Analysis of Optimal Data Fusion Structure in Collaborative Spectrum Sensing in Cognitive Adhoc Networks: A Network Formation Game Based Approach

Project Presentation

June 14, 2011

Presented by Haiming Jin

Outline

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Motivations

Opportunistic Spectrum Access

- **Database-based OSA (Heated, Dyspan 2011)**
  SUs access a geo-location database to obtain local spectrum availability information
- **Sensing-based OSA (Still necessary)**
  SUs rely on spectrum sensing to detect channel availability

Related Literature

On Optimal Sensing and Transmission Strategies for Dynamic Spectrum Access (Xin Liu, Dyspan 2008)

Optimal Sensing-Transmission Structure for Dynamic Spectrum Access (Xin Liu, Infocom 2009)

On Sensing-Access Tradeoff in Cognitive Radio Networks (Kang G. Shin, Dyspan 2010)

Opportunistic Spectrum Access for Mobile Cognitive Radios (Kang G. Shin, Infocom 2011)

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Collaborative Spectrum Sensing

- Reduce the effects of the hidden terminal problem
- Improve the probability of detecting the availability of PUs' channels

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Coalitional Games for Distributed Collaborative Spectrum Sensing in Cognitive Radio Networks
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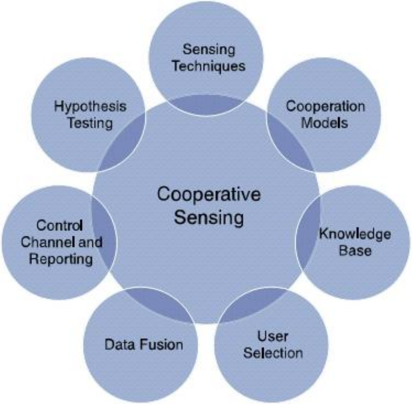

Figure: **Issues to consider in collaborative spectrum sensing in CRNs** (Courtesy of "Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications")

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Optimal→Most reliable→Maximizing correct reporting probability

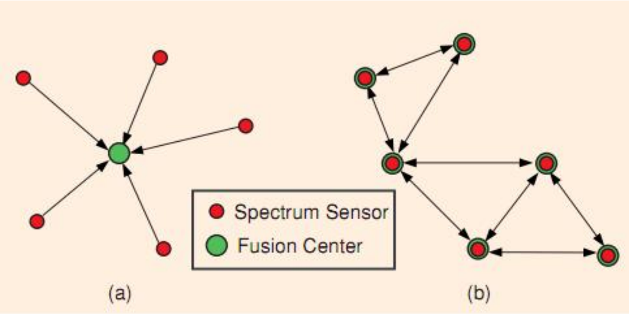

Figure: **Data (Sensing bits) Fusion Structure**
(a) Centralized implementation (b) Distributed implementation
(Courtesy of "Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications")

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1. Introduction
   - Motivations
2. System Model
   - Problem Formulation
   - Related Equilibrium Concepts
   - Objective
3. Preliminary Results
   - Efficient Network Structure
   - Strongly Pairwise Stable Network Structure

Problem Formulation

Network formation game with heterogeneous link strength

A tuple $\mathcal{G}(\mathcal{P}, \mathcal{S}, \mathcal{U})$

- $\mathcal{P}$: The set of players representing the set of SUs conducting data fusion e.g. SUs within a coalition
- $\mathcal{S}$: The strategy space of all the players in which $S_i \in \mathcal{S}$ is the strategy space of player i
- $\mathcal{U}$: The set of utility functions for all the players where $u_i \in \mathcal{U}$ is the utility for player i

A weighted graph $G(V, E, W)$

- V: The vertex set ($V = \mathcal{P}$)
- E: The edge set representing the set of the communication links formed between any two players
- W: The set of weights for each edge that has been formed

