

# **Appendix 2**



**BBN-T—(Verizon Technology Organization)**

**Houston, Texas**  
**E911 Location Technology Field Trial**

**Final Report**

June 4–June 14, 2001

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## Executive Summary

At the request of Verizon Wireless, BBN-T (Verizon Technology Organization) conducted a rigorous location accuracy trial of the Grayson Wireless Geometrix<sup>®</sup> geo-location system in the

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Greater Harris County, Texas PSAP test area from June 4 to June 14, 2001. This report contains a summary of that trial.

The test area consisted of 32 square miles of essentially suburban and highway scenarios. The maximum distance between any two adjacent cell sites in the test area was, approximately, 2.5 miles and the minimum was, approximately, 0.5 mile.

The purpose of the trial was to assess compliance of the Geometrix® system with the FCC requirement for Phase II E911 that a network-based geo-location system shall provide the location of a wireless 911 call with an accuracy of 100 meters, 67% of the time, and 300 meters, 95% of the time. The primary focus of the trial was on assessing the accuracy of the Geometrix® system in locating IS-95 calls in the cellular band. A limited effort was also made to assess the accuracy of the system in locating a mix of IS-95 and AMPS calls, in the cellular band.

The CDMA Development Group (CDG) Test Plan was used as a basis for the trial. 10 suburban and 3 highway scenarios from the CDG Test Plan were tested. For the suburban scenarios, test calls were generated from inside a vehicle, both when it was stationary and when it was moving, when the caller was walking and when the caller was inside buildings. For the highway scenarios, all calls were made from inside a moving vehicle. All told, over 1500 completed calls were made from 45 different locations or stretches of highways.

The results of the analysis showed that the overall accuracy of the Geometrix® system met the FCC requirements for the GHC PSAP test area. This conclusion is based on combining the accuracy data from all the scenarios according to three different weighting profiles, including the data for both AMPS and CDMA calls and using the more strict guidelines of the OET Bulletin No. 71, which require a statistical confidence of 90% for the accuracy estimates.

While the results of the suburban scenarios tested in the GHC PSAP test area were mostly compliant with the FCC requirements and while the results overall were also compliant, none of the results for the highway scenarios were compliant. Consequent to the BBN-T (VTO) testing, Grayson Wireless has come up with two modifications that they expect will significantly improve the performance in the highway scenarios. Of these, one is an algorithmic change and consists of increasing the dynamic range of the received signal reception. Grayson Wireless believes that this modification will result in a better estimate of the time of arrival of the direct path, which in turn will improve the location accuracy of the TDOA algorithm. The other, a non-algorithmic change, uses a time-stamp for the received signal data collection that is closer to the time at which the ground truth is measured for moving vehicles. Based on their re-testing, Grayson Wireless believes that this will yield a smaller calculated error, the distance between the ground truth and the estimated location.

BBN-T recommends an independent re-test of Grayson Wireless's geo-location system for the highway scenarios to verify the improvements in the accuracy due to the modifications of their system.

Finally, this trial focused on the accuracy aspects of the FCC requirements. However, the FCC requirements also imply that the yield, *i.e.*, the ratio of the number of fixes to the total number of call attempts, be at least 95%. In addition, the FCC guidelines as given in the OET Bulletin No. 71 talk about setting limits to the time to obtain a fix. Both these issues are very important from a practical standpoint. In general the accuracy is expected to deteriorate if one were to also set high yield and small time to obtain fix thresholds. Therefore, BBN-T also recommends that the Geometrix® system be re-tested to ensure that it meets the accuracy requirements and the yield requirements under specific time-to-fix constraints.

### 1. Introduction

This report summarizes the results of the location accuracy field trial conducted in Houston, Texas by BBN-T (Verizon Technology Organization, VTO) of the Geometrix® geo-location system from Grayson Wireless. The purpose of the trial was to assess compliance of the Geometrix® system with the FCC requirement for Phase II E911. In essence, the requirement calls for a network-based system to provide the latitude and longitude of an E911 call with an accuracy of 100 meters, 67% of the time, and of 300 meters, 95% of the time.

The primary focus of the trial was on assessing the accuracy of the Geometrix® system in locating IS-95 calls in the cellular band. A limited effort was also made to assess the accuracy of the system in locating a mix of IS-95 and AMPS calls, in the cellular band.

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The system that was tested employed, essentially, a Time Difference of Arrival (TDOA) algorithm for estimating location, i.e., getting a "fix" on the geographical point from which the E911 call was made. The Geometrix<sup>®</sup> system in the Houston trial used a basic 2-element TDOA system, combined with a ranging algorithm to deal with those cases where hear-ability could be achieved, but from fewer than three receivers. In addition, a Surface of Position Clustering (SOPC) algorithm was used to eliminate poor quality signal measurements before a final fix was calculated.

The trial was conducted in a test area in the Greater Harris County (GHC), Texas from June 4 to June 14, 2001. The test area was bordered on the west by State Loop 8, on the north by I-10, on the east by I-610 and on the south by Westpark Drive. The boundary of the test area was determined by the radio coverage provided by 32 selected Verizon Wireless cell sites. Figure 1 illustrates the test area and its boundary. The size of the test area was approximately 32 square miles.

Figure 2 illustrates the geo-location field trial network. Each of the 32 selected cell sites was equipped with a Geometrix<sup>®</sup> Wireless Location Sensor (WLS), i.e., a geo-location receiver. The maximum distance between any two adjacent cell sites was 2.5 miles and the minimum was 0.5 mile.

The test area can be characterized as being mostly a suburban area, even though small parts of it looked like transplants from the urban core, with a few very tall glass and concrete buildings. A large part of the test area was residential. The houses in the residential areas were made mostly of brick, with no basements. There were also many shopping plazas and commercial/business office areas. The test area was bordered on three sides by major highways. It was also criss-crossed by many multi-lane roads.

