Modulation Classification of Satellite Communication Signals Using Cumulants and Neural Networks

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Automatic Modulation Classification

Objective

- Correctly predict the transmitted modulation scheme

Applications

- Automatic receiver reconfiguration
  - Reduce transmission overhead due to modulation coordination
- Interference Mitigation
  - Identify and respond to interferers uniquely
- Spectrum Management
  - Automate violation notification process

Requirements

Classify typical satellite communication signals

- $\Omega = \{\text{BPSK, QPSK, 8–PSK, 16–APSK, 32–APSK, 16–QAM, 64–QAM}\}$

Evaluate performance with

- Various capture lengths
- AWGN, -5 to 20 dB
- Es/No approximation errors < 5 dB
- Phase and frequency offsets
- Nonlinear amplifier drive levels
- DVB-S2 pilots and headers

Assume

- Coarse carrier frequency estimation
- Symbol timing recovery
- Zero ISI, matched pulse shape filters

Classification Method

Cumulants

- Effective at differentiating modulation order
- Well documented in literature

Neural Networks

- Universal function approximator
- Showed increased accuracy over decision tree and SVM

Cumulant Generation

$$S = \{\underbrace{s[n], \dots, s[n]}_{\text{p-q terms}}, \underbrace{s^*[n], \dots, s^*[n]}_{\text{q terms}}\}$$

$$C_{pq}(S) = \sum_{\pi} (-1)^{|\pi|-1}(|\pi|-1)! \prod_{B\epsilon\pi} E\left[\prod_{i\epsilon B} S_i\right]$$

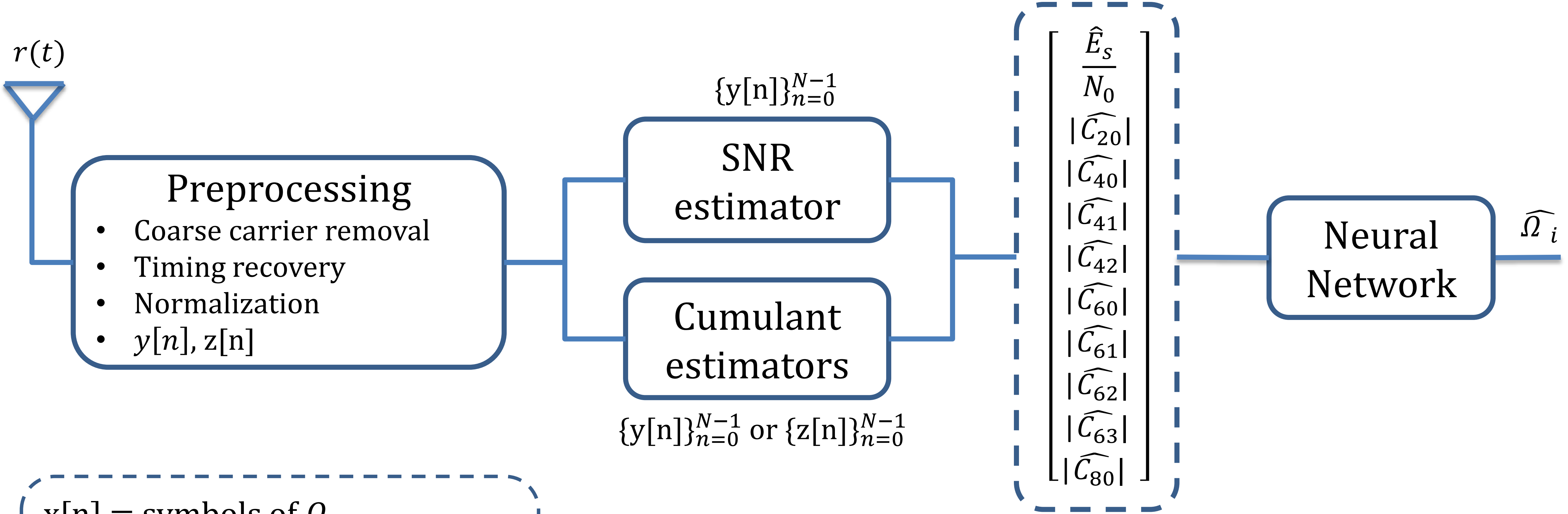
Features

- Probability Density Function
- Spectral Statistics
- Fourier-wavelet
- Cumulants
- Autocorrelation
- Raw IQ
- Centroids

