Adaptive Demodulation Techniques for Next Generation Software Defined Radios

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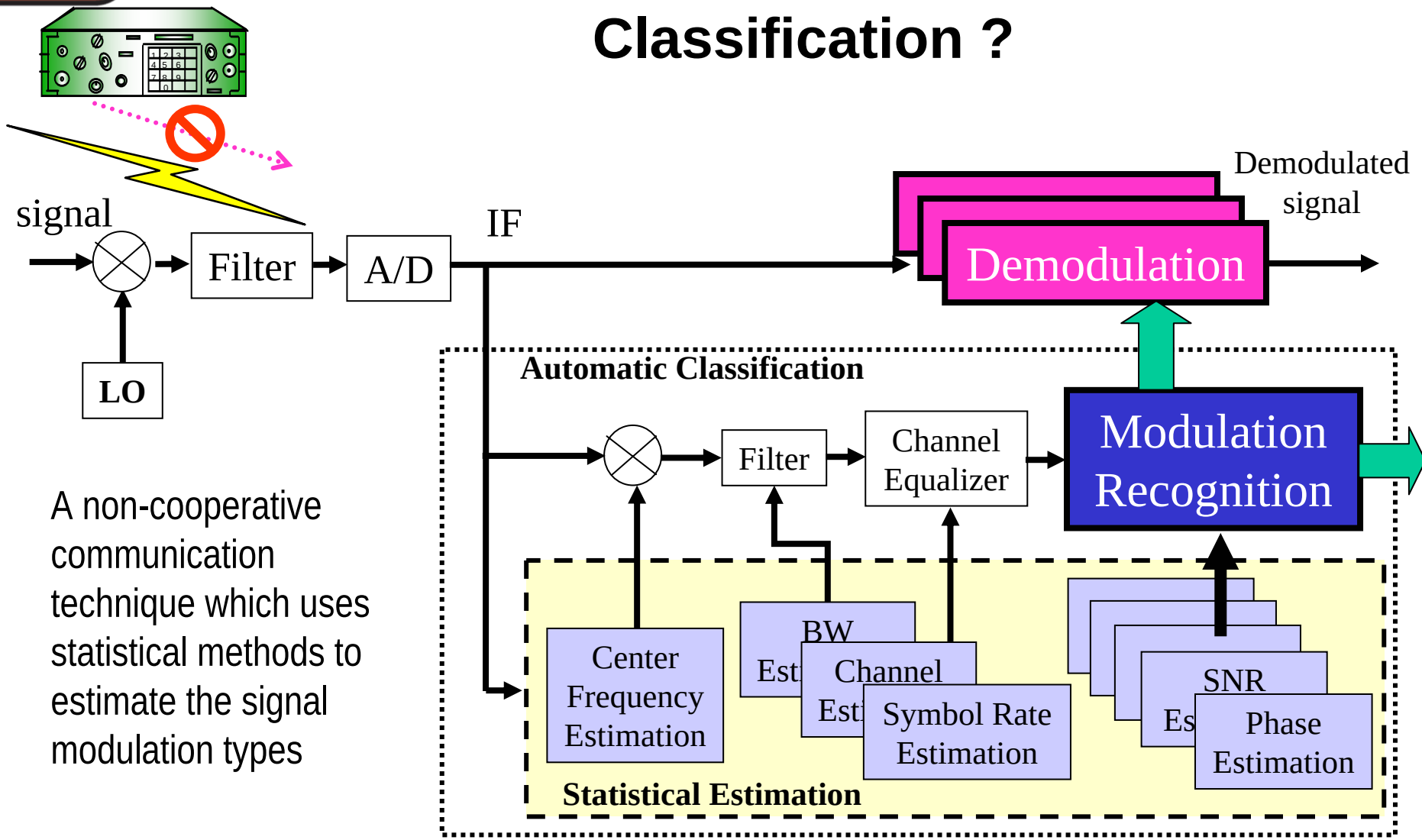
Contents

- Introduction
- Modulation classification overview
- Research on commercial applications
- Challenges

Modulation Classifier

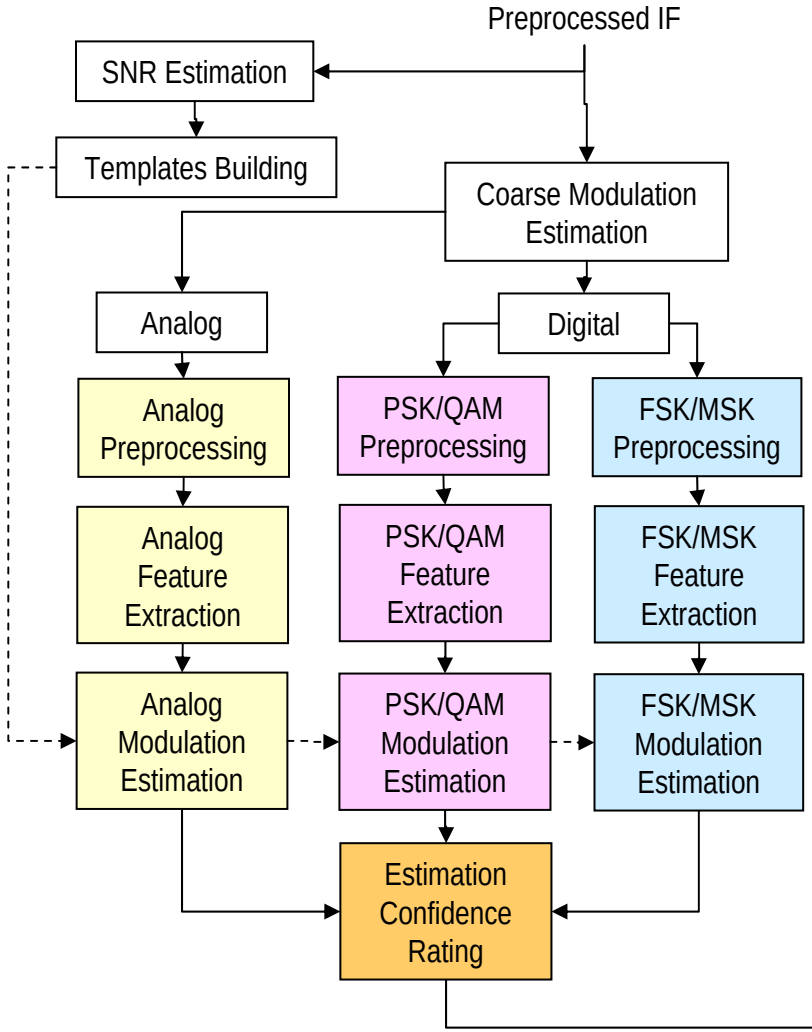
From: http://www.ottawa.drdc-rddc.gc.ca

What is Automatic Modulation Classification ?

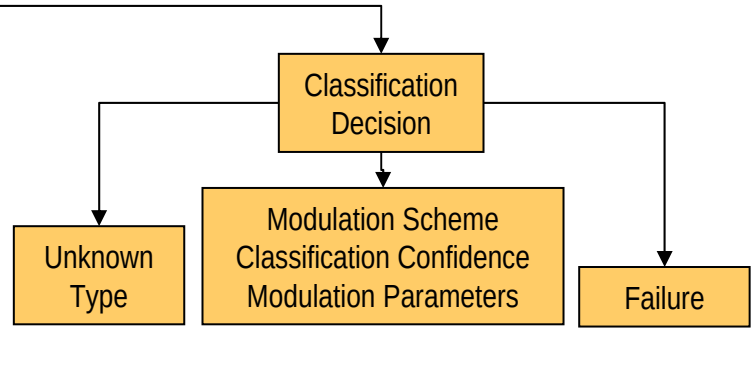


A non-cooperative communication technique which uses statistical methods to estimate the signal modulation types

