Efficient Signal Identification using the Spectral Correlation Function and Pattern Recognition

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Acknowledgement:
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Outline

- Determining Spectrum Efficiency
- Techniques for Signal Identification
- Cyclostationary Analysis
- Biometric Pattern Recognition Techniques
- Results
- Conclusions

How do you Measure Spectrum Efficiency?

- Possible spectrum efficiency metric

$$\eta = \sum_{i=1}^{N_R} \sum_{j=1}^{N_T} \frac{G_{ij} D_{ij} U_{ij}}{AB}$$

Net utility of comm in spectrum block

Size of spectrum block

$N_R, N_T =$ numbers of receivers & transmitters

$G_{ij} =$ Goodput between transmitter j and receiver i

$D_{ij} =$ Distance between transmitter j and receiver i

$U_{ij} =$ Mean Societal value/bit received by j from source i

$A =$ Area within which i, j operate

$B =$ Bandwidth within which i, j operate

Source: J. Peha, M. Sirbu

Example: UHF TV Broadcast Channel in US

$$\eta = \sum_{i=1}^{N_R} \sum_{j=1}^{N_T} \frac{G_{ij} D_{ij} U_{ij}}{AB}$$

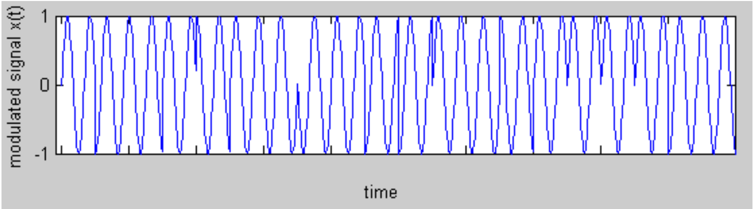
- Parameters:
  - A = area of US
  - B = 6 MHz
  - N_t = number of licensed transmitters
  - N_r = number of listeners served
- Possible ways to increase η:
  - Add transmitters in un-served areas (N_t ,N_r)
  - Improve technology (D_{ij}, G_{ij}, N_r)
  - Add secondary reuse (although D_{ij} small, increases in N_t , N_r , G_{ij} could be substantial)

Signal Identification: Key Enabler for Secondary Use

- Necessary for:
  - Identifying and avoiding interference
  - Assessing spectrum use for dynamic spectrum allocation
- Key approaches
  - Radiometry (i.e., spectral power at a given time)
    - Simple but not very robust
  - Matched filters
    - More accurate but less flexible
  - Cyclostationary Analysis
    - Accurate, flexible, gives modulation parameters
    - Computationally demanding

Spectral Correlation Function

- Limit Cycle Autocorrelation of the Fourier Transform of a signal
  - Amplitude of the sine wave component of $z(t)=x(t+\tau/2)x(t-\tau/2)$ at frequency α (for a fixed offset τ).
- Limit Cycle Autocorrelation is cyclostationary:
  - Process with 2nd order periodicity
- 2-D transformation of a 1-D signal
  - Time → Spectral Frequency and Cycle Frequency



