Empirical study of energy detection-based spectrum sensing for different radio technologies

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Introduction

Despite its practical performance limitations, energy detection has gained popularity during the last years as a spectrum sensing technique for dynamic spectrum access in cognitive radio networks. The main advantages of energy detection-based spectrum sensing are its simplicity, low computational and implementation costs as well as its ability to work irrespective of the actual signal to be detected. Due to the generality of its operating principle, the energy detector performance would not be expected to depend on the type of primary signal being detected. In this context, this work evaluates the performance of energy detection-based spectrum sensing for several real-world primary signals of various radio technologies. The obtained results indicate that certain technology-dependent inherent properties may result in notably different detection performances for various primary signals, but converge under certain conditions. The practical consequences of the different observed performances for several primary radio technologies are illustrated and discussed.

Novelties of this work

- Performance evaluation of spectrum sensing:
  - Traditionally: Theoretical studies or simulations based on simple signals (sine wave carriers, M-PSK/M-QAM,…)
  - This work: Based on captured real-world signals.
- Degrading sources:
  - Traditionally: AWGN.
  - This work: AWGN and other noise sources, as well as propagation environment (implicitly taken into account).
- Studies based on real-world signals:
  - Traditionally: TV signals (IEEE 802.22).
  - This work: TV and other radio technologies (GSM, DCS, UMTS, TETRA, DAB-T, etc). Broader view on energy detection performance.

Energy detection

Test statistic:

No. of samples

$$\mathbb{T} = \sum_{n=0}^{N-1} |\tilde{y}[n]|^2 \qquad \mathbb{T} \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\gtrless}} \lambda$$

Received signal

Occupied channel

Decision threshold

Free channel

Theoretical performance:

Noise power

Signal power

$\gamma = \sigma_{\tilde{x}}^2/\sigma_{\tilde{w}}^2$ is the SNR

$$P_d = Q\left(\frac{\lambda - N(\sigma_{\tilde{x}}^2 + \sigma_{\tilde{w}}^2)}{\sqrt{2N(\sigma_{\tilde{x}}^2 + \sigma_{\tilde{w}}^2)^2}}\right) \rightarrow \boxed{P_d(\gamma) = \mathcal{Q}\left(\frac{\mathcal{Q}^{-1}(P_{fa})\sqrt{2N} - N\gamma}{\sqrt{2N(1+\gamma)^2}}\right)}$$

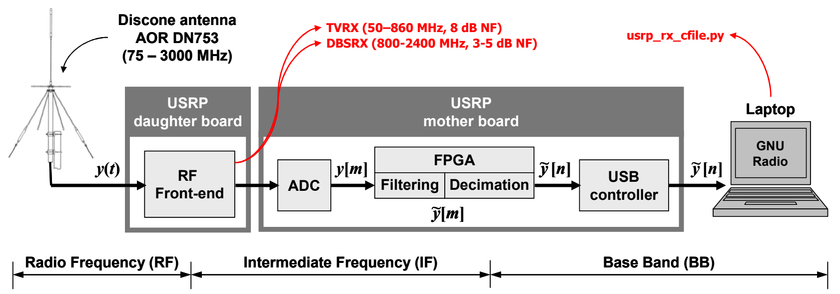
$$P_{fa} = Q\left(\frac{\lambda - N\sigma_{\tilde{w}}^2}{\sqrt{2N\sigma_{\tilde{w}}^4}}\right) \rightarrow \lambda = Q^{-1}(P_{fa})\sqrt{2N\sigma_{\tilde{w}}^4} + N\sigma_{\tilde{w}}^2$$

Limitations (SNR wall):

$$N = 2\left[\frac{Q^{-1}(P_{fa}) - Q^{-1}(P_d)(1+\gamma)}{\gamma}\right]^2 \qquad \sigma_{\tilde{w}}^2 \in [\sigma_{\tilde{w},nominal}^2, \alpha \cdot \sigma_{\tilde{w},nominal}^2]$$

$$\gamma_{wall}(dB) = 10\log_{10}(\alpha - 1)$$

Measurement platform: USRP + GNU Radio



Evaluation methodology

Equipment placed in building roof:
- Direct line-of-sight to nearby primary transmitters.
- High SNR reception conditions.

