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STATUS ON THE DEVELOPMENT AND IMPLEMENTATION OF A TLS ON DCS

This document provides a status of the USA activities in developing a transmitter location system for the IDCS/DCS.
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STATUS ON THE DEVELOPMENT AND IMPLEMENTATION OF A TLS ON DCS

1. Introduction

Transmitter Locations Systems, LLC (TLS LLC) has completed the Phase 2 Proof of Concept demonstration of the applicability of the TLS technology to the NOAA GOES Data Collection System (DCS). The Phase 2 Proof of Concept demonstration was performed on behalf of NOAA at the Wallops Command and Data Acquisition (WCDA) station in Wallops Station, Virginia.

The results of the Phase 2 effort demonstrate that the TLS technology can geolocate fixed DCS platforms within the area of co-visibility of the GOES-E and GOES-W satellites with typical accuracies on the order of 10 miles. For platforms in motion, either on board maritime vessels or more likely on buoys subject to wave motions, the effect of the wave motion causes the FDOA to be poorly determined, resulting in significant errors in the reported geolocation. However, even for these signals the TDOA remains well determined, yielding accurately measured lines of position along which the transmitting platform lies.

Finally, a series of measurements were made on uplink signals (test transmitters) furnished by NOAA as "ground truth" signals. Calculated geolocation coordinates are provided for the measurements of these signals. NOAA evaluated these data against the known locations of the uplink transmitters to assess the performance of the TLS on these "unknown" signal sources.

2. Phase 2 Objective

The primary objective of the Phase 2 effort was to validate the expected geolocation accuracy of the TLS system when applied to NOAA GOES DCS signals. Processing of the DCS signals presented several novel aspects as compared to the standard application of the TLS, which is the geolocation of broadband communications signals being transmitted over geostationary communications satellites.

During Phase 1 the unique aspects of the DCS application were studied in order to both predict the expected accuracy and to define the hardware and software modifications necessary to perform the Phase 2 Proof of Concept. The following Sections provide a brief description of the equipment configuration used in Phase 2. Additional details concerning the Phase 2 configuration are available in the Phase 1 Final Report and the Phase 2 Monthly Status Reports.

2.1 Overall Description

The hardware used for the Phase 2 demonstration consists of an unmodified TLS system adapted to the 74 MHz IF available from the NOAA hardware by a simple upconverter. In one mode of operation, the TLS produces a file containing the raw data samples acquired by the TLS data buffer. Our approach was to set the hardware to acquire this raw data file and then to do all subsequent processing in software specifically developed for the Phase 2 demonstration. The TLS system was augmented by two fast computers to accomplish the processing tasks.

2.1.1 TLS Operating Mode

For this demonstration the TLS is operated in buffered mode, that is, the data samples are acquired and stored in the data buffer before correlation. Both main and phase calibrator bandwidth must be set to 0.5 MHz, and oversampling must be off. For processing in the software correlator, the sampler threshold should be set to 150 mV for best results, though this is not a critical matter. The TLS software setup was modified so the data buffer contents were written to a file after acquisition.

2.1.2 Overall Description

All processing steps through correlation can be done in either a Windows environment or a Linux environment. Automation of processing is most easily accomplished in the Linux environment.

The first processing step is to copy the sampled data file from the directory where it is stored by the TLS system to the "rawfiles" subdirectory in the analysis system of choice, renaming it in the process. The raw data file is then reformatted, extracting signal 1 into a set of three files that are stored in the "reformatfiles" subdirectory. The correlator is then run on the reformatted files to produce a correlator output file, which is directed to the "corrfiles" subdirectory. Then the TDOA and FDOA are extracted from the correlator file and the results are stored in the "processfiles" subdirectory. Finally, the location of the unknown signal is estimated.

For a nominal 10-second observation, the size of the raw data file is approximately 16 Mb, the reformatted files are 2.6 Mb each, the correlator file for 32,768 lags is 140 Mb, and the TDOA/FDOA file contains only a few lines of text.

2.1.3 File Reformat

The six data streams acquired by the TLS in its standard mode of operation using the data buffer are interleaved in the data file that is produced. To reduce the overhead involved in repeated reprocessing of an observation, the first processing step is to reformat the file and undo the interleaving.

2.1.4 Correlation

Each data sample consists of two bits, which are determined from the voltage of the baseband signal at the time of sampling according to Table 1 below.

TABLE 1: SAMPLE VALUE VS. BASEBAND VOLTAGE

Baseband Voltage	MSB	LSB
Voltage >= (+T)	1	1

Voltage > 0, Voltage < (+T)	1	0
Voltage <= 0, Voltage > (-T)	0	1
Voltage <= (-T)	0	0

In the normal mode of operation of the TLS, the four-level quantization scheme is translated to a three-level scheme to accommodate the integrated circuits that perform the correlations. In the software correlator there is no objection to maintaining the four-level scheme, and this has been done. However, different threshold voltages T are required to optimize the correlation process in these two cases, and that for the software correlator the threshold voltage in the TLS should be set to a value of 150 mV.

The standard mode of operation for the demonstration was to process 32,768 lags per dump at a dump rate of 50 dumps per second of data acquisition. Individual measurements consisted of a total of either 512 dumps, yielding a nominal 10-second observation, or 2,048 dumps, yielding a nominal 81 second observation. The requirement on the number of lags is partly set by the range of TDOA over the area of mutual visibility of GOES-8 and GOES-10, and partly by the fractional spectral resolution necessary to digitally filter each one of the 1.5 kHz DCS channels in the 500 kHz data acquisition bandwidth. The requirement on dump rate is set by the anticipated combined frequency drift and change in Doppler shift between the satellites, to provide a reasonable length of time before the local oscillator offset frequency in the TLS needs to be redetermined.

2.1.5 TDOA/FDOA Estimation

The software correlator output file contains a time series of (complex) cross power spectra, one for each dump. These spectra are read in order into the columns of a two dimensional complex array. The estimator for NOAA has a special mode of operation where only the components of the spectrum corresponding to a single one of the DCS channels are read. The column index of this two-dimensional array therefore runs over baseband frequency, and the row index runs over real time (dump number).

