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Automatic Modulation Classification Using A Waveform Signature

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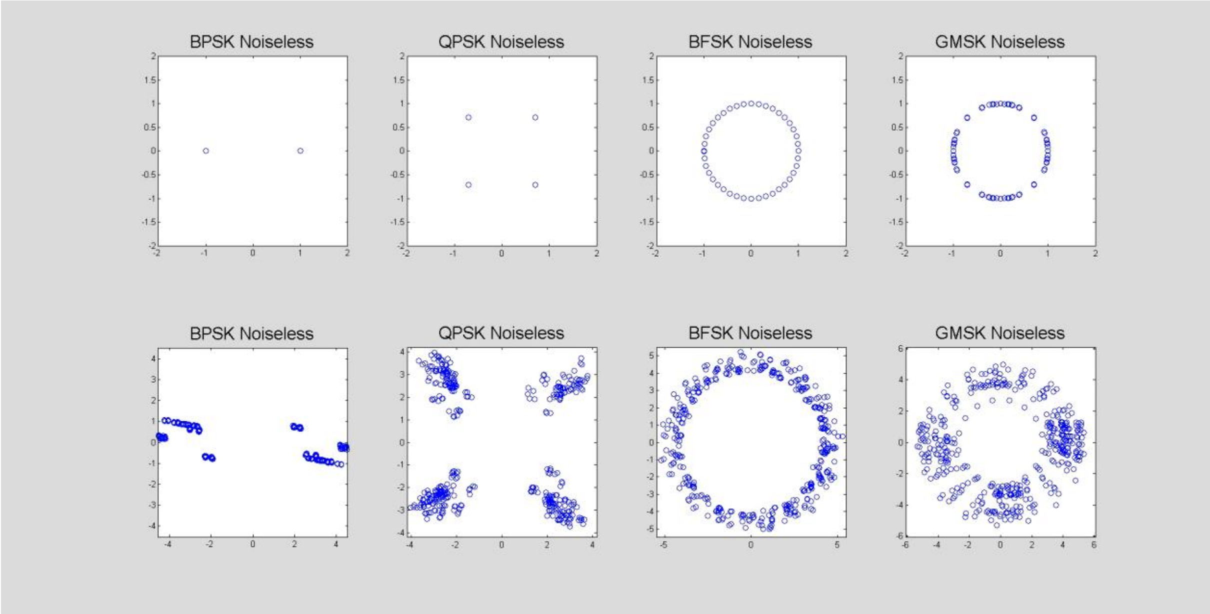
Overview

- Motivation
- What is the Waveform Signature?
- The Cumulant Feature
- The Waveform Signature
- The Received Signal
- Channels Examined
- Performance

Motivation

- How to get the first row, from the second
- Two schools of classification
  - Likelihood vs. Feature
- Likelihood Exhaustion
- Feature Recovery
  - Data Processing Inequality
- Machine Learning
  - Raw I-Q data?
- Want more than just the signal?



What is the Waveform Signature?

N-Dimensional vector that contains the information about the signal and the environment from which it was observed with no information about the data being transmitted.

This work examines a 20-D vector composed of high ordered cumulants.

The Cumulant Feature

The math…

$$\kappa_{n,q} = \kappa(\bar{x}_1, \ldots, \bar{x}_n) = \sum_{P} (-1)^{N_P - 1}(N_P - 1)! \sum_{b=1}^{N_B} \prod_{\eta=1}^{N_\eta} \mathrm{E}\left[\prod_{i \in \eta} \bar{x}_i\right]$$

Where each $\bar{x}_i = \begin{cases} \bar{r}\,; 1 \leq i \leq n - q \\ \bar{r}^*\ n - q < i \leq n \end{cases}$

For the received/observed signal $\bar{r}$

The exhaustive partitioning on the indices $\bar{\mathrm{x}}_i$ of the joint moments

$$m_{|\eta|,\chi} = \mathrm{E}\left[\prod_{i \in \eta} \bar{x}_i\right]$$

The Cumulant Feature (cont.)

