OPPORTUNISTIC SPECTRUM ALLOCATION FOR MAX-MIN RATE IN NC-OFDMA

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NC-OFDM BASICS

• What is NC-OFDM?
  • A method of transmission where some of the subcarriers in OFDM are nulled

• How is it useful?
  • Well suited to make use of non-contiguous spectrum
  • Allows the radios to access the unused spectrum without interfering with the licensed users
  • Enables multiple access system
  • Dynamically adapt to changing spectrum conditions
  • Example: TV white space
NC-OFDM BASICS

Associated challenges:

• It can lead to allocating subcarriers spread over a wide range of frequencies, which leads to higher sampling rate at the receiver causing higher system power consumption.

• It can suffer from high out-of-band radiation due to the high sidelobes of its modulated subcarriers.
EXAMPLE NETWORK

Radio nodes
Interference nodes
Available channels

Controller

Radio nodes
Interference nodes

Available channels
BIG PICTURE: SDR-SDN ARCHITECTURE
NETWORK SETUP AND OBJECTIVES

- $N$ point-to-point links consisting of a transmitter and a receiver node
- Total of $M$ channels; each with bandwidth of $W$ Hz
- All links can potentially interfere with each other, therefore we assume orthogonal spectrum allocation

Goal:

Fair spectrum allocation while considering system power consumption
We introduce the following assumptions.

- A system with perfect channel sensing
- A global controller with complete knowledge
- A perfect control channel between the controllers and nodes
WHY IS SPECTRAL SPAN IMPORTANT?

- Sampling rate increases with increasing bandwidth, which in turn increases the system power consumption.

- Limiting the spectral span allows for fixed sampling rate at ADC/DAC of the receiver.
ADC/DAC POWER CONSUMPTION

(a) ADS62P4x (ADC of USRP radio) and ADS4249

(b) AD 9777 (DAC of USRP radio) and DAC 3162
ADC/DAC POWER CONSUMPTION

- Higher bandwidth requires higher sampling rate.
- Power consumption in ADC/DAC is a function of the sampling rate.
- For large spectrum span ADC/DAC power consumption can dominate the transmission power.
MAX-MIN RATE OPTIMIZATION

**Objective**

**Bandwidth constraint**

\[ B_l \leq b \cdot W \quad \forall l \in \mathcal{N}, \]

**Rate constraints**

\[ r_l^m = c_l^m \cdot a_{lm} \quad \forall l \in \mathcal{N}, \forall m \in \mathcal{M}, \]

\[ r_l = \sum_{m=1}^{M} r_l^m \quad \forall l \in \mathcal{N}, \]

\[ \sum_{l=1}^{N} a_{lm} \leq 1, \quad \forall m \in \mathcal{M}, \]

**Allocation constraints**

\[ a_{lm} \in \{0, 1\} \quad \forall l \in \mathcal{N}, \forall m \in \mathcal{M}. \]
HOW TO SOLVE THIS?

• The problem formulation is an **Integer linear program**, which is an NP-hard problem.

• We solve the integer program using the **MOSEK** solver via CVX in MATLAB.

• MOSEK uses continuous relaxation with a goal of computing **near-optimal solution** instead of finding an optimal solution.

• To compare the results we also find the globally optimal solution in a **brute-force manner (exhaustive search)** by considering all possible channel allocations.
SIMULATION TOPOLOGY

Radio nodes
Interference nodes

Available channels

n_1 \rightarrow n_2 \rightarrow n_3
n_4 \leftarrow n_5 \leftarrow n_6
n_7 \leftarrow n_8
HOW LARGE SHOULD THE SPAN BE?
HOW LARGE SHOULD THE SPAN BE?

Key Takeaways

• It is possible to reduce the spectrum span without incurring a large penalty in Max-Min rate.
• We can modify our goal to “spectrum allocation that maximizes the minimum rate achieved by the cognitive radio links, under a constraint on the maximum permissible spectral span.”
EXAMPLE OF REDUCTION IN SPAN

<table>
<thead>
<tr>
<th></th>
<th>Link 1</th>
<th>Link 2</th>
<th>Link 3</th>
<th>Link 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span w/o constraint</td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Rate w/o constraint (Mbps)</td>
<td>5.95</td>
<td>4.6</td>
<td>5.1</td>
<td>5.8</td>
</tr>
<tr>
<td>Span with constraint</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Rate  with constraint (Mbps)</td>
<td>4.2</td>
<td>4.57</td>
<td>4.21</td>
<td>5.6</td>
</tr>
</tbody>
</table>
SIMULATION RESULTS

Data rate (Mbps)

- With no interference
- With interference but without reallocation
- With interference after reallocation

| L_1 | n_1-n_2 |
| L_2 | n_3-n_4 |
| L_3 | n_5-n_7 |
| L_4 | n_6-n_8 |
USRP N210, with SBX transceiver daughter-card
- Operating spectral range of 400 MHz to 4.4 GHz and Maximum transmit power of 100 mW
- Transmission bandwidth: 1MHz
- Number of subcarriers: 128
GNU RADIO IMPLEMENTATION

Transmitter

Bits → Symbol Mapping

Symbol Mapping → IFFT → CP → P/S → DAC & RF

PN Sync → Allocation vector

Receiver

RF & ADC → Data filter → Sync filter → Sync & frequency offset

Sync & frequency offset → FFT → P/S → Bit Mapping

Allocation vector
CHALLENGES IN EXPERIMENTS

• **Out of band radiation**
  • Introduced the guard band between subcarrier allocation for different communication

• **Synchronization**
  • Allocated dedicated out-of-band channels for each link only for synchronization (Not a scalable solution).
EXPERIMENT ON ORBIT TESTBED

**Parameters**

- **Bandwidth**: 1MHz
- **Subcarriers (SC)**: 112
- **No. of SC used for sync**: 16
- **No. of SC per channel**: 4
- **Channel BW**: 31.25 kHz
- **Tx power**: 1mW
- **Interfering Tx power**: 4mW
- **Span constraint**: 20 channels

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- **n₁-n₂**: With no interference
- **n₃-n₄**: With interference but without reallocation
- **n₃-n₄ (dark)**: With interference after reallocation

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Diagram showing the layout of radio nodes and interference nodes, with distances and data rate measurements for different scenarios.
SUMMARY

• NC-OFDM enables non-contiguous spectrum usage.
• Spectral span can significantly affect system power consumption.
• Spectral span acts as a surrogate for system power consumption.
• We propose a fair spectrum allocation algorithm that also factors in system power consumption.
• Simulations show that it is possible to allocate spectrum in a fair manner while restricting the spectral span.
• We find similar trend in both simulation and experiment.
FUTURE DIRECTIONS

• Scalable synchronization scheme
• Spectrum allocation for NC-OFDMA with incomplete knowledge of spectrum availability
• Design of control plane for NC-OFDM enabled system
QUESTIONS?