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Sub-Nyquist Cognitive Radio

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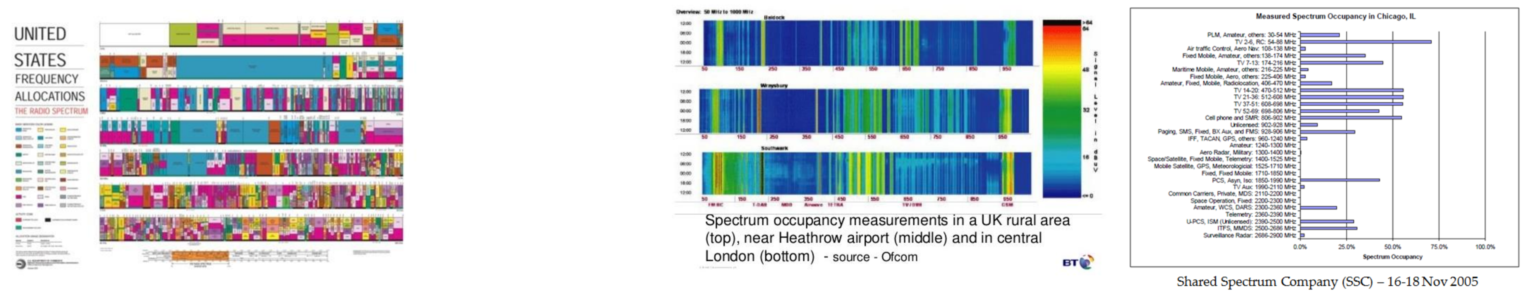
Contributions

- Spectrum sensing from sub-Nyquist samples for Cognitive Radios based on the modulated wideband converter (MWC):
  - Cyclostationary detection: increase robustness to noise
  - Collaborative spectrum sensing: overcome fading and shadowing effects
  - Joint spectrum sensing and DOA estimation: increase efficiency
- Hardware prototype system

Cognitive Radio (CR): Between Sparsity and Scarcity

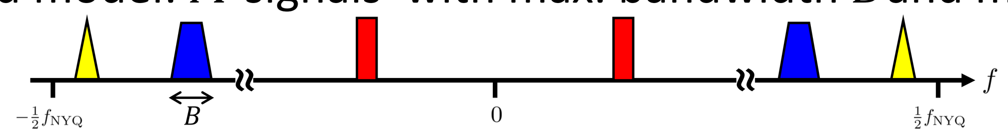
- Address the conflict between spectrum saturation and underutilization
- Grant opportunistic access to spectrum "holes" to unlicensed users
- Perform spectrum sensing task efficiently, in real-time and reliably



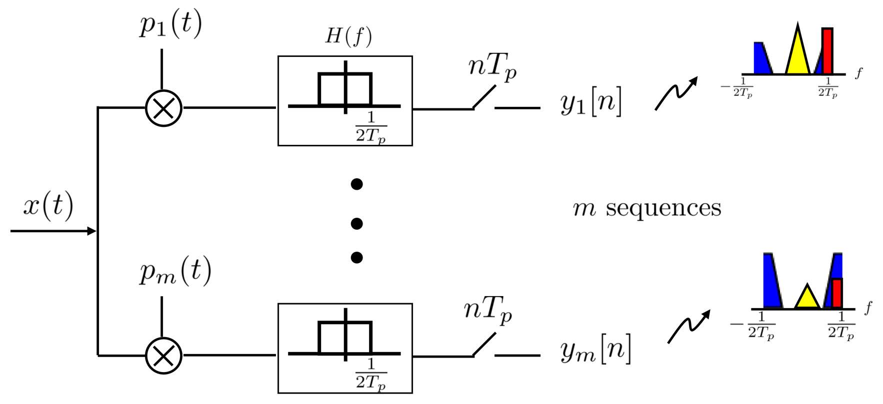
- Nyquist sampling is not an option ⇒ sub-Nyquist sampling
- Joint DOA estimation and spectrum sensing increase CR efficiency

