Cyclo-Stationary based Jammer Detection Algorithm for Wide-band Radios using Compressed Sensing

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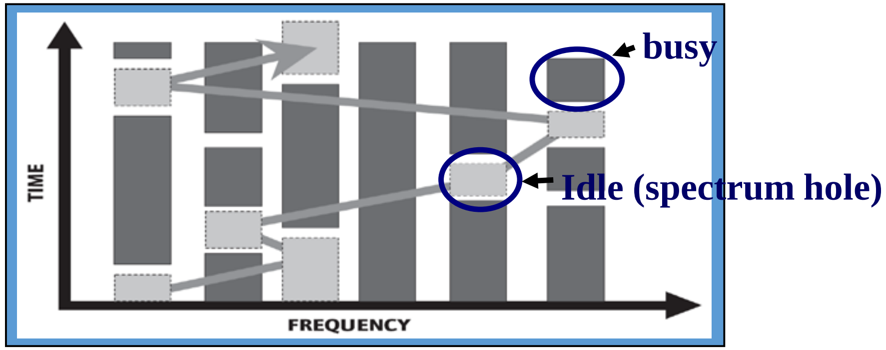
Cognitive Radio

- Spectrum Scarcity



- Cognitive Radio:
  - Environment Awareness and Spectrum Intelligence [1, 2]

- Applications:
  - Dynamic Spectrum Access
  - Communication Electronic Warfare Solutions

[1] J. Mitola and G. Q. Maguire Jr. "Cognitive radio: Making software radios more personal," *IEEE Personal Commun.*, vol. 6, no. 4, pp. 13–18, 1999.
[2] S. Haykin, "Cognitive Radio: Brain-Empowered Wireless Communication," *IEEE Journl. Sel. Areas Commun.,* vol. 23, no. 2, pp. 201–220, Feb. 2005.

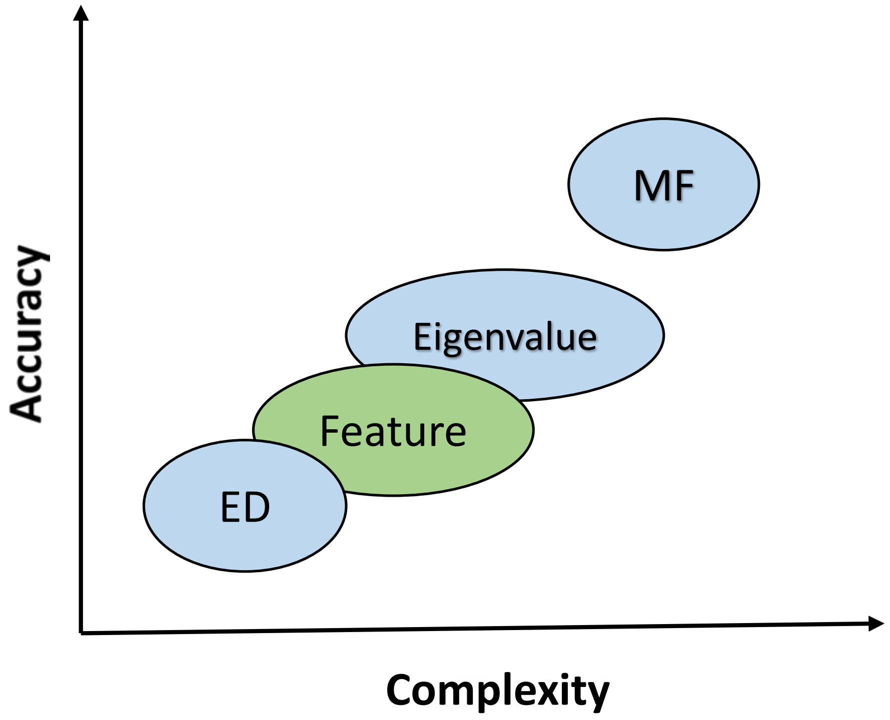
Spectrum Sensing Techniques [3, 4]

- Matched Filter
  - Perfect Knowledge
  - Dedicated receiver structure

- Eigenvalue Detection
  - Max-Min eigenvalues
  - Computational complexity
  - Difficulty to threshold selection

- Feature Detection
  - Cyclo-stationary property
  - Complex processing algorithm

