Spectrum Trading in Cognitive Radio Network: a Two-Stage Market Based on Contract and Stackelberg Game

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Outline

Introduction

What is Cognitive Radio

- A cognitive radio is a transceiver which automatically changes its transmission or reception parameters so wireless communications may have spectrum agility to select available wireless channels opportunistically.

Introduction

Problems

- How to increase spectrum efficiency and alleviate spectrum scarcity for the congested and scarce spectrum.
- How to design a mechanism in which PUs have incentive to open their licensed spectrum for sharing, and SUs have incentive to utilize the new spectrum opportunities.

Introduction

Solutions

- **Cognitive Radio** is a promising paradigm to achieve efficient utilization of spectrum resource by allowing unlicensed users (SUs) to access licensed spectrum
- **Two-stage Market** is an incentive compatible and effective mechanism based on contract theory and Stackelberg game in a Market-driven secondary spectrum trading.

Related Work

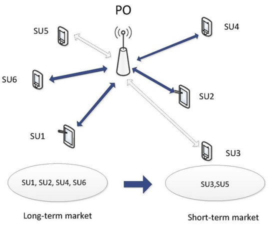
- Spectrum Trading in Cognitive Radio Networks: A Contract-Theoretic Modeling Approach.

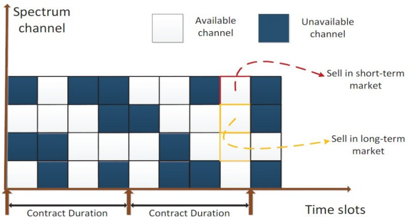
  L. Gao, X. Wang, Y. Xu and Q. Zhang.
  IEEE Journal on Selected Areas in Communications, 2011.

- Investment and Pricing with Spectrum Uncertainty: A Cognitive Operators Perspective.

  L. Duan, J. Huang and B. Shou.
  IEEE Transactions on Mobile Computing, 2011.

System Model





- A single primary spectrum owner(PO) and multiple secondary user(SUs).
- The total transmission is divided into fixed-time interval(time slots)
- The spectrum possessed by PO is under-utilized at each time slot.

Long-term Market

- Long-term market is the first stage of the secondary spectrum trading market.
- Modeled as a monopoly market where PO set particular contracts for different SUs.
- To provide an intuitive and meaningful expression, the contracts are expressed as:

$$C \triangleq \{q, P, g\}$$

Short-term Market

- After long-term, PO and SUs who fail to accept the contracts enter into short-term market.
- Modeled as a Stackelberg game, PO is the leader of game and senses the idle spectrum.
- PO realizes the total available bandwidth in this market.Then announce price π to SUs. Finally, SUs decide the demands for bandwidth from PO

Contracts Formulation

Optimal contracts for SUs

- For a type-α SU, the utility can be obtained as:

$$U(\alpha, q, P) = \log(1 + q\alpha) - P$$

- the optimal contracts for a type-α SU can be written as:

$$best(q, P) = \arg\max U(\alpha, q, P)$$

Contracts Formulation

Optimal contracts for PO

- Part of the cost of PO is performance degradation of PUs induced by the interference of SUs, which can be expressed as $\lambda_1 q^2$. Thus the utility of PO is:

$$U_I(q, P) = \sum_{i=1}^{K} [P(\alpha_i) - \lambda_1 q(\alpha_i)^2] N_{\alpha_i}$$

- The optimal contracts for PO can be written as:

$$best(q, P) = \arg\max U_I(q, P)$$

Stackelberg Game

- PO first decides the sensing amount B_s according to the guaranteed bandwidth for contracts B_n. Sense factor η is used.
- PO then determines the price π to SUs given sensing amount B_s.
- SUs choose their demands of bandwidth ω_i to maximize profit.

Backward Induction

Phase I

- We first obtain SUs' optimal bandwidth demand ω_i for given B_s.
- SU i's utility function can be written as:

$$\mathrm{U}(\omega_i) = \omega_i \log(1 + \frac{p_i h_i}{n_0 \omega_i}) - \pi \omega_i$$

- the total bandwidth demands in short-term market is $Be^{-1-\pi}$.

Backward Induction

Phase II

- we consider how PO choose its price π based on B_s.
- PO's total profit is:

$$U = U_l^{\max} + \min(\pi B e^{-1-\pi}, \pi(B_s\eta - B_n)) - B_s C_s$$

- if $B_n < B_s\eta < Be^{-2} + B_n$, PO's maximized profit is

$$U^{\max} = U_l^{\max} + (B_s\eta - B_n)\log(\frac{B}{B_s\eta - B_n}) - B_s\eta - B_n - B_s C_s$$

- if $B_s\eta > Be^{-2} + B_n$,PO's maximized profit is $U^{\max} = U_l^{\max} + Be^{-2} - B_s C_s$

Backward Induction

Phase III

- We enter into the final step where PO determines the sensing amount B_s to maximize expected profit.
- if $B_n < B_s < B_n + Be^{-2}$

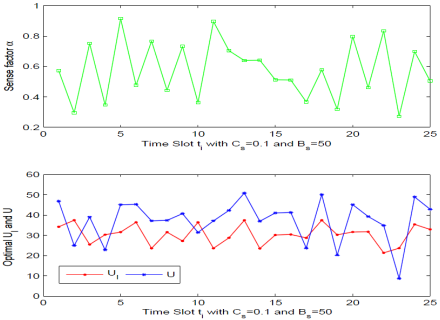
$$E[U^*] = U_l^{\max} - B_s(C_s + \frac{1}{2}) - B_n + \frac{B_n^2(3+g)}{2B_s} + \frac{(B_s - B_n)^2}{4B}(1 - 2\log \frac{B_s}{\ldots}$$

- if $B_s > B_n + Be^{-2}$

$$E[U^*] = U_l^{\max} - \frac{B_n(B_n g + B_n + 2Be^{-2})}{2B_s} + \frac{5Be^{-4}}{4} - B_s C_s - \frac{(B_n + Be^{\ldots}}{2B_s}$$

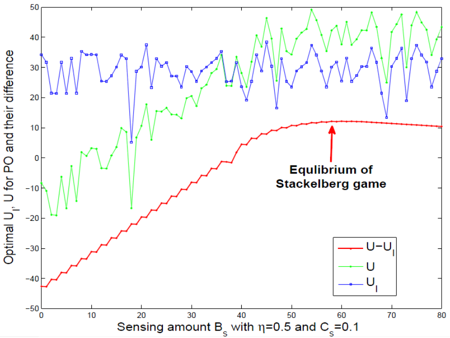
Simulation Result

- the relationship between U_l and U for PO with different sensing factor η



Simulation Result

- the relationship between U_I and U for PO with different sensing amount B_s



Simulation Result

- This figure presents U_I and U for both PO and all SUs. we find that in our teo-stage market, the utilities for both PO and SUs grow larger than traditional one-stage market