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):
  - Cyclic spectrum detection: increase robustness to noise
  - Collaborative spectrum sensing: overcome fading and shadowing effects
  - Joint spectrum sensing and DOA estimation: increase efficiency
  - Hardware prototype system
- Nyquist sampling is not an option ⇒ sub-Nyquist sampling
  - Joint DOA estimation and spectrum sensing increase CR efficiency

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

MWC Sampling scheme
- Multiband model: M signals with max. bandwidth B and max. frequency \( f_{Nyquist} \)
- Analog front-end: aliases the spectrum so that each band appears in baseband
- MWC sampling scheme
- Relation between known discrete time Fourier transforms (DFTs) of the MWC samples and unknown signal Fourier transform:
  \[
  \begin{pmatrix}
  \mathbf{X}[0] \\
  \vdots \\
  \mathbf{X}[M-1]
  \end{pmatrix} = \mathbf{A}
  \begin{pmatrix}
  \mathbf{S}[0] \\
  \vdots \\
  \mathbf{S}[M-1]
  \end{pmatrix}
  \]
- 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
  \[
  S(f) = \frac{1}{2} \left[ N(f + 2f_0) + N(f - 2f_0) \right]
  \]
  Cyclic spectrum exhibits 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

Simulated Results
- Cyclostationary detection
  - Exemplary results
  - Collaborative spectrum sensing
  - Joint ULA and spectrum sensing

Hardware Prototype
- Proprietary MWC card mixes 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

Joint Spectrum Sensing and DOA estimation
- Each transmission \( s_i(t) \) is characterized by a DOA \( \theta_i \) and carrier frequency \( f_i \)
- 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

References

Simulation Results

Simulation Results

Collaborative Spectrum Sensing