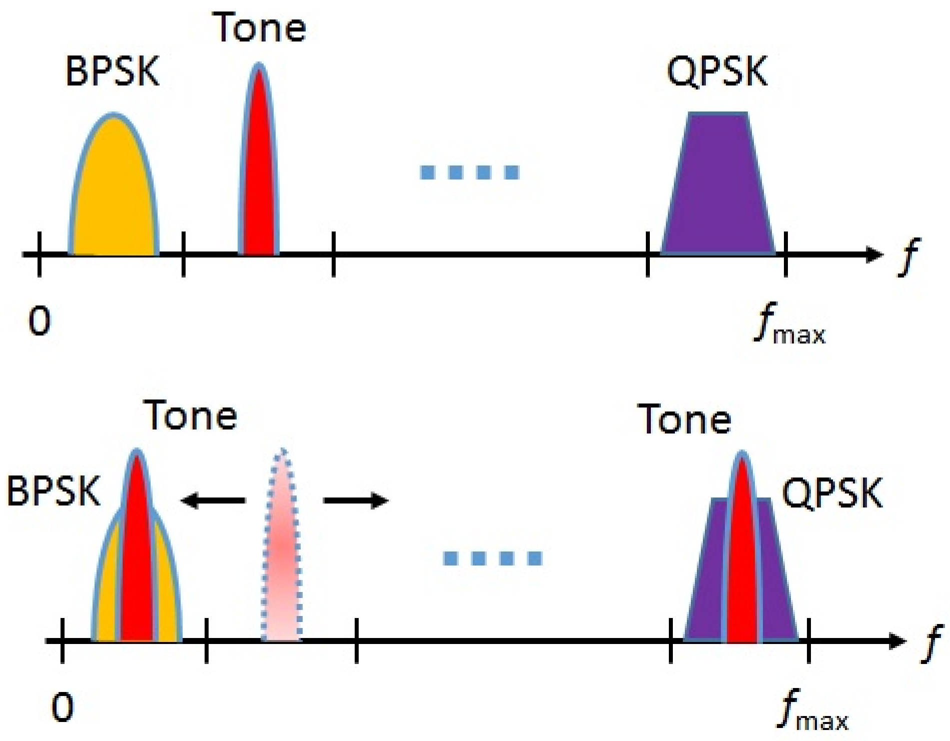
- Energy Detection
  - Simple Implementation
  - Poor performance



[3] I. F. Akyildiz, W. Y. Lee, M. C. Vuran, and S. Mohanty, "Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey," *Computer Networks*, vol. 50, pp. 2127–2159, 2006.
[4] S. Atapattu, C. Tellambura, and H. Jiang, "Energy detection based cooperative spectrum sensing in cognitive radio networks," *IEEE Trans. on Wireless Commun.*, vol. 10, no. 4, pp. 1232-1241, 2011.

Problem Formulation

- ➢Wideband spectrum
- ➢Occupied by various narrowband waveforms
- ➢Narrowband jammer
- ➢Jammers could be one or more



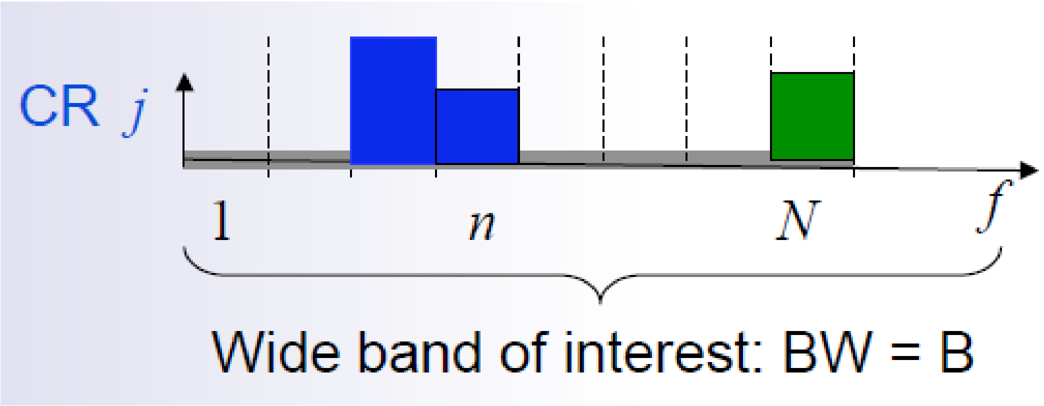
Compressed Sensing [5, 6]