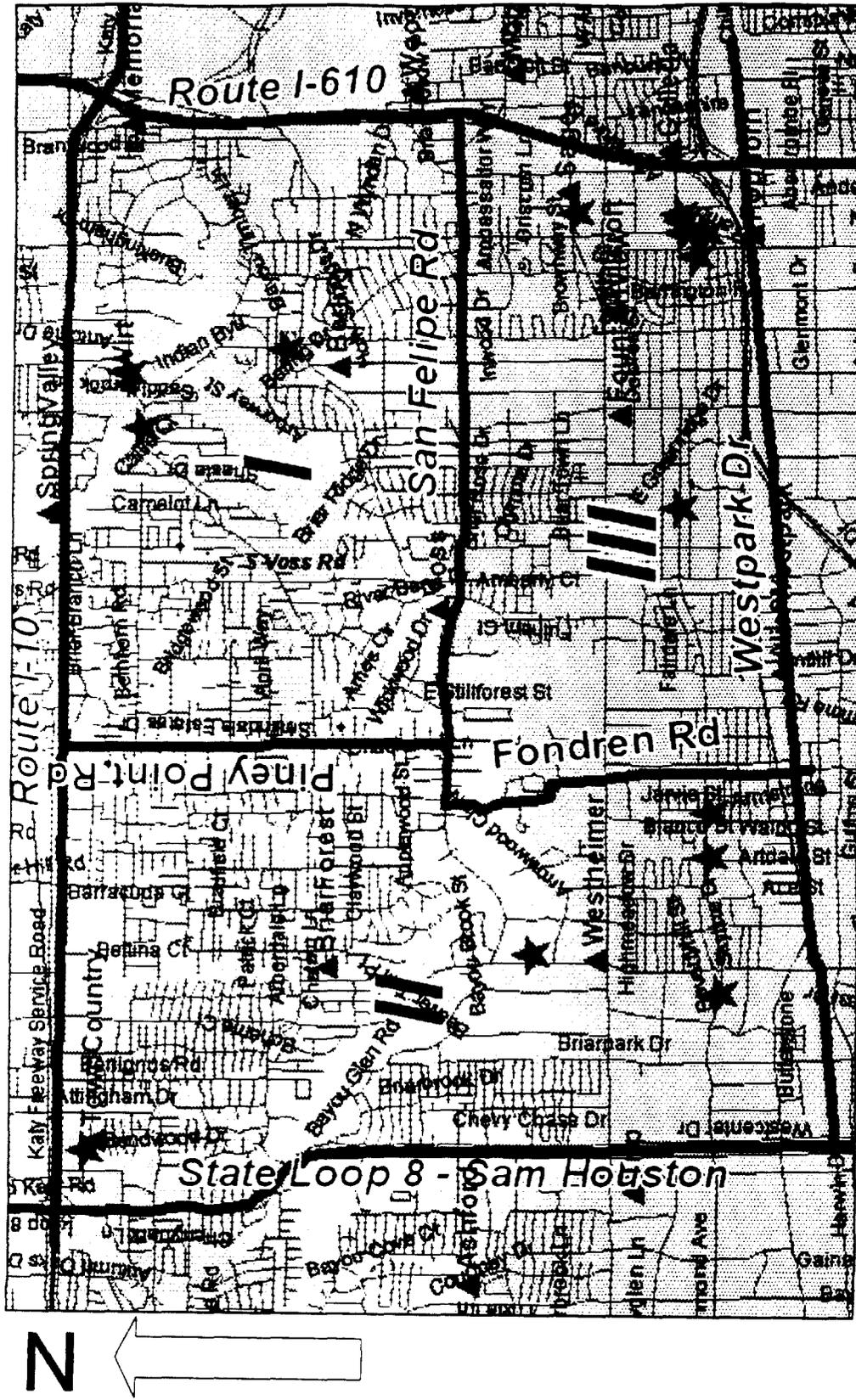


Figure 1: Sectorized Houston testing area

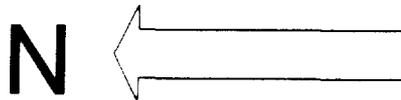
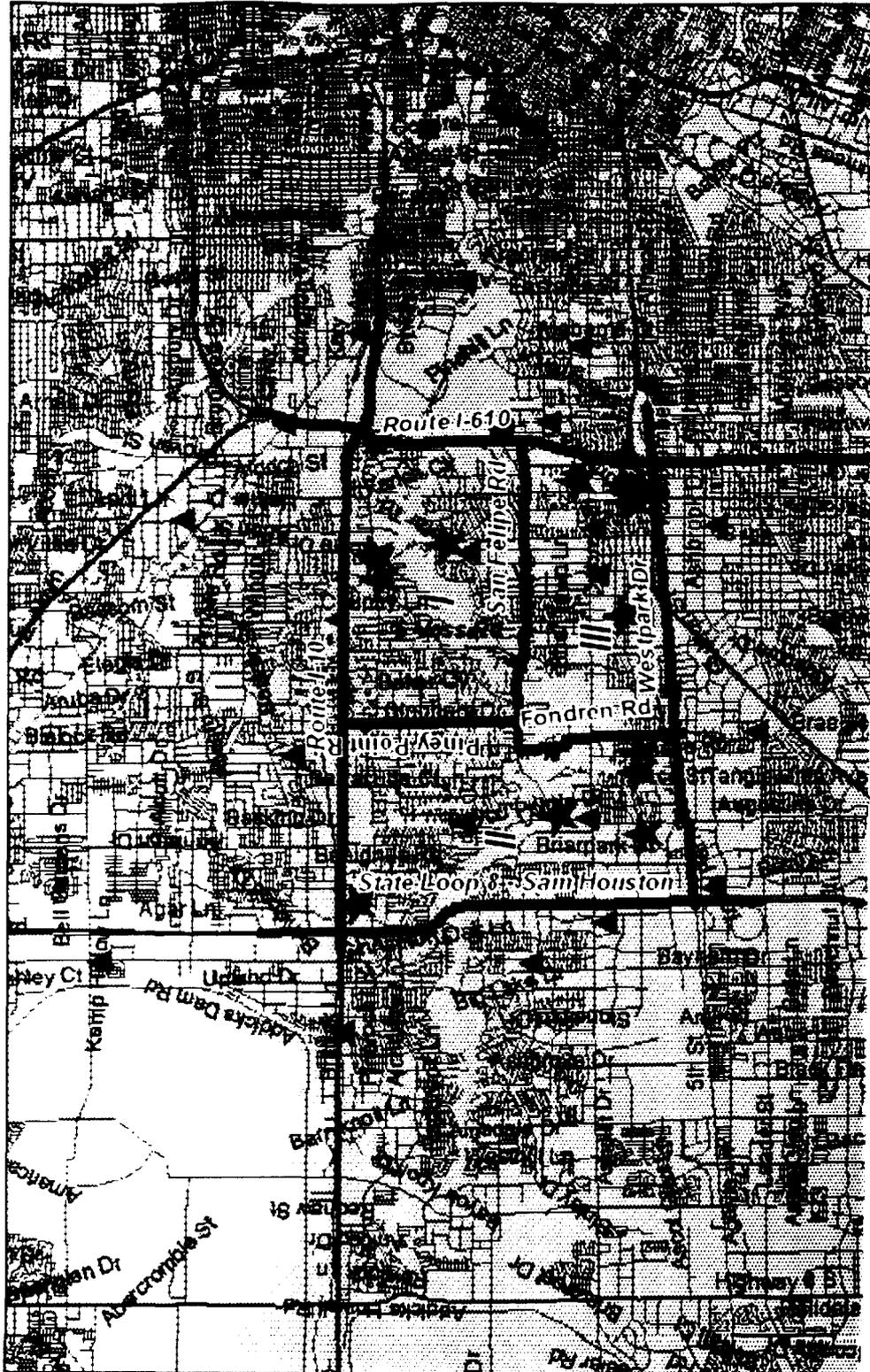


Figure 2: Houston cell sites used in testing

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The CDMA Development Group (CDG) Test Plan was used as a basis for the trial. 10 suburban and 3 highway scenarios from the CDG Test Plan were tested. Table 1 lists the scenarios tested in the Houston Trial. In order to obtain geographical variation for assessing the accuracy of each scenario, the test area was divided into 3 sectors, and, where possible, one location was identified in each sector for each scenario. E911 call location was simulated by calling a local number and by getting the Geometrix<sup>®</sup> system to locate that call. Multiple calls were made for each scenario. A single fix was obtained for each call. For the suburban scenarios, test calls were generated from inside a car, when the car was stationary, when it was moving and when it was inside a parking garage. Test calls were generated outdoors when the caller was stationary, either on a street or in a shopping plaza parking lot, and when the caller was walking. Finally, for the suburban scenarios, test calls were generated inside residential buildings, parking garages, shops and shopping malls. For the highway scenarios, all calls were made from inside a moving vehicle. Three different scenarios were tested: when the vehicle was moving at slow speed in heavy traffic, at moderate speed (30–40 mph) and high speed (50–55 mph).

