Agile Signal Alignment for Congested and Contested Spectrum Access

Nicholas D. Sidiropoulos, Kieran Lynch
(nikos,kieran.lynch)@virginia.edu

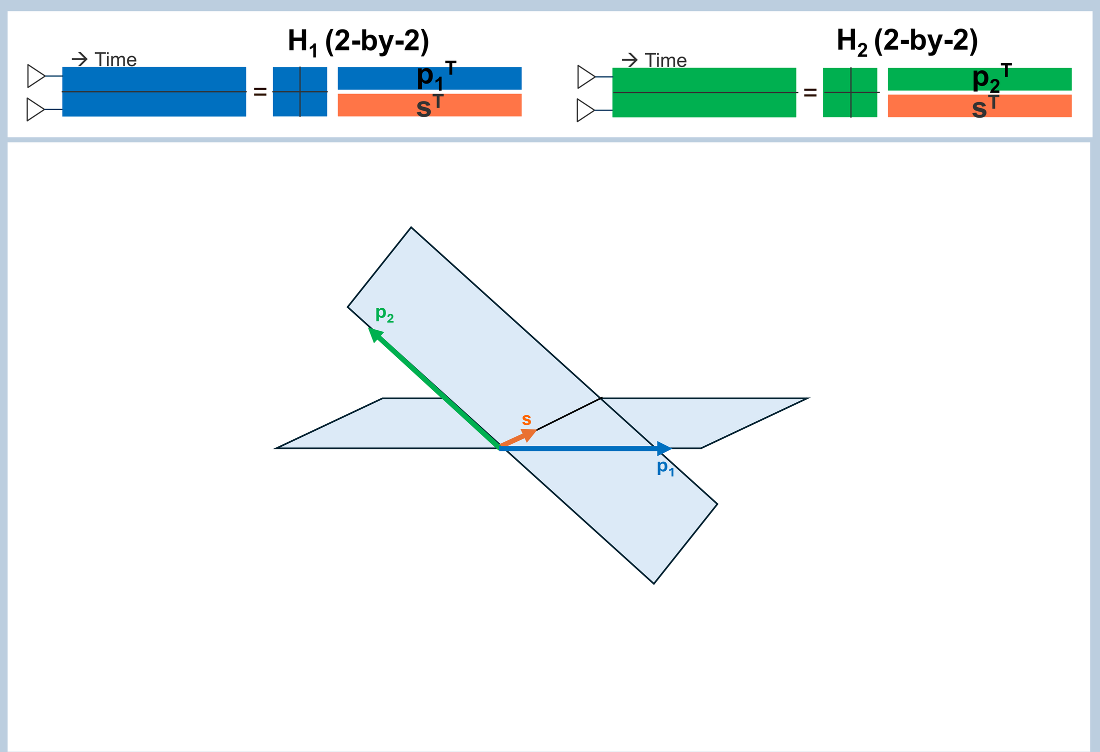
University of Virginia

Problem

- Communicating reliably:
  - Under unpredictable and potentially debilitating interference
  - In congested / contested environments, e.g., WiFi in Manhattan, or under adversarial interference
- Increasing spectrum usage by going underneath other carriers, e.g., FM or analog/digital TV broadcast

Prior State-of-Art

- Signal repetition and subspace intersection [Ibrahim, Karakasis, Sidiropoulos, TWC '22]
- Very different from all other interference mitigation techniques
  - Canonical Correlation Analysis (CCA)
  - Rate loss (relative to interference-free regime) due to repetition
- Requires at least two receive antennas
  - Each transmission → two points on 2-D subspace
  - Intersecting subspaces → span(s)



Theory → Practice

NEWS: No repetition needed!

- Use high-rate linear precoding
  - Matrix Multiplication by known thin precoder
  - $\mathbf{s} = \mathbf{V}\mathbf{m}$
- Main idea: CCA then used to extract signal at ∩ of what was received and the span of the precoder
- Guarantees interference excision with low, controllable rate loss - no need for repetition
- Still need at least two Rx antennas (and a pretty good analog to digital converter)

Complex Baseband

- Model from Repetition CCA (P is $N \times K$)

$$\mathbf{X}_1 = [\mathbf{s},\ \mathbf{P}_1]\,\mathbf{H}_1^H + \mathbf{W}_1$$

$$\mathbf{X}_2 = [\mathbf{s},\ \mathbf{P}_2]\,\mathbf{H}_2^H + \mathbf{W}_2$$

- $\mathbf{s} = \mathbf{V}\mathbf{m}$, $\mathbf{V}$ thin semi-unitary $\Longrightarrow$

$$\mathbf{V} = [\mathbf{s},\ \mathbf{P}_2]\,\mathbf{H}_2^H$$

$$[\mathbf{s},\ \mathbf{V}(:,2:L)] = \mathbf{V}\,[\mathbf{m},\ \mathbf{I}(:,2:L)]$$

$$\mathbf{V} = [\mathbf{s},\ \mathbf{V}(:,2:L)]\,[\mathbf{m},\ \mathbf{I}(:,2:L)]^{-1}$$

