Advanced transceivers for spectrally-efficient communications

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Outline

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Introduction

THE MISSION: maximize the achievable spectral efficiency

$$\eta = \frac{I_{\mathrm{R}}}{TW} \quad [\mathrm{bit/s/Hz}]$$

where

- T,W are respectively the symbol time and the reference bandwidth
- I_{R} is the achievable information rate.

Introduction

Information rate:

$$I(\boldsymbol{c};\boldsymbol{r}) = \mathrm{E}\{-\log_2 p(\boldsymbol{r})\} - \mathrm{E}\{-\log_2 p(\boldsymbol{r}|\boldsymbol{c})\} \tag{1}$$

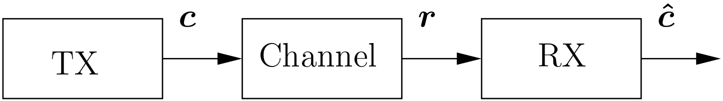
Achievable information rate:

$$I_{\mathrm{R}} = \mathrm{E}\{-\log_2 q(\boldsymbol{r})\} - \mathrm{E}\{-\log_2 q(\boldsymbol{r}|\boldsymbol{c})\} \tag{2}$$

where

- $\boldsymbol{c}, \boldsymbol{r}$ are respectively the transmitted symbols and the observable
- $p(\boldsymbol{r}|\boldsymbol{c})$ is the channel law, and $p(\boldsymbol{r}) = \sum_{\boldsymbol{c}} p(\boldsymbol{r}|\boldsymbol{c})P(\boldsymbol{c})$
- $q(\boldsymbol{r}|\boldsymbol{c})$ is the channel law <u>considered at the detector</u>, and $q(\boldsymbol{r}) = \sum_{\boldsymbol{c}} q(\boldsymbol{r}|\boldsymbol{c})P(\boldsymbol{c})$

What are we going to do?



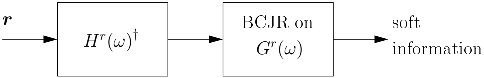
Our march of optimization:

- Receiver: channel shortening.
- Transmitter: optimization of the transmit filter and time-frequency packing technique.
- Transceiver: we will combine all the presented techniques. We will consider, as example, their application to the satellite channel.

Outline

Channel shortening: considerations

Let us consider a discrete-time ISI channel $H(\omega)$



- Optimal detection adopts

$$H^r(\omega) = H(\omega), \quad G^r(\omega) = |H(\omega)|^2$$

  and has complexity $\mathcal{O}(M^\nu)$.

- We consider detectors with memory $L < \nu$. How we should set $H^r(\omega)$ and $G^r(\omega)$?

$$I_{\text{OPT}} = \max_{\boldsymbol{H}^r, \boldsymbol{G}^r} I_{\text{R}}$$

The optimization problem can be a hard task. However it can be solved for Gaussian input [1].

[1] F. Rusek and A. Prlja, "Optimal channel shortening for MIMO and ISI channels," IEEE Trans. Wireless Commun., vol. 11, pp. 810818, Feb. 2012.

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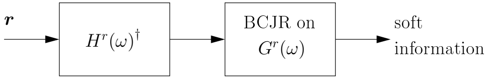

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Channel shortening: a numerical example

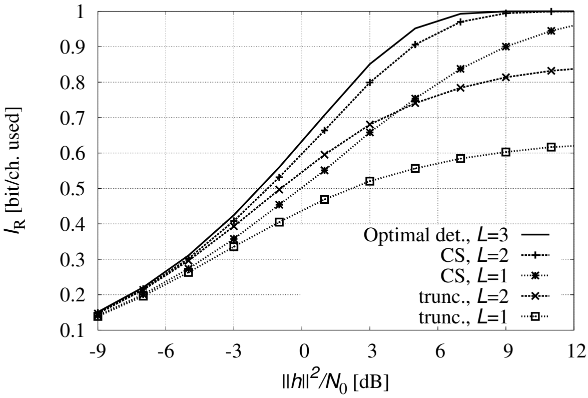


Figure : AIRs of the CS detector on the EPR4 channel for BPSK modulation.

Channel shortening: our work

Our contribution

- Adaptive channel shortening
- Optimized transmit filter for CS detector
- Extension to MIMO-ISI channels
- Extension to continuous-time channels
  - AWGN channel: CS detector and optimal shaping pulse
  - FDM: CS detector

Due to a lack of time we will shortly describe only the Optimal transmit filter for CS detector.