Modulation Classification

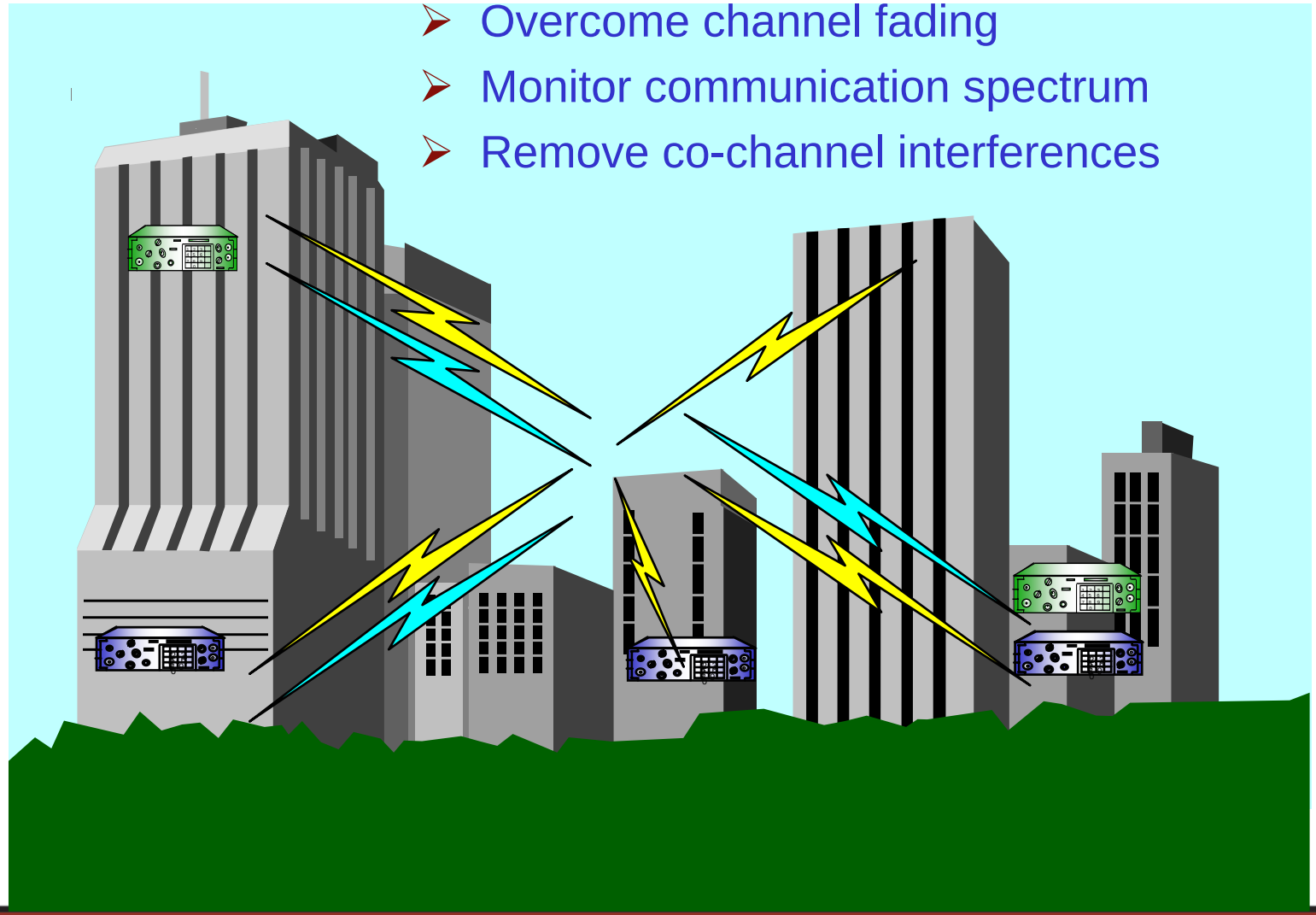


A non-cooperative communication technique which uses statistical methods to estimate the modulation type of a unknown signal

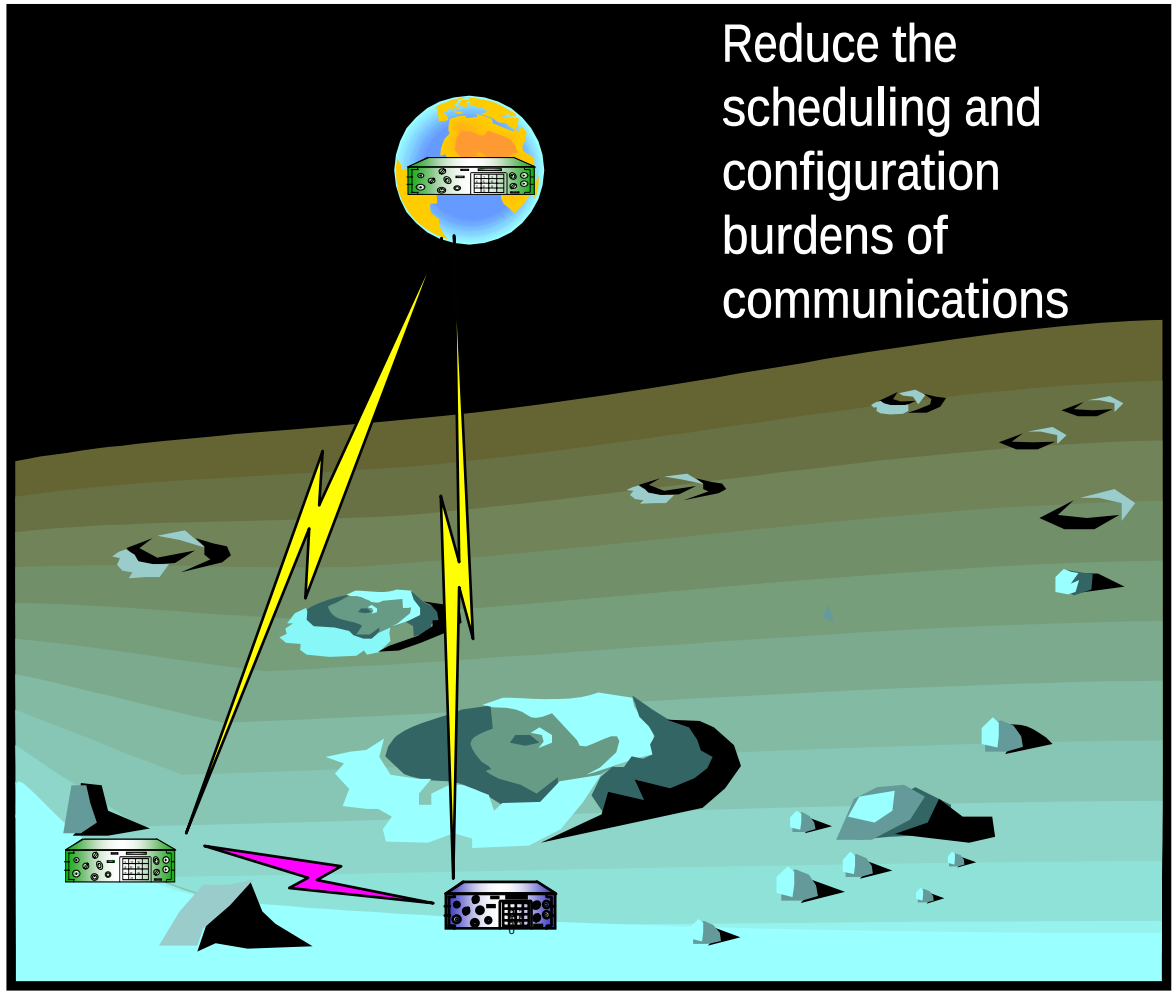


SDR Applications (1)

- Overcome channel fading
- Monitor communication spectrum
- Remove co-channel interferences



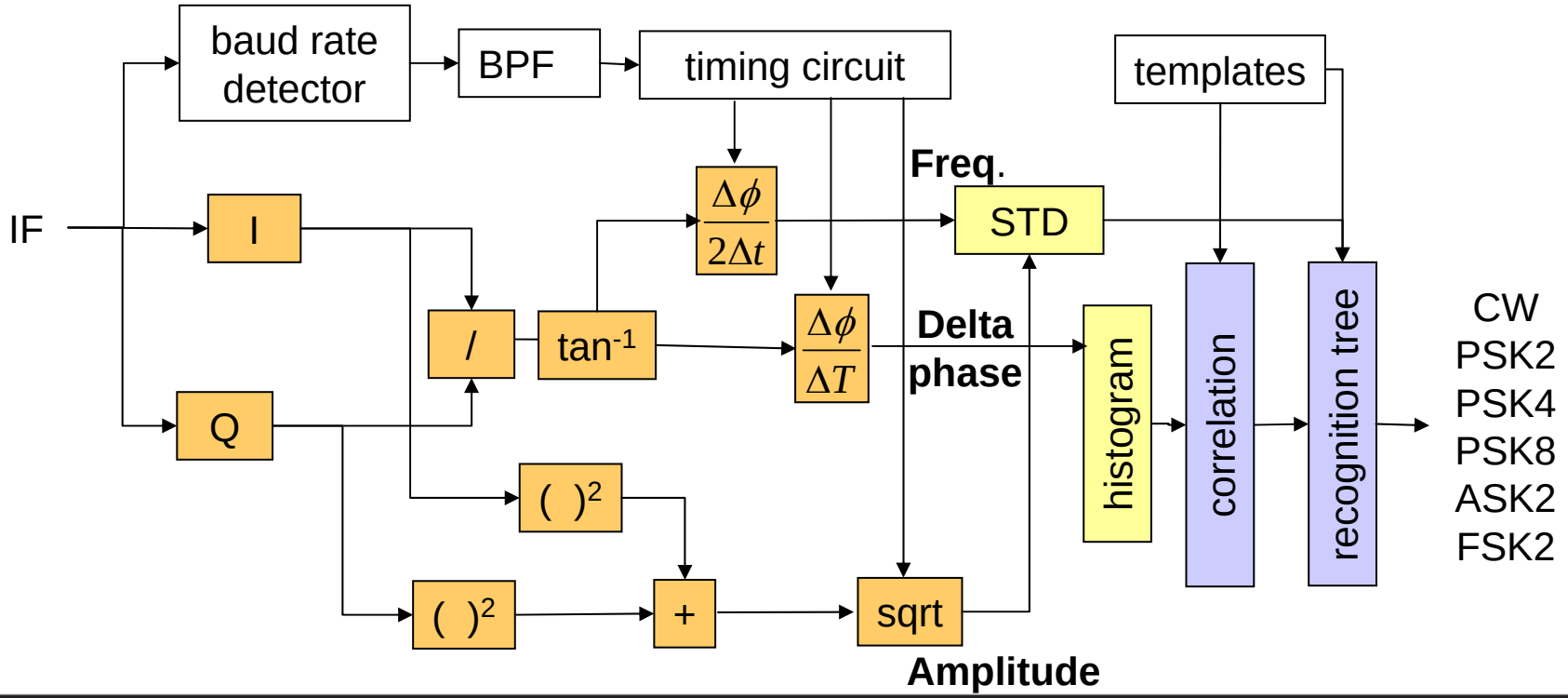
SDR Applications (2)
Deep Space Communication



