Low Complexity Primary User Protection for Cognitive OFDM

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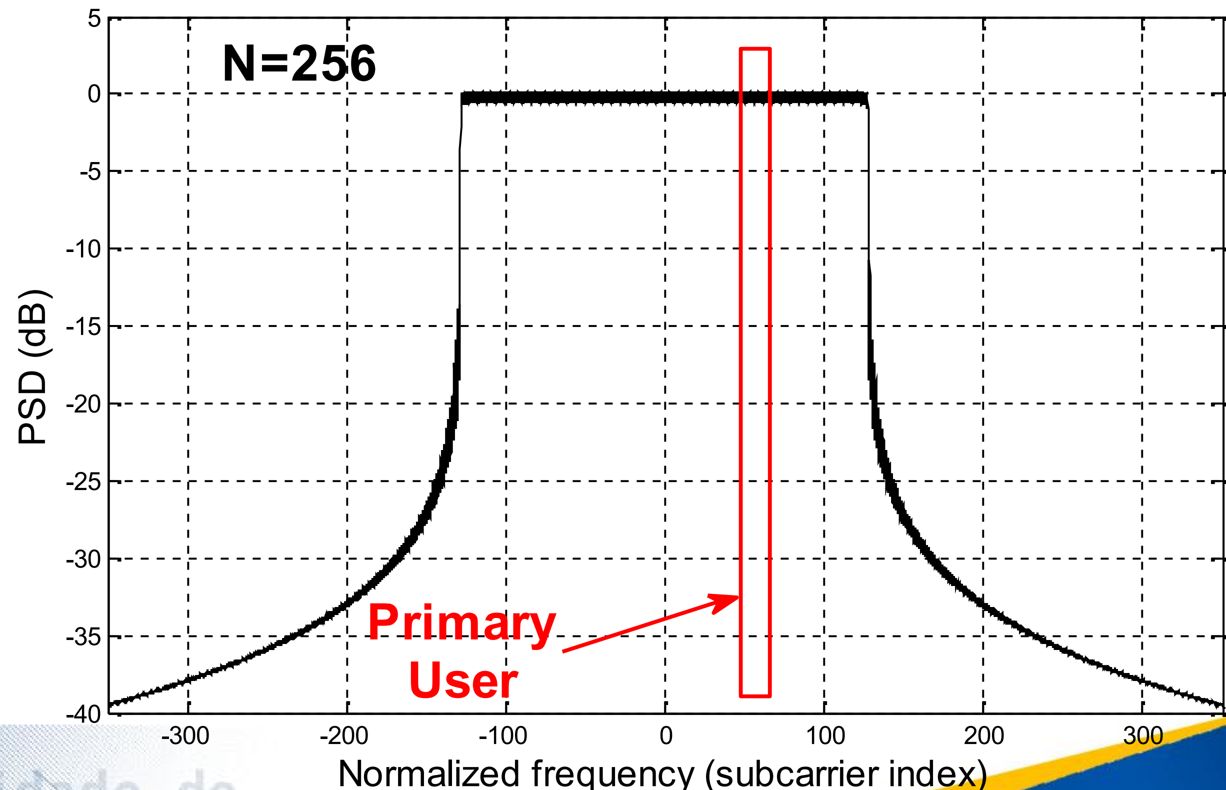
Motivation

- Cognitive OFDM → Nice features
  - Widely adopted modulation scheme
  - High spectrum efficiency
  - Good bandwidth partitioning
- Cognitive OFDM → Challenges
  - High out of band radiation (sidelobes)
  - Significant interference to primary users

Problem Statement

- Narrowband primary user (PU) within secondary user (SU) OFDM band.
- Goal: Minimize power spill over PU band → PU protection