**Table 1—Scenarios Tested**

Scenario	No. of Locations	No. of Fixes
S1 Residential sidewalk—outdoor, stationary	3	122 CDMA 30 AMPS
S2 Residential sidewalk—outdoor, walking	3	123 CDMA
S3 Residential 2-lane street—inside car, stationary	3	119 CDMA 32 AMPS
S4 Residential 2-lane street—inside car, 15-40 mph	3	121 CDMA
S7 Residential house, brick, upper floor—indoor, stationary	3	122 CDMA
S9 Shopping Mall, no atrium or open sky—indoor, stationary	2	120 CDMA 30 AMPS
S12 Parking garage, middle floor—inside car, stationary	3	119 CDMA
S13 Parking garage, middle floor—outside car, stationary	3	123 CDMA
S14 Shopping plaza—outdoor, stationary	3	121 CDMA
S15 Shopping plaza—indoor, stationary	3	120 CDMA
H1 Highway—inside car, heavy traffic	3	93 CDMA
H2 Highway—inside car, 30-40 mph	3	95 CDMA
H3 Highway—inside car, max speed limit	3	116 CDMA

The accuracy was analyzed by comparing the location estimated (estimated latitude and longitude) by the geo-location system to the corresponding ground truth (true latitude and longitude) for each call. For indoors scenarios, where a GPS reading could not be obtained for a location, the ground truth was derived from the GPS measurement of a nearby outdoor location (reference latitude and longitude) along with angle and distance measurements from that outdoor location to the indoor location from which test calls were generated.

The location accuracy of Grayson Wireless's Geometrix<sup>®</sup> system was analyzed for 9 of the 10 suburban scenarios and all 3 of the highway scenarios that were tested. Of the suburban scenarios, only S9, "Shopping Mall, no atrium or open sky—indoor, stationary", was not analyzed, because out of the two locations identified and tested, the validity of the data from

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one of these was considered to be doubtful. The handset used to make a call from this particular location was powered down to unusually low levels. This strongly suggests the existence of a repeater or micro-cell in the vicinity. Since there was no Geometrix® WLS at this suspected repeater/micro-cell location, the data collected would not have been representative of the true Geometrix® system performance. The details of the analysis are given in Section 2. In this section, for each scenario the following are included:

- 1) Addresses of the locations at which the scenarios were tested,
- 2) the number of CDMA and AMPS fixes that were obtained for that scenario,
- 3) the 67<sup>th</sup> percentile of the location estimation error,
- 4) the 95<sup>th</sup> percentile of the location estimation error,
- 5) photographs depicting the scenario,
- 6) the cumulative distribution function (CDF) of the location estimation error
- 7) scatter plots of the estimated locations and the associated ground truth.

Section 3 summarizes the 67<sup>th</sup> and 95<sup>th</sup> percentile performance of each scenario. Section 4 provides an analysis of the overall (aggregate) location accuracy for the 9 suburban and 3 highway scenarios, based on three different weighting profiles. The performance results shown include the aggregate cumulative distribution functions, as well as estimates of the aggregate 67<sup>th</sup> and 95<sup>th</sup> percentile accuracy with a 90% joint confidence level of the underlying statistics. Section 5 provides a conclusion and recommends next steps for further evaluation.

Appendix A gives comments on the test by Grayson Wireless and descriptions of modifications made to the location algorithm that are expected to improve the performance.

## 2. Results by Scenarios

This section contains the results of the trial on a scenario-by-scenario basis. For each suburban scenario, a nominal 40 CDMA calls were made at each of three locations. For two of the scenarios, S1 and S3, an additional 10 AMPS calls were made at each location. For each highway scenario, a nominal 30 CDMA calls were made at each stretch of three separate highways. For each scenario, we provide both verbal descriptions of the test locations and representative photographs of the test sites. For each scenario, we give the cumulative distribution function of the observed location errors, together with the 67<sup>th</sup> percentile and the 95<sup>th</sup> percentiles of the distribution functions.

We also show scatter plots of the computed fix locations and the associated ground truth (or ground truths for moving scenarios), given as latitude and longitude. For those indoor tests for which the ground truth was determined by means of an offset from a base location, the base location is shown as well.

### Scenario S1—Residential sidewalk—outdoor, stationary

#### (CDMA Summary)

Location 1	Near intersection of Glynnway and Briar Road
Location 2	Near intersection of Surrey Lane and Strey Lane
Location 3	Chateaux Dijon, near 5331 Beverly Hill, Apt 22A
Fixes	122
67% error	63 m
95% error	149 m

#### (AMPS Summary)

Location 1	Near intersection of Glynnway and Briar Road
Location 2	Near intersection of Surrey Lane and Strey Lane
Location 3	Chateaux Dijon, near 5331 Beverly Hill, Apt 22A
Fixes	30

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67% error	226 m
95% error	382 m
<b>(CDMA &amp; AMPS Summary)</b>	
Fixes	152
67% error	80 m
95% error	274 m



