Dynamic Spectrum Access in Cognitive Radio Networks

Xiaoying Gan
xgan@ucsd.edu
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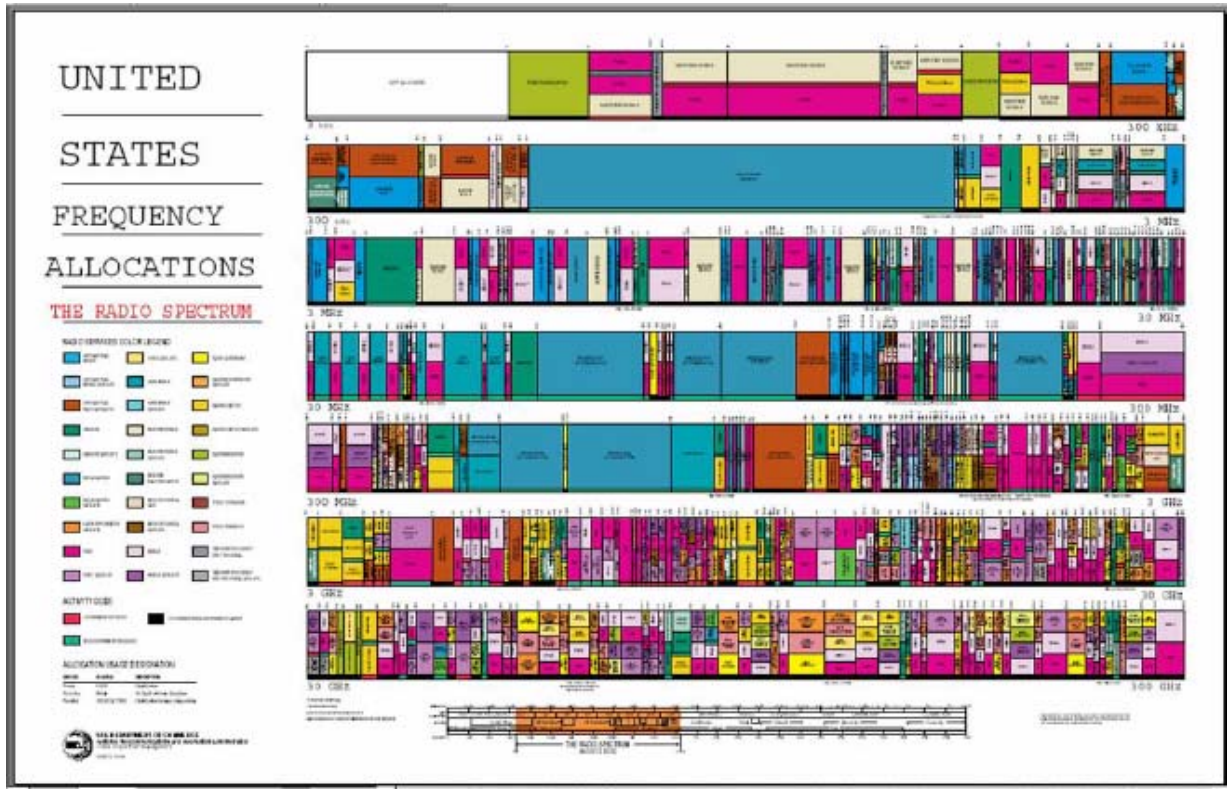
Outline

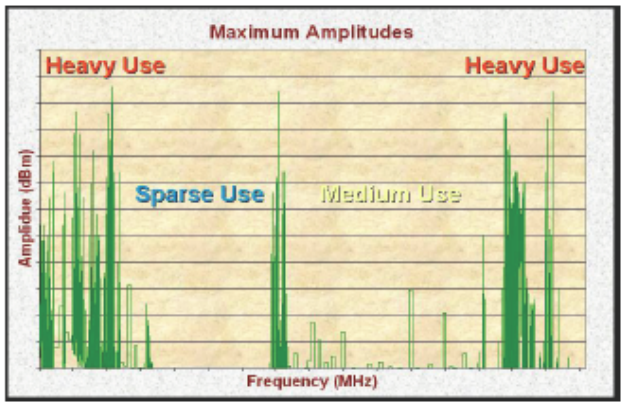
- Introduction
- Cognitive Radio Framework
- MAC sensing
  - Spectrum Occupancy Model
  - Sensing policy
  - Access policy
  - Reward
  - An example
- Design a detailed slot structure

