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Channel Usage Classification Using Histogram-Based Algorithms for Fast Wideband Scanners

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Background

- This study is for spectrum surveillance applications (e.g. CRC's Spectrum Explorer).
- A wideband scanning device is needed since various signals may occupy a wide frequency band.
- Some signals can last long without major fluctuations (e.g. TV signals); some signals are sporadically on and off with fluctuations (e.g. cellular signals).
- To catch short signals, the time between consecutive scans has to be short (i.e. a fast scanner is needed), and the scanning duration has to be long.

- To catch narrow-band signals, the number of scanned channels has to be large enough.
- Basic preliminary channel usage info usually includes multiple (channel#, SNR, AOA, AOA ISD) for each scan. Thus, a pre-processing (first-step) procedure (signal detection, type identification, direction finding) is needed.
- The size of preliminary channel usage info is usually huge.
- After completing scans, the overall channel usage report (active channel#, EST_SNR, EST_AOA, EST_SD) should be obtained ASAP.

Goal

- Develop a set of simple algorithms (second-step procedure) to process the preliminary channel usage info set efficiently to get the overall channel usage report.

Approach

- Use the histogram-based algorithms to process the preliminary channel usage info set to get the overall channel usage report.

Concept

- Statistically, each lobe of a variable histogram from various scans is linearly related to the distribution density of that variable, given that the number of scans is large.
- The related information is embedded in the histograms. No prior knowledge of variable distribution is needed.
- In this study, SNR, AOA and AOA ISD are the interested variables.

Active Channel

- If there are N scans, and among them, there are M detected counts of channel#k, then channel#k is active if (M/N) > ch_threshold.
- For long signals without major fluctuations (e.g. TV signals), ch_threshold ~ 1.
- For signals that are sporadically on and off with fluctuations (e.g. cellular signals), ch_threshold ~ 0.
- In this study, ch_threshold = 0.5.

SNR, AOA, AOA ISD Histograms

- For each active channel, a SNR histogram (*HistSNR*) from its preliminary channel usage info is generated.
- CS(k,1 to 3) are the leftmost, peak and rightmost sample indices of the kth pre-lobe. For each k, the pre-lobes are grouped as follows:

```
if (CS(k,3)-CS(k,2))<=2
 if CS(k+1,2)-CS(k,2)<3
   if HistSNR(CS(k,2))>=HistSNR(CS(k+1,2))
     CS(k,3)=CS(k+1,3);
   else
     CS(k,2)=CS(k+1,2);
     CS(k,3)=CS(k+1,3);
   end
 end
end
```

- For a *HistSNR*, its isolated cluster lobes CS(I,3) were found where I is the final grouped lobe number.

- Valid *HistSNR* lobe is defined when lobe_peak/*HistSNR*_max > 0.8.
- For each valid *HistSNR* lobe, the corresponding AOA and histograms (*HistAOA*, *HistISD*) from their preliminary channel usage info are generated.
- The averaged ISD (AISD) was obtained by weight averaging *HistISD*. The weight average of a histogram is:

$$WA = \sum_{m=m_s}^{m_e} [m \times Hist(m)] \Big/ \sum_{m=m_s}^{m_e} Hist(m)$$

, where m_s, m_e are the start/end sample indices within a histogram lobe.

- CA(k,1 to 3) are the leftmost, peak and rightmost sample indices of the kth pre-lobe. For each k, the pre-lobes are grouped as follows:

```
if (CA(k,3)-CA(k,2))<AISD
  if HistAOA(CA(k,2))>HistAOA(CA(k+1,2));CA_C(k,1)=CA(k,1);
    CA_C(k,2)=CA(k,2); CA_C(k,3)=CA(k+1,3);
   else CA_C(k,1)=CA(k,1); CA_C(k,2)=CA(k+1,2);
    CA_C(k,3)=CA(k+1,3); end; n_cc=2; n_rc=N'-n_cc;
   while (CA_C(k,3)-CA_C(k,2)<=2*AISD)&n_rc>0
        if HistAOA(CA(n_cc+1,2))<=HistAOA(CA_C(k,2))
          CA_C(k,3)=CA(n_cc+1,3);
        else CA_C(k,2)=CA(n_cc+1,2); CA_C(k,3)=CA(n_cc+1,3);
        end; n_cc=n_cc+1; n_rc=N'-n_cc; end;
elseif CA(k+1,2)-CA(k+1,1)<=AISD
       if HistAOA(CA(k+1,2))>=HistAOA(CA(k,2))
CA_C(k,1)=CA(k,1);CA_C(k,2)=CA(k+1,2);CA_C(k,3)=CA(k+1,3);
       elseif  HistAOA(CA(k+1,2))<HistAOA(CA(k,2))
CA_C(k,1)=CA(k,1);CA_C(k,2)=CA(k,2);CA_C(k,3)=CA(k+1,3);
       end; end;
CA(k,1)=CA_C(k,1);CA(k,2)=CA_C(k,2);CA(k,3)=CA_C(k,3); end;
```

where *N'* is the grouped lobe number computed on the fly.

- For a *HistAOA*, its isolated cluster lobes CA(J,3) were found where J is the final grouped lobe number.

- The AOA SDs were calculated from the isolated *HistAOA* lobes.
- Valid *HistAOA* lobe is defined when lobe_peak/*HistAOA*_max > 0.5.
- The weight average of each valid *HistSNR* lobe = EST_SNR.
- The angularly weighted average of each valid *HistAOA* lobe = EST_AOA.
- The angularly weighted average (in degrees) of a histogram is:

$$AWA = \frac{180}{\pi} \times Ang\left[\sum_{m=m_S}^{m_e} e^{j\frac{\pi}{180}[m \times Hist(m)]} \right]$$

, where $Ang[\bullet]$ represents the phase angle of $\bullet$ in radians.

- (EST_SNR, EST_AOA) represents an estimated signal from a transmitter (user) within an active channel.

Simulated and CRC-measured Data

- Simulated part:

