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CHANNEL DEPENDENT MUTUAL INFORMATION IN INDEX MODULATIONS

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Outline

- Introduction
- Problem statement
- Proposed solution
- Results
- Conclusions

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Introduction

- Link Adaptation requires Effective SNR metric

$$\bar{\gamma} = \varphi^{-1}\left(\frac{1}{N}\sum_{n}^{N}\varphi(\gamma_n)\right)$$

- This metric “averages” the SNR (γ_n)of each symbol (of length N) within a codeblock.

- In this way it can be mapped to the corresponding modulation & coding scheme (ESM) in order to carry out Adaptive Code Modulation and better control the error rate.

- In the literature, this mapping is based on the Mutual Information (MI-ESM).

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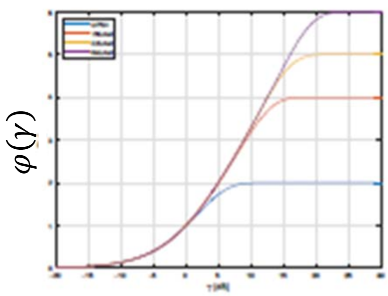
Introduction

- However, MI-ESM involves the expectation of a Random Variable (RV) (without a closed-form solution).

- In the literature, the computation of MI-ESM is performed off-line via Monte Carlo long simulations and the results are stored into a look-up table.



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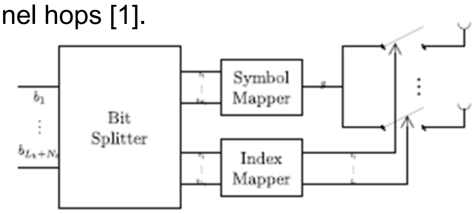
Introduction

HOWEVER

- Index Modulations, such as Spatial Modulation (SM) or Polarized Modulation (PM), convey the information in the radiated symbol and also in the channel hops [1].



- Thus, the constellation of symbols depends on the channel realization at each time instant.

- The computation of MI-ESM cannot be performed off-line due to this channel dependency.

[1] P. Henarejos, A. Pérez-Neira, Dual Polarized Modulation and Reception for Next Generation Satellite Communications , IEEE Transactions on Communications, Vol. 63, No. 10, pp. 3803-3812, October 2015.

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Introduction

- The problem statement is:

  How can MI-ESM be computed in Index Modulation?

- We propose a closed-form expression based on approximations of the integral-based expressions.

- Thanks to these approximations, we are able to obtain very low computational complex expressions with a valid accuracy and

  enable link adaptation for Index Modulations

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Problem Statement

- System model of Index Modulations (SM, PM, etc.)

$$\begin{aligned} \mathbf{y} &= \sqrt{\gamma}\mathbf{H}\mathbf{x} + \mathbf{w} \\ &= \sqrt{\gamma}\mathbf{h}_l s + \mathbf{w} \end{aligned}$$

where $\mathbf{x} = \mathbf{l}s$ is the all-zero vector except at position l, that is 1, γ is the average received SNR, s is the radiated symbol and l is the hopping index.

- The statistics of channel $\mathbf{H}$ depend on the physical domain (spatial, polarization, etc.)

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Problem Statement

- Mutual Information

$$\begin{aligned} I(\mathbf{y}; s, l) &= I(\mathbf{y}|s; l) + I(\mathbf{y}; l) \\ &= H(s) + H(l) - h(s, l|y) \end{aligned}$$

where s and l are independent RV, $H(x)$ is the entropy of X and $h(x)$ is the differential entropy of X. s belongs to a known constellation, such as QAM.

Note that:

$$H(s) = \log_2 S$$
$$H(l) = \log_2 t$$

where S is the size of constellation of s and t is the number of channel elements (number of antennas, polarizations, etc.)

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Problem Statement

- Assuming white Gaussian noise, and after some mathematical manipulations, $h(s,l|y)$ can be expressed as

$$h(S,L|\mathbf{Y}) = \frac{1}{tS}\sum_{s\in\mathcal{S}}\sum_{l=1}^{t}\mathbb{E}\left\{\log_2\left(\frac{\sum_{s'\in\mathcal{S}}\sum_{l'=1}^{t} f_{\mathbf{Y}|S,L}(\mathbf{y},s',l')}{f_{\mathbf{Y}|S,L}(\mathbf{y},s,l)}\right)\right\}$$
$$= \frac{1}{tS}\sum_{s\in\mathcal{S}}\sum_{l=1}^{t}\mathbb{E}_{\mathbf{W}'}\left\{\log_2\left(\sum_{s'\in\mathcal{S}}\sum_{l'=1}^{t} e^{-\gamma\left(\|\mathbf{h}_l s-\mathbf{h}_{l'}s'+\mathbf{w}'\|^2-\|\mathbf{w}'\|^2\right)}\right)\right\}$$

where $f_{\mathbf{Y}|S,L}(\mathbf{y},s,l)$ is the joint probability density function of y, s and l, and $\boldsymbol{W}' \sim \mathcal{CN}(\mathbf{0},\gamma^{-1}\mathbf{I})$.