Classifiers

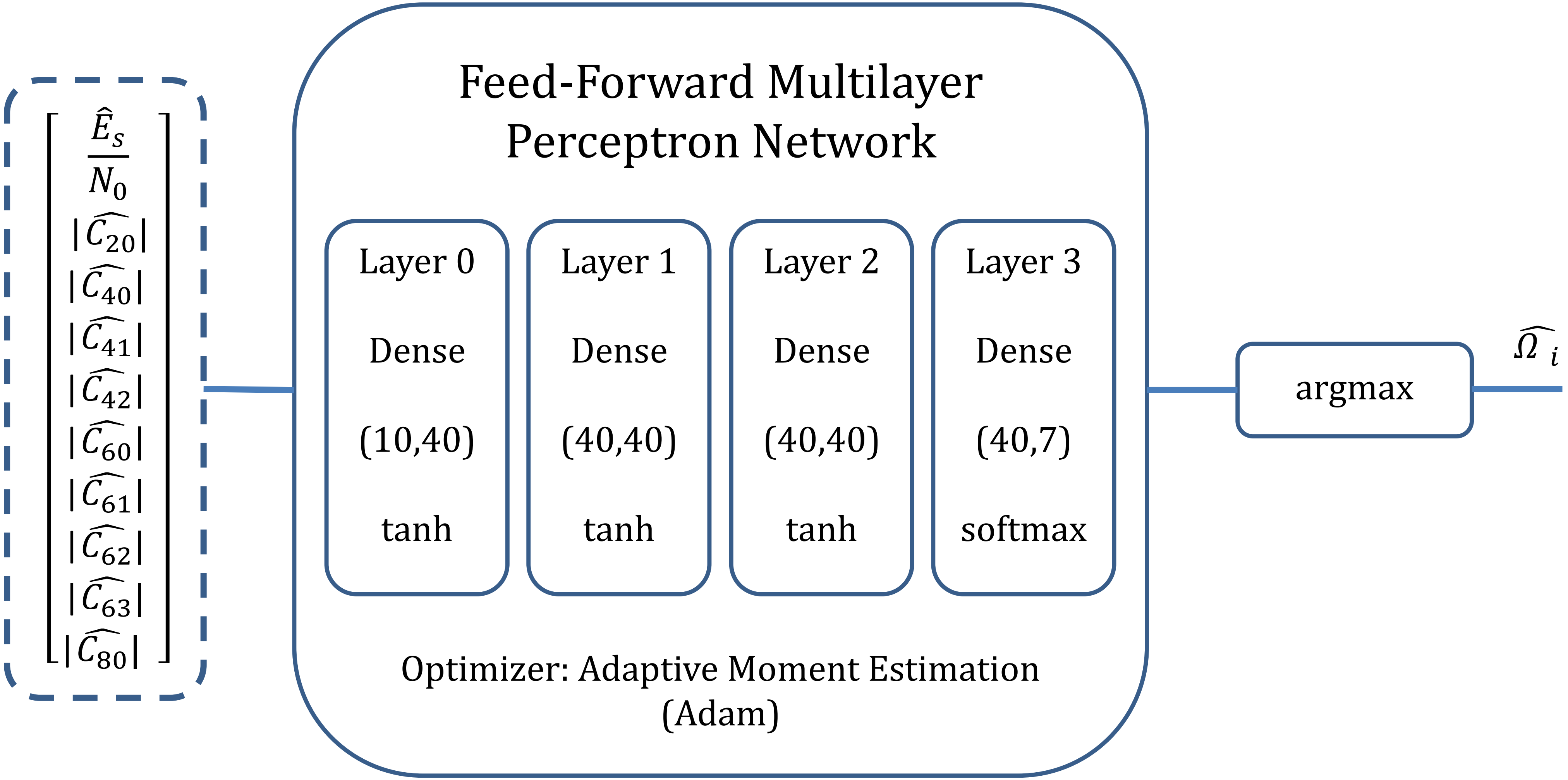
- Decision Tree
- Neural Network
- SVM
- Catalog Comparison
- KNN