- Conventional spectral estimation methods require to operate at or above Nyquist rate
- Requires high rate A/D or bank of low rate A/D for wideband signals

- Compressed Sampling: sub-Nyquist rate sampling and reliable signal recovery via computationally feasible algos
- Applicable to sparse signals

[5] Z. Tian, and G. Giannakis, “Compressed Sensing for Wideband Cognitive Radios,” *Proc. of IEEE Intl. Conf. on Acoustics, Speech and Signal Processing (ICASSP),* pp. IV.1357-1360, Honolulu, April 2007.
[6] Haupt, J.; Nowak, R., "Compressive Sampling for Signal Detection," *Proc. of IEEE Intl. Conf. on Acoustics, Speech and Signal Processing (ICASSP),* pp. III.i509-1512, 15-20 April 2007.

Limits on Sampling Rates



Spectrum occupancy ratio

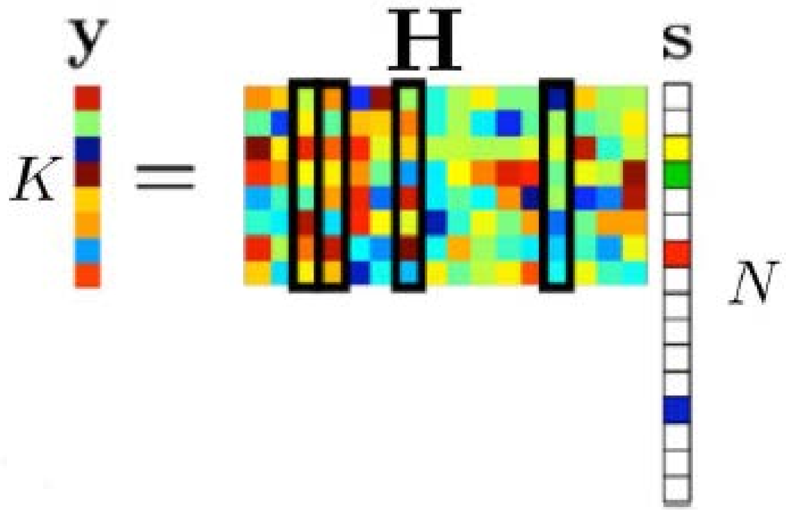
$$r_{nz} = N_{nz}/N \ll 1$$

- Lower bounds on sampling rates f_s
  - Lowest f_s for reconstruction without aliasing
    - Nyquist Rate = $2B$
  - Lowest f_s for reconstruction of CR signals
    - Motivating factor for CR is low spectrum utilization
    - Landau rate = $2B_{eff} = 2r_{nz}B$ < Nyquist Rate

[7] Z. Tian, "Cyclic feature based wideband spectrum sensing using compressive sampling," In Proc. of the *2011 IEEE Int. Conf. on Commun. (ICC' 11)*, pp. 1-5, June 2011.

CS Basics

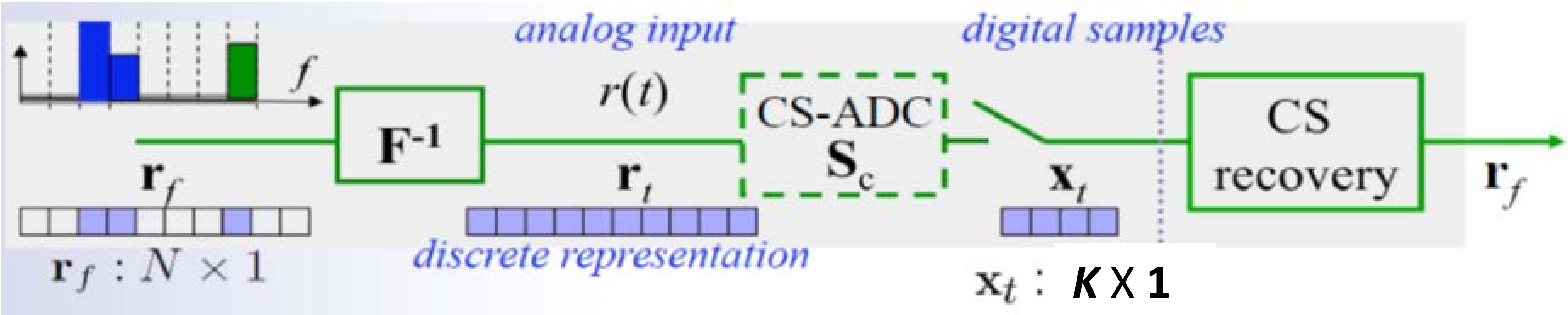
$$\mathrm{y} = \mathbf{H}_{K\times N}\,\mathrm{s}$$



- **s** should be sparse
- **H** can be fat (*K* <= *N*)

- Compressed sensing
  - Given **y** and **H**, unknown **s** can be found with high probability!