The phase calibrator observation is processed first. The chief qualifying characteristic for a phase calibration signal is that it provides a very strong correlation, preferably strong enough so there is a good signal to noise ratio in a single dump. Under the assumption that at worst there is a constant TDOA (slope of phase vs. frequency) and FDOA (slope of phase vs. time) in the observation, an estimate of the TDOA and FDOA can be obtained through the operation of a two-dimensional Fourier transform on the two dimensional data array. After the transform, the column index will run over TDOA, the row index will run over FDOA, and the determination of the location of the peak correlation in row/column coordinates will provide, after a suitable translation of units, the TDOA and FDOA estimate.

2.1.6 Estimation of Uplink Location

The collection of all the TDOA and FDOA values obtained is processed in a standard weighted-least-squares algorithm to determine the location of the unknown transmitter. The quantities that can be estimated from the data include:

- The latitude, longitude, and height of any transmitter
- A position and velocity offset from the ephemeris for any satellite

A single observation of both TDOA and FDOA is generally enough to estimate the position of an unknown transmitter, provided the data were acquired at a time when geographical lines of constant TDOA and constant FDOA were not parallel. In practice, multiple observations are generally taken.

If satellite ephemeris corrections are to be estimated, it is necessary to also obtain and process TDOA and FDOA observations of signals from known geographical locations. These are called "position calibrators". It is desirable to have three or more position calibrators spaced widely in both latitude and longitude.

2.1.7 Diagnostic Software

Software has been provided for the Windows environment that examines a correlator file dump by dump. Additional software is capable of listing the contents of files in various formats.

3. Proof of Concept Demonstration Setup and Analysis Procedures

Data for the demonstration were acquired at Wallops Island between Monday, 25 February 2002 and Friday, 1 March 2002.

3.1 Equipment Setup

NOAA provided a connection to the East (GOES-8) 70 MHz IF from rack 12A2 distribution panel J19, and to the West (GOES-10) IF from rack 12B1 distribution panel J22. The DCS band in this IF ranges from 74.301 MHz (channel 1) to 74.6985 MHz (channel 266). This range of frequencies was translated to a band around 1000 MHz using a frequency synthesizer, power divider, two mixers, and filters. Since the TLS rack software is unable to ingest the true frequencies in the NOAA system, the TLS was instructed to observe a C band frequency of 3950 MHz, which, with a bandwidth setting of 0.5 MHz, caused it to set its frequency conversion oscillators to a nominal 999.75 MHz. The external synthesizer frequency required to place channel 133, the center channel, at 0.25 MHz in the baseband signal was found to be 925.5024 MHz. This was verified by observing the pilot signal in channel 100 at a frequency of 999.95058 MHz in the TLS input signal.

The position of the antenna receiving the GOES-8 signal was measured with a portable GPS receiver to be N37 56.713, W75 27.670. The position of the antenna receiving the GOES-10 signal was measured to be N37 56.719, W75 27.731. The position of the control building was measured by the GPS within the TLS equipment rack to be N37 56 45.123, W75 27 30.525.

With the system set up in this fashion, observations were taken of the entire DCS band with the standard TLS to determine the frequency offset (FO) between the two satellites. This was readily observed to be 284 Hz. The value of the frequency offset over a 24-hour period, determined by an automatic series of 10-second observations of the entire DCS band, is illustrated in Figure 1 below. The variation in FO is due in small part to the Doppler shift resulting from satellite motion, but is due mainly to the effect of changing internal temperature on the satellite frequency conversion oscillators.

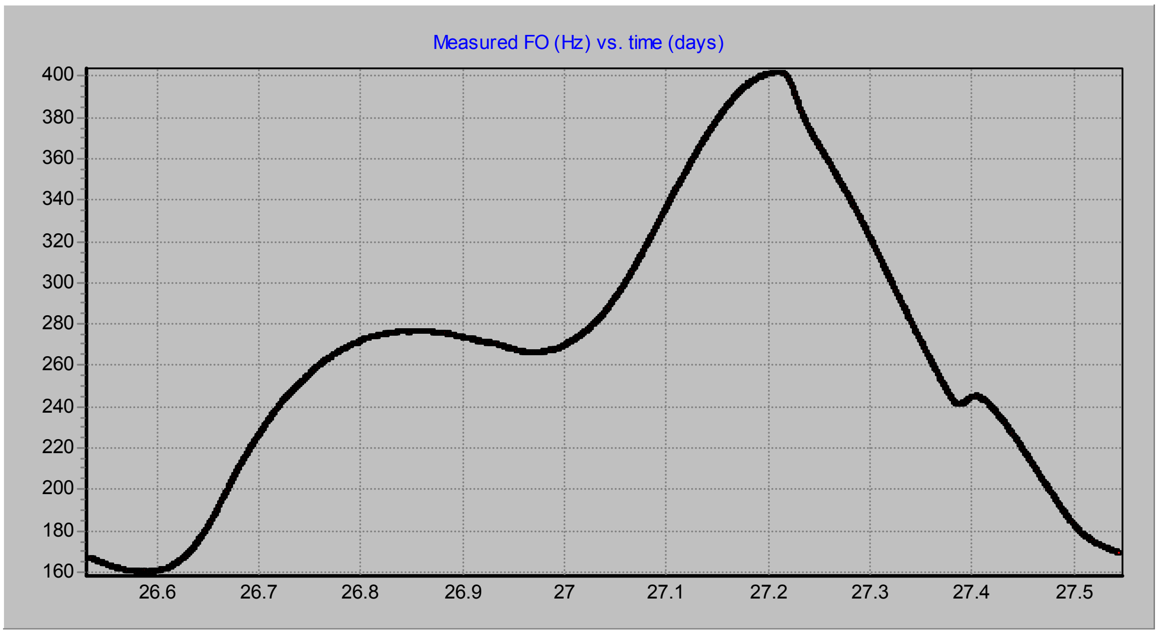

FIGURE 1: MEASURED FO (HZ) VS. TIME (UT DAY OF MONTH, FEB 2002)

Figure 2 below shows the same data with a sliding average of five consecutive observations removed. The day/night difference in the frequency fluctuations seems to be small.