Simulation Diagram

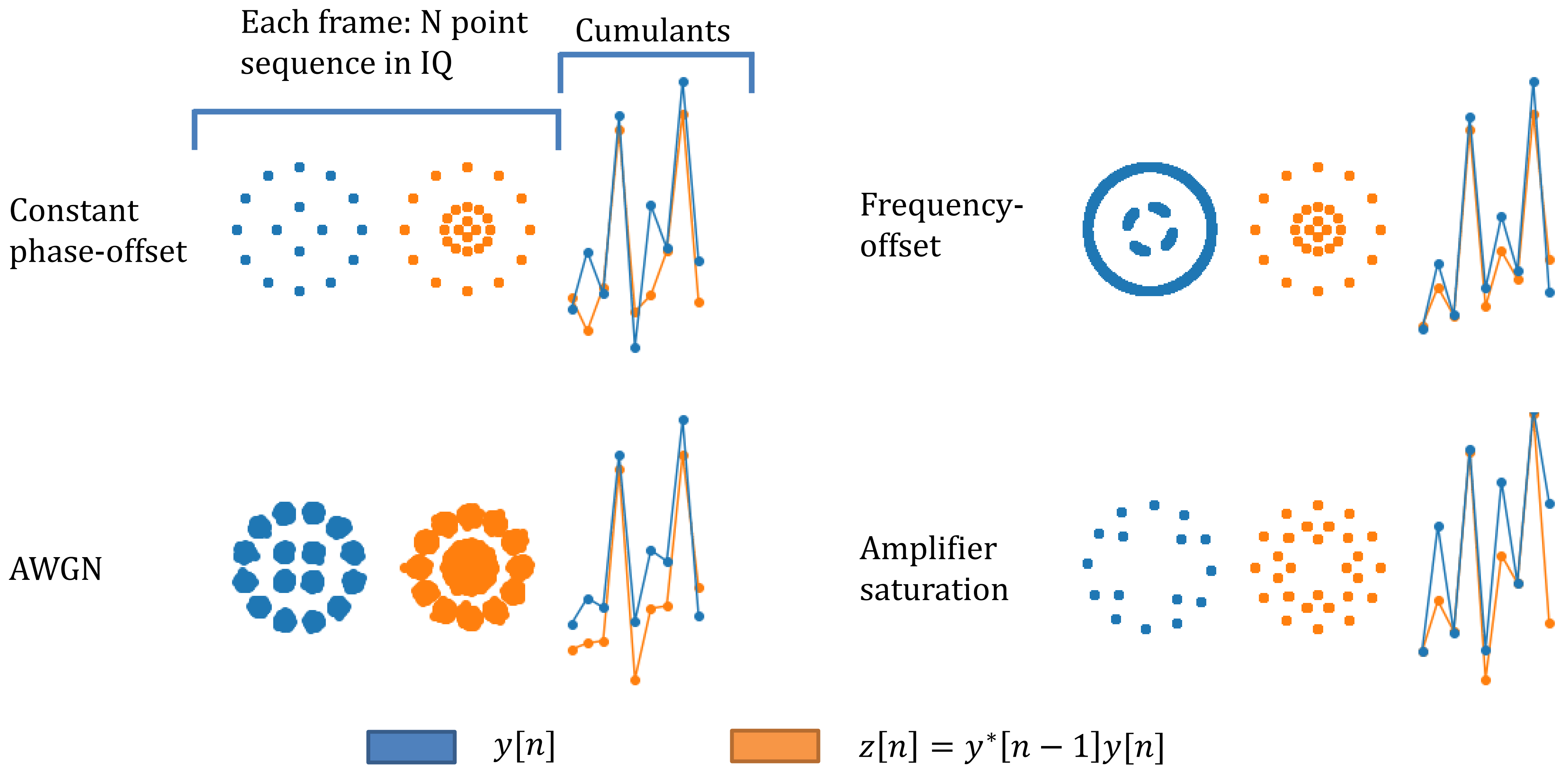


x[n] = symbols of Ω_i
g[n] = Gaussian noise
y[n] $= Ae^{j(2\pi f_o nT+\phi)}x[n] + g[n]$
z[n] $= y[n]y^*[n-1]$

Neural Network Architecture



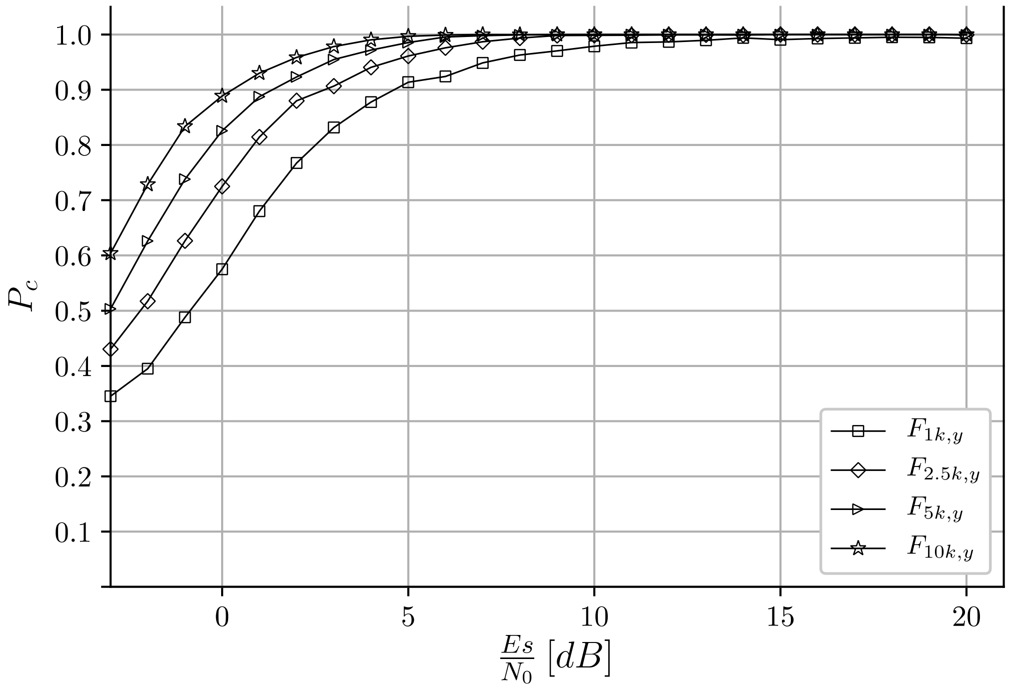
What does the Neural Net see?