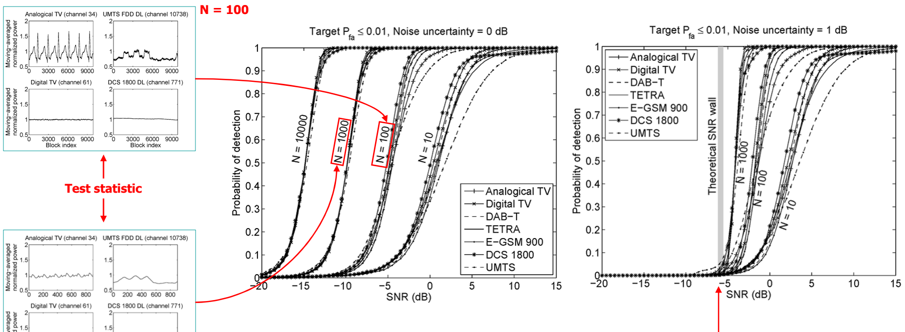
Various radio technologies:
- A/D TV, TETRA, DAB-T, GSM, DCS, UMTS …

Captured signals:
- Optimal RF gain factors, decimation rates, etc.
- $12 \cdot 10^6$ samples were captured.
- First $2 \cdot 10^6$ samples were removed (to avoid transients).
- High-order Butterworth filter (Matlab).

Performance evaluation:
- In terms of the probability of detection (P_d).
- Sequences divided in blocks of N samples (sensing period).
- Signal sequence assumed noise-free (high SNR).
- Variable AWGN added to obtain different SNR values.
- ED principle applied for each set of SNR, N, target P_{fa}/λ.

System	Channel number	f_{start} (MHz)	f_{center} (MHz)	f_{stop} (MHz)	Signal BW (MHz)	Decimation rate (M)	Sampled BW (MHz)	Gain (dB)	Cut-off frequency	Pass band (MHz)
Analogical TV	23 29 34 38	486 534 574 606	490 538 578 610	494 542 582 614	8	8	8	10	0.94	7.52
Digital TV	26 48 61 67	510 686 790 838	514 690 794 842	518 694 798 846	8	8	8	10	0.94	7.52
TETRA	37 44 45 47 53	420.8875 421.0625 421.0875 421.1375 421.2875	420.900 421.075 421.100 421.150 421.300	420.9125 421.0875 421.1125 421.1625 421.3125	0.025	256	0.25	70	0.1	0.03
DAB-T	08A 10A 11B	195.080 209.080 217.784	195.936 209.936 218.640	196.792 210.792 219.496	1.712	32	2	70	0.8	1.6
E-GSM 900 DL	60 113 975	946.8 957.4 925.0	947.0 957.6 925.2	947.2 957.8 925.4	0.2	64	1	70	0.3	0.3
DCS 1800 DL	546 771 786	1811.8 1856.8 1859.8	1812.0 1857.0 1860.0	1812.2 1857.2 1860.2	0.2	64	1	70	0.3	0.3
UMTS FDD DL	10588 10663 10738	2115.1 2130.1 2145.1	2117.6 2132.6 2147.6	2120.1 2135.1 2150.1	5	8	8	70	0.625	5

Experimental results



$$\boxed{P_d(\gamma) = \mathcal{Q}\left(\frac{\mathcal{Q}^{-1}(P_{fa})\sqrt{2N} - N\gamma}{\sqrt{2N(1+\gamma)^2}}\right)} \qquad \boxed{N = 2\left[\frac{Q^{-1}(P_{fa}) - Q^{-1}(P_d)(1+\gamma)}{\gamma}\right]^2} \qquad \boxed{\gamma_{wall}(dB) = 10\log_{10}(\alpha - 1)}$$

Conclusions

- ED can be employed regardless of the signal to be detected.
- ED performance depends on the primary radio technology:
  - Short sensing period (N):
    - High signal variability: Poor detection performance.
    - Low signal variability: Good detection performance.
  - Increasing sensing period (N):
    - Detection performance converges.
- In practice:
  - For fixed operating parameters, P_d might (NOT!) be enough to reliably detect some primary signals.
  - Some primary signals more susceptible to interference.
- ED detection performance may strongly depend on the primary radio technology being detected.