U S WEST, Inc.
Suite 700
1020 Nineteenth Street, NW
Washington, DC 20036
202 429-3134
FAX 202 296-5157

Elridge A. Stafford
Executive Director-
Federal Regulatory

USWEST

Progress Report

June 16, 1995

Mr. H. Franklin Wright
Office of Engineering and Technology
Frequency Liaison Branch
2000 M Street, Suite 480
Washington, D.C. 20554

RE: U S WEST Communications, Inc.
PCS Experimental License
Thirteenth Quarterly Report
Call Sign KK2XCC, Boulder, Colorado
File Numbers; 2148-EX-PL-91, 3306-EX-ML-92, 3630-EX-ML-93, 3630-EX-R-93, 4064-EX-ML-93

Dear Mr. Wright:

Enclosed please find U S WEST Communications' thirteenth quarterly report addressing the above referenced authorization for PCS field trials in Boulder, Colorado.

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

Sincerely,

Elridge Stafford

Enclosure

U S WEST

Wireless Personal Communications

Experiments

Quarterly Progress Report #13
FCC Experimental License
KK2XCC

June 16, 1995

Submitted to

Federal Communications Commission
Frequency Liaison Branch
2000 M Street, Suite 480
Washington, D.C. 20554

Prepared by

U S WEST Technologies
Wireless Communications Services
4001 Discovery Drive
Boulder, Colorado 80303

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Executive Summary

This quarterly report summarizes field testing conducted by U S WEST Technologies in the Boulder Industry Test Bed (BITB) from March 1, 1995 through June 1, 1995. During this quarter tests involving emissions in the 1850 MHz to 1990 MHz band were conducted on one system. The system used was the Joint Technical Committee (JTC) Technical Ad-hoc Group (TAG) 2 upbanded IS-95 CDMA air interface technology.

Plans for the next quarter include two technology field tests to be performed in conjunction with the Joint Technical Committee (JTC), a TDMA based system (upbanded IS-54) and a hybrid CDMA/TDMA system (Omnipoint).

1 Introduction

This report summarizes field testing conducted by U S WEST Technologies in the Boulder Industry Test Bed (BITB) under FCC Experimental License KK2XCC. The period covered by this quarterly report is from March 1, 1995 through June 1, 1995.

2 Field Testing

TAG 2 field testing was conducted in the BITB using radio and network equipment provided by Qualcomm. The choice to use Qualcomm's equipment for the JTC field test and represent the TAG 2 upbanded IS-95 technology was agreed upon by the manufacturer's comprising TAG 2. This field test was the second JTC TAG test to be tested in the BITB. It is part of an ongoing effort by U S WEST to provide a PCS network (consisting of over forty-five cell sites) and Field/RF engineering support to the JTC in an effort to provide the PCS industry with the opportunity to evaluate the performance of all of the proposed PCS TAG air interface technologies.

The following high tier cell sites were used, 1) Walnut Central Office (WCO), 2) Table Mesa Central Office (TMCO), and 3) Green Mountain Mesa (GMM). These sites were also used during the JTC TAG 5 (upbanded GSM) field test that was conducted in the Fall of 1994 in the BITB. The WCO used a 3-sector cell, the GMM used a 2-sector cell, and the TMCO used a single sector cell.

The antennas at the GMM and TMCO cell sites utilized a 120 degree azimuth beamwidth, while the WCO antennas utilized a 105 degree azimuth beamwidth. Three antennas comprised a single sector, one for the transmitter (the middle antenna) and two for receiver diversity. The single frequency used was 1952.99 MHz for the forward link and 1872.99 MHz for the reverse link. The cell site separation distances used were as follows: 1) WCO to GMM: 1.8 miles, 2) GMM to TMCO: 1.8 miles, and 3) WCO to TMCO 3.2 miles. The high tier cell layout used for JTC TAG field testing was chosen in such a manner that it provided a generic layout for all JTC TAG technologies, thus the cell layout was not optimized for any particular JTC TAG technology.

Qualcomm provided a QTSO (Qualcomm Telephone Switch Office) which was located in the 28th St Lab. A T1 line was provided from each cell site to the QTSO using T1 lines provisioned for the captive BITB network. A single T1 was provided from the QTSO to a Class 5 switch located in the captive BITB network. Landline phones, enabling voice connectivity from mobile test phones to landline phones, were provided using an additional T1 line that connected the Class 5 switch to landline phones located in the 28th St Lab.

Installation and test of the Qualcomm equipment took place from May 1 to 12, 1995. Each cell site generally consisted of a base station, a base station controller, and diagnostics monitor equipment per cell sector. Actual field testing began on May 15th and followed a TAG 2 and JTC approved field test plan. Field testing will be concluded by June 2, 1995.

Field testing included isolated cell coverage measurements, two-cell coverage and handoff measurements, three-cell coverage and handoff measurements, power control measurements, and quasi-stationary and hi speed voice quality measurements. The overall objective of these field measurements was to measure the performance of the proposed TAG air interface in a common propagation environment.

Forward link data was collected using a van that contained Qualcomm's diagnostic monitor equipment. Two mobiles were located inside the van, each directly interfaced with a diagnostics monitor. One mobile had a roof mounted antenna and the second mobile had an antenna mounted inside the van. This test setup also included simultaneous measurements to be taken during forward and reverse link transmission, which reduced test time significantly. Drive routes were pre-planned and consisted of the same drive routes that are used for all high tier JTC TAG tests. Reverse link data was collected at each of the cell sites as well as the QTSO (at the 28th St Lab) using diagnostic monitor equipment.

Markov test calls were used during actual data measurements for both the forward and reverse links. During Markov test calls, the mobile and the vocoder selector within the QTSO use statistical models and synchronized psuedo-random generators to generate and verify data bits and the data rate over the air. Thus, the Markov test calls statistically represent the data rates and bit streams of the TAG 2 variable rate vocoder during a typical voice call.

Collected data generally included mobile received signal strength, mobile output power, mobile receive pilot Ec/Io, vehicle latitude, vehicle longitude, cell receive Eb/No per antenna, and frame error rate. Careful attention was taken by Qualcomm, U S WEST, and the National Telecommunications and Information Administration (NTIA), representing the Independent Observer, to ensure that proper engineering practice was followed during data collection and all parts of the field test. Per JTC agreement, the measured TAG 2 data will be available to members of the JTC.

Also per JTC agreement, U S WEST and the NTIA are tasked to analyze measured data and write a final report, with TAG 2 approval, to be presented to the JTC within forty-five days of the field test.

A 'Participant's Day' was held on June 1, 1995 at the BITB that provided interested parties of the PCS industry the opportunity to be given a demonstration of the TAG 2 equipment and observe the TAG 2 system performance. This event was sponsored by Qualcomm and hosted by U S WEST.

3 Future Research

As indicated in previous quarterly reports, the BITB facility has been offered to the JTC as a facility for PCS air interface technology field testing. U S WEST is still committed to test all of the TAG technologies. However, due to TAG field test equipment availability, a new schedule of field testing has been modified to accommodate each of the TAG groups.

Thus, the following is the latest TAG field test schedule. Upbanded IS-54 (TAG 4), based on TDMA, is scheduled for July to August 1995. Omnipoint (TAG 1), based on a hybrid CDMA/TDMA technology, is scheduled for August to September 1995. PACS (TAG 3), based on TDMA, has committed for September to October, 1995. Wideband-CDMA (TAG 7), has been delayed, due to equipment availability. It is estimated that the TAG 7 field test will take place possibly during other TAG field tests, pending other TAG agreement, or during the October to November 1995 timeframe.

U S WEST has continued to provide ongoing support with each of these TAGs regarding overall planning of the field tests. Such planning includes designing the field tests, writing test plans, identifying data collection methods, and preparing the BITB network facilities and cell sites for equipment installation and test.

The Test Reports of TAG 5 (PCS1900) and the Personal Handyphone PHP) field tests, conducted in October 1994 and November 1994 respectively in the BITB, have been enclosed as part of this FCC Quarterly Report as attachments. These Test Reports were written by U S WEST and the NTIA and were presented to the JTC in a timely fashion.

ENCLOSURE

Test Reports of TAG 5

(PCS1900)

Joint Technical Committee JTC (AIR)/95.01.30-025

Standards Project: JTC (AIR)

Title: **Test Report for The TAG 5, Technology Field Testing at BITB.**

Abstract: This technology field test was performed at the U S WEST Boulder Industry Test Bed (BITB) in cooperation with the Joint Technical Committee (JTC). PCS1900 is one of several possible PCS technologies working toward a JTC standard. This test measured coverage in a common environment, demonstrated functionality, and measured performance in the presence of interference. Test data is presented here, with no attempt to make comparisons between technologies. The test lasted from October 17 through November 23, 1994. During the last three days, approximately twenty visiting organizations were hosted. Manufacturers supplying the PCS1900 equipment and participating in the testing were Motorola and Northern Telecom Inc., with support from the entire JTC-TAG 5. The Institute for Telecommunication Sciences acted as an independent observer.

Sources:

Mike Laflin, ITS, 303-497-3506
Ty Larson, U S WEST 303-541-6539
Lester Rand, NTI. 214-684-2633
Ken Riordan, Motorola 708-632-5324

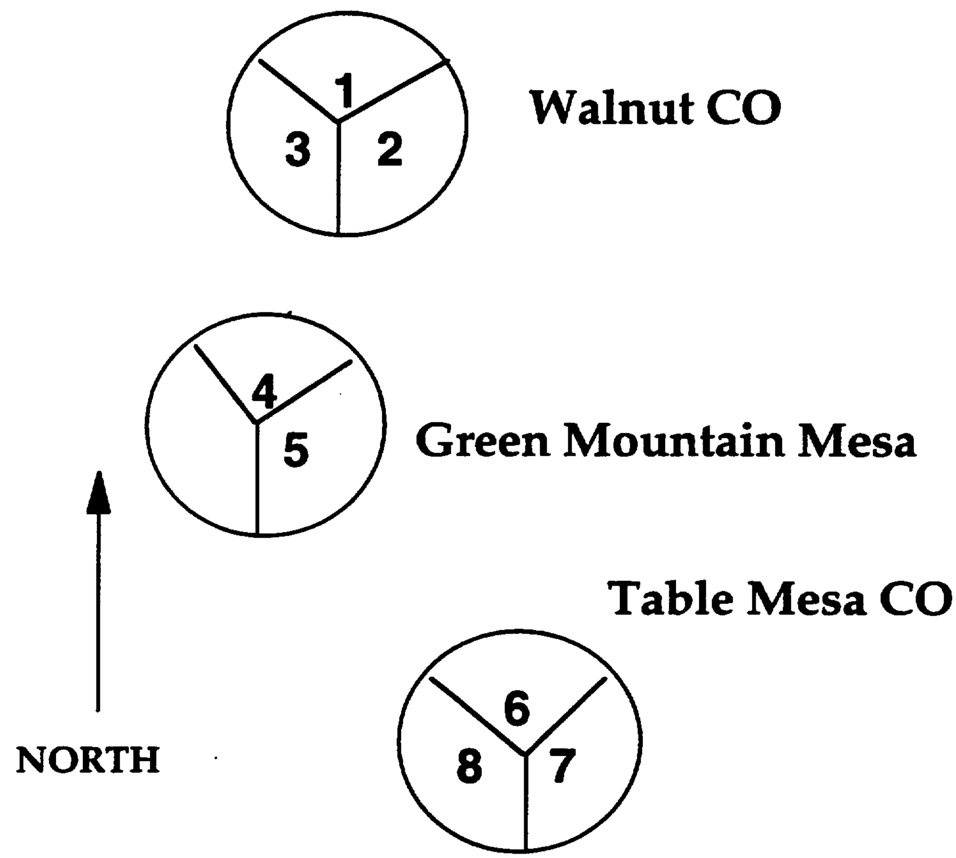
Date: January 30, 1995

Distribution: Participants in the Joint Technical Committee (JTC)

Figure 2.1.2 outlines the cell sector numbering convention used for this test. The southwest face of the Green Mountain Mesa (GMM) cell faces the mountains, and was not used. The cell separations are as follows:

WCO to GMM: 1.8 mi.
GMM to TMCO: 1.8 mi.
WCO to TMCO: 3.2 mi.

FIGURE 2.1.2 Cell Sector Numbering Designation and Orientation



2.2 Cell Site Configuration

The cell site configuration is summarized in Table 2.2.1. The Walnut CO and Table Mesa CO cells are serving cells in light urban and suburban areas, respectively. The Green Mountain Mesa cell, since it is at a 400-foot elevation relative to the valley floor, is used for an interior site, as well as a serving site to fill in potential coverage holes between the other two.

Table 2.2.1 PCS1900 Cell Site Configuration

Cell Site Description	Table Mesa CO	Walnut CO	Green Mountain Mesa(Outdoor BTS)
Cell site equipment	Radios-3 Band pass filter-3 Preselectors-3 -48VPSU-1 Cards: Kilo port switch-1 Generic processors-2 Transcoder-1 Digital radio Intrfce mod.-3 Generic clock-1 Digital PSU-1	2 Way coupler-3 Radios-3 Radio Tx PSU-3 Clock modules-2 Digital PSU--6 Alarm board-3 Main receive splitter-3 Diverse receice splitter-3 Receiver-3 Frame processor: Main board-3 Time slot mgt DCU-4 Base common function rack: PCM T1 IF-2 Switching-4 Control-2	Radios-3 (used 2) Receiver-3 Splitter-6 Frame processor-3 Base commo function unit-1 Tx PSU-3 Clock module-2 Digital PSU-2 Alarm board-3 Diplexer-3 Main PSU-2
Test use of site	Server, height above local	Server, height same as local	Server and interferor, tall tower.
Type of coverage	Light urban	Suburban	Suburban, Rural
Latitude	39deg 58'41.1" North Lat.	40deg1'4.5" North Lat.	39deg59'31.2" Nort Lat.
Longitude	105dg14'31.8"West Long.	105dg16'27.6" West Long	105dg16'20.1" W Long.
USGS 7.5' Quadrangle. Note: Niwot Quad completes area.	Louisville	Boulder	El Dorado Springs
Height above valley floor	29'	73'	400'
Ground elevation at site, feet	5410	5370	5800
Number of sectors	3	3	2
Number of T1's, giving a total of 2 to Texas	1 Shared (24 DSO's)	1 (19 DS0's)	1 Shared (5 DS0's)
Number of antennas	9	9	6
Orientation of sector	N, SW, SE	N, SW, SE	N, SE
Antenna azimuthbeamwidth	120 degrees	105 degrees	120 degrees
Antenna elevation beamwidth	7 degrees	7 degrees	12 degrees
Antenna gain, dBi	15.6	16.6	13.5
Antenna null filling	no	no	yes
Antenna beam squint	no	no	1 degree down

1.0 Purpose

This technology field test was performed at the U S WEST Boulder Industry Test Bed (BITB) in cooperation with the Joint Technical Committee (JTC). The TAG 5 technology (PCS1900) is one of several possible PCS technologies working toward a JTC standard. This test measured coverage in a common environment, demonstrated functionality, and measured performance in the presence of interference. Test data is presented here, with no attempt to make comparisons between technologies. The test lasted from October 17 through November 23, 1994. During the last three days, approximately twenty visiting organizations were hosted. Manufacturers supplying the PCS1900 equipment and participating in the testing were Motorola and Northern Telecom Inc., with support from the entire JTC-TAG 5. The Institute for Telecommunication Sciences acted as an independent observer.

This report describes the test plan, method, and results for the Technology Field Trial conducted by Technology Ad Hoc Group (TAG) Five. The trials were conducted at the US Technologies Boulder Industry Test Bed (BITB) located in Boulder Colorado. The technology tested is the US PCS variant of the GSM and DCS 1800 Standards.

The testing was carried out, by TAG 5, in fulfillment of the Joint Technical Committee on Wireless Access (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 Test Plan Administration Guide JTC(AIR)/94.09.23-707.

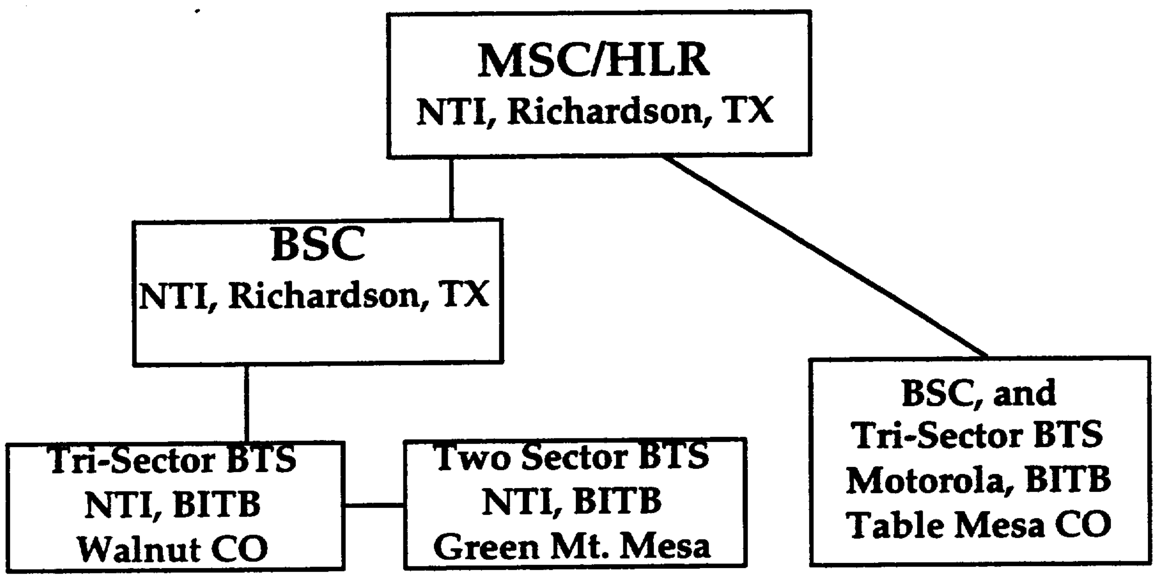
Three basic areas of performance were tested. These are received signal strength and voice quality as a function of position (coverage), system functionality including handover, and performance in an interference situation. Voice quality during handover and under co and adjacent channel interference were examined using an expert listener technique.

2.0 Test Configuration

2.1 System Configuration

The system configuration tested is shown in Figure 2.1.1. Note that T1 back haul is used between Richardson, Texas, and Boulder, Colorado. Three new high tier cell sites at the BITB were utilized and interconnected as shown in Figure 2.1.1. Also, the equipment manufacturer, Motorola or Northern Telecom, is indicated. The partial T1 link between Green Mountain Mesa and Walnut CO is line of sight microwave. Each cell sector has three antennas, one transmit and two receive, which are provided by U S WEST. Equipment manufacturers were Motorola, Northern Telecom, Western Multiplex (microwave T1 link), Andrew, CelWave, and DAPA (antennas), and Anritsu/Wiltron (test equipment.)

FIGURE 2.1.1 System Block Diagram of PCS1900 Test Configuration



List of Figures

TAG 5 TECHNOLOGY FIELD TRIAL
FINAL REPORT

DECEMBER 20, 1994

U S WEST DOCUMENT NUMBER:
T-09-02-004276-00.01

Prepared By

U S WEST Technologies, Inc.
Radio Technology Group

Abstract

This technology field test was performed at the U S WEST Boulder Industry Test Bed (BITB) in cooperation with the Joint Technical Committee (JTC). PCS1900 is one of several possible PCS technologies working toward a JTC standard. This test measured coverage in a common environment, demonstrated functionality, and measured performance in the presence of interference. Test data is presented here, with no attempt to make comparisons between technologies. The test lasted from October 17 through November 23, 1994. During the last three days, approximately twenty visiting organizations were hosted. Manufacturers supplying the PCS1900 equipment and participating in the testing were Motorola and Northern Telecom Inc., with support from the entire JTC-TAG 5. The Institute for Telecommunication Sciences acted as an independent observer.

To obtain copies, contact:

Document Management
U S WEST Technologies
4001 Discovery Drive - Suite 260
Boulder, CO 80303
(303) 541-6822

Document Owner:	Ty Larson
Document Authors:	Matt Dillon, Vladan Jevremovic, Mike Laflin, Michelle Owens, and Ty Larson.

Document Distribution: Unlimited

Document History

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Date	December 20, 1994
Description	Draft

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Antenna bandwidth, MHz	1850-1990	1710-1990	1850-1910 Rx 1910-1990 Tx
No. of Tx, Rx ant. per sector	1,2	1,2	1,2
Antenna manufacturer	Celwave	DAPA	Andrew
Antenna model number	PD10251-BD	68000	PC-5NOF-0191-113 Rx, Tx isPC-5NOF-0193-113
Cable run, ft. Andrew LDF5-50A foam, 7/8", 1.91 dB/100ft at 1900, 10" min. bend radius	76	140	140
Est. cable loss, with N male connectors, and with a lightning arrestor	2.0	3.2	3.2
Number of radios	3	3	2
Base station electronics manufacturer	Motorola	NTI	NTI
Equipment space	Large room, first floor, off loading dock	Lab space, third floor, with hoist	Field truck
Power at site:	220V 6A 3 ph 110V 15A sgl p	-48V, 25A	220V, 6A, sgl ph 110V, 15A, sgl p
Type of equipment	Indoor, 3 sector	Mini, 2 sector	Indoor, 3 sector
Base station power control disabled	yes	yes	yes

2.3 PCS1900 Frequency Settings

The frequency settings are given in Table 2.3.1

Table 2.3.1 Frequency Settings

Cell Face #	Site, Direction	Channel #	Base Rx, MHz	Base Tx, MHz
1	WCO, N	562	1860.2	1940.2
2	WCO, SE	574	1862.6	1942.6
3	WCO, SW	586	1865.0	1945.0
4	GMM, N	598	1867.4	1947.4
5	GMM, SE	610	1869.8	1949.8
6	TMCO, N	622	1872.2	1952.2
7	TMCO, SE	634	1874.6	1954.6
8	TMCO, SW	646	1877.0	1957.0

3.0 Calibration

Two types of calibration were performed on the system. In the first the transmitter parameters were characterized. This includes transmit power, phase error, and magnitude error. In the second the system reporting of rxlev for the base and the mobile were characterized.

3.1 Base Station Transmitter Characteristics

The transmitter parameters were measured for the TMCO and WCO sites. The GMM site was not characterized as that site was not on the air at the time the test equipment was available. Measurements were made by Michael Barrick of Anritsu Wiltron using the Anritsu MS8604A. The JTC would like to thank Anritsu Wiltron and especially Mr. Barrick for their assistance with this field trial. The table below list the results for the two cell sites.