Sub-Nyquist rate Sampling



- Received signal: $r(t)\colon t \in [0, NT_s]$
  - Discrete representation: $\mathbf{r}_t \leftrightarrow \mathbf{r}_f = \mathbf{F}\mathbf{r}_t$
- Linear sampling: $\mathbf{x}_t = \mathbf{S}_c\mathbf{r}_t = \mathbf{S}_c\mathbf{F}^{-1}\mathbf{r}_f$
  - Compression: $\mathbf{S}_c\colon K \times N$
- Various designs of random samplers [8, 9]

[8] Kirolos, S., et al., "Analog-to-Information Conversion via Random Demodulation," *in Proc. 2006 IEEE Dallas/CAS Workshop on Design, Applications, Integration and Software,* pp. 71-74, Oct. 2006.

[9] Zhuizhuan Yu; Hoyos, Sebastian; Sadler, B.M., "Mixed-signal parallel compressed sensing and reception for cognitive radio," *in Proc. IEEE International Conference on Acoustics, Speech and Signal Processing 2008. (ICASSP)*, pp. 3861-3864, 2008.

Sub-Nyquist rate Sampling

- Estimation is achieved by solving the following convex optimization problem:

$$\arg\min_{\mathbf{r}_f} \|\mathbf{r}_f\|_1, \qquad s.t. \quad \mathrm{x}_t = \mathbf{S}_c \mathbf{F}^{-1} \mathbf{r}_f$$

- Techniques to Solve the above problem:
  - Linear Programming: Basis Pursuit
  - Iterative greedy algorithms: Matching Pursuit [10] and Orthogonal Matching Pursuit [11]

Formally the l_n-norm of x is defined as:

$$\|x\|_n = \sqrt[n]{\sum_i |x_i|^n}$$

[10] Marco Duarte, Michael Wakin, and Richard Baraniuk, ”Fast reconstruction of piecewise smooth signals from random projections,” (SPARS Workshop, November 2005).
[11] Joel Tropp and Anna Gilbert, ”Signal recovery from random measurements via orthogonal matching pursuit,” *IEEE Trans. on Information Theory,* vol. 53, no. 12, pp. 4655-4666, December 2007.

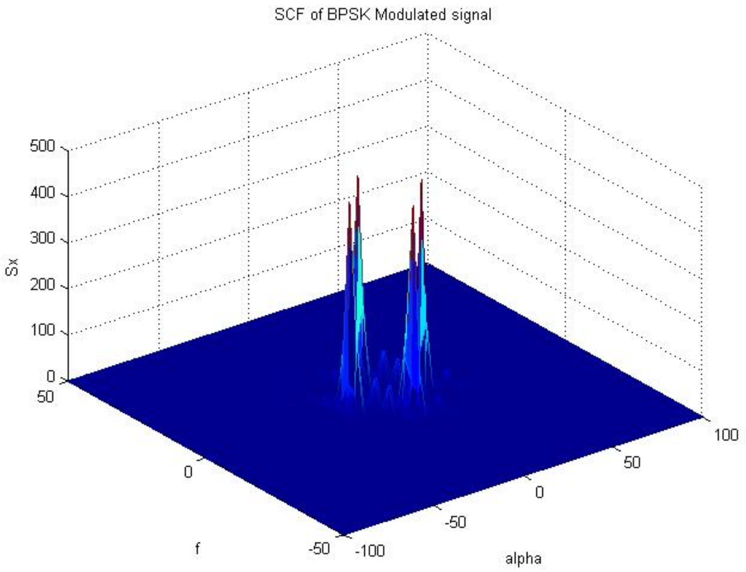
(Cyclo-stationary) Feature Detection [12]-[14]