- 3rd order example

$$\kappa_{3,0} = \{\langle(m_{3,0})\rangle\} - \{\langle(m_{2,0})(m_{1,0})\rangle + \langle(m_{2,0})(m_{1,0})\rangle + \langle(m_{2,0})(m_{1,0})\rangle\} + \{\langle(m_{1,0})\rangle\langle(m_{1,0})\rangle\langle(m_{1,0})\rangle\}$$

$$\kappa_{3,0} = m_{3,0} - 3m_{2,0}m_{1,0} + m_{1,0}^3$$

$$\{\cdot\} \rightarrow \text{partition } (P)$$
$$\langle\cdot\rangle \rightarrow \text{block } (B)$$
$$(\cdot) \rightarrow \text{part } (\eta)$$

The Cumulant Feature (cont.)

- Useful properties
  - Additive (independence)

$$x = a + b \rightarrow \kappa_{n,q}^{(x)} = \kappa_{n,q}^{(a)} + \kappa_{n,q}^{(b)}$$

  - Gaussian Reduction

$$n \geq 3 \rightarrow \kappa_{n,q}^{(Gaussian)} = 0$$

  - Homogeneity (Scalability)

$$\kappa_{n,q}(c \cdot \bar{x}) = c^n \kappa_{n,q}(\bar{x}) \rightarrow \tilde{\kappa}_{n,q} = \frac{c^n \kappa_{n,q}}{\left(c^2 \kappa_{2,1}\right)^{\frac{n}{2}}}$$

The Waveform Signature

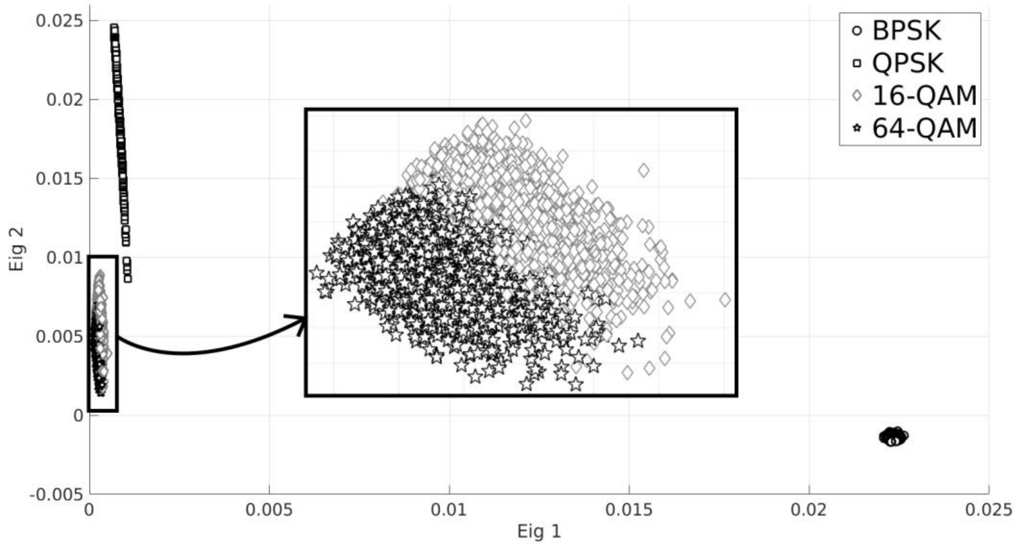
$$\hat{\kappa}_{n,q} \equiv \left|\text{estimator of } \kappa_{n,q}\right|$$

Combination of cumulants of even order 2-10

$$\boldsymbol{ws} = [\hat{\kappa}_{2,0}, \hat{\kappa}_{2,1}, \hat{\kappa}_{4,0}, \hat{\kappa}_{4,1}, \hat{\kappa}_{4,2}, \hat{\kappa}_{6,0}, \hat{\kappa}_{6,1}, \hat{\kappa}_{6,2}, \hat{\kappa}_{6,3}, \hat{\kappa}_{8,0}, \hat{\kappa}_{8,1}, \hat{\kappa}_{8,2}, \hat{\kappa}_{8,3}, \hat{\kappa}_{8,4}, \hat{\kappa}_{10,0}, \hat{\kappa}_{10,1}, \hat{\kappa}_{10,2}, \hat{\kappa}_{10,3}, \hat{\kappa}_{10,4}, \hat{\kappa}_{10,5}]$$

$$\boldsymbol{ws}^{\{\rho\}} = \text{PCA}(\boldsymbol{WS}, \rho)$$

PCA Decomposition Visualization



ρ=2

The Received Signal

The received signal is the channel convolved with the signal with additive noise.

