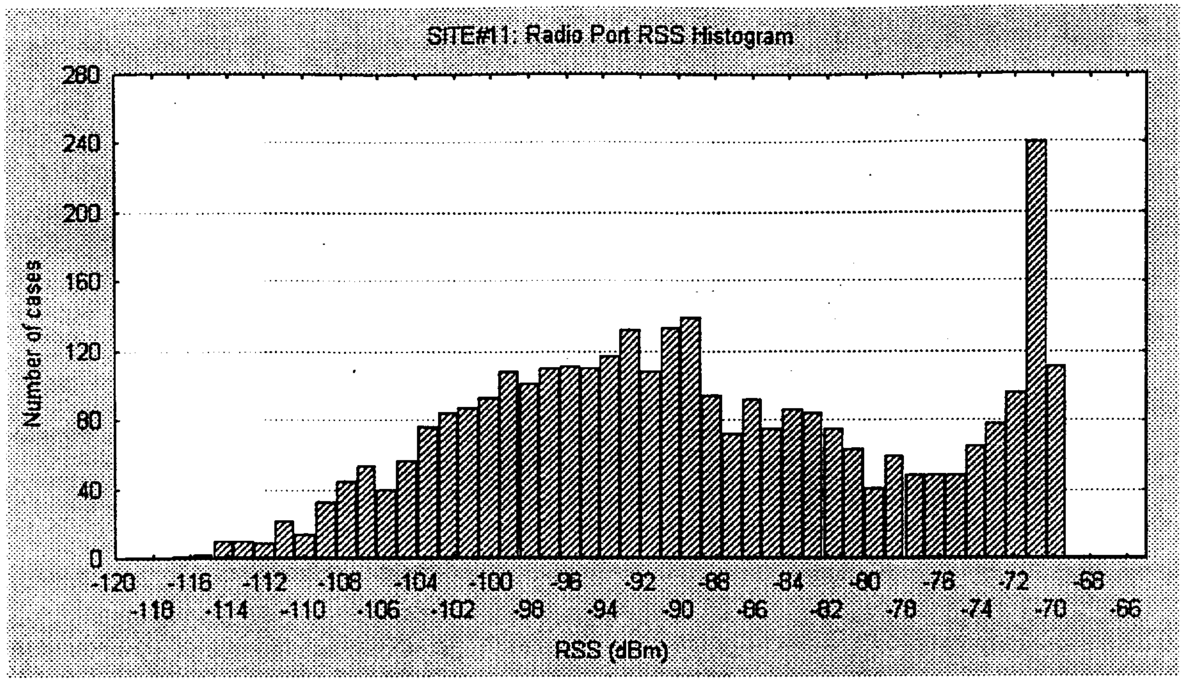

Figure 4.2.4.4. Base Station 11 received signal histogram

Figure 4.2.4.5 is base Station 11 WER % histogram. We see that most of the data (~ 55%) points had WER < 5%.

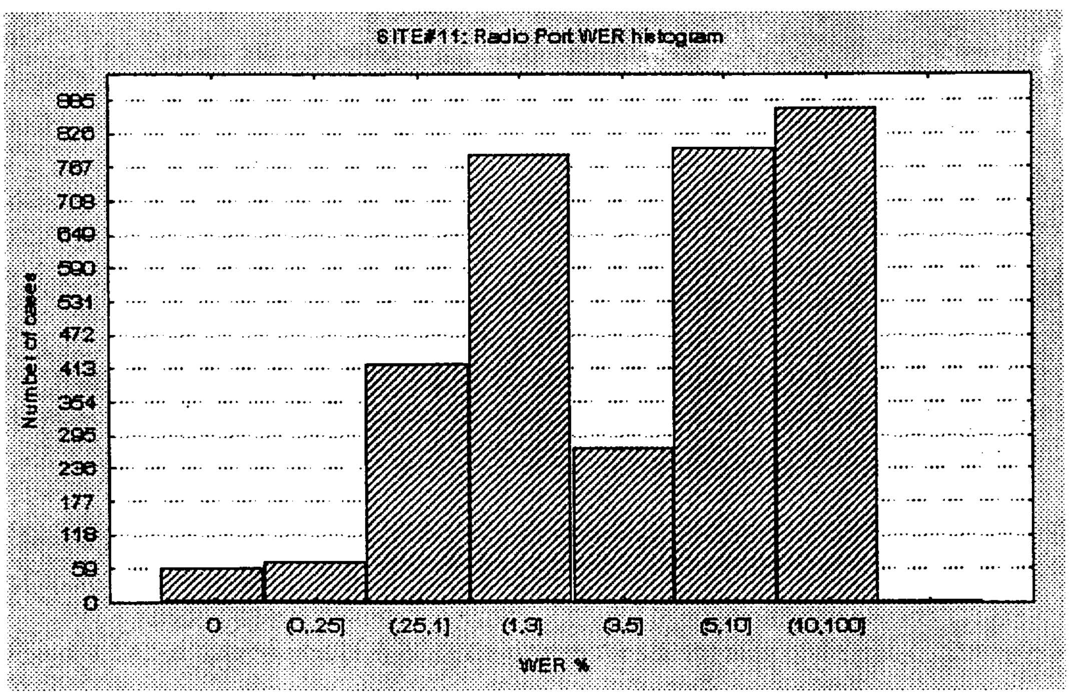

Figure 4.2.4.5. Base Station 11 WER % histogram

4.3 Link balance analysis

4.3.1 Methodology

The purpose of link balance analysis was to determine if the uplink and downlink were balanced, and if not, which link was weaker. The presence of severe imbalance may contribute to a higher WER % at a weaker link, and thus limit a coverage in a cell.

For this analysis, the data for RP Site 1, 3, 9 and 11 was combined into a single file. The uplink and downlink data had already been collocated using GPS data as a key, which ensured that the analysis was fair. The first analysis was to plot separate diagrams of uplink and downlink WER % versus Receive Signal Strength. Both uplink and downlink RSS values were rounded to an integer value. For a particular uplink RSS value (for example, -98 dBm), all uplink WER % were averaged, to get (in this example) uplink WER of 8%. The same procedure was repeated for all available uplink RSS values greater than -118 dBm. The final result is represented at Figure 4.3.1.1.