**Figure 3: Near intersection of Glynway and Briar Road**



**Figure 4: Near intersection of Surrey Lane and Strey Lane**

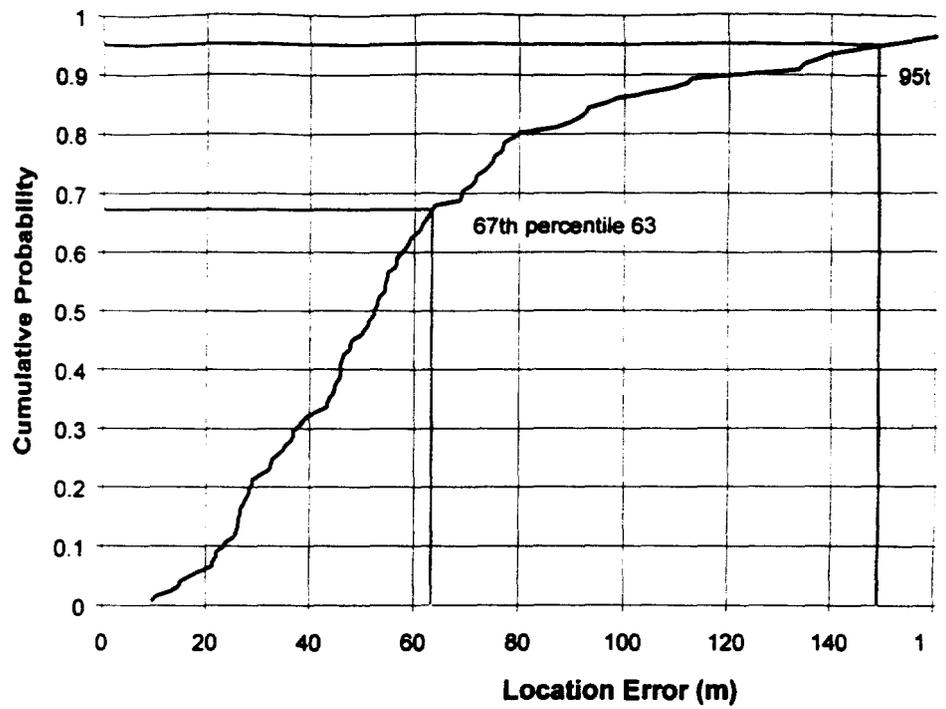


**Figure 5: Chateaux Dijon, near 5331 Beverly Hill, Apt 22A**

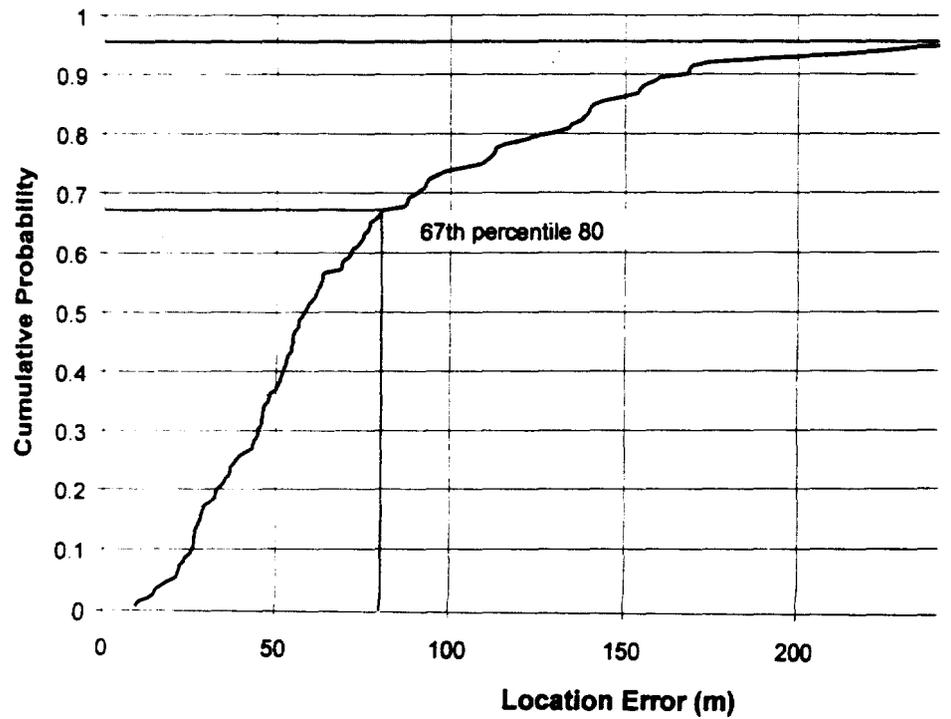


**Figure 6: Chateaux Dijon, near 5331 Beverly Hill, Apt 22A—  
AMPS call**

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**Figure 7: Cumulative Distribution Function for S1 (CDMA)**



**Figure 8: Cumulative Distribution Function for S1 (CDMA & AMPS)**

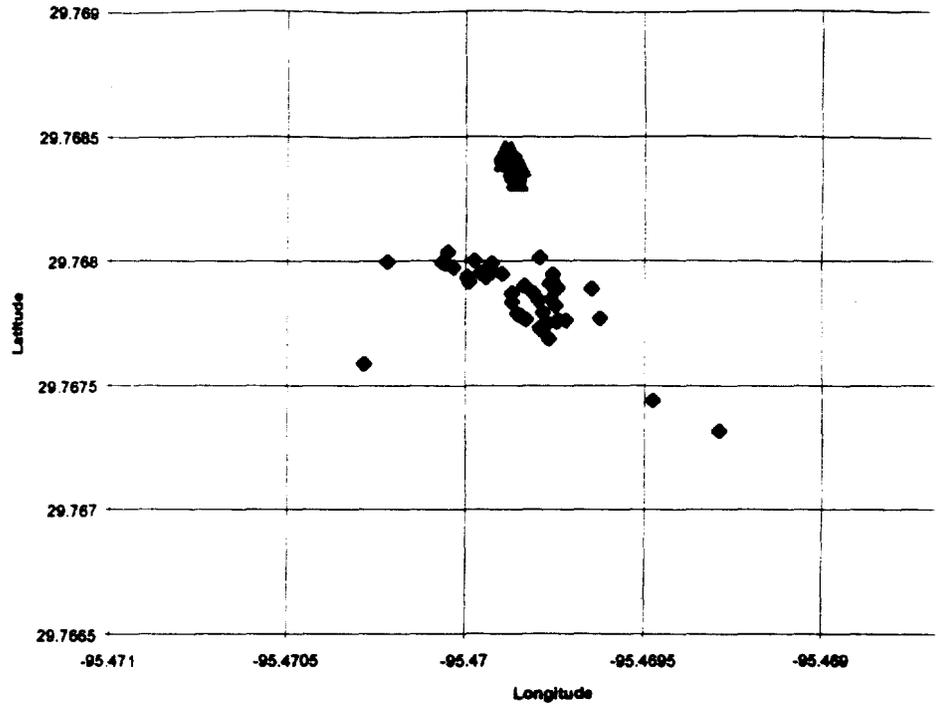
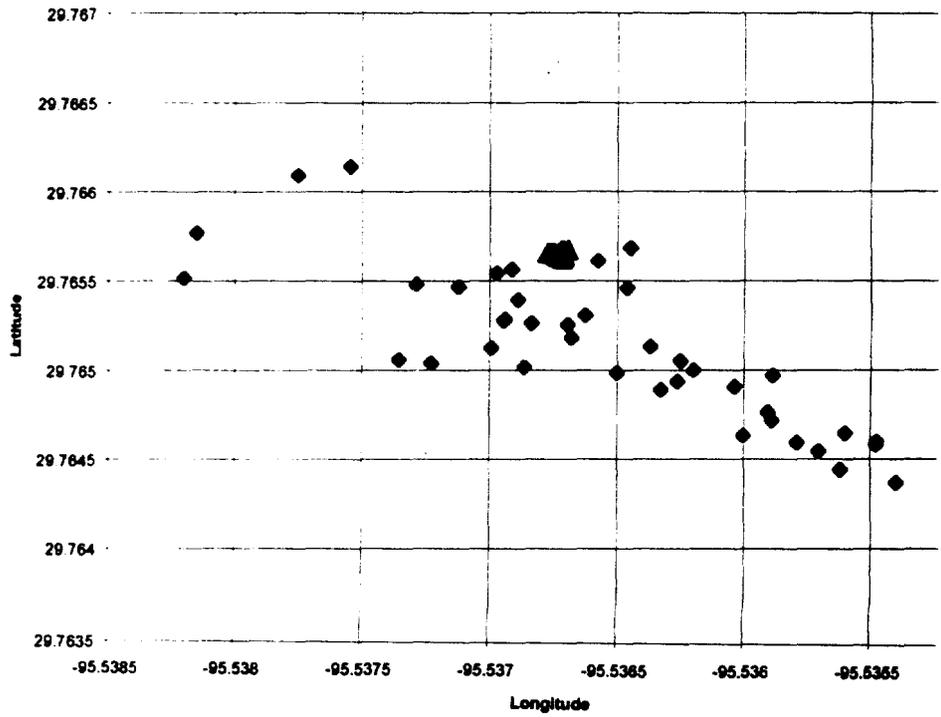