FCC Policy & Spectrum Scarcity

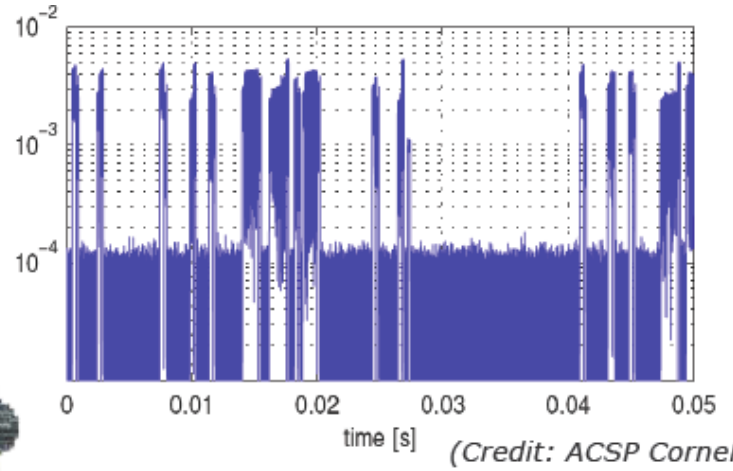


- Little Sharing
- Static Allocation
- Rigid Requirements on how to use

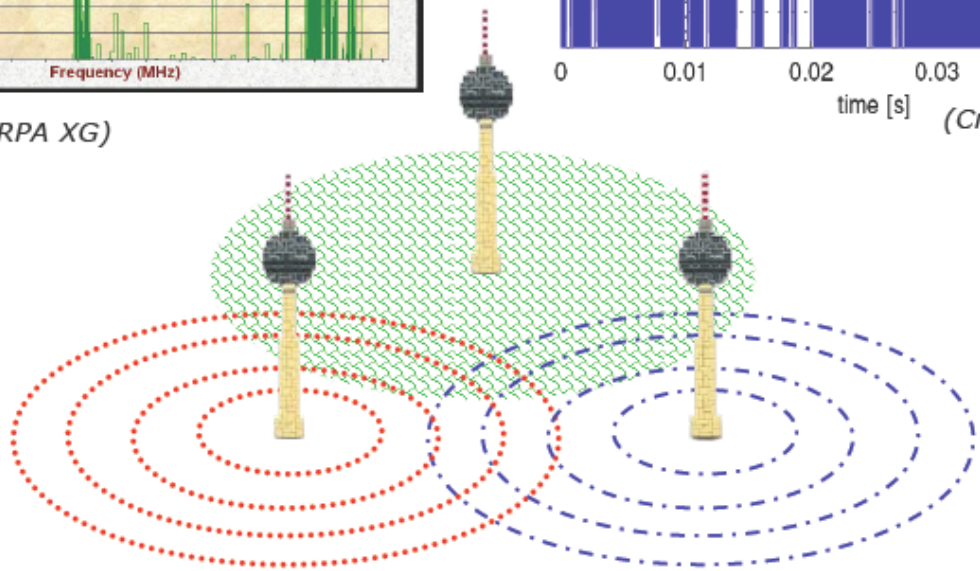
Spectrum Opportunities in Spectrum, Time & Space



(Credit: DARPA XG)

