Modulation Classification with Machine Learning

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Idealized received signal…

Transmitted Signal

Path Loss

$$r(t) = s(t) \times c + n(t)$$

Received Signal

Gaussian Noise

…looks more like this in reality

Modulation by Residual Carrier Random Walk Process

Convolution with Time-Varying Channel Impulse Response

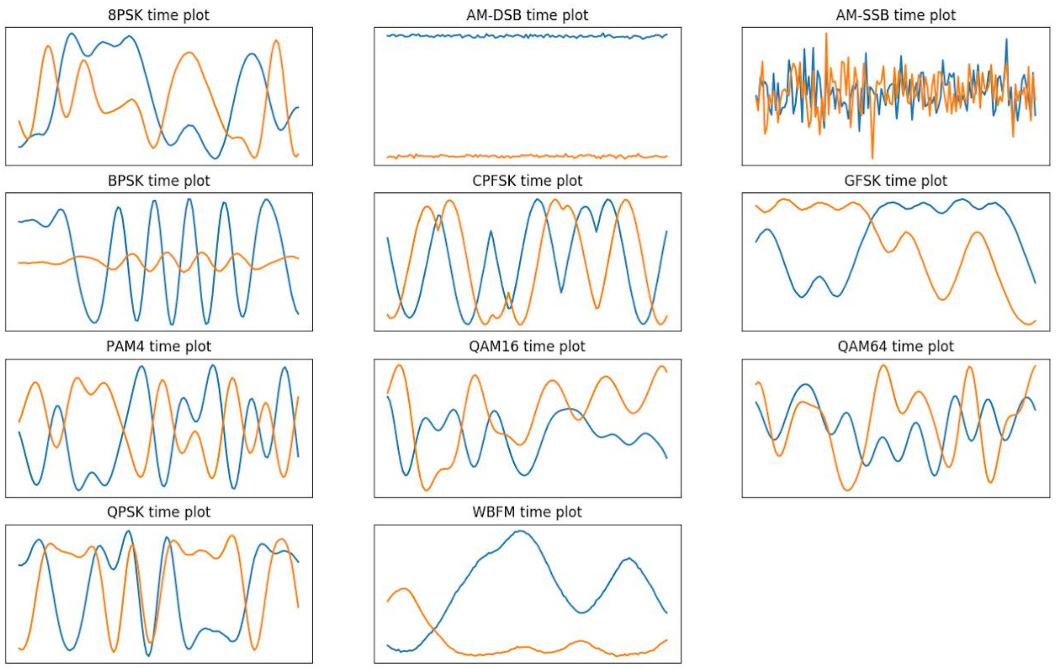
$$r(t) = e^{j n_{Lo}(t)} \int_{\tau=0}^{\tau_0} s\big(n_{clk}(t-\tau)\big) h(t,\tau)\, d\tau + n_{add}(t)$$

Received Signal

Resampling by Residual Clock Random Walk Process

Additive Noise (may not be white)