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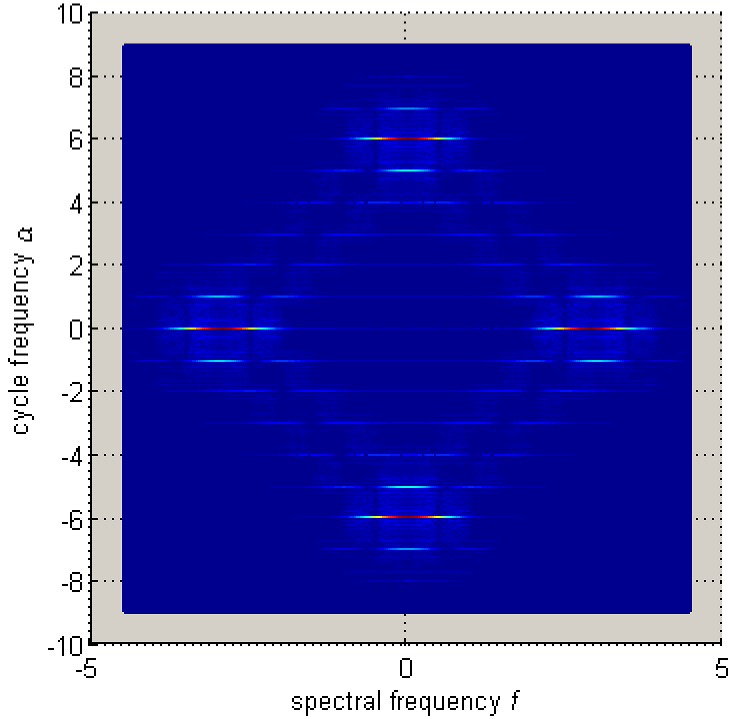
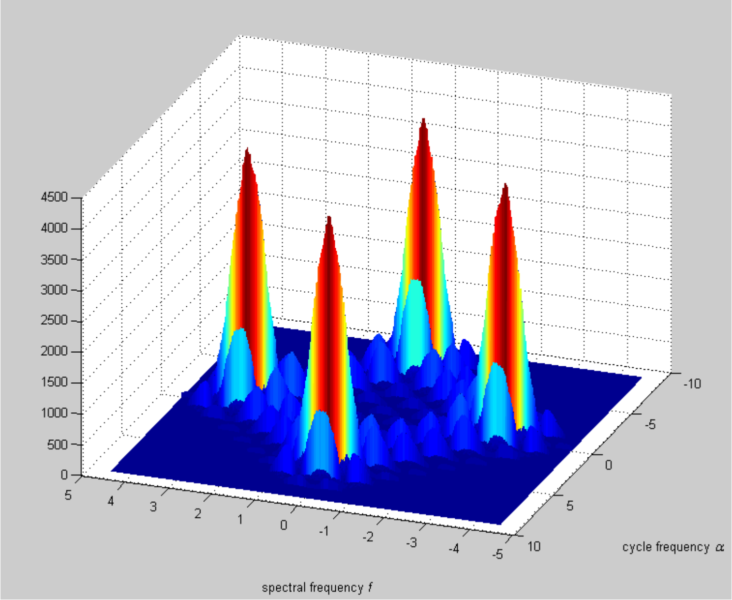
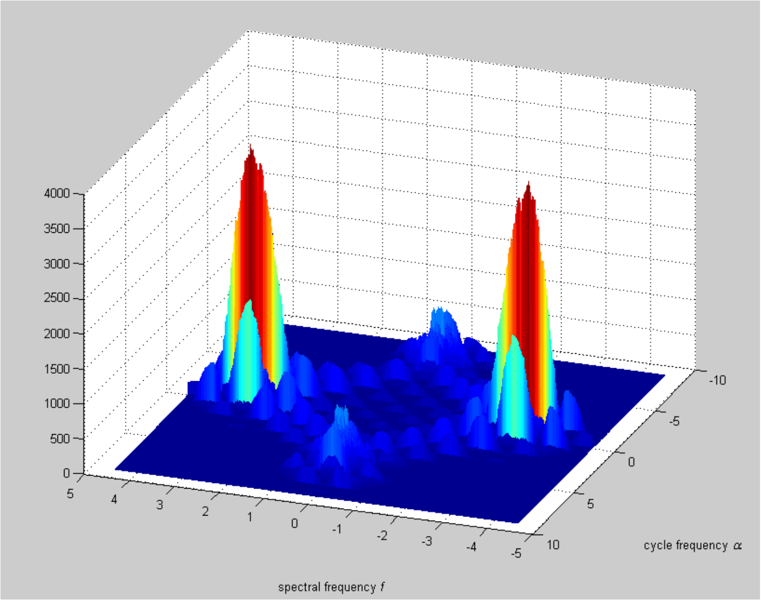