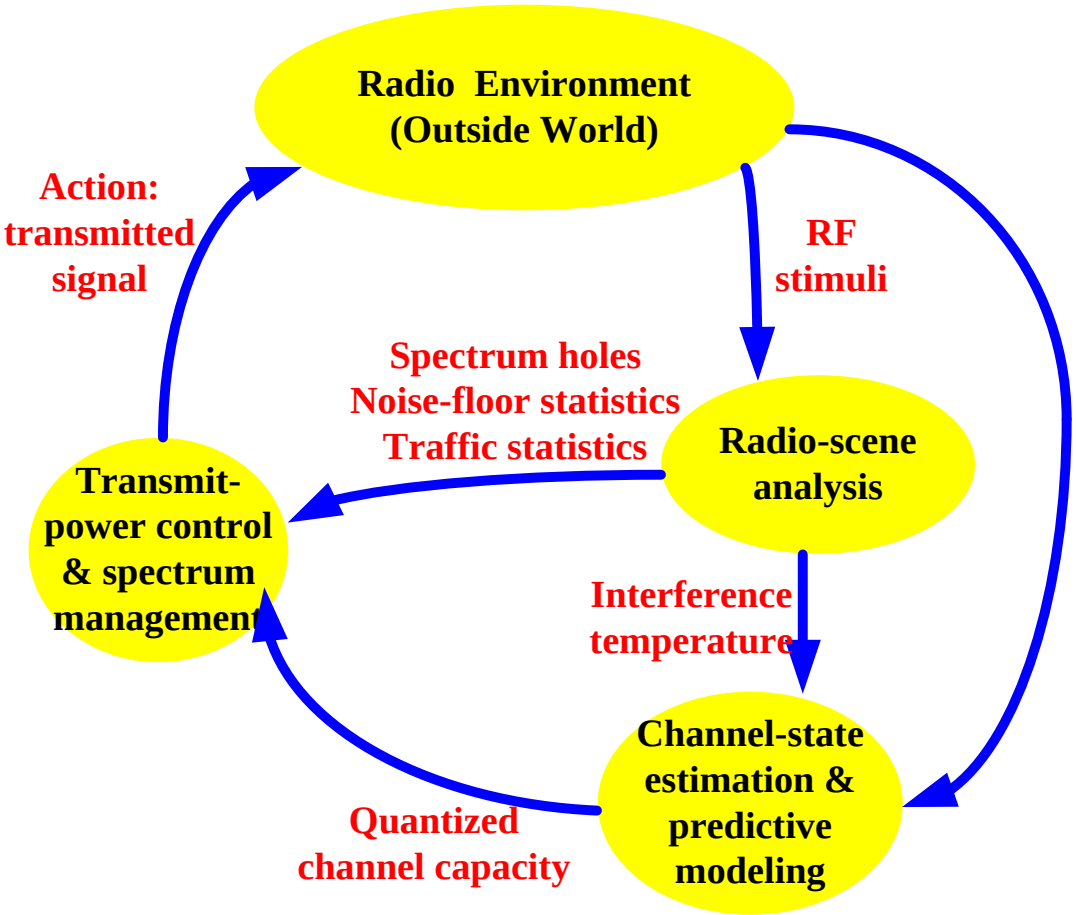


(Credit: ACSP Cornell)



(Credit: SPAN UCD)

Cognitive Radio Framework



PHY sensing

MAC sensing

Simon Haykin (McMaster University), "Cognitive Radio: Brain-empowered Wireless Communications", IEEE JSAC, Feb. 2005