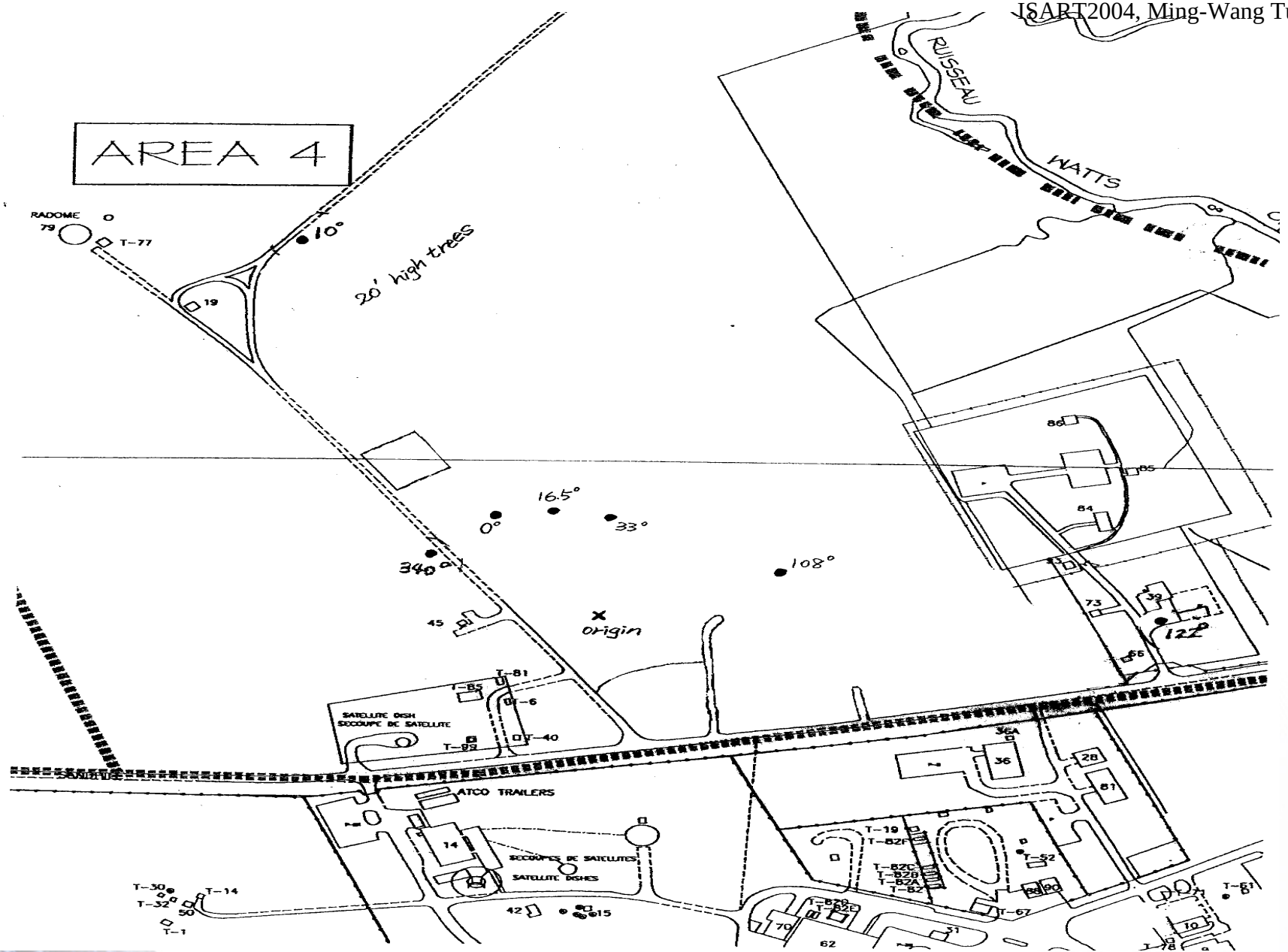
  1000-sample-per-signal normal distribution was used for the SNRs, the SNRs, AOAs and AOA ISDs in preliminary channel usage info set.

- CRC-measured part:

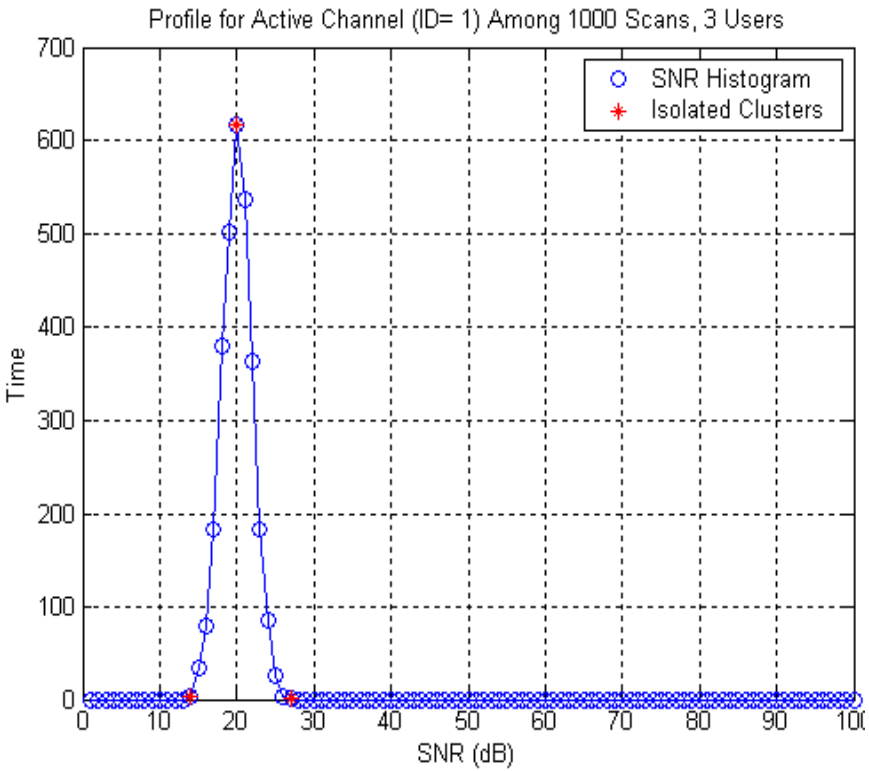
- For each scenario in CRC-measured data, around 5000 data scans were collected with 300 ms between consecutive scans with one 25 KHz channel using the same frequency center as the TX signal. The scanned data were preprocessed using a 2.5 kHz FFT resolution (400 us time span for each scan) to determine the SNRs, AOAs and AOA ISDs.

TABLE I. CRC-MEASURED SCENARIOS

Scenario	TX Location (degree, meter)	Description
1	(0, 110)	Clear LOS
2	(108, 100)	Clear LOS
3	(340, 110)	Clear LOS
4	(16.5, 110)	Clear LOS
5	(33, 110)	Clear LOS
6	(122, 300)	Beside a building
	RX Location (degree, meter)	
7	(10, 350)	Behind 20’ high trees


AREA 4
RADOME
79
T-77
19
10°
20' high trees
0°
16.5°
33°
340°
108°
45
origin
RUISSEAU
WATTS
86
85
84
83
73
39
122
66
T-81
T-85
T-6
T-40
T-89
SATELLITE DISH
SECOUPE DE SATELLITE
ATCO TRAILERS
14
SECOUPES DE SATELLITES
SATELLITE DISHES
T-30
T-32
50
T-14
T-1
42
15
T-19
T-82F
T-82C
T-82B
T-82A
T-82
T-82D
T-82E
T-52
T-67
70
62
36A
36
28
81
T-61
10

- Simulated Scenario: 3 signals with AOA ~ |*N*(20/40/60-dg, 2/3/4-dg SD)|, AOA ISD ~ |*N*(0, 2/3/4-dg SD)| for signal 1/2/3, SNR ~ |*N*(5 to 40-dB, 2-dB SD)| for each signal.
- The AOA ISDs/SDs were set purposely to be independent of the SNRs. In practice, as the SNR increases, the AOA SD decreases.