Each Modulation has a Different Spectral Correlation Function (SCF)



BPSK



QPSK

Our Approach

- Introduce modified SCF that can be computed very quickly
- Apply Pattern Recognition Techniques to the Spectral Correlation Function
  - These methods are used extensively in Biometric Recognition
  - Examples: Facial, iris, thumb print recognition
- Based on 2000 simulated training signals per class, 0 dB SNR

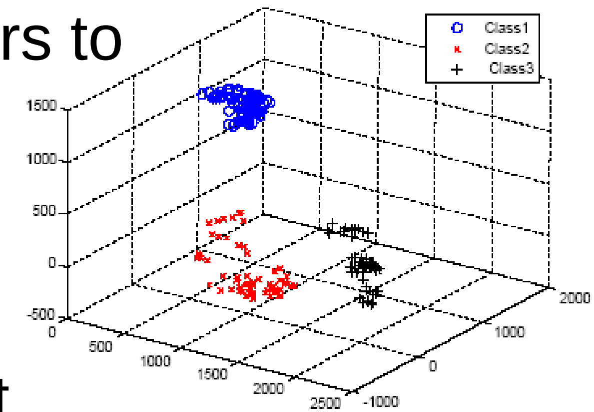
New Efficient SCF Computation: up to 1500x Faster!

- Based on symmetries of SCF and efficient smoothing techniques
- For a signal of length N = 1000*
  - Complete SCF computed in: 59.7 seconds
  - New SCF computed in: 0.17 seconds
- N = 3000*
  - Complete SCF > 17 minutes vs 0.66 seconds with new implementation
- New SCF closer to a **real time application**!

$* \; f_c = 3, f_{dat} = 1, f_s = 9, M = N/10$

Principal Component Analysis

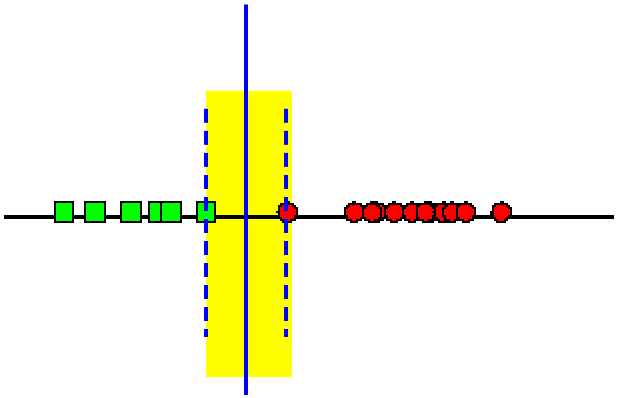
- Vectorize the SCF from each training signal
- Construct covariance matrix from training vectors
- Find eigenvectors and eigenvalues of the covariance matrix
- Keep the eigenvectors corresponding to the largest eigenvalues
- Project training set onto these eigenvectors to create classes
- SCFs of test signals are projected onto the eigenvectors. The class of the test signal is considered to be the class of the projected training sample with the nearest distance to the projected test sample.

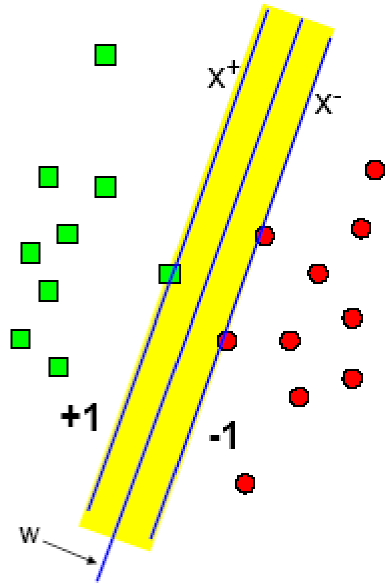


Marios Savvides

Support Vector Machines (SVM)

- This technique finds vectors that maximize the margin boundaries between classes