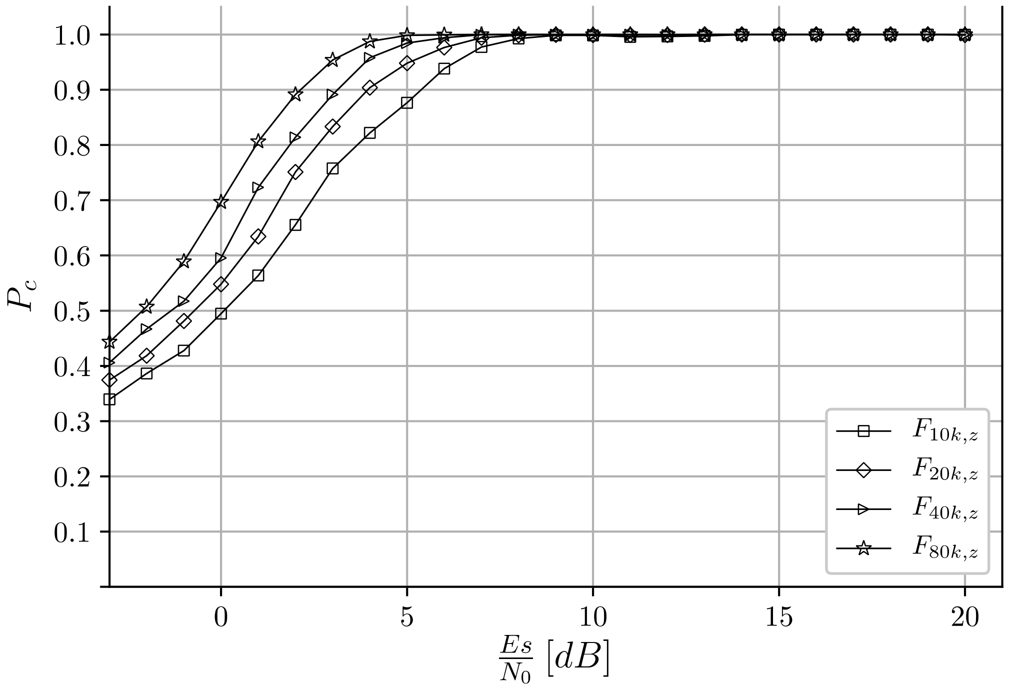
Vector Length Analysis

Feature vector generated from

$\{y[n]\}_{n=1}^{N}$
$N = \{1k, 2.5k, 5k, 10k\}$



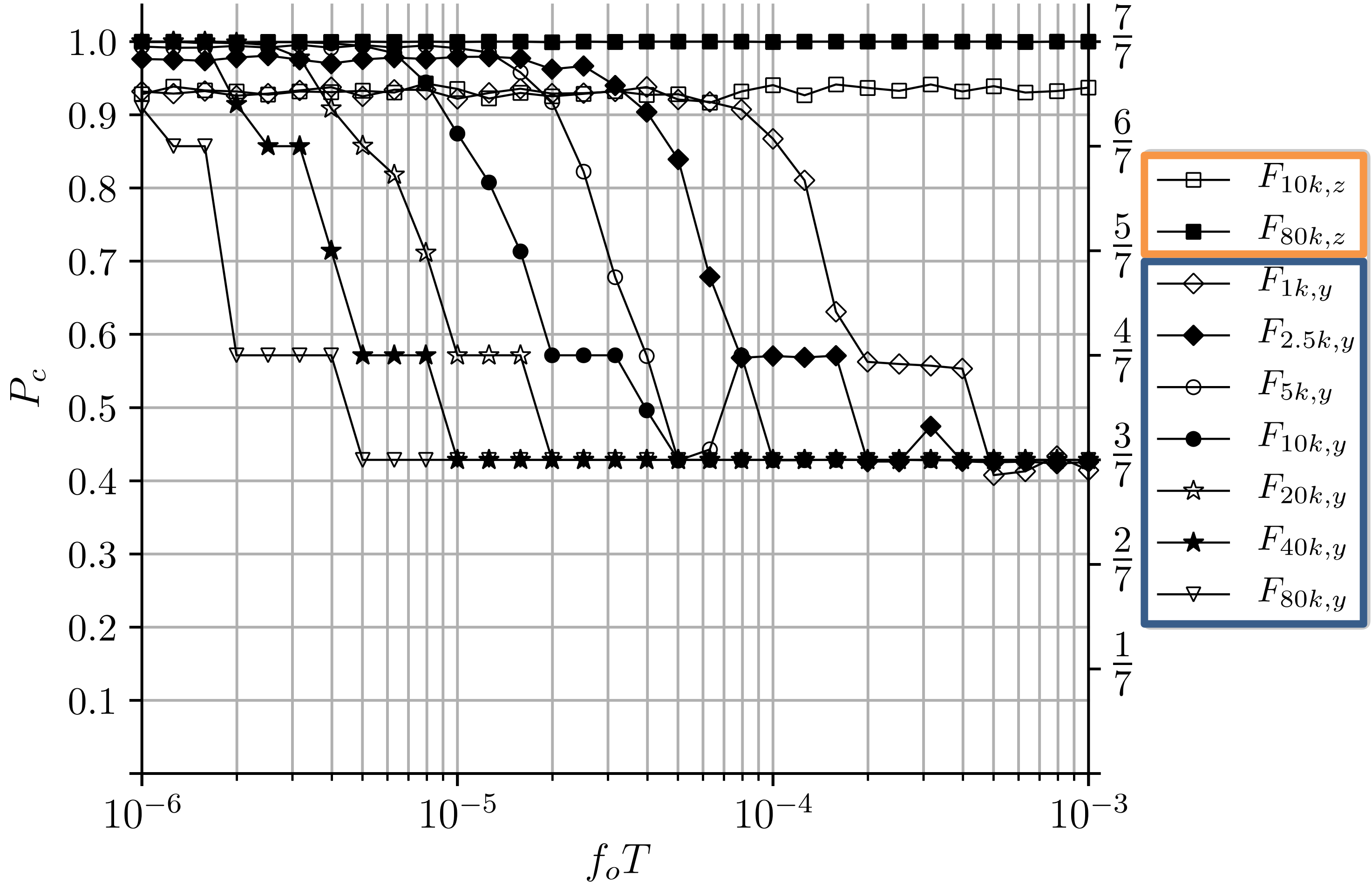
$\{z[n]\}_{n=1}^{N}$
$N = \{10k, 20k, 40k, 80k\}$