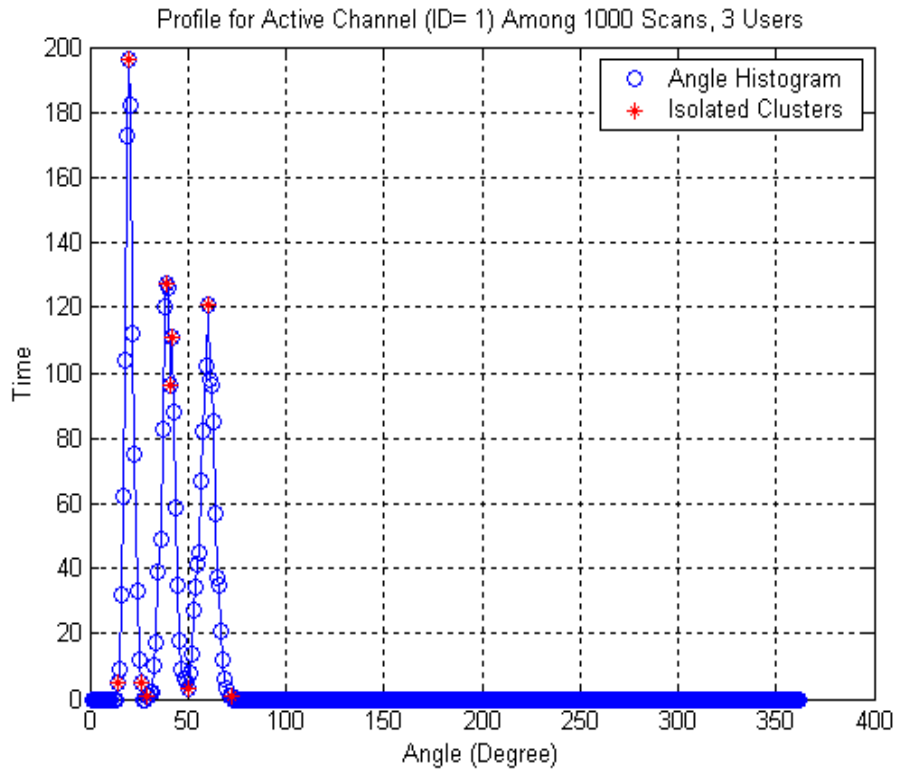
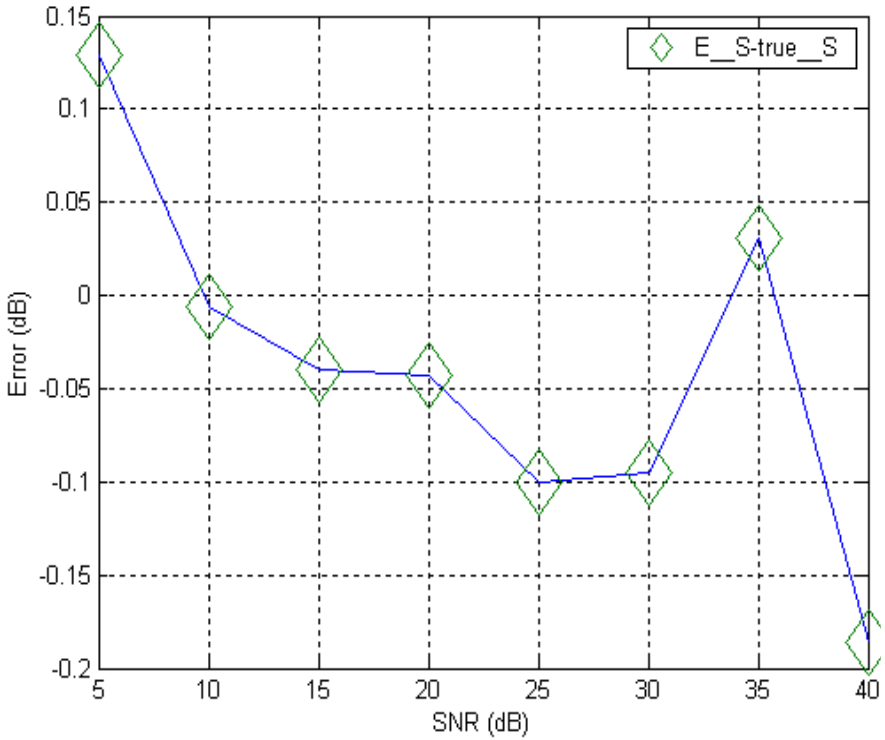
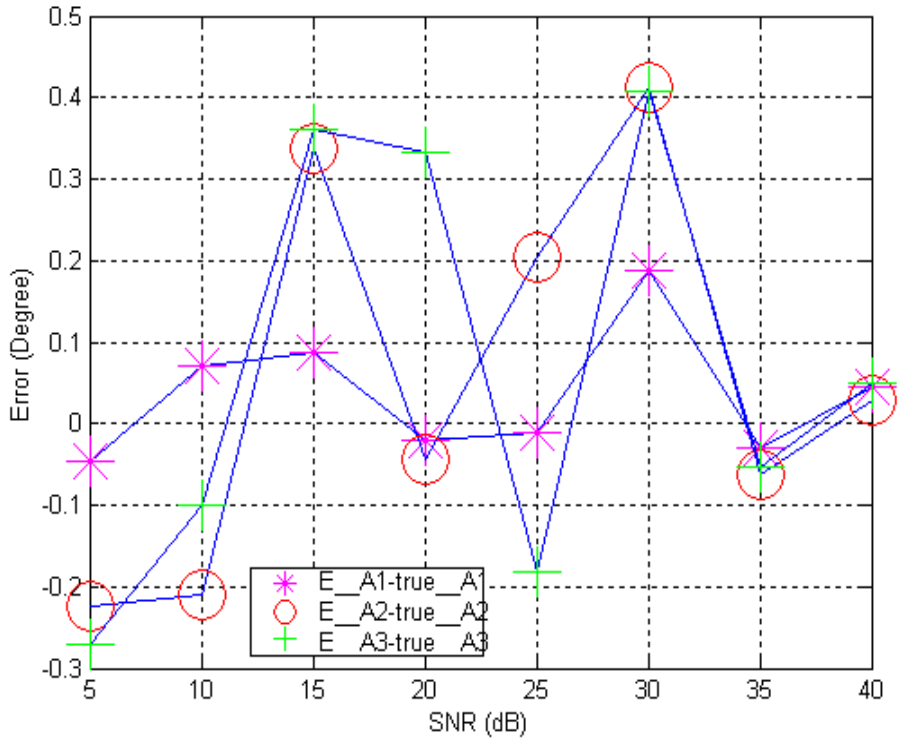