Automatic Modulation Classification



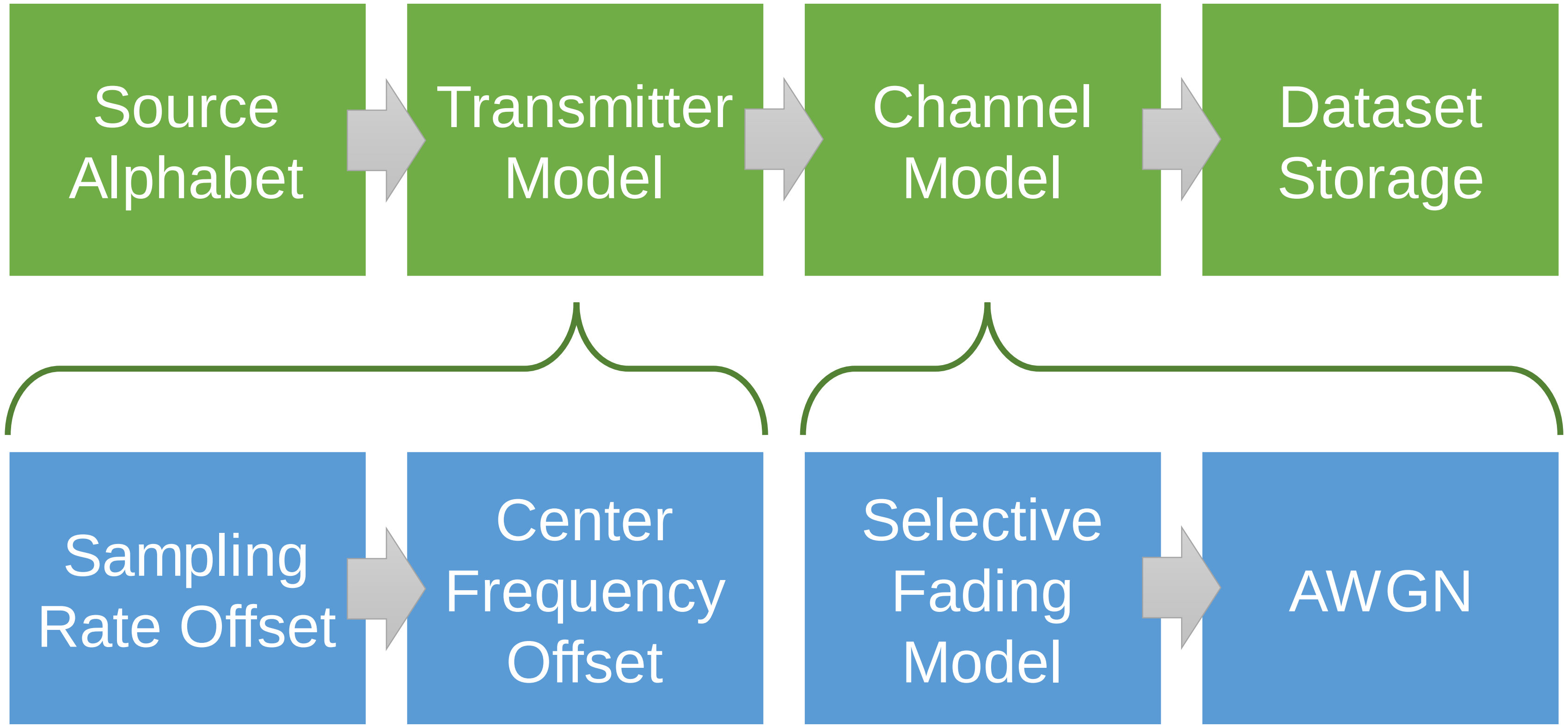
Times Series Samples from radioML dataset

An N-class classifier problem

Benchmarked by **radioML**

1) What does **radioML** model?
2) What is the current state of the art of AMC?
3) Is convolutional neural net (CNN) the best approach to AMC?

Channel Modeling by radioML



Rayleigh Fading Model

Model signal transmission with a lot of scattering

Channel modeled as a zero-mean Gaussian Process (By Central Limit Theorem)

Amplitude gain follows **Rayleigh Distribution**

$$X^2 = \sqrt{I^2 + Q^2}$$

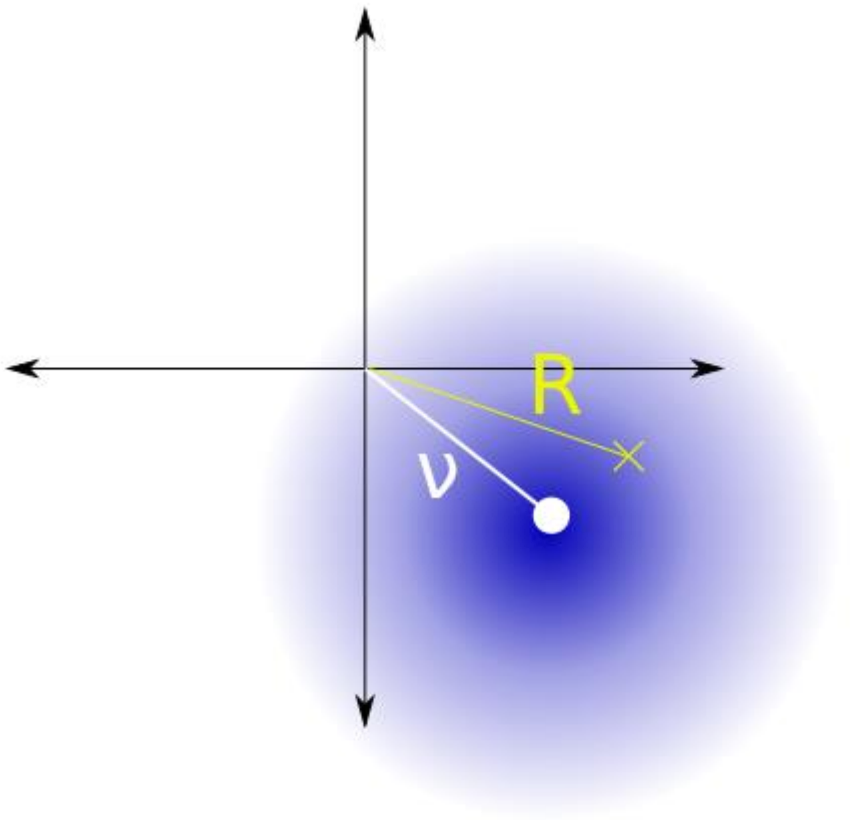
Signal transmission in Manhattan follows Rayleigh Distribution