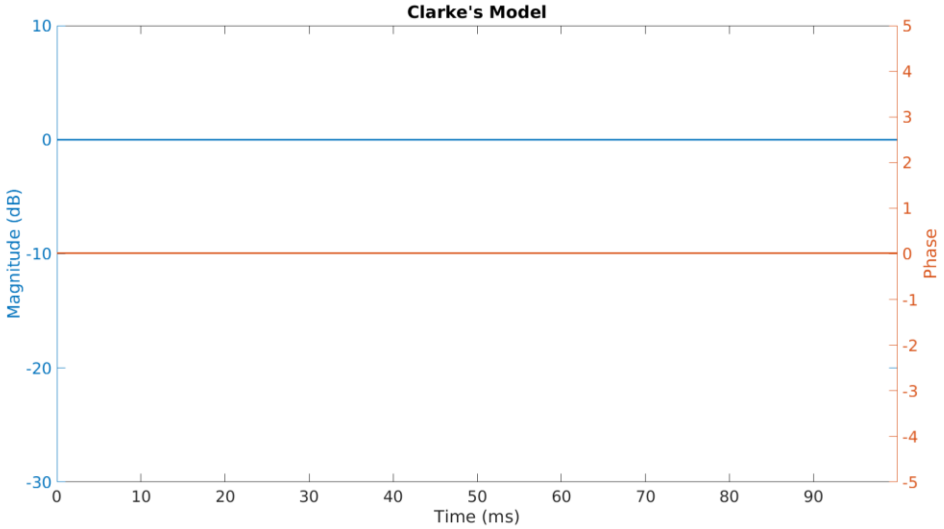
The signal is the convolution of symbols and a pulse shape.

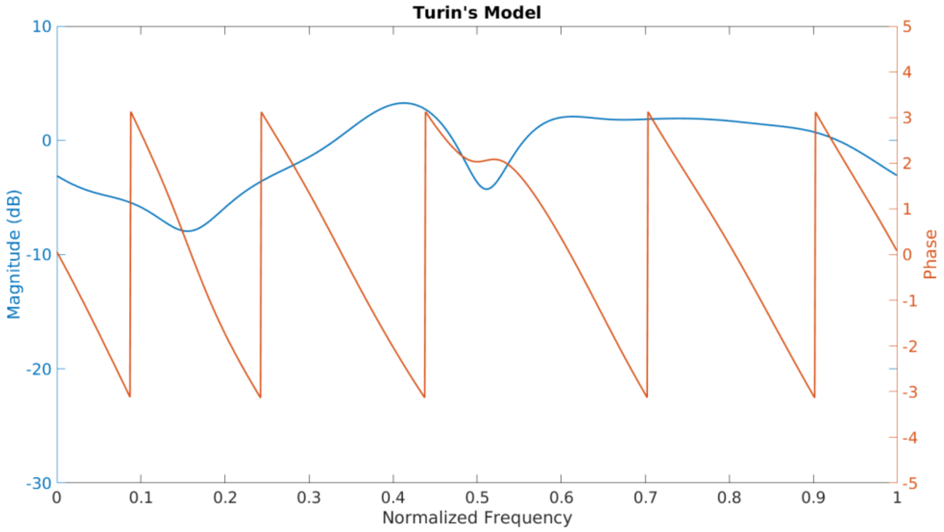
$$r(t) = h(t,\tau) * \big(p(t) * s(t)\big) + n(t)$$