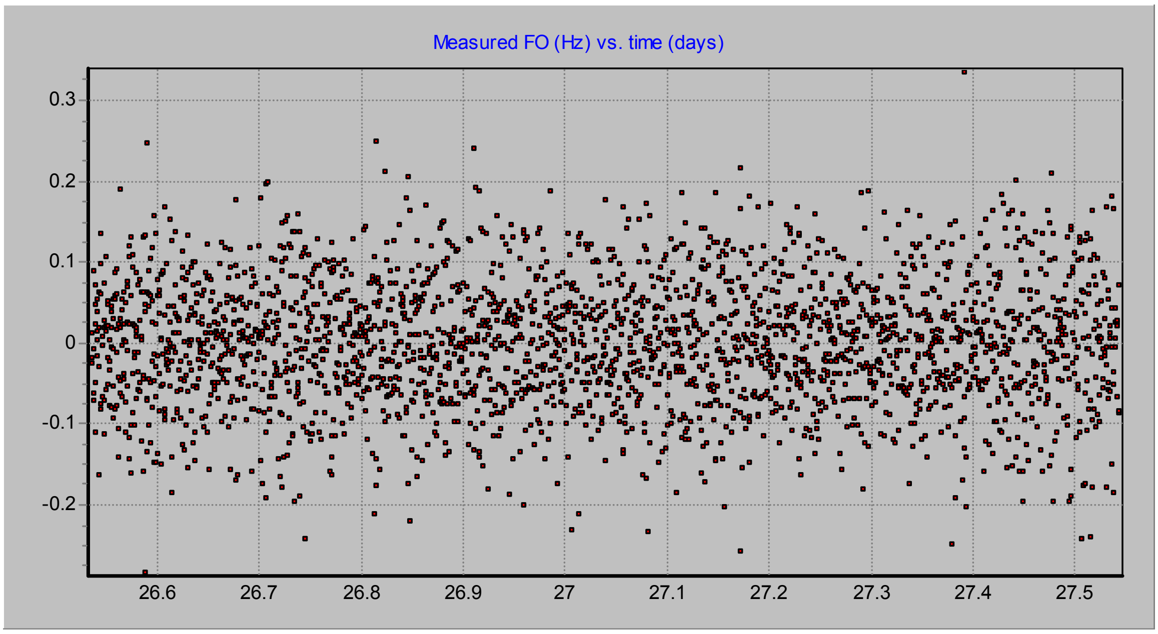

FIGURE 2: THE SAME DATA AS FIGURE 1 WITH A SLIDING AVERAGE REMOVED

3.2 Data Acquisition

During the time periods when raw data files were acquired for position location, the TLS was operated continuously taking 10-second observations of the whole spectrum to track the frequency offset. Then, just before the time for a raw data file acquisition, the continuous acquisition was stopped and the length of the desired raw data file was entered. It is necessary to command the start of the observation four seconds before the actual desired start time. At the completion of the acquisition, the raw data file was re-named and moved to a different file directory for storage.

3.3 Data Correlation

The data files were correlated using both the non-interactive Linux software and the Windows software with a graphic interface. In every case, correlation was performed with 32,768 lags centered on a TDOA of 8000 microseconds to accommodate signals from the continental United States and the Pacific Rim. The correlator coherent integration time was 1/50 second.

All of the 10-second observations were entirely correlated. The first halves of the 81-second observations were correlated. Correlation of the 81-second observations was shortened to maintain the correlator output file at a size that could be written to compact disc storage.

3.4 TDOA/FDOA Estimation

Software was written to identify which channels were active during the acquisition period. The criterion roughly enforced was to demand a correlated power of at least two per cent of the power of the pilot signal in channel 100 at the same time. This criterion chooses only very strong signals for processing; there are many other transmissions not meeting the criterion that could be processed and located.

4. Data Analysis and Results

The data analysis proceeded in two parts. First, two data files were processed to extract all active signals with good correlation SNR in order to perform a general analysis of the detectability of the DCS signals and to evaluate such issues as the quality of the satellite ephemeris, day-night variations in ionospheric effects, variations due to transmit channel number, *etc.* The second part of the data analysis focused on the geolocation of “ground truth” signals uplinked by NOAA in order to assess the geolocation accuracy of the system. The results of the data analysis for these two cases are presented in Sections 4.1 and 4.2, respectively.

4.1 General Analysis of Detectability and Geolocation Consistency

For the first data analysis task we concentrated our efforts on two of data files: R1014908484 at 59-14:59:59 (hereafter identified as data set “A”), and R1014980485 at 60-11:00:00 (hereafter identified as data set “B”). These files were acquired during daytime and nighttime, and it was expected that they would contain many signals from the same transmitters, as many data collection platforms transmit on an hourly schedule.

NOAA has provided information concerning the transmitters expected to be active during these two intervals. This information is summarized in Table 2 below for signals that were processed for which latitude and longitude data are available.

TABLE 2: EXPECTED TRANSMITTER ACTIVITY AND THEIR REPORTED POSITIONS

DCS Channel Number	Repetition Period (hours)	First Transmission (hhmmss UTC)	Reported Latitude (degrees)	Reported Longitude (degrees)
4	4	030000	38.2358	-107.7575
		030100	38.2378	-107.7589
6	4	030000	47.1847	-122.2292
		030100	47.2661	-122.2286
9	1	000000	43.8883	-76.4483
		000100	32.2950	-75.2406
10	3	000100	56.2500	-121.6200
		020000	48.7183	-124.2261
13	3	020100	46.7719	-71.2053
		020000	41.0781	-76.4314
		000000	-30.0000	-70.5833
		000100	-31.0167	-70.6000
15	1	000000	30.6667	-89.1667
16	3	020100	49.9433	-125.5081
19	3	000100	53.3258	-100.2667
		000000	49.2111	-99.1458
		020000	50.6858	-64.5800
		020100	47.8958	-71.8883
21	4	030000	41.4761	-75.1725
		030100	41.0619	-75.2483
30	3	000000	45.0708	-119.4900
31	1	000040	47.4336	-98.0286
		000020	47.8056	-98.7158
		000100	47.2292	-98.1244
36	4	030100	44.7367	-103.6742
		030000	40.6736	-111.4033
42	4	030100	47.9167	-113.8333
		030000	43.6139	-116.2517
50	1	000100	35.1011	-121.1169
		000000	46.0833	-131.0000
51	1	000000	39.3000	-76.8800
52	4	030100	42.5750	-96.6833
		030000	40.8731	-95.5783
55	4	030000	34.6172	-89.9417
		030100	37.3722	-80.8625
59	3	000000	15.6711	-96.4972

