Sensing-based Resource Allocation In Cognitive Radio Networks

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Mostly based on

Outline

• Cognitive radio concept

• Two important topics in cognitive radio networks
  • Spectrum sensing
  • Resource allocation

• Sensing based resource allocation in
  ✔ CDMA-based cognitive radio networks
  ✘ OFDMA-based cognitive radio networks

• Conclusion and suggestions
Motivation

UNITED STATES FREQUENCY ALLOCATIONS
THE RADIO SPECTRUM
Motivation

Measured Spectrum Occupancy Averaged over Seven Locations

- PLM, Amateur, others: 30-54 MHz
- TV 2-6, RC: 54-88 MHz
- Air traffic Control, Aero Nav: 108-138 MHz
- Fixed Mobile, Amateur, others: 138-174 MHz
- TV 7-13: 174-216 MHz
- Maritime Mobile, Amateur, others: 216-225 MHz
- Fixed Mobile, Aero, others: 225-406 MHz
- Amateur, Fixed, Mobile, Radiolocation, 406-470 MHz
- TV 14-20: 470-512 MHz
- TV 21-36: 512-608 MHz
- TV 37-51: 608-698 MHz
- TV 52-69: 698-806 MHz
- Cell phone and SMR: 806-902 MHz
- Unlicensed: 902-928 MHz
- Paging, SMS, Fixed, BX Aux, and FMS: 928-966 MHz
- IFF, TACAN, GPS, others: 960-1240 MHz
- Amateur: 1240-1300 MHz
- Aero Radar, Military: 1300-1400 MHz
- Space/Satellite, Fixed Mobile, Telemetry: 1400-1525 MHz
- Mobile Satellite, GPS, Meteorological: 1525-1710 MHz
- Fixed, Fixed Mobile: 1710-1850 MHz
- PCS, Asyn, Iso: 1850-1990 MHz
- TV Aux: 1990-2110 MHz
- Common Carriers, Private, MDS: 2110-2200 MHz
- Space Operation, Fixed: 2200-2300 MHz
- Amateur, WCS, DARS: 2300-2360 MHz
- Telemetry: 2360-2390 MHz
- U-PCS, ISM (Unlicensed): 2390-2500 MHz
- ITFS, MMDS: 2500-2686 MHz
- Surveillance Radar: 2686-2980 MHz
Dynamic Spectrum Access

- Dynamic Spectrum Access
  - Dynamic Exclusive Use Model
  - Open Sharing Model
  - Hierarchical Access Model
  - Primary/Secondary User
  - Spectrum Underlay
  - Spectrum Overlay
  - Spectrum interweave

Cognitive Radio
CRN Operation Models

Underlay

Overlay

Primary user

Secondary user
CR Operation Models

Interweave Paradigm

- Primary user
- Secondary user

Time

Frequency

Frame $n$

- Sensing: $\tau$
- Data Transmission: $T-\tau$

Frame $n+1$

- Sensing: $\tau$
- Data Transmission: $T-\tau$
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Spectrum sensing

\[ H_0 : x(q) = v(q) \]
\[ H_1 : x(q) = h(q)s(q) + v(q), \quad q = 1, \ldots, Q \]
Spectrum sensing

• Performance of Spectrum sensing
  • Pd: Detection probability
  • Pf: False alarm probability

• Spectrum sensing challenges
Cooperative spectrum sensing

- CSS challenges
  - Non ideal Sensing and Reporting channels
  - Resource efficiency in CSS
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Resource Allocation (RA) in CRNs

• Wireless Resources depending on the technology
  • Frequency bands
  • Time slots
  • Orthogonal codes
  • Transmit power

• RA in interweave CRNs
  • Sensing based Resource Allocation
    • Maximize the throughput
    ✓ Minimize the energy consumption
    • Maximize the energy efficiency metric
Energy Consumption Minimization

- Transmit power allocation in a multicarrier-CDMA network with known sensing parameters.

\[
\text{Minimize } \sum_{i=1}^{N} \sum_{k=1}^{A_i} P_{i}^{(k)} \]

subject to

1. \( \sum_{k=1}^{A_i} P_{i}^{(k)} \leq P_{\text{max}}, \ i = 1, ..., N \)

2. \( \sum_{k=1}^{A_i} b_{i}^{(k)} \geq R_{i}, \ i = 1, ..., N \)

3. \( |F_{i}| = A_{i}, \ i = 1, ..., N \)

Energy Efficiency Maximization

- Sub-channel assignment in CRN consisting M SUs and N sub-channels, with known sensing parameters.