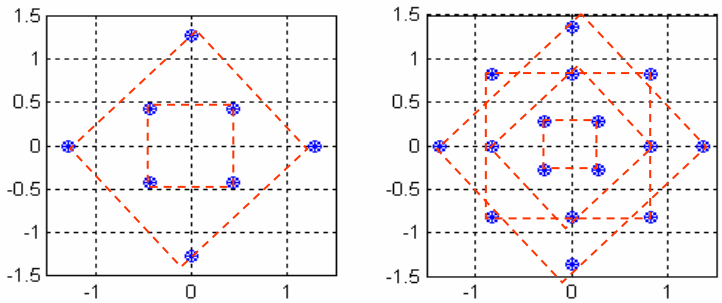
Modulation Classification Overview

Feature Extraction: Amplitude, Differential Phase, and Frequency

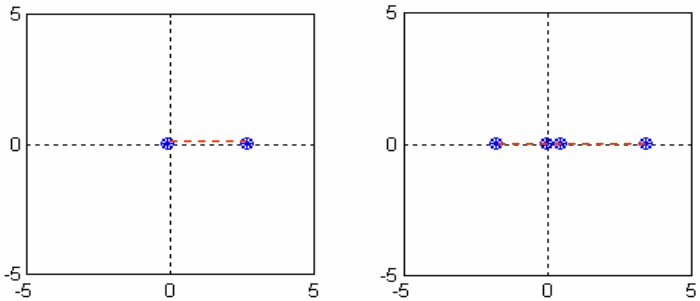
- Input: IF
- Feather: Amplitude, phase, diff phase, frequency
- Statistics: histogram, STD
- Classifier: max correlation, decision tree
- Reference: Liedtke 1984



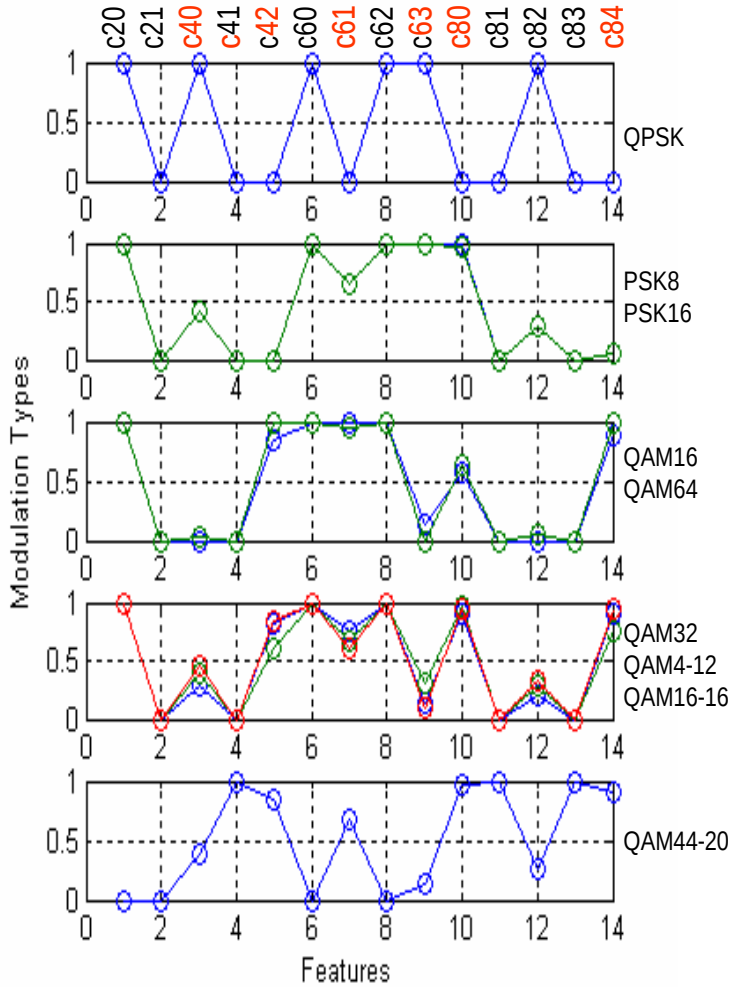
Higher-order Transform of Constellations



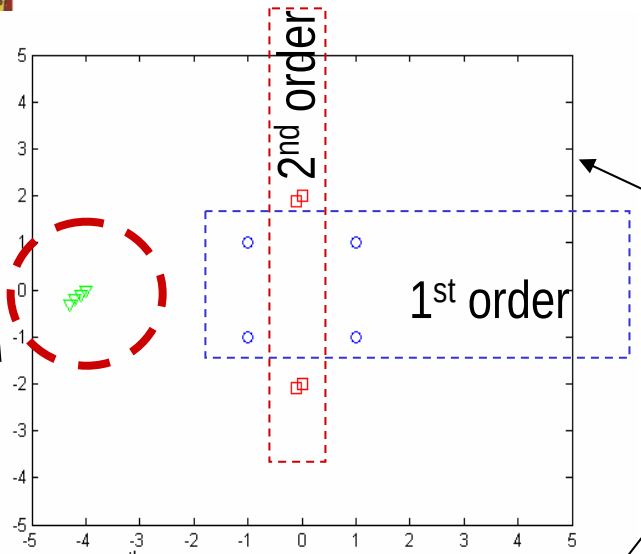
V29-8 and V29-16 constellations



The 4th order constellations

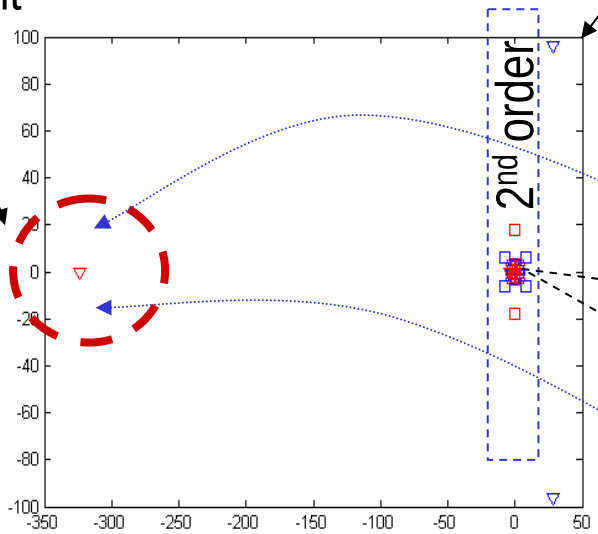


Higher-order Statistical Features

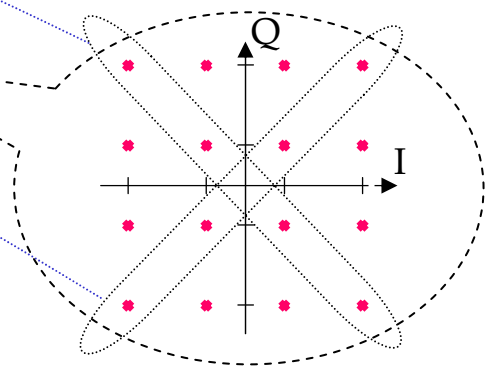


4th order transformation of QPSK

4th order dominant points



4th order transformation of QAM16



Power-law:

