Blind null-space tracking for MIMO Underlay Cognitive Radios

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Introduction

Motivation:
- The electromagnetic spectrum is running out
- Almost all frequency bands have been assigned
- The spectrum is expensive ⇨ Services are expensive

Solution: Cognitive Radios + MIMO:
- A radio that adapts and makes intelligent decisions.
- The unlicensed user learns where it should NOT transmit in order to not interfere with the licensed user of the spectrum.

Noam and Goldsmith proposed the BNSL Algorithm [1].

In this work, we extend the BNSL Algorithm to the case of time-varying channels.

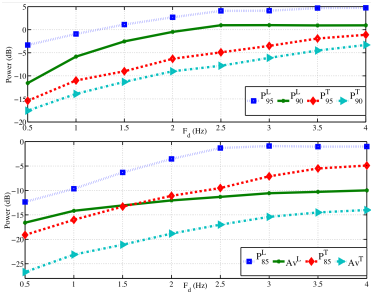
BNST Algorithm

1. The ST starts performing a sweep of the BNSL algorithm.
2. The ST searches over a smaller set of parameters since it knows where to search.
3. When the ST senses that it does not transmit in the null-space it performs “modified” rotations.

Advantages:
- Small rotations
- Less interference while the ST adapts
- More robust to Doppler effect

Disadvantages:
- No slots left for information transmission to the SR.
- More sensitive to the noise when the “Red” Link is close to the Noise floor.

Trade-off between how “small” are the rotations and how much interference ST causes to PU

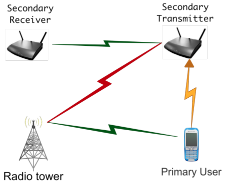


The BNSL Algorithm

Consider the example in the Figure below.
- The Secondary Transmitter (ST) wants to learn the null space of the red channel.
- It changes the orientation of its antennas using the yellow transmit power:
  - If it causes too much interference to the Radio Tower, the PU will increase its transmit power
  - If not, the PU will decrease it.

Critical Assumptions:

1. ST has more antennas than the Radio Tower.
2. Red channel is constant.



Transmit & Track I

Motivation: The secondary system uses too much of its transmission time to learn the channel.
Basic Idea: Superimpose the information signal to the learning signal.

Consider one time period of learning where the ST sends the same signal $x(t) = r_1$ for N time slots.

It also sends an information signal $r_2(t) = c(t)r_1$. Then:

$$y_1(t) = H_{12}T(r_1 + r_2(t)) + n_1(t)$$
$$y_2(t) = H_{22}T(r_1 + r_2(t)) + n_2(t)$$

The PR calculates the quantity: $Q_1(y_1) = \frac{1}{N}\sum_{t=1}^{N} \| y_1(t) \|^2$

The learning process should remain the same. ⇨ $E\left\{ |1 + c(t)|^2 \right\} = 1$

The SR should be able to decode the message ⇨ $E\{c(t)\} \neq -1$

Superimpose the information in the phase of the learning signal

References

1. Yair Noam, Andrea J. Goldsmith, ``Blind Null-Space Learning for Spatial Coexistence in MIMO Cognitive Radios," arXiv preprint: http://arxiv.org/pdf/1202.0366.pdf.
2. Alexandros Manolakos, Yair Noam, Konstaninos Dimou, Andrea Goldsmith, “Blind Null-space Tracking for MIMO Underlay Cognitive Radio Networks”, Submitted to IEEE Globecom 2012.
3. Thomas M. Cover, ``Enumerative Source Encoding", IEEE Transactions on Information Theory, IT-19(1):73--77, January 1973.

Channel Model

N_t, N_r : The antennas of ST and PR respectively $N_t > N_r$

$H_{12}(t)$: The channel between ST and PR.

T_{FB} : Time needed the ST senses the reaction from the PU

Rayleigh Fading independent Fading with Doppler F_D

Performance Metrics

Interference to the PR when the ST uses pre-coding matrix T(t):

$$\| H_{12}T \| = \max_{\|x_2\| \neq 0} \frac{\| H_{12}Tx_2 \|_2}{\| x_2 \|_2}$$

The tracking is successful if:

$$\Pr\left\{ 10\log_{10} \frac{\| H_{12}(t)T(t) \|}{\| H_{12}(t) \|} \leq -P_{Th} \right\} = 0.95$$

Transmit & Track II

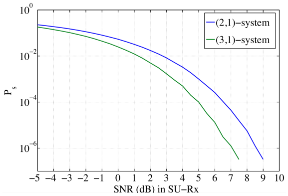
The SR estimates and subtracts the average over the N slots ⇨ $\bar{y}_2 = \frac{1}{N}\sum_{t=1}^{N} y_2(t)$

Enumerative Encoding leads to a more robust to the noise system

The SR does not need to know the learning signal nor the channel, nor the pre-coding matrix.

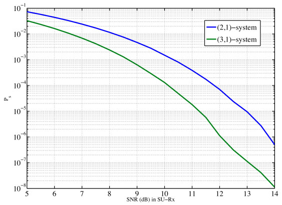
$$c(t) = \begin{cases} e^{j\frac{2\pi}{3}} & \textit{transmits} \quad 0 \\ e^{-j\frac{2\pi}{3}} & \textit{transmits} \quad 1 \end{cases}$$

“BPSK-like” signals



$$c(t) = \begin{cases} -0.8 + 0.98j & \textit{transmits} \quad 00 \\ -0.8 - 0.98j & \textit{transmits} \quad 01 \\ -1.85 + 0.53j & \textit{transmits} \quad 10 \\ -1.85 - 0.53j & \textit{transmits} \quad 11 \end{cases}$$

“QPSK-like” signals



The learning process remained essentially the same. Difference in interference was 0.12dB.

Null-Space Variations

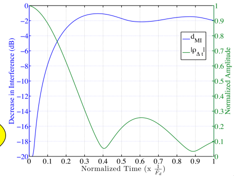
What is the relation between the Doppler and the null-space variations?

Normalized Autocorrelation of a SISO channel h(t) ⇨ $\rho_{\Delta t} = \frac{E\left\{ h(t)h(t+\Delta t)^* \right\}}{E\left\{ |h(t)|^2 \right\}}$

Interference after Δt seconds. ⇨ $d_{MI}(\Delta t) = 10\log_{10}\left(E\left\{ \frac{\| H_{12}(t+\Delta t)N(H_{12}(t)) \|}{\| H_{12}(t+\Delta t) \|} \right\} \right)$

Example:
- Doppler $F_D = 6.48Hz$
- 3 antennas in ST
- 1 antenna in Radio tower

Null-space changes much faster than expected!



Work in Progress

1. Introduce the notion of Null-Space Coherence Time.
2. Study the connection of the “Null-Space Coherence Time” with the channel coherence time.
3. Tuning is needed in order the algorithm to become a real protocol.
   - The ST should choose a Primary User to “sense” its Power variations. Which one?
   - If the “Red” Link is close to the noise floor, then the Algorithm fails to track the channel.
4. Find a “Transmit & Learning” technique where the Secondary System uses more degrees of freedom.

Conclusions

- The null-space changes much faster than the channel coherence time can explain.
- We proposed a tracking algorithm that enhances the BNSL algorithm.
- The Secondary system can transmit information and learn simultaneously.

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