Figure 9: Scatter plot for Scenario S1, Location 1 (CDMA)





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**Houston, Texas**  
**E911 Location Technology Field Trial**

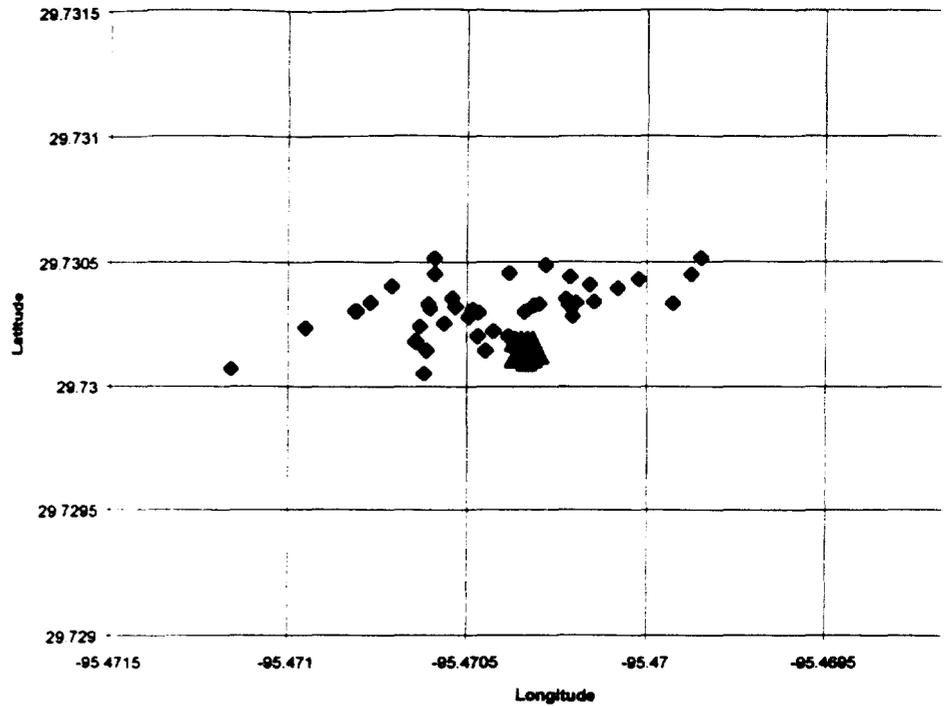
**Final Report**

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Iftekhar Rahman  
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**Figure 10: Scatter plot for Scenario S1, Location 2 (CDMA)**

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**Figure 11: Scatter plot for Scenario S1, Location 3 (CDMA)  
Scenario S2—Residential sidewalk—outdoor,  
walking  
(CDMA Summary)**

Location 1	On Briar Road, between Glynnway and Maple Valley
Location 2	On Bunker Hill Road, between Valley Forge and Bay Hurst
Location 3	Chateaux Dijon, near 5331 Beverly Hill, Apt 22A
Fixes	123
67% error	52 m
95% error	94 m



**Figure 12: On Briar Road, between Glynnway and Maple Valley**



**Figure 13: On Briar Road, between Glynnway and Maple Valley**



**Figure 14: On Briar Road, between Glynnway and Maple Valley**



**Figure 15: On Bunker Hill Road, between Valley Forge and Bay Hurst**



**Figure 16: On Bunker Hill Road, between Valley Forge and Bay Hurst**



**Figure 17: Chateaux Dijon, near 5331 Beverly Hill, Apt 22A**



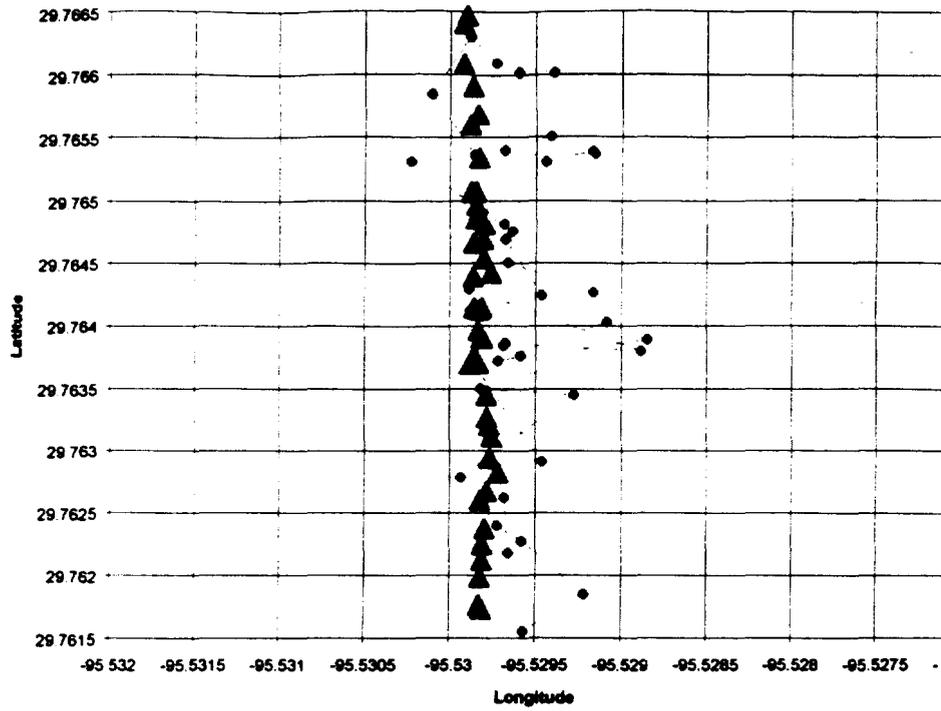


Figure 20: Scatter plot for Scenario S2, Location 2 (CDMA)