Table 3.1 Transmitter parameters from Anritsu MS8604A.

Frequency (MHz)	RMS Phase Error (Deg) %	RMS Magnitude Error %	Power Out (dBm)	Occupied Bandwidth*
1954.60	1.84	1.48	36.30	243.00
1957.00	1.30	1.71	36.81	243.00
1950.00	3.95	1.13	36.79	244.00
1940.20	2.27	0.89	36.66	244.00
1942.50	2.48	1.27	36.51	244.00
1952.20	2.00	1.52	36.72	242.00

*Occupied bandwidth for 99% of the power (not a PCS1900 specification).

3.2 RXLEV Calibration

The accuracy of the rxlev reports from both the base station and the mobile station were calibrated by connecting the base and the mobile together via coax cable, high power and variable attenuators, and two directional couplers. The signal source for the MS reporting test was the BTS and the MS for the BTS reporting accuracy. The antenna on the handset was replaced with a hardline connector so that it was connected directly to the coax. The handset was then placed in a shielded enclosure to prevent coupling from the radiated fields in and around the base site. Losses through the configuration were calibrated using a signal generator and a spectrum analyzer. **It was not possible to calibrate the loss from the antenna connector into the handset front end.** Transmitted power was measured via the directional couplers.

The procedure was to establish a call at some lower attenuation level, measure the transmitted power, calculate the received power, and compare that to the reported rxlev.

The attenuation was increased and the received power and reported power recorded. The table below lists the results from the test.

Table 3.2.1 Handset/Base Station Calibration.

Hand Set: Motorola #22, Measured at TMCO				
Link	Frequency (MHz)	RSL Measured (dBm)	RSL Reported (rxlev) (dBm)	difference (dB)
Up	1874.6	-52.5	-51	1.5
Up	1874.6	-72.5	-71	1.5
Up	1872.2	-52.5	-52	-0.5
Up	1872.2	-72.5	-72	-0.5
Down	1954.6	-45.5	-50	-4.5
Down	1954.6	-65.5	-70	-4.5
Down	1952.2	-45	-49.5	-4.5
Down	1952.2	-65	-70	-5.0
Handset: Motorola #24, Measured at TMCO				
Up	1874.6	-53	-51	2.0
Up	1874.6	-73	-71	2.0
Up	1872.2	-53	-53	0.0
Up	1872.2	-73	-73	0.0
Down	1954.6	-45.5	-50	-4.5
Down	1954.6	-65.5	-70	-4.5
Down	1952.2	-45	-50	-5.0
Down	1952.2	-65	-70	-5.0
Handset: Northern Telecom #498, Measured at WCO				
Up	1862.2	-56	-57	-1.0
Up	1862.2	-76	-78	-2.0
Down	1942.6	-45	-49	-4.0
Down	1942.6	-65	-70	-5.0
Handset: Northern Telecom #473, Measured at WCO				
Up	1862.6	-55.5	-57	-1.5
Up	1862.2	-76	-78	-2.0
Up	1865	-55.5	-59	-4.5
Up	1865	-76	-80	-4.0
Down	1942.6	-44.5	-48	-3.5
Down	1942.6	-76	-78	-2.0
Down	1945	-44.5	-49	-5.5
Down	1945	-64.5	-66	-1.5

4.0 Functionality Testing

4.1 Testing Methodology

The primary focus of this test is on the air interface. Evaluation of handover testing was baised towards general functionality and call quality. Manufacturers configured their respective sites with generic handover parameters. And that, because of time constraints, there was no practical opportunity to optimize any parameters which impacted inter-BSC performance. Selection of Cell Site locations was greatly limited to facilities readily available to US WEST. As such, the chosen locations were in no way optimal with respect to RF system planning.

The system parameters were set as follows:

TMCO:

Intercell handover delta = 1 dB
Intracell handover delta = 4 dB
Intercell Access min = -105 dBm
Intracell Access min = -100 dBm

WCO:

Intercell handover delta = 1 dB
Intracell handover delta = 4 dB
Intercell Access min = -105 dBm
Intracell Access min = -100 dBm

These settings were chosen to induce handovers between the two cell sites since there was a lack of sufficient signal overlap between the two.

This portion of the functionality testing examined the performance of the system during handover. Two links were established so that voice quality could be measured on the uplink (mobile to base) and on the downlink (base to mobile) simultaneously. The two mobile units were place side by side in the carrier inside the test vehicle. The test vehicle was then driven on routes that would pass through the coverage area of each cell site and each sector within a cell site. Handover was barred to the Green Mountain Mesa (GMM) site allowing handover only between the Table Mesa Central Office (TMCO) site and the Walnut Central Office (WCO) site.

The testing was done using Motorola handset number 22 on the uplink and handset number 24 on the downlink. The handsets were connected to the Motorola EMMI logging equipment which was in turn connected to one of two laptop computers for control and recording. For each link a report sample was taken approximately once each second. Each sample reported the following data:

1) handover type, if any (either between two rf channels or between time slots for a given carrier)
2) sample time
3) mode (idle or dedicated)
4) channel number (rf carrier)
5) bsic (base station identity code)

6) rxlev (received signal level)
7) rxqual (measure of bit error rate)
8) time slot number
9) timing advance
10) for each neighbor
    - channel number
    - bsic
    - rxlev
11) link budget (difference between rxlev and the access min)
12) access min (minimum signal level required to access channel).

Voice quality tapes were played/recorded continuously on the up and down links while the testing was conducted. Each time a handover occurred, the link, channel to, time, tape counter position, and geographic location were recorded. No GPS data was recorded.

4.2 Data and Discussion

Three types of handover were observed. The first occurred between the sectors at a given cell site. The second between two different cell sites. A third type of handover was observed, only at the TMCO site, between time slots of a given rf channel.

Data collected from the handover testing was analyzed to determine the change in the rxlev and rxqual values before and after handover. The time between successive handovers was also examined. This would give an indication of any "ping-ponging" (it should be noted that the handover deltas were set at 1 and 4 dB). A total of 63 rf channel to rf channel handovers were examined in the analysis that follows.

4.2.1.1 Change in Average rxlev

The average rxlev before and after handover was calculated on six consecutive samples before and after handover. The first sample after handover was discarded to allow the handset to stabilize. In cases where another handover occurred before six samples were accumulated the average was calculated on the number of samples available. This corresponds with an approximately 3 second average (average of logarithmic values).

Handover cause values and specific handover algorithms were not made available by the manufacturers. Therefore, no additional investigation into handover performance was made.

Figure 4.2.1.1.1 shown below presents a histogram of the change in the average rxlev before and after handover. The ordinate represents the frequency of occurrence and the abscissa gives the difference, in dB, in the average rxlev before and after handover. Superimposed on this is a cumulative distribution of the rxlev differences.

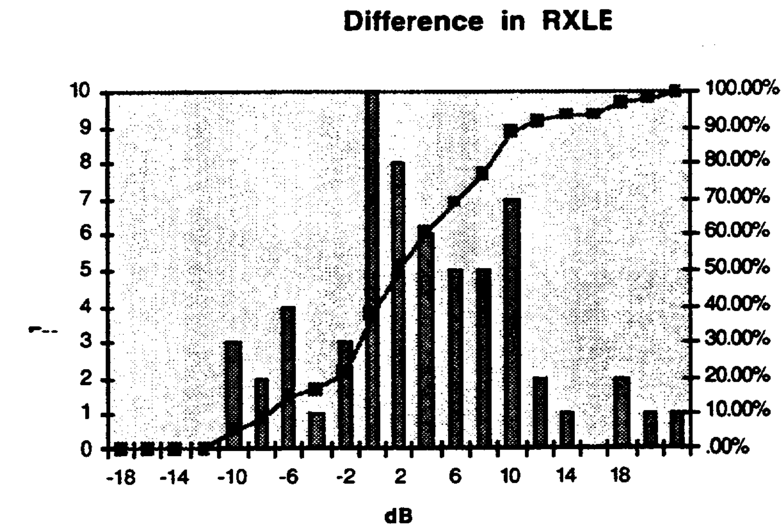


Figure 4.2.1.1.1 Histogram of rxlev difference (source before-source after) during Handover.

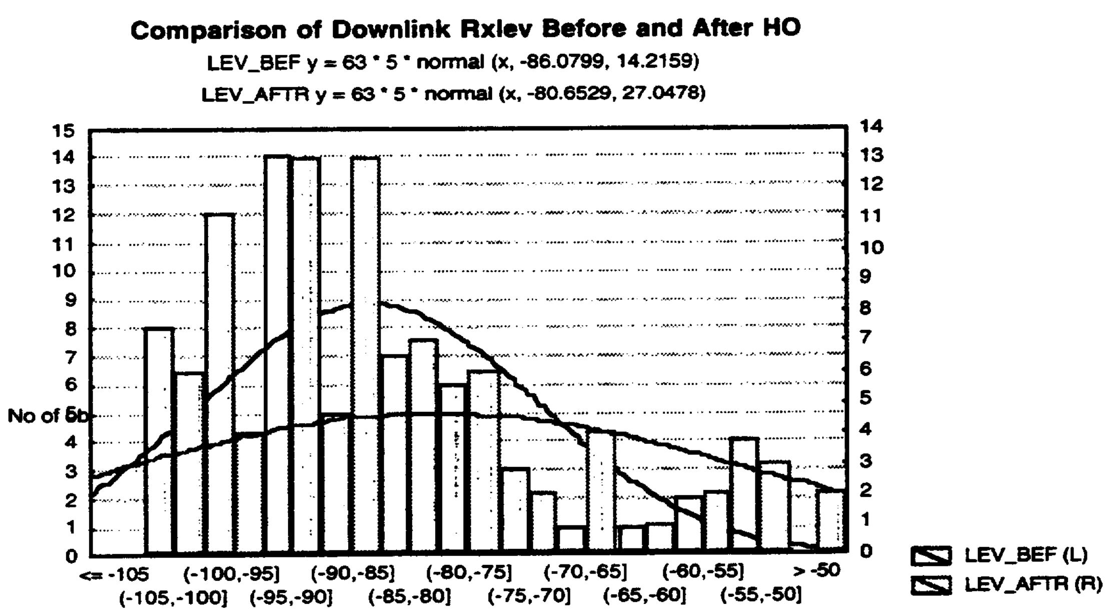


Figure 4.2.1.1.2 Histogram with normal distribution fit for rxlev before/after handovers.

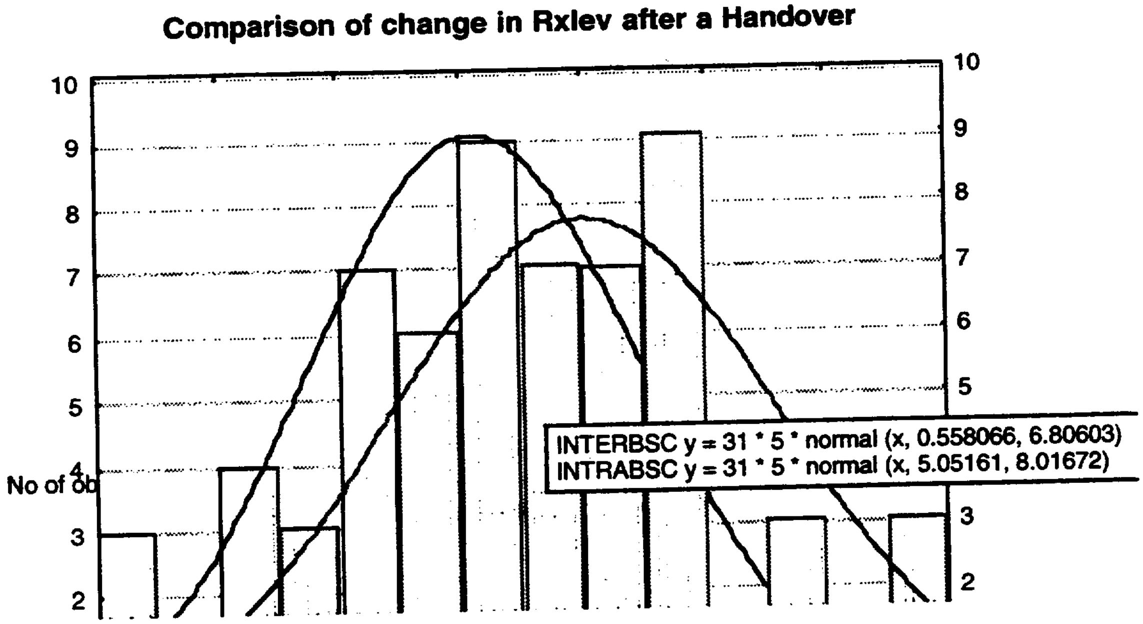


Figure 4.2.1.1.3 Histogram of change in rxlev per handover type inter/intra BSC

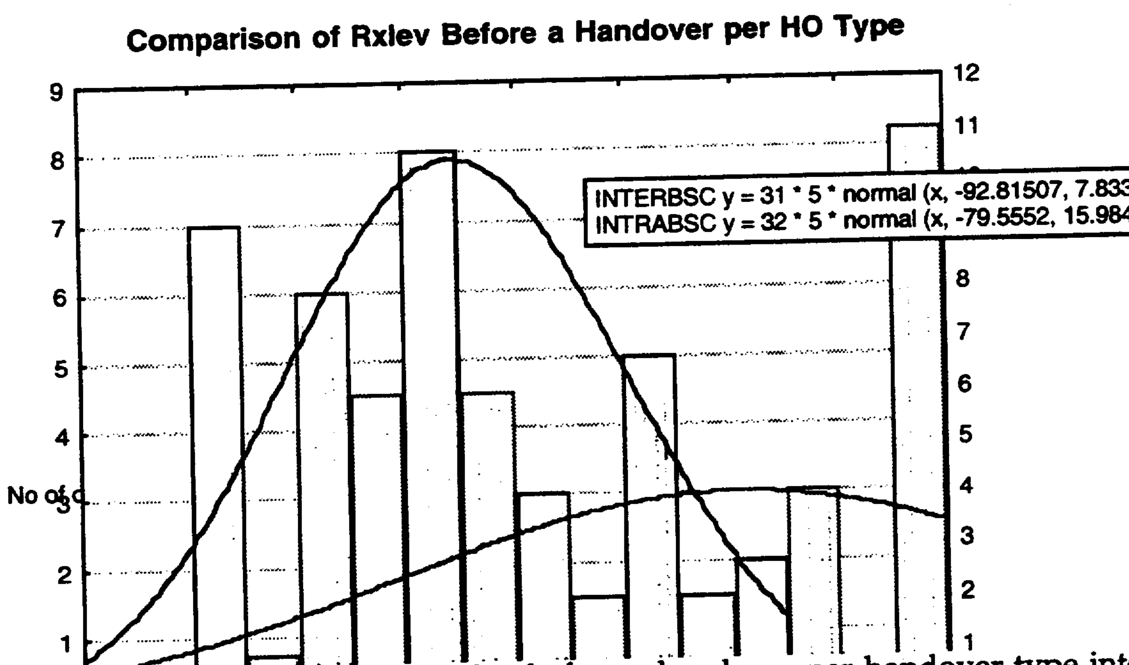


Figure 4.2.1.1.4 Histogram of rxlev before a handover per handover type inter/intra BSC

Figure 4.2.1.1.4 illustrates that the rxlev between the cells was fairly low (22% below -100 dBm), meaning that the cells did not have enough overlap to always complete and ensure a silent transition to the inter-bsc neighbor.

4.2.1.2 Change in Average rxqual

The change in the average rxqual before and after handover is calculated in the same manner as described in section 4.2.1.1.

Figure 4.2.1.2.1 shown below presents a histogram of the change in the average rxqual before and after handover. The ordinate represents the frequency of occurrence and the abscissa gives the difference in the average rxqual before and after handover. Superimposed on this is a cumulative distribution of the rxqual differences.

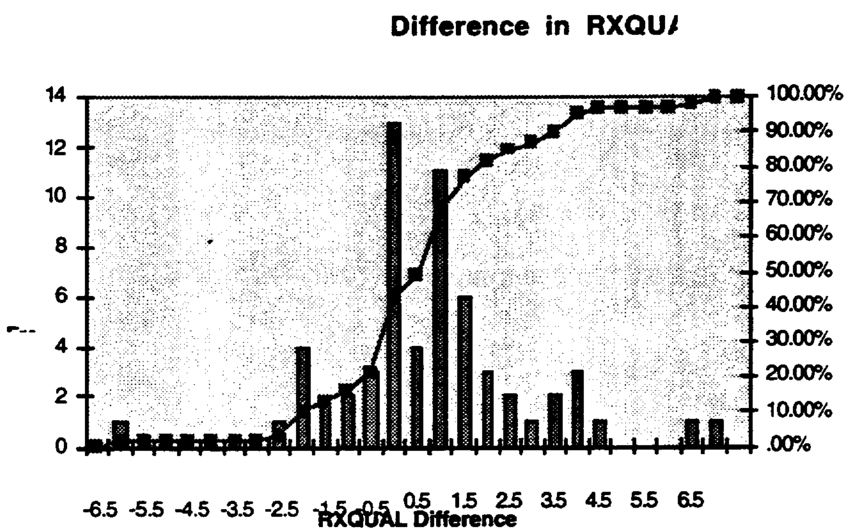


Figure 4.2.1.2.1 Histogram of rxqual during handover.

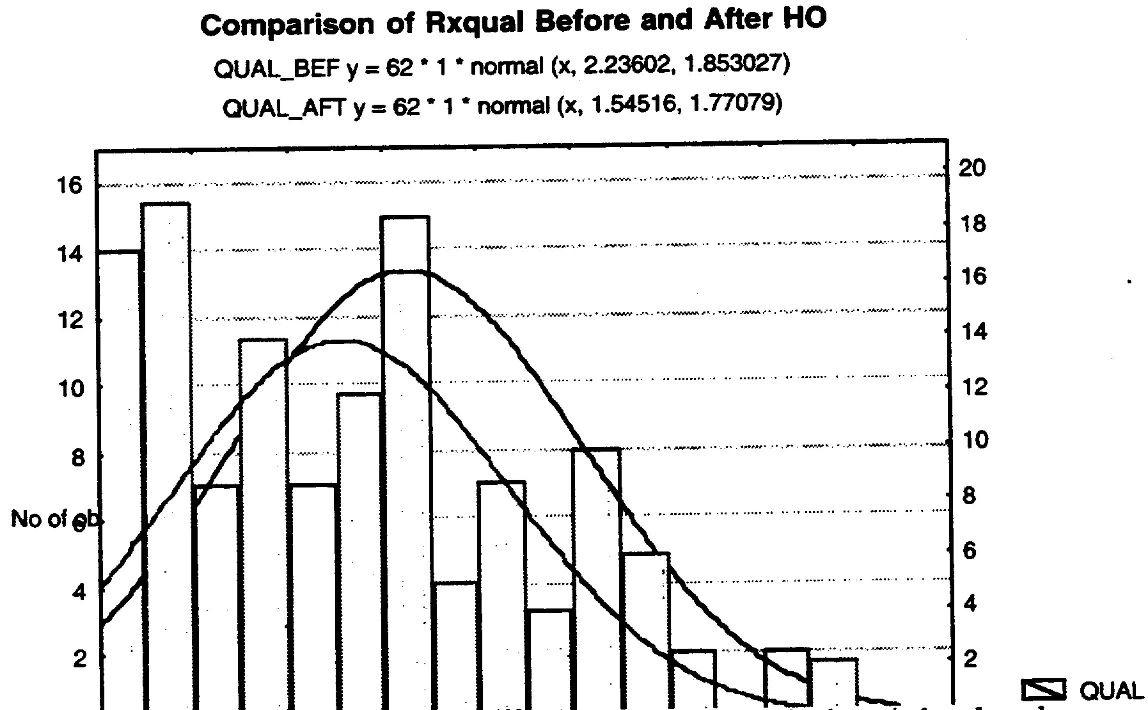


Figure 4.2.1.2.2 Histogram with normal fit of rxqual before/after handovers

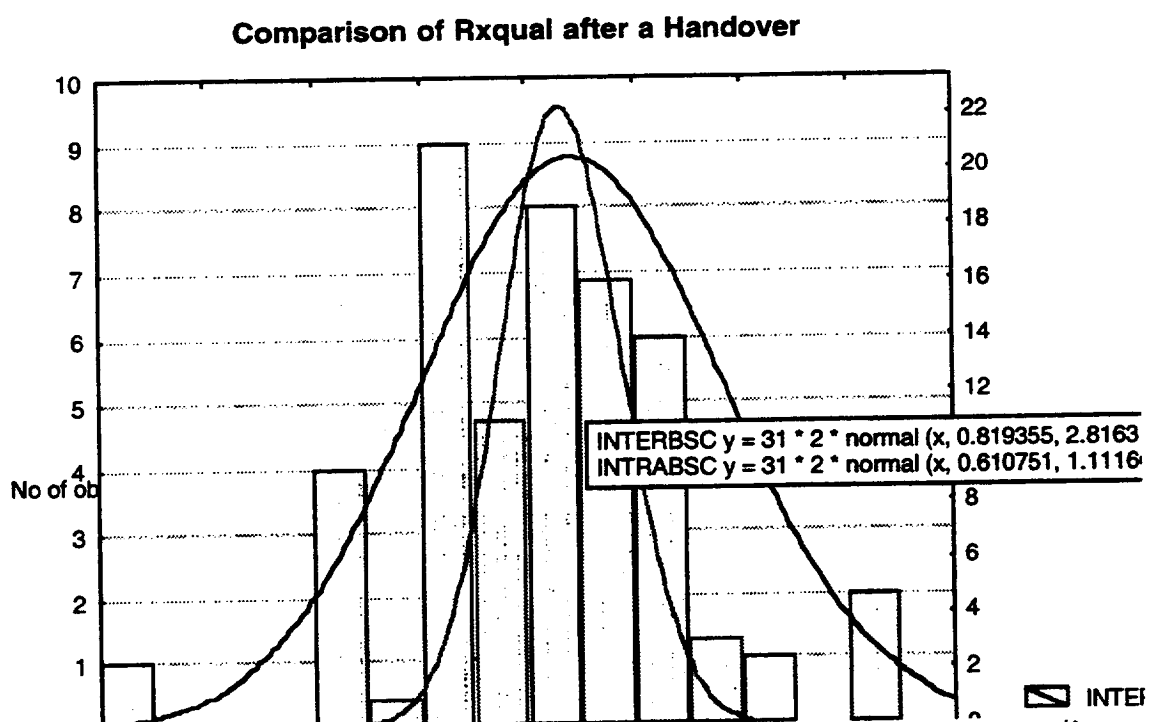


Figure 4.2.1.2.3 Histogram of change in rxqual per handover type inter/intra BSC

4.2.1.3 Time Between Successive Handovers

Time between successive handovers was calculated for handovers occurring within an individual EMMI log file.