Rician Fading Model

Model signal transmission with direct line of sight and scattering

Channel modeled as **non-zero mean** Gaussian Process

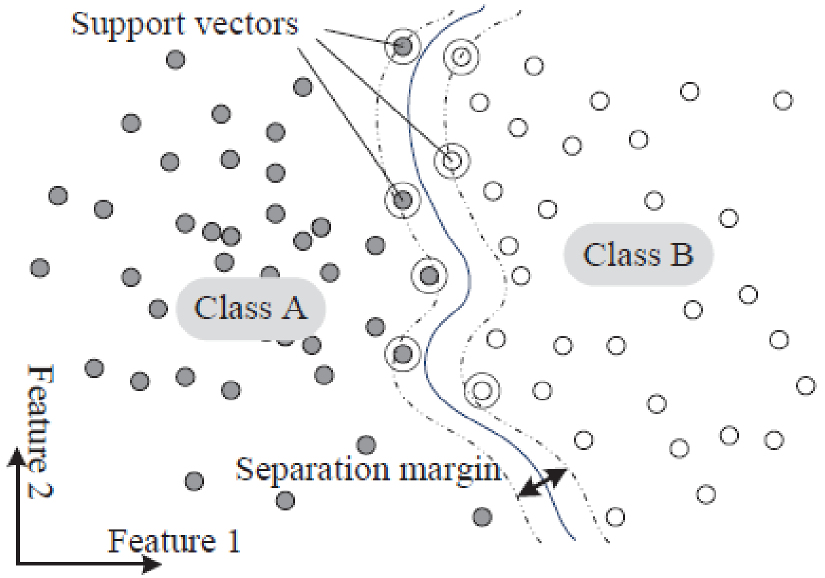
Amplitude Gain follows **Rice distribution**



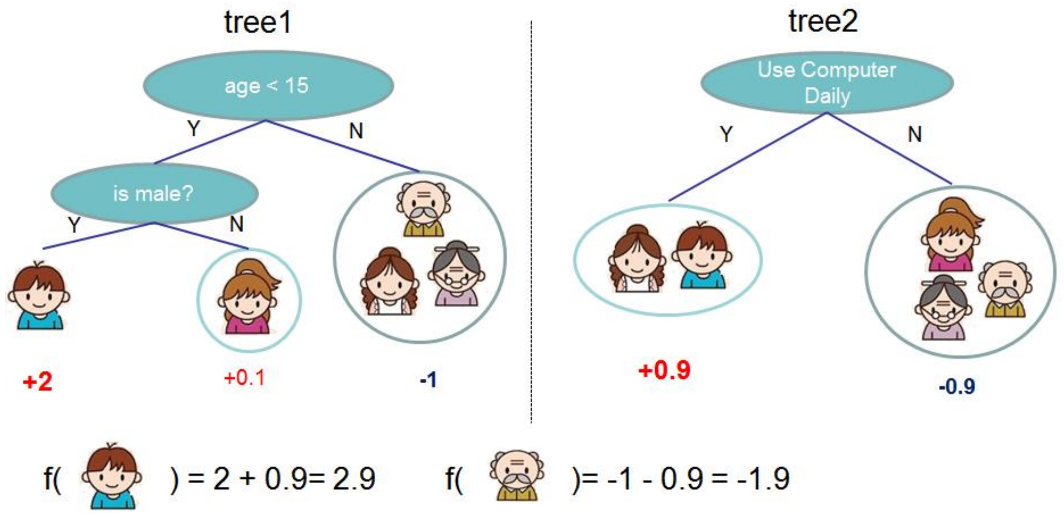
Visualization of Rice Distribution

Current State of the Art in AMC

Research focuses on machine learning algorithm (feature-based)



Support Vector Machines (SVM)



Boosted Trees

What features can be extracted to train the model?