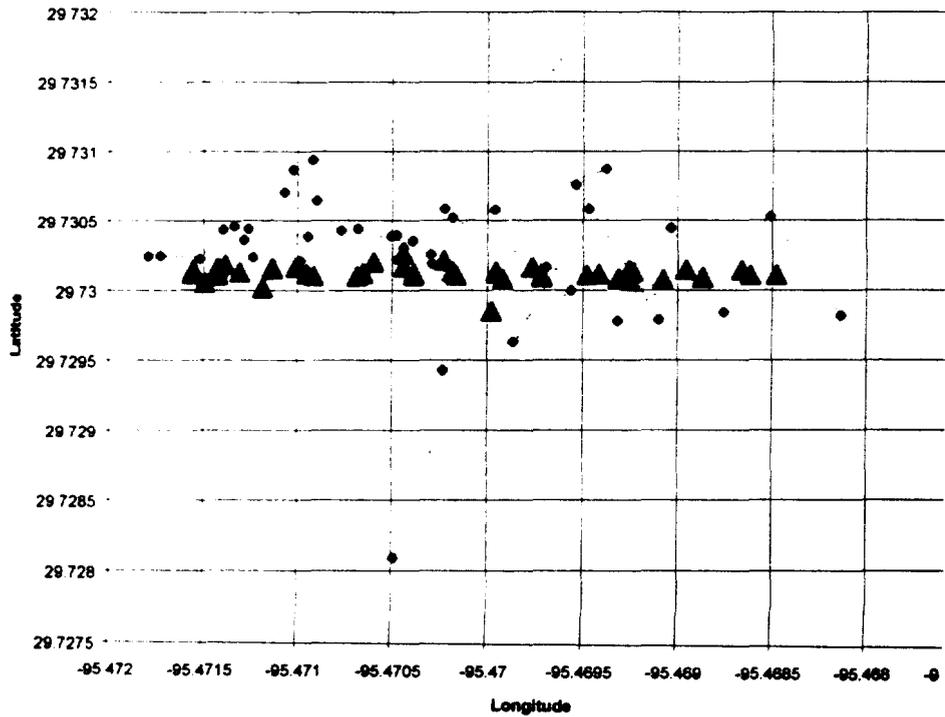


Figure 21: Scatter plot for Scenario S2, Location 3 (CDMA)

**Confidential**

**Scenario S3—Residential 2-lane street—inside  
car, stationary  
(CDMA Summary)**

Location 1	Memorial Creole, near 10220 Memorial Drive
Location 2	On Surrey Lane, near intersection with Strey Lane
Location 3	Chateaux Dijon, near 5331 Beverly Hill, Apt 22A
Fixes	119
67% error	78 m
95% error	161 m

**(AMPS Summary)**

Location 1	On Shady River, near intersection with Pine Shadows
Location 2	On Bunker Hill Road
Location 3	Chateaux Dijon, near 5331 Beverly Hill, Apt 22A
Fixes	32
67% error	154 m
95% error	313 m

