Game Theoretic Spectrum Access In Cognitive Radio Networks

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1. An Auction Framework

Problem addressed: how to allocate spectrum of primary users to secondary users

System model:
A set of PUs on non-overlapped spectrum bands
SUs can access PUs' spectrum under the temperature constraint at every PU n

$$\sum_{i=1}^{M} p_i g_{in} \le P_n \quad \forall n \in \mathcal{N}$$

Solutions proposed: a spectrum auction framework
SINR auction: the auction game has a unique NE under certain condition
Power auction: in large system, the auction game has a unique NE under certain condition

Algorithm 1 Two-dimensional spectrum auction algorithm

Price announcing: Each PU n announces a reserve bid β_n and a price $\pi_n > 0$.
Bidding: Based on β_n and π_n, each SU i submits a bid (a_i, b_i) where $a_i \in \mathcal{N}$ and $b_i \ge 0$.
Spectrum allocation: Each SU i is allocated a transmission power p_i from PU a_i as follows:

$$p_i = \frac{P_{a_i}}{g_{ia_i}} \frac{b_i}{\sum_{j \in \mathcal{M}, a_j = a_i} b_j + \beta_{a_i}}.$$

Payment collection: Each SU i pays PU a_i a payment $C_i = \pi_{a_i} \gamma_i g_{ia_i}$ in the SINR auction and $C_i = \pi_{a_i} p_i g_{ia_i}$ in the power auction.

A distributed no-regret learning algorithm to converge to a correlated equilibrium

Algorithm 2 No-regret learning algorithm: SINR auction

Initialization: For each SU i, let p denote a random number between 0 and 1 and $a_i^* = \min_{n \in \mathcal{N}} \pi_n g_{in}$ (if a_i is not a singleton, randomly choose one), set $p^0_{a_i = a_i^*} = p$ and $p^0_{a_i = N+1} \models 1 - p_{a_i}$. Let T_0 be a sufficient iteration duration.
for $t = kT_0$, $k = 1, 2, 3, \cdots$ **do**
Select spectrum a_i according to probability $p_i^t(a_i)$ and use best response update to converge to the NE of the bidding game.
When the NE is achieved after sufficient time, update the average regret R_i^t.
Let a_i^t denote the spectrum i selects for iteration t, let μ be a large constant, calculate p_i^{t+1} as:

$$\begin{cases} p_i^{t+1}(a_i) & = \frac{1}{\mu} R_i^t, \quad \forall a_i \neq a_i^t \\ p_i^{t+1}(a_i) & = 1 - \sum_{n \in \mathcal{N}, n \neq a_i^t} p_i^{t+1}(n), \quad a_i = a_i^t \end{cases}$$

end for

2. Spectrum Access with Channel Switching Cost

System model:
A CRN of multiple channels, each characterized by a channel availability probability (activity of PUs)

Challenge addressed: how SUs can opportunistically access unused spectrum of PUs
1). learn the channel availabilities
2). coordinate with other SUs to avoid collision
3). minimize channel switching cost

Mathematic model: multi-armed bandit problem (MAB) with multiple players

Proposition: block-based channel access (BCA)
Idea: stay at a channel for b_f slot to learn channel availability if no collision and randomly (or intelligently) switch to another channel if collision

Analytical result: BCA has logarithmic regret (gap to the system optimum)

3. Imitation-based Spectrum Access

System model:
A large number of SUs access multiple PU channels

Problem addressed: design efficient spectrum access policy for rational SUs

Game formulation: model the interaction among SUs as a congestion game, has a unique efficient NE
Challenge: how to reach the NE

Algorithm proposed: imitation
Core idea: a rational player mimics the action of other players with higher payoff to improve its own

Algorithm 1 Spectrum access policy based on proportional imitation rule: executed at each SU j for each iteration

1: **Initialization**: set the imitation rate σ and the imitation threshold ϵ_U
2: Randomly select a SU j'
3: **if** $U_j < U_{j'} - \epsilon_U$ **then**
4: Switch to the channel of where j' stays with probability $p = \sigma(U_{j'} - U_j)$
5: **end if**

The dynamic induced by the algorithm converges to the unique NE (also the system optimum)

[1] L. Chen, S. Iellamo, M. Coupechoux, P. Godlewski. An Auction Framework for Spectrum Allocation with Interference Constraint in Cognitive Radio Networks. In Proc. IEEE Infocom 2010, San Diego, CA, USA, Mar. 2010.
[2] L. Chen, S. Iellamo, M. Coupechoux. Opportunistic Spectrum Access with Channel Switching Cost for Cognitive Radio Networks. Submitted to ICC 2011.
[3] S. Iellamo, L. Chen, M. Coupechoux. Imitation-based Spectrum Access Policy for Cognitive Radio Networks. Submitted to WCNC 2011.