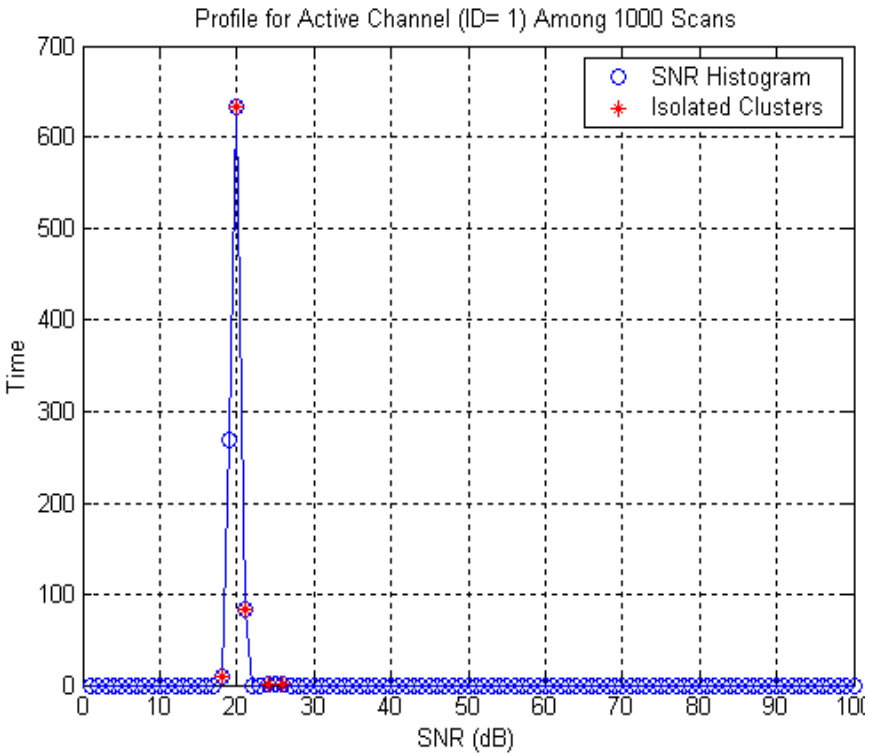
TABLE II. SIMULATED TEST RESULT

SNR	5	10	15	20	25	30	35	40
E_S	5.129	9.9943	14.96	19.957	24.9	29.9	35.0	39.814
E_A1	19.954	20.071	20.086	19.980	19.990	20.2	20.0	20.044
E_A2	39.777	39.790	40.337	39.957	40.205	40.4	39.9	40.028
E_A3	59.730	59.901	60.360	60.333	59.818	60.4	59.9	60.050
SD_A1	2.0001	2.0013	2.0001	2.0033	2.0032	2.00	2.00	2.0016
SD_A2	2.8839	2.8868	2.5853	2.5821	2.5823	3.16	2.58	2.8957
SD_A3	3.4577	2.9001	3.1633	3.1634	3.1938	3.16	3.16	2.8725





- CRC Test18 Scenario: Location scenario 6 (TX at (122 dgs, 300 meters) beside a building) with a 905 MHz FM signal and high RX. AOA static error (~8 dgs) comes from inaccurate angle alignment between the TX and RX.
- AI_A~SD_A for various SNRs, especially from 20 to 35 dB.



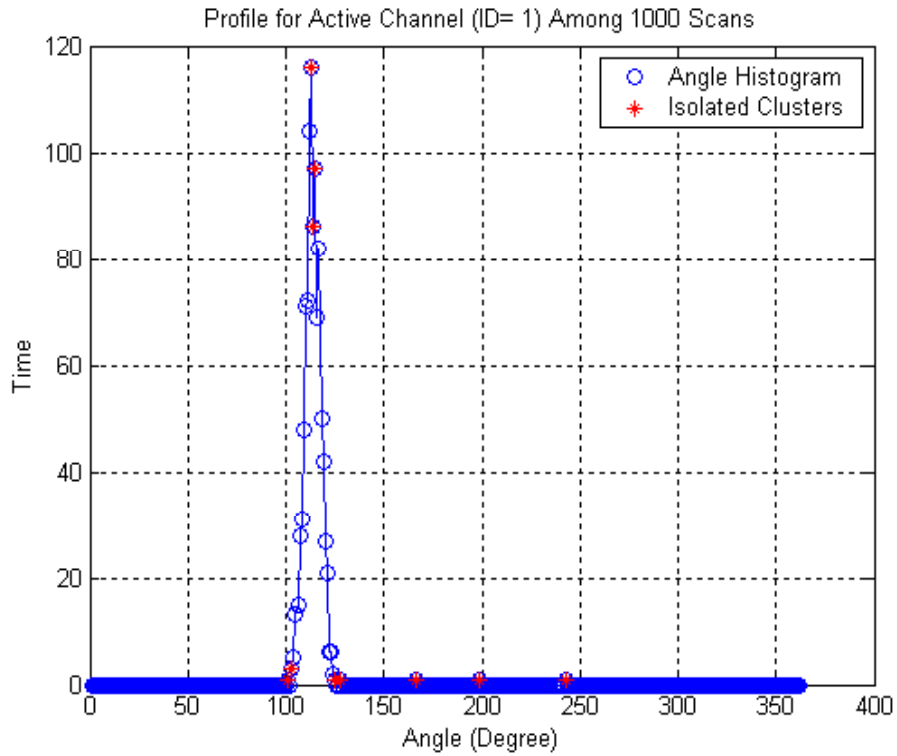
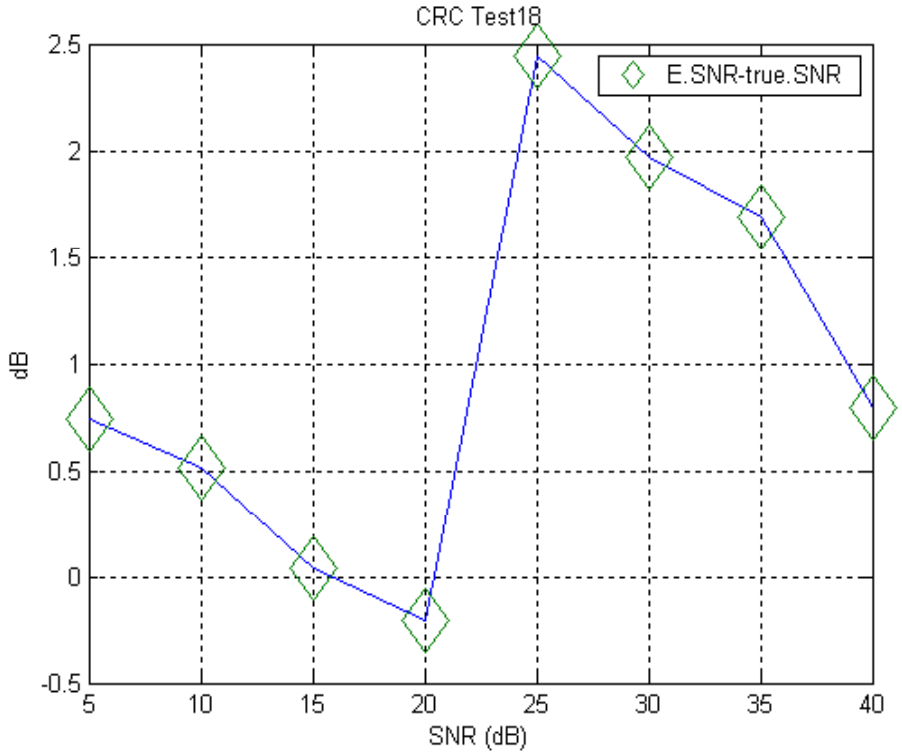
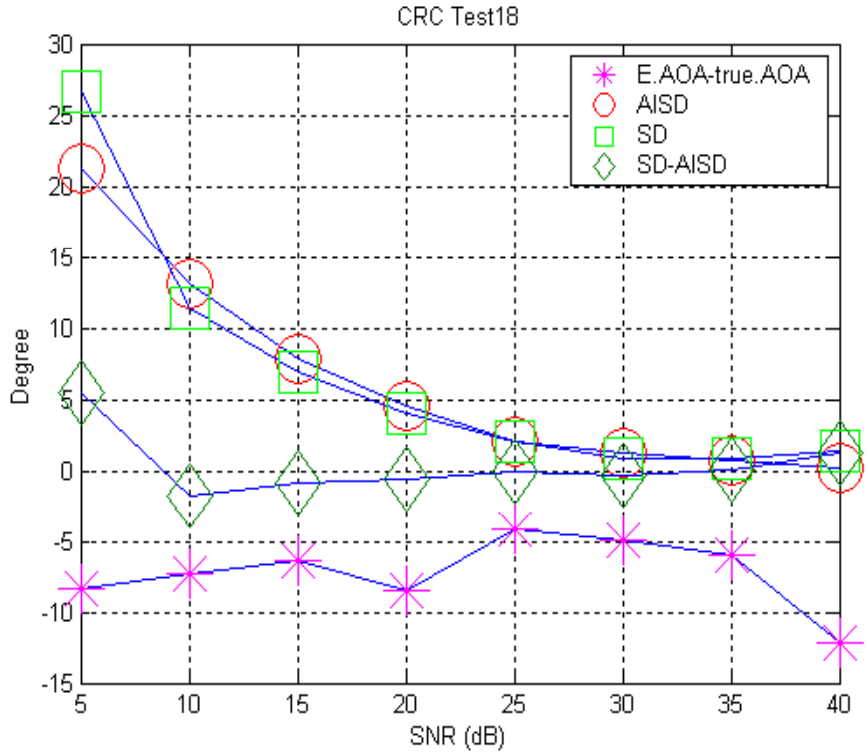