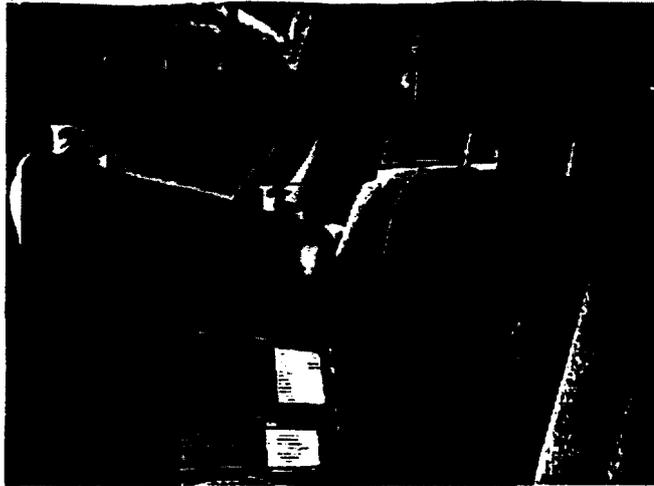
**(CDMA & AMPS Summary)**

Fixes	151
67% error	89 m
95% error	190 m



**Figure 22: Memorial Creole, near 10220 Memorial Drive**

**Confidential**





**BBN-T—(Verizon Technology Organization)**

**Houston, Texas**  
**E911 Location Technology Field Trial**

**Final Report**  
June 4–June 14, 2001

Iftexhar Rahman  
Rajamani Ganesh  
David Freeman  
Nabil Hinnawi

**Figure 23: On Surrey Lane, near intersection with Strey Lane**



Figure 24: On Surrey Lane, near intersection with Strey Lane

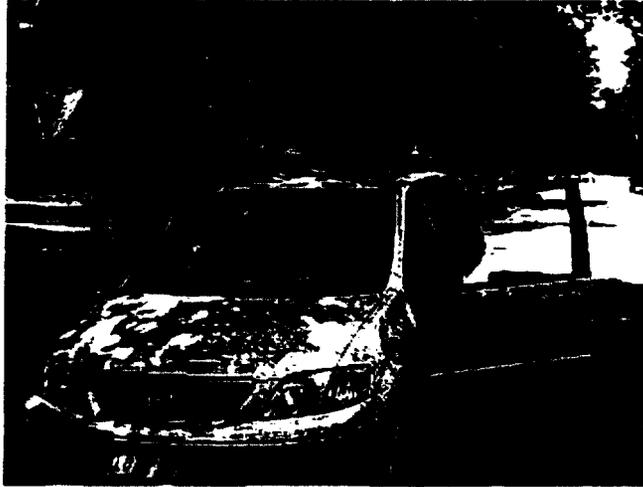


Figure 25: On Bunker Hill Road—AMPS call



Figure 26: On Bunker Hill Road—AMPS call

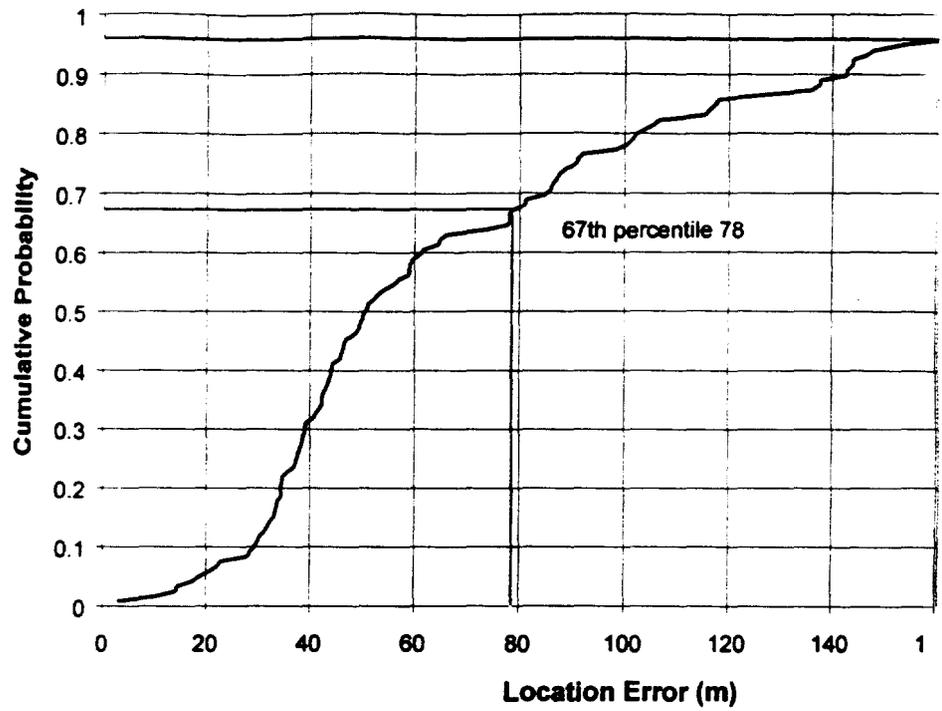


**Figure 27: Chateaux Dijon, near 5331 Beverly Hill, Apt 22A**

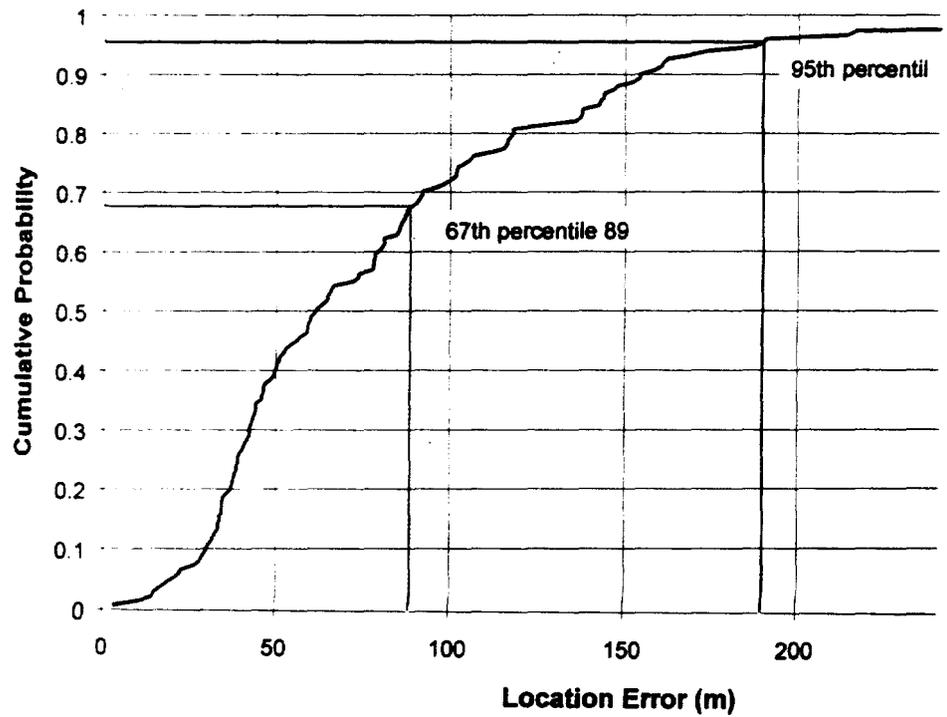


**Figure 28: Chateaux Dijon, near 5331 Beverly Hill, Apt 22A—  
AMPS call**

**Confidential**

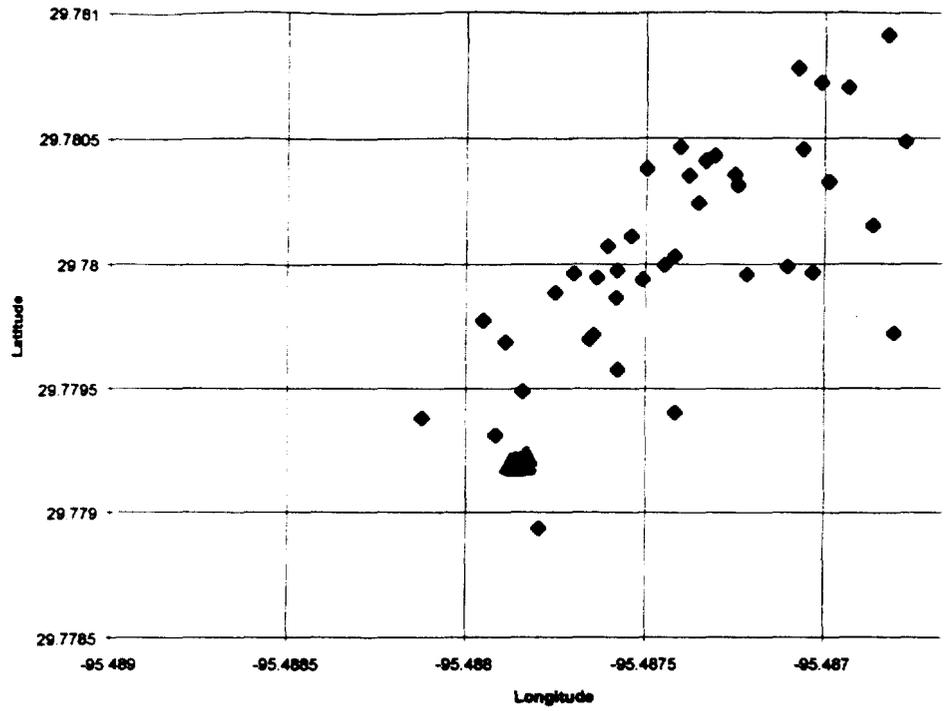


**Figure 29: Cumulative Distribution Function for S3 (CDMA)**

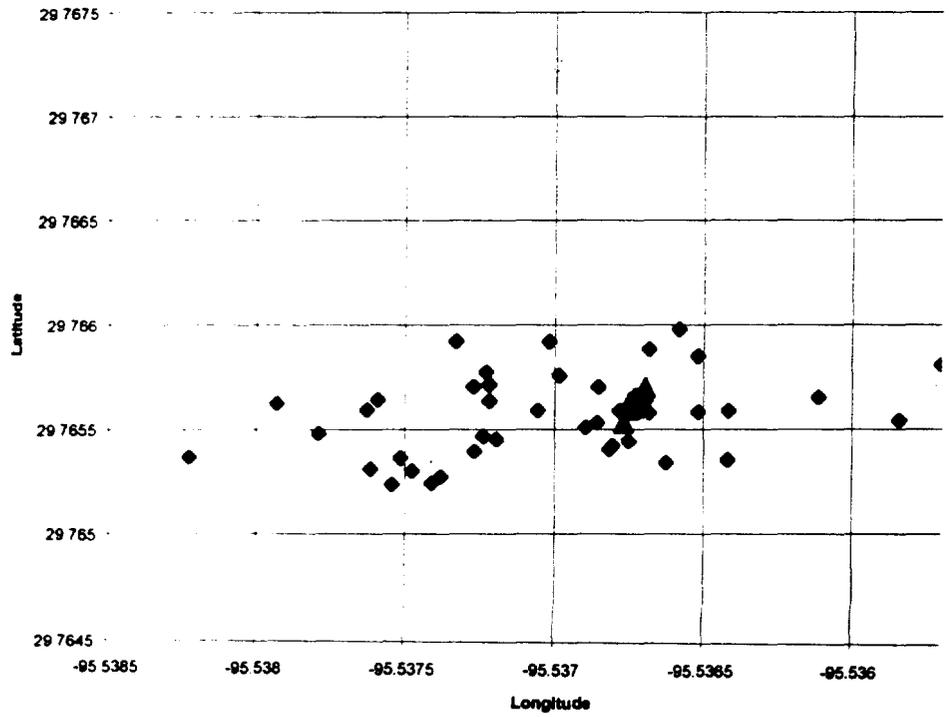