$$r^4(k)$$

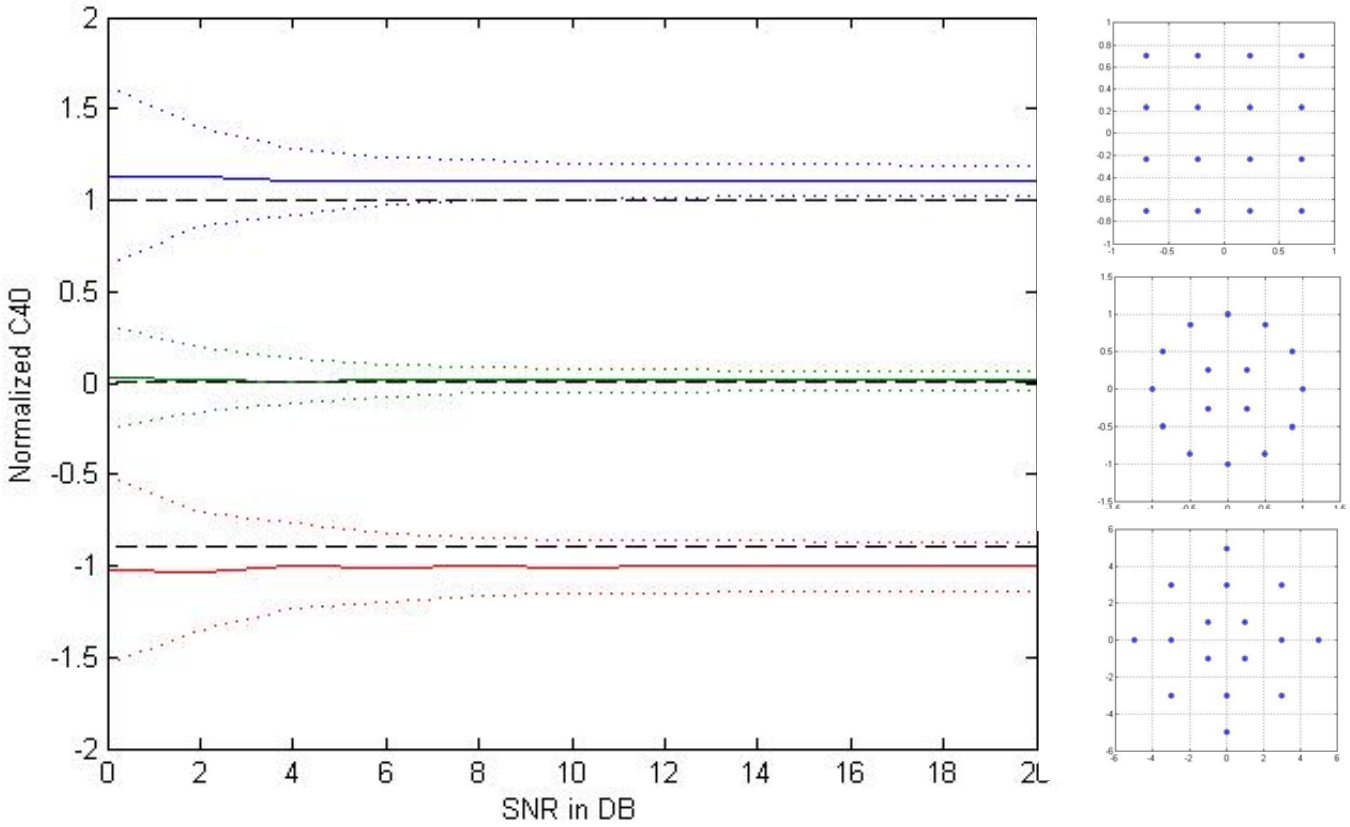
Moment:

$$m_{40} = \sum_{k=1}^{K} r^4(k)$$

Cumulant:

$$C_{40} = m_{40} - 3m_{20}^2$$

Cumulants vs. SNRs



Cyclic Spectral Analysis

Baseband

Time varying autocorrelation

$$R_{xx^*}(t, t+\tau) = E\left\{x(t)x^*(t+\tau)\right\}$$

Cyclic autocorrelation

$$R^{a}_{xx^*}(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} R_{xx^*}(t, t+\tau)e^{-j2\pi at}dt$$

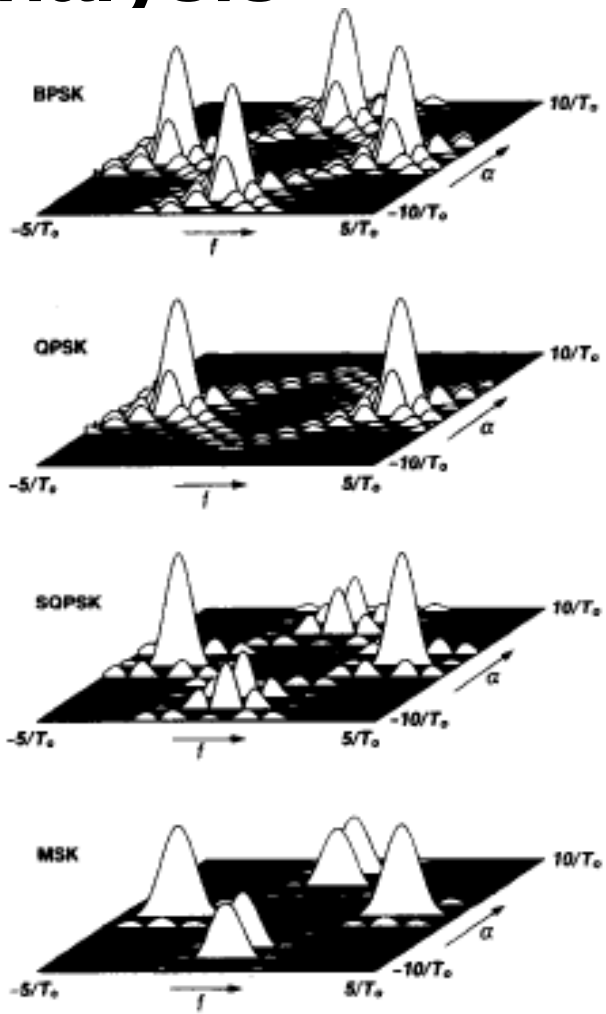
Spectrum correlation density

$$S^{a}_{xx^*}(f) = \int_{-\infty}^{\infty} R^{a}_{xx^*}(\tau)e^{-j2\pi f\tau}d\tau$$

Cycle Freq

Decision ← Templates

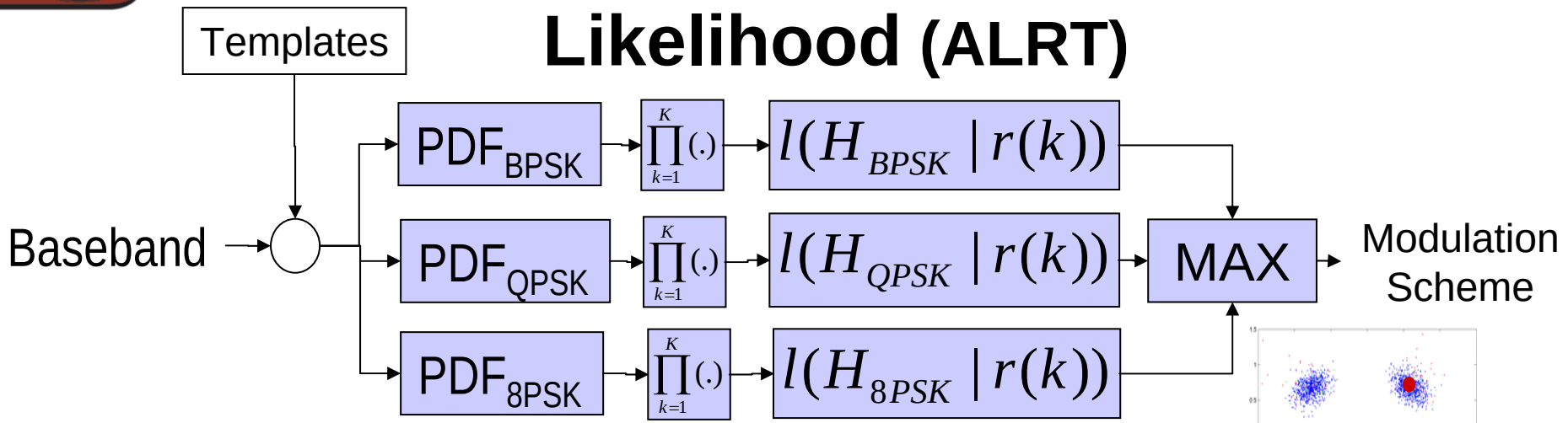
- Input: IF
- Features: cycle frequencies
- Reference: Menguc, 2004



