SubNyquist Electronic Surveillance

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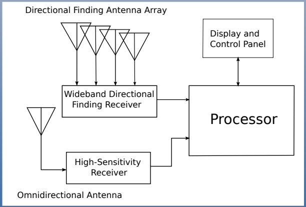
Electronic Support Measures (ESM)

- The task is to detect all RF emitters, for identifying presence of threats.
- It has a passive monitoring system.
- While ESM signals are very dense, *e.g.* can be of millions of pulses per second, they have very sparse TF representations.
- ESM systems can be noise limited, rather than sparsity limited.



Techniques for ESM receivers

- Instantaneous Frequency Measurements: limited spectral sensitivity.
- Rapid Frequency Swapping A/D's: limited temporal sensitivity.
- Wideband Analog to Digital Convertors: multi GHz A/D's.
- Proposal: Sub-Nyquist Analog to Information Convertor.

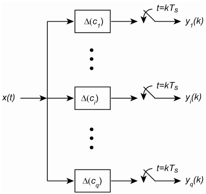
SubNyquist Sampling

- Why?
  1. Sampling at the rate of Nyquist is difficult or costly for some applications, *e.g.* Wideband A/D's and Wideband Digital Receivers.
  2. It is waste of resources, if we sample at a rate, much higher than the information rate.
  3. Allows us to have an application specific sampling strategy, *i.e.* exploring signal structures.
- How?
  1. Using underlying signal structures, *e.g.* sparsity.
  2. Incorporating non-uniform sampling (random?) in the sensing framework.
  3. Non-linear reconstruction of signals.

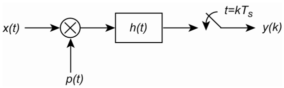
SubNyquist Sampling

- What would be the challenges?
  1. *Analog Hardware*: How efficiently can we design the analog part?
  2. *Computational Complexity*: How efficient can we implement the non-linear recovery algorithm?
  3. *Noise Sensitivity*: Sensitivity to the input noise?
  4. *Robustness*: How much the sub-Nyquist algorithm is sensitive to the signal model mismatch and circuit design tolerances.

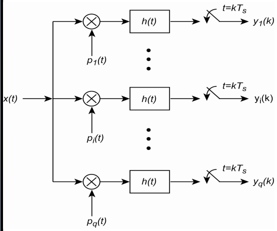
SubNyquist Sampling Techniques



Multi-coset Sampling
(Feng&Bresler 1996)



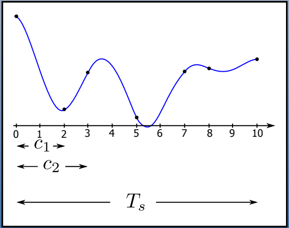
Random Demodulator
(Triopp et al. 2007)

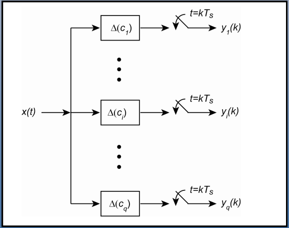


Modulated Wideband Convertor
(Mishali and Eldar 2010)

Multi-coset Sampling Framework

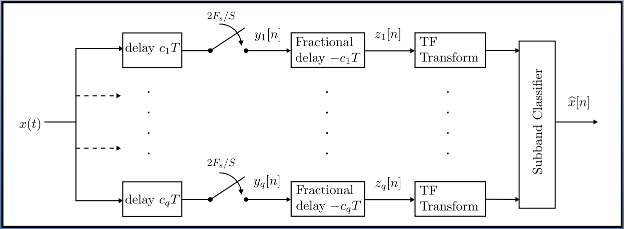
- Non-uniform sampling technique [Feng and Bresler, 1996].
- Sparse multiband signal model.
- A subspace method for reconstruction by Feng et al.
- A convex optimisation problem for reconstruction by [Mishali and Eldar 2009].





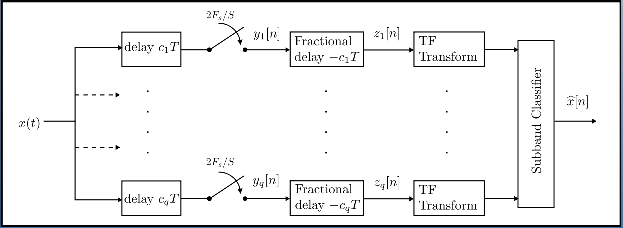
Proposed SubNyquist Sampling Framework

- A Multicoset sampling strategy.
- Avoiding any complicated operations *e.g.* SVD, ℓ_1 minimisation.
- The signal model have to fit into the ESM.

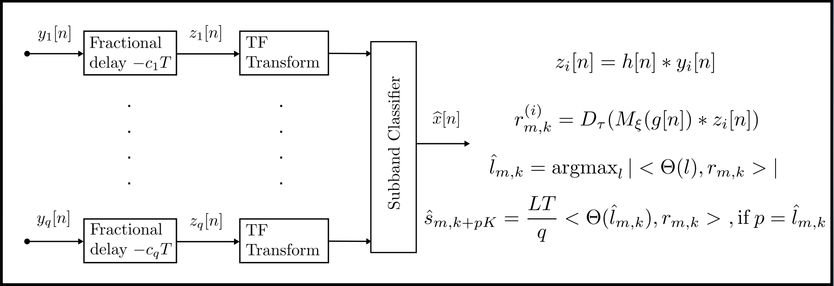


Components of Proposed Framework

- *A bank of multicoset channels:* it has distinguished delays.
- *Digital Fractional Delay (DFD) filters*.
- *Time-Frequency transform:* STFT surrently has been used.
- *Subband Classifier:* Composed of a linear operator (Harmonic Frame), followed by a simple maximum-absolute value operator.