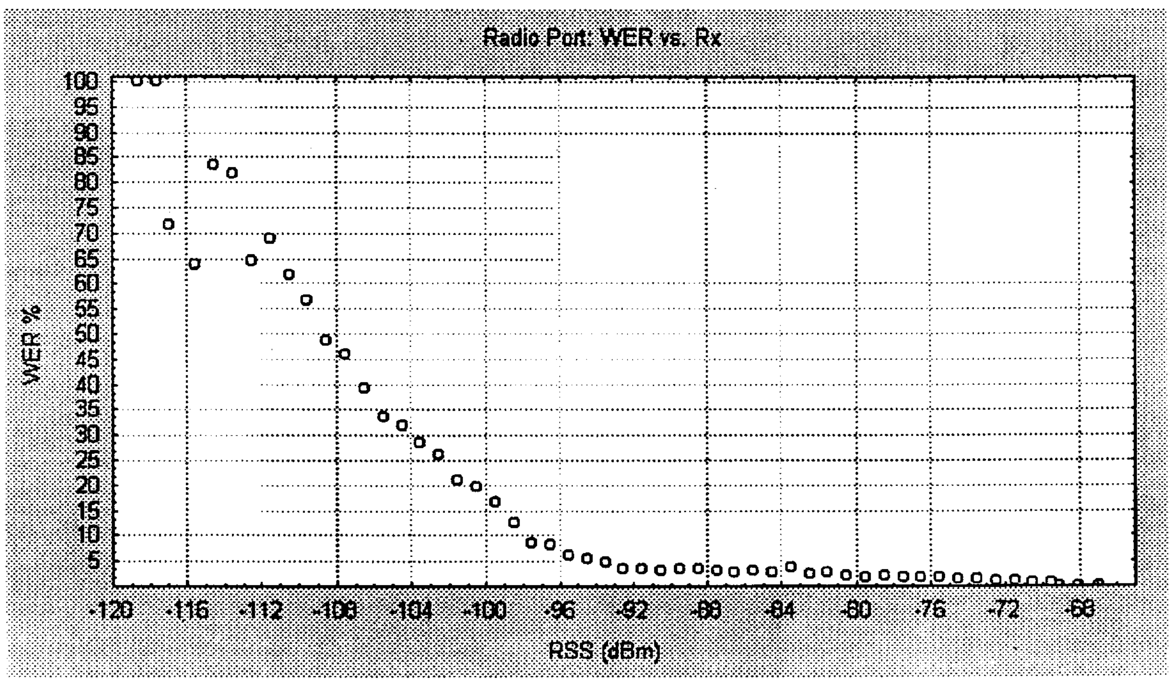

Figure 4.3.1.1. Uplink WER % versus Rx (dBm)

The methodology described in the previous paragraph used to calculate the uplink WER vs Rx diagram was used to determine downlink WER vs. Rx. The result is shown on Figure 4.3.1.2.

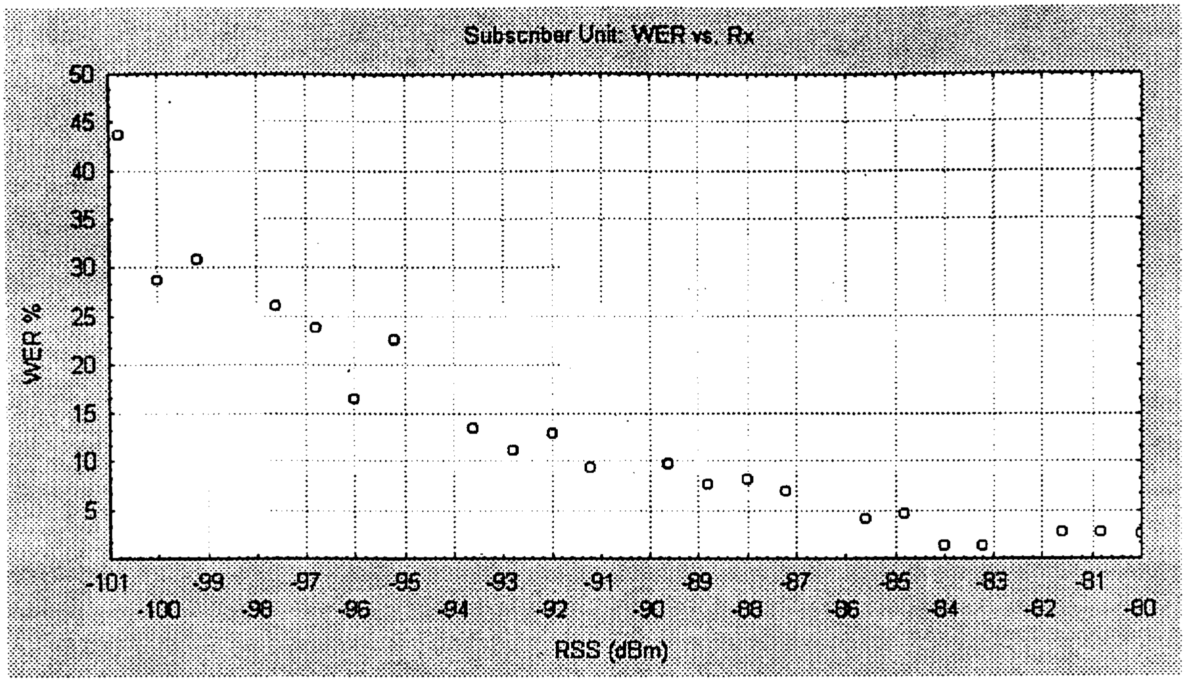

Figure 4.3.1.2. Downlink WER % versus Rx (dBm)

Comparison of figures 4.3.1.1 and 4.3.1.2 show that for the same recorded uplink and downlink WER % (for example, 10%) we have different Receive Signal Strength levels; -98 dBm for uplink (Base Station) and -91 dBm for downlink (SU). To determine the difference between uplink and downlink RSS levels quantitatively, we take a difference in uplink and downlink RSS readings for each data point, and plot their histogram. Histogram of the difference, $RSS_{downlink}$- RSS_{uplink} is shown on figure 4.3.1.3. The link difference has a mean of 14.46 dB and a standard deviation of 5.6 dB.