Maximize \[ \eta = \frac{R}{E} \]

subject to

\[ \sum_{n=1}^{N} x_{m,n} \leq 1, \ m = 1, \ldots, M \]

\[ \sum_{m=1}^{M} x_{m,n} \leq 1, \ n = 1, \ldots, N \]

\[ x_{m,n} \in \{0, 1\} \]

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System Model

- Sensing
- Reporting
- Channel access

\[ \tau \quad \eta \quad \tau - \tau \eta \]
Spectrum sensing phase

- Hypothesis test at the $i$th SUs

\[ x_i(q) \sim \begin{cases} 
  n_i(q) & H_0 \\
  n_i(q) + h_is(q) & H_1 
\end{cases} \]

- $s(q)$ is the PU’s signal which is assumed to be unknown deterministic
- $n_i(q)$ is the Gaussian noise with zero mean and variance $\sigma_0^2$
- $q = 0, \ldots, Q - 1$ is the time index, and $Q$ equals $\tau f_s$
Spectrum sensing phase

- Energy detector

\[ y_i = \frac{1}{\sigma_i^2} \sum_{q=0}^{Q-1} (x_i(q))^2 \sim \begin{cases} \chi^2_Q & H_0 \\ \chi^2_Q(Q\gamma_i) & H_1 \end{cases} \]

- On-OFF Censoring

\[ u_i = \begin{cases} 1 & y_i \geq \lambda_i \\ \times & y_i < \lambda_i \end{cases} \]

Counting Rule (OR) at Fusion Center

\[ P_F = 1 - \prod_{i=1}^{M} \left((1-p_{f_i})(1-p_{e_i}) + p_{f_i}p_{e_i}\right) \]

\[ P_D = 1 - \prod_{i=1}^{M} \left((1-p_{d_i})(1-p_{e_i}) + p_{d_i}p_{e_i}\right) \]
Transmission phase

• Uplink CDMA (Code Division Multiple Access)
Transmission phase

- Conventional single user matched filter
- SIC (Successive Interference Canceller) detector at SBS
Problem Formulation (1)

Joint Optimization of Spectrum Sensing and Power Allocation

Problem P1

Minimize \( E_T = \sum_{i=1}^{M} \left[ (\Phi_s i^T + \Phi_r i \frac{\eta}{M} ((1 - \rho_{0i}) \pi_0 + (1 - \rho_{1i}) \pi_1)) \right] \)

\[ + (T - \tau - \eta)((1 - P_F)\pi_0 + (1 - P_D)\pi_1) \sum_{i=1}^{M} P_i \]

subject to

1. \( R_i \approx (1 - \frac{\tau + \eta}{T})(1 - P_F)\pi_0 \log(1 + \frac{P_i}{\sum_{k=i+1}^{M} P_k + N_0W}) \geq \alpha_i \)

2. \( P_D \geq \bar{P}_D \)

3. \( P_F \leq \bar{P}_F \)

4. \( \lambda_i \geq 0, P_i > 0, \quad i = 1, \ldots, M \)
Joint optimization

- **Problem P2**

\[
\text{Minimize } E_T = \sum_{i=1}^{M} \left[ \Phi_{s_i} \tau + \Phi_{r_i} \frac{\eta}{M} \left( p_{f_i} \pi_0 + p_{d_i} \pi_1 \right) \right] \\
+ N_0 W (T - \tau - \eta) \left( (1 - P_F) \pi_0 + (1 - P_D) \pi_1 \right) \\
\left( \exp \left( \frac{\sum_{i=1}^{M} \alpha_k}{\pi_0 (1 - \frac{\tau + \eta}{T}) (1 - P_F)} \right) - 1 \right)
\]

subject to

1. \( P_D \geq \bar{P}_D \)
2. \( P_F \leq \bar{P}_F \)
3. \( 0 \leq p_{f_i} \leq 1, \quad i = 1, ..., M \)

- P2 is not convex in general but can be represented as a monotonic optimization problem.
Monotonic Optimization Problem

• Definition:

\[
\text{Minimize}\{f(z) | z \in \mathcal{G} \cap \mathcal{H}\}
\]

\[
\mathcal{G} = \{z \in \mathcal{R}_+^n | g(z) \leq 0\}
\]

\[
\mathcal{H} = \{z \in \mathcal{R}_+^n | h(z) \geq 0\}
\]

is a Monotonic Optimization Problem iff

• \(f(z), g(z), h(z) : \mathcal{R}_+^n \rightarrow \mathcal{R}\) are monotone increasing.