MWC Sampling scheme

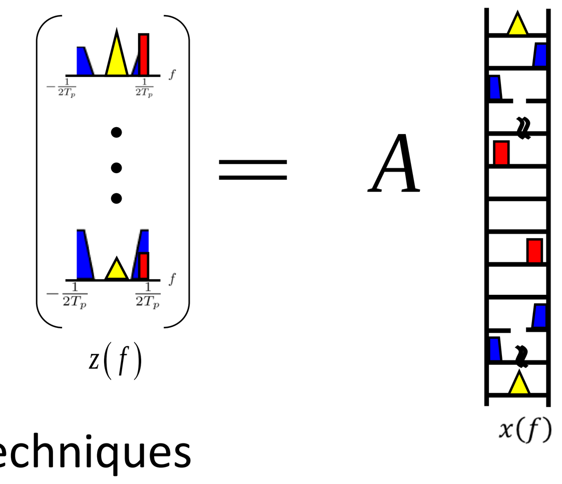
- Multiband model: M signals with max. bandwidth $B$and max. frequency f_{Nyq}



- Analog front-end: aliases the spectrum so that each band appears in baseband



- Relation between known discrete time Fourier transforms (DTFTs) of the MWC samples and unknown signal Fourier transform:



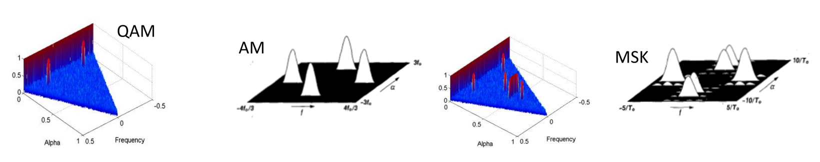
- Signal reconstruction using compressed sensing techniques

Goal: increase robustness to noise, fading and shadowing effects, and allowing for joint DOA estimation and spectrum sensing

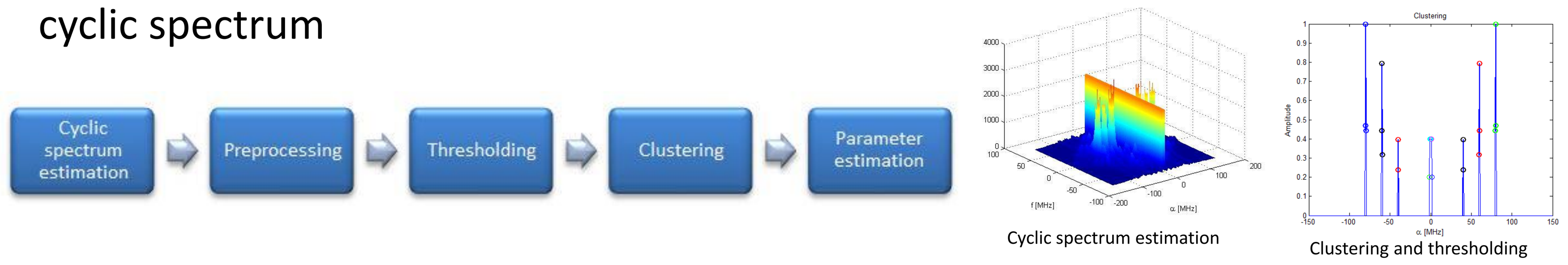
Cyclostationary Detection

- Cyclic spectrum measures the correlation between two frequency-shifted versions of $x(t)$ as $S_x^\alpha(f) = \mathbb{E}\left[X(f+\frac{\alpha}{2})X^*(f-\frac{\alpha}{2})\right]$

Cyclic spectrum exhibit spectral peaks at frequency locations that depend on carrier frequencies and bandwidths