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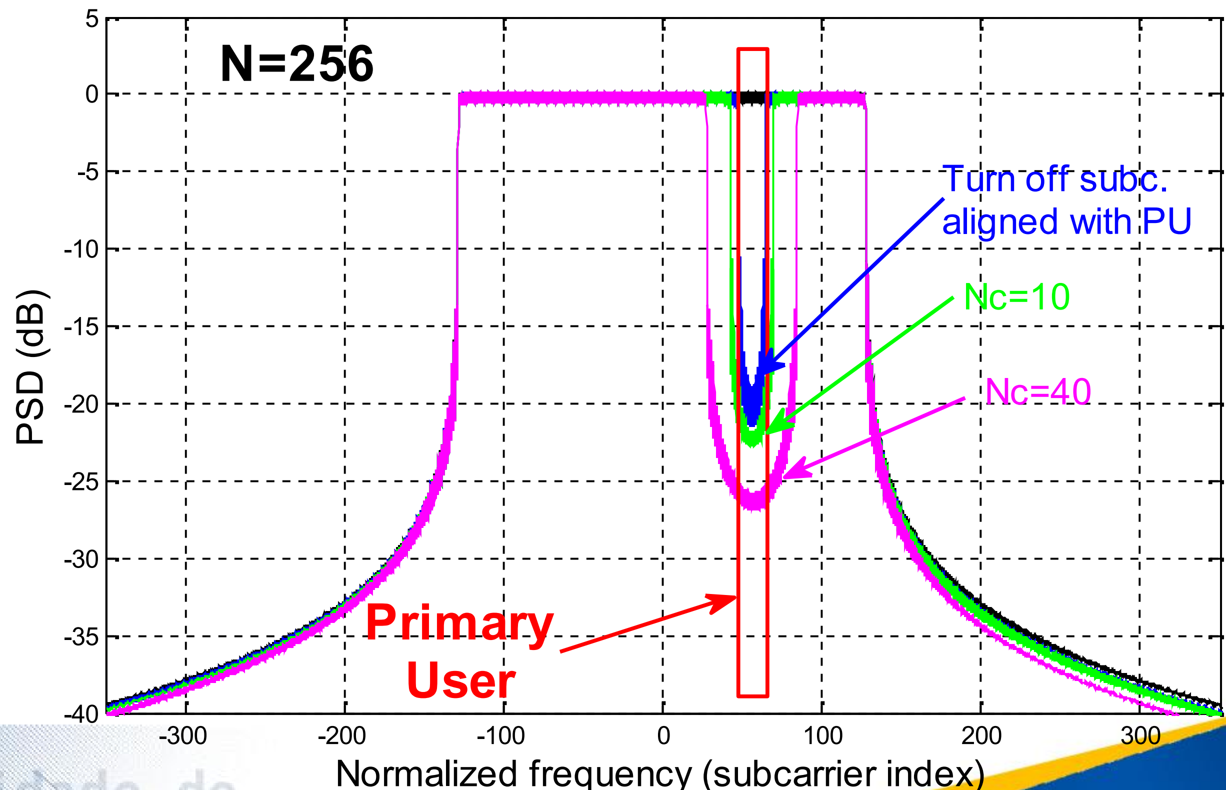


Current solutions

- Symbol Precoding
- Active interference cancellation (AIC)
  - Focus is set here
  - Online complexity is a concern

Signal model (for AIC)

- Cognitive SU OFDM transmission with N subcarriers
- PU band $\mathcal{B}$ is covered by N_P contiguous SU subcarriers.
- N_P (aligned with band $\mathcal{B}$) plus N_C subcarriers for OBR reduction
- Remaining $N_D = N - N_P - N_C$ subcarriers unaffected for data transmission.

$$\boldsymbol{x} = [\ x_0 \quad x_1 \quad \cdots \quad x_{N-1}\ ]^T = \alpha \boldsymbol{S}\boldsymbol{d} + \boldsymbol{T}\boldsymbol{c}$$

Subcarrier Coefficients; Power split; Data symbols; Cancellation coefficients

- OFDM symbol spectrum is given by $X(f) = \sum_{k=0}^{N-1} x_k \phi_k(f) = \boldsymbol{x}^T \boldsymbol{\phi}(f)$

$$\phi_k(f) = M e^{-j\pi \frac{M}{N}\left(\frac{f}{\Delta_f} - k\right)} \operatorname{sinc}_M \left[\frac{1}{N}\left(\frac{f}{\Delta_f} - k\right)\right] \mathcal{G}(f)$$