For similar classification performance, classification based on {z[n]} required ~15x more symbols

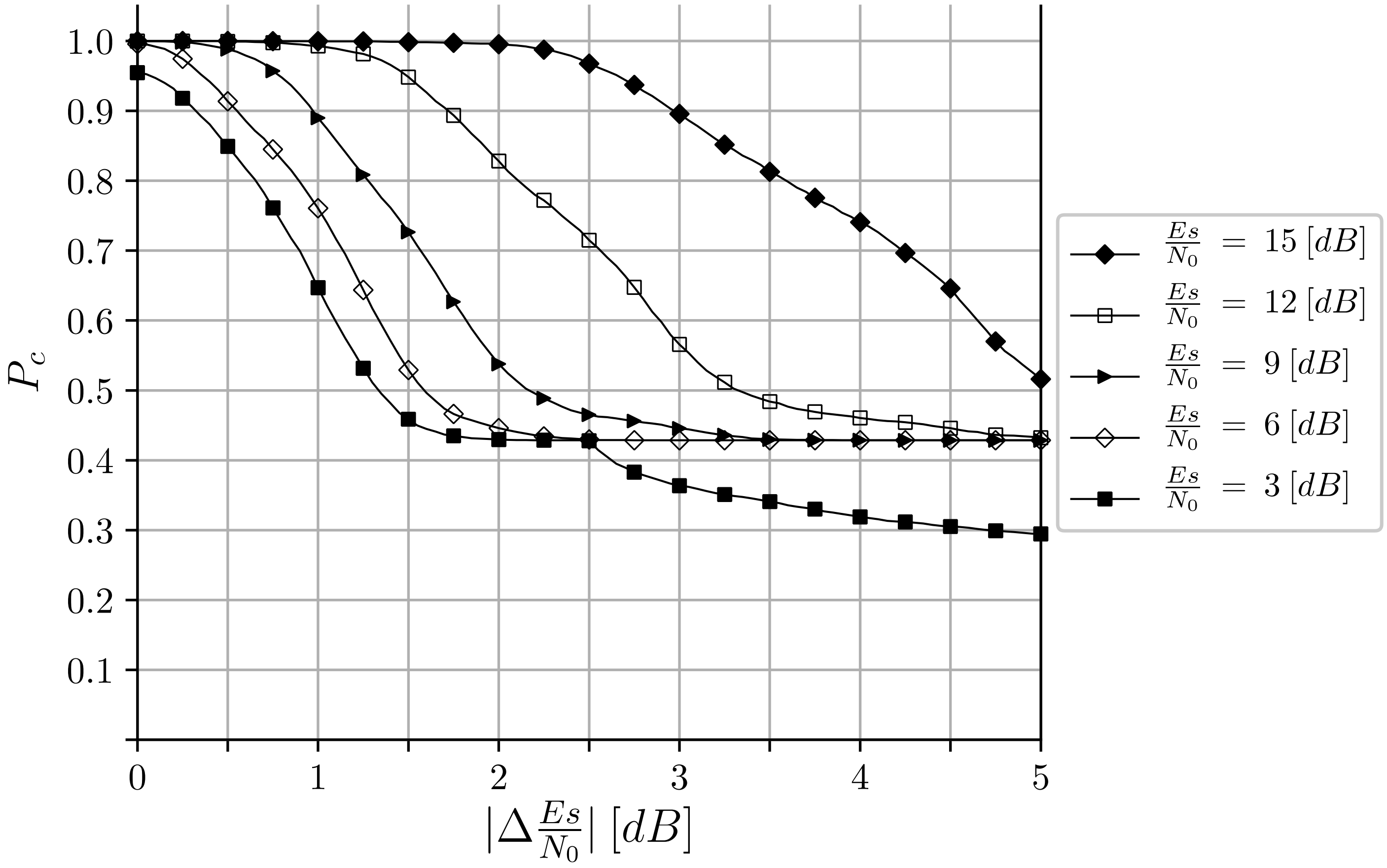
Frequency Offset

- Frequency offset imposes upper bound on y[n] sequence length
- z[n] converts fixed frequency offset into fixed phase offset
- Cumulant magnitudes are not impacted by constant phase offset