Figure 4.2.1.3.1 shown below presents a histogram of the time between successive. The ordinate represents the frequency of occurrence and the abscissa gives the time, in seconds, between handovers. Superimposed on this is a cumulative distribution of the time between handovers.

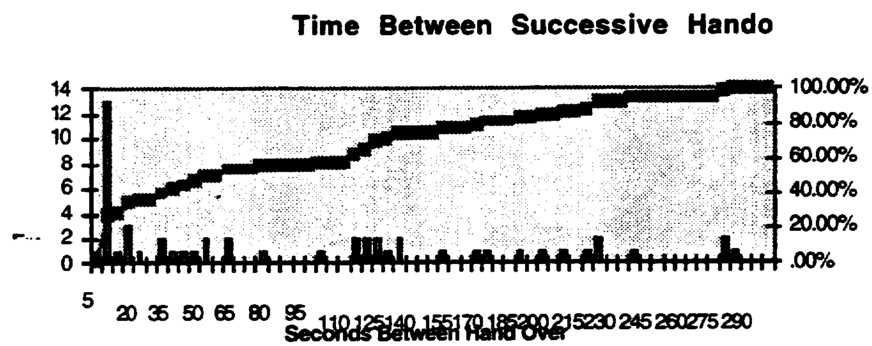


Figure 4.2.1.3.1 Histogram of time between successive handovers.

Table 4.2.1.3 lists, in tabular form the data used in the analysis presented in the handover test results.

Table 4.2.1.3.1 Tabulated handover data.

#	HO	HO time	HO time delta	chan from	chan to	rxlev before (dBm)	rxlev after (dBm)	lev delta (dB)	qual before	qual after
File 1108001.dxl downlink										
1	1	13:22:54		634	646	-96.167	-89.5	6.667	4.667	1.333
2	2	13:23:06	0:00:12	646	634	-88.333	-85.8333	2.5	1.333	0.5
3	3	13:25:22	0:02:16	634	646	-51	-52.6667	-1.6667	0.83333	1.66667
4	4	13:30:09	0:04:47	646	562	-101.667	-101.5	0.166667	4.166667	6.66667
5	5	13:30:17	0:00:08	563	622	-101.5	-92.6667	8.83333	6.66667	0
6	6	13:32:21	0:02:04	622	562	-103.333	-102.6	0.73333	5.16667	5
file 1108001.uxl uplink										
7	1	13:23:00		634	646	-96.1667	-90.8333	5.3333	3	1.66667
8	2	13:24:18	0:01:18	646	634	-93	-85.5	7.5	2	1.83333

9	3	13:25:22	0:01:04	634	646	-50.6667	-57.3333	-6.6667	0	0.66667
10	4	13:30:05	0:04:43	646	562	-97.3333	-97.6667	-0.3333	0.83333	1
file 1108002.dxl downlink										
11	1	13:43:48		574	586	-74.8333	-65.6667	9.16667	0	0
12	2	13:47:36	0:03:48	586	562	-95.3333	-89.5	5.833333	2.333333	1.166667
13	3	13:49:32	0:01:56	562	622	-102.667	-92.8333	9.833333	4.5	1
file 1108002.uxl uplink										
14	1	13:43:48		574	586	-77.5	-67	10.5	0.166667	0
15	2	13:44:53	0:01:05	586	562	-70.5	-73.3333	-2.83333	0	0
16	3	13:45:13	0:00:20	562	586	-77.1667	-77.5	-0.33333	0	0
17	4	13:46:55	0:01:42	586	562	-74.3333	-75.8333	-1.5	0.666667	0
18	5	13:49:31	0:02:36	562	622	-99	-92.1667	6.833333	3.333333	0.833333
19	6	13:52:22	0:02:51	622	586	-102.167	-101.833	0.333333	4.833333	3
file 1108003.dxl downlink										
20	1	15:19:44		546	634	-55.3333	-49.6667	5.666667	0	0
21	2	15:20:39	0:00:55	634	646	-53.8333	-50.5	3.333333	0	0
22	3	15:22:55	0:02:16	646	634	-53.5	-52.3333	1.166667	0	0
23	4	15:23:15	0:00:20	634	646	-67	dropped			
file 1108003.uxl uplink (up and down links not same runs)										
24	1	15:57:32		622	586	-97.5	-89.1667	8.333333	4.166667	0.666667
25	2	15:57:41	0:00:09	586	562	-90.5	-82.6667	7.833333	1.333333	0.333333
26	3	15:59:38	0:01:57	562	586	-80.6667	-77	3.666667	0.666667	0
27	4	16:02:53	0:03:15	586	574	-92.5	-93.6667	-1.16667	2.666667	1.166667
28	5	16:03:40	0:00:47	574	622	-94.1667	-90.6667	3.5	2.666667	1.333333
29	6	16:08:25	0:04:45	622	646	-61.3333	-56.5	4.833333	0	0
30	7	16:09:18	0:00:53	646	634	-57	-63.6667	-6.66667	0.666667	0
file 1108004.dxl downlink										

31	1	16:34:19		574	634	-76.5	-77.1667	-0.66667	0	0.166667
32	2	16:34:28	0:00:09	634	562	-76.1667	-83.6	-7.43333	0	0.6
33	3	16:34:34	0:00:06	562	574	-83.6	-67	16.6	0.6	0
34	4	16:34:56	0:00:22	574	634	-89.5	-81.6667	7.833333	2.666667	0
35	5	16:37:04	0:02:08	634	622	-96.8333	-85	11.83333	2.666667	1.666667
36	6	16:39:12	0:02:08	622	562	-96	-101.5	-5.5	3	4.166667
37	7	16:39:21	0:00:09	562	574	-100.5	-70.8333	29.66667	3.833333	0
38	8	16:42:42	0:03:21	574	622	-83.6667	-81	2.666667	1.333333	3.333333
39	9	16:43:27	0:00:45	622	586	-78.1667	-88.3333	-10.1667	2.833333	4.333333
file 1108004.uxl uplink										
40	1	16:34:46		574	634	-80.1667	-79.8333	0.333333	0	0
41	2	16:37:01	0:02:15	634	622	-96.8333	-84.6667	12.16667	3.333333	2.666667
42	3	16:39:05	0:02:04	622	562	-93.3333	-94.8333	-1.5	3.5	4.666667
43	4	16:39:38	0:00:33	562	622	-90.6667	-92	-1.33333	2.833333	5
44	5	16:39:40	0:00:02	622	562	-92	-95.3333	-3.33333	5	3
45	6	16:39:49	0:00:09	562	574	-95.5	-86.1667	9.333333	2.333333	2.333333
46	7	16:42:49	0:03:00	574	622	-84	-83.3333	0.666667	2.166667	0.666667
47	8	16:43:25	0:00:36	622	586	-82.6667	-90.6667	-8	2.333333	3.166667
48	9	16:43:33	0:00:08	586	562	-90.6667	-87.1667	3.5	3.166667	2
49	10	16:43:51	0:00:18	562	622	-95	-95.8333	-0.83333	4.666667	3.833333
file 1108005.dxl downlink										
50	1	17:01:11		622	562	-93.1667	-104.2	-11.0333	2.333333	4.8
51	2	17:01:17	0:00:06	562	622	-104.2	-87.6667	16.53333	4.8	0.333333
52	3	17:05:06	0:03:49	622	562	-91.8333	-94.5	-2.66667	3.166667	1.166667
53	4	17:05:14	0:00:08	562	574	-94.5	-93.6667	0.833333	1.166667	0.833333
file 1108005.uxl uplink										

54	1	16:52:39		622	586	-88	-99.6	-11.6	0	6.4
55	2	16:52:45	0:00:06	586	622	-99.6	-89.8333	9.766667	6.4	0
56	3	16:53:19	0:00:34	622	586	-88.6667	-89.1667	-0.5	0	0
57	4	16:57:04	0:03:45	586	562	-76.8333	-85.8333	-9	0	2.166667
58	5	16:57:12	0:00:08	562	574	-85.5	-65.5	20	2.333333	0
59	6	16:57:27	0:00:15	574	622	-83.8333	-79.3333	4.5	1.833333	0.833333
60	7	17:01:01	0:03:34	622	562	-93.1667	-100.8	-7.63333	2.5	4
61	8	17:01:07	0:00:06	562	622	-100.8	-94.1667	6.633333	4	0.333333
62	9	17:05:11	0:04:04	622	562	-93.3333	-91.6667	1.666667	5.666667	1.833333
63	10	17:05:20	0:00:09	562	574	-91.8333	-82.6667	9.166667	1.5	1.666667

5.0 Coverage Testing

5.1 Coverage Methodology

The physical configuration of the cell sites followed that of the test plan, and is given in section 2. The BTS power was set to 8 watts, such that the nominal output was approximately 100 w ERP (50 dBm) for all of the cells. The two drive vehicles were minivans.

5.1.1 Table Mesa

The coverage at this site was taken by driving the radials away from the site and filling in-between the radials as time permitted. The mobile was a portable handheld unit which was mounted inside the van on a wood structure. The structure was located between the two front captains chairs 2 feet back from the front window of the van and one foot below the roof. The mobile was allowed to handoff within the site to maintain the call as long as possible. Generally, calls were originated close to the cell site and driven away until the lack of radio signal would cause the call to drop. The mobile would not be able to re-originate at that location because of the setting of the minimum access which was set higher than the sensitivity of the radio. The other sites in the system were turned off for the coverage testing, so that the sensitivity of the weakest link at noise level determined the range.

5.1.2 Walnut

The coverage test for the Walnut CO was conducted in a similar manner to that used for the Table Mesa CO site.

5.1.3 Green Mountain Mesa

Similar methods were used for this site as were used at the Table Mesa site. At this site the inboard duplexer in the compact BTS (the TX/RX branch) was bypassed. This was due to narrow band antenna's that were used for this site. The 2nd RF path was routed with external cables to bypass the TX/RX antenna port for this RF branch on both sectors.

5.1.4 Walnut Out of van Antenna

In this case the mobile (portable) was attached to a roof with a mag mount Omni antenna. It was mounted in the center of the vehicle roof. The coverage collection preceded as in the previous tests. This test was optional and done at the manufacturers discretion.

5.2 Table Mesa CO Coverage Data and Discussion

Coverage plots were made to show received signal level and street information for the Table Mesa CO cell site. Superimposed on the coverage plots are the results of the MOS tests (discussed at a later section of this report). The density of the streets provides a representation of the density of the environment. Each plot was scaled to show the coverage area. The plots for the TMCO, WCO, and GMM are found in Appendix C.

For the Table Mesa site the following coverage plots are provided:
5.2.1 - Table Mesa Total Coverage Rxlev Uplink
5.2.2 - Table Mesa Total Coverage Rxlev Downlink

The data was collected at the mobile, GPS and at the BTS. All three sources were collated with respect to time and combined to provide a file with location, speed, and up/downlink information about the radio link. On the uplink this information was collected (sampled) every 6 seconds. The downlink information was collected every 480 ms. The collated file contained 1 second data as shown in table 1.

Table 5.2.1

Data in File	Description of Data
hour, minute, second	Current time of log file
lat, long	Position, updated every second
chan	Channel number of TCH
uplink Rxlev	A "0" Rxlev corresponds to -110 dBm and proceeds to Rxlev of 63 = -47 dBm
uplink Rxqual	Raw bit error rate scale from 0-7 Rxqual shown in table 2
downlink Rxlev	A "0" Rxlev corresponds to -110 dBm and proceeds to Rxlev of 63 = -47 dBm
downlink Rxqual	Raw bit error rate scale from 0-7 Rxqual shown in table 2
speed	Provided in miles per hour
timing advance	Time mobile advances transmitting timeslot due to distance (1 TA = 0.5 km)
mobile transmit power	Provided in dBm, maximum value 30
neighbor list	Rxlev, BSIC and channel number for up to 6 neighbors

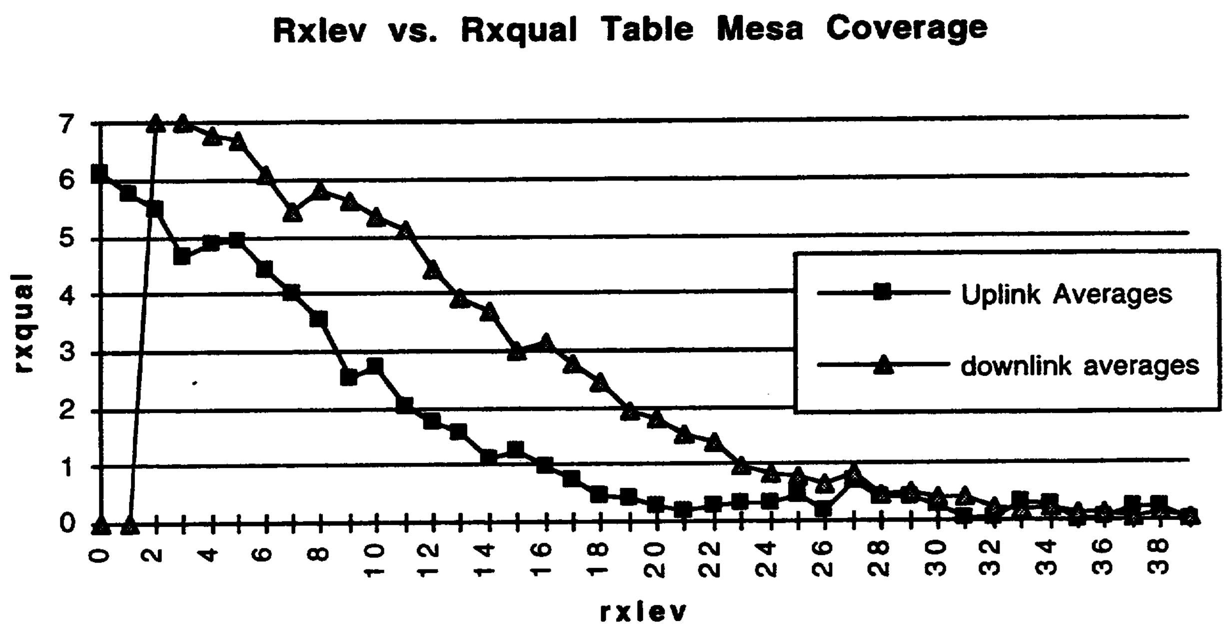
Table 5.2.2

Rxqual Value	Raw Bit Error Rate %
0	<0.2
1	0.2 to 0.4
2	0.4 to 0.8
3	0.8 to 1.6
4	1.6 to 3.2
5	3.2 to 6.4
6	6.4 to 12.8
7	>12.8

Empty records due to the slow sample rate on the uplink measurement were filled in with -1 values to denote no data.

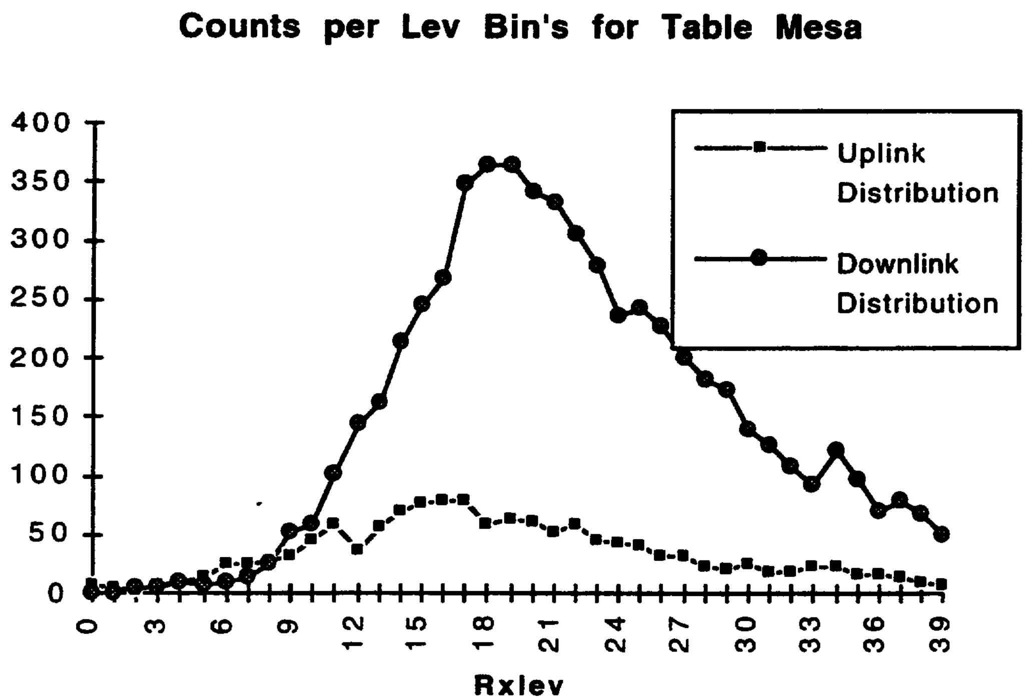
The graph for Rxlev vs. Rxqual is shown in figure 5.2.1. It contains the Rxlev versus Rxqual values for the coverage run (6583 points of data).

Figure 5.2.1



The number of occurrence per level for the total number of data points for the up/downlink is shown 5.2.2. The amount of data for the downlink was higher due to the different data collection rate.

Figure 5.2.2



The distance vs. downlink receive level (Rxlev) is shown below per sector and again for the overall data taken for this cell. A portion of the wide variation in the Rxlev data is due to the hilly terrain surrounding this site which covered approximately 75 sq. km. This very rough coverage estimate is obtained by mapping the boundary of the drive test radials for Rxlevs above -100 dBm measured at the in vehicle portable. This excluded sections not driven. To the North lies an East-West directed valley. The opposite side of this valley rises up again at about at 4-5 km. This creates a coverage shadow down in the valley but enhanced illumination on the opposite (North) side. A large number of samples were collected on this North side due to the choice of drive routes. There is 40 dB of variation per timing advance unit (0.5 km) from close to the cell to far away from the cell (7 km). A histogram of the number of occurrences of Rxlev values per segmented distance is shown to partially explain the flatness of the propagation slopes.

Figure 5.2.3

Table Mesa Distance vs. Downlink Rxlev per Sector

South-East y = -76.743-2.667*x+eps

North y = -81.201-1.165*x+eps

South-West y = -75.102-2.891*x+eps

CHAN: > 122

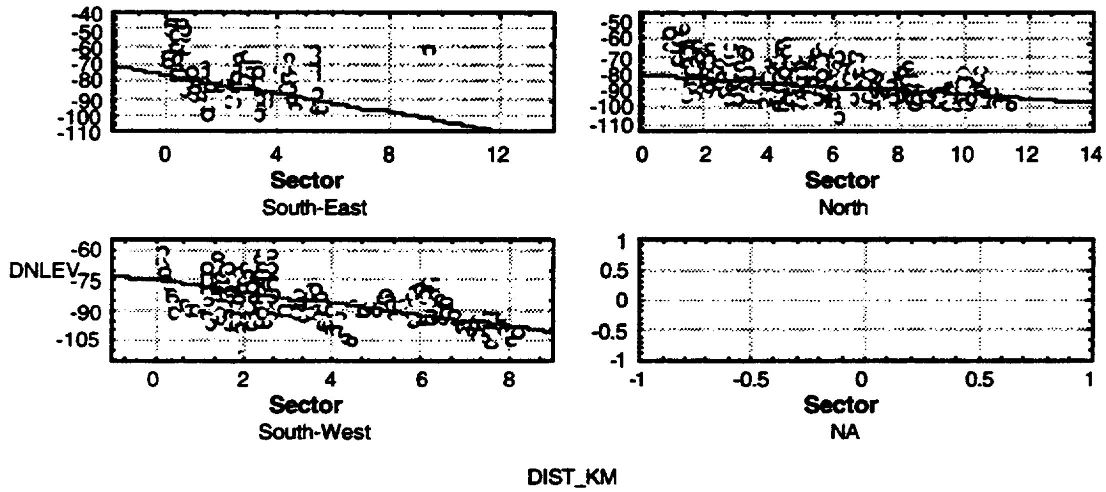


Figure 5.2.4

Table Mesa Distance vs. Downlink Rxlev

y = -79.427-1.534*x+eps

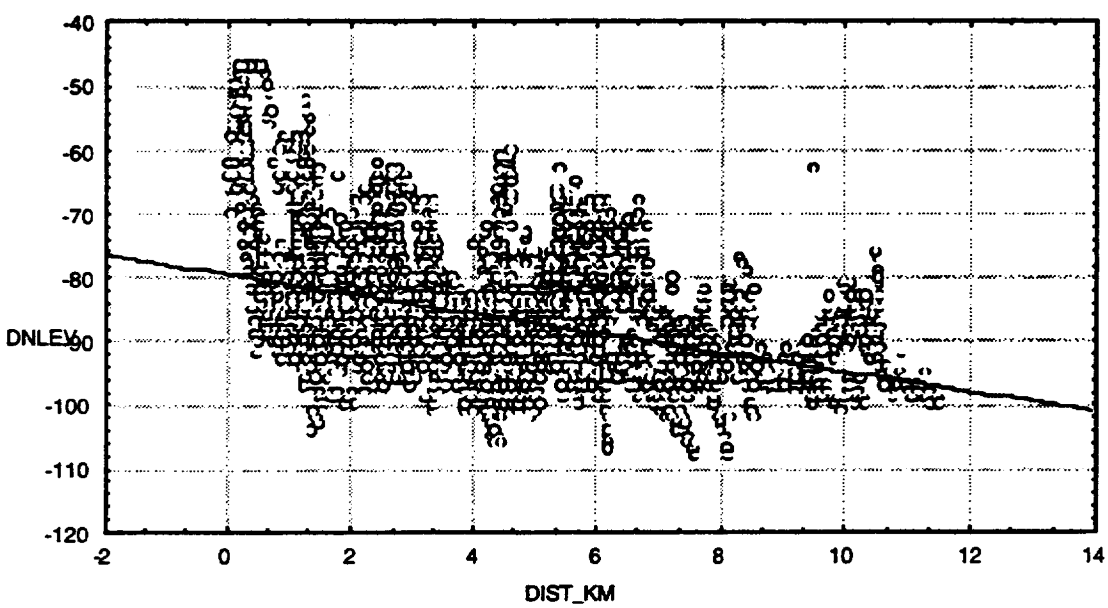
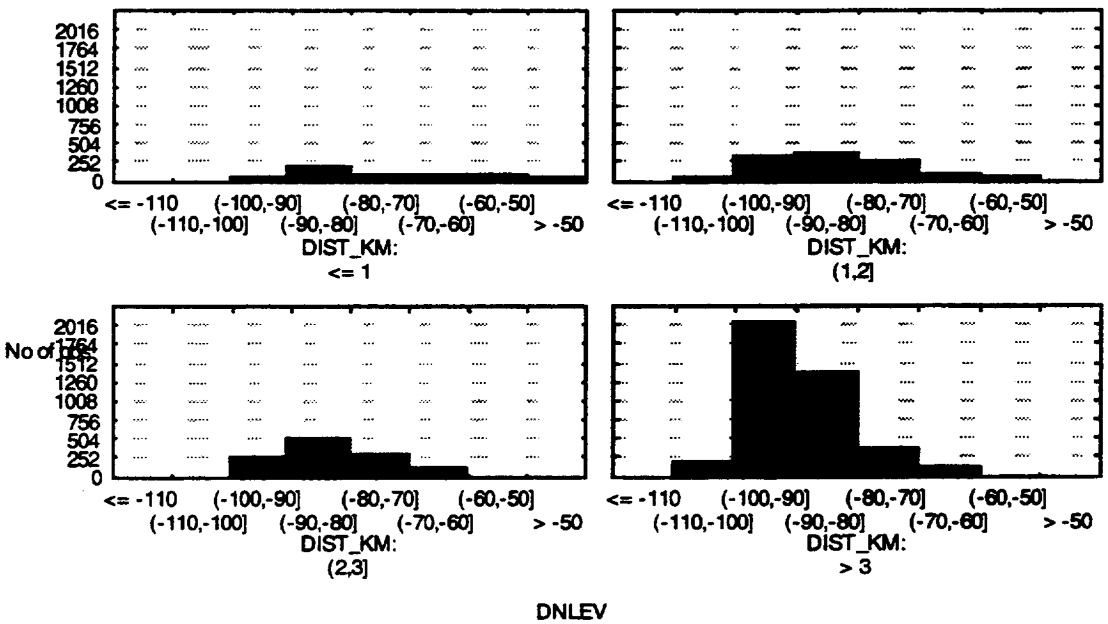


