# Optimal Pilot Patterns Considering Optimal Power Loading for Cognitive Radios in the Two Dimensional Scenario

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# Contents

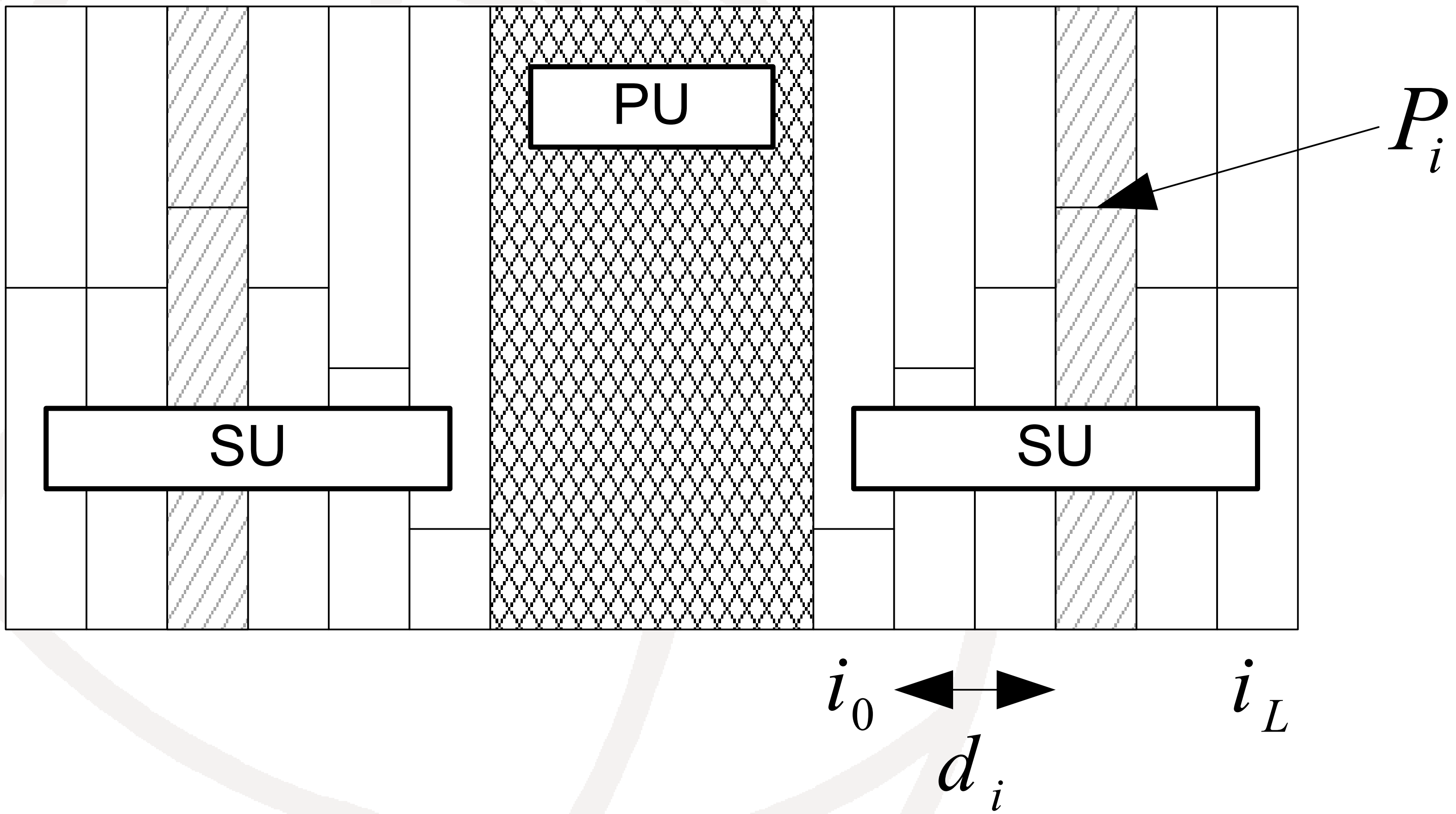
# Cognitive Radio Principles

- Spectrum crowding
  - Increasing information drives increasing spectrum demand
  - Practical spectrum range is heavily congested
  - Expensive spectrum
- Temporal underutilization
  - 15% - 85%, wide geographic dispersion [1]
  - 7% for suburban environments [2]
- Efficient utilization
  - Interference control
  - Maximize transfer rates