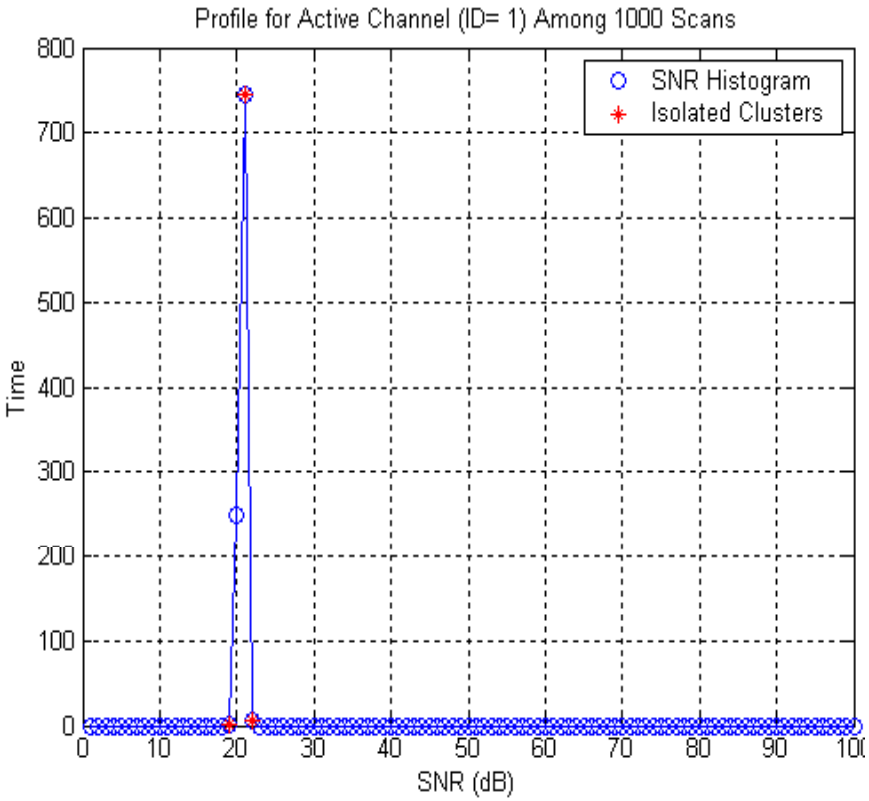
TABLE III. CRC TEST18 RESULT

SNR	5	10	15	20	25	30	35	40
E_S	5.7	10.5	15.0	19.8	27.4	32.0	36.7	40.8
E_A	113.58	114.73	115.59	113.57	117.89	117	116	109.87
AI_A	21.248	13.152	7.7716	4.5715	2.0420	1.21	0.74	0.1770
SD_A	26.664	11.326	6.9228	4.0318	2.0029	0.82	0.82	1.4204





- CRC Test23 Scenario: Location scenario 7 (TX at (10 dgs, 350 meters) behind 20' high trees) with a 39 MHz FM signal and high RX.
- AI_A~SD_A for various SNRs, especially from 20 to 35 dB.