Cyclic-moment based features

Cyclic-moment based features can be computed by the m^{th} order statistics of the n^{th} power of the instantaneous or time delayed signal :

$$s_{nm} = f_m\left(x^n(t) \ldots x^n(t+T)\right)$$

Examples of x(t) : Amplitude, Phase, Instantaneous frequency etc.

With these features, we can obtain a set of statistics that distinguishes modulation schemes

Moments

Recall that the n^{th} order moment is computed by

$$E[X^n]$$

Examples of moments : mean (1^{st} moment), variance (2^{nd} moment)

The moment generating function is defined by

$$E[e^{tX}]$$

Cumulants

The cumulant generating function is

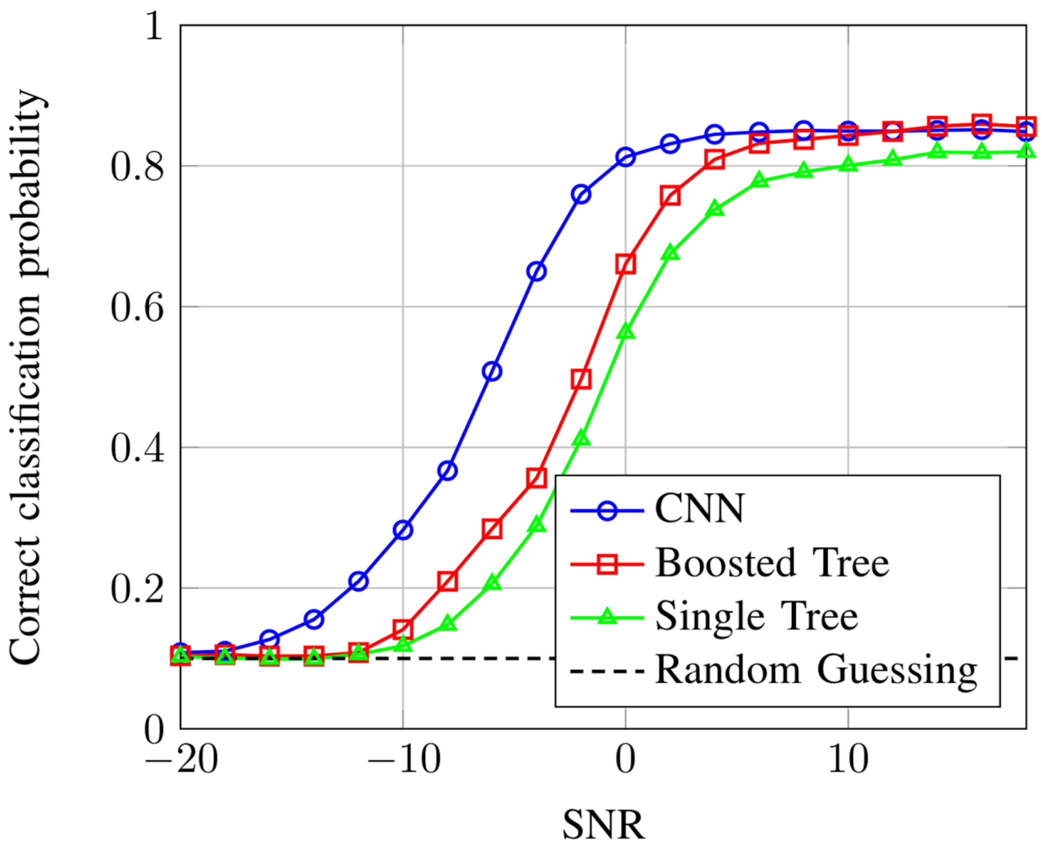
$$K(t) = \log(E[e^{tX}])$$

Expand it into power series expression:

$$K(t) = \sum_{n=1}^{\infty} \kappa_n \frac{t^n}{n!} = \kappa_1 + \kappa_2 \frac{t^2}{2} + \cdots$$

1st Cumulant 2nd Cumulant

Performance Comparison



The noisier the received signal, the lower the accuracy

CNN outperforms traditional machine learning algorithms

Short time nature of the dataset makes it harder to compute expert features

In Conclusion…

radioML takes into account of harsh realistic effects of the transmitter and channel

Current State of the Art AMC methods focuses on machine learning and extracting features from the signal itself

CNN shows a lot of promise in modulation classification

Thank You !
Any Questions?