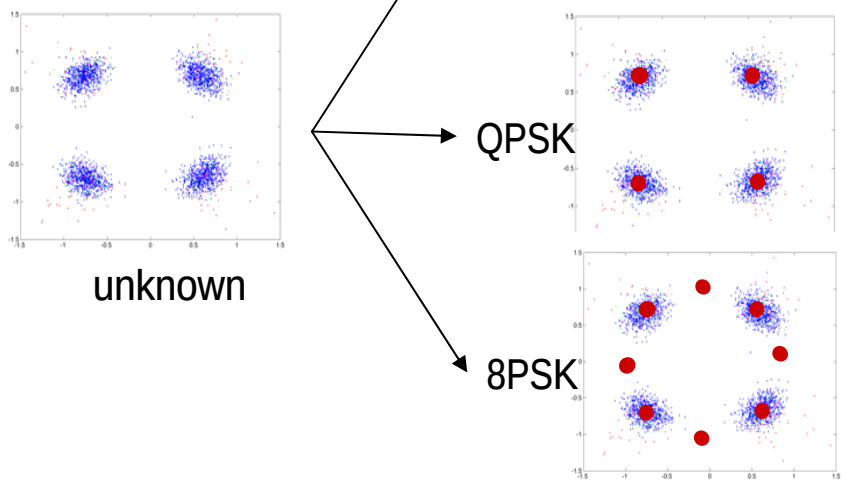
Theoretical spectrum correlation magnitude

Gardner and Spooner 1992

Feature Classification: Maximum Likelihood (ALRT)

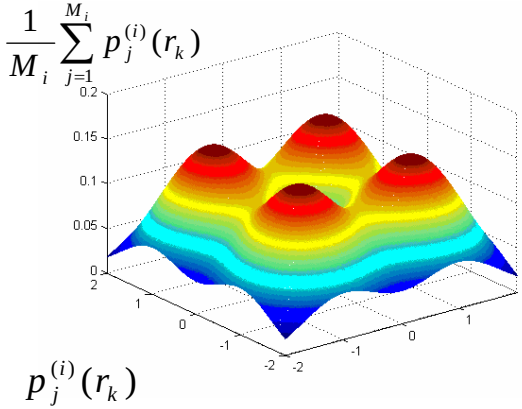


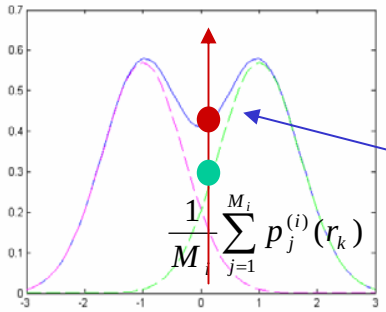
- Input: baseband
- Feature: Complex envelop
- Classifier: maximum likelihood
- References: Polydoros and Kim 1995



Feature Classification: Histogram Correlation

ALRT



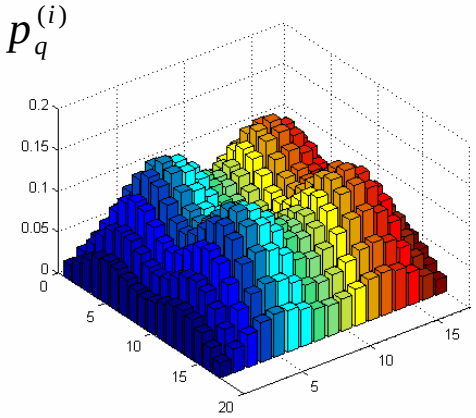


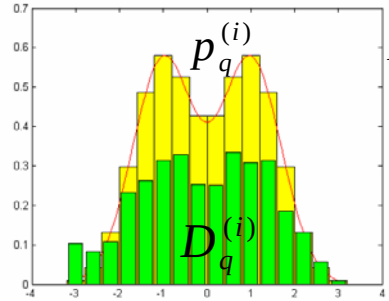
$$G(H_i \mid r_K) = \prod_{k=1}^{K} \left\{ \frac{1}{M_i} \sum_{j=1}^{M_i} p_j^{(i)}(r_k) \right\}$$

$$p_j^{(i)}(r_k) = \frac{1}{2\pi\sigma^2} \exp\left\{ -\frac{\left\| r_k - b^{(i)}(j) \right\|^2}{2\sigma^2} \right\}$$

Quantize

HIST





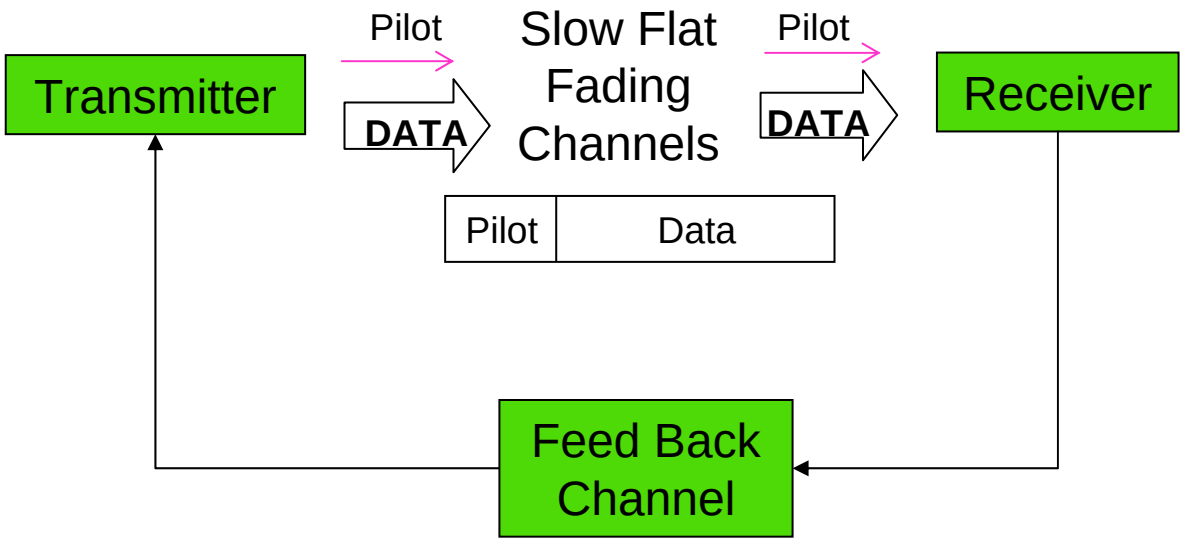
$$L(H_i \mid r_K) = \sum_{k=1}^{K} \log p^{(i)}(r_k) = \sum_{q=1}^{Q} \sum_{k \in \Omega_q} \log p^{(i)}(r_k) \leftarrow \sum_{k=1}^{Q} \log p_q^{(i)} D_q^{(i)}$$

- Input: baseband/IF
- Feature: frequency/diff phase
- Classifier: max correlation
- References: Liedtke 1984

Research on Commercial Applications

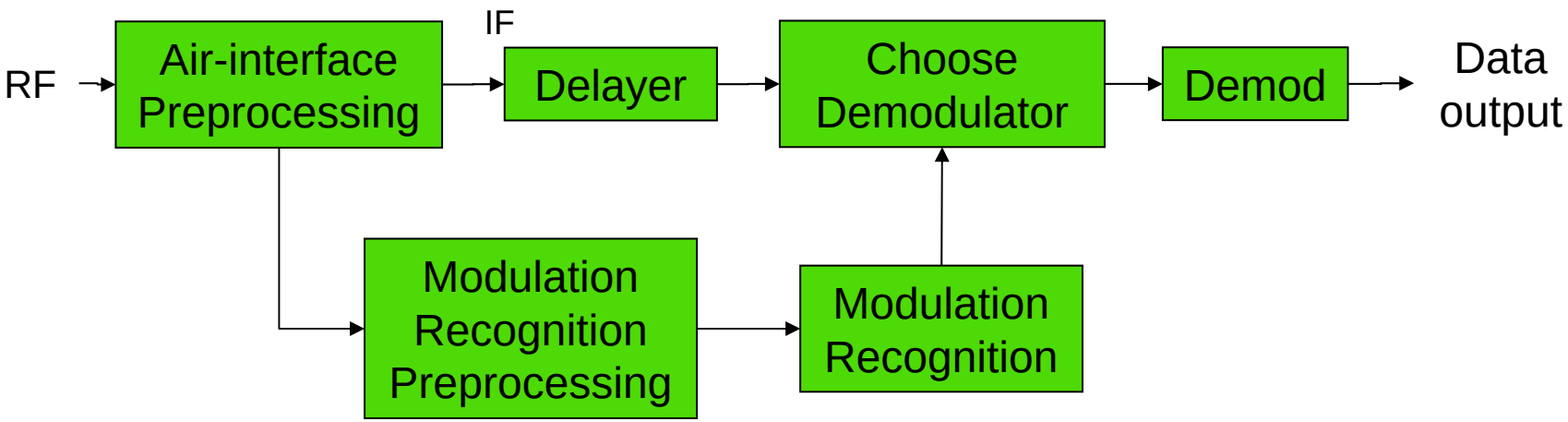
Research on Adaptive Modulation Based on SDR - Cooperative

- Maintain a constent BER by varying modulation schemes
- Modulation schemes: QPSK, 16QAM, and 64QAM
- Data frame based modulation recognition
- A pilot symbol is used in forward channel
- Reference: Jain, P.; Buehrer, R.M, “Implementation of adaptive modulation on the Sunrise software radio,” The proceedings of the 45th Midwest Symposium on Circuits and Systems, Volume: 3 , 4-7 Aug 2002. Pages:III-405 - III-408