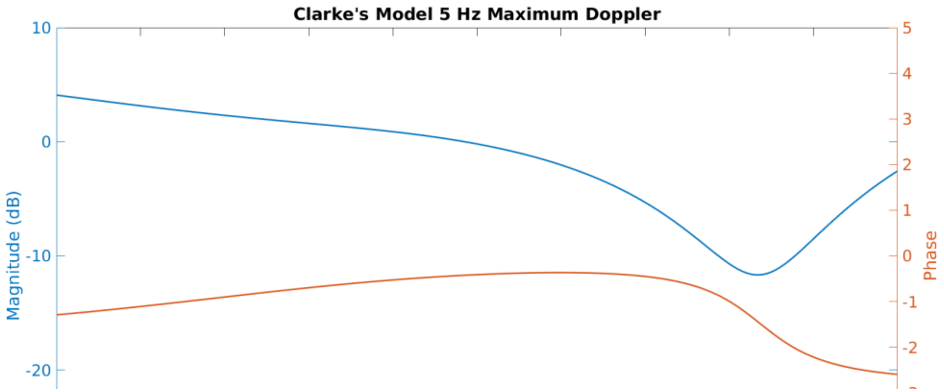
Or look at it as the combined channel and pulse shaping convolved with the symbols.

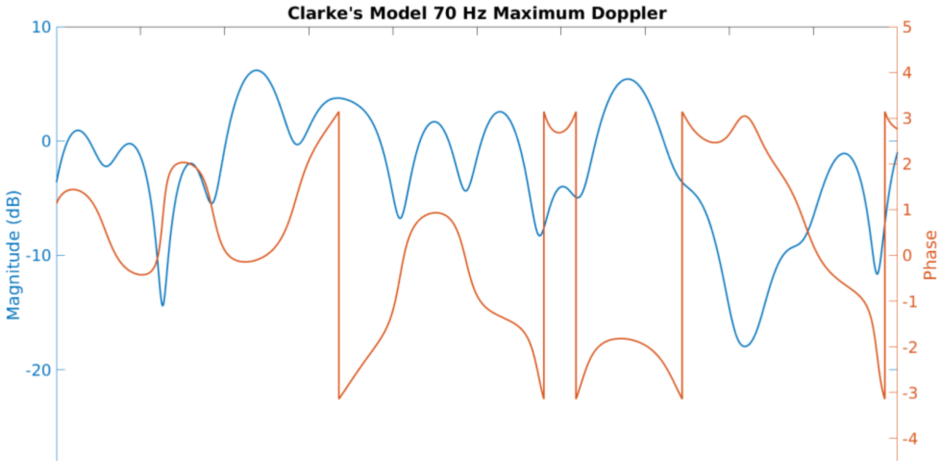
$$r(t) = h_p(t,\tau) * s(t) + n(t)$$