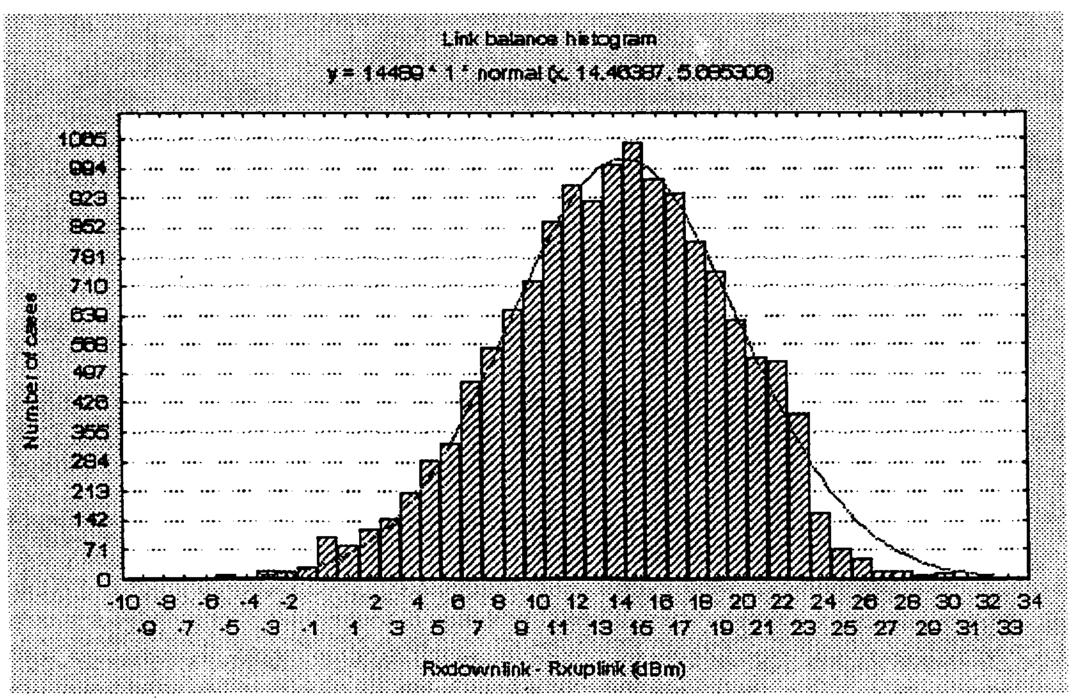

Figure 4.3.1.3. SU Rx-Base station difference Rx histogram

Based on figures 4.3.1.1 - 4.3.1.3 we can determine if the system was uplink or downlink limited. As an example, let us take a certain Rx power level on the downlink, Rxdownlink = -92 dBm. From figure 4.3.1.2 we see that the corresponding WER reading is WERdownlink = 13%. To find the Rx-WER pair on the uplink that corresponds to the chosen point on the downlink, we have to take into account figure 4.3.1.3. According to figure 4.3.1.3, Rxuplink = Rxdownlink - 14.46 dB; therefore for Rxdownlink = -92 dBm, we have Rxuplink = -106.5 dBm. From figure 4.3.1.1, we see that for Rxuplink = -106.5 dBm, we get WERuplink = 39%. It is clear that for this particular Rx power level reading, WERuplink is greater than the WERdownlink. If we repeat this analysis for any other Rx power level reading on figure 4.3.1.2, we get the same result; WERuplink is consistently higher than the WERdownlink. Therefore, the system is uplink limited.

5. HAND-OFF TESTING

The purpose of hand-off testing was to determine the hand-off operational functionality. PACS technology was design to support low speed (up to 35 miles) hand-off. As per JTC requirements, low speed handoff testing was conducted in downtown Boulder at pedestrian speed, using the same setup as described in 4.1. In addition to low speed hand-off testing, high speed handoff testing was done as optional test, upon request of TAG 3 members. High speed hand-off was conducted in South Boulder, using different low tier cell sites, and undertaking several runs with speed ranging from 10 to 60 mph.

5.1 Low speed handoff

5.1.1 Testing Methodology

The routes were chosen in downtown Boulder, at pedestrian speed. The same RP sites that were used for coverage testing were used for low speed handoff runs. Handoff was allowed between RP sites. The routes were chosen to maximize the number of handoffs between RP Sites. Typically, a call was initiated within a block of a RP site, and the SU cart was then pushed along the sidewalk of a street toward a particular base station. A run was considered completed when SU went out of coverage and dropped a call. Although a typical run consisted of only one handoff between two base stations, some runs had multiple handoffs from more than 2 base station, due to the choice of a particular route, RP sites configuration, and propagation environment.

The uplink handoff data was collected while recording Harvard sample voice quality sentences on the uplink. Similarly, the downlink handoff data was collected while recording Harvard sentences on the downlink. Uplink and downlink recordings were done at the same time. Voice test results during handoff are given in section 7.

5.1.2 Low speed handoff testing results

The 3 handoff parameters tracked are:

- The difference between RSS before and after handoff (RSSnew-RSSold)
- The difference between WER before and after handoff (WERnew-WERold)
- The time elapsed between two successive handoffs (Hold time, or Dwell time)

There were a total of 30 handoffs recorded during 14 runs. The results are summarized in the Table 5.1.2.1 All values were calculated based on readings immediately before and after individual handoff occurred (one second difference)

Handoff No.	Rxnew-Rxold (dBm)	WERold-WERnew (%)	Hold time (sec)
1	2	2	80
2	0	2	140
3	0	0	39
4	0	0	14
5	0	0	38

5	0	0	28
6	-2	0	77
7	0	0	56
8	0	0	36
9	0	3.75	81
10	5	0.25	150
11	0	4	87
12	0	0	37
13	2	-0.25	47
14	-2	2	75
15	19	2.5	53
16	0	0	13
17	-2	-1.25	46
18	0	1.25	68
19	14	1.75	56
20	5	0	116
21	4	6.75	40
22	0	0	52
23	0	0	80
24	0	0	51
25	0	0	88
26	1	0.25	50
27	0	0	42
28	0	0	38
29	0	0	26
30	0	0	28

Table 5.1.2.1 Handoff parameters statistics

From Table 5.1.2.1, it can be seen that the minimum holding time was 13 seconds. This implies that there was no 'ping-pong' effect during the handoff. Out of 30 handoffs, 11 had no changes in RSS <u>and</u> WER readings before and after handoff. This is unusual, since handoff is initiated when either RSS or WER deteriorate significantly with respect to neighboring RP site RSS or WER readings. There was one instance when both RSS <u>and</u> WER had worse readings after the handoff than before the handoff. For all other cases (18 out of 30), either RSS or WER (or both) improved after a handoff.

5.2 High Speed handoff

High speed handoff testing was not a part of original JTC test requirements for a low tier technology, but was done as an optional test, by the request of, and with approval of TAG 3. The purpose of high speed testing was to determine handoff functionality for speed greater than 35 mph.

5.2.1 Methodology

High speed handoff was recorded at speeds of 20,30,40,50 and 60 miles per hour, along Broadway, near the Table Mesa shopping center. There were 3 RP sites involved in the high speed testing, and they were labeled RP Site 17, 18 and 19. For these tests the output power of the RPs was 0.8 watts (29 dBm) feeding into a 9 dBi shaped pattern antenna, giving an EIRP of 38 dBm (6.3 W). An SU was placed inside the test van, while SU antenna and GPS were mounted on top of the vehicle roof. There were 2 runs completed for each speed; northbound and southbound. The calls were initiated close to the first cell (RP Site 17 for southbound runs, RP Site 19 for northbound), and the vehicle would then drive away along Broadway, trying to keep the speed constant. Both uplink and downlink data were collected for each run.

5.2.2 High speed handoff testing results

Maps 5.2.2.1 and 5.2.2.2 show the high speed handoff mapping by RP site numbers, for vehicle speed of 40 and 60 miles per hour, respectively. On those plots, the run route to the left of Broadway is southbound run, and the one to the right is northbound run. We see that the handoff hysteresis is less pronounced for 40 mph runs than for 60 mph runs. It should be pointed out that special consideration would be needed in the cell layout plan to support up to 60 mph handoff, while not necessarily needed to support up to 35-40 mph. We confirm this assertion by pointing out that the RP site coverage for both runs was roughly centered around the cell that the call was registered to, as seen, for example, for RP Site 19 from Map 5.2.2.1. However, for 60 mph case, RP site coverage is shifted toward the position of incoming vehicle, as shown on Map 5.2.2.2. Therefore, we conclude that the speed higher than 40 mph indeed affect coverage, and cause the coverage to change its pattern .