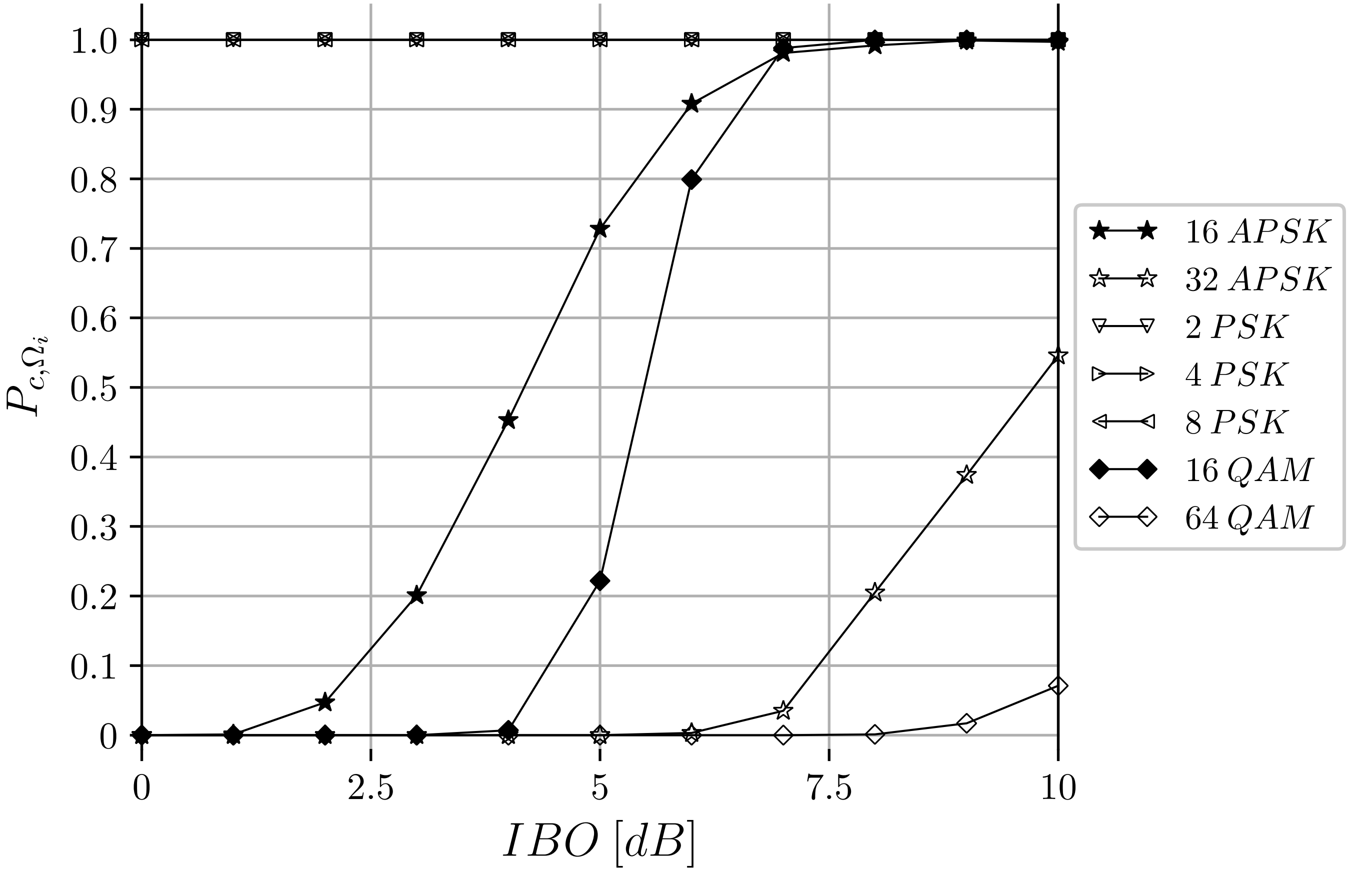
Es/No Approximation Error

- Neural net requires SNR estimation
- Imperfect estimation of SNR will degrade performance
- Most sensitive to error at low Es/No
- y[n] and z[n] exhibit similar responses to Es/No error
- Results provide accuracy requirements for SNR estimator



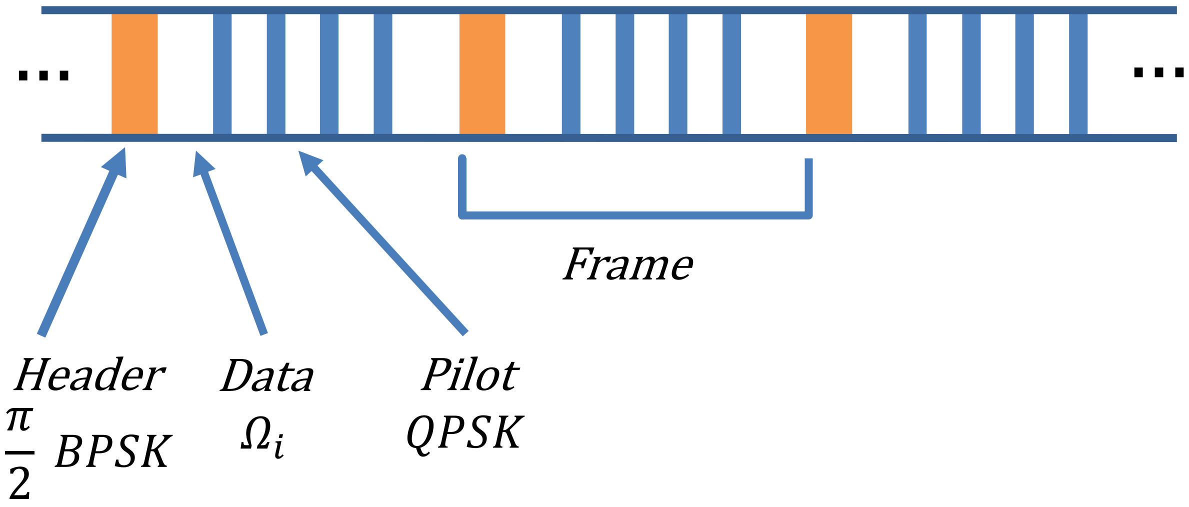
Nonlinear Amplifier

- Previous results in literature did not account for nonlinear amplification
- Amplifier simulated using Saleh model using coefficients from operational TWTA
- PSK – only one ring, not impacted by amplifier
- Classification of higher order modulations experienced significant degradation at levels where a user could expect to operate
- Additional input features needed to train neural network over this dimension