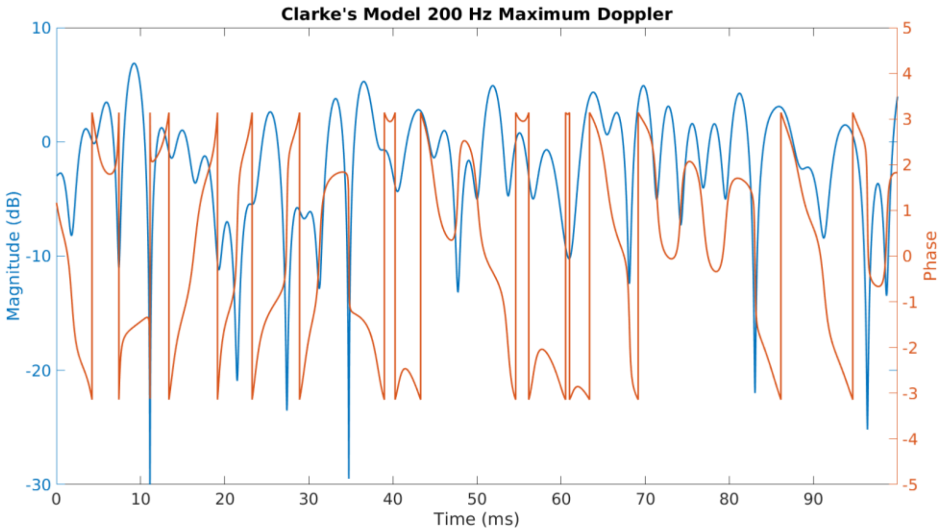
Channels examined











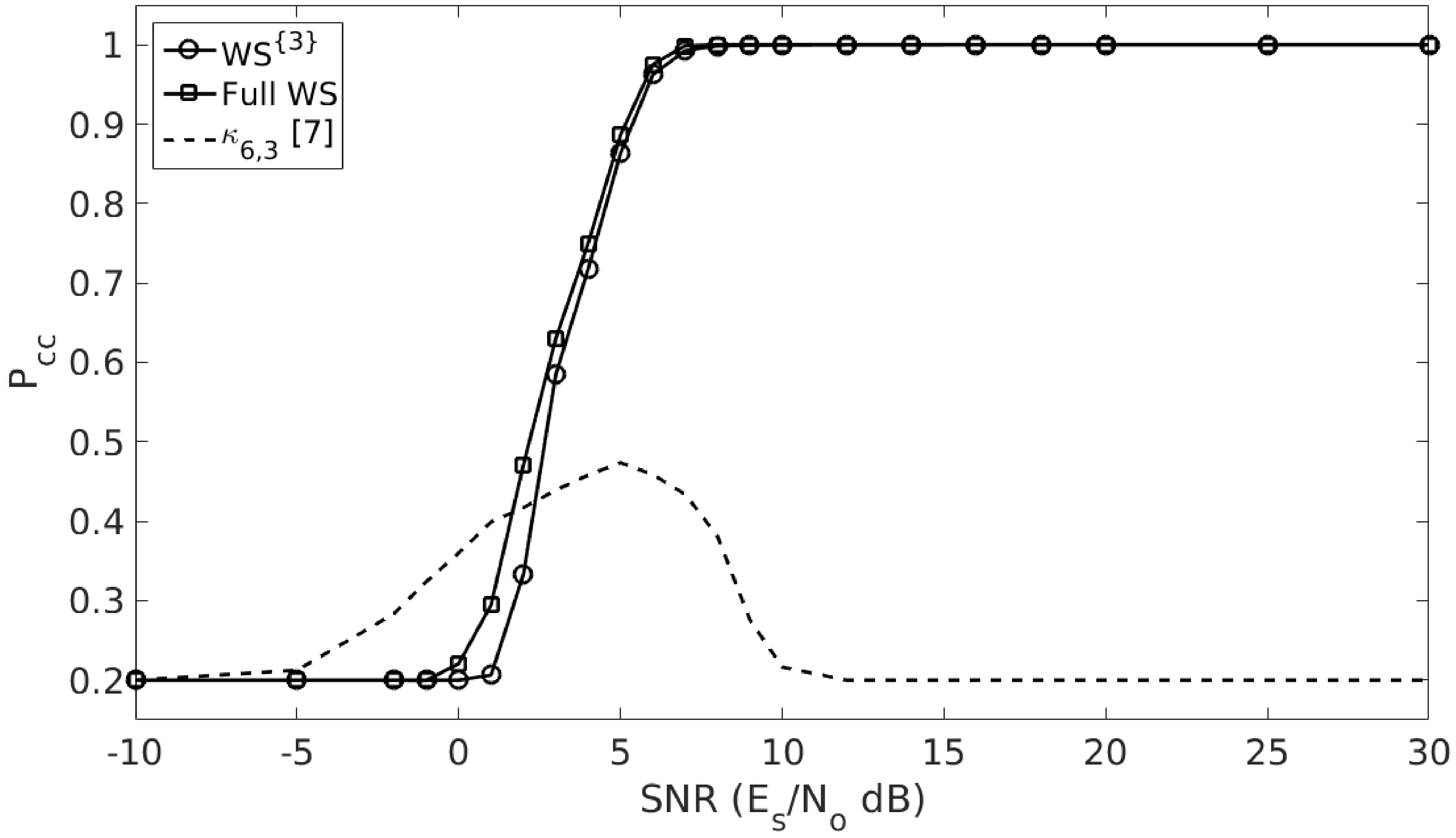
Performance

Classification between

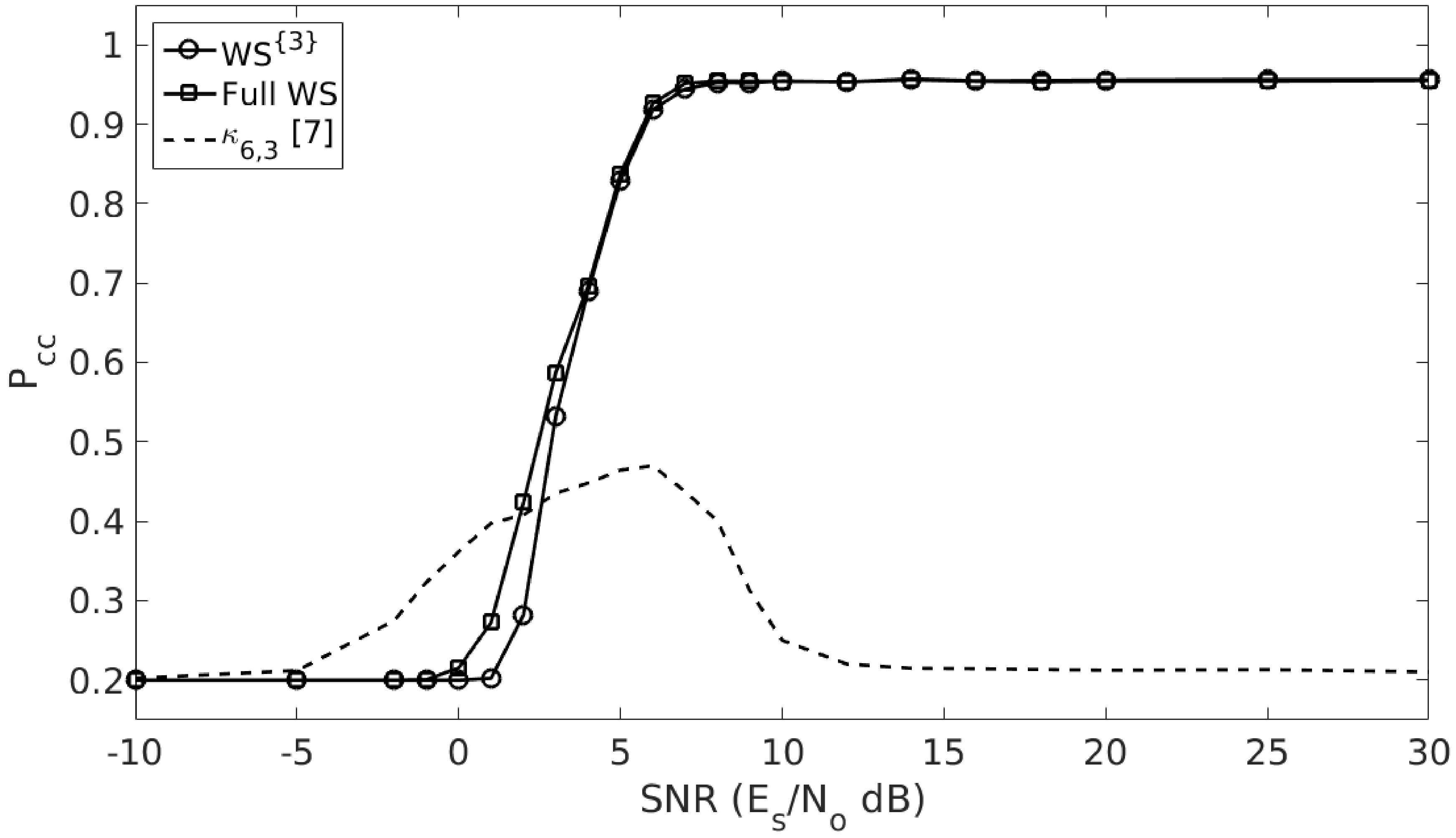
- BPSK
- QPSK
- 8PSK
- 4PAM
- 16QAM

- For phase blind cumulants ($\kappa_{4,2}$) QPSK and 8PSK have the same feature value
- While examining just the real component would make 4PAM and 16QAM identical