• \(\mathcal{G} \cap \mathcal{H} \subseteq [0, b] \subseteq \mathcal{R}_+^n\) is a close set.
Joint optimization

- **Problem P3**

  \[
  \text{Minimize} \quad \log(E_T) = \log(X_1(p_f)) + \log(X_2(p_f)) \\
  \text{subject to} \quad (1) \quad P_D \geq \bar{P}_D \\
  \quad (2) \quad P_F \leq \bar{P}_F \\
  \quad (3) \quad 0 \leq p_{fi} \leq 1, \quad i = 1, ..., M
  \]

- $X_2(p_f)$ is an increasing and $X_1(p_f)$ is a decreasing function of 

  \[
  p_f = [p_{f1} \ldots p_{fM}]
  \]

- Objective of P3 is a difference of increasing functions and can be represented as a monotonic optimization problem.
Joint optimization

- Problem P4

Minimize

$$t + Y_2(p_f)$$

subject to

1. $$t - Y_1(p_f) \geq -Y_1(1)$$
2. $$P_D(p_f) \geq \bar{P}_D$$
3. $$P_F(p_f) \leq \bar{P}_F$$
4. $$0 \leq p_{f_i} \leq 1, \ i = 1, \ldots, M, \ 0 \leq t \leq Y_1(0) - Y_1(1)$$

- Polyblock/Copolyblock algorithms are suggested by Tuy for solving monotonic Maximization/Minimization problem.

Problem Formulation (2)

Separate Optimization of Spectrum Sensing and Power Allocation

• Problem Q1

\[
\begin{align*}
\text{Minimize} & \quad E_{CSS} = \sum_{i=1}^{M} \left[ \Phi_{s_i} \tau + \Phi_{r_i} \frac{\eta}{M} (p_{f_i} \pi_0 + p_{d_i} \pi_1) \right] \\
\text{subject to} & \quad (1) \quad P_F = 1 - \prod_{i=1}^{M} ((1 - p_{f_i})(1 - p_{e_i}) + p_{f_i}p_{e_i}) \leq \bar{P}_F \\
& \quad (2) \quad P_D = 1 - \prod_{i=1}^{M} ((1 - p_{d_i})(1 - p_{e_i}) + p_{d_i}p_{e_i}) \geq \bar{P}_D \\
& \quad (3) \quad 0 \leq p_{f_i} \leq 1, \quad i = 1, \ldots, M \\
\end{align*}
\]

• Monotonic Optimization Problem
Separate Optimization

• **Problem Q2**

Minimize

\[ E_{\text{Trans}} = \left( \sum_{i=1}^{M} P_i \right) (T - \tau - \eta)((1 - P_F)\pi_0 + (1 - P_D)\pi_1) \]

subject to

1. \[ R_i \approx \left(1 - \frac{\tau + \eta}{T}\right)(1 - P_F)\pi_0 \log\left(1 + \frac{P_i}{\sum_{k=i+1}^{M} P_k + N_0 W}\right) \geq \alpha_i \]

2. \[ P_i > 0, \quad i = 1, ..., M \]

• **Optimal value happens when**

\[ R_i^* = \alpha_i \quad i = 1, ..., M \]
Numerical Results

- $M=5$, $\bar{P}_F = 0.5$, $\bar{P}_D = 0.95$
- Effect of sensing parameters on energy consumption,
Numerical Results

- Effect of sensing parameters on energy consumption,

\[
\gamma = 0 \text{ dB} \quad \alpha_i = 1 \text{ bit/s/Hz} \\
\gamma = -5 \text{ dB} \quad \alpha_i = 1 \text{ bit/s/Hz}
\]
Numerical Results

- Effect of fusion rule on energy consumption

![Graph showing energy consumption comparison]

- $0.04 \text{ dBmJ}$
- $1.42 \text{ dBmJ}$
Numerical Results

- Comparison of joint and separate optimization

\[ \alpha_i = 1 \text{ bit/s/Hz} \]

\[ \alpha_i = 0.5 \text{ bit/s/Hz} \]
Numerical Results

- Comparison of joint and separate optimization
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Conclusion

• Spectrum sensing based resource allocation in CDMA-based cognitive radio networks is considered.

• Joint and separate optimization of sensing parameters and Transmitted powers are studied.

• Numerical results provided suggest that

  • Joint optimization method saves the energy consumption significantly in lower sensing SNRs.

  • It has a very close performance to the separate method in high sensing SNRs.
Suggestions

• In this work,
  • uplink power allocation problem for the secondary users,
  • A single channel cognitive radio network with CDMA multiple access of secondary users,
  • Sensing time is fixed.

• Suggestions,
  • The downlink counterpart of the current problem,
  • its extension for the the multi-channel cognitive radio networks,
  • Optimizing the sensing time.
Thanks for your attention!