Interference Avoidance in Wireless Systems

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What Is Interference Avoidance?

- Each transmitter knows its channel (or average)
- Receiver broadcasts covariance
- Users greedily adjust modulation
- Receiver tracks codeword changes
- (Amazingly) everything settles down to an optimum

Where Are We Now?

- Interference avoidance can be used on:
  - fading/dispersive channels
  - asynchronous systems
  - multiuser MIMO systems
- REALLY want multiple mutually interfering transceivers
  - Not quite there yet
  - Might need interference-tropic (seeking) methods

Brass Tacks: Vector Channel Model

$$\mathbf{r} = \sum_{\ell=1}^{L} \mathbf{H}_\ell \mathbf{x}_\ell + \mathbf{n}$$

- User ℓ input vector $\mathbf{x}_\ell$: dimension N_ℓ
- Channel matrix $\mathbf{H}_\ell$: $N \times N_\ell$ $(N \geq N_\ell)$
- Received vector $\mathbf{r}$: dimension N
- Additive noise $\mathbf{n}$: dimension N

Multicode CDMA

- Each $\mathbf{x}$ is a superposition of independent information streams:

$$\mathbf{x} = \mathbf{S}\mathbf{b}$$

- where

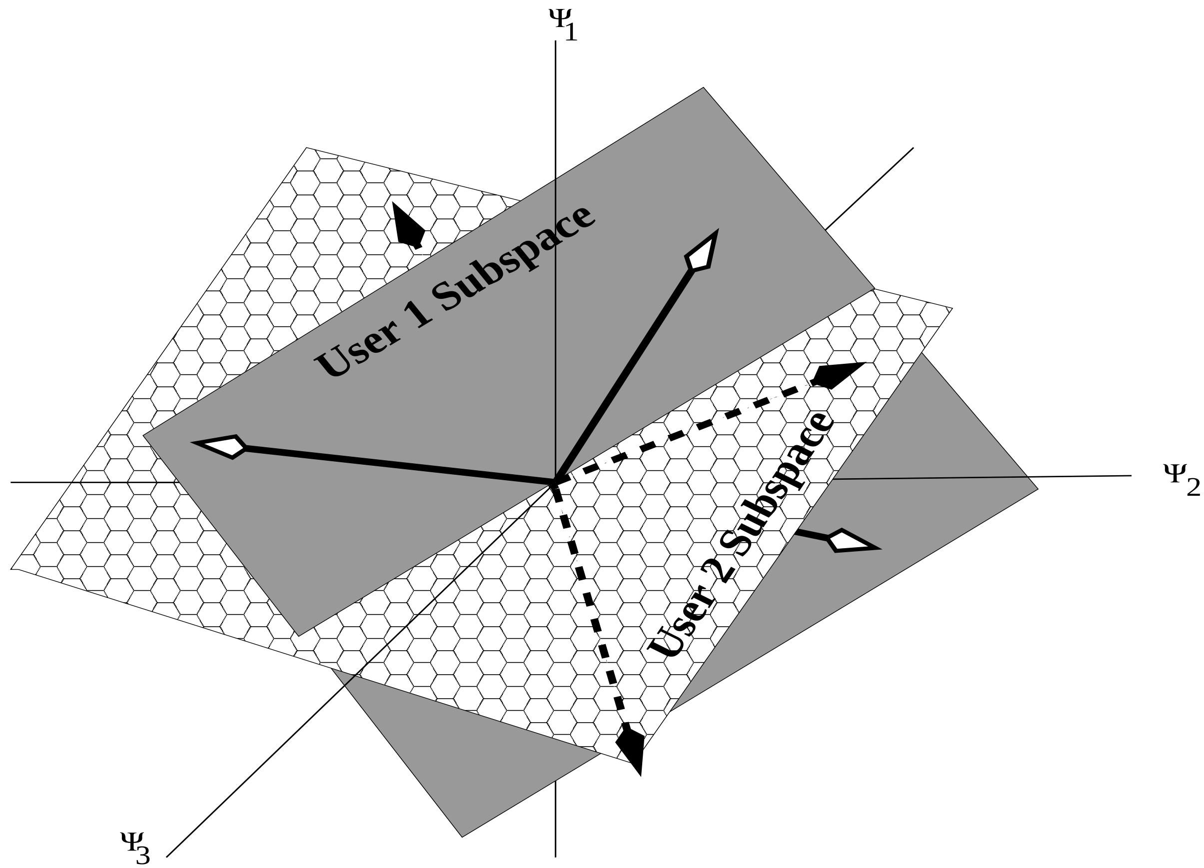
$$\mathbf{S} = \begin{bmatrix} | & | & \cdots & | \\ \mathbf{s}_1 & \mathbf{s}_2 & \cdots & \mathbf{s}_B \\ | & | & \cdots & | \end{bmatrix}$$