Channel shortening: optimal transmit filter

We now assume that the transmitted symbols are a precoded version of the information symbols

Optimization problem

$$\max_{P(\omega)} I_{\mathrm{OPT}}$$

such that

$$\int_{-\pi}^{\pi} |P(\omega)|^2 \mathrm{d}\omega = 2\pi \qquad .$$

Solution

$$|P(\omega)|^2 = \max\left(0, \frac{N_0}{\sqrt{|H(\omega)|^2}} \sqrt{\sum_{\ell=-L}^{L} A_\ell e^{j\ell\omega}} - \frac{N_0}{|H(\omega)|^2}\right)$$

where A_ℓ have Hermitian symmetry.

Channel shortening: numerical results

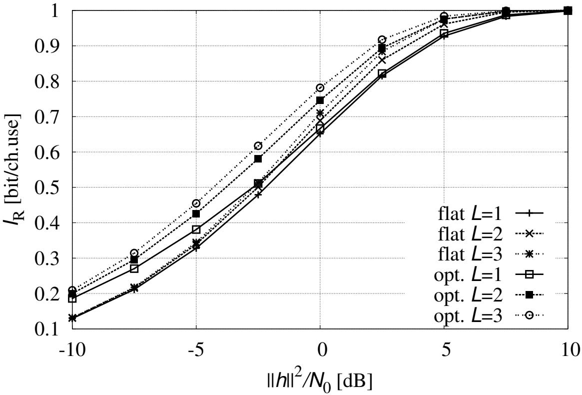


Figure : AIRs for BPSK modulation when different values of the memory L are considered at receiver.

Channel shortening: numerical results

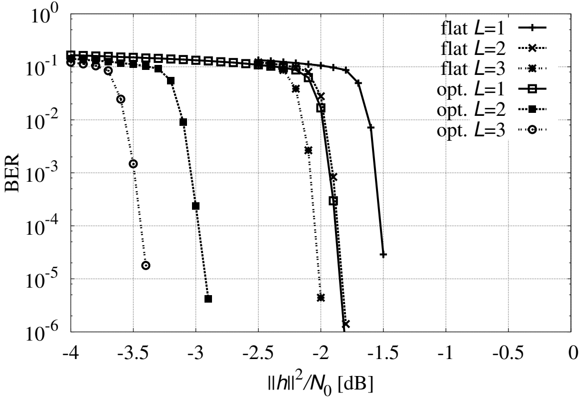
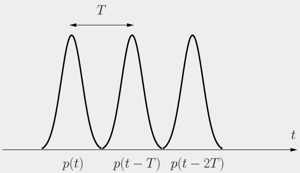


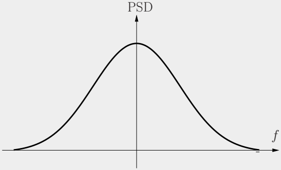
Figure : Bit error rate for BPSK modulation, 64,800 DVBS2 LDPC code with rate 1/2, for different values of the memory L considered at receiver.

Outline

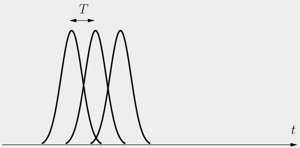
Time packing

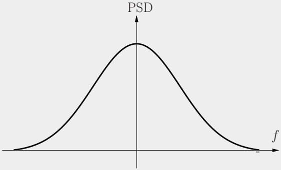
What we usually do...





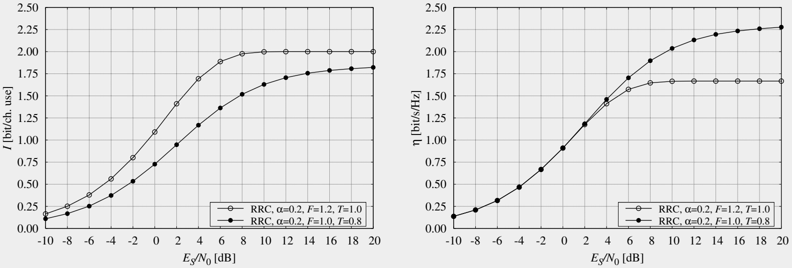
...and what we could do





Time packing

What's the point?



$$\eta = \frac{I_{\mathrm{R}}}{TW}$$

Time packing

Original faster-than-Nyquist

- In FTN, T is selected as the smallest value giving no reduction of the minimum Euclidean distance with respect to the Nyquist case [2].
- Extended to both time and frequency by Rusek and Anderson [3].

time-frequency packing

- We use low-complexity receivers
- We accept a degradation of the information provided the spectral efficiency is increased
- In other words, if we keep the same code, the performance degrades but an improvement is obtained by using a code with lower rate (higher overhead)

[2] J. E. Mazo. A geometric derivation of Forneys upper bound. In: Bell System Tech. J. 54 (1975), pp. 10871094.