62	4	030000	39.9308	-106.7044
		030100	37.7217	-108.7328
63	3	020000	20.8483	-100.8247
64	4	030000	37.0381	-107.8736
69	1	000000	26.6483	-81.8717
		000030	40.8117	-73.7650
70	4	030000	33.4186	-111.0089
		040000	38.9589	-104.8356
75	1	000000	29.2486	-94.4125
76	1	000045	33.9044	-109.9536
		000015	43.5153	-119.2925
		000030	47.9678	-123.6347
		000100	37.3444	-107.9203
92	1	000000	47.2697	-114.9161
		000045	42.5769	-121.8936
		000100	42.9764	-121.4237
		000015	42.6314	-121.5597
105	4	030000	39.0650	-96.7567
		030100	39.0644	-96.7544
107	4	030000	27.3575	-82.5439
		030100	27.3581	-82.5506
109	1	000000	40.7333	-77.3483
		000015	41.3417	-75.5167
		000030	40.3558	-77.4183
		000045	40.1078	-77.0469
		000100	41.8161	-76.6903
112	4	030000	39.1083	-119.7111
		030100	40.9083	-109.4222
113	1	000000	42.8983	-68.8933
		000100	38.4636	-74.7019

Not every channel was active in both observations. Table 3 below shows the observed activity for each of the two data sets. The “A” data set contained a total of 36 signals meeting the correlation power criteria. The “B” data set contained 38 signals meeting this criterion.

TABLE 3: DATA ACQUIRED BY CHANNEL

Chan	A	B		Chan	A	B		Chan	A	B
04	♦	♦		50		♦		105	♦	♦
06	♦	♦		51	♦	♦		107	♦	♦
09	♦	♦		52	♦	♦		109	♦	♦
10		♦		55	♦	♦		112	♦	♦

13		◆		59	◆			113	◆	◆
15	◆	◆		62		◆		117	◆	◆
16	◆			63		◆		119		◆
19	◆			64	◆	◆		125		◆
21	◆	◆		68	◆	◆		126	◆	
30	◆			70	◆	◆		129	◆	◆
31	◆	◆		75	◆	◆		134		◆
36	◆			76	◆	◆		136		◆
42	◆	◆		82	◆	◆				
43	◆	◆		86	◆	◆				
45	◆	◆		90	◆	◆				
47	◆			92	◆	◆				

4.2 Signal Location Estimation

Ephemerides for the satellites were provided by NOAA according to Table 4 below. All position estimation has been done with respect to this ephemeris extrapolated to days 59 and 60.

TABLE 4: SATELLITE EPHEMEREDES

	GOES-8	**GOES-10**
Epoch	56-12:00:00	56-06:00:00
Semimajor Axis (km)	42163.1847	42168.2013
Eccentricity	0.00019410	0.00024445
Inclination	0.22933015	0.18924137
RA Asc Node	274.52152860	104.77967760
Arg of Perigee	89.06158903	311.80778360
Mean Anomaly	256.78888220	52.75013885

The position determination analysis has been done both with and without DECal™ differential corrections to the provided day 56 ephemeris based on position calibrator measurements. Where differential corrections were applied, the signals listed in Table 5 were used as position calibrators on the assumption that their latitudes and longitudes as reported by NOAA are the true positions of the uplink transmitters.

TABLE 5: SIGNALS USED AS POSITION CALIBRATORS

DCS Channel	Reported Latitude (degrees)	Reported Longitude (degrees)
4	38.2358 N	107.7575 W
9	43.8883 N	76.4483 W
55	34.6172 N	89.9417 W
92	47.2697 N	114.9161 W
112	39.1083 N	119.7111 W

The observations were separated into three groups. The first group consisted of 17 signals apparently originating from stationary platforms for which latitude and longitude data were available from NOAA. The second group consisted of 3 signals apparently originating from moving platforms for which latitude and longitude data were available from NOAA. The third group consisted of 8 stations for which no latitude and longitude data were available. Only the first two groups were analyzed further.

4.3 Stationary Platform Analysis and Results

Table 6 summarizes the results for the fixed platforms. The Table indicates the nominal latitude of the platforms as reported by NOAA, the calculated latitude and longitude from the TLS data and the distance between the calculated and reported locations.

In the Table, "Uncal A" and "Uncal B" refer to the station positions calculated based on the day 56 ephemeris without applying the DECal™ differential corrections to the satellite ephemeris, while "DECal A" and "DECal B" refer to the station positions calculated using DECal™ differential corrections derived from the position calibrators (position calibrator stations are indicated in the Table in red typeface). The column labeled Improvement indicates the improvement (or degradation, for negative values) in the position error achieved by using DECal™.