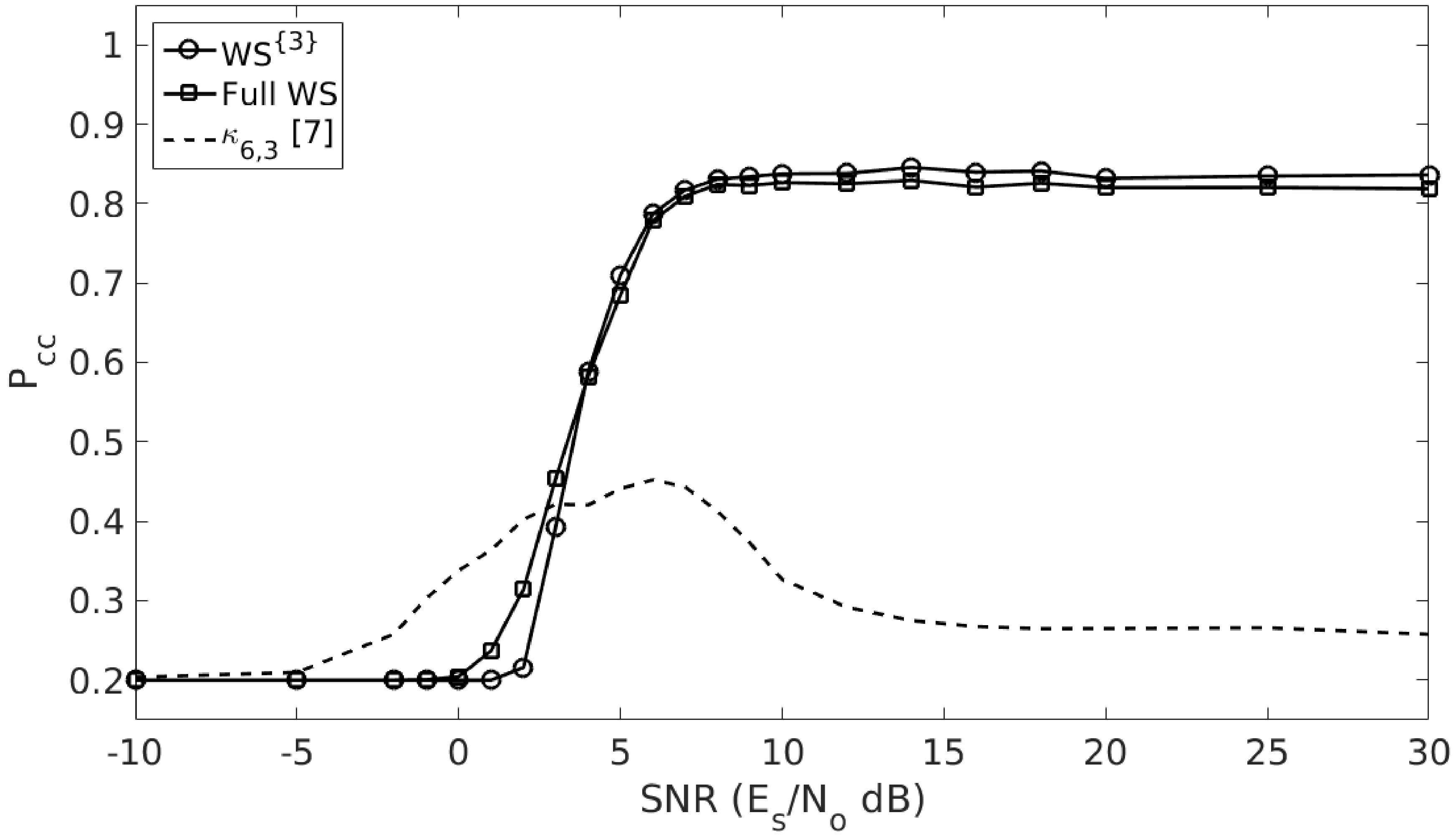
Performance - Clarke



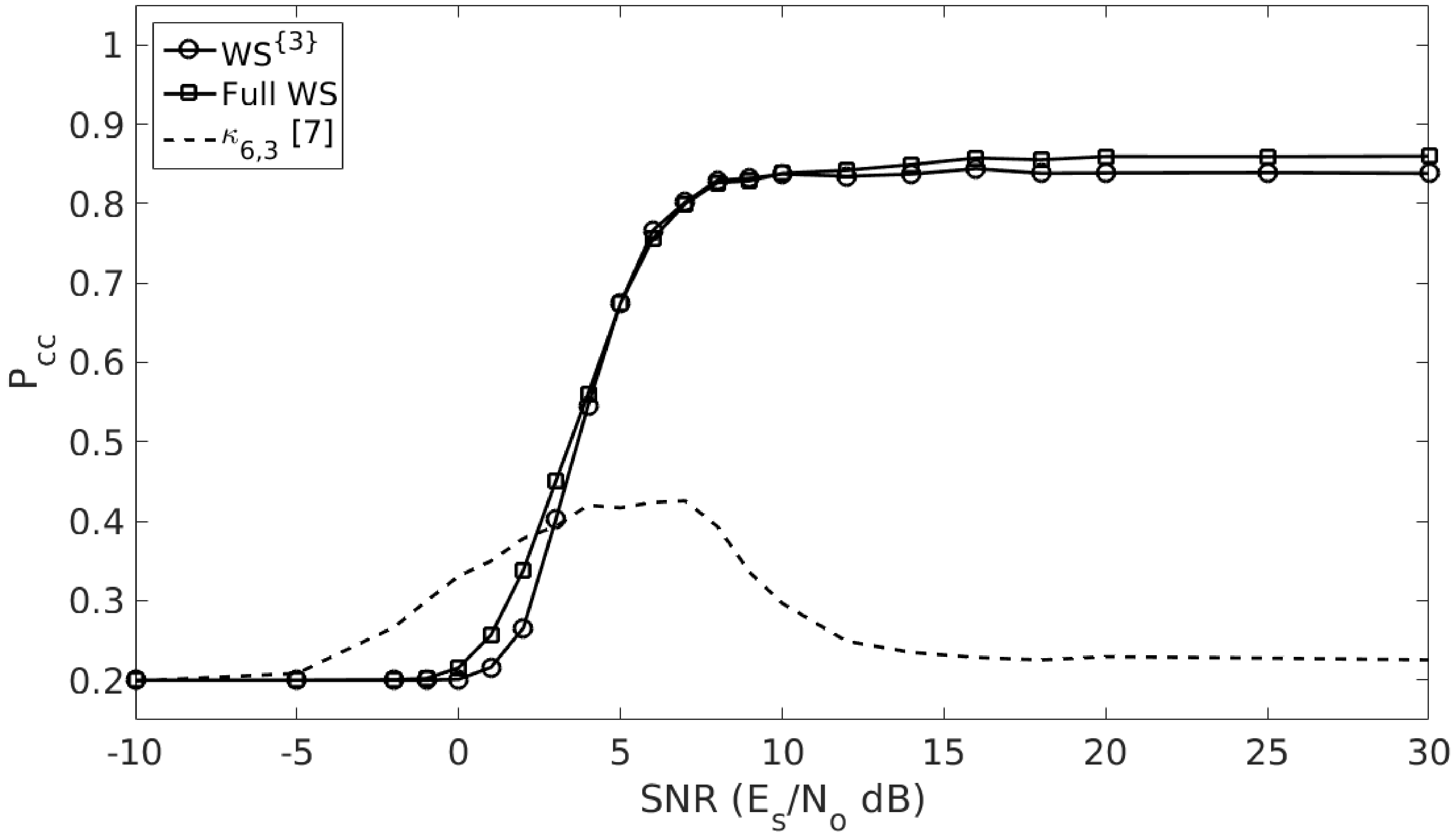
Performance – Clarke70



Performance – Clarke200



Performance - Turin



Summary

- Feature-based classifiers are less computationally complex
- Individual features have limited application
- The Waveform Signature gives a statistical snapshot of the waveform without retaining the Raw I/Q
- Instead of trying to recover an ideal feature value, the feature set can be learned and used for classification
- The feature set can be compressed with minimal loss of performance

Questions?