Advanced transceivers for spectrally-efficient communications

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June 20th, 2014
Outline

1. Introduction
2. Channel shortening
3. Time packing
4. Satellite channel
5. Spectrally-efficient communications over the satellite channel
6. Publications

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THE MISSION: maximize the achievable spectral efficiency

\[ \eta = \frac{I_R}{TW} \text{ [bit/s/Hz]} \]

where
- \( T, W \) are respectively the symbol time and the reference bandwidth
- \( I_R \) is the achievable information rate.
Information rate:

\[ I(c; r) = \mathbb{E}\{-\log_2 p(r)\} - \mathbb{E}\{-\log_2 p(r|c)\} \]  \hspace{1cm} (1)

Achievable information rate:

\[ I_R = \mathbb{E}\{-\log_2 q(r)\} - \mathbb{E}\{-\log_2 q(r|c)\} \]  \hspace{1cm} (2)

where

- \( c, r \) are respectively the transmitted symbols and the observable
- \( p(r|c) \) is the channel law, and \( p(r) = \sum_c p(r|c)P(c) \)
- \( q(r|c) \) is the channel law considered at the detector, and \( q(r) = \sum_c q(r|c)P(c) \)
What are we going to do?

- **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.
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Advanced transceivers for spectrally-efficient communications
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 $G^r(\omega)$?

$$I_{OPT} = \max_{H^r, G^r} I_R$$

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

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

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Channel shortening: a numerical example

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

- Adaptive channel shortening
- Optimized transmit filter for CS detector
- Extension to MIMO-ISI 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.
We now assume that the transmitted symbols are a precoded version of the information symbols.

**Optimization problem**

\[
\max_{P(\omega)} I_{OPT}
\]

such that

\[
\int_{-\pi}^{\pi} |P(\omega)|^2 d\omega = 2\pi.
\]

**Solution**

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

where \( A_\ell \) 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.
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Advanced transceivers for spectrally-efficient communications
Time packing

What we usually do...

\[ p(t) \quad p(t - T) \quad p(t - 2T) \]

...and what we could do

\[ \text{PSD} \quad f \]

Advanced transceivers for spectrally-efficient communications
What’s the point?

\[ \eta = \frac{I_R}{TW} \]
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)

Time packing: numerical results

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

Advanced transceivers for spectrally-efficient communications
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

\[ \sum_k c_k p(t - kT) \]

\[ h_i(t) \rightarrow \text{Satellite transponder} \rightarrow HPA \rightarrow h_o(t) \]

\[ s(t) \rightarrow w(t) \rightarrow r(t) \]

Figure: Block diagram of the satellite channel.

Advanced transceivers for spectrally-efficient communications
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. ⇒ CS detector for MIMO-ISI channels.

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Spectrally-eff. comm. over the sat. channel

Satellite transponder for user with $\ell = 0$

from adjacent transponders

Figure: System model.
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).
Spectral-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-efficient communication over the satellite channel

Figure: Modcodes of TF packing with bandwidth optimization (TF pack., $W_{opt}$). Comparison with DVB-S2.
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