Proposed PSD based AIC

- In reported AIC, OFDM symbols given as $\boldsymbol{x} = \alpha \boldsymbol{S}\boldsymbol{d} + \boldsymbol{T}\boldsymbol{c}$
- We propose generating $\boldsymbol{c} = \boldsymbol{\Theta}\boldsymbol{d}$, with $\boldsymbol{\Theta}$ fixed such that

$$\boldsymbol{x} = (\alpha \boldsymbol{S} + \boldsymbol{T}\boldsymbol{\Theta})\boldsymbol{d} = \boldsymbol{G}\boldsymbol{d}$$

Memoryless and static

- Then the signal PSD can be aproximated

$$P_x(f) \approx E\left\{|X(f)|^2\right\}$$
$$= \boldsymbol{\phi}^H(f)E\{\boldsymbol{x}\boldsymbol{x}^H\}\boldsymbol{\phi}(f) = \boldsymbol{\phi}^H(f)\boldsymbol{G}E\{\boldsymbol{d}\boldsymbol{d}^H\}\boldsymbol{G}^H\boldsymbol{\phi}(f)$$

- Then, if $E\{\boldsymbol{d}\boldsymbol{d}^H\} = \boldsymbol{I}_{N_D}$, $\boldsymbol{G}$ can be optimized offline ➡ Low online complexity!
- Cancellation coefficients optimization → Derivation of weight matrix $\boldsymbol{\Theta}$

Derivation of cancellation coefficients

- With the proposed definition, the problem can be stated as

$$\min_{\boldsymbol{\Theta}} \int_{\mathcal{B}} P_x(f)\mathrm{d}f \quad \text{s.t.} \quad \int_{-\infty}^{\infty} P_x(f)\mathrm{d}f \leq P_{\max}$$

- Using $P_x(f) \approx \mathrm{tr}\{\boldsymbol{G}^H \boldsymbol{\Phi}(f)\boldsymbol{G}\}$ ….

$$\min_{\boldsymbol{\Theta}} \mathrm{tr}\{\boldsymbol{G}^H(\boldsymbol{\Theta})\boldsymbol{\Phi}_{\mathcal{B}}\boldsymbol{G}(\boldsymbol{\Theta})\} \qquad \text{s.t.} \quad \mathrm{tr}\{\boldsymbol{G}^H(\boldsymbol{\Theta})\boldsymbol{\Phi}_{\mathcal{T}}\boldsymbol{G}(\boldsymbol{\Theta})\} \leq P_{\max}$$

$$\boldsymbol{\Phi}_{\mathcal{B}} \triangleq \int_{\mathcal{B}} \boldsymbol{\Phi}(f)\mathrm{d}f$$

$$\boldsymbol{\Phi}_{\mathcal{T}} \triangleq \int_{-\infty}^{\infty} \boldsymbol{\Phi}(f)\mathrm{d}f$$

$$\boldsymbol{G} = \alpha\boldsymbol{S} + \boldsymbol{T}\boldsymbol{\Theta}$$

- Which has LS (unconstrained) solution:

$$\boldsymbol{\Theta}_{\mathrm{LS}} = \alpha\bar{\boldsymbol{\Theta}}_{\mathrm{LS}},$$
$$\bar{\boldsymbol{\Theta}}_{\mathrm{LS}} \triangleq -(\boldsymbol{T}^T\boldsymbol{\Phi}_{\mathcal{B}}\boldsymbol{T})^{-1}(\boldsymbol{T}^T\boldsymbol{\Phi}_{\mathcal{B}}\boldsymbol{S}),$$

- If $\boldsymbol{\Theta}_{\mathrm{LS}}$ satisfies the power constraint then it's the optimal solution, else…

$$\min_{\boldsymbol{\Theta}} \mathrm{tr}\{\boldsymbol{G}^H(\boldsymbol{\Theta})\boldsymbol{\Phi}_{\mathcal{B}}\boldsymbol{G}(\boldsymbol{\Theta})\} \qquad \text{s.t.} \quad \mathrm{tr}\{\boldsymbol{G}^H(\boldsymbol{\Theta})\boldsymbol{\Phi}_{\mathcal{T}}\boldsymbol{G}(\boldsymbol{\Theta})\} = P_{\max}$$