Why Applying Non-cooperative Demodulation

- Environment limitation and restriction
- Elimination of the signal overhead information
- Attractive for packet data services



Deference Between Military and Commercial Applications

	SIGINT	SDR
Real time	classification	demodulation
SNR	low	high
Candidates	unlimited	limited
QoS	friend / foe	packet loss
Pulse shape	unknown	known
Bandwidth	unknown	known
Baud rate	unknown	known
Blindness	more	less

Research of Nolan et al.
Reduce Form Constellation

Assume:

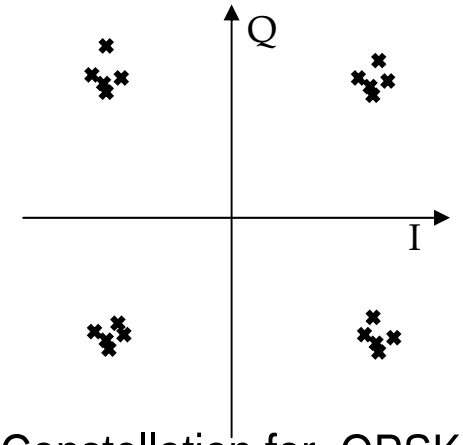
- Equally likely
- Symmetrical QAM/PSK

Purpose:

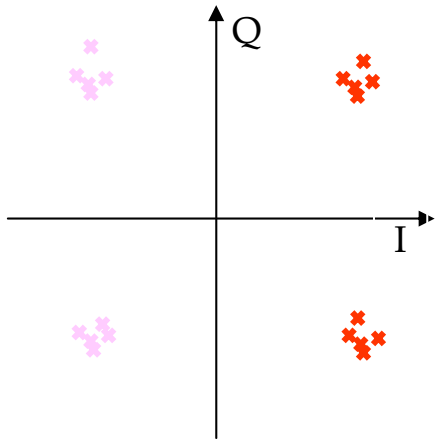
- Reduce the processing time

Issues:

- Low utilization of available information
- May need longer data length for randomness



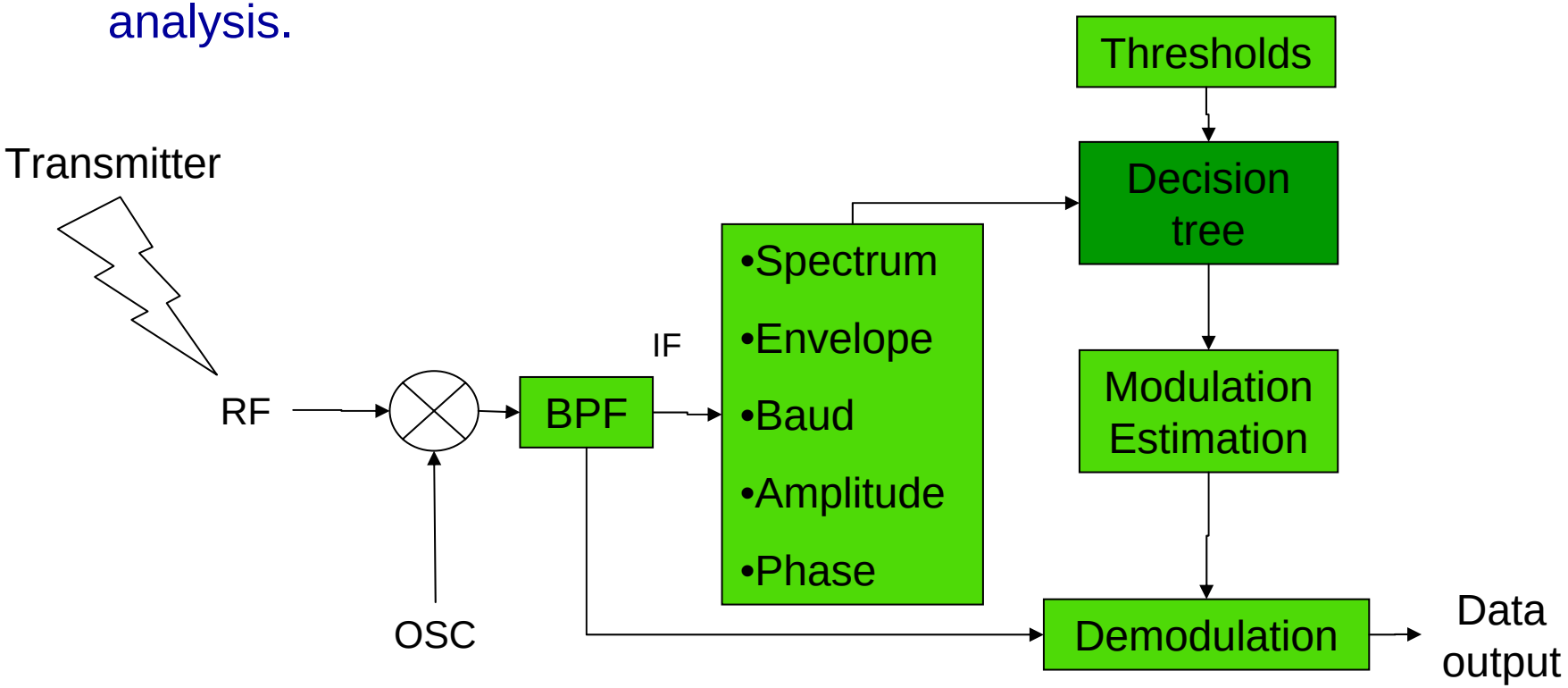
Constellation for QPSK



Reduced form constellation

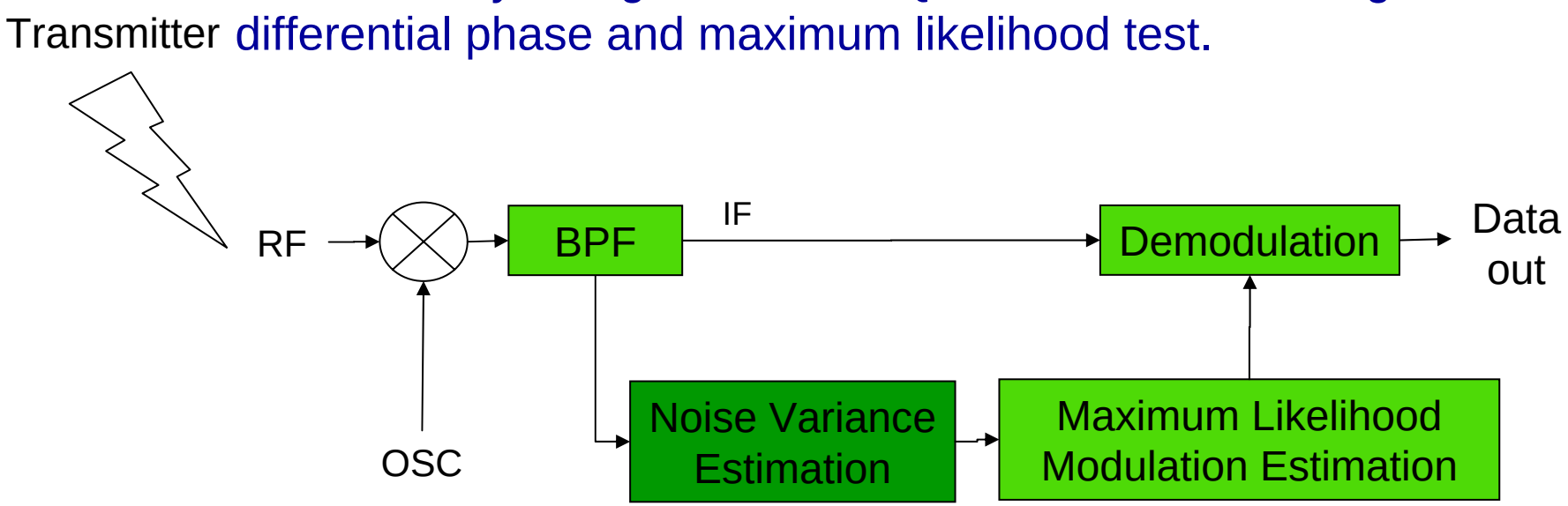
Adaptive Receiver – Ishii et al.

- Automatically recognize BPSK, QPSK, 8PSK, pi/4QPSK, 16QAM, FSK, MSK, GMSK, AM, FM, CW, and SSB using decision tree for spectrum, variance, and baud detection analysis.



Blind Modulation Estimation Umebayshi et al.