TABLE 6: GEOLOCATION RESULTS FOR STATIONARY PLATFORMS

Channel 4 (position calibrator)				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	38.2358	107.7575		
Uncal A	38.6959	107.9227	53.4	
DECal A				
Uncal B	38.4055	107.6501	21.1	
DECal B				
Channel 6				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	47.1847	122.2292		
Uncal A	48.1264	122.5777	67.3	
DECal A	47.4975	122.3392	22.3	45.0
Uncal B	46.8945	122.1758	20.3	
DECal B	47.0473	122.2307	9.5	10.8
Channel 9 (position calibrator)				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	43.8883	76.4483		
Uncal A	44.0156	76.5184	9.5	
DECal A				
Uncal B	43.6316	76.4562	17.8	
DECal B				

Channel 21				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	41.4761	75.1725		
Uncal A	41.7443	74.8494	25.1	
DECal A	41.7815	74.8273	27.8	-2.7
Uncal B	41.4061	75.3389	9.9	
DECal B	41.5629	75.2480	7.2	2.7

Channel 31				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	47.8056	98.7158		
Uncal A	47.8632	98.6146	6.2	
DECal A	47.5581	98.6569	17.4	-11.2
Uncal B	47.2270	98.7043	40.1	
DECal B	47.5552	98.6583	17.6	22.5
Channel 42				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	43.6139	116.2517		
Uncal A	44.8272	121.5536	279.2	
DECal A	44.2038	121.3546	259.5	19.7
Uncal B	44.1420	121.2297	252.6	
DECal B	44.1562	121.2341	253.0	-0.4
Channel 51				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	39.3000	76.8800		
Uncal A	39.5318	76.5277	24.8	
DECal A	39.5251	76.5311	24.4	0.4
Uncal B	39.0136	76.6775	22.6	
DECal B	39.0541	76.6571	20.8	1.8
Channel 52				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	40.8731	95.5783		
Uncal A	41.1317	95.5118	18.3	
DECal A	40.8380	95.5602	2.6	15.7
Uncal B	40.8480	95.5148	3.8	
DECal B	40.8725	95.5107	3.5	0.3
Channel 55 (position calibrator)				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	34.6172	89.9417		
Uncal A	34.8818	90.0046	18.7	
DECal A				
Uncal B	34.9445	89.9077	22.8	
DECal B				

Channel 64				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	37.0381	107.8736		
Uncal A	37.3723	107.7528	24.1	
DECal A	36.8944	107.7345	12.6	11.5
Uncal B	37.2188	107.8349	12.7	
DECal B	37.0199	107.8280	2.8	9.9
Channel 70				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	33.4186	111.0089		
Uncal A	33.9056	110.9984	33.8	
DECal A	33.3758	110.9582	4.2	29.6
Uncal B	33.8592	111.1656	31.9	
DECal B	33.5145	111.1400	10.1	21.8
Channel 76				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	43.5153	119.2925		
Uncal A	44.4101	119.4140	62.4	
DECal A	43.8110	119.2511	20.6	41.8
Uncal B	43.4530	119.1372	8.9	
DECal B	43.4480	119.1360	9.2	-0.3
Channel 92 (position calibrator)				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	47.2697	114.9161		
Uncal A	47.6627	115.1509	29.4	
DECal A				
Uncal B	46.7012	114.5414	43.2	
DECal B				
Channel 105				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	39.0650	96.7567		
Uncal A	39.2098	96.8214	10.6	
DECal A	38.8880	96.8642	13.6	-3.0
Uncal B	39.0093	96.6104	8.8	
DECal B	38.9487	96.6190	11.0	-2.2

Channel 107				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	27.3575	82.5439		
Uncal A	27.4311	82.6489	8.2	
DECal A	27.2581	82.6915	11.4	-3.2
Uncal B	27.8689	82.3976	36.6	
DECal B	27.4718	82.5001	8.4	28.2
Channel 109				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	40.7333	77.3483		
Uncal A	41.2375	76.9312	41.3	
DECal A	41.2366	76.9316	41.2	0.1
Uncal B	40.6660	77.2167	8.3	
DECal B	40.7786	77.1579	10.5	-2.2
Channel 112 (position calibrator)				
	Lat (deg N)	Long (deg W)	Accuracy (mi)	Improvement (mi)
Actual	39.1093	119.7111		
Uncal A	39.8670	119.8639	53.2	
DECal A				
Uncal B	39.4310	119.9371	25.4	
DECal B				

It is clear from an examination of the data that Channel 42 is an evident outlier for both data set A and data set B. The logical conclusion of this is that the location of the Channel 42 platform is incorrectly reported in the NOAA database. The results for Channel 42 were therefore excluded from further analysis.

For the 16 remaining signals the mean position error was 30.4 miles for data set A (daytime) and 20.9 miles for data set B (nighttime data). Upon excluding the 5 signals selected as position calibrators the mean position errors for the remaining 11 signals (prior to applying the DECal corrections) were 29.3 miles for data set A and 18.5 miles for data set B. After applying the DECal corrections to the satellite ephemeris, the mean position errors for these signals were 18.0 miles for data set A and 10.1 miles for data set B. These results are summarized in Table 7.

TABLE 7: MEAN AND RMS POSITION ERRORS FOR STATIONARY SIGNALS (EXCLUDING CHANNEL 42)

	With Position Calibrators		***Without Position Calibrators***	
	mean (mi)	**rms (mi)**	**mean (mi)**	**rms (mi)**
Uncal A	30.4	4.7	29.3	5.8
DECal A			18.0	3.0
Uncal B	20.9	2.8	18.5	3.6
DECal B			10.1	1.6

It is important to keep in mind that this analysis assumes that the latitudes and longitudes contained in the NOAA DCS database are error-free. While it is apparent from the data that (with the exception of channel 42) the positions must be in reasonably good agreement with the reported positions, there may be at least some small errors in their reported positions.

Subject to this caveat, several conclusions concerning stationary DCS platforms can be drawn from this analysis.

1. TLS measurements made at night appear to improve geolocation accuracy by about 50% as compared to daytime measurement. This result was expected based on the predicted ionospheric effects.

2. The ephemeris data available from NOAA are very good quality. Although DECal did improve the results overall, the uncorrected ephemeris yielded usable results.

3. Applying DECal corrections to the ephemeris produced about another 50% improvement in the geolocation results when compared to the results without DECal processing.

4. Typical geolocation accuracies on the order of 10 miles can be achieved using nighttime measurements with DECal processing.