- This can be efficiently solved using → gsvd, Lagrange multipliers

- Optimal coefficients have closed form solution

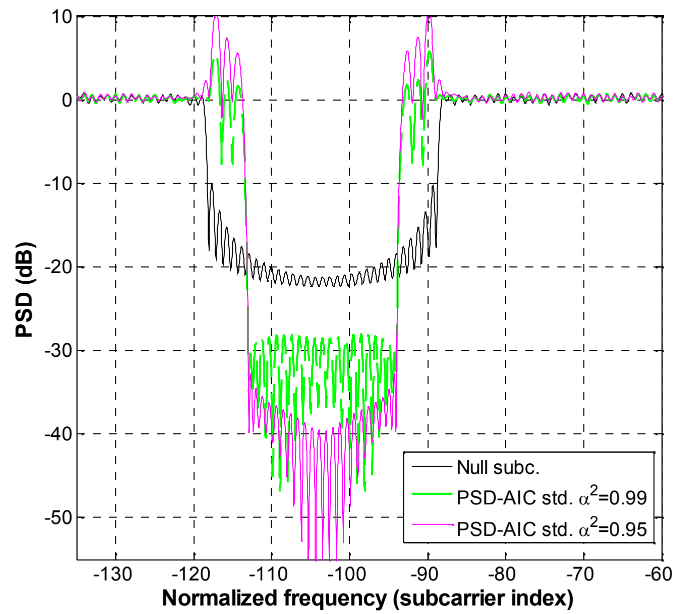
$$\boldsymbol{\theta}_i = -\alpha\boldsymbol{X}(\boldsymbol{D}_A^2 + \lambda\boldsymbol{D}_B^2)^{-1}(\boldsymbol{D}_A\boldsymbol{U}^H\boldsymbol{p}_i + \lambda\boldsymbol{D}_B\boldsymbol{V}^H\boldsymbol{q}_i)$$

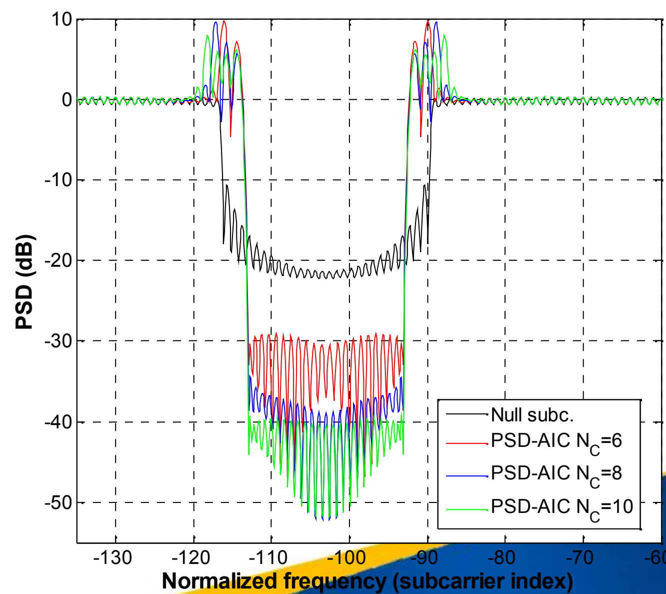
Weight optimization results

Mean notch depth over PU band

	$N_C = 6$	$N_C = 8$	$N_C = 10$
Full load	-17.8	-17.8	-17.8
Null subcarriers	-20.6	-21.1	-21.6
PSD-AIC $\alpha^2 = 0.99$	-28.1	-31.9	-36.8
PSD-AIC $\alpha^2 = 0.98$	-30.2	-36.2	-40.3
PSD-AIC $\alpha^2 = 0.97$	-32.0	-38.6	-41.8
PSD-AIC $\alpha^2 = 0.96$	-33.6	-39.9	-42.5
PSD-AIC $\alpha^2 = 0.95$	-34.9	-40.7	-43.1