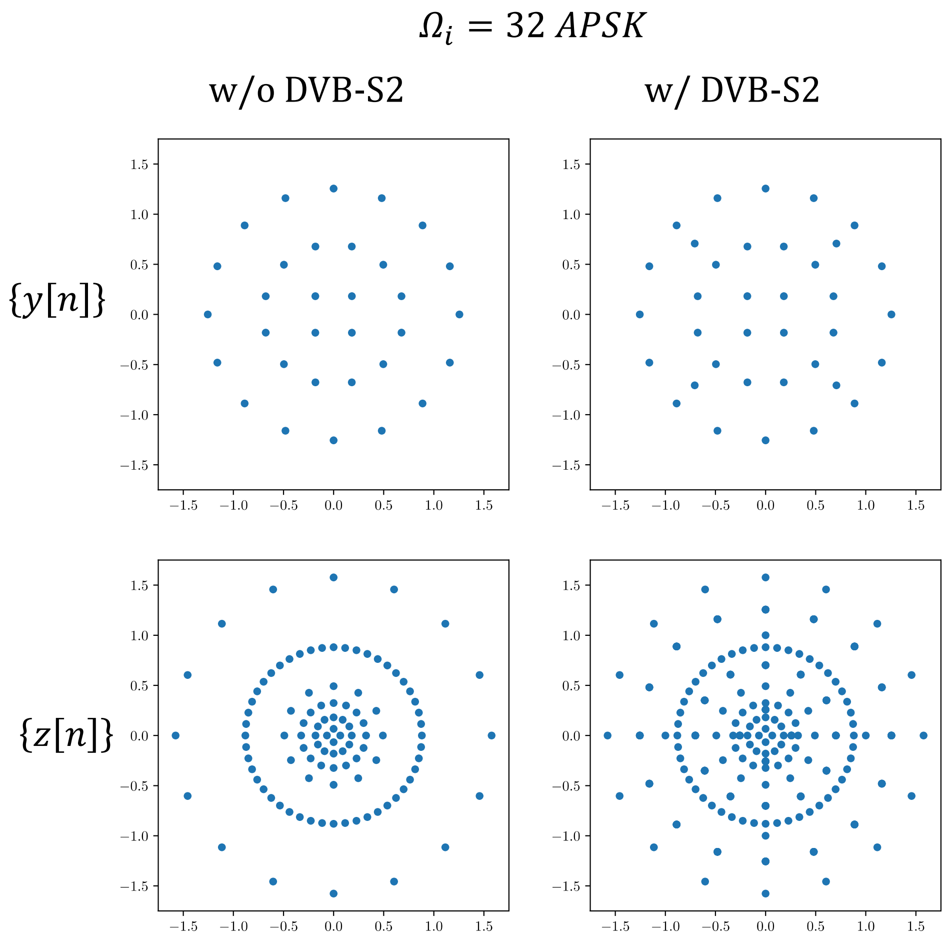


DVB-S2 Pilots and Headers

DVB-S2 Framing Structure



- Previous research has not measured impact of pilots/headers on classifier performance
- DVB-S2 physical layer extends alphabet of received symbols, due to inclusion of headers/pilots
- Unable to classify 16 APSK using z[n] at 20 dB Es/No
- Classifier performance degradation due to DVB-S2 framing was < 5% in most cases



IQ constellations of 32 APSK with and without DVB-S2 physical layer

Next Steps and Conclusions

Next Steps

- Investigate additional features
- Implement a SNR approximation algorithm
- Classify modulation types in lab
- Add timing acquisition and carrier removal
- Classify live signals