4.4 Moving Platform Analysis and Results

Table 8 summarizes the results for the fixed platforms. The Table indicates the nominal latitude of the platforms as reported by NOAA, the calculated latitude and longitude from the TLS data and the distance between the calculated and reported locations. Since the position errors for the moving platforms are much larger than the corrections introduced by DECal, the data were processed only using the nominal satellite ephemeredes.

TABLE 8: GEOLOCATION RESULTS FOR MOVING PLATFORMS

Channel 15			
	Lat (deg N)	Long (deg W)	Accuracy (mi)
Actual	30.6667	89.1667	
Uncal A	33.6821	78.6571	660.9
Uncal B	39.0093	96.6104	729.3
Channel 75			
	Lat (deg N)	Long (deg W)	Accuracy (mi)
Actual	29.2486	94.4125	
Uncal A	22.1530	95.1473	494.1
Uncal B	24.7872	94.9063	310.8
Channel 113			
	Lat (deg N)	Long (deg W)	Accuracy (mi)
Actual	42.8983	68.8933	
Uncal A	30.6422	76.0612	924.7
Uncal B	48.7736	63.8557	481.2

At first it would appear that the geolocation for moving platforms are sufficiently inaccurate to draw any conclusions about the true platform location. However, when the TDOA and FDOA accuracies are examined independently, it is clear that the position errors for two of the signals (channels 75 and 113) result primarily from the poorly determined FDOA due to the phase fluctuations induced by the (presumably wave) motion. This can be seen graphically in the position ellipse map for these signals, shown in Figure 3.

It can be seen in the Figure that the semi-major axes of the position ellipses for all three platforms line up along the expected directions of the lines of constant TDOA, indicating that the measurement errors are in the FDOA dimension.

With regard to the channel 15 signal, the good agreement of the two measurements and their alignment along a line of constant TDOA suggest that this platform is not located in the Mobile, Alabama area as indicated by its reported latitude and longitude, but is more likely located off the southeastern coast of the US near South Carolina.

When this result was verified it confirmed that the moving platforms did provide accurate TDOA measurements, resulting in an accurate line of position along which the platform lies.

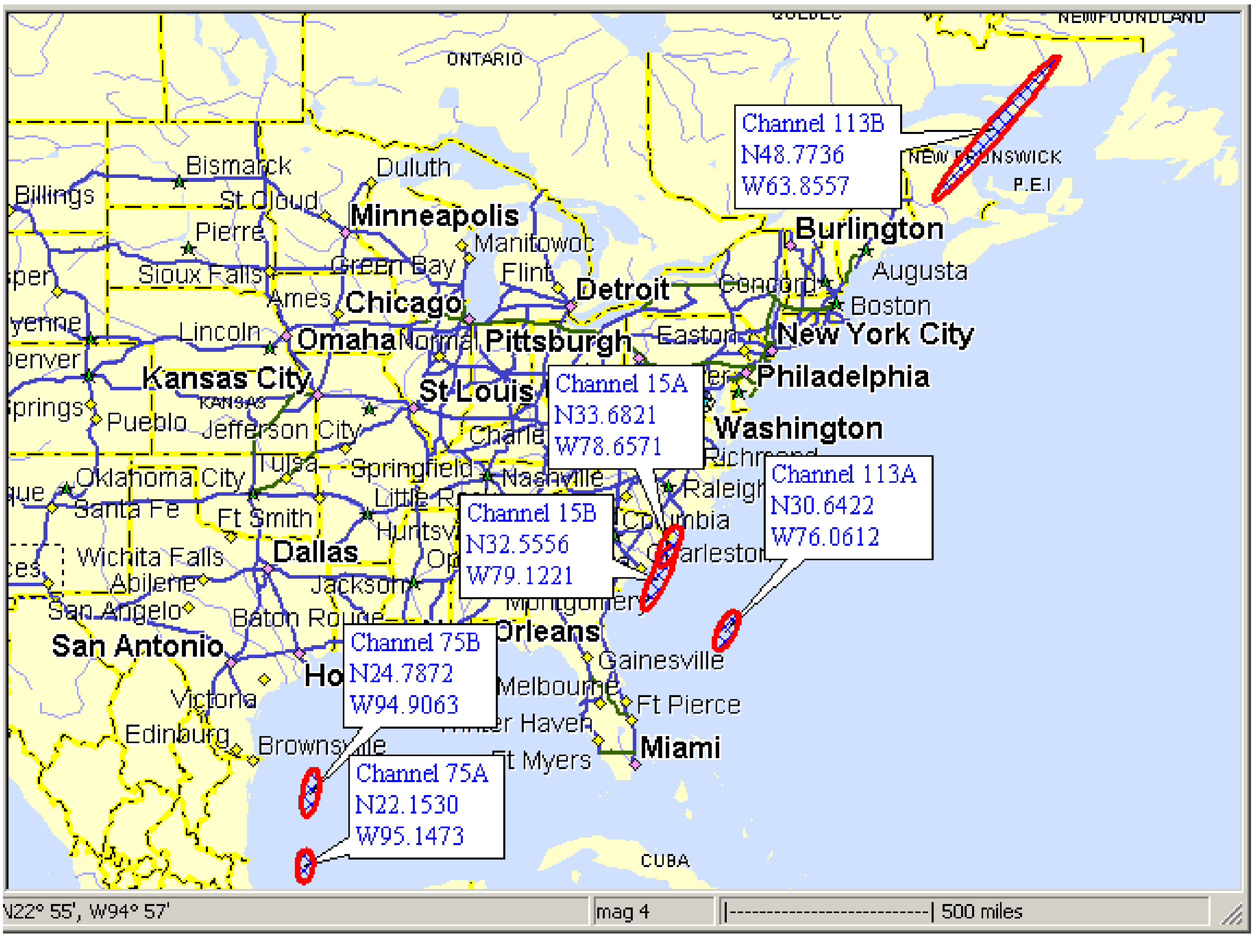

FIGURE 3: POSITION ELLIPSES FOR MOVING PLATFORMS

5. Geolocation Results for "Ground Truth" Signals

During the Phase 2 Proof of Concept NOAA arranged to uplink signals from known locations in order to provide a blind test of the geolocation accuracy of the TLS. These signals were uplinked hourly according to a fixed schedule. NOAA initially provided the following schedule and channel numbers for the "ground truth" signals:

Transmit Time (mm:ss)	Channel Number
00:00	151
15:00	151
30:00	195, 196
45:00	151

After processing several data files spanning time periods 00:00, 15:00, 30:00 and 45:00 we find that our experience matches the schedule given by NOAA – no transmissions were found on channel 151 in the 40 second intervals beginning at 15 and 45 minutes past the hour, and no signals were found in channel 196 in the 40 second intervals beginning at 30 minutes after the hour.