Figure 5.2.5

Histogram per Distance Segment for Downlink

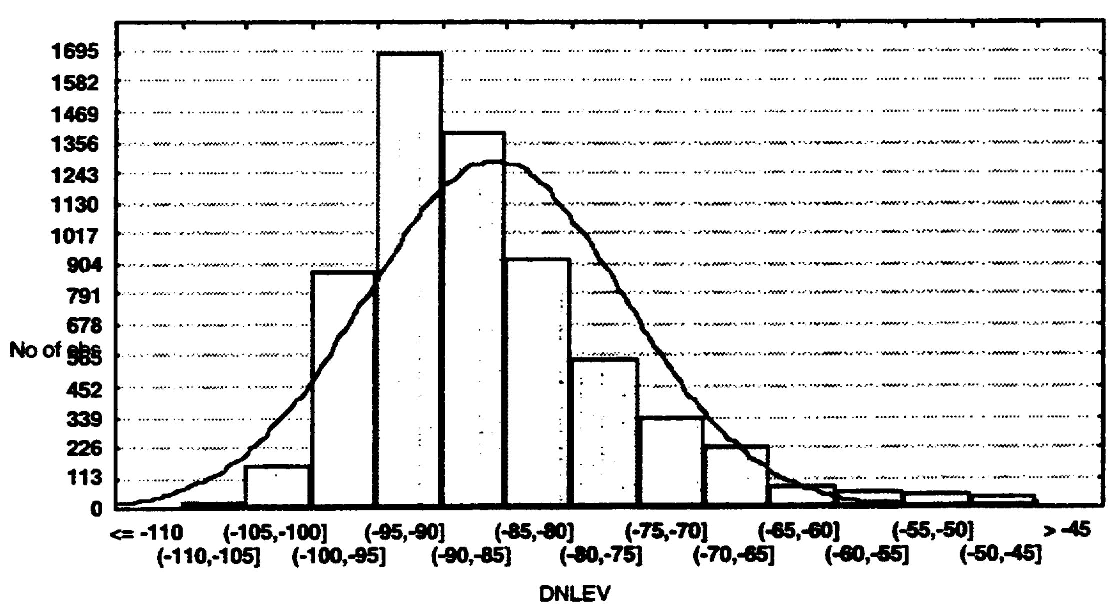


The curve fit shown is linear regression based on all of the data points included in the plot. The large number of samples at distances further away weight the linear fit to distance vs. downlink Rxlev such that it does not follow expectations. The graph below shows a histogram of Rxlevs measured.

Figure 5.2.6

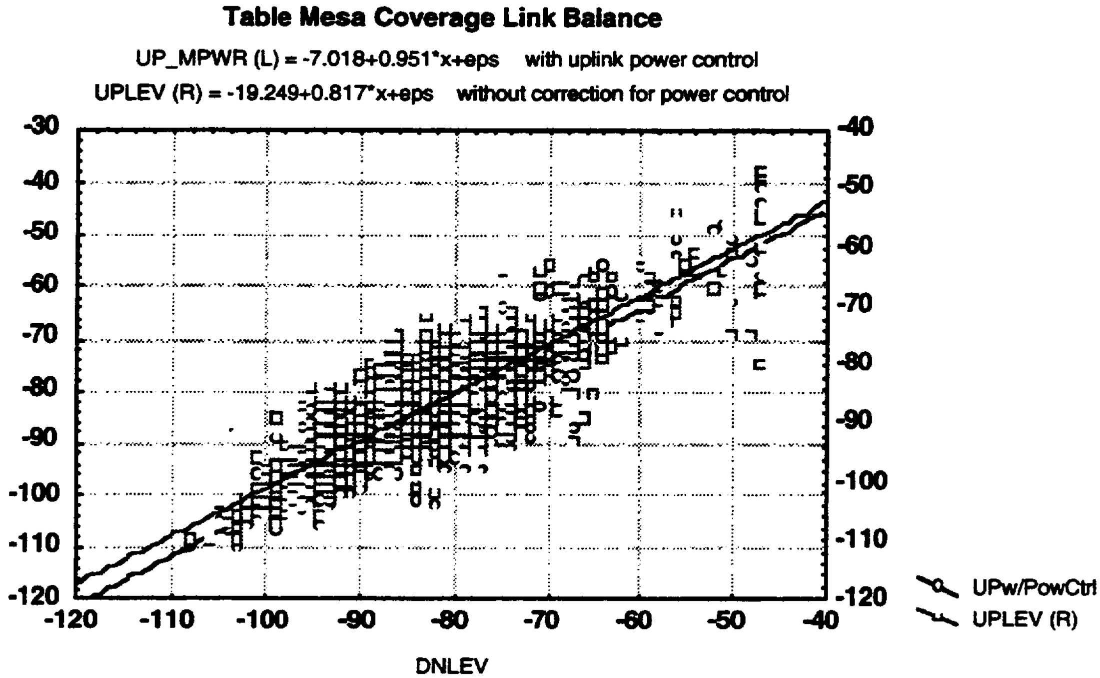
Histogram of Downlink Rxlev

y = 6393 * 5 * normal (x, -85.92913, 9.89147)



The following plots illustrate some of the analysis performed on the coverage data. The link balance chart shows that the links were nearly equal.

Figure 5.2.7



The next two graphs show a scatter plot of the Rxlev vs. Rxqual values for the Table Mesa coverage runs. They indicate the spread of Rxqual values over the Rxlev range. The number of Rxqual values of 0 help to pull the average down at higher Rxlev values even through poor Rxqual's do occur even in the -80 to -90 dBm range. If the Rxlevs were averaged for each qual bin the slope and intercept of the fit would be different. approximately -100 dBm the Rxqual values of 0 no longer appear and the average Rxqual is greater then 2.

Figure 5.2.8

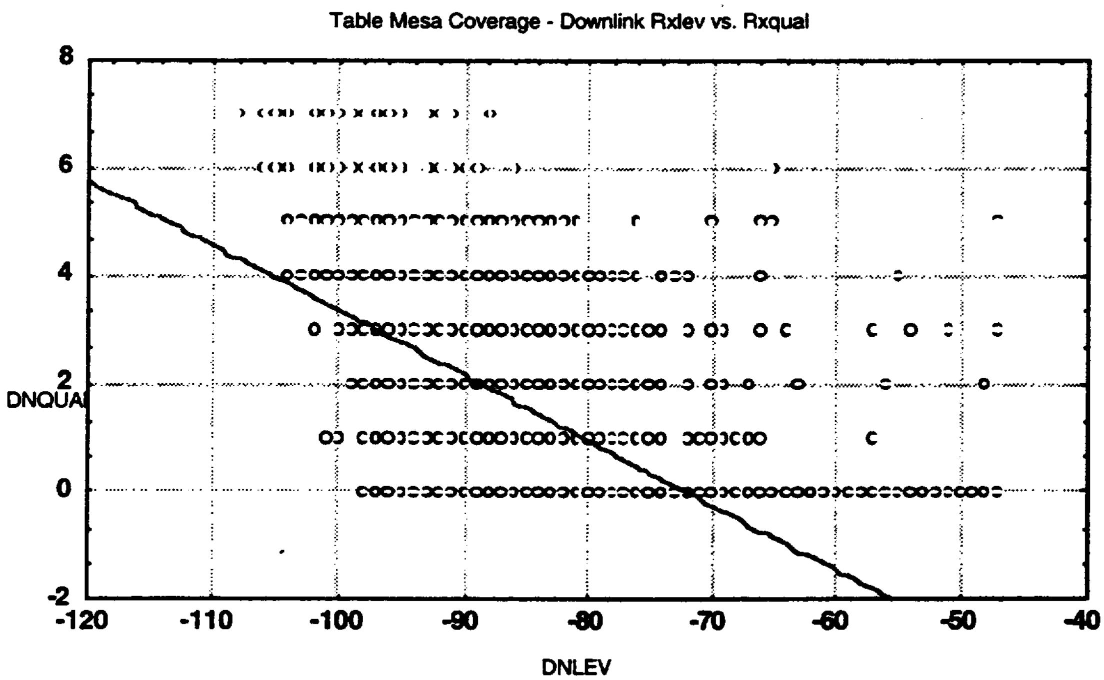
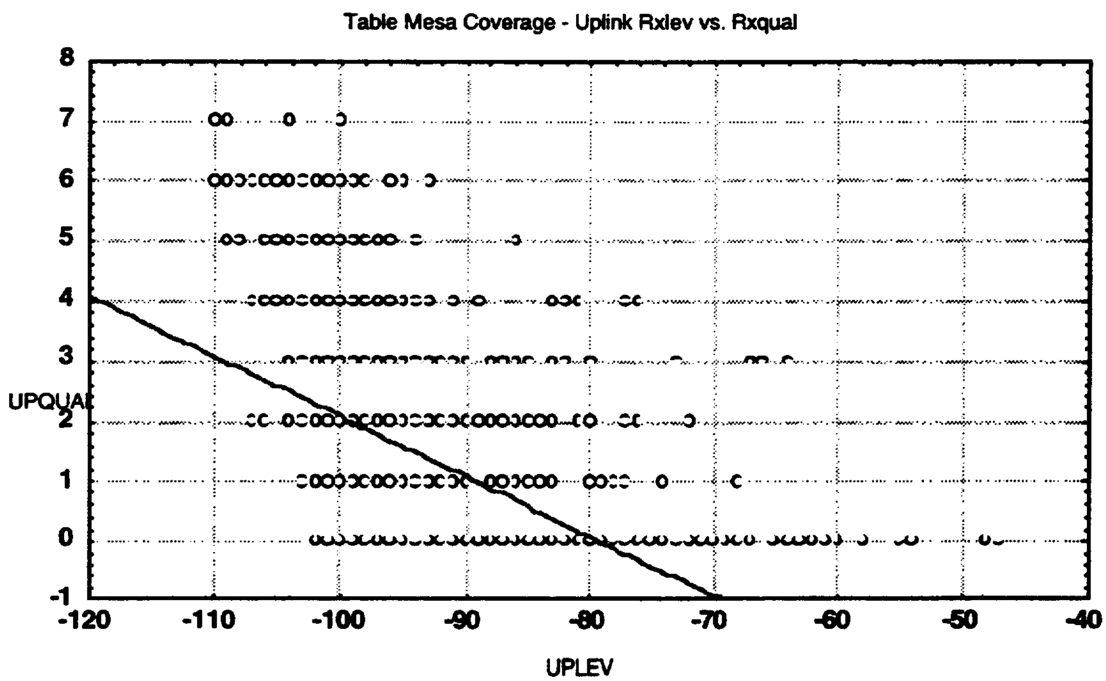


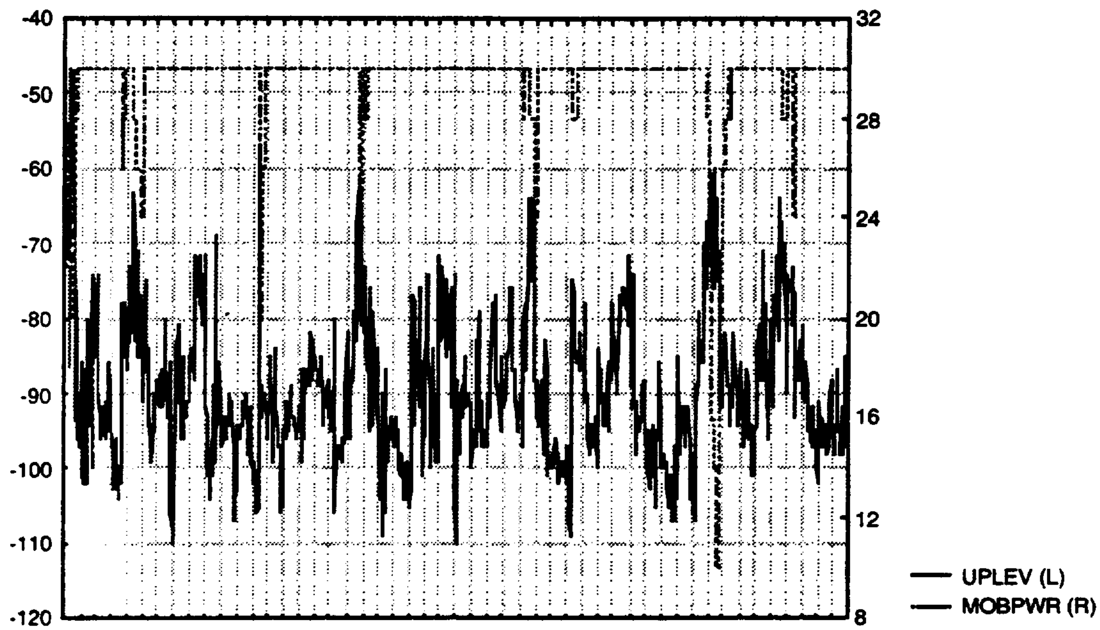
Figure 5.2.9



A function generally of interest is the power control of the mobile and base station. The BCCH carriers were the only frequencies on the air and there was no base station power control (downlink) for these tests. Mobile power control was enabled and the effectiveness is shown below. The mobile was transmitting at its highest power level (30 dBm) 90.4% of the time due to the setting of the power control parameters. The power control setting seem to be set for around 70 dBm before the mobile would power down. Below the x axis is time.

Figure 5.2.10

Table Mesa Uplink Rxlev and Mobile Transmit Power



5.3 Walnut CO Coverage Data and Discussion

Coverage plots were made to show received signal level and street information for the Walnut CO site. The density of the streets provides a representation of the density of the environment. The MOS scores from the voice quality testing are also shown to augment the levels shown for a total system coverage picture. The noise limited environment allowed the drive range to extent quite a bit further than the 1.8 mile design radius, so this map has been scaled to show the extent of coverage. The other scale of maps show mostly the 1.8 mile radius concentrating where the voice quality data was taken. The plots are presented in appendix C.

The radio data was collected from the ABIS interface at the BTS-BSC E1 link on an HP37900D protocol analyzer, which was post processed by NT to provide ASCII/space delimited data file. The GPS and dead reckoning location data were collected on a PC connected to a Trimble navigation unit in the van. The GPS data was collected at 1 Hz rate and the radio data was collected at the 480 ms rate. The collated records had radio data every 480 ms with the GPS data repeated to fill in the extra records.

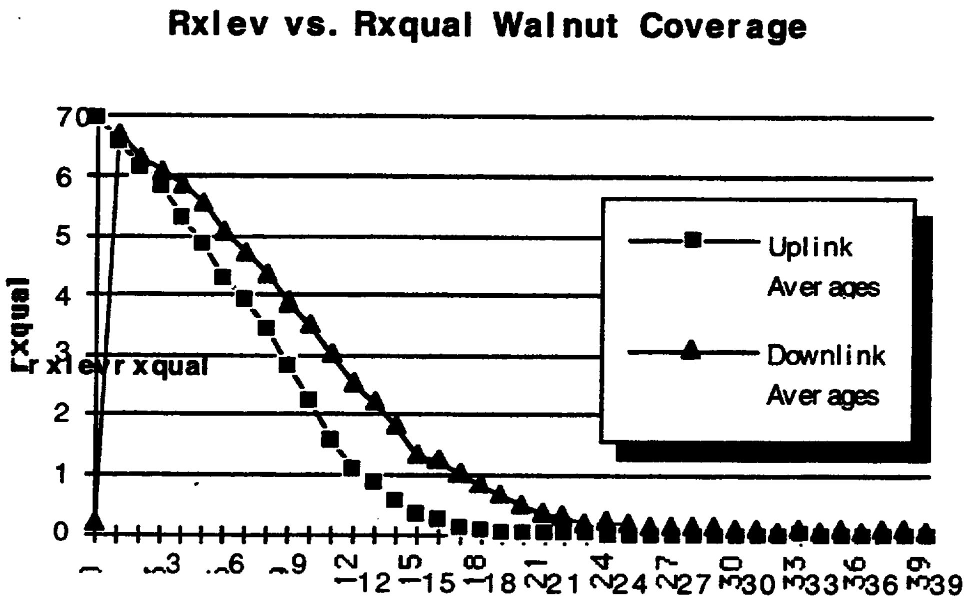
Table 3

Data in File	Description of Data
hour, minute, second	Current time of log file
lat, long	Position, updated every second
uplink Rxlev	A "0" Rxlev corresponds to -110 dBm and proceeds to Rxlev of 63 = -47 dBm
uplink Rxlev ave.	
uplink Rxqual	Raw bit error rate scale from 0-7 Rxqual shown in table 2
uplink Rxqual ave.	
downlink Rxlev	A "0" Rxlev corresponds to -110 dBm and proceeds to Rxlev of 63 = -47 dBm
downlink Rxlev ave.	
downlink Rxqual	Raw bit error rate scale from 0-7 Rxqual shown in table 2
downlink Rxqual ave.	
speed	Provided in miles per hour
timing advance	Time mobile advances transmitting timeslot due to distance1 TA = 0.5 km
timing advance ave.	
mobile power step	30 dBm - Power Step *2 for Mobile Tx Power
neighbor list	Rxlev, BSIC and cell neighbor number for up to 6 neighbors

NT provided a collated file for each approximately 20 minutes of run time. These were combined per site and used for this report.

Rxlev vs. Rxqual average for the Walnut coverage run is shown in the figure 5.3.1. There were 16,384 points. The higher clutter downtown location provided greater decorrelation between the two receive antennas. This provided for greater diversity gain in the base station receiver over the 3 dB gain expected in order two diversity when the branches are correlated.

Figure 5.3.1



The distribution of counts per level for the up/downlink is shown below.