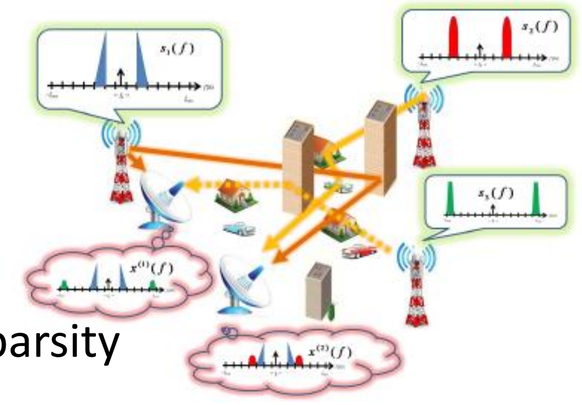
- Recover cyclic spectrum from MWC sub-Nyquist samples by computing the correlation of frequency-shifted versions of the samples
- Estimate transmissions bandwidth and carrier frequencies from reconstructed cyclic spectrum



Cyclostationary detection outperforms energy detection in low SNR regimes

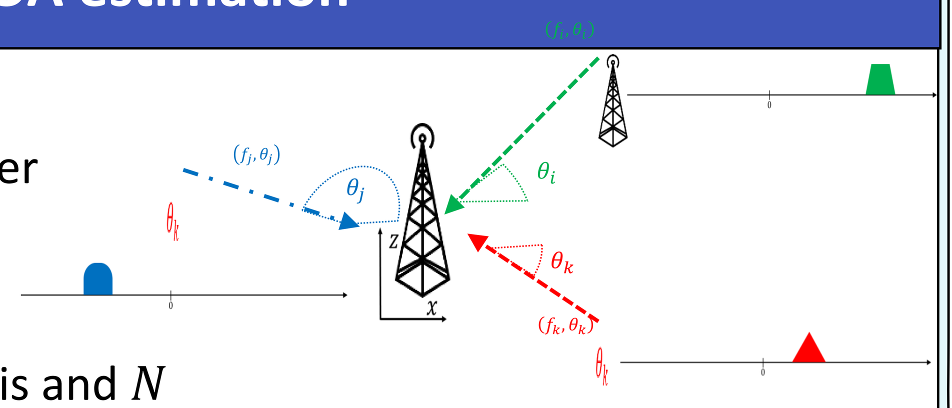
Collaborative Spectrum Sensing

- Problem: fading and shadowing effects
- Proposed solution: collaborative spectrum sensing
- **Centralized** approach:
  - Each CR sends measurements to a fusion center
  - Goal: recover joint support at the fusion center
  - Extension of CS algorithms to account for joint sparsity
- **Distributed** approach:
  - A vector is shared within the network through random walk
  - Goal: recover joint support within the network
  - Random distributed IHT: derived and proved to converge to true solution



Joint Spectrum Sensing and DOA estimation

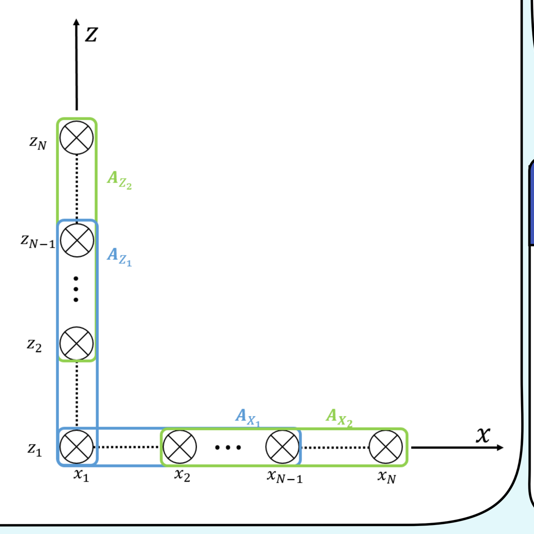
- Each transmission $s_i(t)$ is characterized by a DOA θ_i and carrier frequency f_i



- L-shape ULA with N sensors in x axis and $N+1$ sensors in z axis:
- Naïve approach: apply ESPRIT in each axis separately: estimate $f_i\cos(\theta_i)$ and$f_j\sin(\theta_j)$