6. INTERFERENCE TESTING

Interference testing consisted of co-channel and adjacent channel interference measurements. All measurements were conducted at Walnut CO, in a semi-lab environment. RP Site 3 was used as a server. SU was stationary on the 3rd floor of Walnut CO. Anritsu Signal Generator, was in the same room as an SU , and served as interferor. The setup was not ideal, because the indoor measurement reduced the shadowing. However, outdoor measurement was not possible, for two reasons. First, the SU s did not have the capability of displaying neighboring list channels, so no data about the interferor was available from a single SU. Second, when we used 2 SUs to track server and interferor independently, we were not able to hold a call on either of them in the areas where interference was pronounced. Therefore, the setup we finally came up with was optimum, under given circumstances.

6.1 Testing methodology

For both co-channel and adjacent interference, RP Site 3 was acting as a server. Interferor (Anritsu Signal Generator MG 3670B) was placed in a room at the 3rd floor of Walnut CO.

The SU under test was placed in the same room as interferor. Interferor and SU were connected to a PC, where signal and Word Error Rate were reported. Interference power level was measured on Anritsu Transmission tester MS 8604A. Because in this test both the base station and SU were stationary, the signal level at the SU was time constant. Interference level, however, were changed by adjusting the power level of the Signal Generator. The change in interference level while keeping server signal constant, corresponds to changing signal to interference ratio (C/I). The goal was to generate a table of different C/I readings versus WER readings reported by SU. As explained before, these measurements differ from the outdoors measurements, because we encounter less lognormal shadowing, but they do give an insight on how C/I affects WER.

For co-channel interference measurements, both server and interferer were tuned to channel 515 (1971.5 MHz uplink). Signal level measured from RP Site 3 at the SU was -63 dBm. Interference level was changed manually, by adjusting the power output on the Signal Generator. Starting from -93 dBm (measured at SU), interference level was being increased, until the WER started showing non-zero values. Because the whole process was semi-manual, and because number of errored frames increases rapidly past certain C/I threshold, we were only able to capture a C/I threshold, without being able to produce a whole table of C/I versus WER.

Similarly, for adjacent channel interference, we captured only C/A threshold. Server was tuned to Channel 515, while interferer was at Channel 517 (1971.8 MHz uplink). Signal level at an SU was -63 dBm, while initial interferor power level was -78 dBm. Interferor level was increased, until non-zero WER values were reached.

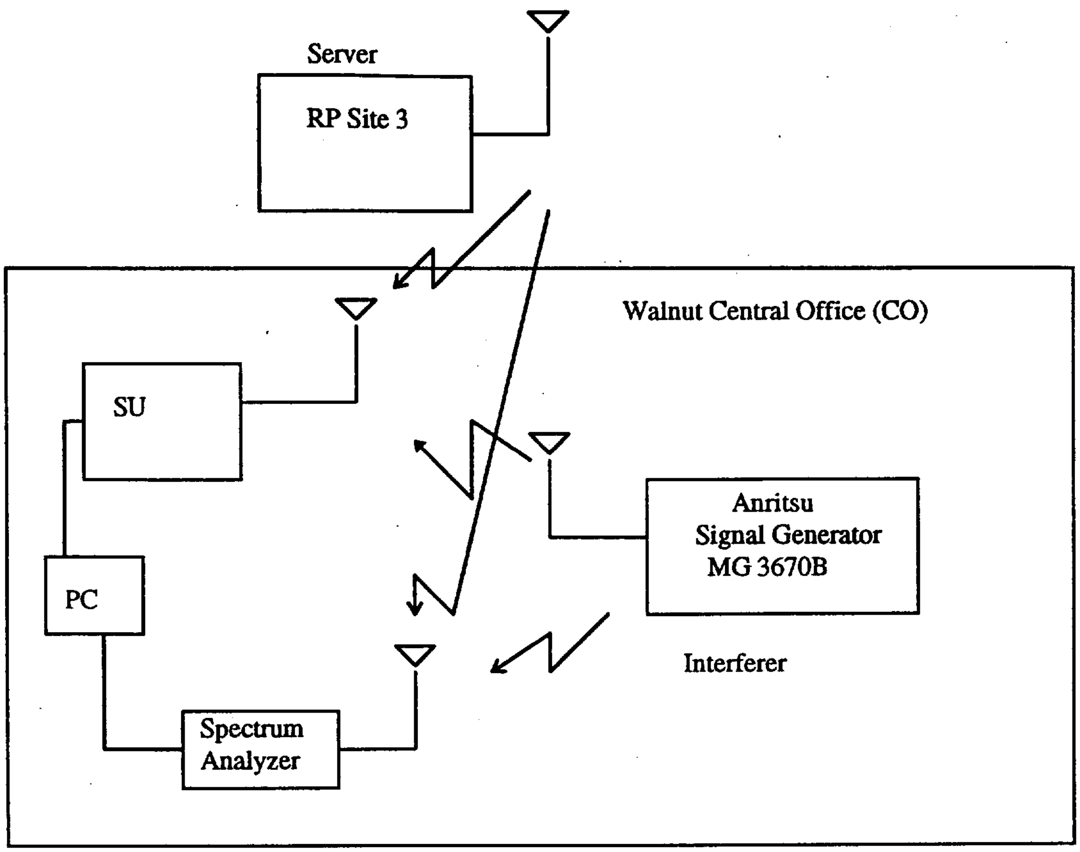

Figure 6.1.1: Interference measurement setup

6.2 Interference results

The threshold level for C/I (co-channel interference) was measured to be 9 dB. That means that for C/I > 9 dB, WER=0. When C/I < 9 dB, WER > 0.

The threshold level for C/A (adjacent channel interference) was measured to be -17 dB. In other words, for C/A > -17 dB, WER=0. For C/A < -17 dB, WER > 0.

Quantitative description of interference results was not possible, as explained in the previous section.

7. Voice Quality

7.1 Data Collection Methodology

7.1.1 Test Stimuli

Prerecorded Harvard test sentences on digital audio tapes (DATs) were used in the voice quality tests. The source tapes were recorded and provided by USWAT and were the same tapes used in previous TAG tests. They consisted of ten Harvard sentences, which are phonetically balanced and include all sounds in the American English language. The digitally recorded sentences were 75-80 seconds in length. DAT recorders were electrically connected to the Subscriber Unit (SU) and landline phones. A call was established between the SU and landline phones and the test sentences were transmitted over the radio link in either the uplink or downlink direction. Voice samples of transmitted sentences were recorded onto DATs. For the quasi-stationary test, one set of Harvard sentences were played for each run: ten sentences spoken by a male, and 10 sentences spoken by a female.