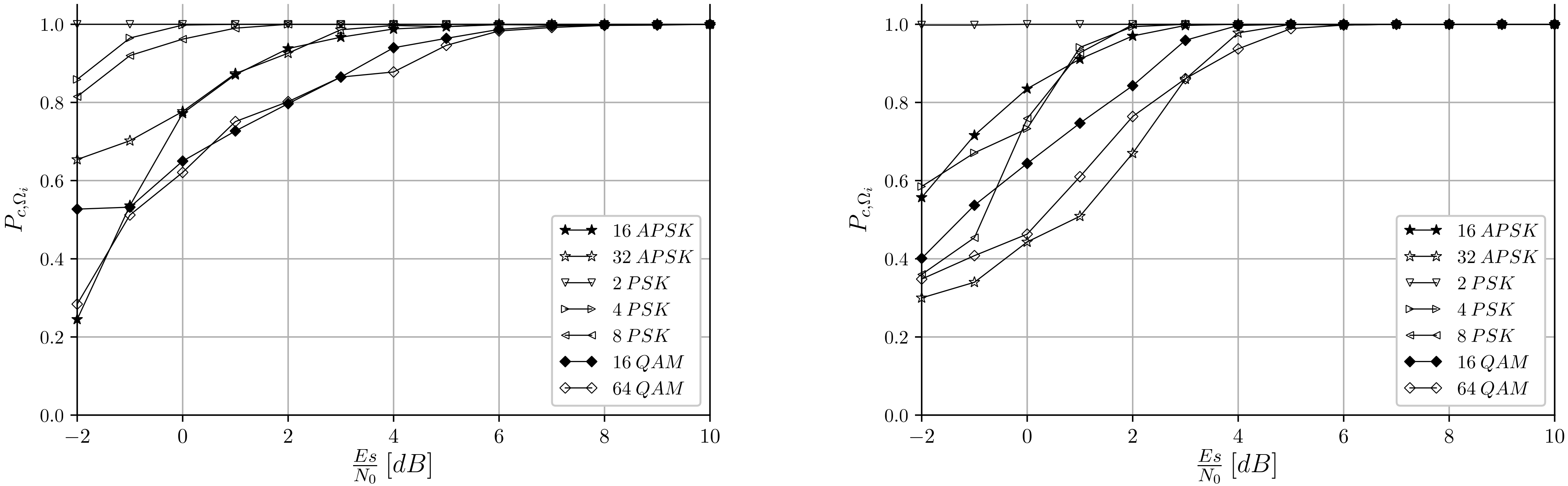
Conclusions

- Created modulation classifier using cumulants and a neural network
- Evaluated performance over
  - Capture length
  - AWGN
  - Constant frequency and phase offset
- Extended previous work in field to include analysis over
  - SNR approximation error
  - Nonlinear amplifier distortion
  - DVB-S2 physical layer effects

Questions?

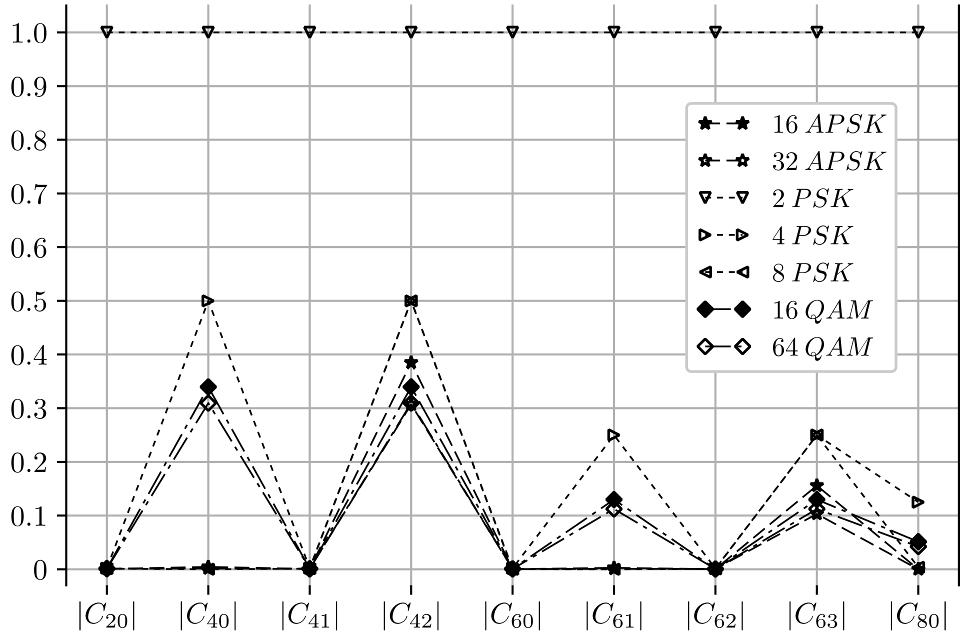
Backup Slides

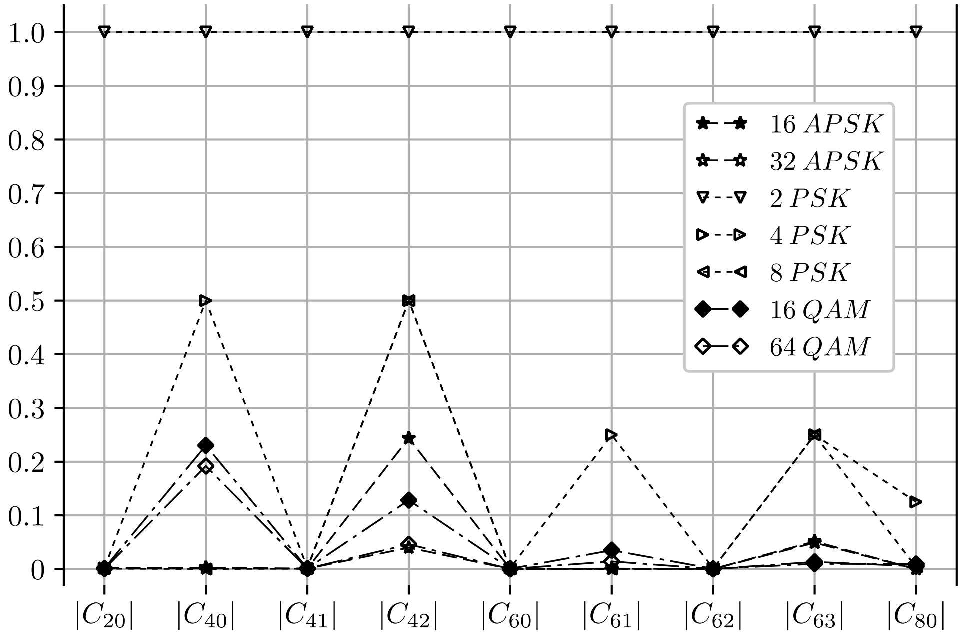
Classification by Modulation



Left: y[n]
Right: z[n]

Cumulant Magnitudes





Left: y[n]
Right: z[n]

DVB-S2 Pilots and Headers, Cont.

Probability of classifying modulation type with DVB-S2 headers (H) and pilots (P)

Es/No = 20 dB

z[n] signal type