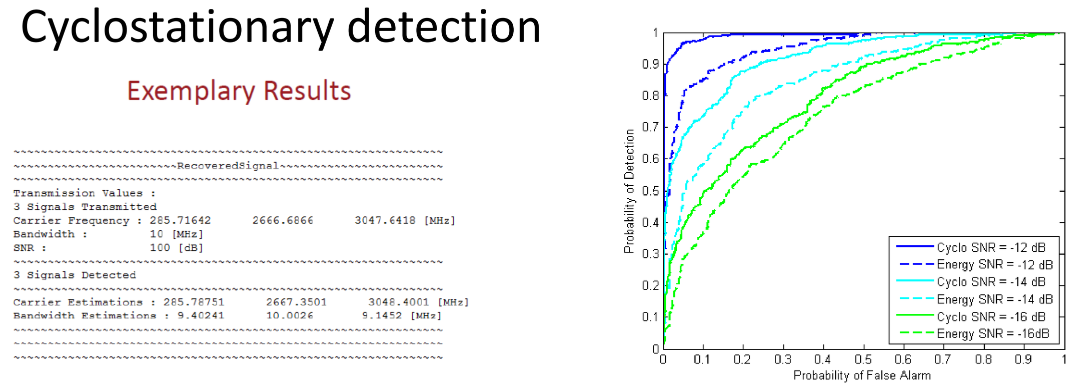
Pairing problem

- To overcome pairing problem, compute cross correlation matrices between ULAs and perform joint SVD
- Compute θ_i and f_i from the paired eigenvalues