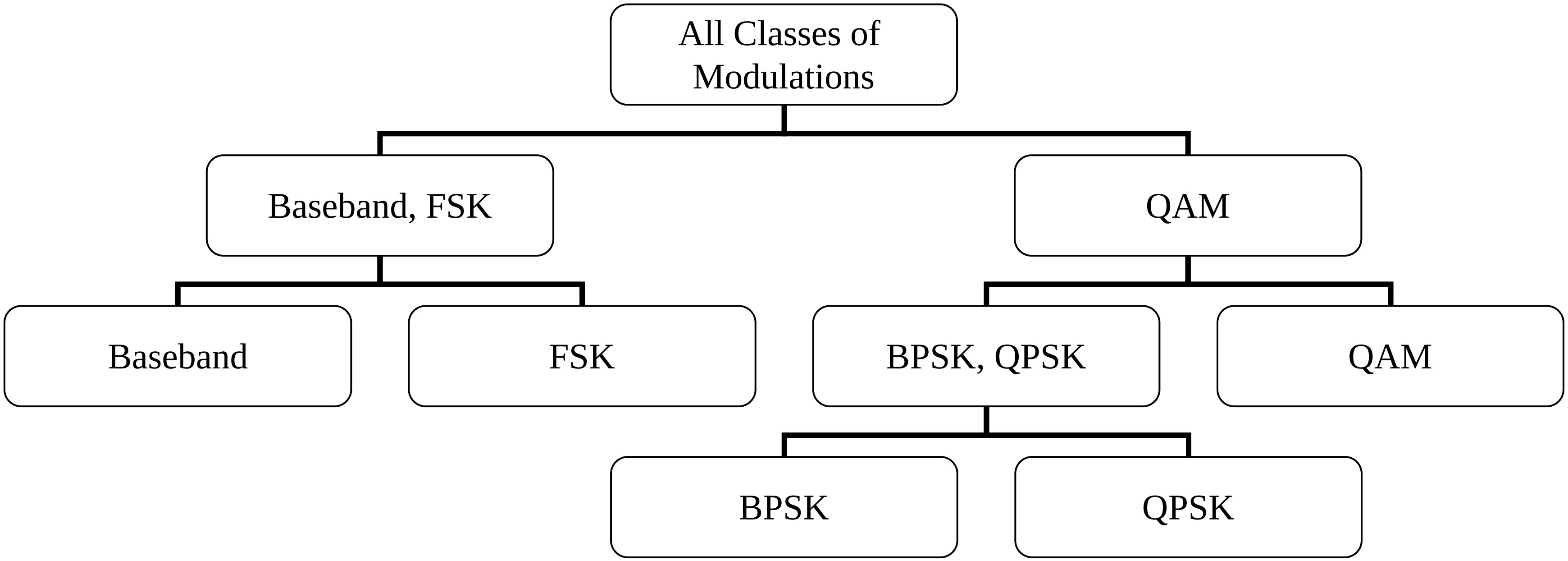
Marios Savvides

- SVMs are designed for two class problems but can extend to multiple classes through decision trees
- Trained 4 SVMs where each solves a two class problem for a grouping of the signal modulation schemes

We Considered a Five Class Pattern Recognition Problem

- Baseband
- Frequency Shift Keying (FSK)
- Binary Phase Shift Keying (BPSK)
- Quadrature Phase Shift Keying (QPSK)
- Quadrature Amplitude Modulation (QAM)

