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

Boyan Soubachov, Neco Ventura
University of Cape Town
{boyan,neco}@crg.ee.uct.ac.za
Contents

- Introduction
- Overview - OFDM-based Cognitive Radios
- Related Research & System Model
- Problem Formulation
- Optimal Solution
- Simulation Results
- Conclusion
- Standardization Aspects
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

Cape Town, South Africa, 12-14 December 2011
Two-Dimensional Variance

Frequency

Time

P D D P PU PU P D D D P
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

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

- 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

\[ \varepsilon_{\text{int}} \leq \frac{d_{p,p'}}{8} \cdot \max \left| \frac{\partial^2 H(p, p')}{\partial t^2} \right| \]

\[ \varepsilon_p = \hat{H}_p - H_p = P^{-1}n_p \]

- 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

\[ \epsilon = \min_{i} |\epsilon_p| + \epsilon_{\text{int}} \]

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

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