Figure 5.3.2

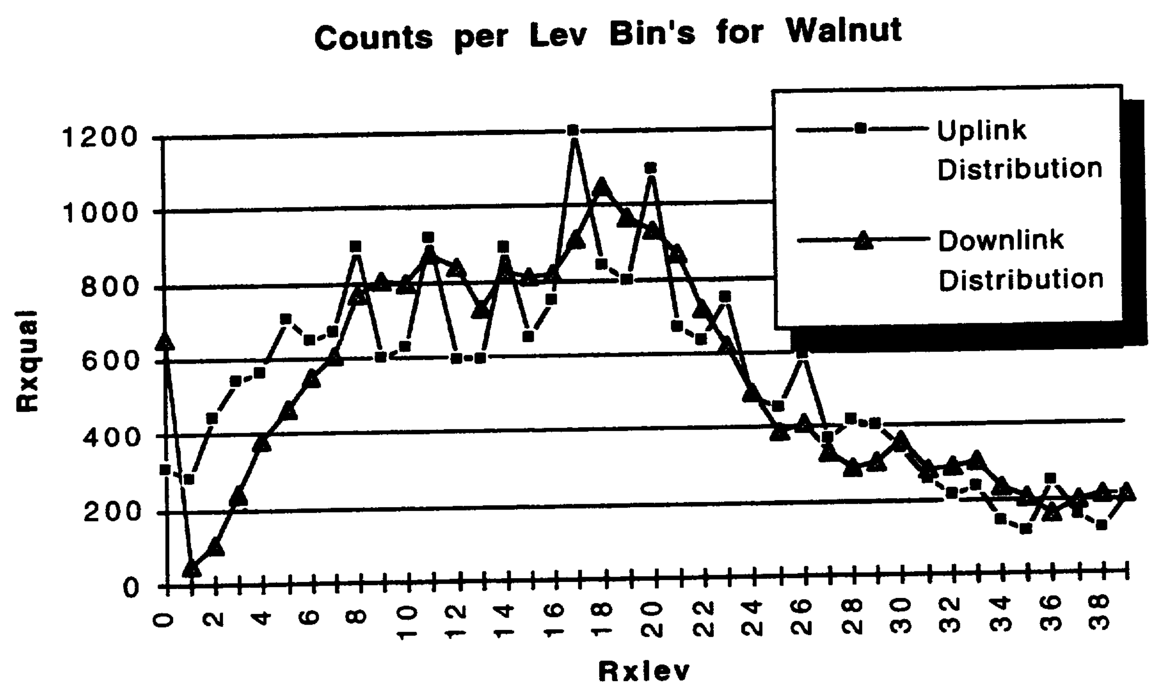
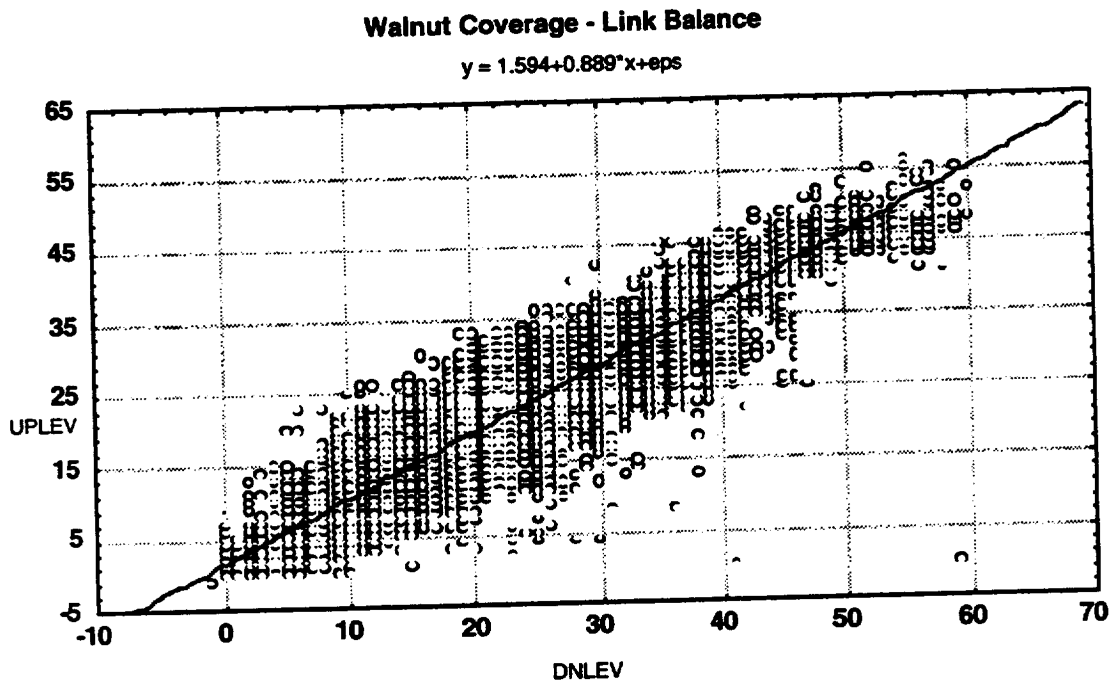


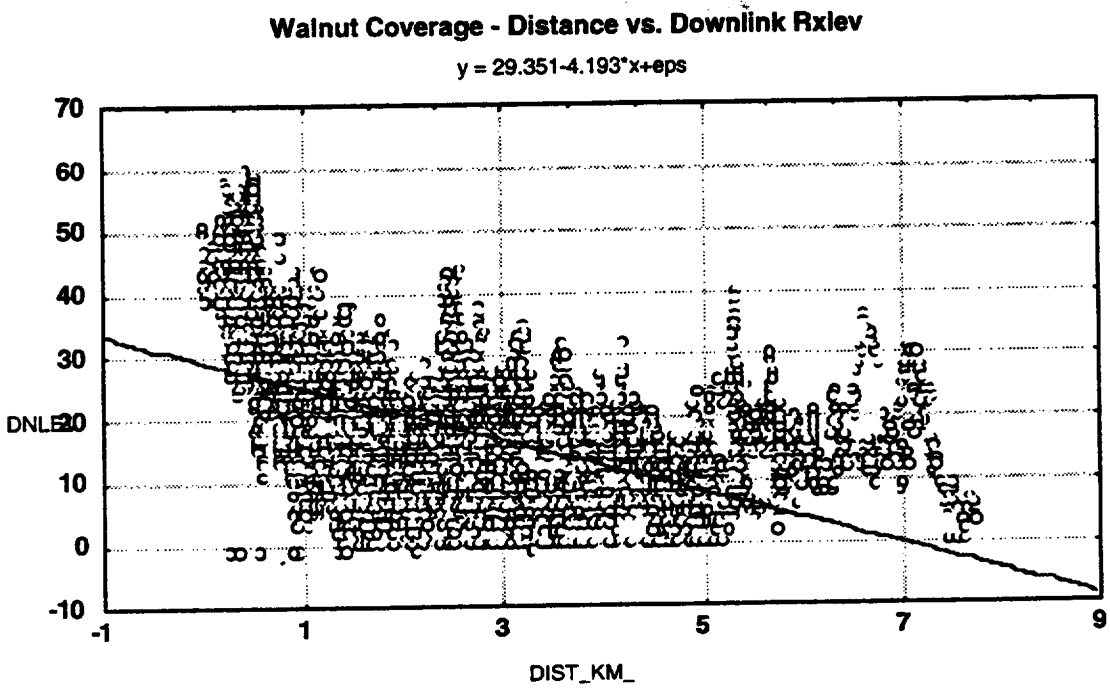
Figure 5.3.3 shows a scatter plot of the uplink Rxlev versus downlink Rxlev (in GSM scaled units). The figure, referred to as a link balance, chart shows that the links are roughly equal. Handset power control was disabled.

Figure 5.3.3



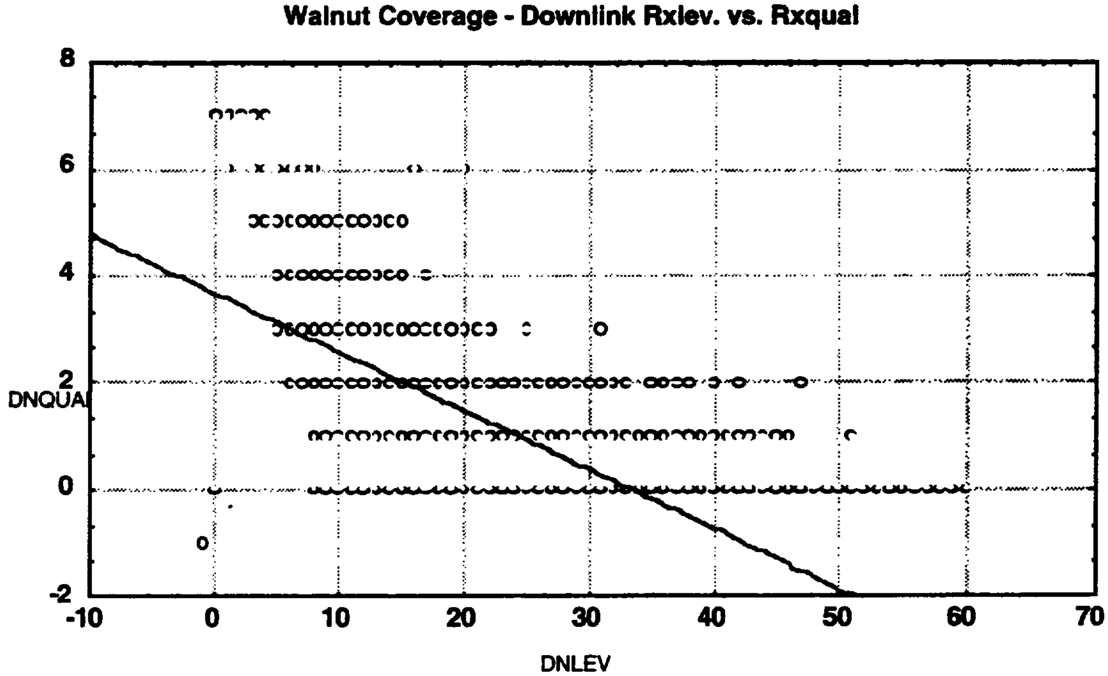
The distance vs. downlink Rxlev, shown in figure 5.3.4, is a good indicator of the type of clutter that this site encountered. The high propagation slope of 4.193 reflects the loss of coverage range for a large portion of this cell due to a ridge along the north side of the cell's coverage (this site sits in the bottom of the valley mentioned in the TMCO coverage section). Although the site was fairly high it had surrounding building that limit its range quite severely. The coverage was approximately 50 sq. km. The linear fit shown in the plot is calculated on the full data set.

Figure 5.3.4



The scatter plot of Rxlev and Rxqual, figure 5.3.5, shows the ranges of values that can be seen at different levels. The linear fit was calculated for the full data set. If the level were averaged for each Rxqual bin then fit the slope and intercept would be similar to that of figure 5.3.1. If this is compared to the Table Mesa scatter plot, this plot can be seen to have fewer poor Rxquals at Rxlevs > -90 dBm. It should be noted that the NT BTS reports, as the Rxlev, the total combined power from the diversity branches.

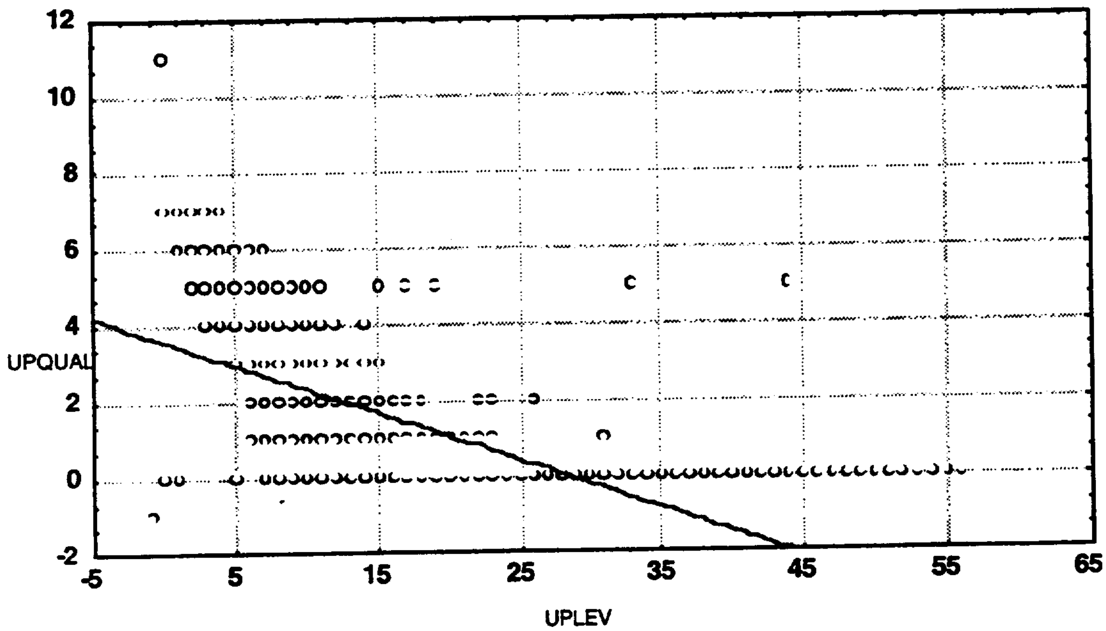
Figure 5.3.5



Walnut Coverage - Downlink Rxlev. vs. Rxqual
8
6
4
2
0
-2
DNQUAL
-10
0
10
20
30
40
50
60
70
DNLEV

Figure 5.3.6

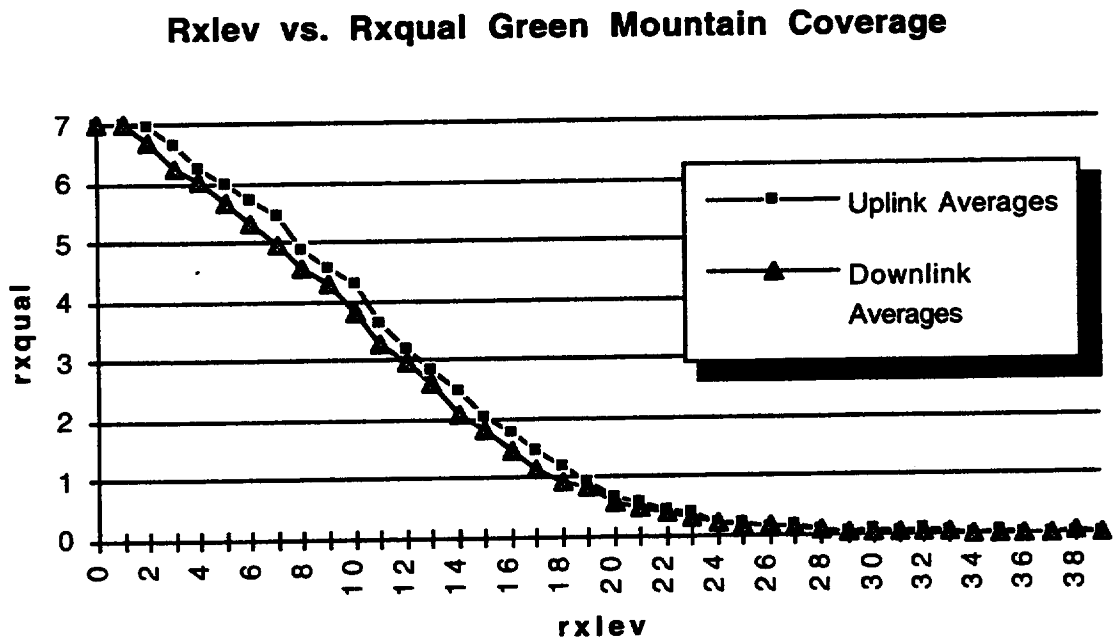
Walnut Coverage - Uplink Rxlev. vs. Rxqual



5.4 Green Mountain Mesa Coverage Data and Discussion

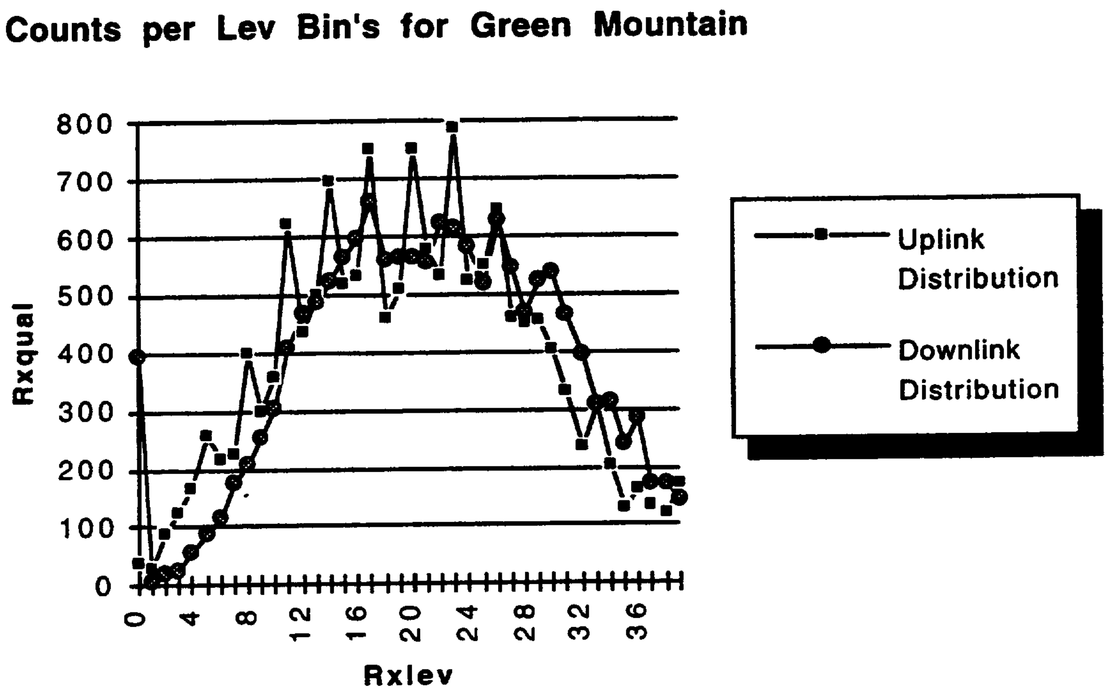
The same data collection methods were used for this site as for Walnut site. A look at the Rxlev vs. Rxqual is shown in the figure 5.4.1 below. There were approximately 12,000 data points for this graph.

Figure 5.4.1



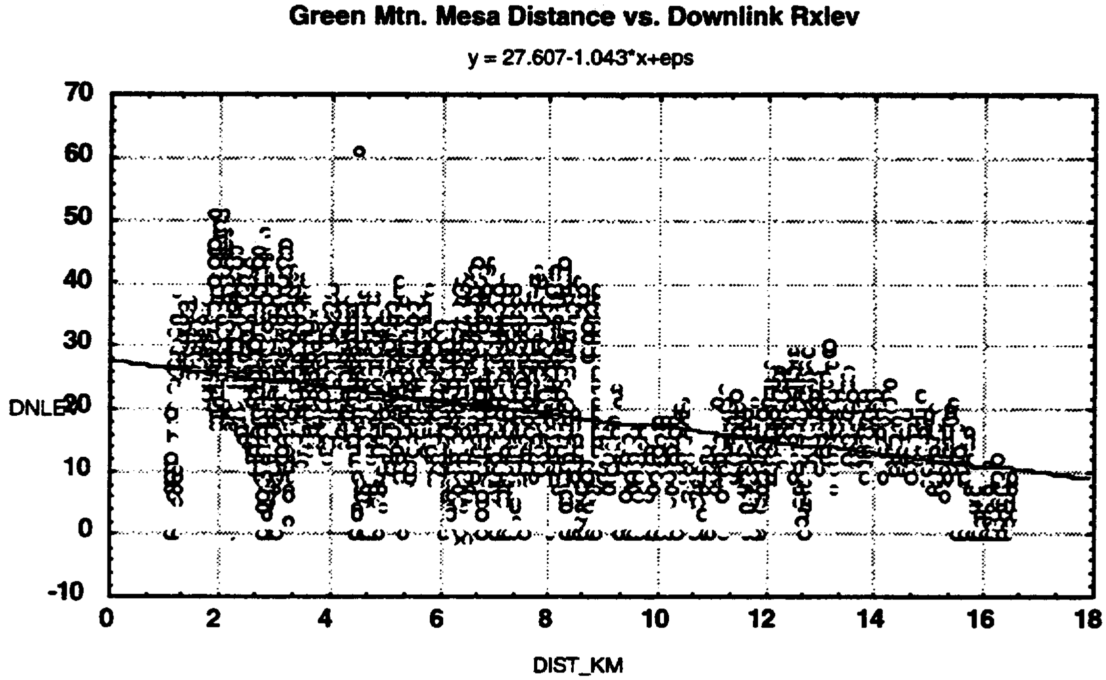
The statistical distribution of counts per level for the up/downlink is shown in figure 5.4.2 below.

Figure 5.4.2



The distance vs. the downlink level (in GSM scale units) for this site, is shown in figure 5.4.3. One can compare the Walnut site with this high hill top-unobstructed site to get a good view of the difference between these two sites. The propagation slope is low due to height of the antenna above the surrounding terrain. This site seems to be so high that line of sight coverage extends quite far out along the drive route. Also, only main roads were driven which also reduces the clutter loss. The coverage was approximately 110 sq. km. mapping to the boundary of the drive test region.

Figure 5.4.3



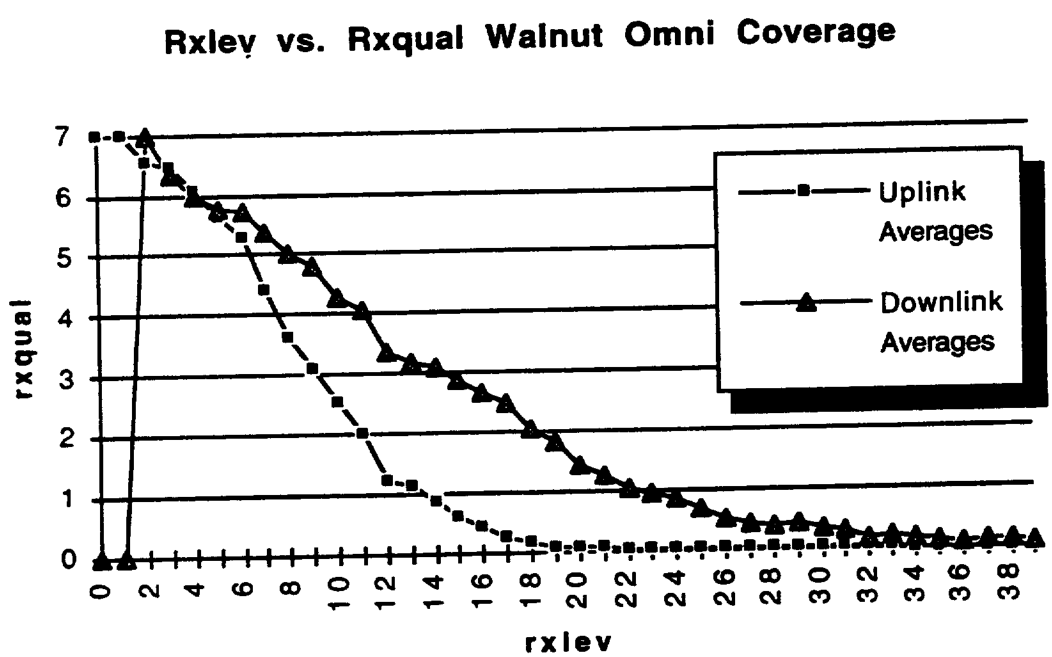
Coverage plots were made to show receive signal level and street information. The density of the streets provides a representation of the density of the environment. The MOS scores from the voice quality testing are also shown to augment the levels shown for a total system coverage picture. The noise limited environment allowed the drive range to extent quite a bit further than the 1.8 mile design radius, so this map has been scaled to show the extent of coverage. Coverage plots for this site are found in Appendix C.

5.5 Walnut CO Van Top Antenna Coverage Data and Discussion

Optional coverage data was taken for the Walnut CO site. Here the mobile antenna was mounted on top of the van, rather than inside. An Andrew 2 dBi magnetic mount rooftop antenna was used. A 2m foam loaded coax cable with insertion loss 0.3 dB was used between the rooftop antenna and the mobile unit inside the van.

The same data collection methods were used for this site as for the Omni -Walnut Co. site. A look at the Rxlev vs. Rxqual average is shown in the figure 5.5.1. This shows the diversity benefit on the uplink due to urban setting which provided some decorelation between the antenna. This run was done at much higher speed which tends to spread out Rxqual curve.