Theory

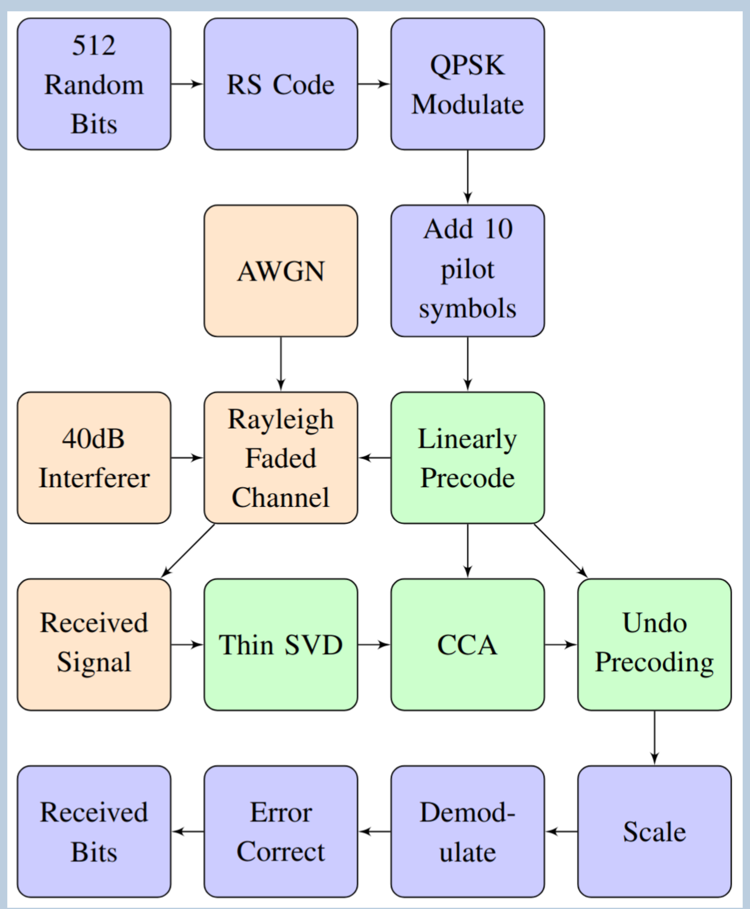
- For CCA to yield Range(s) up to scaling:
  - Matrix $[\mathbf{s},\ \mathbf{P}_1,\ \mathbf{P}_2]$ must be full column rank.
  - Matrices $\mathbf{H}_1$, $\mathbf{H}_2$ must be full column rank.
- Only linear independence, no orthogonality of signal and interference needed!
- Necessary "sizing" conditions: $N \geq 1 + K + L - 1 = K + L$ and $M \geq K + 1$.
  - N - Length of linearly precoded signal
  - K - Number of interferers
  - L - Info-bearing message length
  - M - Number of Rx antennas