PHY sensing

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

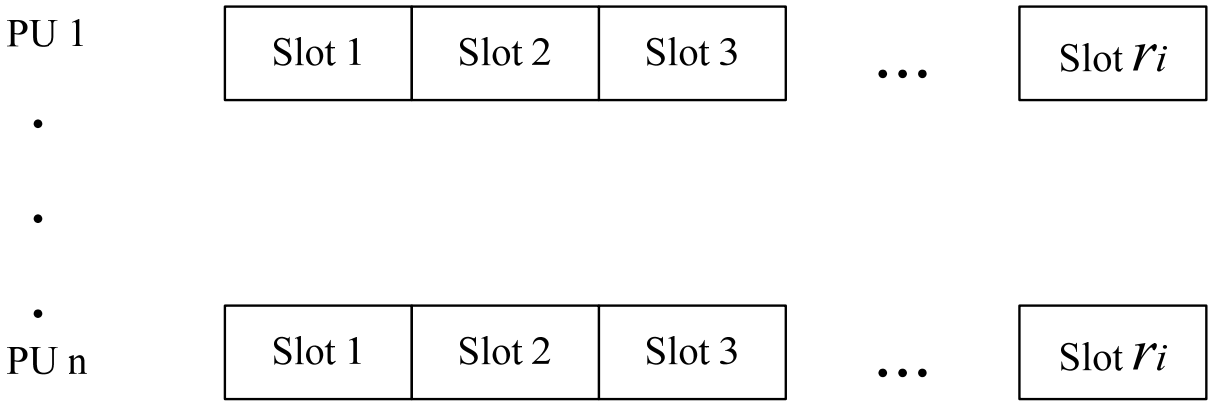
In CR systems, PHY sensing is firstly applied to find the spectrum opportunity. But how to use this opportunity?

MAC sensing

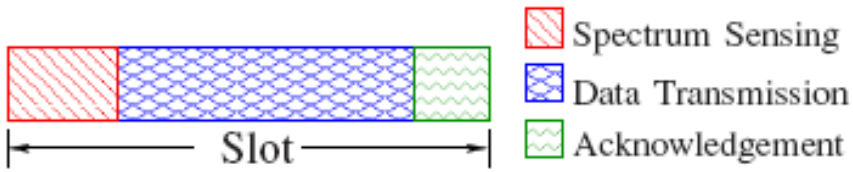
- If we only have one PU channel, we only need to sense and access;
- If we have several PU channels and we don't want to simultaneously sensing them together due to power constrain, then we should do:
  - Opportunity tracking and learning
  - Opportunity access
- In a word, choose some channels to sense, then find whether it's OK for access, finally, check whether you have make a good choice ☺