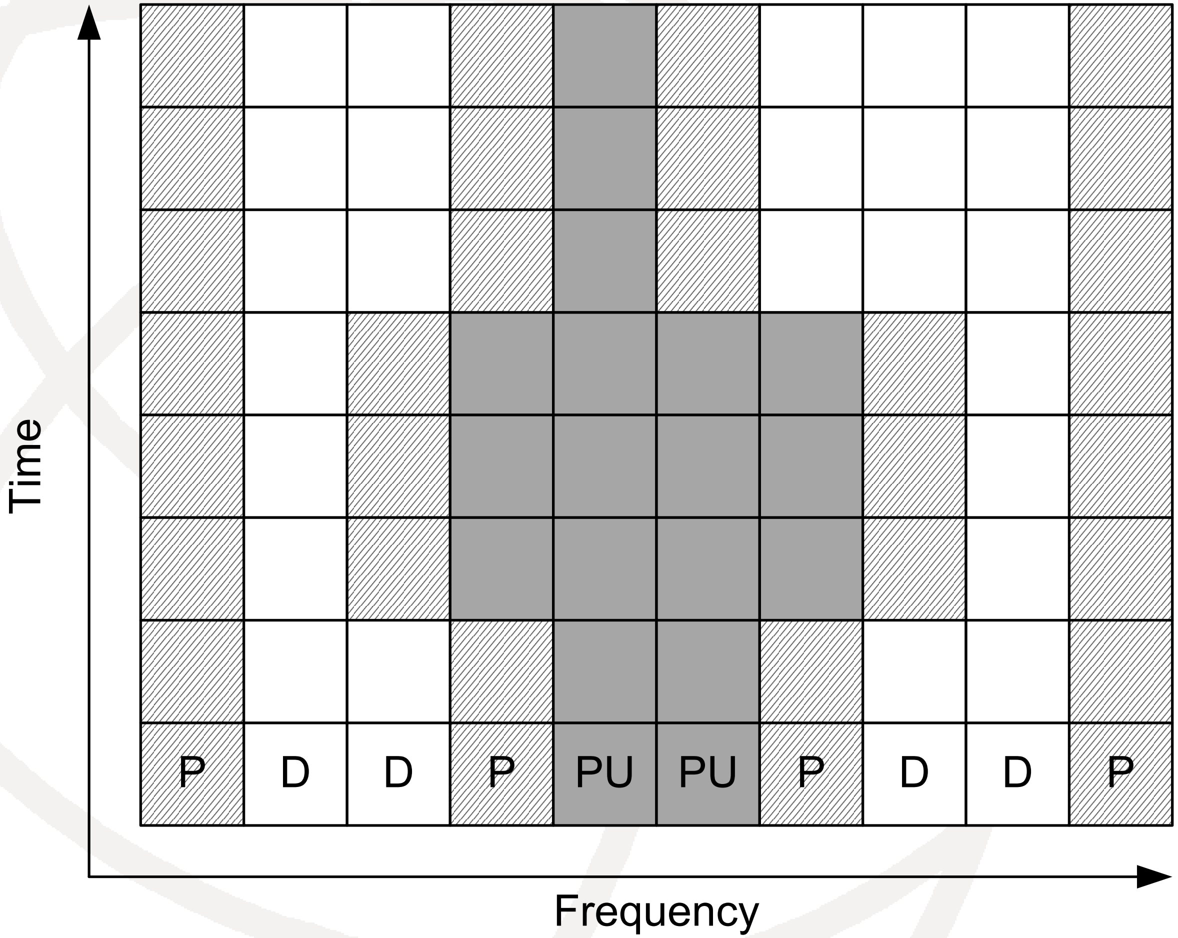
# OFDM-based Cognitive Radios

- OFDM modulation approaches Shannon limit
- Sets of sub-carriers assigned to different users
- Sub-carriers interfering with primary users (PUs) may be disabled
- Optimal, instantaneous utilization of spectrum

# Visualization



# Two-Dimensional Variance



# Optimal Power Loading

- Secondary/CR users (SUs) need to maintain interference to PUs below a threshold [3]
- Waterfilling is optimal for contiguous OFDM but not non-contiguous (NC) OFDM
- Optimal, NC-OFDM waterfilling requires that channels closer to the PUs have less power [4]

# Optimal Power Loading Formulation

- $$P_i^* = \frac{1}{\lambda \cdot \frac{\partial I_{SU}}{\partial P_i}} - \frac{\sigma^2 + I_{PU}}{|H(i)|^2}$$

- Note: sub-channels closer to the PU will have less power assigned to them.

# Optimal Pilot Patterns

- Channel estimation greatly reduces BER
- LS & MMSE estimators are most common
- LS is low complexity & less accurate, MMSE is high complexity & more accurate
- Both need to be as close as possible to the PU in order to reduce estimator MSE [4].

# LS Estimator Error

- Linear interpolation assumed
- $$\varepsilon_{\text{int}} \leq \frac{d_{p,p'}{}^2}{8} \cdot \max \left| \frac{\partial^2 H(p,p')}{\partial i^2} \right|$$
- $$\varepsilon_p = \hat{\mathbf{H}}_p - \mathbf{H}_p = \mathbf{P}^{-1} \mathbf{n}_p$$
- Note: the error decreases exponentially when closer to the PU & increases when SNR decreases

# Contradicting Aspects

- Optimal CR pilot patterns require new pilots adjacent to PU
- Optimal power loading will assign less power to adjacent sub-channels
- A solution is required to find optimal placement when both aspects are considered!