**Figure 30: Cumulative Distribution Function for S3 (CDMA & AMPS)**

**Confidential**

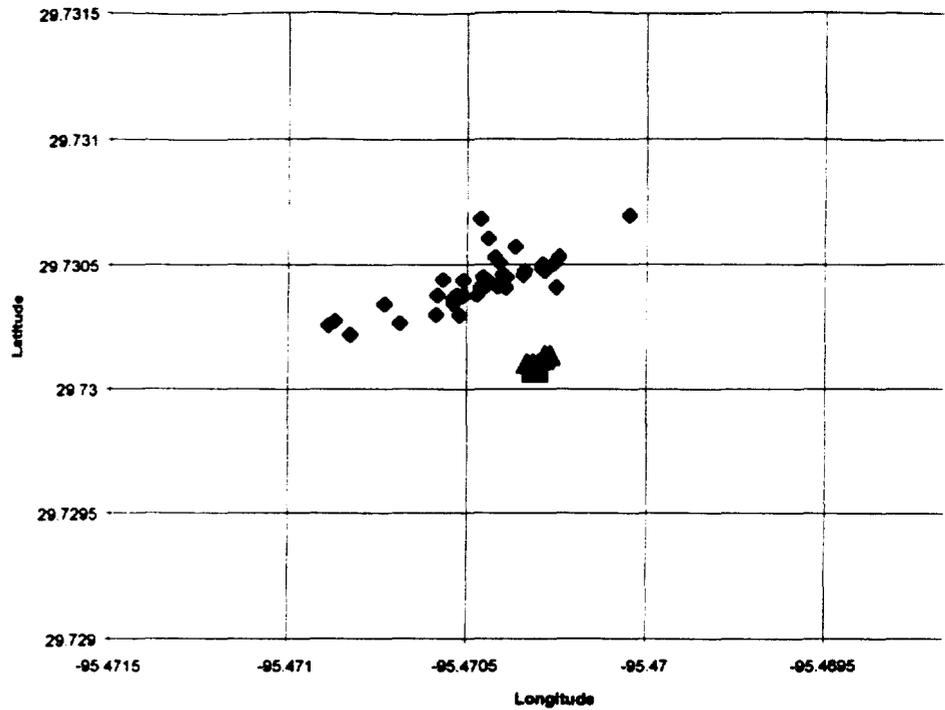


**Figure 31: Scatter plot for Scenario S3, Location 1 (CDMA)**



**Figure 32: Scatter plot for Scenario S3, Location 2 (CDMA)**

**Confidential**



**Figure 33: Scatter plot for Scenario S3, Location 3 (CDMA)  
 Scenario S4—Residential 2-lane street—inside  
 car, 15-40 mph  
 (CDMA Summary)**

Location 1	Off Sage, on Pine Forest, Bayou Glen and Maple Valley, Pine Shadows, Briar Drive, Gle Tree and Shady Wood
Location 2	Strey Lane and streets off it
Location 3	Chateaux Dijon, near 5331 Beverly Hill, Apt 22A
Fixes	121
67% error	59 m
95% error	125 m



Figure 34: Strey Lane and streets off it



Figure 35: Chateaux Dijon, near 5331 Beverly Hill, Apt 22A

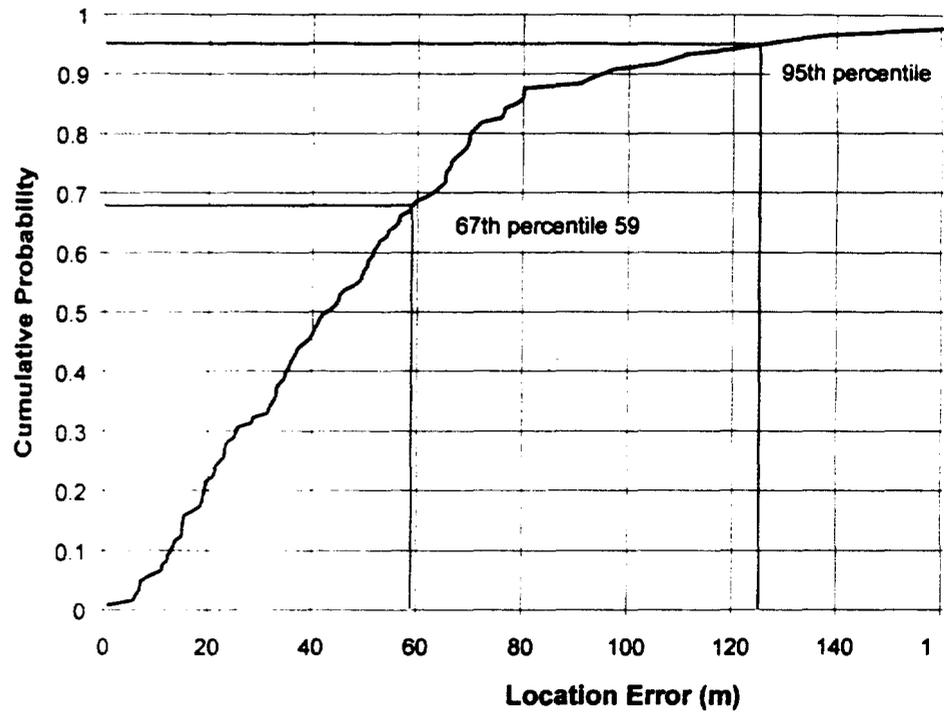


Figure 36: Cumulative Distribution Function for S4 (CDMA)

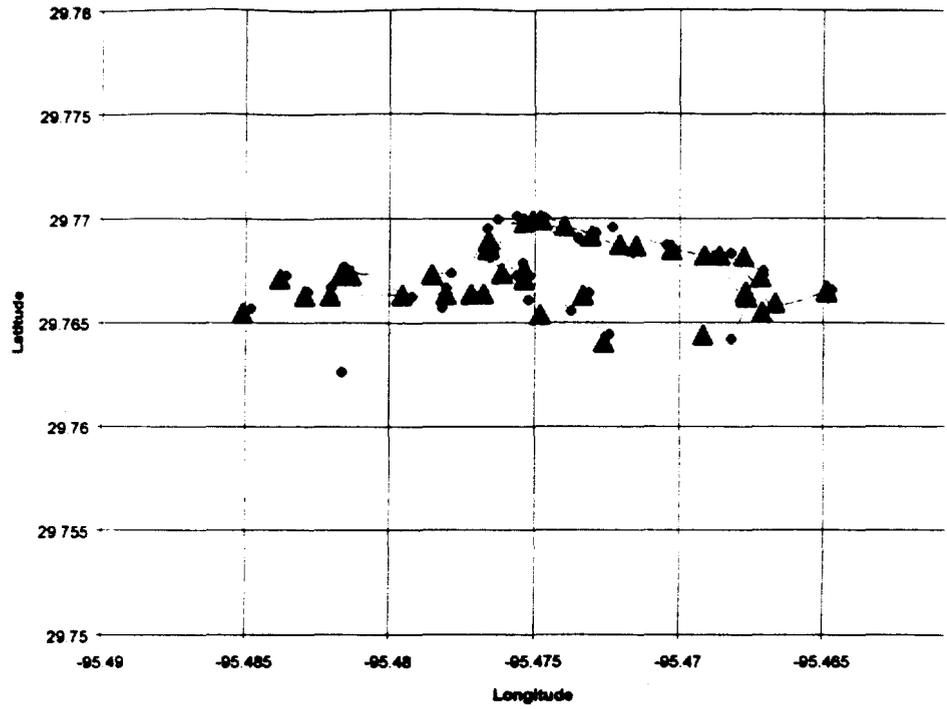


Figure 37: Scatter plot for Scenario S4, Location 1 (CDMA)