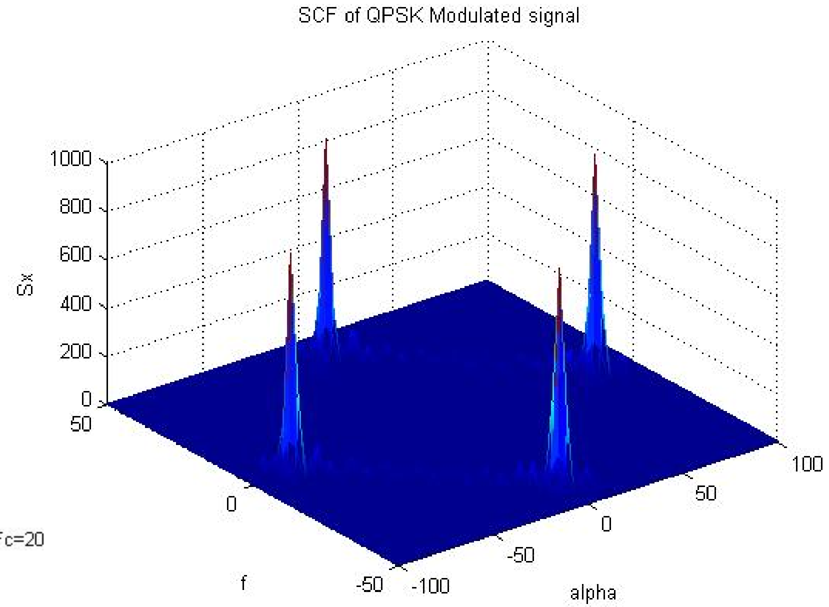
- Good performance at medium-to-low SNRs
- Higher implementation complexity than EDs
- Cyclo-stationarity of the modulated signals
  - Periodic with T_0 : $\mu_s(t+T_0)=\mu_s(t), \qquad R_s(t+T_0,\tau)=R_s(t,\tau)$
- Peak detection in Spectral Correlation Function (SCF)
- SCF is sparse is both angular and cyclic frequency domain

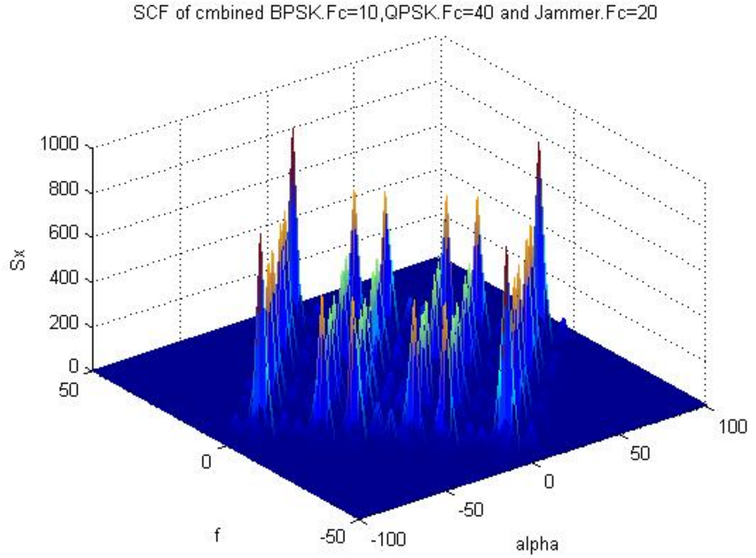
- AWGN is WSS and has no cyclic correlations

[12] W.A. Gardner, “Spectral correlation of modulated signals: Part I – analog modulation," *IEEE Trans. on Commun.*, vol. 35, no. 6, pp. 584–594, Jun 1987.
[13] W.A. Gardner, W. Brown, and C. Chen. “Spectral correlation of modulated signals: Part ii–digital modulation," *IEEE Trans. on Commun.*, vol. 35, no. 6, pp. 595–601, Jun 1987.
[14] W. A. Gardner, A. Napolitano, and L. Paura. “Cyclostationarity: Half a century of research,” *Signal Process.*, vol. 8, no. 4, pp. 639–697, April 2006.