7.1.2 Test Conditions - Quasi-Stationary Test

Quasi-stationary tests were conducted at points 100 meters (≅ one block) apart. The measurements were consistent with measurements taken during previous low-tier testing at BITB. A total of 120 measurements (on the forward and reverse links) were collected at 60 different grid points.
Voice recordings were taken for the same duration (sample time) at all locations. The recordings were taken as a member of the testing staff walked continuously, while pushing a cart in which the SU and DAT recorder were located, in a 10 meter circle over the sample time. The measurement locations were recorded with a GPS. For each location, both uplink and downlink voice recordings were taken at the same time. Engineering data, including received signal strength (RSS) and Word Error Rate (WER), were also collected at the same time at each location.
Later, the taped voice samples were digitized into a Macintosh SoundEdit 16 application at a rate of 16 bits, 22 kHz. All data were stored in a 1.2 Gbyte hard drive. For MOS testing, the first sentence of the male speaker and the last sentence of the female speaker of each recorded sample were dropped to avoid the possible inclusion of sentences that had been cut short due to the starting of a recording too late or the stopping of a recording too soon. Therefore, during MOS testing, a total of 18 sentences (out of the original 20 sentences) were presented to listeners for each sample. Voice quality of the quasi-stationary samples was assessed using both the MOS and expert listener methodologies, described below.

7.1.3 Engineering Data

During each quasi-stationary run, the following engineering data were collected and recorded every second: Word Error Rate, Received Signal Strength (in dBm), and Transmit Power. The following information was also collected each second: GPS time, latitude and longitude. Additionally, notes describing the physical location of each quasi-stationary point were taken during the run.
For the voice quality data analysis, average WER and RSS were assessed. To do so, word error rate was averaged over the length of a given voice sample. For RSS, dBm's per second were converted to mW using the following formula: dBm = 10 * log (x mW/1mW). The resultant powers were then averaged over the length of a voice sample, then converted back into dBm's.

7.2 Voice Quality Assessment Methodology

7.2.1 MOS Methodology

7.2.1.1 Subjects

Thirty-six subjects were recruited from the Boulder area to participate. One to two extra subjects were scheduled per day in case there were any that did not show. Three of the 4 days include data from 8 subjects, and the fourth day includes data from 7 subjects. Subjects were run in groups of three, four, or five at a time, for a total of eight groups. Every listener within a group listened to the same samples. A total of four sets of unique voice stimuli were used, with two groups listening to each set of stimuli. Each of the following age ranges were represented within the subject pool: 18-25 yrs, 25-35 yrs, 35-45 yrs, 45-55 yrs, and over 55 yrs. Subjects consisted of 14 males and 17 females. Subjects were cordless but non-cellular telephone users. Subjects were paid $35.00 for their participation, or subjects deferred receipt of payment to the organization from which they were recruited. When 9 subjects were run on a given day, one subject was dropped from the data set. The decision to disclude a given subject was based on demographics, so that the optimal number of subjects in each age range and gender were maintained.

7.2.1.2 Schedule and Resources

Testing occurred between November 27, 1995 and November 29, 1995 at the U S WEST Advanced Technologies Human Factors lab in Boulder, CO. Each testing session lasted approximately two hours. Jaye Matthews was the experimenter. Two or three testing sessions were conducted per day.

7.2.1.3 Methodology

Subjects first filled out a consent form and a demographic survey. The experimenter then read procedural instructions to them (see Appendix 7.A). After instructions were read by the experimenter participants were shown how to use the computer and mouse (if necessary). For training, subjects were presented with ten practice samples of voice segments and given a chance to rate them (see Appendix 7.B). The practice samples included one 64 kbps wireline sample, 2 samples collected from the field (one with an expert listener rating of 3, and one with an expert listener rating of 1), and 7 MNRU (Modulated Noise Reference Unit) samples. The MNRU samples were used at the request of the TAG 3 vendors. MNRUs have been used in subjective tests as a reference condition with impairment that sounds similar to the impairment in the coders being tested. The impairment produced by the MNRU is denoted as Q and is defined as the ratio in dB of speech power to speech correlated noise power. For the TAG 3 Listener Panels, MNRUs were produced by artificially adding Gaussian (white) noise of varying ratios of Signal to Noise (SNR) to the 64kb Harvard sentence samples. MNRU samples played during training were at the following dB levels: 5dB, 10dB, 15dB, 20dB, 25dB, 30dB, 40dB.

Once training was complete, each subject provided an Opinion Score for 33 voice segments. Thirty segments were field test samples; the remaining three were one 64 kbps wireline, one good (expert listener rated 3) field sample and one poor (expert listener rated 1) field sample. For each group of listeners, a total of 43 samples were rated. The order of presentation of each voice segment (presented after training) was randomized. Each segment consisted of 18 Harvard sentences. Nine sentences were spoken by a male and, nine were spoken by a female. The order of presentation of male or female sentences first was also randomized.

Subjects answered the following questions after each segment using the computer: 1) How would you rate the overall QUALITY of the sound? (on a 5-point scale: Excellent, Good, Fair, Poor, Bad) ; 2) How annoying are any ADDITIONAL sounds you may hear? (on a 5-point scale, from Not at All Annoying to

Extremely Annoying); and 3) Would this be ACCEPTABLE as portable service (Yes or No)? (see Appendix 7.B)

Subjects were given two breaks during each the session. After all segments were presented, subjects filled out a post-trial questionnaire (see Appendix 7.C), and a receipt of payment form.
The answers to question one (How would you rate the overall QUALITY of the sound?) were averaged across all subjects for each sample, and the resulting score is the Mean Opinion Score (MOS) for that sample. This methodology allowed us to obtain MOSs for a total of 120 samples, or 60 locations of forward and reverse link transmissions.

7.2.2 Expert Listener Methodology

Voice segments were also rated using an expert listener methodology before results of listener panels were analyzed. A 3-point scale of acceptability was utilized: Definitely acceptable, Marginally acceptable, and Unacceptable. The expert listener, Jaye Matthews, was trained to emulate the responses of panels of listeners to question number 3) Would you consider this acceptable as portable service. USWAT has been conducting voice quality tests since 1993, and has numerous voice samples and analysis for such technologies as DECT, WACs, and PHS. A training software package was compiled which outlined samples of each type of acceptability level determined by listener panel testing. The expert listener was trained using this software package until she demonstrated a reasonable level of proficiency in matching listener panel ratings of acceptability. Note: the training samples are limited to those samples we had listener panel data on, therefore it is unlikely that all types of digital noise and distortions were represented in the training material.
Listener panel responses to question three: Would this be ACCEPTABLE as portable service? were transferred to a 3-point scale of acceptability (percent acceptability):

Definitely acceptable (more than 70% of subjects rated acceptable),
Marginally acceptable (30 to 70% rated acceptable), and
Not acceptable (below 30% of subjects rated acceptable).

