Implementation of Interference Avoidance

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Outline

- Motivation
- Quick overview of IA
- Analytical results
- Implementation of IA using WINLAB’s Testbed
- Future Work
- Conclusions
Motivation

Our wish!
“Give everyone maximum possible SIR”

Granted!
“Greedily place your signal energy where there’s least interference”
Motivation

If everyone does it (at single base) the resulting signature set is ‘good’

- Maximum sum capacity (information theory)
- Users achieve maximum possible common SIR
Motivation

- Good for licensed bands
- Might be even better for unlicensed bands

How to do it?

- Measure interference
- Agile radios
Analysis

$$A_1 b_1 s_1(t) \oplus r(t)$$

$$Z(t) = \sum_{k>1} A_k b_k s_k(t) + n(t)$$

Signal space representation (M users and N dimensions):

$$A_i b_i s_i(t) \Rightarrow A_i b_i \begin{bmatrix} s_{i1} \\ \vdots \\ s_{iN} \end{bmatrix} = A_i b_i s_i$$

$$r(t) \Rightarrow r = S A b + n$$

$$S = [s_1 \cdots s_M]$$

$$Z(t) \Rightarrow Z = \sum_{k>1} A_k b_k s_k + n$$
Minimize Interference

\[
\text{SIR} = \frac{s_1^T s_1}{s_1^T E(ZZ^T) s_1}
\]

Find \( s_1 \) = \( \arg \min \left( \frac{s_1^T (E(ZZ^T)) s_1}{s_1^T s_1} \right) \)

\[
= \arg \min \left( \frac{s_1^T R_1 s_1}{s_1^T s_1} \right)
\]
Illustration

\[ \| S(f) \|^2 \]
Illustrating Signal Space

High-power interferer

Users place themselves optimally in the remaining two dimensions
How to do it?

Say we don’t know interference in advance
Build an estimate over $L$ bit intervals!

$$\hat{R}_r = \frac{1}{L} \sum_{l=1}^{L} r_l r_l^T$$

Then for user 1: $\hat{R}_1 = \hat{R}_r - (A_1)^2 s_1 s_1^T$

Algorithm

Find $x^* = \arg \min_{x} \left( \frac{x^T \hat{R}_1 x}{x^T x} \right) = \arg \min_{x} \left( x^T \hat{R}_1 x \right)$ subject to $x = 1$

Set $s_1 = A_1 x^*$
Simulation Outline

\[ S = \text{optimum signature matrix} \]

\[ S_b \oplus n \rightarrow \text{Build } \hat{R}_r \rightarrow \text{After L bits, estimate } \hat{R}_1 \rightarrow \text{Find } x^* \rightarrow \text{SIR}^* = \frac{x^* \hat{R}_1 x^*}{x^* \hat{R}_1 x^*} \]

Compare SIR* to known maximum SIR:

\[ \frac{s_1^T s_1}{s_1^T R_1 s_1} = \frac{1}{M} \frac{1}{N - 1 + N_0} \]

Where

\[ R_1 = \sum_{k>1} s_k s_k^T + N_0 I \]
Convergence as a function of bit intervals

16 users and 13 dimensions; $||s(t)||^2=1, N_0=1$
1000 iterations
Convergence as a function of bit intervals

16 users and 13 dimensions; \(||s(t)||^2=1, N_o=1\)
1000 iterations
Convergence as a function of SNR

16 users and 13 dimensions; \( \|s(t)\|^2 = 1 \)
1000 iterations
Use of Training Sequence

\[ \hat{\mathbf{R}}_r = \frac{1}{L} \sum_{i=1}^{L} (SAb_i + n)(SAb_i + n)^T \]

\[ = \frac{1}{L} SA\left(\sum_{i=1}^{k} b_i b_i^T + \ldots + b_k b_k^T\right)A^T S^T + \frac{1}{L} \sum_{i=1}^{L} nn^T \]

How to get good \( \hat{\mathbf{R}}_r \) quickly?

- use columns of an orthogonal matrix as bit vectors
Effect of Training Sequence

16 users and 13 dimensions, $N_o = 0$
Effect of training sequence

16 users and 13 dimensions, 1000 trials
Training Sequence: Issues

- In unlicensed bands, different systems may not know how to synch.
- If you advertise where you are, you make it easier for other systems to avoid you.
Interference Avoidance on WINLAB’s Wireless Testbed

\[ \sum A_k b_k s_k(t) \]

Wideband receiver

Quad DSP Processing Core

\[ \hat{X}_1^* \]

Estimate \( R_1 \)

Find \( X_1^* \)

Explicit feedback channel
Issues to explore

- Feedback channel
- Behavior of IA in the presence of other systems
- Specific processing requirements
- Convergence of IA over several types of channels using RF simulator
Conclusions

- Interference avoidance
  - Maximizes sum capacity
  - All users share same max SIR
- Need:
  - Interference estimation
  - Agile radio
- Possible mobility constraints
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