KUIPER TEST BASED MODULATION LEVEL CLASSIFICATION UNDER UNKNOWN FREQUENCY-SELECTIVE CHANNELS

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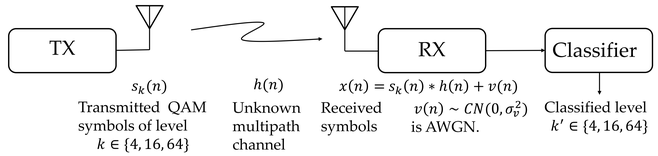
Objective

Goal: To classify modulation level of received signal of known modulation type, e.g., QAM, PAM, PSK, under unknown multipath channel.



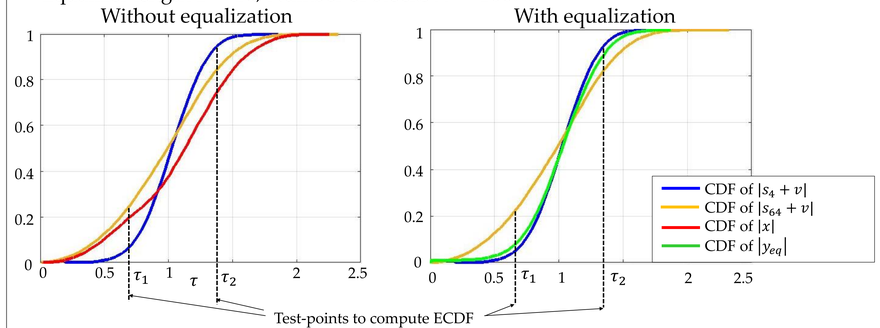
- Feature-based classification techniques, such as reduced Complexity Kuiper (rcK), use distribution $|x(n)|$ for QAM, and PAM and distribution of $\angle x(n) - \angle x(n-1)$ for PSK level classification under AWGN channel [1][2].
- Under unknown multipath channel, the magnitude and phase features of $x(n)$ get distorted resulting in high classification error.
- We propose to use blind equalizer to mitigate effect of channel and improve classification accuracy.

Proposed CMA-rcK Approach

1. Blind equalization using Constant Modulus Algorithm (CMA):
   - Divide received symbols $x(n)$ in M non-overlapping blocks each of size L.
   - Update CMA filter weights for M iterations:
     $\mathbf{w}_i = \mathbf{w}_{i-1} - \mu(|y(i)|^2 - 1)y^*(i)\mathbf{x}_i$,
     where $y_i = \mathbf{w}_{i-1}^H \mathbf{x}_i, \mathbf{x}_i = [x(iL-1), x(iL-2), \dots, x(iL-L)]^T$
2. Equalization symbols using final filter weight $\mathbf{w}_M$: $y_{eq}(i) = \mathbf{w}_M \mathbf{x}_i, i = 1,2,\dots,M$.
   - Estimate output SNR: $\hat{\gamma} = \frac{\frac{1}{M}\sum_i |y_{eq}(i)|^2}{||\mathbf{w}_M||^2 \sigma_v^2} - 1$
3. Modulation level classification using reduced complexity Kuiper (rcK):
   - Compute empirical CDF of feature of y_{eq} at predefined test-points t: $F_{y_{eq}}(t)$.
   - Compute Kuiper distance between $F_{y_{eq}}(t)$ and CDF of feature for level l at SNR $\hat{\gamma}$:
     $V_l = \sum_{t \in T} \left| F_{y_{eq}}(t) - F_l(t) \right|$, where T is set of pre-defined test-points.
   - Estimated level: $k' = \min_l V_l$

Illustration

Consider classification between $\{4, 64\}$ −QAM.
Transmitted signal: s_k = 4-QAM, channel: $h = [1, 0.5]$, SNR = 10 dB.
Equalizer length $L = 20$, Number of blocks $M = 200$.