Cont'd

Investment of SU i on the link it establishes to SU j:

$$I_i^j = P_{c,i,j}(P_{i,j}) = \frac{1}{2}\left(1 + \sqrt{\frac{\bar{\gamma}_{i,j}}{1+\bar{\gamma}_{i,j}}}\right) \quad (1)$$

- $P_{c,i,j}(P_{i,j})$[1]: The correct reporting probability depending on the reporting power $P_{i,j}$ from SU i to SU j with Rayleigh fading and BPSK modulation
- $\bar{\gamma}_{i,j} = \frac{P_{i,j}h_{i,j}}{\sigma^2}$: SNR in the report channel from SU i to SU j

Assumption: Every SU has the same overall investment budget $\mathcal{I}$.

[1] Digital Communications. B Sakar. Prentice Hall. 2011

Cont'd

Utility of any arbitrary SU i:

$$\begin{aligned} U_i(G) &= \sum_{j\neq i} R(i,j) = \sum_{j\neq i} \max_{p(i,j)\in P(i,j)} r(p(i,j)) \\ &= \sum_{j\neq i} \max_{p(i,j)\in P(i,j)} r_{ii_1} r_{i_1 i_2} \cdots r_{i_{M-2}j} \\ where,\ & r_{ij} = r_{ji} = \varphi(P_{c,i,j}) + \varphi(P_{c,j,i}) \\ & \varphi(P_{c,i,j}) = P_{c,i,j} - \frac{1}{2} \end{aligned} \tag{2}$$

Value of this particular graph:

$$V(G) = \sum_i U_i(G) \tag{3}$$

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Related Equilibrium Concepts

Network Efficiency:

- A network structure represented by the graph $G(V, E, W)$ is efficient if for any arbitrary graph $G^{'}(V, E', W')$ the condition $V(G) > V(G')$ holds.

Nash Stable Network:

- Given any overall investment profile $\mathbf{I}$, the graph $G(\mathbf{I})$ is Nash stable if there exists no SU i and investment profile $\mathbf{I}_i^{'}$ such that $U_i(G(\mathbf{I}_{-i}, \mathbf{I}_i^{'})) > U_i(G(\mathbf{I}))$

Strongly Pairwise Stable:

- A graph $G(\mathbf{I})$ is strongly pairwise stable if it is Nash Stable and there is no pair of SUs (i, j) and joint deviation $(\mathbf{I}_i^{'}, \mathbf{I}_j^{'})$, such that $U_k(G(\mathbf{I}_{-i,-j}, \mathbf{I}_i^{'}, \mathbf{I}_j^{'})) > U_k(G(\mathbf{I}))$ where $k = i, j$.

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Objective

The efficient and Nash-stable network structure $G(V, E, W)$ that maximizes the reliability of sensing bits reporting within the network, i.e. satisfying:

$$G^* = \arg\max_G V(G) \tag{4}$$

Given that SUs strategically allocate their investment budgets in the reporting channels they establish with other SUs.

- **Efficient**→Reliability
- **Nash-stable**→Distributed and voluntary formation

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Efficient Network Structure

Theorem 1:

- The unique efficient network structure is the symmetric star where the hub SU invests an equal amount in all links with peripheral SUs.

Proof:

- **Lemma 1:** If the contribution function φ is convex, then unique efficient network is a star where one SU, namely the hub, is connected to all other agents and peripheral SUs are only connected with the hub.

For more detail please refer to the project report.

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Strongly Pairwise Stable Network Structure

Theorem 2:

- A strongly pairwise stable network in our model must be a star in which all agents are connected.

Proof:

- **Lemma 2:** Given that φ is linear and a graph G is strongly pairwise stable, if there exists a SU i that invests in multiple links, then all of the neighbors of SU i invest completely their investment budget to the link to SU i.
- **Lemma 3:** Given that graph G is a connected network which is not a tree, if φ is linear, then G is not strongly pairwise stable.

For more detail please refer to the project report.

Thanks