The expert listener ratings match this 3-point scale in the following ways:

Green = Definitely acceptable,
Yellow = Marginally acceptable, and
Red = Unacceptable.

For the quasi-stationary voice measurements, a single rating was given for each sample, and later compared to the listener panel results, see data analysis below. Percent acceptability ratings along with average RSS and average WER are plotted in Maps 7.3.5.1 through 7.3.5.12.

7.3 Voice Quality Data Analysis and Discussion

7.3.1 MOS Data Analysis and Discussion

Voice quality ratings from question one were averaged across subjects in order to obtain a Mean Opinion Score (MOS) for each sample. Recall, a MOS was generated for each of 60 locations around Boulder, in both the forward and reverse links at each location (n = 120).

The histogram of all MOS scores is diagrammed in Figure 7.3.1.1 below. Overall the voice samples were rated favorably, with 88% of the samples being rated between fair (3.0) and excellent (5.0). The average of all MOSs is 3.680, with a standard deviation of 0.6975.

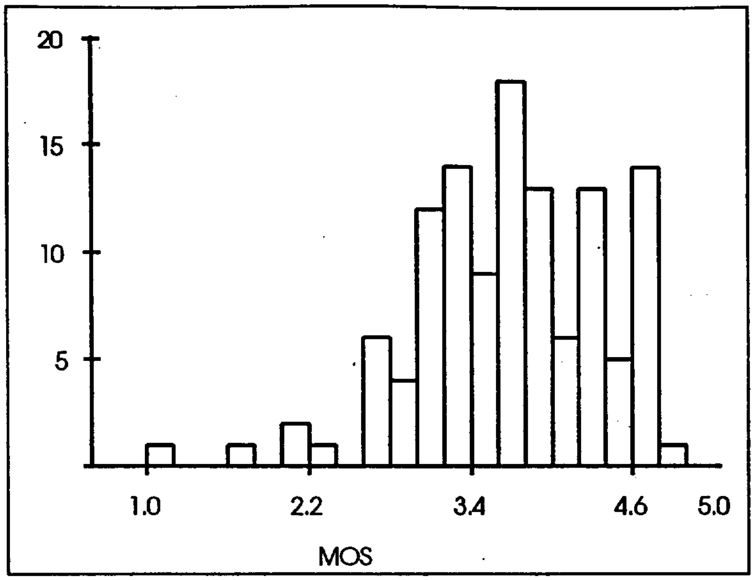

Figure 7.3.1.1 Frequency Distribution of all MOSs

Downlink and uplink MOSs are compared to one another in Figures 7.3.1.2 and 7.3.1.3, below. The median for the downlink MOSs is 3.43, while the median for the uplink MOSs is 4.25. The averages (means) of MOSs by link type are 3.413 and 3.914 for the downlink and uplink, respectively. A paired t-test reveals that there is a statistically significant difference in MOSs between the two links (t-stat= -4.695, with 54 d.f., p = 0.001: therefore, reject H_0 at α=0.05).