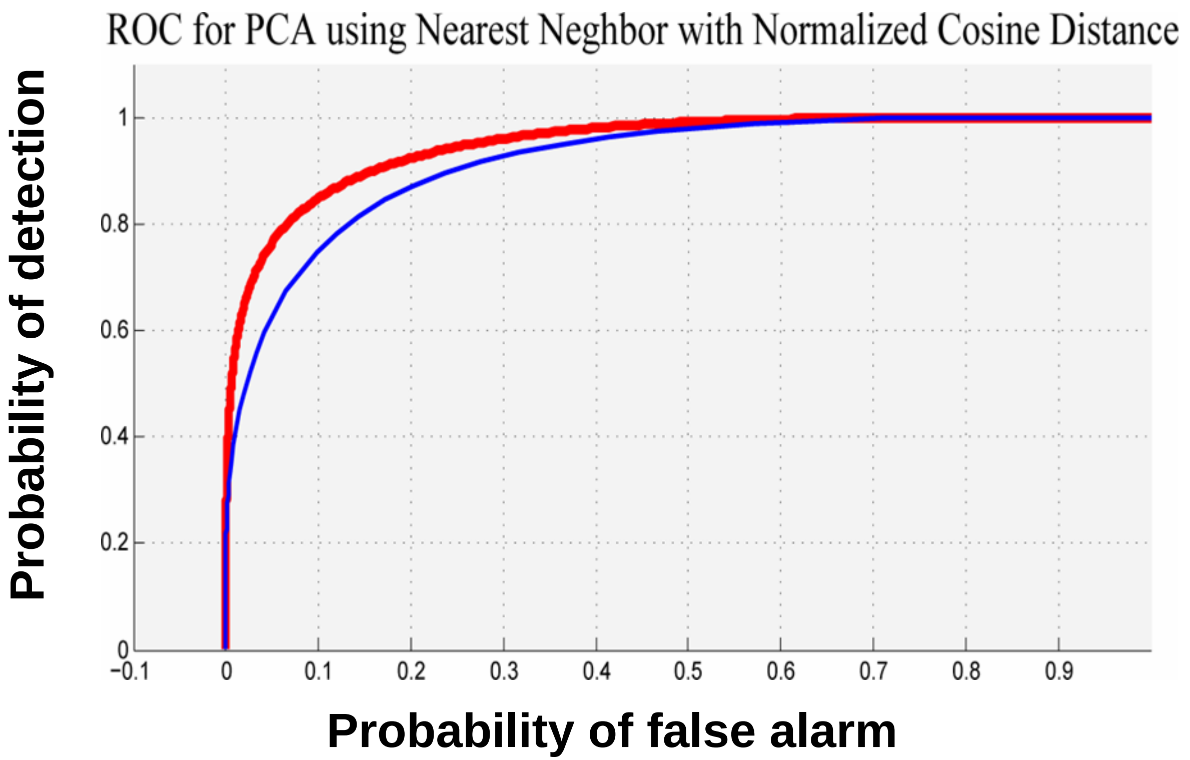
Decision Tree for SVM



- All SVMs in the decision tree are linear
- Only 2 or 3 inner products per sample are required for classification