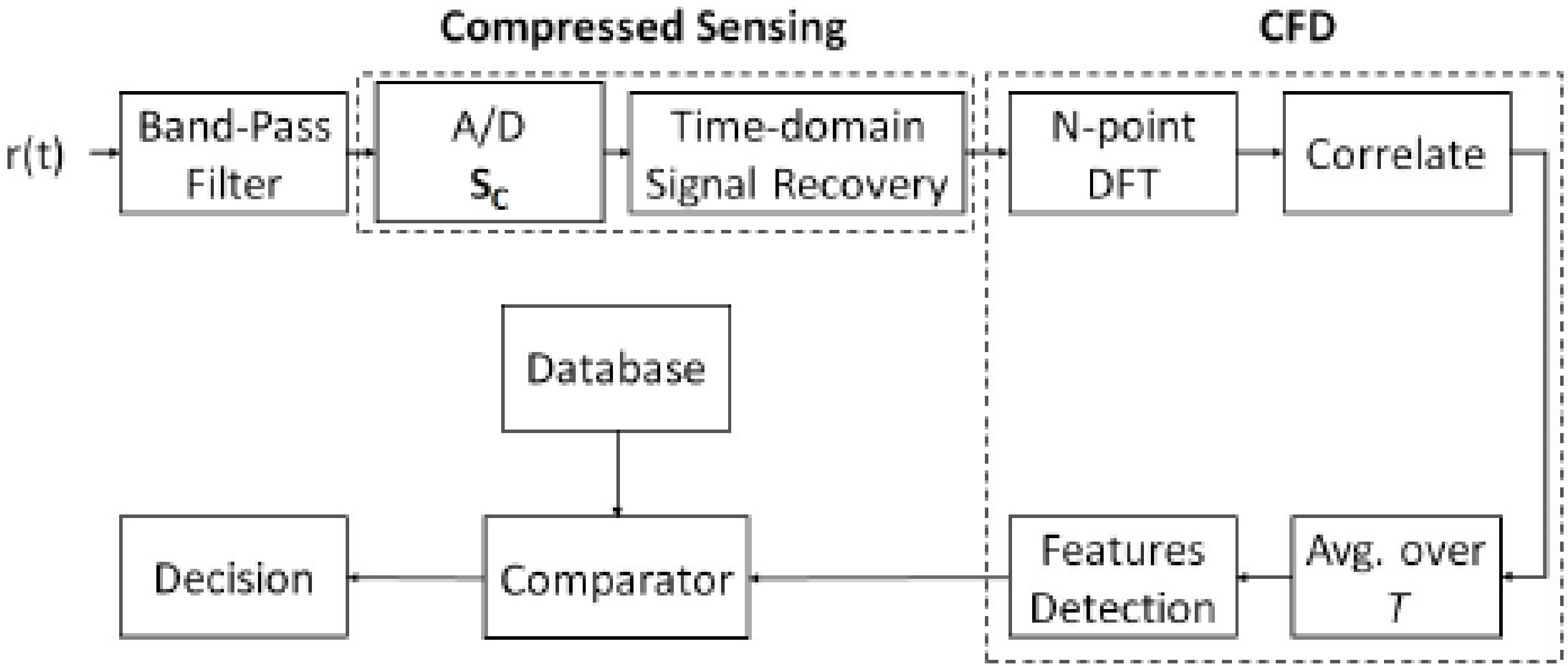
(Cyclo-stationary) Feature Detection







Jammer detection in wideband



A generic block diagram of the implementation of proposed algorithm.

Experimental Setup

- Wideband spectrum of 50 ΔHz
- 5 sub-bands of 10 ΔHz
- Legit waveform = BPSK / QPSK
- Jamming signal = pulse tone / sine wave
- SNR = 0dB
- Compression ratio (*K/N*) = 0.25 ~ 1.0
- 1000 Monte-Carlo runs
- Test scenarios
  - Sub-band 1 and sub-band 5 has legit signal
  - Sub-band 3 has jamming signal