- Without equalization: CDF of $|x|$ is closer to CDF of $|s_{64}| \Rightarrow k' = 64$-QAM ✗
- With equalization: CDF of $|y_{eq}|$ is closer to CDF of $|s_4| \Rightarrow k' = 4$-QAM ✓

Numerical Results

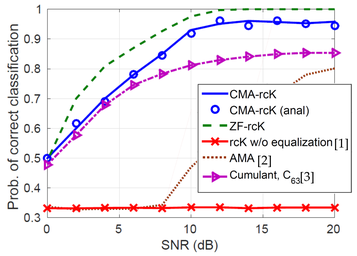


Fig. 1: {4, 16, 64}-QAM classification under channel-1

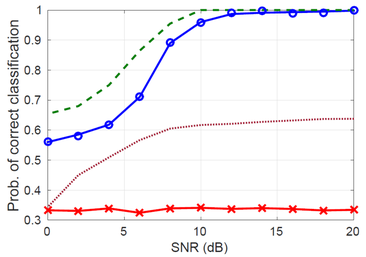


Fig. 2: {2, 4, 6}-PSK classification under channel-1

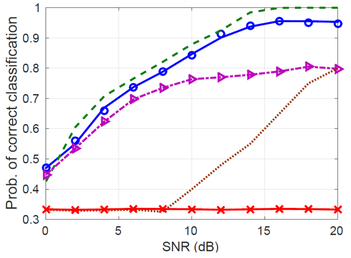


Fig. 3: {4, 16, 64}-QAM classification under channel-2

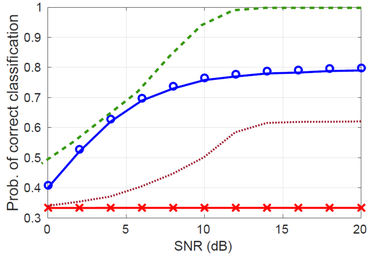


Fig. 4: {2, 4, 6}-PSK classification under channel-2

- **Simulation parameters:**
  Number of blocks: $M = 200$, Equalizer length: $L = 20$
  Total number of symbols used = $ML = 4000$.
- Performance of QAM and PSK level classification under 2 channel models is shown.
- Channel-1: 4-tap block fading channel with $h(0) = 1$, $h(1), h(2), h(3) \sim CN(0, 0.05)$.
- Channel-2: 3-tap block fading model derived by sampling LTE-Extended Vehicular A (EVA) model at 1MHz: $h(0) \sim CN(0, 0.95), h(1) \sim CN(0, 0.28), h(2) \sim CN(0, 0.11)$.
- ZF –rcK assumes perfect knowledge of channel for zero-forcing equalization, therefore it has better accuracy than other schemes.
- Alphabet Matched Algorithm (AMA) decides the level by directly computing the distance between equalized symbols from constellation points of candidate levels. This method does not take into account the SNR in classification.
- Cumulant based classifier cannot classify PSK levels due to same cumulant values of M-PSK (M>2). The performance for QAM level classifier suffers due to small difference in cumulants of 16 and 64-QAM.

Conclusion

- The proposed CMA-rcK technique outperforms existing methods under frequency-selective channels by reducing the feature distortion caused by the channel.
- Unlike Cumulant based method, CMA-rcK can classify PSK levels.
- AMA based classifier does not perform well as it does not take into account the SNR of the equalized symbols in order to decide the modulation level.
- Classification accuracy depends on frequency selectivity of the channel. The accuracy under channel-2 is worse than in channel-1, since channel-2 exhibits more frequency selectivity due to larger values of higher order taps.

References

[1] Urriza, "Computationally Efficient Modulation Level Classification Based on Probability Distribution Distance Functions," *IEEE Commun. Let*, May 2011.
[2] Barbarossa, "Classification of digital constellations under unknown multipath propagation conditions," in *SPIE 4045, Digital Wireless Communication II, 175*, 2000.
[3] Orlic, "Multipath channel estimation algorithm for automatic modulation classification using sixth-order cumulants," *Electronics Letters*, vol. 46, no. 19, pp. 1348–1349, Sep. 2010.