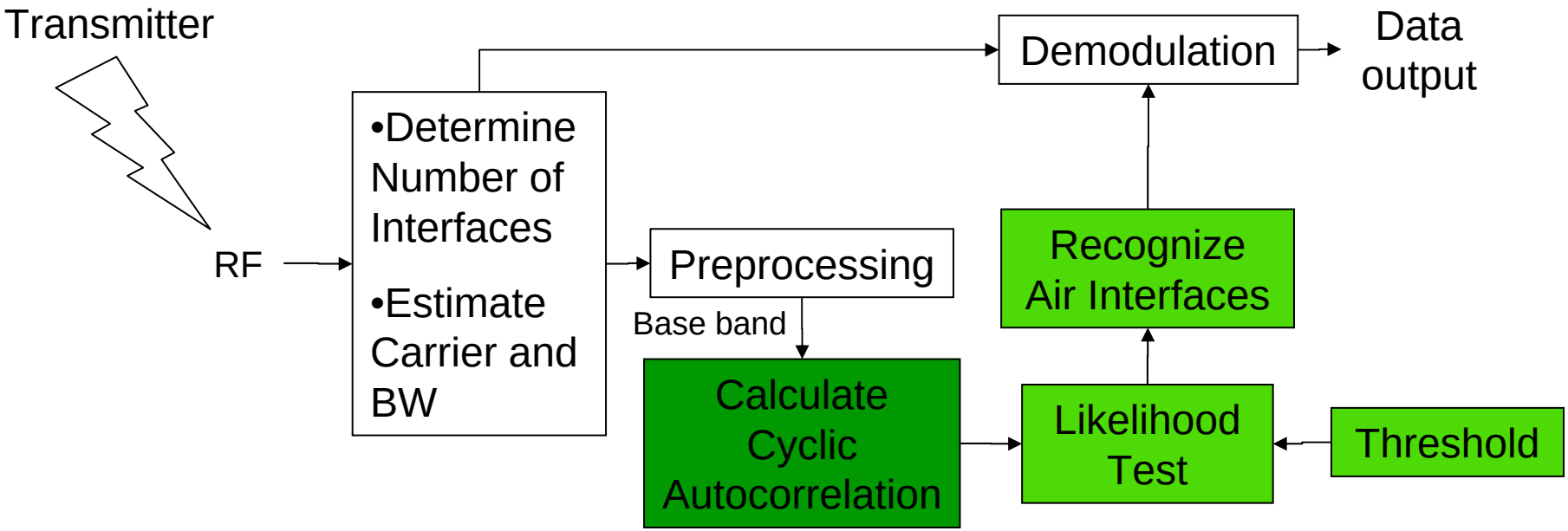
- Automatically recognize BPSK, QPSK, 8PSK, and 16QAM using amplitude and differential phase variances. Channel gain estimation is discussed (2000).
- Automatically recognize BPSK, QPSK, and 8PSK using differential phase and maximum likelihood test.



Research of Menguc and Jondral (1) Air Interface Identification for SDR

Identify (Verify?)

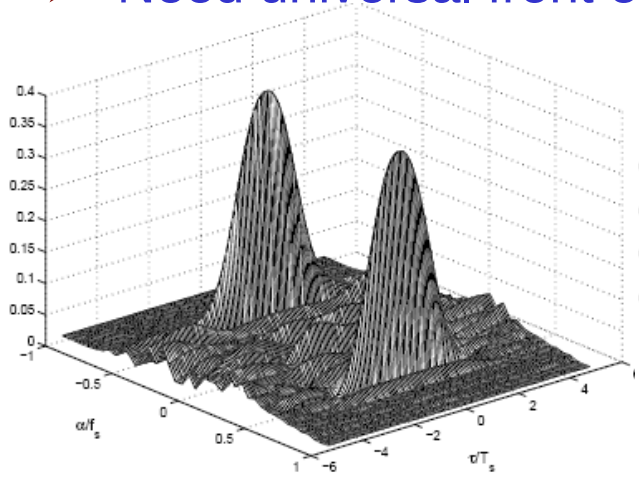
- TDMA-GMSK
- OFDM-PSK/QAM
- CDMA-QPSK



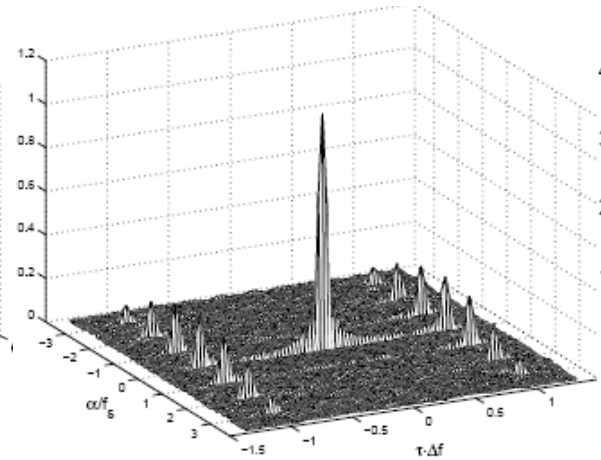
Research of Menguc and Jondral (2) Magnitude Plot of the Cyclic Autocorrelation Estimations

Issues

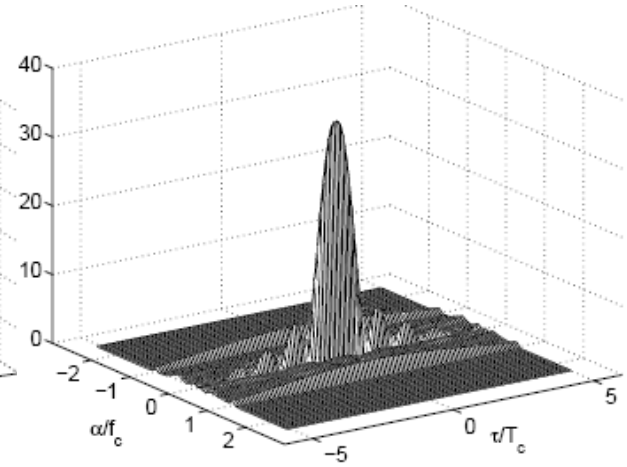
- Processing speed
- Need universal front end



GMSK



OFDM



CDMA

* O. Menguc, “Air interface identification for software radio systems,” Ph.D. Dissertation, University of Fridericiana Karlsruhe, Nov. 30, 2004.

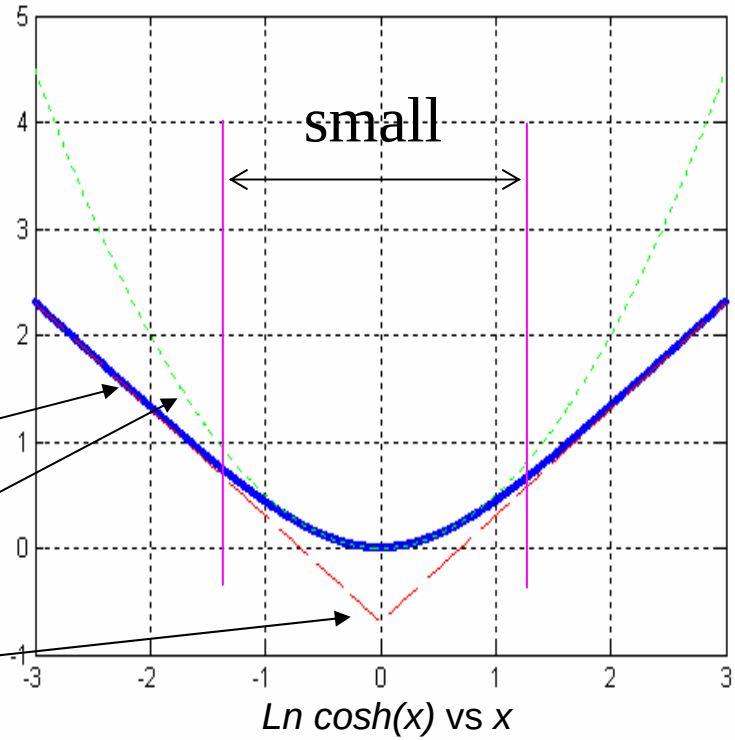
Research of Simon and Divsalar (1) Data Format classification for SDR

- Discriminate NRZ and Manchester code
- Reduce complexity
- Extend to non-coherent case