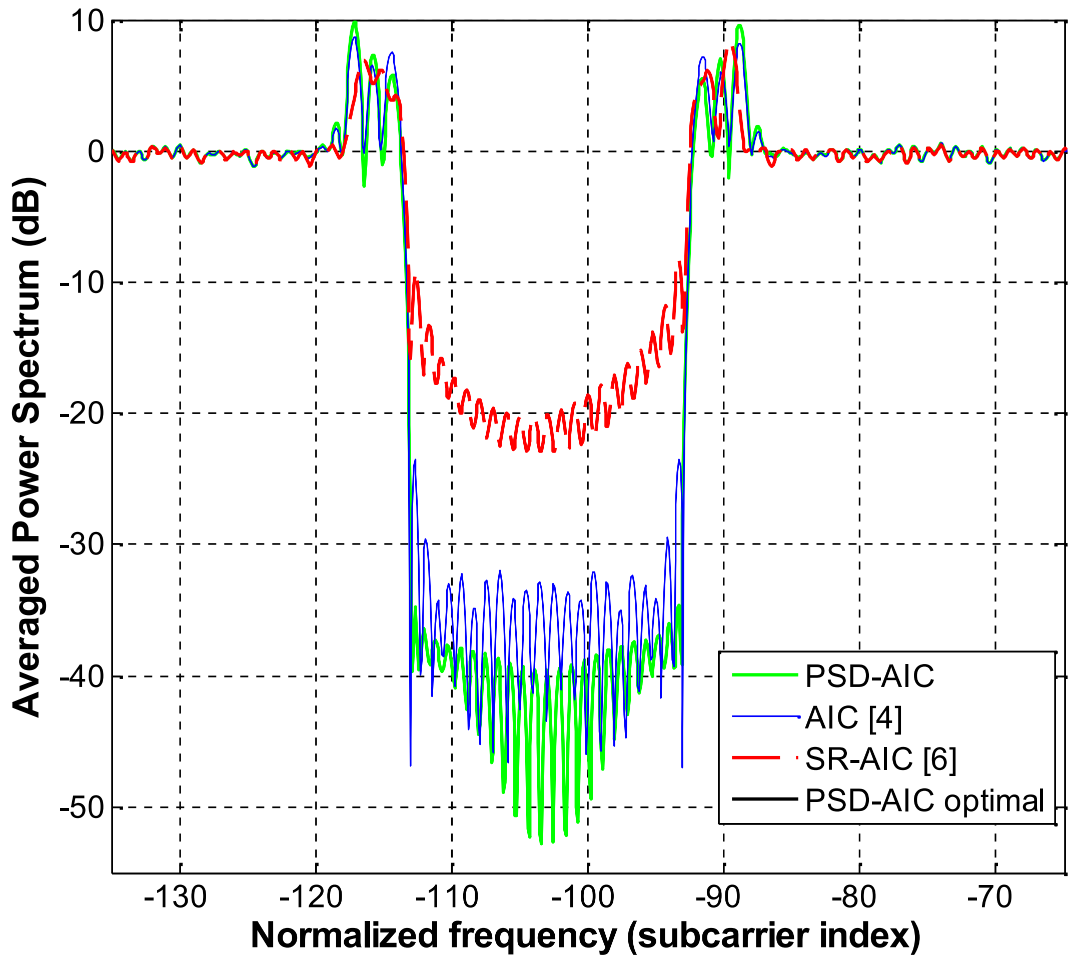
Mean notch depth is expressed in dB. $N = 1024$, $N_P = 20$.





- Very good PU protection performance
- Very low implementation cost → $\boldsymbol{c} = \boldsymbol{\Theta d}$

Comparison with available AIC solutions



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Conclusions

- Novel AIC design
  - Weight optimization based on PSD
    - Offline approach
    - Low implementation cost → Enables placement optimization
- Low implementacion cost → much lower
- Better protection performance

Thanks!