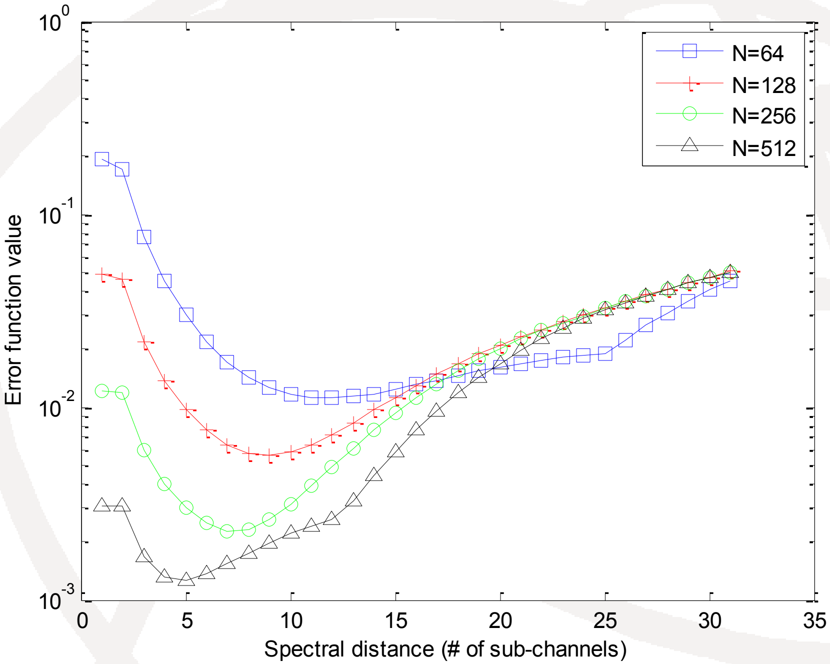
# Problem Formulation

- $$\varepsilon = \min_i \left|\varepsilon_p\right| + \varepsilon_{\text{int}}$$

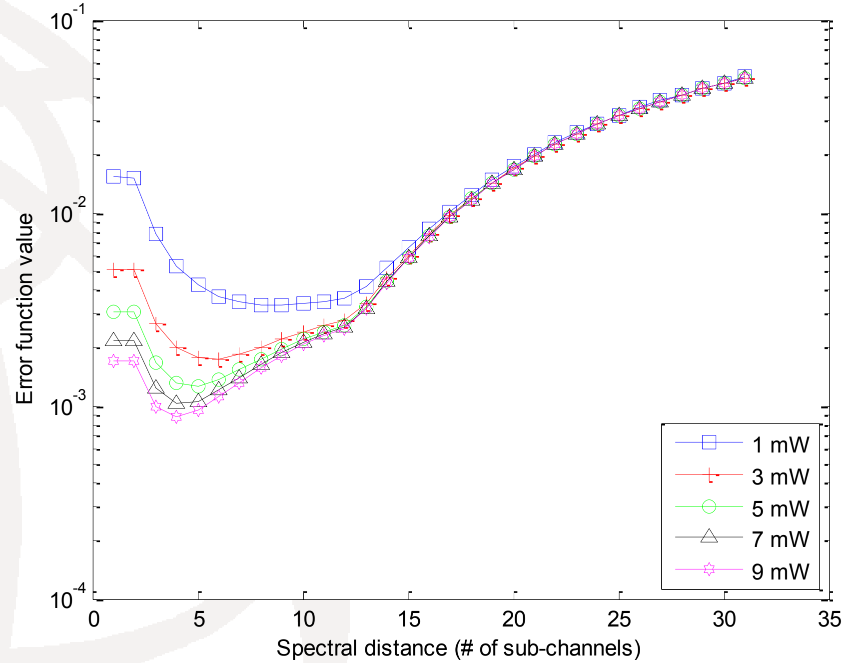
$$= \frac{\sigma^2 + I_{PU}(i)}{P_i^*}$$

$$+ \frac{(i - i_L)^2}{8} \max \left| \sum_{l=0}^{L-1} \frac{-4\pi^2 \tau_l^2}{N_{fft}^2} \alpha_l \exp\left( \frac{-2j\pi\tau_l i}{N_{fft}} \right) \right|$$

# Simulation Results




Fixed Interference Threshold




Fixed PU Bandwidth

# Conclusion

- An inter-dependence was identified where optimal power loading needs to be considered for optimal pilot patterns
- A naïve 2-dimensional optimization problem was proposed and simulated
- It was found that the new optimal pilot placements are drastically different

# Standardization Aspects

- Power loading & pilot pattern algorithms will need to be implemented & standardized
- The optimal versions of both algorithms cannot coexist together
- The proposed algorithm allows both aspects to be optimally implemented

# References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