Precoders

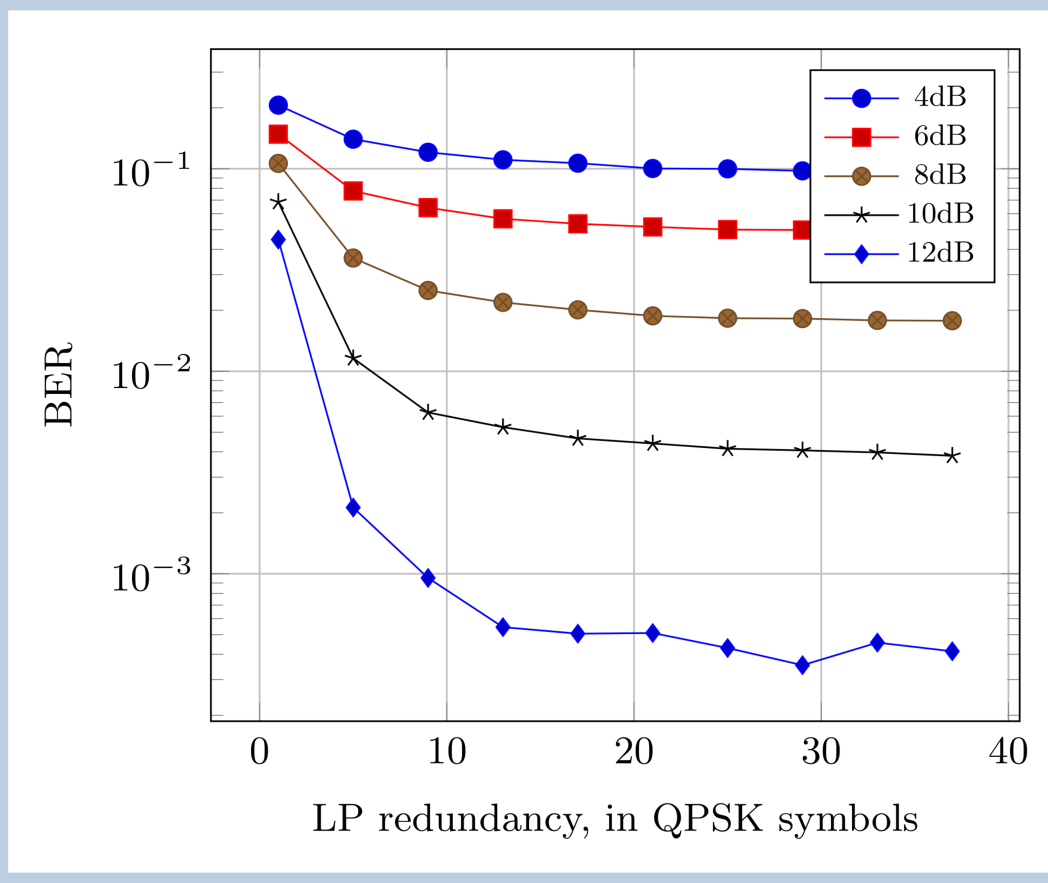
Options for $\mathbf{V}$:

1) Subset of inverse DFT (IDFT) matrix columns:
   - Corresponds to multicarrier (OFDM) modulation; null subcarriers can cancel interferers
   - Performs slightly worse than other options
2) Subset of columns of identity matrix:
   - Corresponds to using null symbols in the time domain
   - Simple
3) Random semi-unitary matrix:
   - Pseudo-random generation
   - Higher complexity due to required matrix-vector multiplication.
   - Unauthorized detection difficult
   - Unauthorized decoding difficult