[3] F. Rusek and J. B. Anderson. The two dimensional Mazo limit. In: Proc. IEEE International Symposium on Information Theory. Adelaide, Australia, Nov. 2005, pp. 970974.

Time packing: numerical results

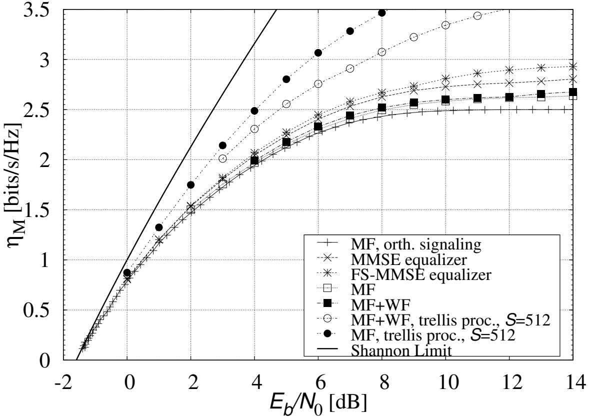


Figure : ASE for 8PSK with a RRC pulse having $\alpha = 0.2$.

Time packing: numerical results

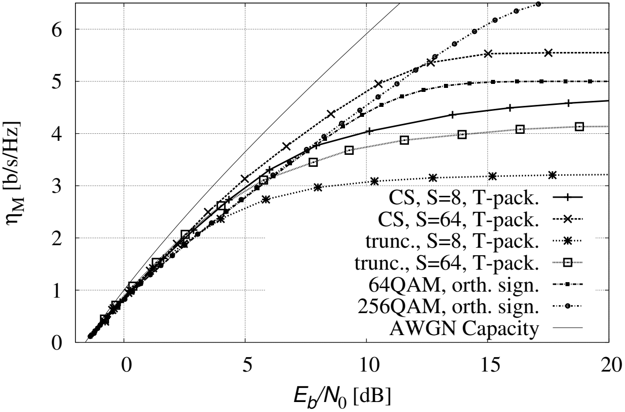


Figure : ASE for time packing and CS detection when the modulation is QPSK, with Gray mapping and RRC pulse $\alpha = 0.2$.

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Satellite channel

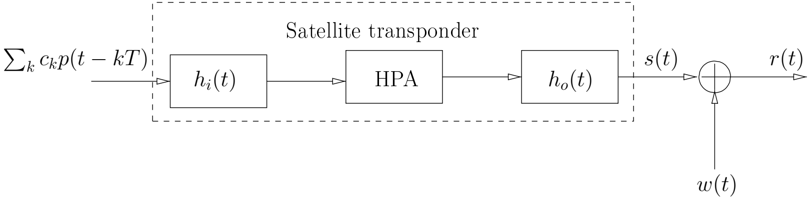

Figure : Block diagram of the satellite channel.

Satellite channel

- A suitable approximate model is based on a *simplified* Volterra-series expansion [4].
- PSK modulations: the model reduces to a linear AWGN channel.

  ⇒CS detector for AWGN continuous-time channels.
- APSK modulations: the model reduced to a MIMO-ISI channel.

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[4] G. Colavolpe and A. Piemontese, "Novel SISO detection algorithms for nonlinear satellite channels," IEEE Wireless Communications Letters, vol. 1, pp. 22-25, February 2012.

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Spectrally-eff. comm. over the sat. channel

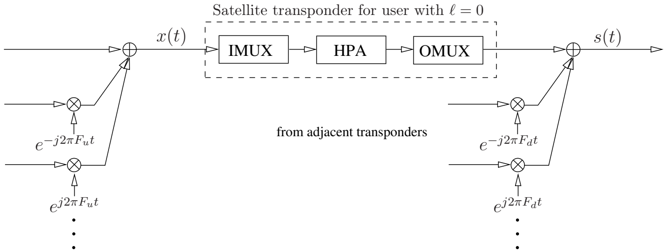


Figure : System model.