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Problem Statement

- Due to the channel dependency, the expectation cannot be computed off-line since it depends on the channel realization.
- The expectation has to be computed at each time instant where the link adaptation has to take place.
- It requires a very high complex computation to be carried out on-line.

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Proposed Solution

- Following the approach of [1], we compute the Taylor Series Expansion of the expectation function, which yields into its moments.

- The first order approximation is:

$$I_{(1)}(\mathbf{y}; s, l) \simeq \log_2\left(\frac{tS}{\mathfrak{G}(\mathcal{D}_{sl})}\right)$$

where $\mathcal{D}_{sl} \doteq \sum_{s' \in \mathcal{S}} \sum_{l'=1}^{t} e^{-\gamma\left(\|\mathbf{x}_{sl}-\mathbf{x}_{s'l'}\|^2\right)}$, $\mathbf{x}_{sl} \doteq \mathbf{h}_l s$ and $\mathfrak{G}(\mathbf{x})$ is the geometric mean of $\mathbf{x}$.

- The second order approximation is more involved and it can be found in the paper

[1] P. Henarejos and A. I. Perez-Neira, "Capacity analysis of index modulations over spatial, polarization, and frequency dimensions," IEEE Trans. Commun., vol. 65, no. 12, pp. 5280–5292, Dec. 2017.

Results

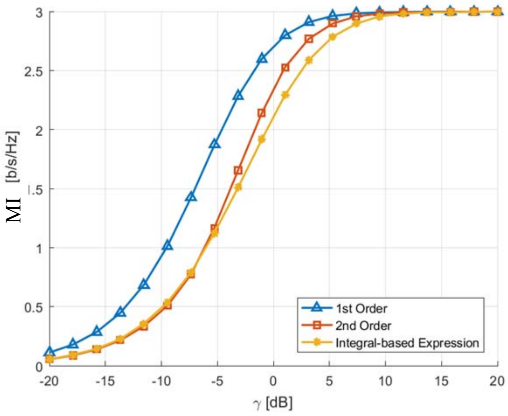
- We compare the first and second order approximations with the integral-based expression.

- We generate a very large number of Rayleigh channel realizations and average the MI results to obtain a smooth curve.

- As expected,
  - as we increase the order of the approximation, the curve becomes tighter and closer to the integral-based expression;
  - The approximation is an upper bound $f\left(\mathbb{E}_X\{x\}\right) \leq \mathbb{E}_{\boldsymbol{X}}\{f(\mathbf{x})\}$

Results

- We simulate a 2×2 MIMO channel (1 bit) conveying a QPSK symbol (2 bits).



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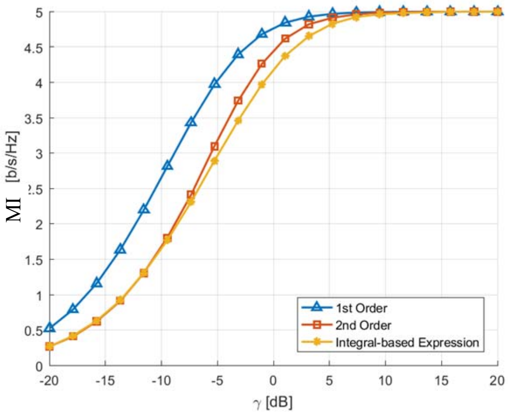
Results

- Other schemes: 2×2 MIMO channel (1 bit) conveying a 16-QAM symbol (4 bits).



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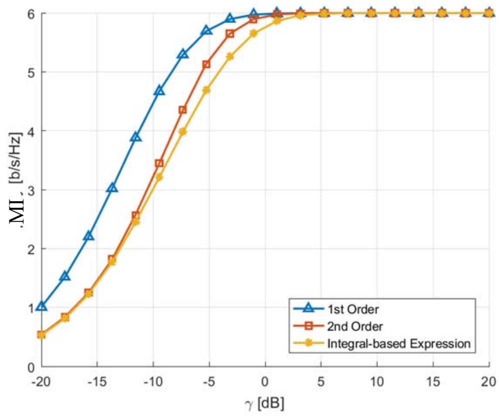
Results

- Other schemes: 4×4 MIMO channel (2 bit) conveying a 16-QAM symbol (4 bits).



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Conclusions

- We introduced the problem of implementing link adaptation in Index Modulations, such as Spatial Modulation or Polarized Modulation.
- If the channel is time varying, it is **unaffordable** to compute the Mutual Information at each time instant.
- With our approach it is **possible** to obtain a smooth curve by using closed-form expressions, **decreasing** the computational complexity and allowing to perform the link adaptation.
- Finally, we depicted the first and second order approximations compared with integral-based expression for several configurations and constellation size.

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Thank you!

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