Use two curves approximate *ln cosh(x)* in order to simplify the ML computation

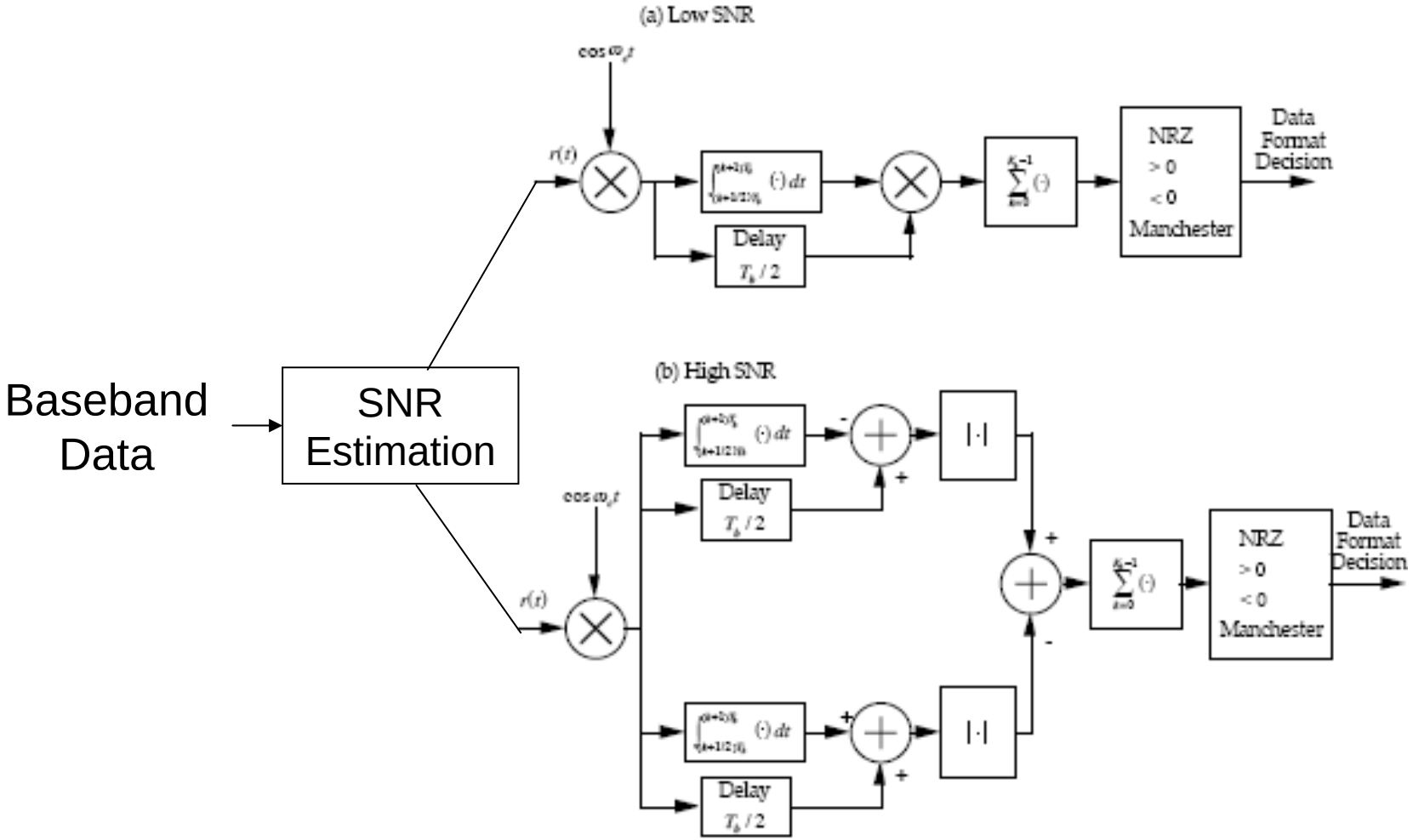
$$\sum_{n=0}^{K_b-1} \ln\cosh\left(\frac{2\sqrt{2P}}{N_0} r_{k,NRZ}\right) < \sum_{n=0}^{K_b-1} \ln\cosh\left(\frac{2\sqrt{2P}}{N_0} r_{k,Manchester}\right)$$

$$\ln\cosh(x) \cong \begin{cases} x^2/2; & x \text{ small} \\ |x| - \ln 2; & x \text{ large} \end{cases}$$



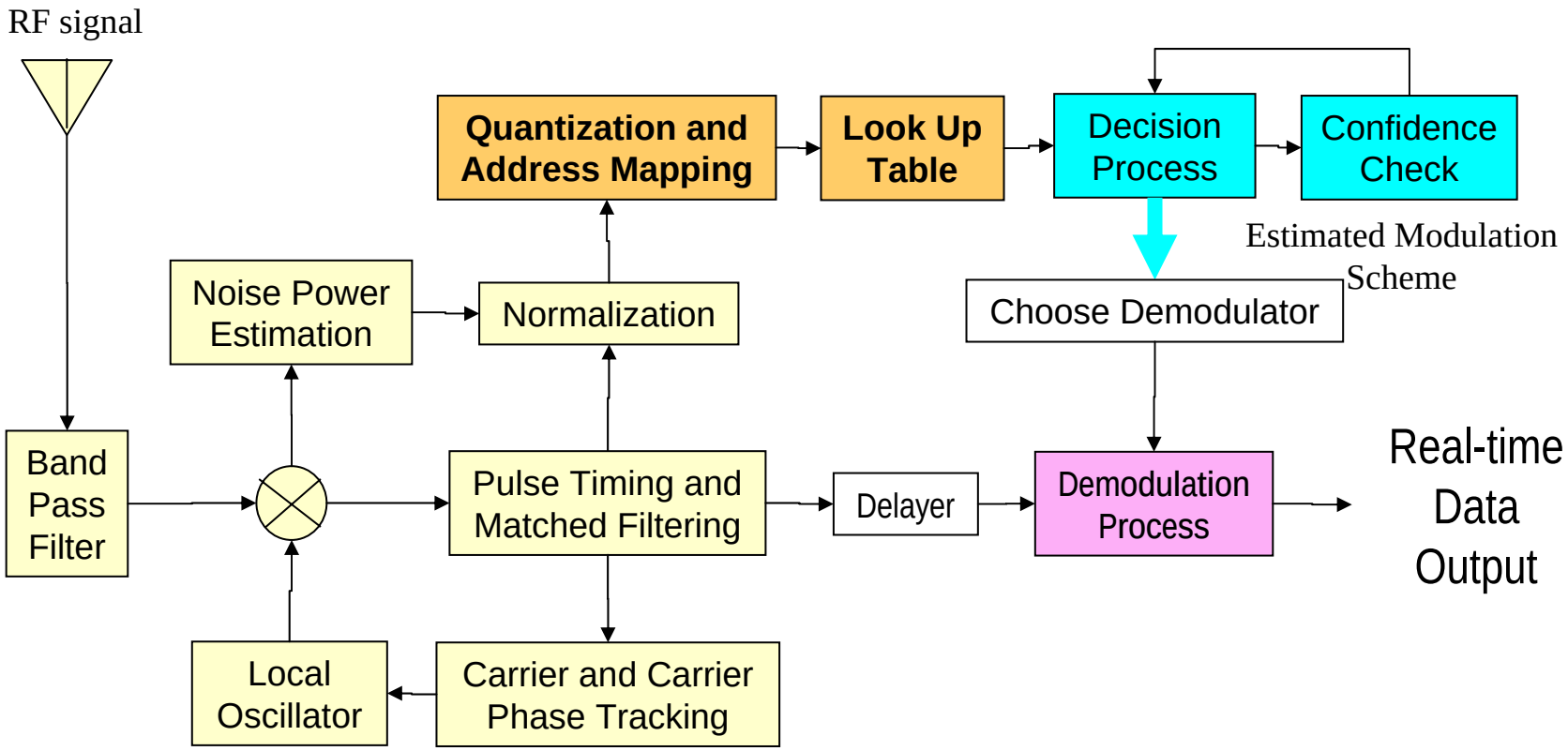
Ln cosh(x) vs *x*

Research of Simon and Divsalar (2) Reduced Complexity ML Implementation



Other Research Results on Modulation Classification Based on SDR

- Gu et al. “Channelized receiver platform of SDR based on FPGAs, Proceedings of The 5th IEEE International conference on ASIC, Vol.2, Oct. 2003, pp.840-843.
- Yang, “An enhanced SOFM method for automatic recognition and identification of digital modulations,” Proceedings of the 2nd IEEE International Workshop on Electronic Design, Test and Applications (DELTA’04), Jan. 2004, pp.174-179.
- Ko et al. “Modulation type classification Method using wavelet transform for adaptive demodulator,” Proceedings of 2004 International Symposium on Intelligent Signal processing and Communication System, Vol.46, Oct. 1995, pp.211-222.
- Hooftand Darwish, “A reconfigurable software digital radio architecture for electronic signal interception, identification, communication and jamming,” *COTS Joural*, April 2002, pp.31-35.


RF signal
Quantization and Address Mapping
Look Up Table
Decision Process
Confidence Check
Estimated Modulation Scheme
Noise Power Estimation
Normalization
Choose Demodulator
Band Pass Filter
Pulse Timing and Matched Filtering
Delayer
Demodulation Process
Real-time Data Output
Local Oscillator
Carrier and Carrier Phase Tracking

Summary

- Adaptive modulation is not only an important information warfare practice but also an effective tool to maximize the data capacity and minimize the transmission error in SDR applications.
- Automated modulation classification is a solution in handling the non-cooperative communication problem for SDR.
- Blind estimation of modulation parameters such as center frequency offset, carrier phase, pulse shape, symbol rate, and bandwidth is critical to the robustness of modulation classification.
- A good modulation classifier should be able to identify modulation scheme fast and robust.

Future Work

- Faster estimator
- Shorter data length
- Lower SNR
- Better channel estimation
- Better QoS