Spectrally-eff. comm. over the sat. channel

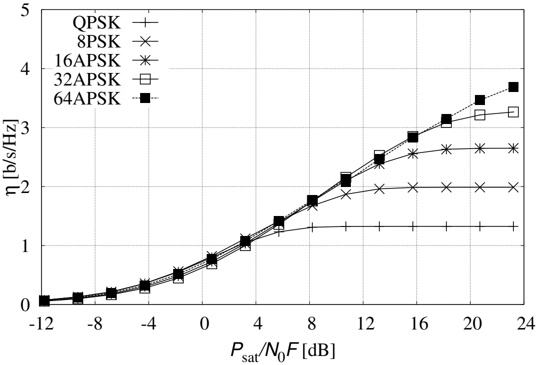


Figure : Spectral efficiency of DVB-S2 modulations with roll-off 0.2, data predistortion, and memoryless detection. Comparison with a constellation of increased cardinality (64APSK).

Spectrally-eff. comm. over the sat. channel

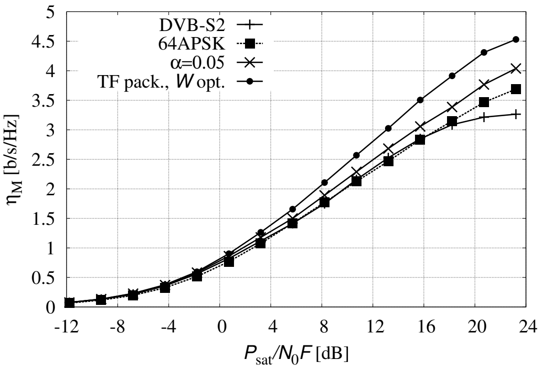
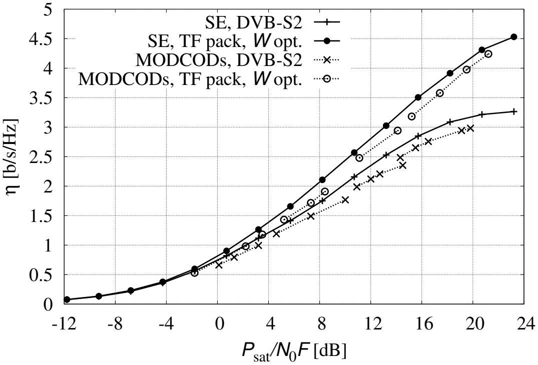


Figure : Spectral efficiency of TF packing with bandwidth optimization (TF pack., W opt.). Comparison with DVB-S2, 64APSK and roll-off reduction.

Spectrally-eff. comm. over the sat. channel



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Publications

Journals

- A. Modenini, F. Rusek, and G. Colavolpe "Optimal transmit filters for ISI channels under channel shortening detection," IEEE Transactions on Communications, vol. 61, pp. 4997-5005, December 2013.
- A. Piemontese, A. Modenini, G. Colavolpe, and N. Alagha "Improving the spectral efficiency of nonlinear satellite systems through time-frequency packing and advanced processing," IEEE Transactions on Communications, vol. 61, pp. 3404-3412, August 2013.
- G. Colavolpe, A. Modenini, and F. Rusek, "Channel Shortening for Nonlinear Satellite Channels," Communications Letters, IEEE , vol.16, no.12, pp.1929-1932, December 2012.
- G. Colavolpe, Tommaso Foggi, A. Modenini, and A. Piemontese, "Faster-than-Nyquist and beyond: how to improve spectral efficiency by accepting interference," Opt. Express 19, 26600-26609 (2011).

Publications

Conferences

- A. Piemontese, A. Modenini, G. Colavolpe, and N. Alagha, "Spectral Efficiency of Time-Frequency-Packed Nonlinear Satellite Systems," in 31th AAIA International communications satellite systems conference, Florence, Italy, October 2013.
- G. Colavolpe, and A. Modenini, "Iterative carrier syncrhonization in the absence of distributed pilots for low SNR applications," in Proc. Intern. Workshop of Tracking Telemetetry and Command System for Space Communications. (TTC'13), European Space Agency, Darmstadt, Germany, September 2013.
- A. Modenini, F. Rusek, and G. Colavolpe, "Optimal transmit filters for constrained complexity channel shortening detectors," in Proc. IEEE Intern. Conf. Commun. (ICC'13), Budapest, Hungary, June 2013, pp. 1688-1693.
- A. Modenini, G. Colavolpe, and N. Alagha, "How to significantly improve the spectral efficiency of linear modulations through time-frequency packing and advanced processing," in Proc. IEEE Intern. Conf. Commun. (ICC'12), Ottawa, Canada, June 2012, pp. 3430-3434.

Patents

- G. Colavolpe, A. Modenini, A. Piemontese, and N. Alagha, "Data detection method and data detector for signals transmitted over a communication channel with inter-symbol interference," assigned to ESA-ESTEC, The Neederlands. International patent application n. F027800186/WO/PCT, December 2012.