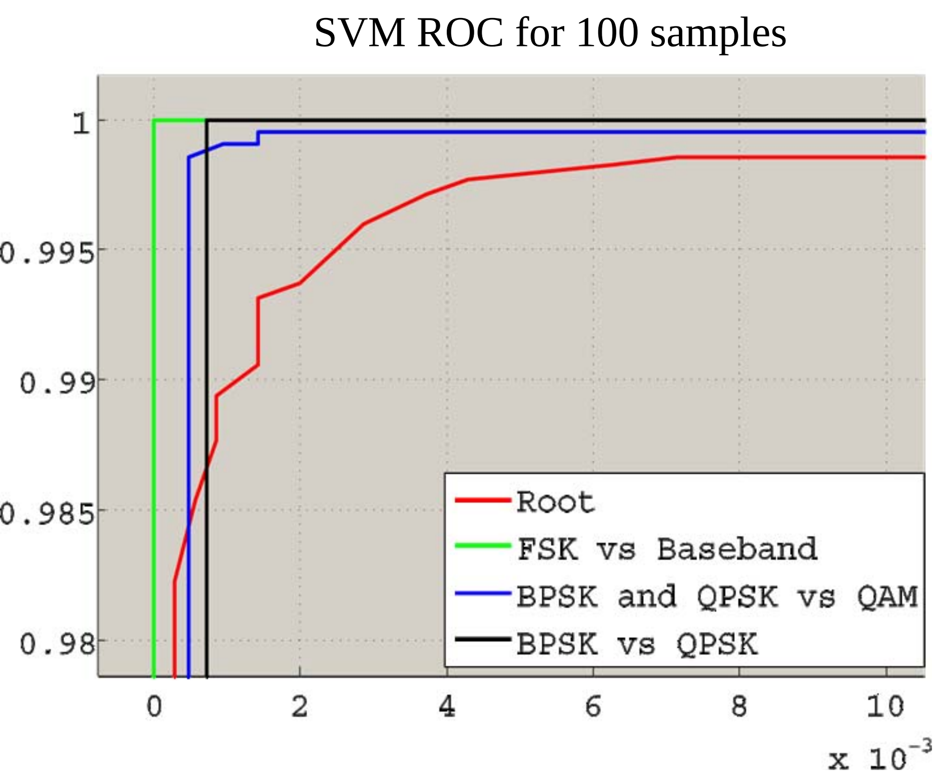
Nearest Neighbor in PCA Projection

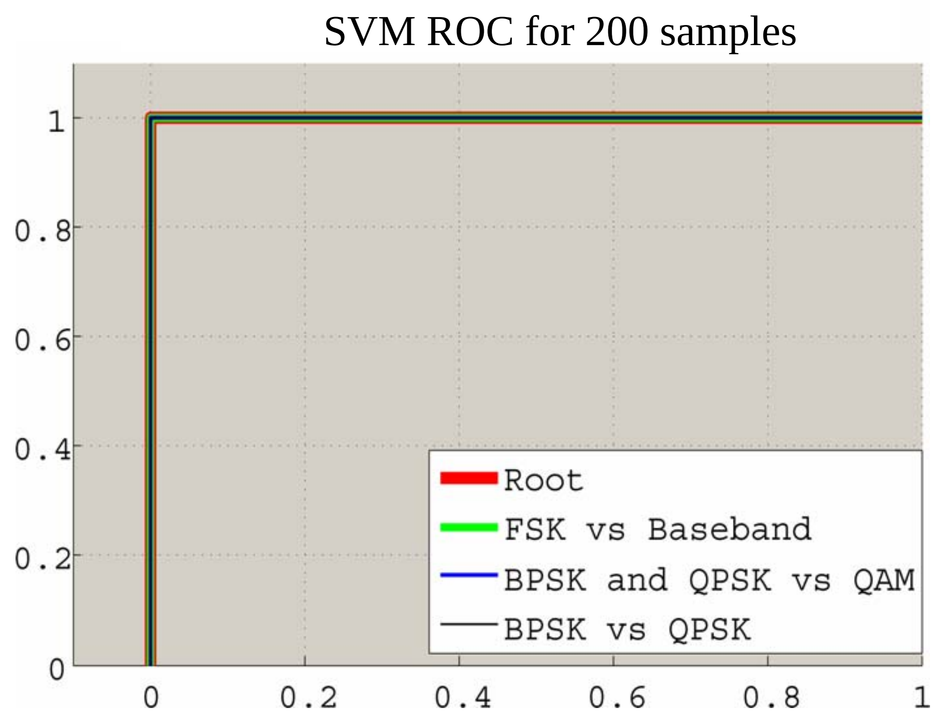
- Equal error rate (EER) of 0.126 for ~200 samples (red) and 0.143 for ~100 samples (blue)



Support Vector Machines

- Performance using five eigenvectors





Summary

- Spectrum utility is more complicated than simply the % time a frequency is used within a given area: should also consider factors such as range and societal value
- Computationally efficient signal identification is critical for dynamic spectrum access
- Spectrum Correlation Functions can be used to identify and extract signal parameters
- New format SCF combined with a Support Vector Machine for pattern recognition is very effective
- Perfect classification for SVMs on ~200 point signals and near perfect on ~100 point signals despite high noise levels.
- Feasible for use in real-time applications when used in conjunction with SCF optimizations