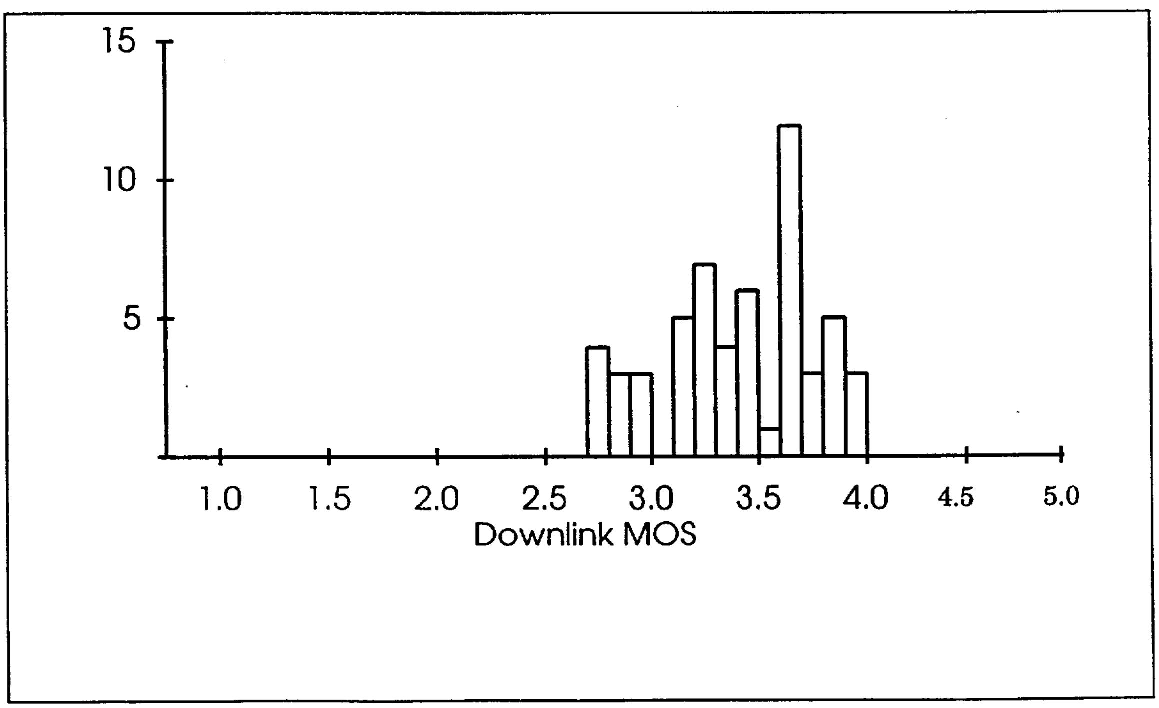

Figure 7.3.1.2 Frequency Distribution of Downlink MOS

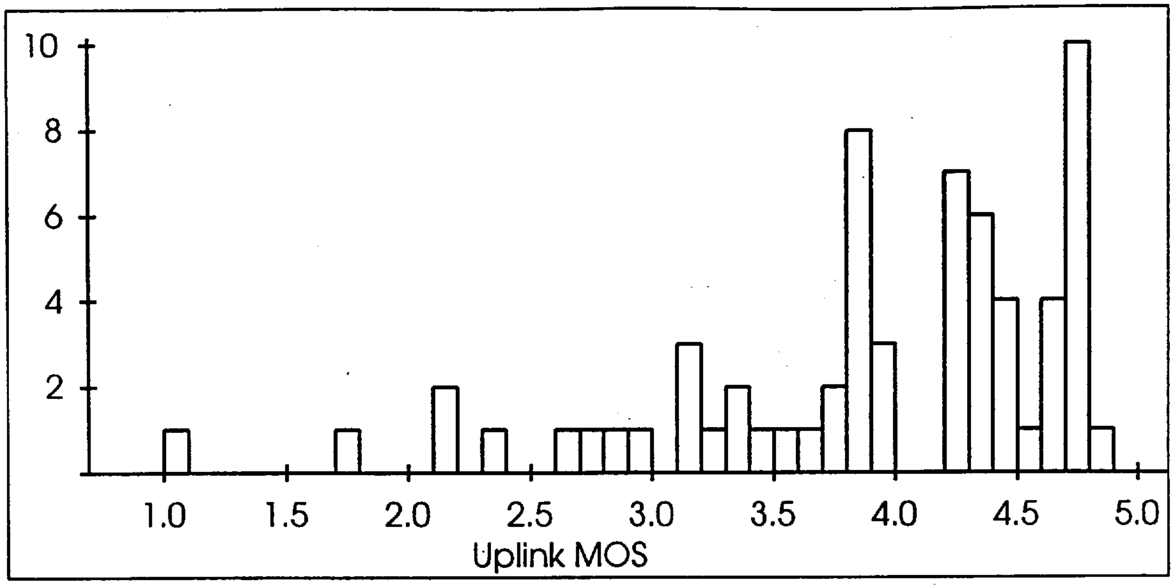

Figure 7.3.1.3 Frequency Distribution of Uplink MOS

Figure 7.3.1.4 compares all MOS scores against one objective measure: average RSS (dBm). Figures 7.3.1.5 and 7.3.1.6 compare MOSs with average WER on the downlink and uplink, respectively.