For the time intervals beginning on the hour (channel 151) and half-hour (channel 195), Table 9 lists the data sets that were processed.

TABLE 9: DATA SETS PROCESSED FOR GROUND TRUTH SIGNALS

File Name	Start UT (day-hh:mm:ss)	Data Set Identifier
Channel 151		
R1014908484	59-14:59:59	151A
R1014912013	59-16:00:00	151B
R1014980485	60-11:00:00	151C
R1014984085	60-12:00:00	151D
R1014987685	60-13:00:00	151E
Channel 195		
R1014906688	59-14:30:03	195A
R1014913819	59-16:30:00	195B
R1014978685	60-10:30:00	195C
R1014982285	60-11:30:00	195D
R1014985885	60-12:30:00	195E

From these data sets ground truth signals were detected for data sets 151A, 151C, 151D, 195A, 195B, 195C, 195D and 195E. No signals were detected in channel 151 for data sets 151B or 151E.

For the data sets in which ground truth signals were detected, Table 10 provides the calculated positions of the ground truth transmitters. These positions were derived using the nominal satellite ephemeris data provided by NOAA without DECal processing. The data were processed this way since no list of calibrator stations was available for the data sets taken at 30 minutes past the hour. If NOAA provides the needed calibrator information these data can be reprocessed with DECal corrections.

TABLE 10: CALCULATED LATITUDE AND LONGITUDE FOR GROUND TRUTH STATIONS

Data Set ID	Latitude (degrees N)	Longitude (degrees W)
Channel 151:		
151A	38.0290	122.2455
151C	37.7859	122.1478
151D	38.1311	122.1917
Channel 195:		
195A	38.9911	77.5419
195B	38.9875	77.3160
195C	39.0487	77.4977
195D	39.2729	77.2296
195E	39.1985	77.3744

The coordinates for the ground truth stations were not available at the time the report was submitted. It was suggested, if NOAA provide the actual latitudes and longitudes for the ground truth stations, TLS LLC will perform the statistical analysis of the mean position errors for these stations to report the actual ground location.

The position ellipses for the ground truth stations are depicted in Figures 4 and 5.

