Dynamic Spectrum Access in Cognitive Radio Networks

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Outline

- Introduction
- Cognitive Radio Framework
- MAC sensing
  - Spectrum Occupancy Model
  - Sensing policy
  - Access policy
  - Reward
  - An example
- Design a detailed slot structure
FCC Policy & Spectrum Scarcity

- Little Sharing
- Static Allocation
- Rigid Requirements on how to use
Spectrum Opportunities in Spectrum, Time & Space

(Credit: SPAN UCD)

(Credit: DARPA XG)

(Credit: ACSP Cornell)
Cognitive Radio Framework

Radio Environment (Outside World)

- RF stimuli
- Spectrum holes
- Noise-floor statistics
- Traffic statistics

Radio-scene analysis

- Interference temperature
- Quantized channel capacity

Channel-state estimation & predictive modeling

Transmit-power control & spectrum management

Action: transmitted signal

PHY sensing

MAC sensing

PHY sensing

- Non-cooperative sensing
  - Match filter
  - Energy detection
  - Cyclostationary feature detection

- Cooperative sensing

In CR systems, PHY sensing is firstly applied to find the spectrum opportunity. But how to use this opportunity?
MAC sensing

- If we only have one PU channel, we only need to sense and access;

- If we have several PU channels and we don’t want to simultaneously sensing them together due to power constrain, then we should do:
  - Opportunity tracking and learning
  - Opportunity access

- In a word, choose some channels to sense, then find whether it’s OK for access, finally, check whether you have make a good choice 😊
Transmission structure: synchronous slot

PU’s structure

PU 1
.
.
.
PU n

SU’s structure

SU will start sensing only if there are some data to be transmitted.
Spectrum Occupancy Model

- a discrete-time Markov model

Limited Sensing: can only sense and access a subset of channels in each slot
Sensing policy

\[ \pi_s \]

- Choose the sensing action \( s \) (channel index) in each slot
Access policy

Access policy: \( \Phi_a \)

- If the observation results \( \Theta_{a_s}(t) \) is idle, then access this slot \( \Phi_a = 1 \)
- If the observation results \( \Theta_{a_s}(t) \) is busy, then wait until the next slot \( \Phi_a = 0 \)

In this stage, we have combine PHY sensing with MAC sensing.
Immediate Reward:
- If the chosen channel $a$ is idle, a unit reward is accrued.
- If the chosen channel $a$ is busy, no reward; wait until the next slot.

$$R(t) = S_a(t)\Phi_a(t)B_a$$

Objective: choose sensing policy $\pi_s$ to maximize Immediate Reward, throughput or others.
A simple example: greedy approach

$$\Omega(t) = [\omega_1(t), \ldots, \omega_N(t)]$$

$$\text{reward} = \left( \omega_a(t) \beta_a + (1 - \omega_a(t)) \alpha_a \right) B_a$$

$$a_*(t) = \arg \max_{a=1,\ldots,N} \left( \omega_a(t) \beta_a + (1 - \omega_a(t)) \alpha_a \right) B_a$$
The sequence of operations in a slot

At the end of slot $t$, belief vector is updated based on action $a_\ast(t)$ and the observation $\Theta_{a_\ast}(t)$

$$
\omega_i(t + 1) = \begin{cases} 
1 & \text{if } a_\ast(t) = i, \Theta_{a_\ast}(t) = 1 \\
0 & \text{if } a_\ast(t) = i, \Theta_{a}(t) = 0 \\
\omega_i(t) \beta_i + (1 - \omega_i(t)) \alpha_i & \text{if } a_\ast(t) \neq i
\end{cases}
$$
How to introduce feedback

- In most cases, sensing error can't be ignored.

- Acknowledgement will be considered

\[ \omega_i(t + 1) \triangleq \Pr[S_i(t) = 1|\Omega(t), a_*, K_{a_*}] \]

\[ = \begin{cases} 
    \omega_i(t)\beta_i + (1 - \omega_i(t))\alpha_i & \text{if } a_* \neq i \\
    1 & \text{if } a_* = i, K_{a_*} = 1 \\
    \frac{\epsilon(\omega_{a_*}\beta_{a_*} + (1 - \omega_{a_*})\alpha_{a_*})}{\epsilon(\omega_{a_*}\beta_{a_*} + (1 - \omega_{a_*})\alpha_{a_*}) + (\omega_{a_*}(1 - \beta_{a_*}) + (1 - \omega_{a_*})(1 - \alpha_{a_*}))} & \text{if } a_* = i, K_{a_*} = 0 
\end{cases} \]

\[ \left( \Pr[S_{a_*}(t) = 1|\Omega(t), K_{a_*} = 0] \right) \]
What we can do

- You can design your own objective reward, your own sensing scheme, access scheme (including PHY sensing), even your own model, only if they are reasonable 😊
How to design a detailed slot structure (1)

- Within a slot, how many time shall we use for spectrum sensing?
- Sensing error is a function of sensing time.
How to design a detailed slot structure (2)

- Ideal acknowledge doesn’t make sense in practical systems, How can we design the acknowledge model? with some delay?


Thank you!