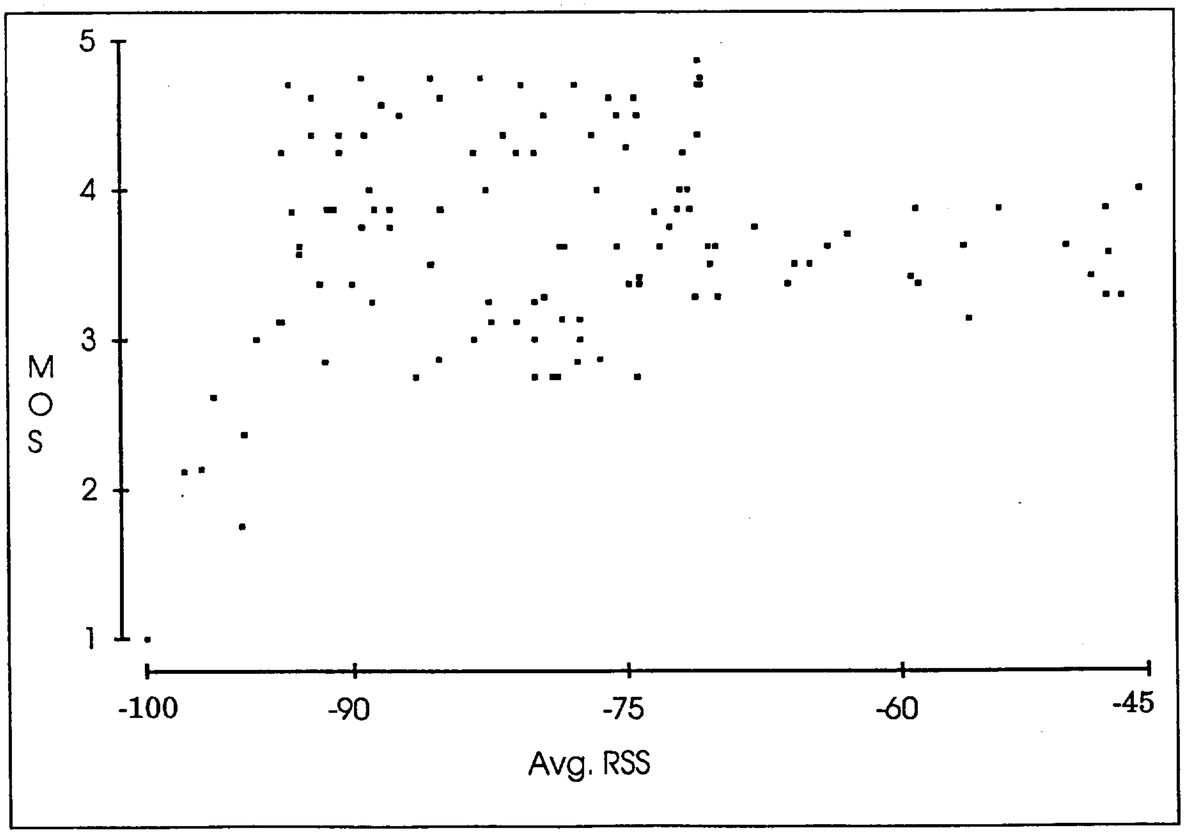

Figure 7.3.1.4

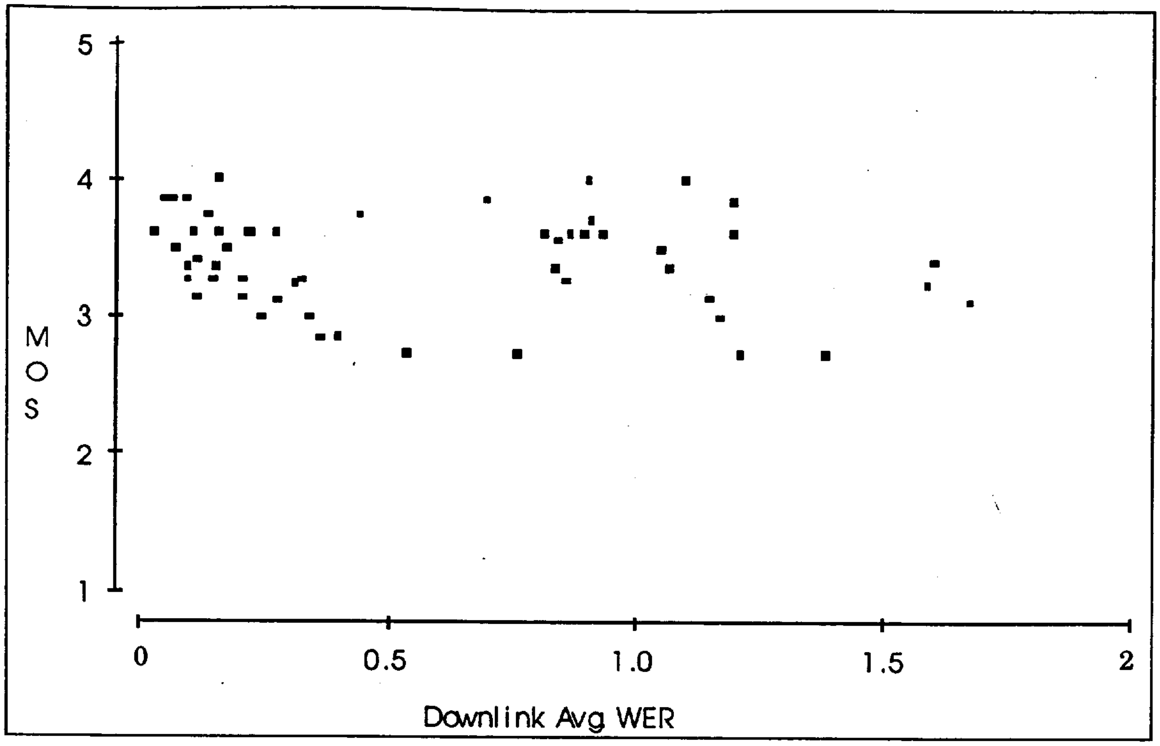

Figure 7.3.1.5

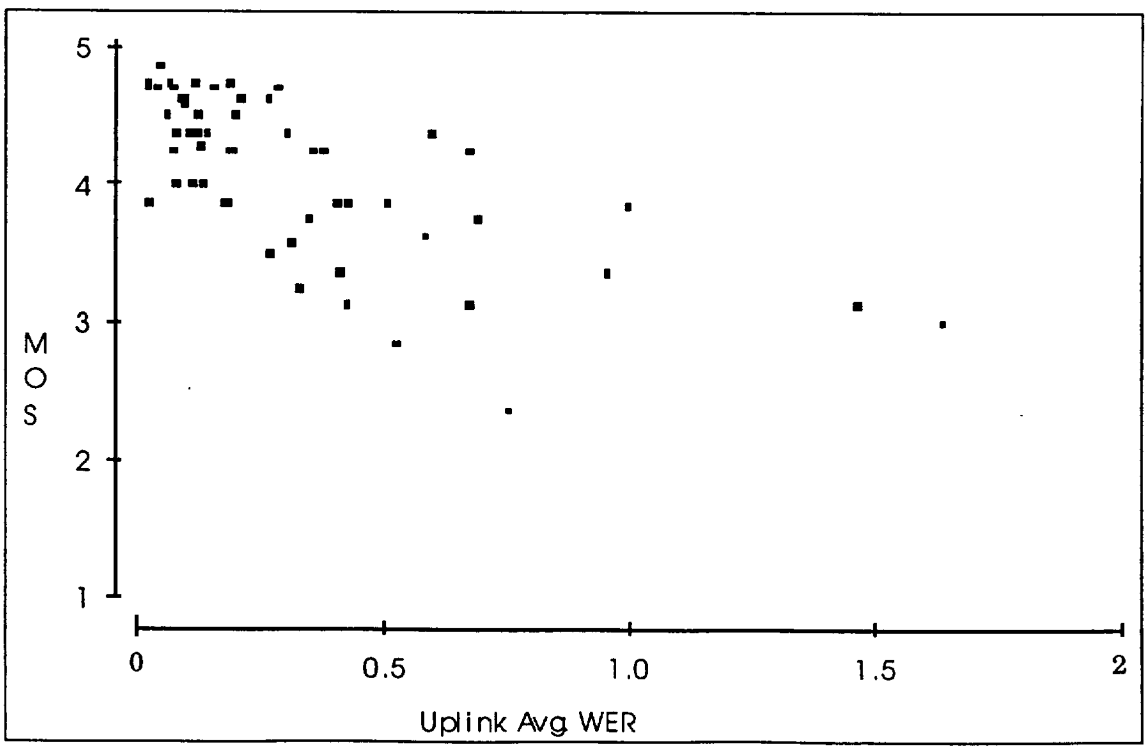

Figure 7.3.1.6

Figures 7.3.1.5 and 7.3.1.6 indicate that while the uplink samples show a relatively high correlation between high MOS and low WER, the downlink samples do not.

Further statistical analysis on MOS scores and engineering data from the downlink and uplink runs illustrates the differences between the two links.

Figure 7.3.1.7 is a Pearson Product-Moment correlation table of downlink data and outlines the correlation coefficients of MOS vs. RSS and WER. The results reveal that there is a linear correlation between MOS and EL and between MOS and RSS, but surprisingly little correlation between MOS and WER or WER and RSS.

Pearson Product-Moment Correlation

	MOS	EL	Avg. RSS	Avg. WER
MOS	1.000			
EL	0.526	1.000		
Avg. RSS	0.475	0.140	1.000	
Avg. WER	-0.052	0.079	-0.139	1.000

Figure 7.3.1.7 Downlink

A Spearman Rank Correlation was performed to analyze the ranks of MOS vs. the ranks of the various engineering measures, in order to consider possible non-linear relationships. Figure 7.3.1.8 diagrams the results.

Spearman Rank Correlation

	MOS	EL	Avg. RSS	Avg. WER
MOS	1.000			
EL	0.540	1.000		
Avg. RSS	0.549	0.239	1.000	
Avg. WER	-0.246	-0.281	-0.423	1.000

Figure 7.3.1.8 Downlink

The Spearman Rank Correlation does illustrate that the non-linear correlations are stronger that the linear correlations, but they are still not as high as expected.

Figure 7.3.1.9 is a Pearson Product-Moment correlation table of uplink data and outlines the correlation coefficients of MOS vs. RSS and WER. The results reveal some correlations between averaged engineering measures and MOS, the highest being WER at -0.550 (the negative sign denotes higher MOS corresponds to lower WER, as expected). Therefore, there does appear to be a linear relationship between MOS and the engineering measures. Notice that the correlation between MOS and WER is stronger than the correlation between WER and RSS.

Pearson Product-Moment Correlation

	MOS	EL	Avg. RSS	Avg. WER
MOS	1.000			
EL	0.849	1.000		
Avg. RSS	0.627	0.564	1.000	
Avg. WER	-0.550	-0.571	-0.397	1.000

Figure 7.3.1.9 Uplink

There is a linear relationship between MOS and the engineering measures, but there may be stronger relationships that are non-linear, as a Spearman Rank Correlation table might reveal. A Spearman Rank Correlation was performed to analyze the ranks of MOS vs. the ranks of the various engineering measures, in order to consider possible non-linear relationships. Figure 7.3.1.10 diagrams the results. There appear to be strong non-linear relationships between RSS, WER and MOS. Note that the non-linear relationship between MOS and WER is stronger than the linear relationship between the two.

Spearman Rank Correlation

	MOS	EL	Avg. RSS	Avg. WER
MOS	1.000			
EL	0.735	1.000		
Avg. RSS	0.647	0.642	1.000	
Avg. WER	-0.783	-0.669	-0.737	1.000

Figure 7.3.1.10 Uplink

Note, the engineering values were averaged over the entire voice sample length. By analyzing the engineering data within the voice sample time frame, further insight may be gained on the behavior of MOS. By considering the minimum and maximum values for WER and RSS over the length of a given sample, we might see higher correlations to MOSs.

7.3.2 Expert Listener Data Analysis and Discussion

Recall, the expert listener ratings were performed on a 3 point scale, and were made in an attempt to emulate listener panels' ratings of acceptability (vs. MOS).

Figures 7.3.2.1 and 7.3.2.2 show the relationship between expert listener (EL) ratings and listener responses to question three, or %acceptability [p(A)]. Percent acceptability is the percent of listeners rating a given sample as acceptable.