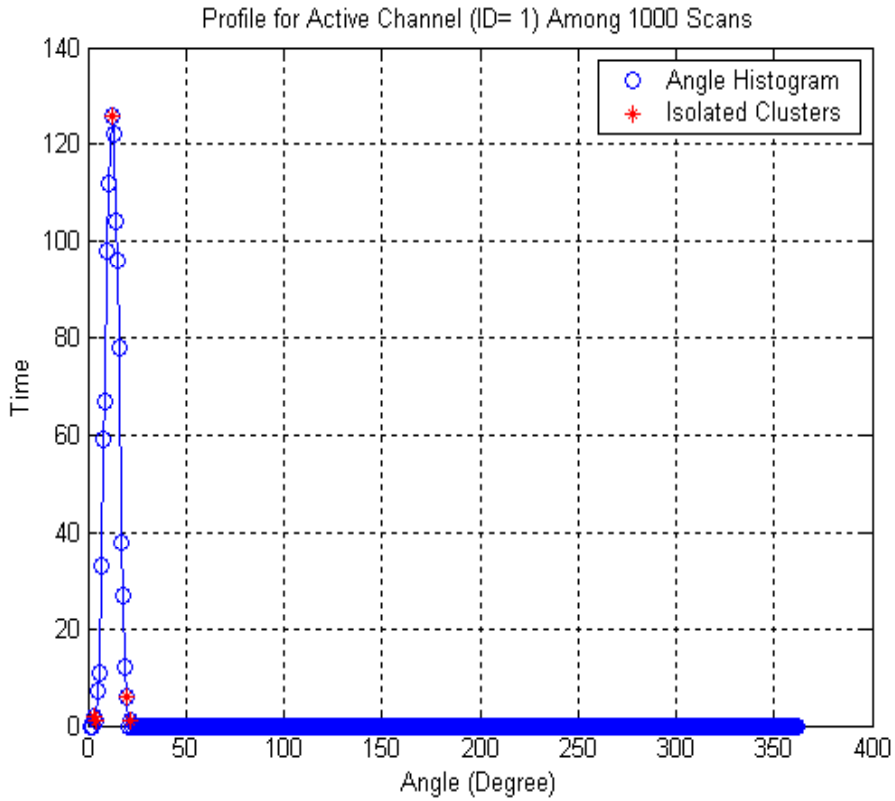
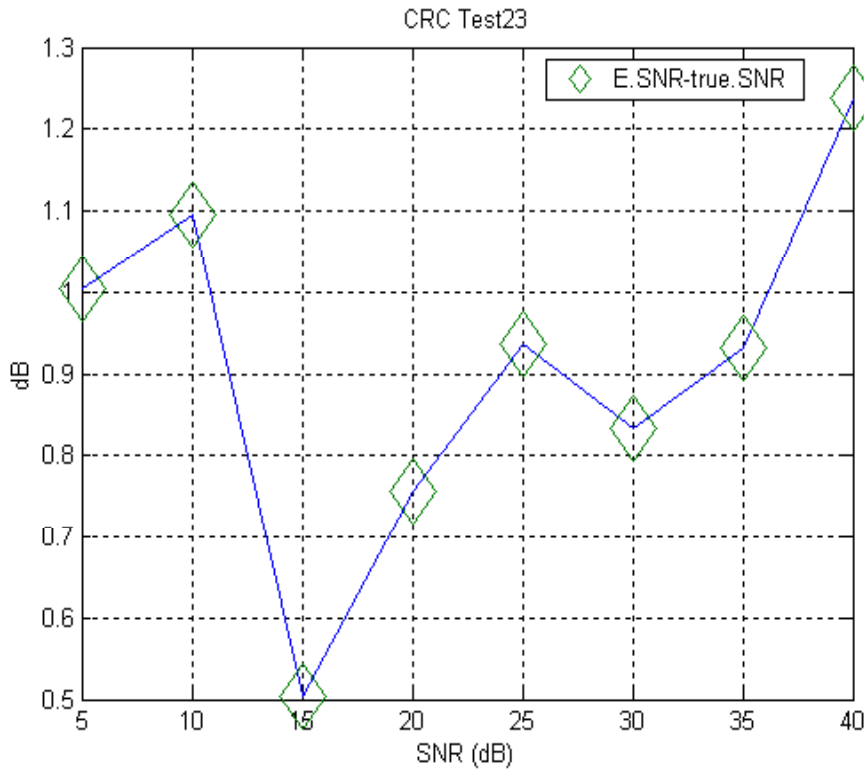
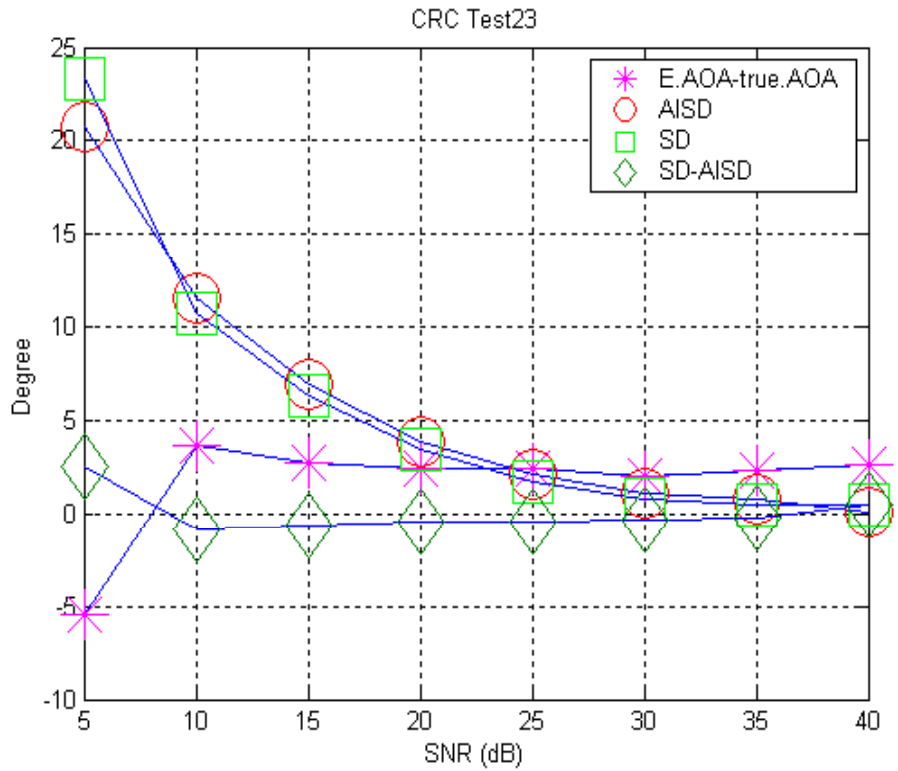


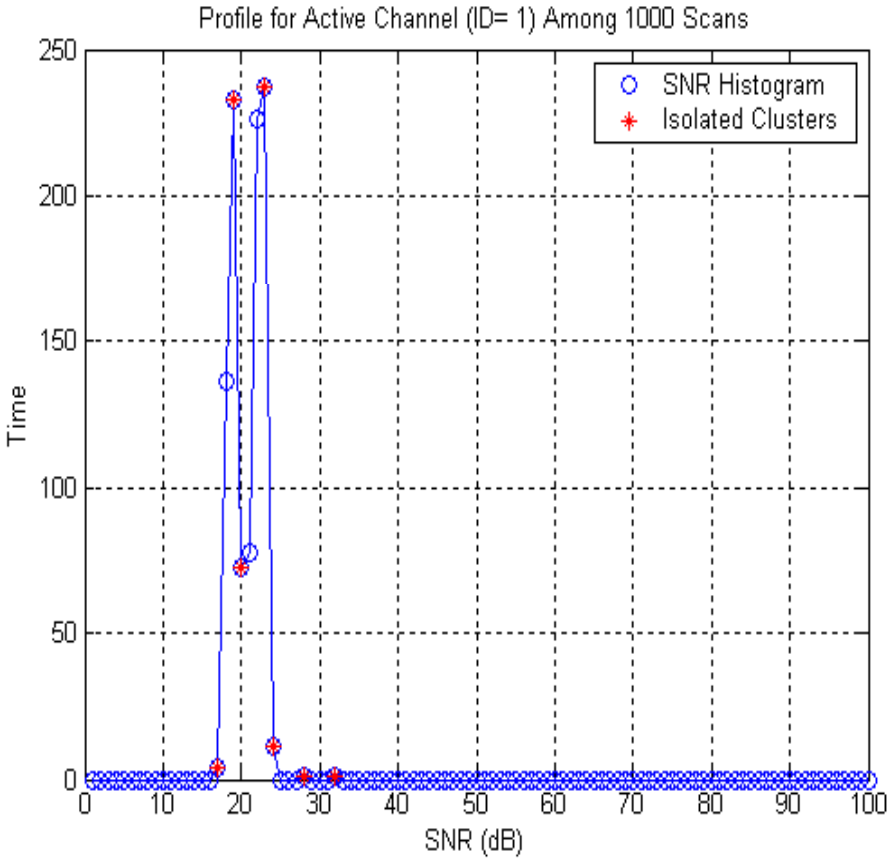
TABLE IV. CRC TEST23 RESULT

SNR	5	10	15	20	25	30	35	40
E_S	6.0043	11.095	15.504	20.756	25.936	30.8	35.9	41.237
E_A	4.5275	13.709	12.703	12.388	12.422	12.0	12.4	12.657
AI_A	20.759	11.531	6.9510	3.8350	2.1150	1.15	0.79	0.0750
SD_A	23.299	10.686	6.3475	3.4539	1.7096	0.82	0.52	0.5241





- CRC Test17 Scenario: Location scenario 6 (TX at (122 dgs, 300 meters) beside a building) with a 905 MHz AM signal and high RX. Again, the AOA static error (~8 dgs) exists.