- and

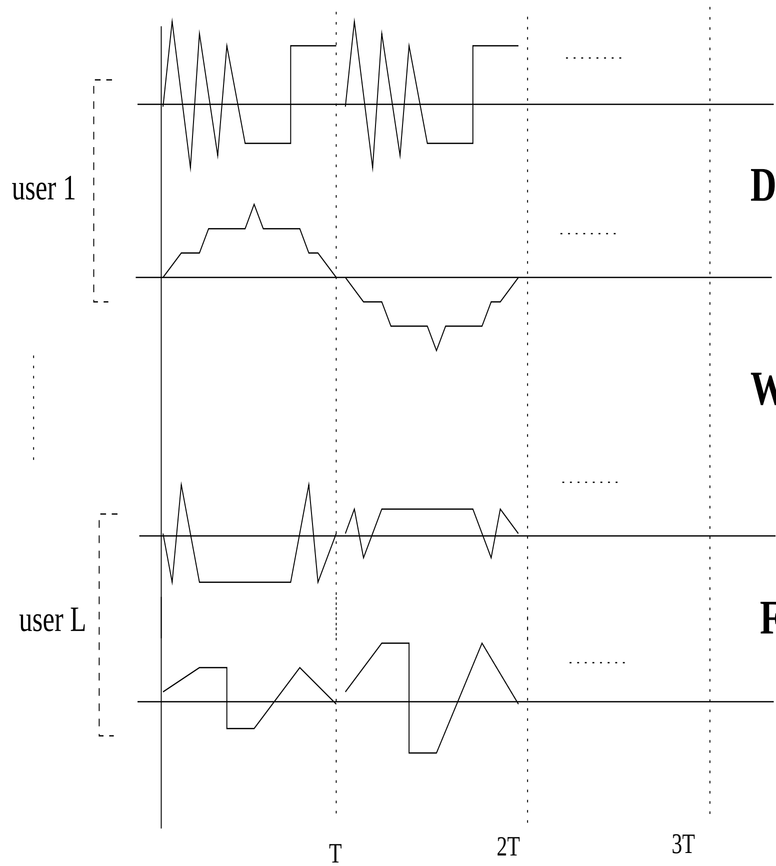
$$\mathbf{b}^\top = \begin{bmatrix} b_1 & \cdots & b_B \end{bmatrix}$$

- B: number of codewords used

Multicode Pictorial Representation



Yet Another Multicode Picture



Distinct waveform per symbol stream

Waveform scaled by symbol value

Frame synchrony (with guard time)

Our General approach to MAC

- different users in different signal spaces
- different dimensions and potential overlap
- all subspaces of the receiver signal space
- use multicode CDMA