Figure 5.5.1



Similar routes as those for the Walnut coverage were used for the drive test with the roof top antenna. In a comparison of these similar geographical points (3602 matched) the mean roof top downlink received signal level was 8.25 dB greater than that of Walnut with the portable in the van interior. The maximum range was 12.8 km as opposed to 7.7 km for the in van antenna. Figure 5.5.2 shows a histogram of the range exhibited by the in-van antenna coverage runs while figure 5.5.3 shows that of the roof-top antenna coverage runs. The distance is in km.

Figure 5.5.2

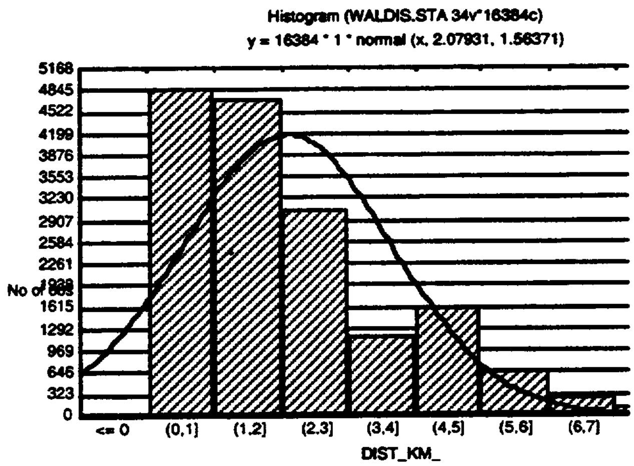
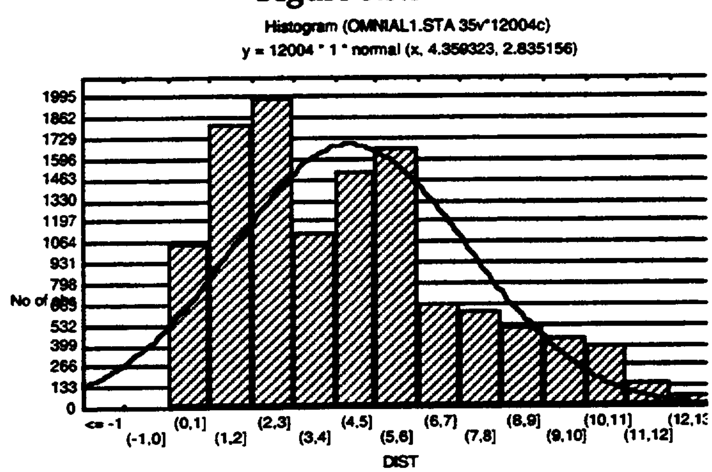


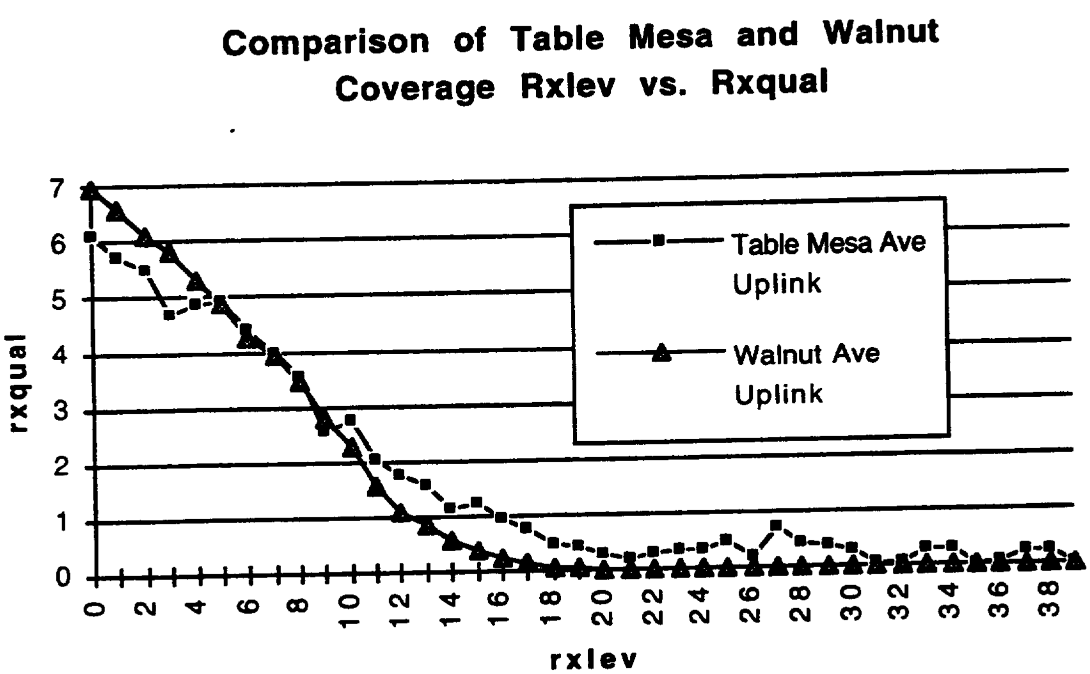
Figure 5.5.3



5.6 Comparison of Coverage Data

Comparing the Table Mesa site and the Walnut site on the uplink shows that both sites had similar sensitivity (see figure 5.6.1). The major difference in the data was that the Walnut site provided over 16,383 samples (overall average 1.07 Rxqual) while the Table Mesa site had 1390 samples (overall average 1.39 Rxqual). The larger number of points measured at Walnut was a result of the higher sample rate used at that site. The differences between these two sites might include different terrain characteristics, different delay spread, different BTS and MS equipment which would affect the overall average as well as different drive ranges/routes.

Figure 5.6.1



6.0 Interference Testing

Interference measurements were done for downlink only. Frequency hopping and DTX were not employed during these tests.

The drive route consisted of a square route that encountered good to poor C/I or C/A conditions. The route was repeated for each test scenario: no interference, co-channel, and adjacent channel.

For the co-channel interference measurement, WCO North face was used as the working sector (intended source). GMM North face was used as the co-channel interference source. Both the GMM North sector and the WCO North sectors were tuned to the same frequency. A second carrier, at a different frequency, was powered up on the GMM North sector. This carrier was used to measure the received level of the interfering signal from GMM at the victim mobile. Note that in this configuration the channel used for monitoring the interference level fades independently of the actual interfering signal.

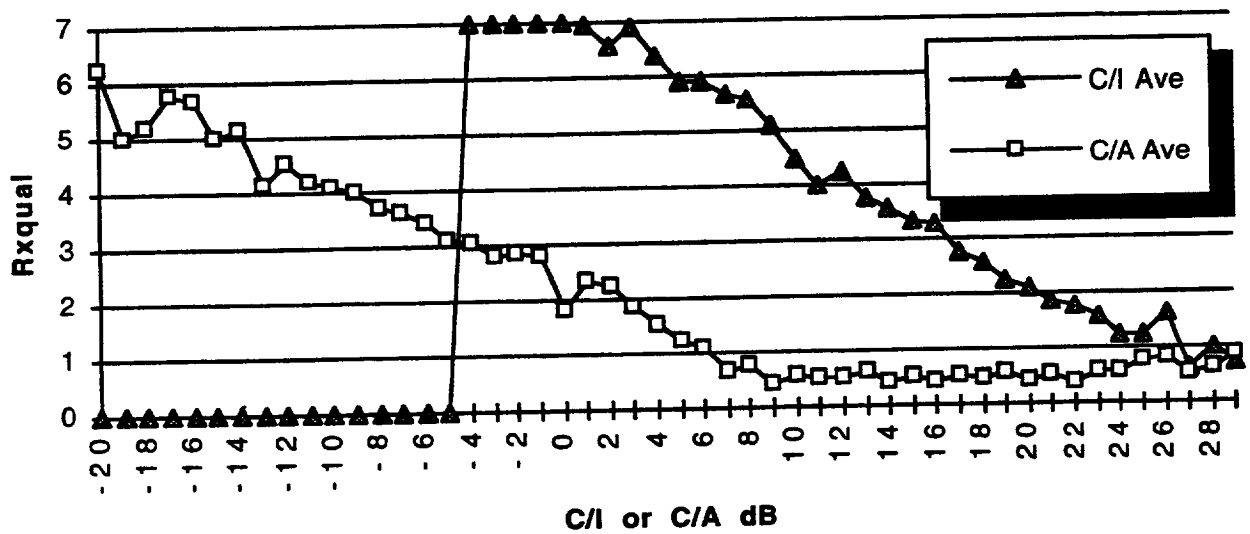
A route was chosen that would provide signal levels that would be above the noise floor. Most signal levels were greater than -100 dBm or 10 in GSM Rxlev units. This route was repeated for three cases with no interference present as a reference case. A table shows the effect of the C/I to average Rxqual for the cochannel case.

C/I (dB)	Rxqual Ave.
0-10	6
10-15	4.3
15-20	3.1
20-40	1.27

The comparison of the two interference cases is shown in figure 6.1 with respect to the average Rxqual at that C/I or C/A level. NT comments, "It can be remarked that the nominal 18 dB adjacent channel protection is well reflected by the relative spacing of the curves. This 18 dB figure holds for a marginally compliant equipment, well consistent with the 20 dB shown on the curves."

Figure 6.1

Cochannel and Adjacent Channel Interference



In general, the MOS scores showed that voice was degraded for Rxqual averages in the grouping of 3-7. As indicated in the above chart this group's midpoint would correspond to around 9 dB.

The scatter plot of the C/I vs. Rxqual shows the range of Rxqual values that occur for the C/I and C/A ranges. The spread of the Rxqual values is in part due to the difference between the method of calculating the interference (measuring test frequencies), this will in some cases lead to Rxqual values which do not truly correspond to the interference. However, on average this method of measurement is valid and did seem to portray the system as expected. The scatter plots throughout the report are merely linear regression of the two axes. The dB values are not linearized before the error is minimized, Statistica was used to provide the curve fits for all of these plots, including those of rxqual and rxlev. The scatter plots are used to show the spread of the data and not to represent the best curve fit available due to time constraints on the report writers.

Figure 6.2

Co-channel Interference vs. Downlink Rxqual

y = 6.765-0.204*x+eps

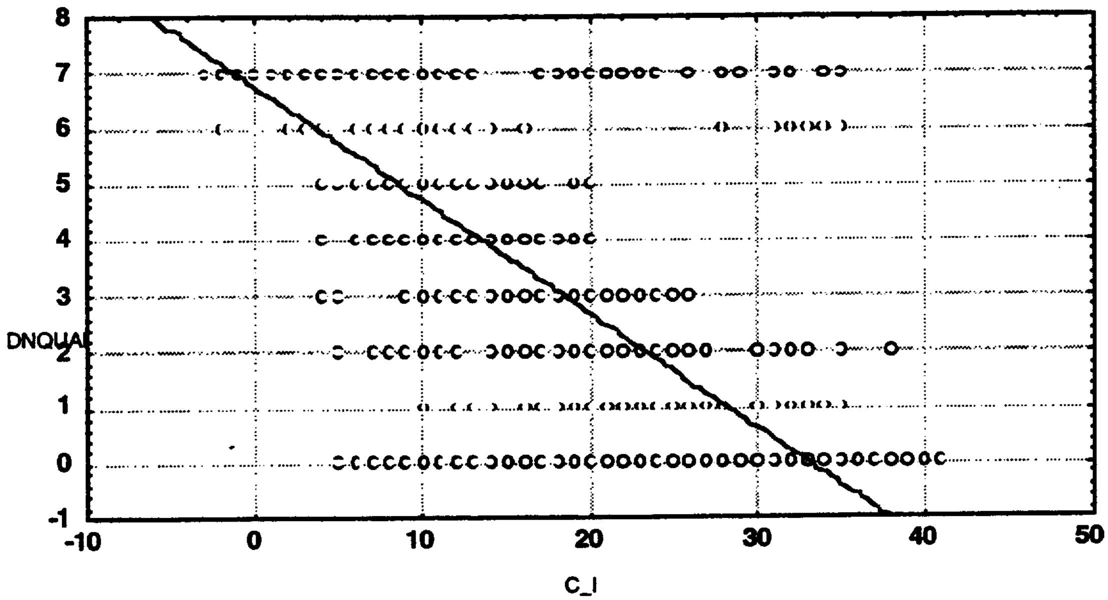
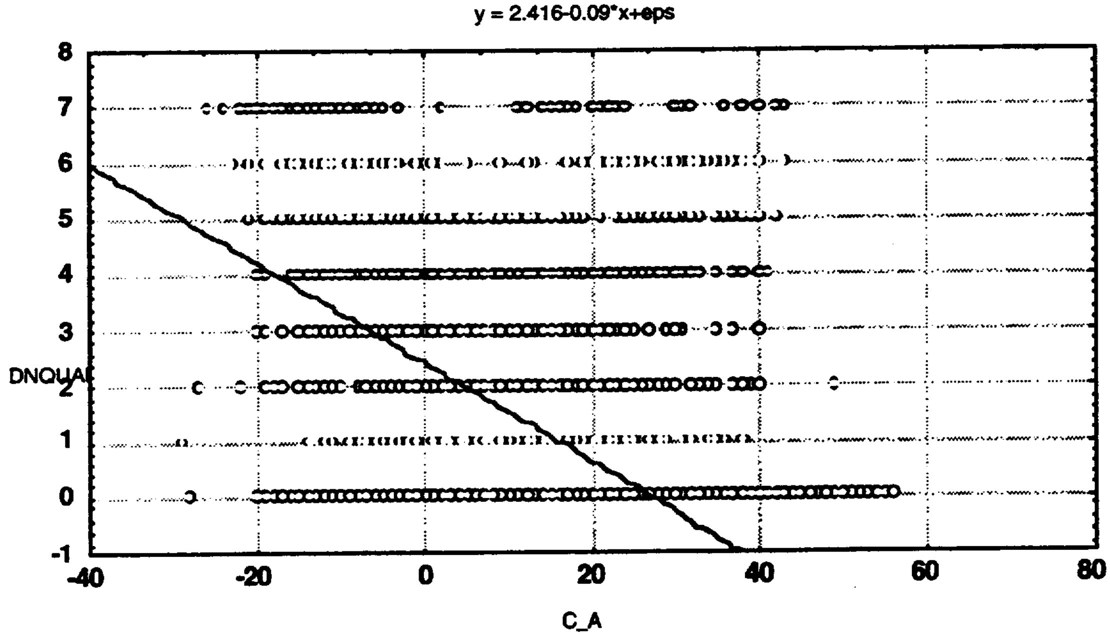


Figure 6.3

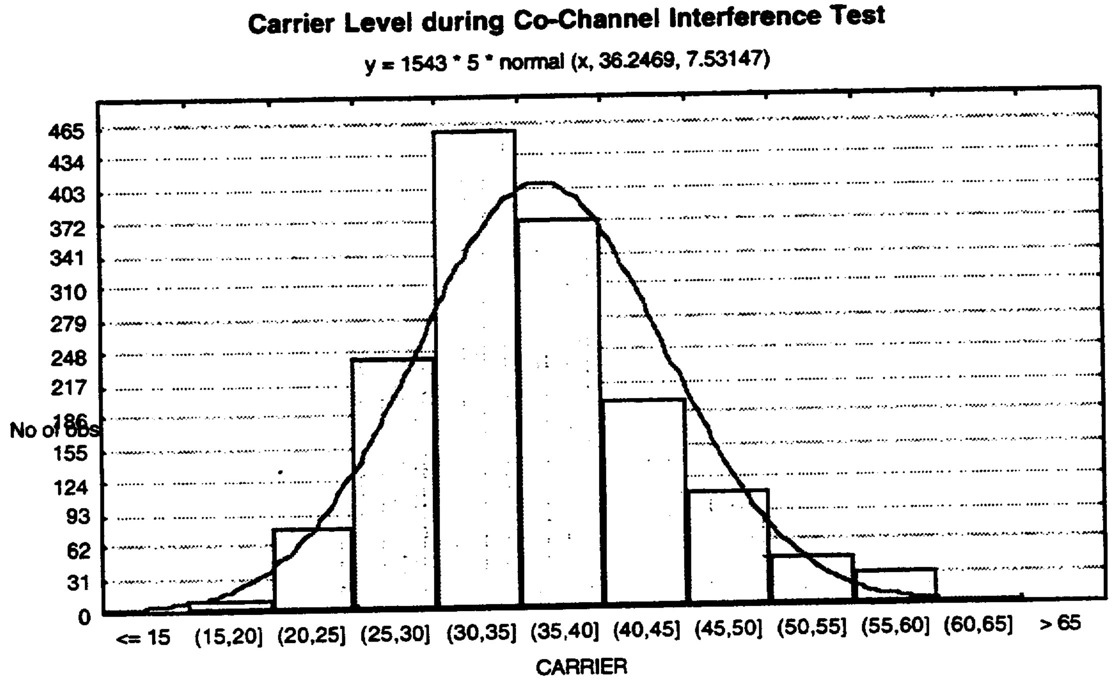
Adjacent Channel Interference vs.Downlink Rxqual

y = 2.416-0.09*x+eps



The carrier level must be above the noise floor to ensure that the Rxqual values are due to the interference, which is shown in the histogram in figure 6.4. The term carrier level is used in the graph to denote the test signal and is not the cochannel frequency since it is the combination of the carrier and interference source. The X-axis is in GSM Rxlev units.

Figure 6.4



7.0 Voice Quality

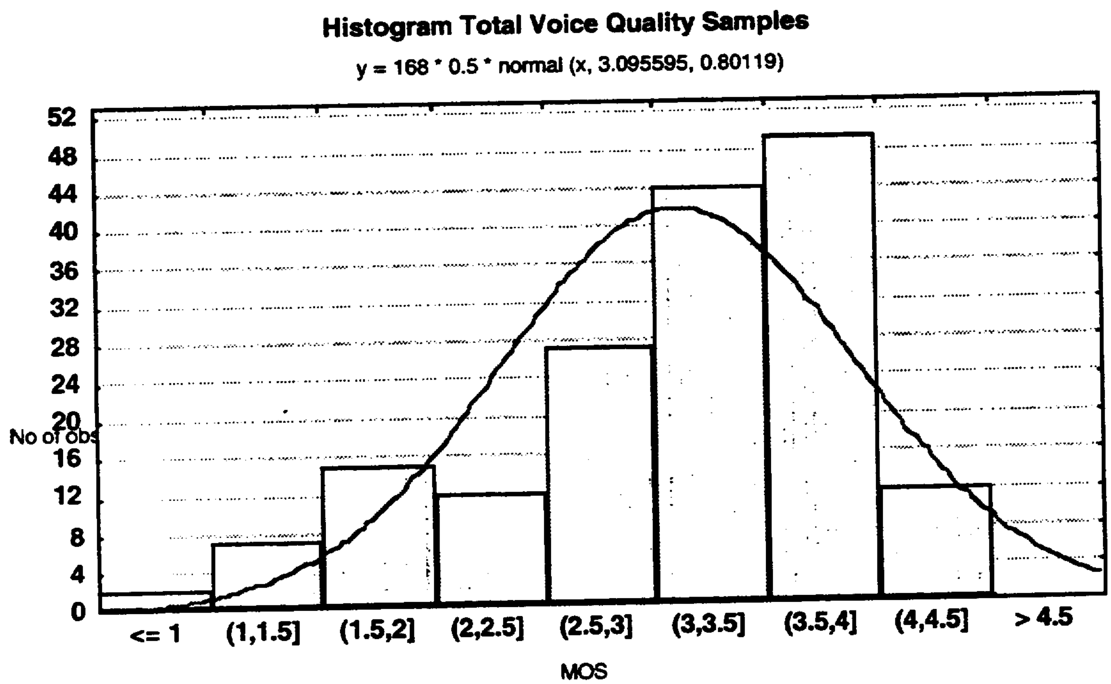
7.1 Voice Quality Data Collection Methodology

The MOS radio data was collected at each point along a 0.5 mile increment grid that enclosed the expected coverage for the Table Mesa and Walnut sites. The voice and radio data were taken for two cases of vehicle speed. In one case the vehicle traveled 10 meters over the sample time; in the other the vehicle traveled 100 meters. While the vehicle was in motion, a source tape would be played across each link simultaneously, one from the base to the mobile and one from the mobile to the base, and recorded at the opposite end. The source consisted of standard Harvard sentences, both male and female. For the Table Mesa site Rxlev and Rxqual data were collected over 2-5 minutes per location and for only one of the two links. Here it is assumed that the radio conditions for two links would be similar. The Walnut Rxlev and Rxqual data were collected simultaneously for the two separate links so that comparison to exact degradation's in MOS and Rxqual/Rxlev values was possible. The measurement location was recorded manually; GPS data were not recorded. There were always two mobiles transmitting in the vehicle during the voice testing. The mobiles were located within the vehicle and placed on a wooden carriage between the two front seats. The files were post processed, depending on the format, by USW to provide rxlev/rxqual information for each geographical location/grid point. Rxlev and Rxqual are averaged over the entire voice sample time. Therefore, the Rxlev and Rxqual values for a given MOS score do not reflect the occurrence of short term degradation due to shadowing or fading which may have affected the score.

7.2 Voice Quality Data and Discussion

The histogram of the total MOS scores is shown below in figure 7.2.1.

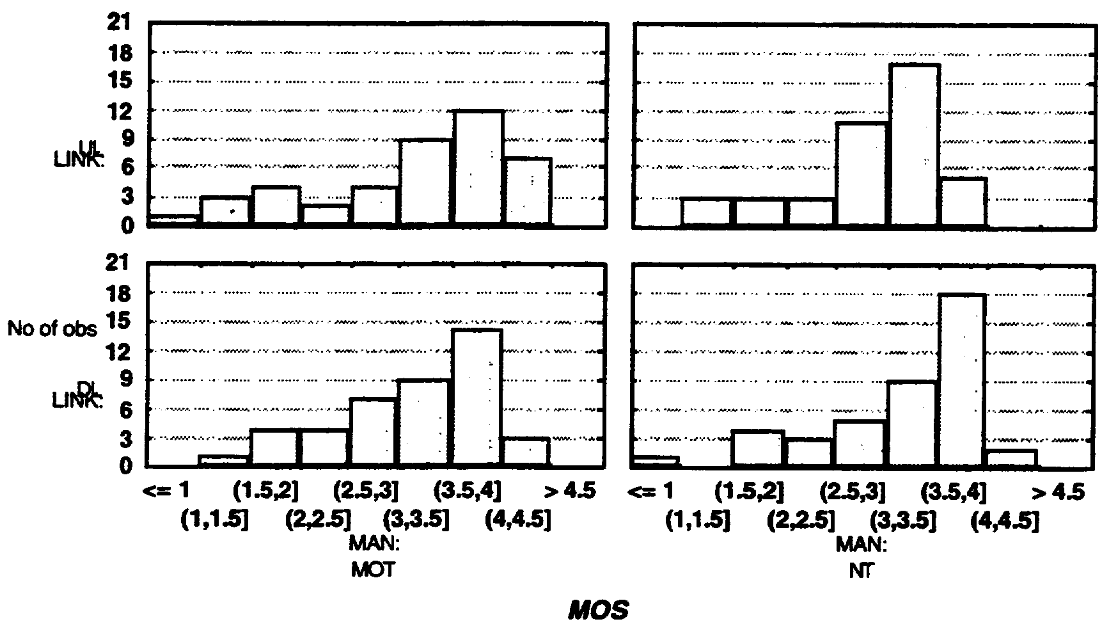
Figure 7.2.1



The following histogram, figure 7.2.2, shows the number of MOS scores delineated by manufacturer and by link type. The two plots on the left are for the Motorola equipment while those on the right are NTI. The upper plots are for the uplink, the lower represent the down link. One must be careful in comparing the results for the two manufacturers in that their equipment was deployed in different geographic locations and therefore experienced different operating conditions.