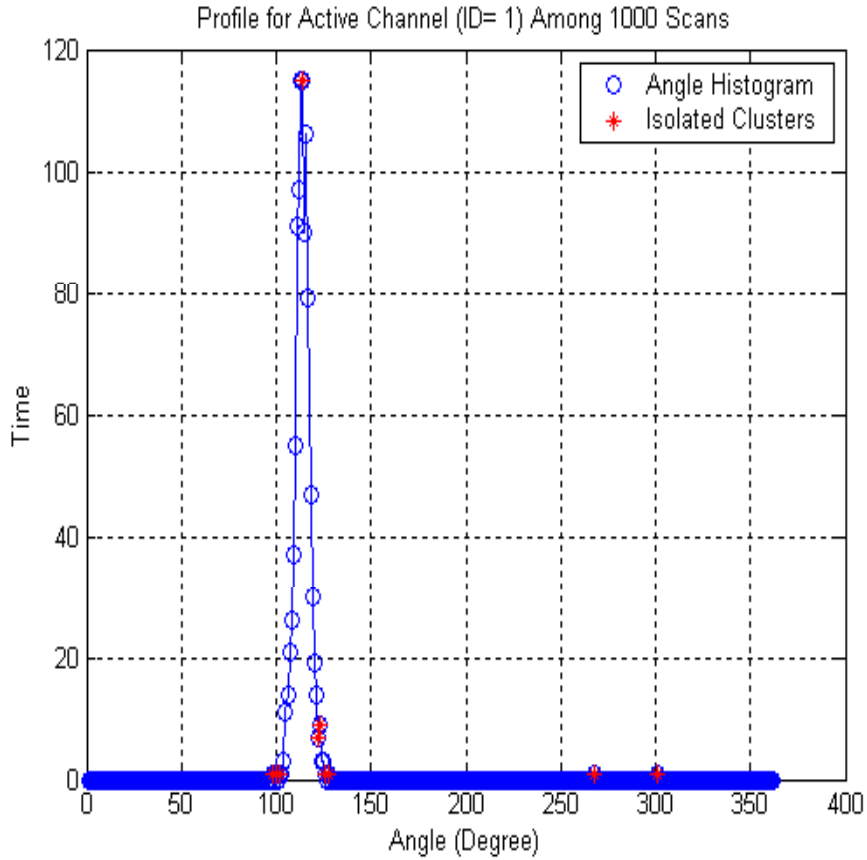
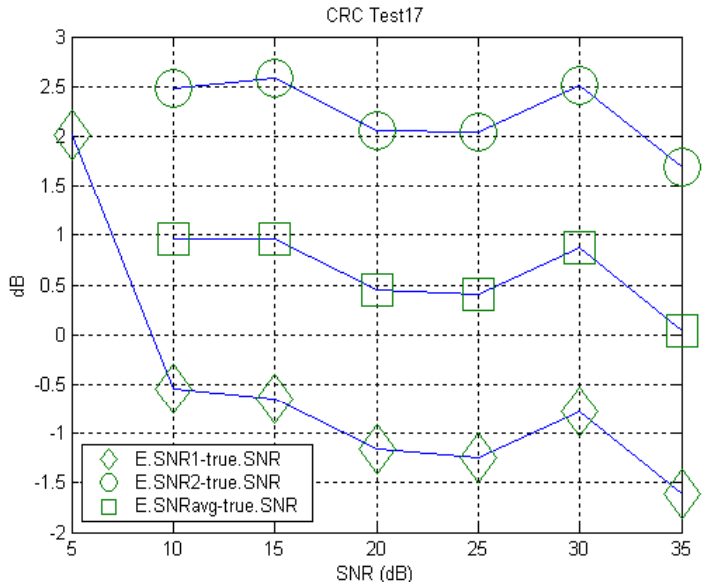
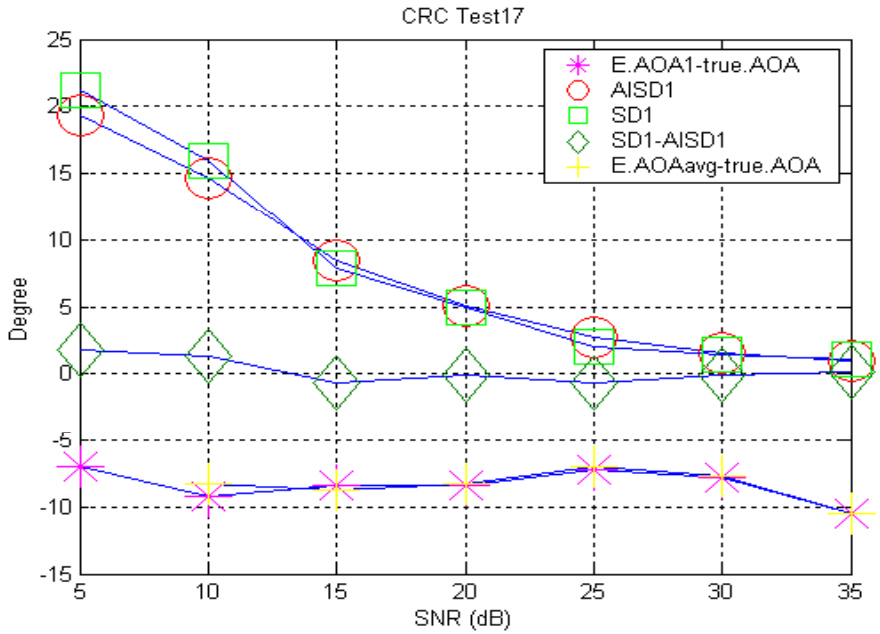
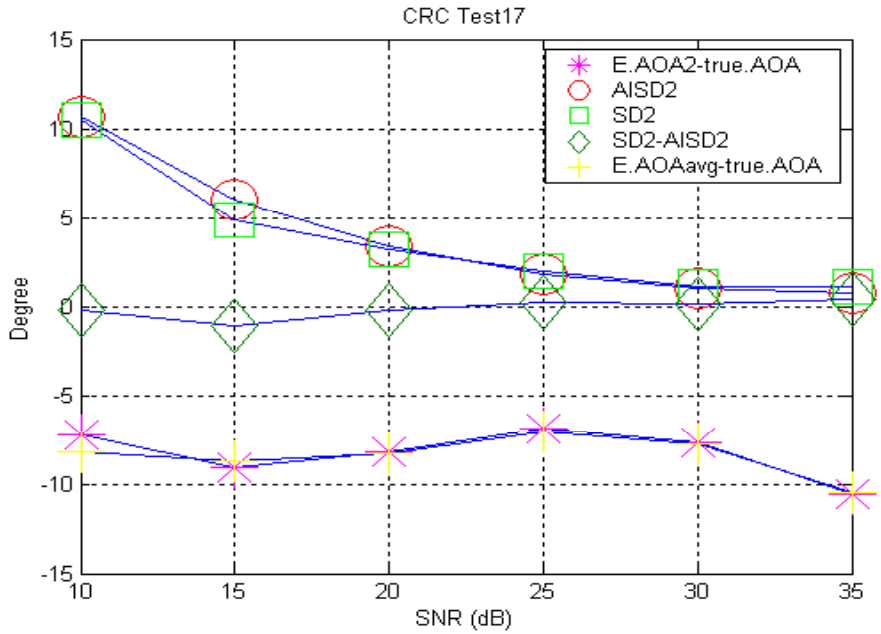