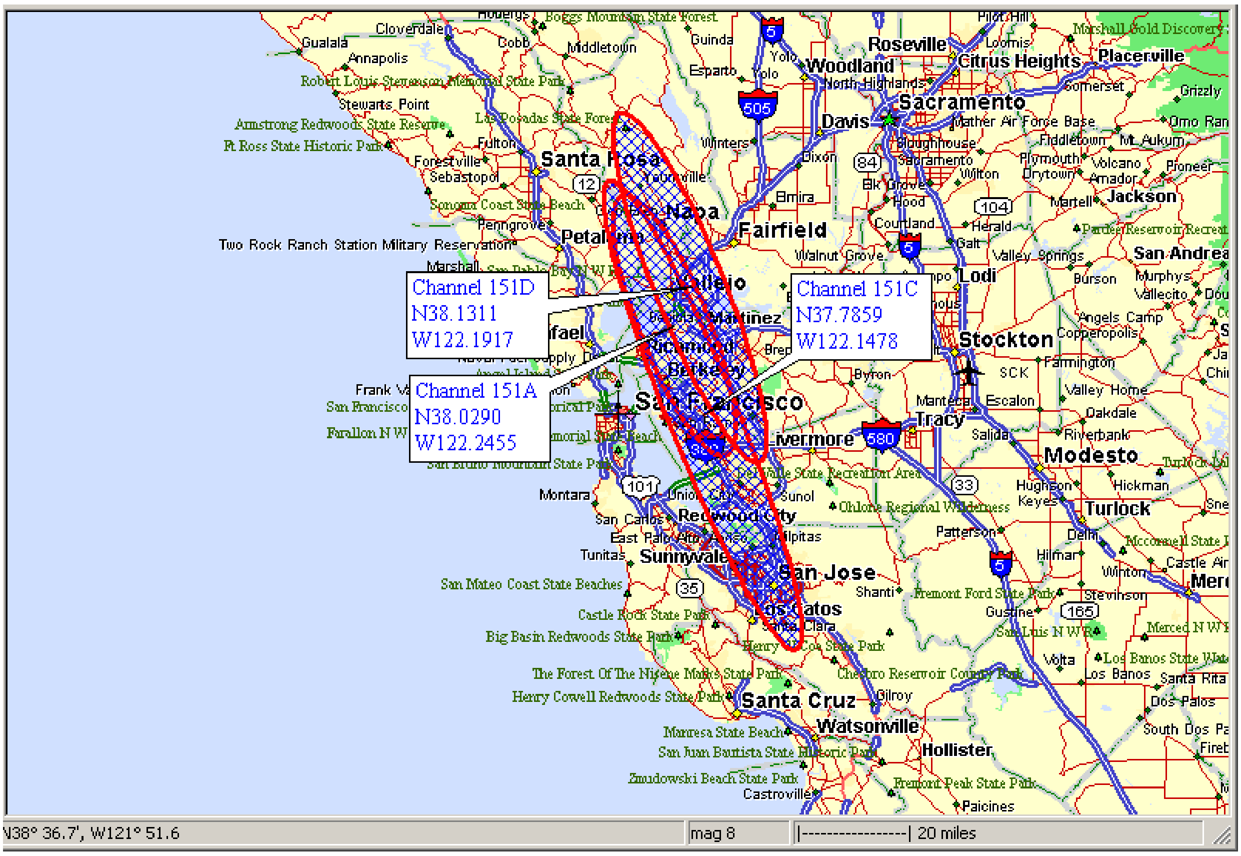

FIGURE 4: POSITION ELLIPSES FOR CHANNEL 151 GROUND TRUTH TRANSMITTER

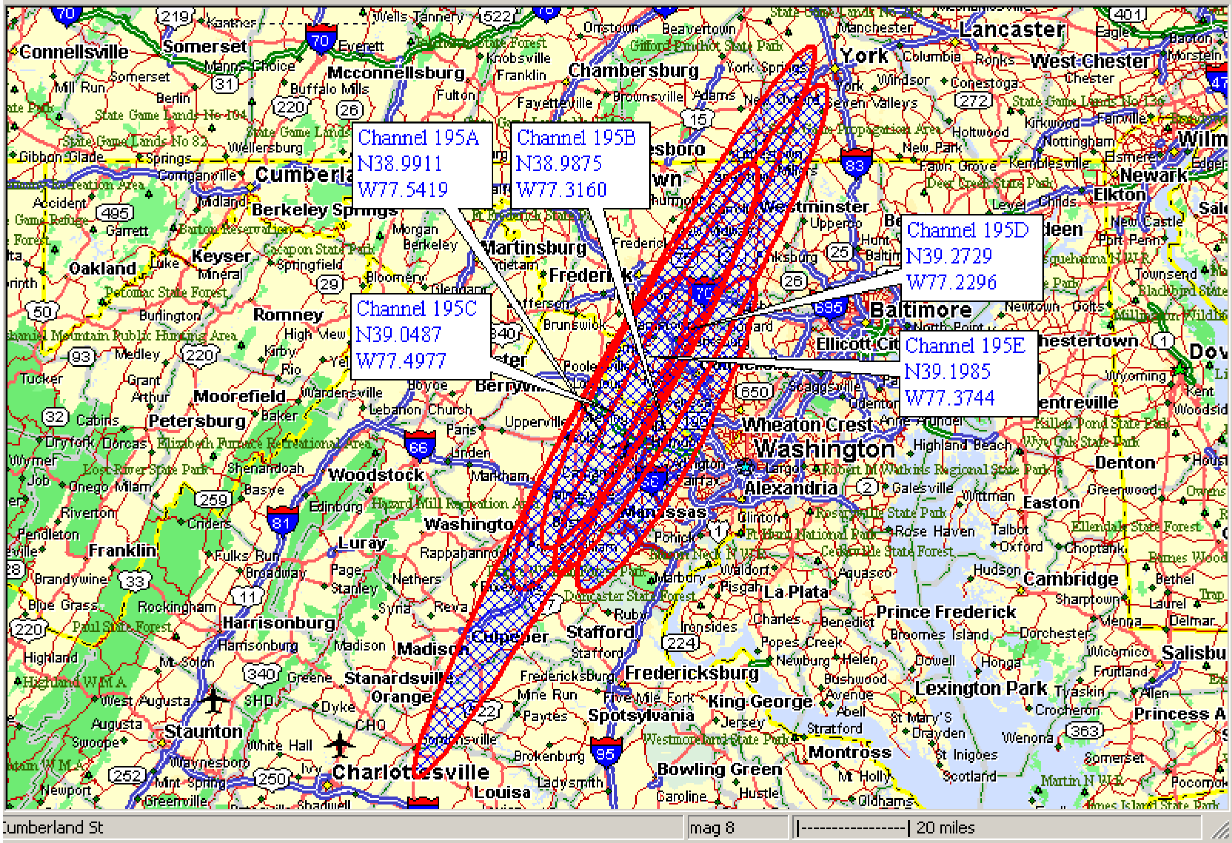

FIGURE 5: POSITION ELLIPSES FOR CHANNEL 195 GROUND TRUTH TRANSMITTER

6. Position Ellipse Sizing

The geolocation position ellipses are generally sized on the basis of the RMS errors in a series of measurements of the same signal. Since the results reported herein are generally based on single observations of each "unknown" signal the position ellipses were all sized based on the assumed *a priori* errors in the data. Until sufficient experience is gained with the NOAA DCS application, the ellipse sizes should be considered somewhat arbitrary and subject to further refinement as more experience is gained.

7. Conclusion

Interference location in the GOES DCS frequency band was successfully demonstrated using the TLS system. All unknown transmitter were located within the specified boundaries require by NOAA. Understanding the complexities of the DCS environment, NOAA believe the TLS system will benefit the management of its RF resources and help to provide a better service for the DCS users and the GOES family.

Phase 3 will involve the actual construction and delivery of a TLS for use with the GOES DCS network. Because of the substantial differences between the GOES DCS network and the current applications of other TLS models, we anticipate that this Task will involve significant changes to the data processing and analysis software. The system construction will consist of two main tasks: hardware construction and software development.

a.) Hardware Construction. The construction of the TLS for use with the GOES DCS will draw upon the system studies and design developed in Phase 1 and validated in Phase 2. The hardware configuration will largely be identical to other TLS models, with some modification to adapt the current design to the GOES DCS. The areas in which the design will be modified are primarily the RF front end hardware, which will be configured for operation at S-band, as well as any special design considerations based on the specifics of the installation site, presumed to be the Wallops Island CDA site.

b.) Software Development. The existing TLS software will require some modifications for use with the GOES DCS. The narrowest processing bandwidth of the current TLS hardware is 62.5 kHz. This means that each measurement will include components contributed by each of the DCS channels containing active transmissions during the integration period. The most straightforward way to isolate the signal of interest from these extraneous signals is by software post-processing of the correlated data using Fourier transform methods. Some rudimentary aspects of this software will be developed as part of the Phase 2 effort. However, the development of a fully functional automated processing system to perform this signal isolation will be a major activity of the Phase 3 effort. The software development effort will proceed in parallel with the hardware procurement and system construction.

NESDIS continues to investigate the transmitter location system and evaluate the benefits it has on the DCS service and the GOES system. Implementation of Phase 3 has not been determined. The USA continues to evaluate plans for operating the TLS in the GOES environment.