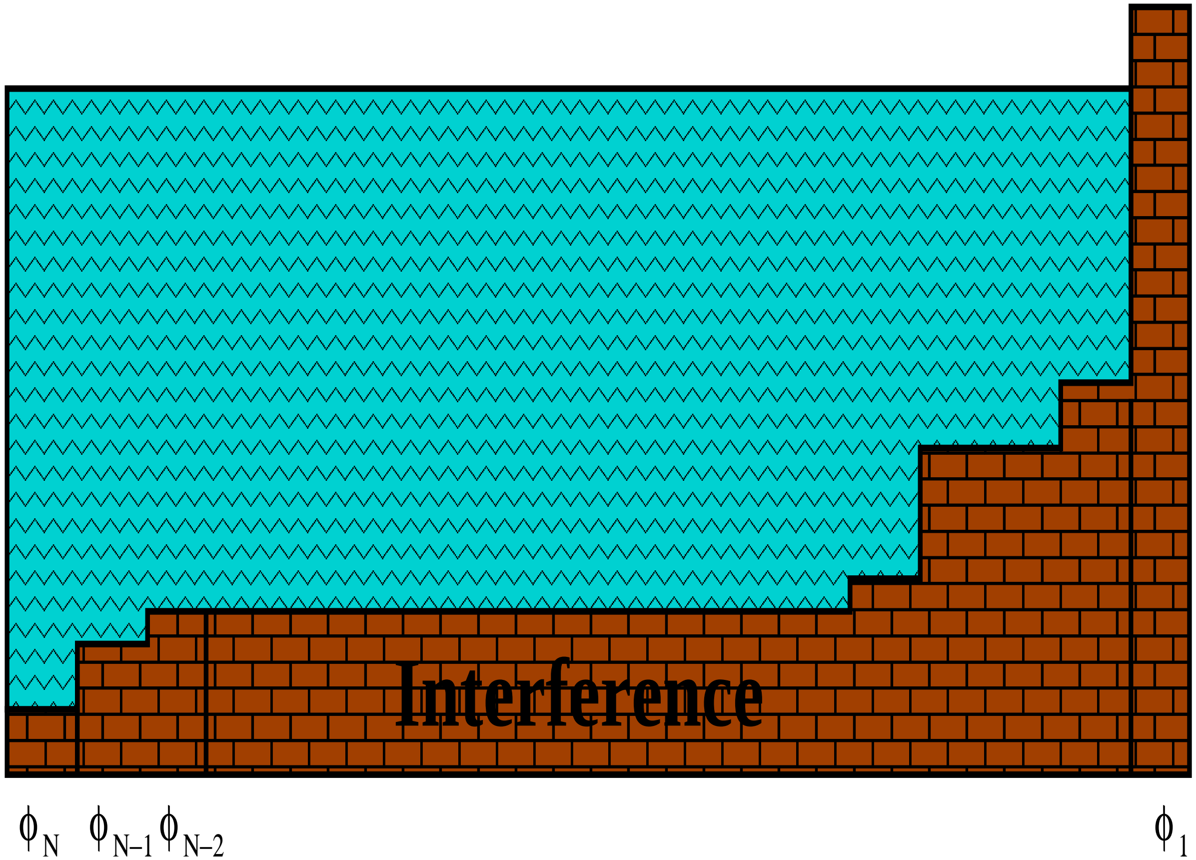
Interference Avoidance

- Done from the perspective of each infostream (each codeword $\mathbf{s}_{ij}$)
- A variety of replacement procedures and codeword orderings
- Guaranteed to converge *in class*
- A given user's codewords share the same SINR
- Optimal convergence proofs have been bears
- Empirically always converges to optimum

IA Iteration Possibilities

- MMSE: use MMSE filter coeffs as codeword (Ulukus & Yates)
- GREEDY: highest SINR codeword (and corresponding filter at receiver)
- LAGGED: use linear combo of current and greedy target
- RANDOM: do any other CW which increases your SINR.

EMERGENT Waterfilling



Whitening Approach Details

- Whitening:

$$\mathbf{Q}_k \mathbf{R} \mathbf{Q}_k^\top = \mathbf{S}_k \mathbf{S}_k^\top + \mathbf{Q}_k \left[\sum_{\ell \neq k} \mathbf{H}_\ell \mathbf{S}_\ell \mathbf{S}_\ell^\top \mathbf{H}_\ell^\top + \mathbf{W} \right] \mathbf{Q}_k^\top$$

- set

$$s_{kj} = \arg \min_{|\mathbf{x}|=1} \mathbf{x}^\top \left[\mathbf{S}_k \mathbf{S}_k^\top - \mathbf{s}_{kj} \mathbf{s}_{kj}^\top + \mathbf{Q}_k \left[\sum_{\ell \neq k} \mathbf{H}_\ell \mathbf{S}_\ell \mathbf{S}_\ell^\top \mathbf{H}_\ell^\top + \mathbf{W} \right] \mathbf{Q}_k^\top \right] \mathbf{x}$$

SINR Improvement Approach Details

- set

$$s_{kj} = \arg\max_{|\mathbf{x}|=1} \mathbf{x}^\top \mathbf{H}_k^\top \mathbf{R}_k^{-1} \mathbf{H}_k$$

where

$$\mathbf{R}_k = \left[\sum_\ell \mathbf{H}_\ell \mathbf{S}_\ell \mathbf{S}_\ell^\top \mathbf{H}_\ell^\top + \mathbf{W} - \mathbf{H}_k \mathbf{s}_{kj} \mathbf{s}_{kj}^\top \mathbf{H}_k^\top \right]$$

Sum Capacity and IA

- Sum Capacity:

$$C = \frac{1}{2}\log\left[\det\left(\underbrace{\sum_{\ell=1}^{L}\mathbf{H}_\ell\mathbf{S}_\ell\mathbf{S}_\ell^\top\mathbf{H}_\ell^\top + \mathbf{W}}_{\mathbf{R}}\right)\right] - \frac{1}{2}\log(\det\mathbf{W})$$

- Simultaneous waterfilling $\rightarrow$ maximum sum capacity
  - assuming each user has enough codewords to waterfill
- IA (optimal) fixed point is mutual waterfilling

IA: not necessarily iterative waterfilling

- Iteratively replace each user's codewords until convergence
  - Iterative waterfilling $\rightarrow$ maximum sum capacity [Yu, et al, 2001]
- Randomly replace codewords until convergence
  - Simultaneously waterfilled ensembles $\rightarrow$ maximum sum capacity
- Too few codewords (true waterfilling impossible) still converges
  - Sum capacity max'ed? (not known, suspect yes)

IA and OFDM Channel Models

- Use tones as basis
- Obviously complex representations possible, but ...
  - Single-sided: trouble with too few dimensions (not enough eigenvectors)
  - Double-sided: unrealizable codewords
- Could adapt with some redefinitions and algebraic play
- We use real representations for “notational simplicity”

Conclusions

- Interference + Multiaccess Channels = maximum sum capacity
  - Iterate per user (iterative waterfilling)
  - Iterate other ways (emergent waterfilling)
- Iteratively increases sum cap when true waterfilling impossible
- Can apply IA to any vector channel problem:
  - general dispersive channels,
  - multiuser MIMO
  - asynchronous systems, etc.
- Future: independent mutually interfering systems – interference channel