TABLE V. CRC TEST17 RESULT

SNR	5	10	15	20	25	30	35
E_S1	7.0068	9.4573	14.349	18.841	23.754	29.224	33.384
E_S2	-	12.476	17.585	22.056	27.042	32.513	36.690
E_A1	114.96	112.75	113.55	113.58	114.81	114.19	111.54
E_A2	-	114.78	112.95	113.81	115.10	114.32	111.42
AI_A1	19.368	14.653	8.4600	5.0516	2.6765	1.4971	0.9963
AI_A2	-	10.676	5.9791	3.3824	1.8153	1.0352	0.7481
SD_A1	21.162	15.924	7.8082	4.9334	2.0090	1.4271	1.1189
SD_A2	-	10.466	4.8993	3.1677	2.0024	1.1326	1.1211
ESavg	-	10.967	15.967	20.449	25.398	30.869	35.037
EAavg	-	113.77	113.25	113.70	114.96	114.26	111.48







Study of Limitation: Various SNR and AOA fluctuations between 2 (Signal_1/2) angularly close signals were simulated.

- Signal_1: SNR1 ~ |*N*(5:5:40-dB, 1:5-dB SD)|,
  AOA1 ~ |*N*(21-dg, 1:5-dg SD)|,
  AOA1 ISD ~ |*N*(0, 1:5-dg SD)|.
- Signal_2: SNR2 ~ |*N*(40-dB, 1:5-dB SD)|,
  AOA2 ~ |*N*(20-dg, 1:5-dg SD)|,
  AOA2 ISD ~ |*N*(0, 1:5-dg SD)|.
- AOA ISDs/SDs were set purposely to be independent of the SNRs.
- 1000 and 25 samples (scans) were used.

TABLE VI. RESULT FOR SIGNAL_1 (1000 SCANS)

SNR1	5	10	15	20	25	30	35	40
E_S1	5.5007	9.958	14.958	19.958	24.958	30.0	35.1	39.990
E_A1	21.002	21.020	21.020	21.020	21.020	21.0	21.0	-
E_S2	4.9085	9.921	14.921	19.921	24.921	30.0	34.7	39.968
E_A2	21.076	21.071	21.071	21.071	21.071	21.1	21.0	-
E_S3	5.8986	9.9716	14.876	19.876	24.814	30.3	37.3	39.723
E_A3	21.005	21.117	21.117	21.117	21.118	21.1	-	-
E_S4	-	9.5632	14.750	19.720	25.041	29.7	34.3	39.237
E_A4	-	21.157	21.152	21.139	21.11	21.1	21.0	-
E_S5	-	-	17.137	22.397	25.539	30.1	35.2	38.677
E_A5	-	-	21.021	21.017	20.115	21.2	20.1	-

TABLE VII. RESULT FOR SIGNAL_2(1000 SCANS)

SNR1	5	10	15	20	25	30	35	40
E_S1	40.021	40.021	40.021	40.021	40.021	40.0	40.0	39.990
E_A1	20.007	20.007	20.007	20.007	20.007	20.0	20.0	-
E_S2	40.031	40.031	40.031	40.031	40.031	40.0	39.8	39.968
E_A2	20.014	20.014	20.014	20.014	20.014	20.0	20.1	-
E_S3	38.644	38.644	38.644	38.644	38.619	40.1	37.3	39.723
E_A3	19.941	19.941	19.941	19.941	19.942	19.9	-	-
E_S4	-	38.302	38.302	38.554	38.548	38.6	40.6	39.237
E_A4	-	20.139	20.139	20.130	20.111	20.2	20.1	-
E_S5	-	37.878	37.878	37.853	37.580	40.9	40.2	38.677
E_A5	-	20.034	20.034	20.034	19.947	19.8	20.2	-

- The smaller AOA/SNR SDs and the bigger SNR1 lead to the more accurate the E_S and E_A.
- As the SNR1 increases to 40 (35 in one case) dB, both signals tend to be merged.
- The estimations fail when AOA/SNR SDs are big (4, 5-dg/dB) and SNR1 is low (5, 10-dB).
- In general, when the AOA/SNR SDs are not significant, the histogram-based algorithms can estimate close signals with great accuracy.

TABLE VIII. RESULT FOR SIGNAL_1 (25 SCANS)

SNR1	5	10	15	20	25	30	35	40
E_S1	5.08	10.08	15.08	20.08	25.08	30.1	35.1	40.04
E_A1	21	21	21	21	21	21	21	-
E_S2	5.2	10.2	15.2	20.2	25.2	30.2	34.9	40.16
E_A2	20.960	20.960	20.960	20.960	20.960	21.0	21.1	22.191
E_S3	5.6	9.5714	14.571	19.571	24.571	29.6	-	41.167
E_A3	21.268	-	-	-	-	-	-	23.385

TABLE IX. RESULT FOR SIGNAL_2 (25 SCANS)

SNR1	5	10	15	20	25	30	35	40
E_S1	40	40	40	40	40	40	40	40.04
E_A1	19.75	19.75	19.75	19.75	19.75	19.8	19.8	-
E_S2	40.12	40.12	40.12	40.12	40.12	40.1	39.7	40.16
E_A2	19.240	19.240	19.240	19.240	19.240	19.2	19.4	19.088
E_S3	41.533	41.533	41.533	41.533	41.533	41.5	41.5	41.167
E_A3	-	-	-	-	-	-	-	18.120

- For 25 scans, the estimations are not as accurate as the 1000-scan case. However, when the AOA/SNR SDs are not significant (<3-dg/dB), the histogram-based algorithms can estimate close signals with great accuracy, even when the number of scans is low.
- By CRC-measured results, when SNR is larger than 25 dB, its AOA SD is less than 3 dgs. Thus, for actual signals with large SNR, the histogram-based algorithms may estimate with great accuracy using small number of scanned samples.

Conclusions

- It is effective to use the histogram-based algorithms to process the preliminary channel usage info set to get the overall channel usage report.
- When the SNR is significant, only a small number of scanned samples may be needed for the histogram-based algorithms.