Figure 7.2.2

Histogram of MOS per link/Manufacture



In general, the Table Mesa site had higher average Rxlev values for the grid points th the Walnut site, yet the scores do not show a marked improvement for this site. The histograms for average Rxlev and Rxqual are shown to quantify the increased average signal strength that the Table Mesa site provided.

Figure 7.2.3

Histogram Rxlev of Grid Locations

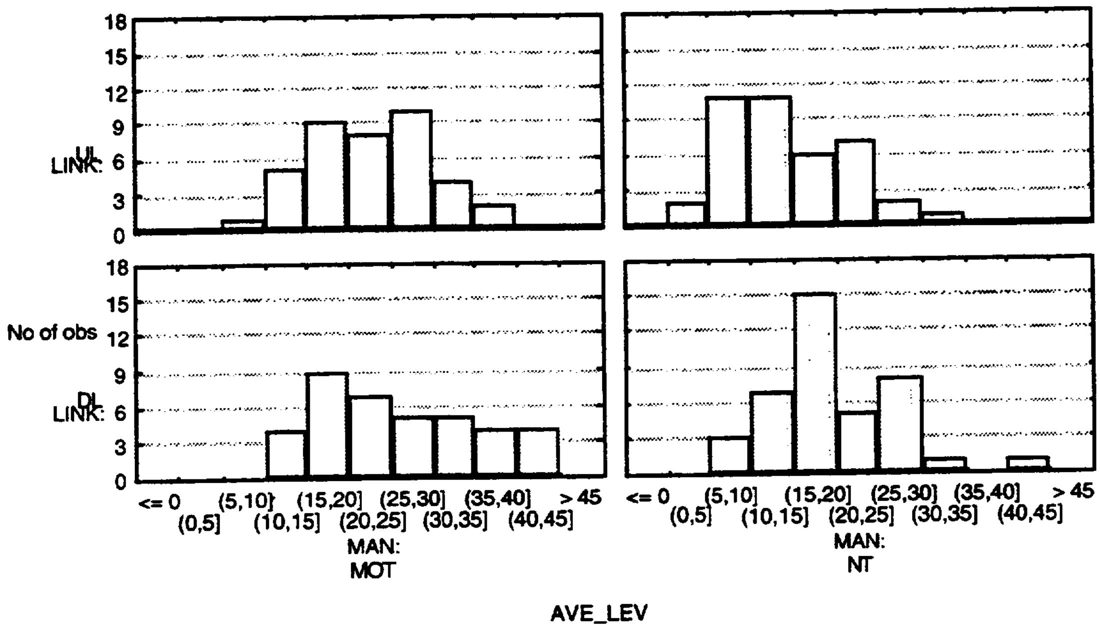
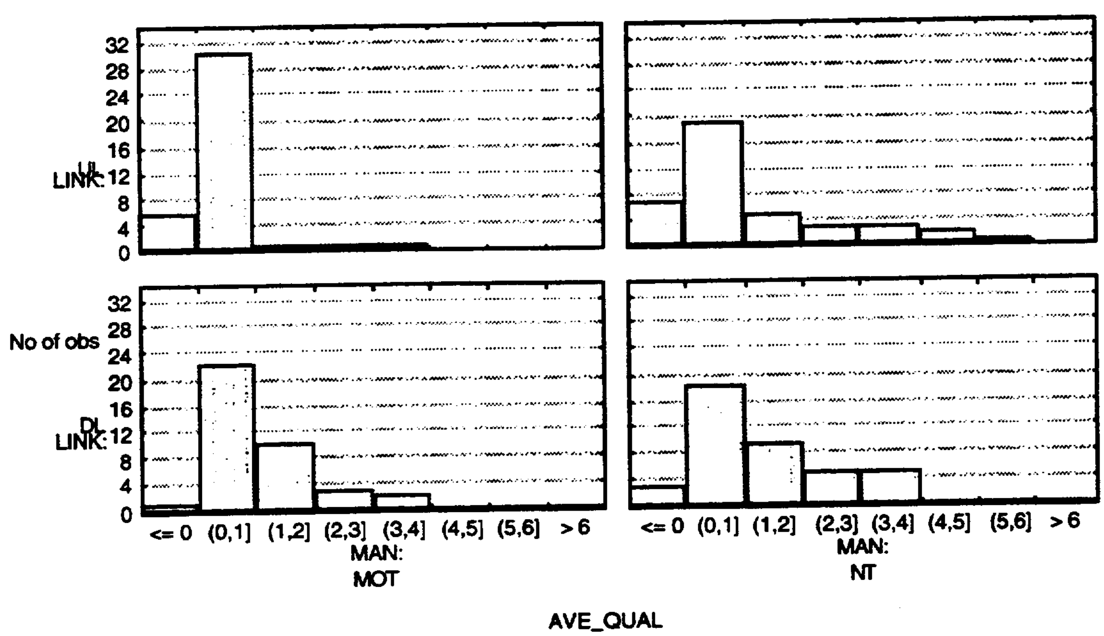


Figure 7.2.4

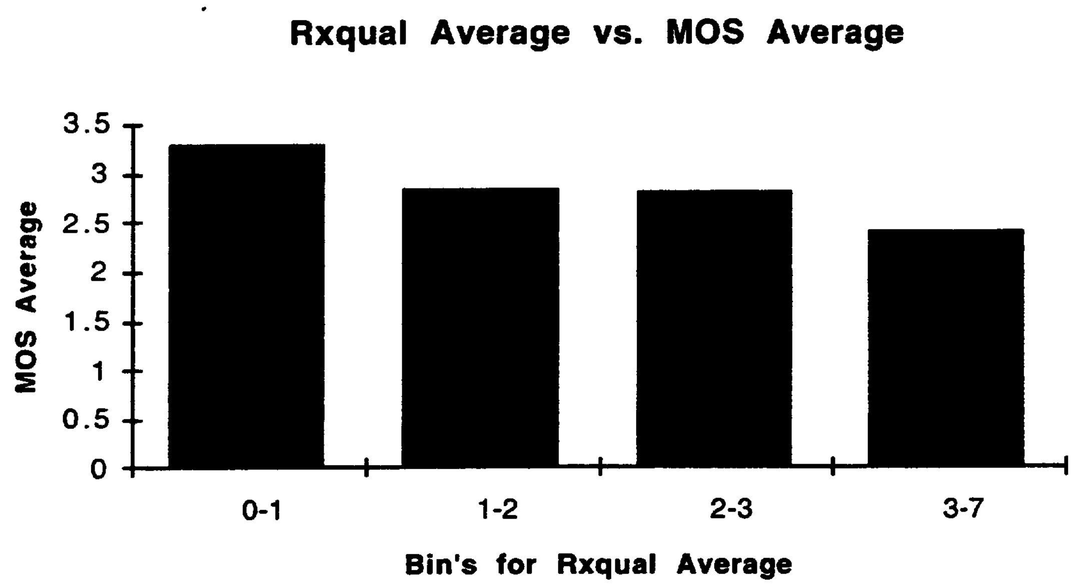
Histogram Rxqual for Grid Locations



There is some correlation between the Rxqual and MOS scores if averaged as shown below. If the Rxqual average is above 3, the MOS average suffers. Again, it must be pointed out that the average Rxqual is not itself an accurate indicator of the instantaneous Rxqual at any given time during the voice sample. A small number of poor Rxquals can significantly influence the MOS score while not affecting the average Rxqual.

Rxqual Range	MOS Average
0-1	3.27
1-2	2.82
2-3	2.8
3-7	2.41

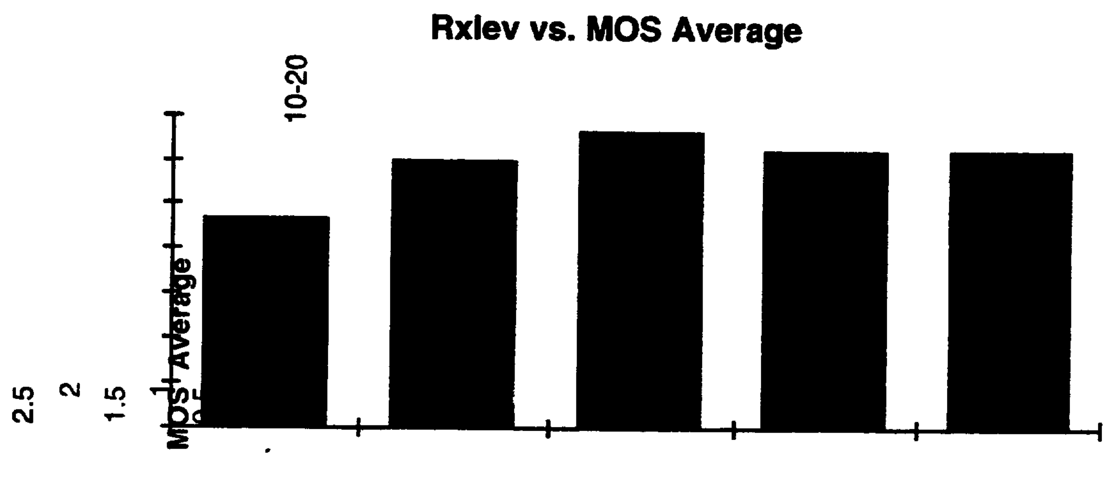
Figure 7.2.5



For the average Rxlev a similar correlation takes place at the lowest Rxlev range where Rxqual is significantly degraded. In the Rxlev range between 0-10 the MOS score is degraded. This is a reflection of the increased Rxqual values at these low Rxlev ranges.

Rxlev Range	MOS Average
0-10	2.32
10-20	2.99
20-30	3.3
30-60	3.1
ALL	3.09

Figure 7.2.6



However, if the radio parameters are not at the sensitivity level there is poor correlation between the average Rxlev and Rxqual values. In many cases the average values overwhelm small poor quality areas where the MOS score is low for seemingly good averages. Two examples of this effect are shown. Presented here are two instances of different up and downlink MOS scores which from the average values make little sense. First, the Motorola location 3F which was at a fairly high average Rxlev.

	MOS	Rxlev Average	Rxqual Average
uplink	3.57	28	0.01
downlink	1.29	31	0.1

The digression in MOS scores can be found by looking at the difference between the uplink and downlink maximum Rxqual average values, where apparently a few Rxqual's of 4 degraded the downlink voice quality.

Figure 7.2.7

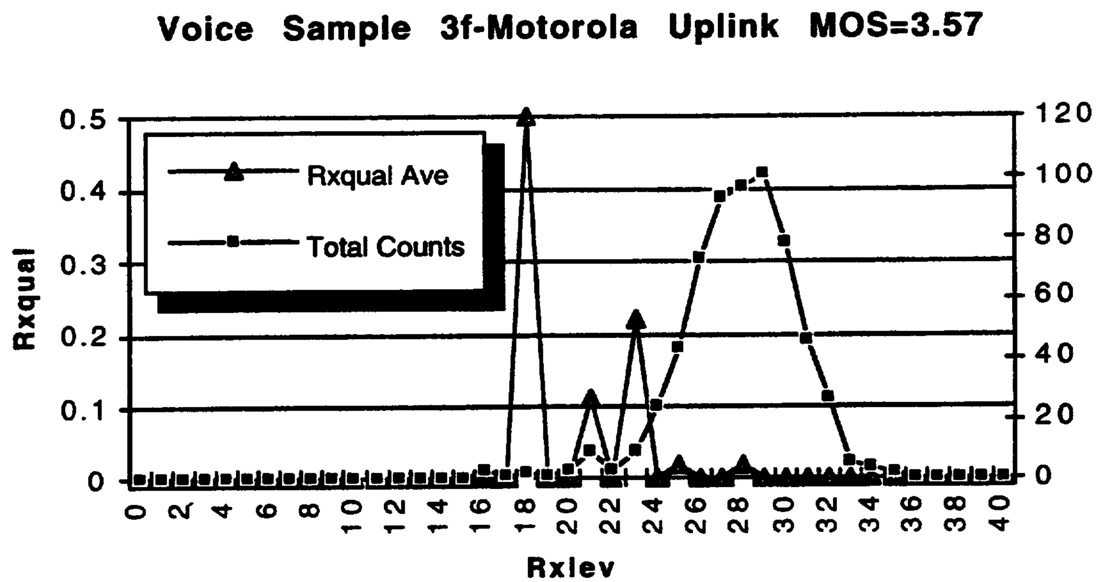
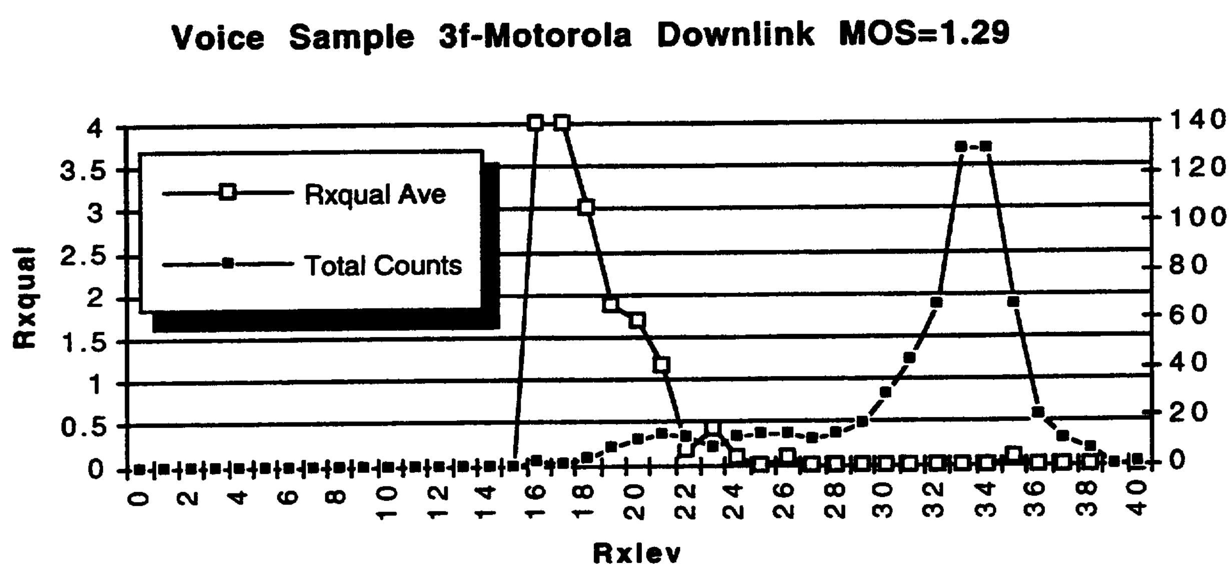


Figure 7.2.8



Next, is an example at very low signal levels of the Rxqual and Rxlev statistics for location 43F for the Walnut site. It is interesting to see such a high MOS score for the downlink considering the Rxqual's that are present.

	MOS	Rxlev Average	Rxqual Average
uplink	1.88	4.7	5.66
downlink	3.38	5.7	3.73

Figure 7.2.9

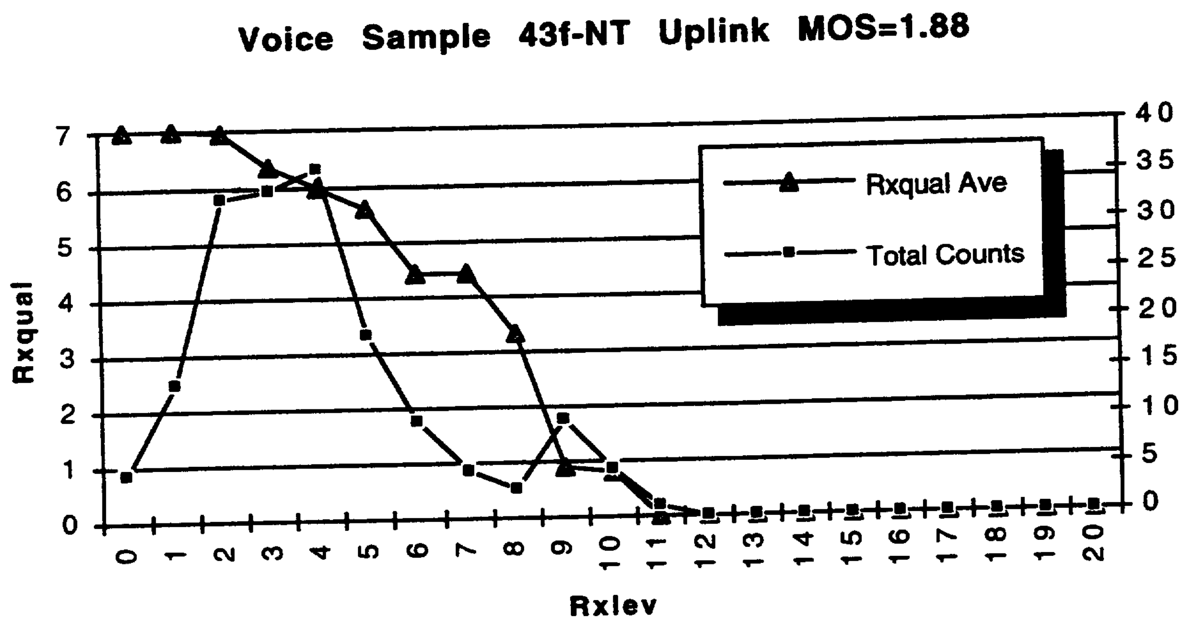
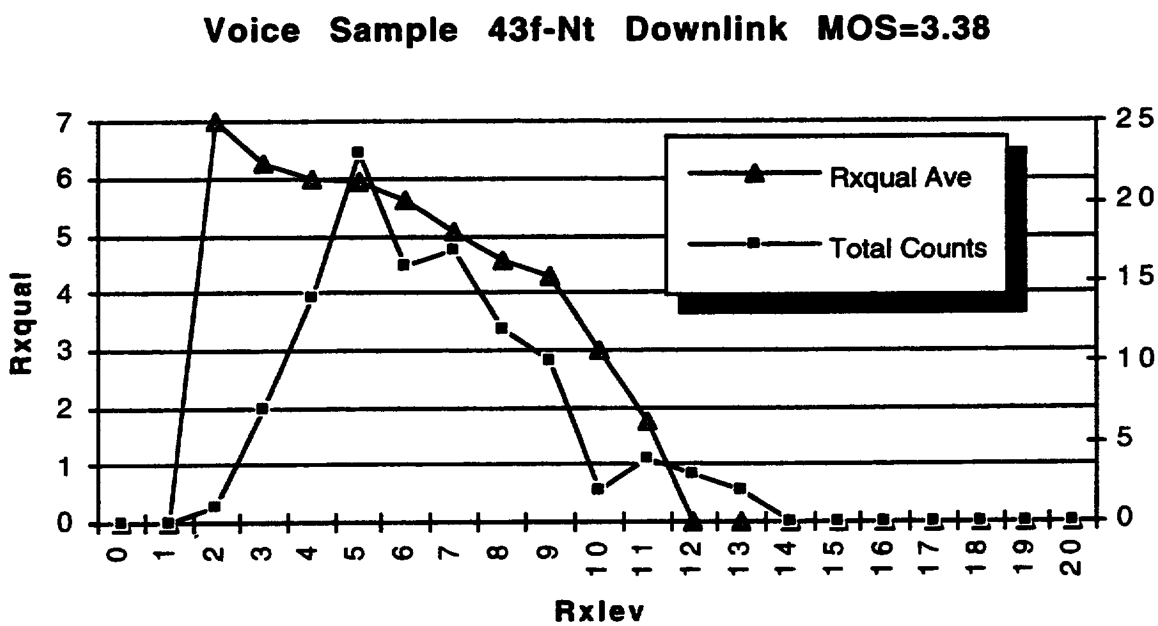


Figure 7.2.10



Voice Sample 43f-Nt Downlink MOS=3.38
Rxqual Ave
Total Counts
Rxqual
Rxlev
7
6
5
4
3
2
1
0
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

7.3 Voice Quality Assessment Methodology

7.3.1 Voice Sample Collection

A one-minute six-second voice segment was recorded every 0.5 miles in a grid pattern around two cell sites, and represents either uplink or downlink transmission from or to a PCS-1900 handset at each location. Eighty samples were taken using two Motorola handsets (one uplink, one downlink) and focused on a grid area around the Table Mesa cell site in South Boulder. Eighty samples were taken using Northern Telecom handsets and centered around the Walnut cell site in downtown Boulder. (see Appendix C) The voice segments were recorded onto metal Type IV audio tapes. Later the taped voice segments were digitized into a Macintosh SoundEdit 16 application at a rate of 16 bits, 22 kHz. All data was stored in a 102 Gbyte hard drive. Simultaneously the objective measures, rxlev and rxqual, were recorded via applications supplied by Motorola and Northern Telecom.

7.3.2 Subjects

Thirty subjects were recruited from the Boulder area to participate. Two groups of eight subjects and two groups of seven subjects were presented with 40 PCS-1900 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.

7.3.3 Schedule and Resources

Testing occurred between November 19, 1994 and December 1, 1994 at U S WEST Technologies, Boulder, CO. Each testing session lasted approximately two hours. Michelle Owens was the experimenter.

7.3.4 Methodology

Subjects first filled out a consent form. 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 each voice segment were randomized. A total of 160 samples were presented. The sentences were delivered directly from Macintosh SoundEdit 16 files and into eight handsets to each subject.