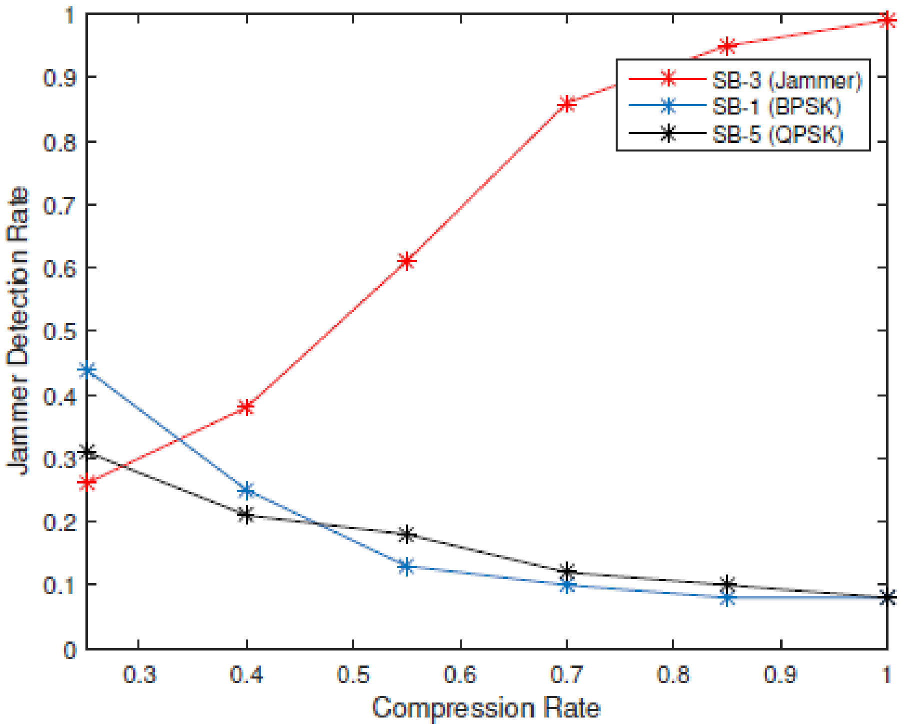
  - Sub-band 1 has legit signal
  - Sub-band 5 has legit + jamming signal

Experimental results

Test I:

➢Sub-band 1 and sub-band 5 has legit signal

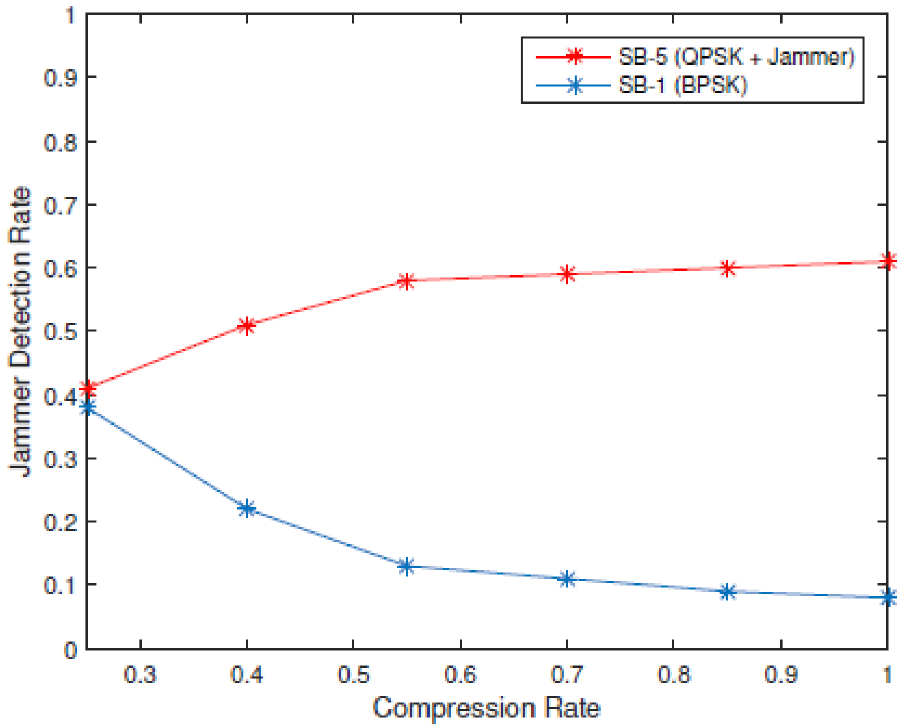
➢Sub-band 3 has jamming signal



Test II:

➢Sub-band 1 has legit signal

➢Sub-band 5 has Licit + jamming signal



Conclusion & Future Work

- A jammer detection algorithm was proposed for wide-band CRs using compressed sensing.
- Appears to perform well within some limitations:
  - High wrong classification rate due to simple parameter comparisons.
  - Requirement to maintain databases with licit waveforms parameters.

- Future works may include:
  - Improved classification → neural networks or SVM classifiers.
  - Formulate intelligent anti-jamming strategies for WB cognitive radios.

Thanks for your Attention

Suggestions / Questions