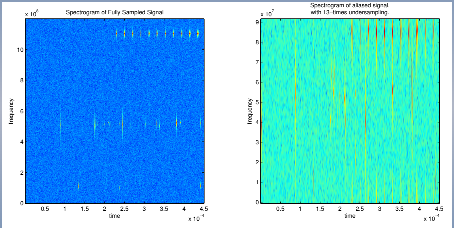
Low-Complexity MC Reconstruction Algorithm



- Θ : Harmonic Frame
- $\hat{x}[n]$ can be reconstructed using inverse TF transform.

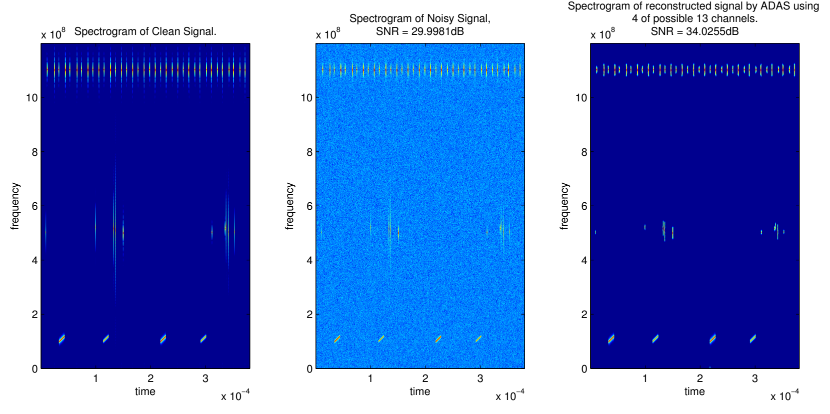
Assumptions and Properties of Proposed Framework

- *Approximate Disjoint Aliased Support (ADAS):* it is different to the sparsity.

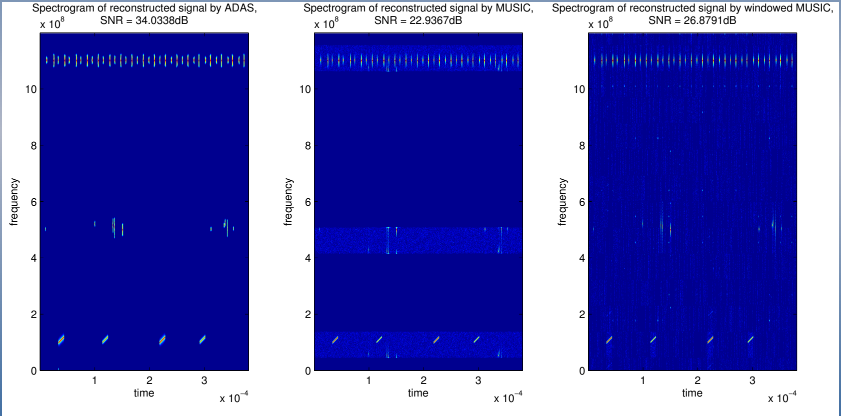


- *Does not require random sampling:* optimal delay parameters can be yielded using Harmonic Grassmannian Frames (HGF).
- *Practical Issues with DFD filters:* finite length filters introduce distortion $\rightarrow$ Combining TF and DFD filters.

Evaluation with Radar ESM signals



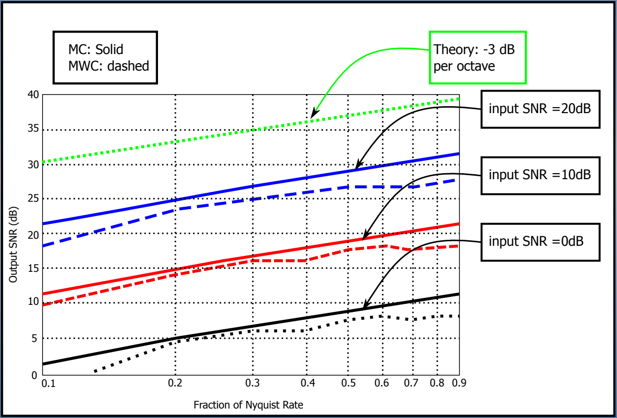
Comparison with MUSIC type recoveries [Feng and Bresler, 1996]



Advantages of the Proposed Method:

- Non-iterative: it may be pipelined.
- Can use only a few Multi-coset channels, *e.g.* as few as $q = 2$.
- Uses a different signal model, *i.e.* ADAS, which matches well to some classes of signals, *e.g.* ESM.
- Simple analog hardware (digitiser): periodic non-uniform sampling pattern: easier to implement than a random sampling pattern.
- Large Dynamic Range, *e.g.* 70 dB, which makes it suitable for the low probability of intercept signals.
- Continuously monitoring wideband RF signals, in a contrast with the rapid frequency swapping technique.

Noise Folding in Sub-Nyquist Sampling



Conclusions

- A low SWAP subNyquist algorithm was presented for ESM application.
- The proposed technique uses parsimonious signal structures.
- When ESM signals are structrally sparse in some TF domains, we can assure signal recovery, by selecting a moderate undersampling factor.
- The proposed algorithm out performs the canonical MUSIC based recovery algorithms for the given ESM signals.

Future Work

- An optimal TF selection to maximise coherent processing gain.
- Sensitivity and robustness analysis.
- More simulations around about comparisons with canonical methods.
- Further optimisation of implementation of DFD filters.

Thanks for your attention.