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); and
3) Would this be ACCEPTABLE as portable service? (Acceptable or Not Acceptable)

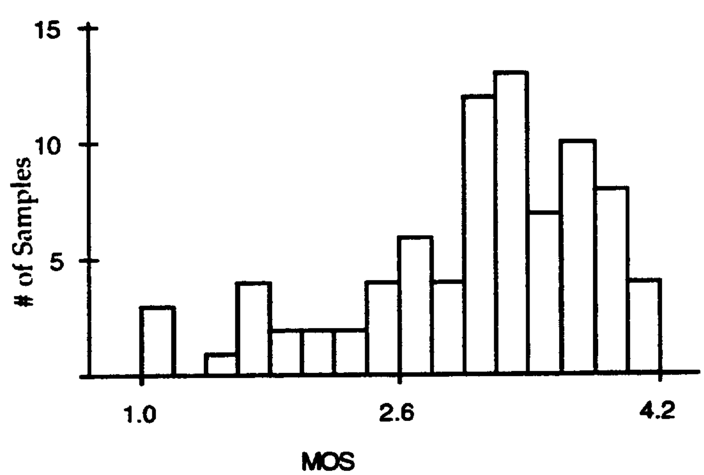
A computer application recorded subjects' responses to each voice segment. After all segments were presented, subjects filled out a post-trial questionnaire and a receipt of payment form.

7.4 MOS Data Analysis and Discussion

7.4.1 Data Analysis

Voice quality ratings from question one were averaged across subjects in order to obtain a Mean Opinion Score (MOS) for each sample. 20% of MOSs fell within the poor quality range of 0 and 2.49 (out of 5.00), 43% fell within the fair quality range of 2.50 and 3.49, and 37% fell within the good to excellent voice quality range of 3.50 to 5.00. Overall the voice samples were marked favorably, with 80% of the samples being rated between fair and excellent. The frequency distribution is skewed to the right. (see Figure 7.4.1.1) The mean MOS is 3.09 and standard deviation is 0.801.

Figure 7.4.1.1



Figures 7.4.1.2 and 7.4.1.3 show comparisons of MOS against two objective measures: average rxlev and average rxqual (0=good qual). MOSs show a large variance in scores at all levels of rxlev and rxqual. The engineering measures, averaged over the entire voice sample, do not appear to be accurate predictors of listener satisfaction.

Figure 7.4.1.2

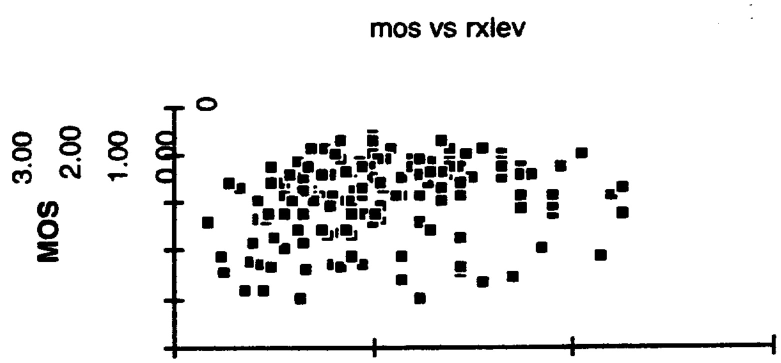


Figure 7.4.1.3

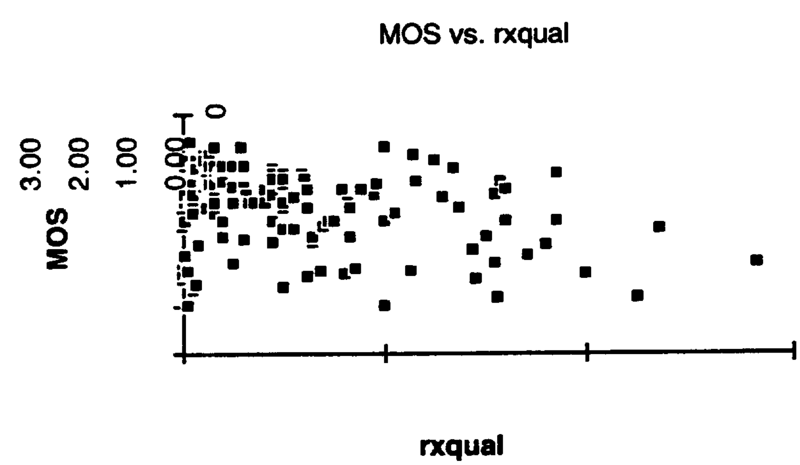


Figure 7.4.1.4 is a Pearson Product-Moment correlation table and outlines the correlation coefficients of MOS vs. average rxlev and rxqual. The correlation coefficient between MOS and average rxlev is 0.217. Between MOS and average rxqual it is -0.343. Note, an rxqual of 0 = good, whereas an MOS of 1.00 = bad, thus revealing a negative relationship. The coefficients are quite low, therefore there does not appear to be a linear relationship between MOS and average rxlev or between MOS and average rxqual.

Figure 7.4.1.4

Pearson Product-Moment Correlation

	mos	rxlev	rxqual
mos	1.000		
rxlev	0.217	1.000	
rxqual	-0.343	-0.666	1.000

MOS vs. average rxlev and average rxqual are not linearly related but may still reveal a consistently increasing or decreasing trend. For instance, the variables may consist of a logarithmic relationship. A Spearman Rank Correlation was performed to analyze the ranks of MOS vs. the ranks of rxlev and rxqual. In this case, the log (rxlev) or l (rxqual) would reveal the same coefficients as rxlev and rxqual. The coefficients for MOS vs. rxlev and rxqual are 0.277 and -0.266, respectively. There is neither a linear nor logarithmic relationship between MOS and the engineering measures.

Figure 7.4.1.5

Spearman Rank Correlation

	mos	lev	qual
mos	1.000		
lev	0.277	1.000	
qual	-0.266	-0.732	1.000

Note, the values used for rxlev and rxqual above were averages over the entire leng of the samples. By analyzing the engineering data within the 1 minute-6 second time frame, further insight may be gained on the behavior of MOS. By taking into consideration minimum rxlev or maximum rxqual, we may better understand the nature of the MOSs.

7.4.2 Expert Listener Analysis and Discussion

Voice segments were analyzed utilizing the expert listener methodology was used. This analysis was done before the results of panels of listeners were analyzed. A 3-point scale of acceptability was utilized:

1) Definitely acceptable (or "Green"),
2) Marginally acceptable ("Yellow"), and
3) Unacceptable ("Red").

The expert listener, Michelle Owens, was trained, prior to PCS-1900 testing, to emulate the responses of panels of listeners to question three: Would this be ACCEPTABLE as portable service? The expert listener attempts to match the following 3-point scale for question three:

1) >70% of subjects rate sample as acceptable (Green),
2) 30 - 70 % of subjects rate sample as acceptable (Yellow), and
3) <30% of subjects rate sample as acceptable (Red).

Figures 7.4.2.1 and 7.4.2.2 show the relationship between expert listener (EL) ratings and listener responses to question three, or % acceptability [p(A)]. Recall, % acceptability is the % of listeners rating a given sample as acceptable.

Figure 7.4.2.1

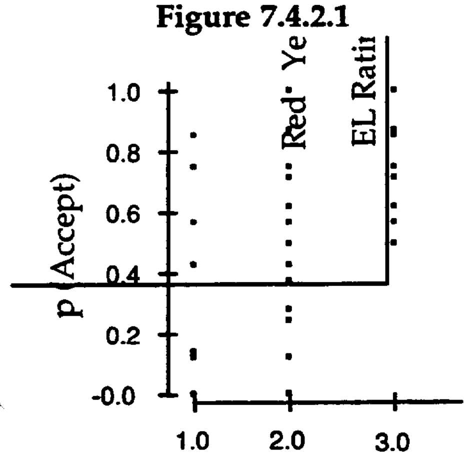


Figure 7.4.2.2

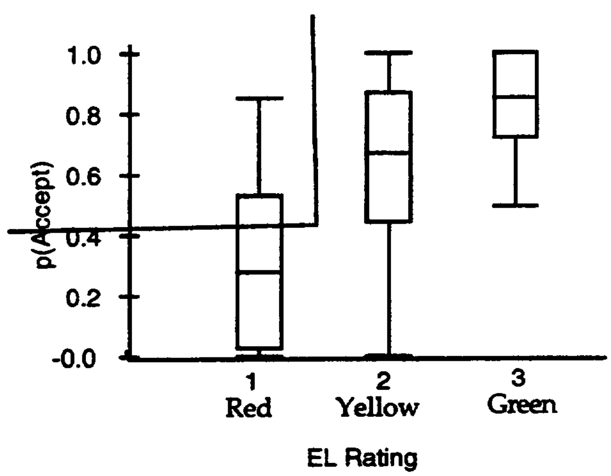
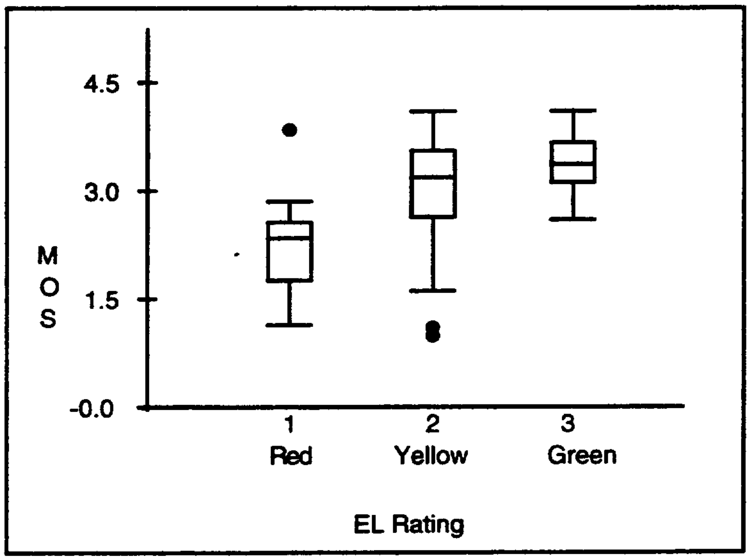


Figure 7.4.2.1 on the left shows the p(A) data in relation to EL categories. Figure 7.4.2.2 on the right shows more of a summary of the data. The boxes represent the middle half of the data (from the 25th percentile to the 75th percentile). The lines intersecting the boxes are the median p(A)s for each of the EL ratings. The lines extending out of the boxes depict the spread of the data. A large variance in p(A) is seen for each EL rating. A rating of red, for instance, includes samples that were described as acceptable by 90% of the listeners. A rating of yellow includes samples rated as high as 100% acceptable and as low as 0% acceptable. A rating of green includes samples rated as low as 50% acceptable. The boxes are elongated, which also show the large spread in data. From these figures, EL ratings do not appear to be accurate predictors of listener responses to question 3: % acceptability.

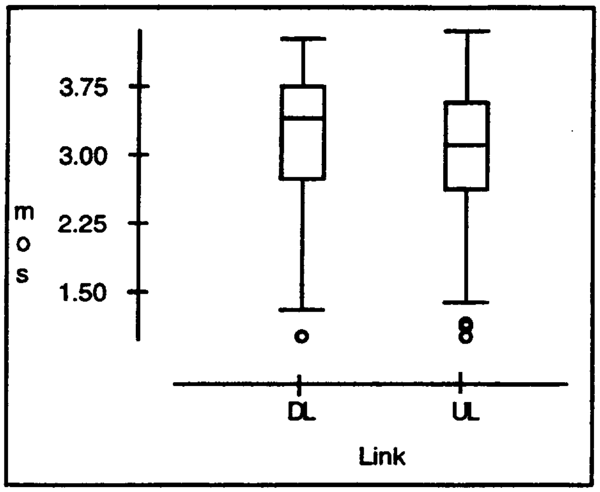
When we examine the relationship between listener responses to question 1 (MOS) and to question 3 [p(A)] we see that they are highly correlated as we would expect. The Pearson Product-Moment correlation coefficient between these factors is 0.892. We would then expect the relationship between MOS vs. EL to be similar to p(A) vs. EL. This appears to be true (see Figure 7.4.2.3). The EL ratings of red and yellow include nearly the full spread of MOSs. In other words, EL ratings do not appear to be accurate predictors of MOS. The green EL rating, however, is slightly more encouraging. It corresponds to an MOS in the fair to excellent range.

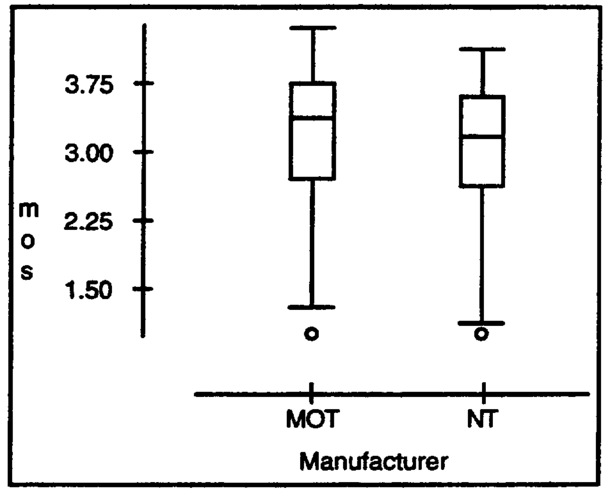
Figure 7.4.2.3



By breaking down MOS further by manufacturer and by type of link we see similar distributions for each. Figures 7.4.2.4 and 7.4.2.5 show that MOSs for uplink are slightly lower overall than downlink. Northern Telecom MOSs are slightly lower than Motorola's. However, a paired t-test reveals there is no significant difference betwee Motorola's and Northern Telecom's MOSs (t-stat = -0.87, df = 83, $p > 0.05$). Furthe., there is no significant difference between uplink and downlink MOSs (t-stat = 1.61, df = 83, $p > 0.05$).

Figure 7.4.2.4 **Figure 7.4.2.5**





It is possible that EL ratings, rxlev, and rxqual can be predictors of MOS when all are taken together. Figure 7.4.2.6 shows a Pearson Product-Moment correlation table for each of these factors. The table reveals correlation coefficients between one factor and each of the other factors. MOS to each EL, rxlev, and rxqual are low. A multiple regression analysis was completed in order to determine if MOS is related to a combination of EL, rxlev and rxqual. The analysis did not consider interactions among factors. The result is an R squared (adjusted) of 36.8%, and t-scores are low. In other words, only 36.8% of the variance can be explained by EL, rxlev, and rxqual together. The F-ratio is high (16.3) which means EL, rxlev, and rxqual reliably account for the 36.8% of variance. Including all factors into the equation, at least at first glance, does not seem to offer any substantial predictive power over MOS.

Figure 7.4.2.6

Pearson Product-Moment Correlation

	MOS	EL	rxlev	rxqual
MOS	1.000			
EL	0.539	1.000		
rxlev	0.434	0.277	1.000	
rxqual	-0.515	-0.478	-0.728	1.000

EL ratings, average rxlev, and average rxqual have not offered much insight into the behavior of MOS during this trial. One must wonder: how valid are the MOSs? Are MOSs really giving us an accurate view of listener satisfaction to these samples? By gathering listeners' comments from post-test questionnaires, more information is available about the nature of MOSs. Namely, it is evident from questionnaires that there are several types of distortions in quality possible in the recordings of the PCS-1900 according to listeners:

1) Muting and synthesization of human voice (e.g. "mechanical voice", "blanks"),
2) Fading within a voice sample ("voice becoming faint"),
3) Background noise, especially "echo" (prevalent in most samples), and
4) Distortions in higher frequencies ("ringing" or "shrill" sounds during higher frequencies, "inability to hear the letter 's' ").

Most importantly, the nature of the distortions are judged differently by different listeners. In other words, each of the above distortions are weighed on different scales by each listener. Distortions 1) and 2) are most likely related to signal strength, therefore voice samples exhibiting these characteristics were judged more harshly by those listeners who give them more weight. The same is true for distortions 3) and 4), which seemingly are not affected by signal strength, and may even be more obvious the absence of 1) and 2). In this case we see lower MOSs in samples with high rxlev and low rxqual. The Expert Listener made ratings based on distortion types 1) and 2). This may also explain why EL ratings were not better predictors of MOS.

One listener mentioned a concern over his ability to "focus for 2 hours". It is possible that the experimental design was not the most ideal. By being asked to judge the overall quality of a sample (over 1 minute) a listener tends to average the score to include good parts and bad parts. Their ratings then might be affected more by how the latter part of sample sounds. They are affected by what is fresh in their minds (recency effect). They may also have been overly influenced by how the beginning of a sample sounded (primacy effect). Because of the length of a given sample, it may have been difficult to concentrate and make an accurate judgment on the entire sample. Alternative experimental design considerations are necessary to ensure this isn't occurring in testing.

7.5 MOS Conclusions

- **Alternative design considerations are necessary to ensure that MOSs are valid. This is most likely due to this test methodology used during the JTC test. Additionally, the method of averaging the Rxlev and Rxqual over the test period seems to hide their relavance to the MOS predictions.**
- Average Rxlev and rxqual do not appear to be accurate predictors of MOSs for this test.
- EL ratings do not appear to be accurate predictors of MOSs.
- There are four different types of distortions present in the recordings of PCS-1900, according to the panels of listeners:
  1) Muting and synthesization of human voice,
  2) Fading within a voice sample,
  3) Background noise, especially "echo", and
  4) Distortions in higher frequencies of sound.

- The types of distortions are weighted differently by individual listeners, which may help explain the wide variance in MOS scores.

8.0 Building Penetration Loss Measurements

8.1 Testing Methodology

As an option, building penetration loss measurements were conducted on 341 public buildings in Boulder. All three cells were operating for this experiment. The data is representative of a fully deployed system. These measurements do not, in any way reflect the performance of the system under test. Building attenuation is the same for any radio transmission technology. The results presented here are given to assist system planners and are courtesy of the various field trial participants and especially US WEST who supplied the bulk of the participants for this experiment.

There were total of fourteen PCS 1900 handsets used in the building penetration loss measurements. Motorola provided 4 handsets and Northern Telecom provided 10. Both types of handsets had handoff capability, and were capable of providing Received Sign Strength (RSS), cell sector (channel) ID, occupied time slot and RxQual (Frame Error Rate) readings on the display. Out of these four, only RSS and channel ID data were collected in this measurement. Motorola handsets had RSS reading in dBm. The Northern Telecom handsets had RSS reading in GSM Rxlev units which were later converted to dBm. All collected data were downlink only, collected by the participants by reading off the handsets display. Each participant had one handset from which to take readings.

Each of fourteen participants in the building penetration loss data collection was assigned an area (residential or suburban) at which the data were to be collected. There were no overlapping areas among the assigned areas. The goal for each participant was to collect data at the ground level at each accessible business building within the area. Each participant was asked to collect the following data for each building:

- Downlink RSS (inside and outside the building)
- Channel ID
- Building address
- Building description (brick/concrete, large or small windows, single or multiple stores, etc.)
- Position of the front entrance (North, South, etc.)

Outside RSS measurements were conducted near the front entrance. The total of 4 outside RSS measurements were taken for each building, giving some degree of spatial averaging on a 1 meter radius area. Inside RSS measurements were taken 2-3 meters inside the front door, away from any pillars or other structure. Inside RSS readings were taken similarly to outdoor readings. During the data readings off the handsets display, handsets were not immediately adjacent to the user's head. All the time during the data collection all handsets were in the idle mode, reading the BCCH. Hence no actual calls were in process during the data collection.

8.2 Data Analysis

The single most important data for the analysis purpose is the difference (Δ) between outdoor and indoor RSS. This difference accounts for the first wall penetration loss. Since four different indoor and outdoor RSS readings were collected for each building, the first step was to find the mean (m) and standard deviation (σ) for indoor and outdoor RSS for each building. The penetration loss Δ is then calculated as the difference of the mean outdoor and indoor power level. There are two distinct procedures to calculate standard deviation for each building. The first one is to assume that four collected measurements are the only possible RSS readings that could occur at the given location. The second is to assume that four collected measurements are only a subset of all possible outcome of RSS measurements at given location. If the number of readings taken is infinite, these two standard deviations are identical. However, we took only four readings, so these standard deviations are not the same. By comparing standard deviations calculated using these two methods, we can see if the chosen number of distinct measurements at each location (four in this case) is sufficient enough so that the second method can be approximated with the first.

After we establish the statistics for all data points (Δ and σ_Δ for each building), we proceed to evaluate the overall mean and standard deviation for data points for all buildings. The next step is to make a distinction between different types of buildings (brick/concrete, large/small windows, single/multiple stores). The analyzed data is presented in the six different groups. For each of these groups, we presented the total data, regardless of the position of the building relative to the BTS (line of sight or non-line of sight).

1) Building penetration loss versus sample frequency - density function; Figure 8.2.1
2) Building penetration loss versus sample percentage - cumulative function; Figure 8.2.2
3) Building penetration loss versus the type of the building; Figures 8.2.3, 8.2.4
4) Building penetration loss versus the indoor and outdoor σ; Figures 8.2.5, 8.2.6
5) Building penetration loss versus the average power level; Figure 8.2.7
6) σ_Δ calculated versus σ_Δ measured; Figure 8.2.8

Figure 8.2.1

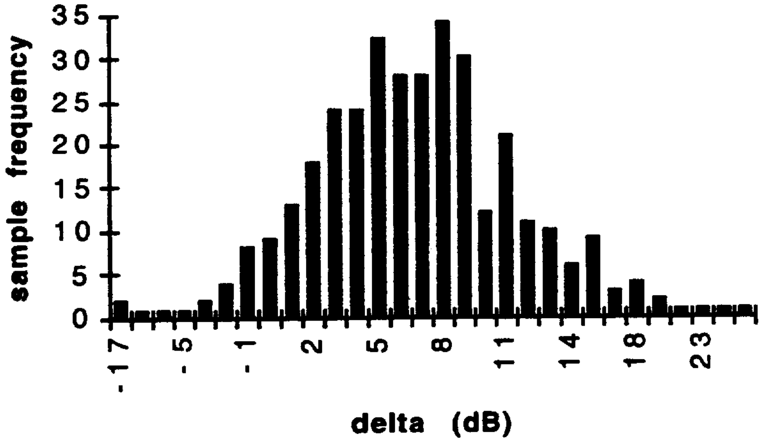


Figure 8.2.2