Simulation Results

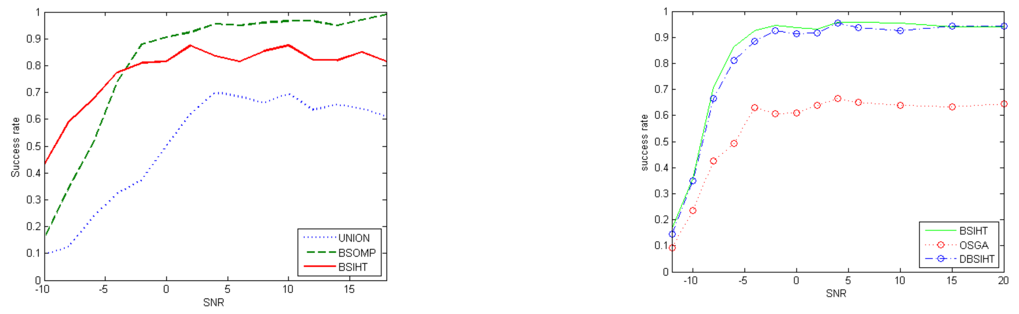
- Cyclostationary detection



Nyquist rate	10 GHz
Sampling rate	1.09 GHz
Transmissions	3 BPSK

11% Nyquist rate

- Collaborative spectrum sensing

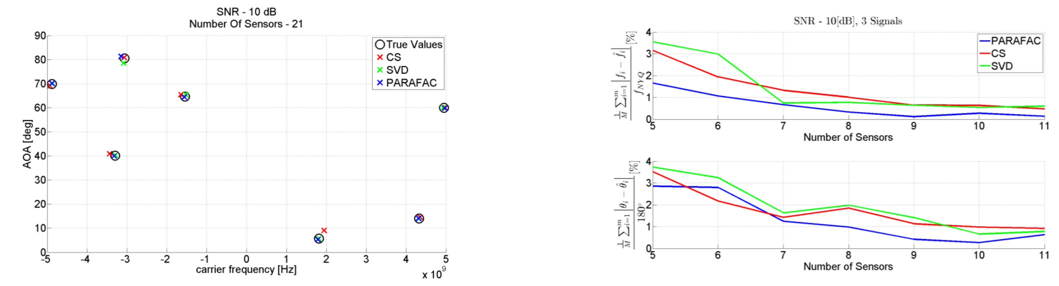


Nyquist rate	6.1 GHz
Sampling rate	360 MHz
Transmissions	3 QPSK

6% Nyquist rate

Left: centralized
right: distributed

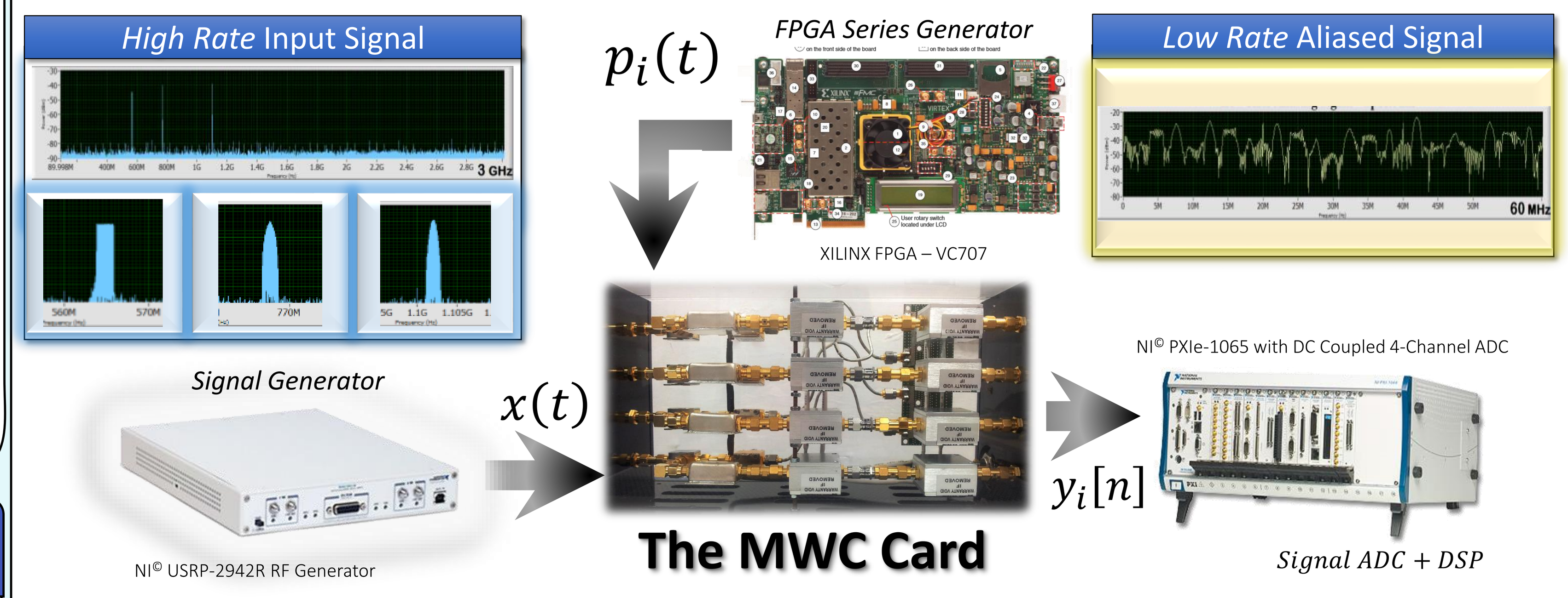
- Joint DOA and spectrum sensing



Nyquist rate	10 GHz
Sampling rate	1.05 GHz
Transmissions	7 (left), 3 (right)

11% Nyquist rate

Hardware Prototype



- Proprietary MWC card mixes with input with the mixing sequences
- Input is generated live by National Instruments USRP-2942R
- Entire digital processing is done under LabVIEW environment
- Input signal Nyquist rate – 6GHz
- Sub-Nyquist sampling rate – 3*120MHz
- **Just 6% of Nyquist rate**

References

- [1] M. Mishali and Y. C. Eldar, "From theory to practice: Sub-Nyquist sampling of sparse wideband analog signals," IEEE Journal of Selected Topics in Signal Processing, 2010
- [2] A. Paulraj, R. Roy, and T. Kailath, "Estimation of signal parameters via rotational invariance techniques - ESPRIT," Information Systems Laboratory, 1986
- [3] D. Liu and J. Liang, "L-shaped array-based 2D DOA estimation using parallel factor analysis," WCICA, 2010