System Flowchart

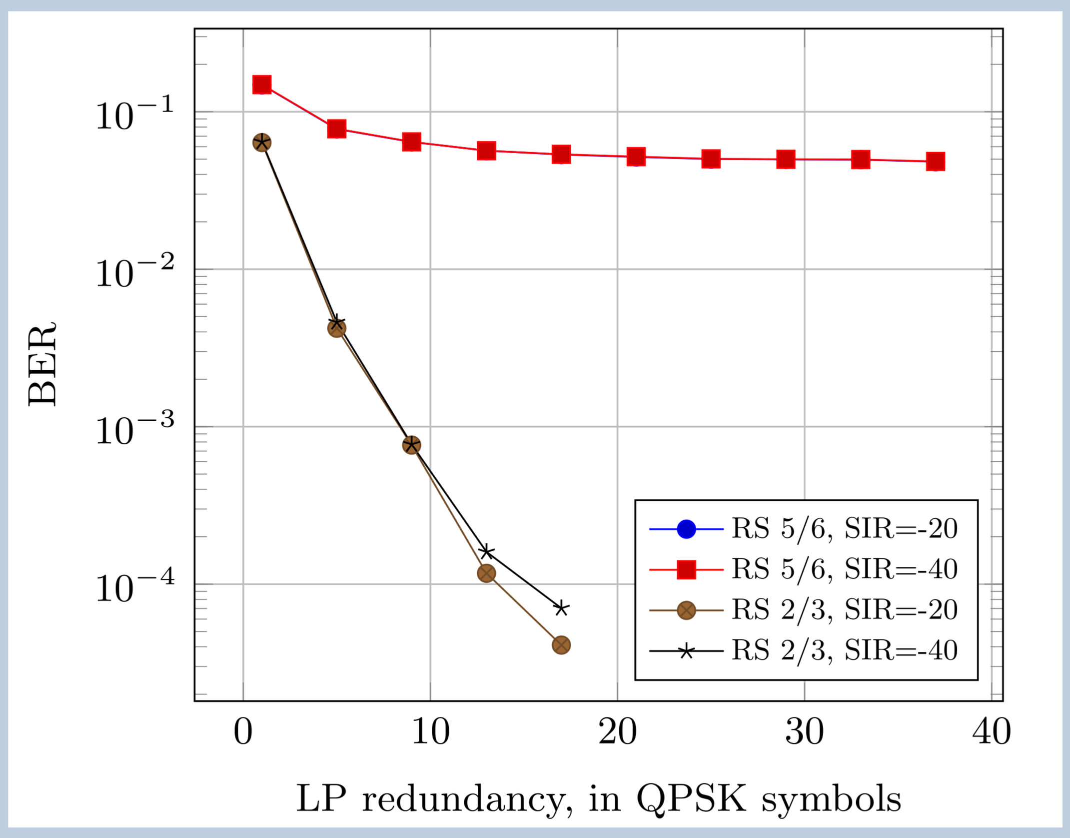


How Much Redundancy



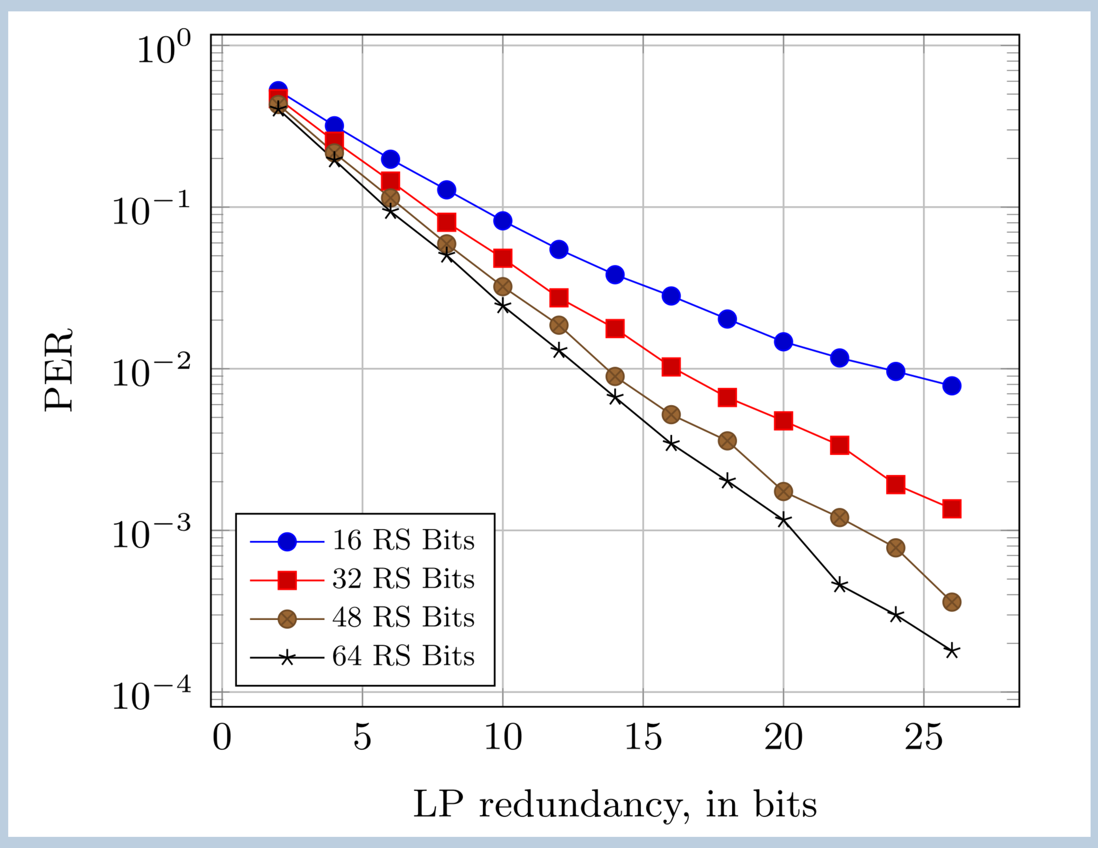
BER before RS correction vs. LP redundancy @ -40dB SIR

Reed Solomon and SIR



BER after RS correction vs. LP redundancy for different RS rates and SIR (in dB) combinations (SNR = 6 dB)

Trade-off: LP vs GF



PER as function of LP and RS redundancy (SNR = 8 dB, SIR =-40 dB)

Take-home

- "Arbitrary" (up to ADC limits) interference can be excised by linear precoding and multiple receive antennas
- Significant benefit for little redundancy
- Different precoders have different advantages and disadvantages
- Currently working on lab SDR implementation
- Commercialization (patent pending)