Transmission structure: synchronous slot

PU's structure



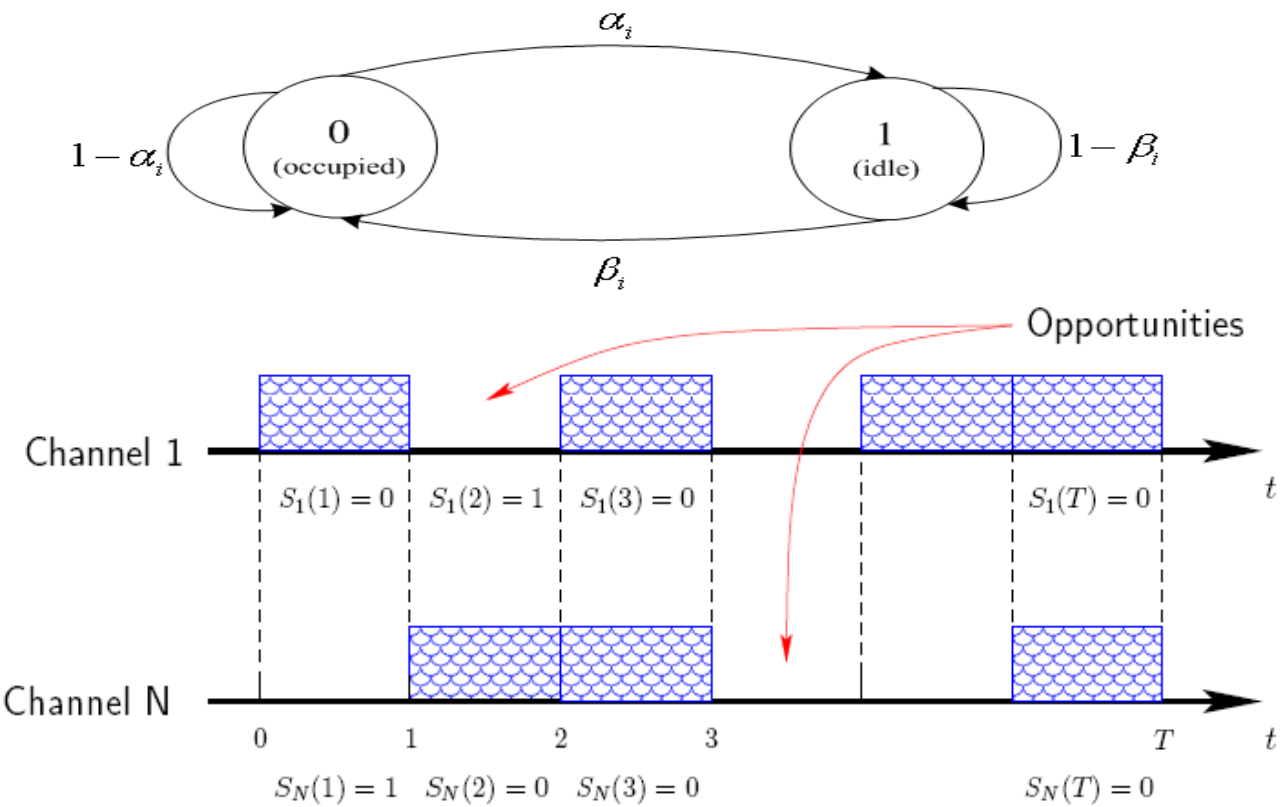
SU's structure



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

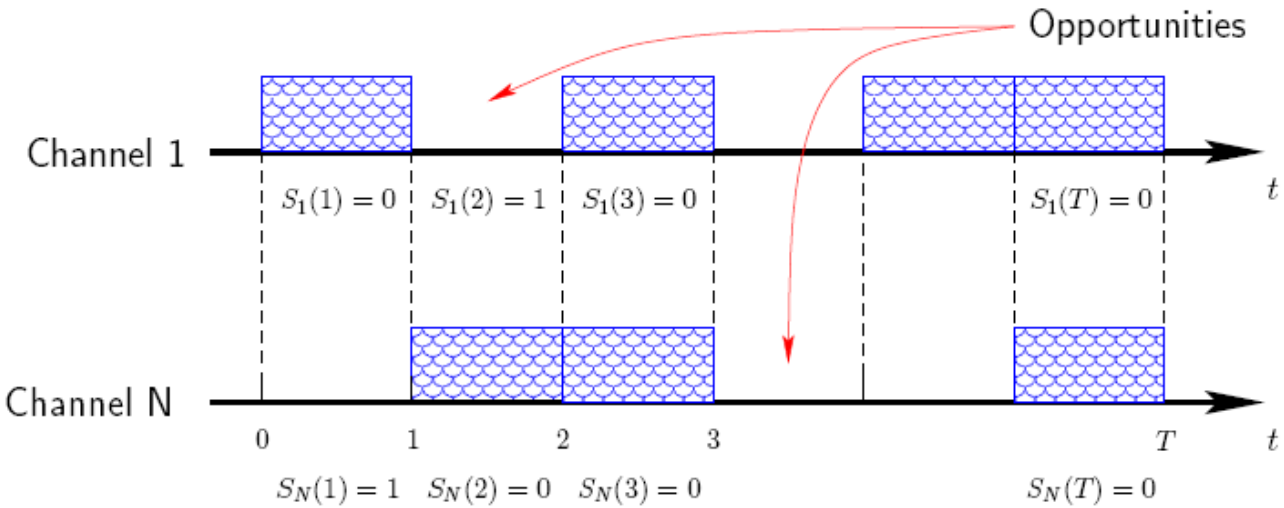
Spectrum Occupancy Model

- a discrete-time Markov model



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

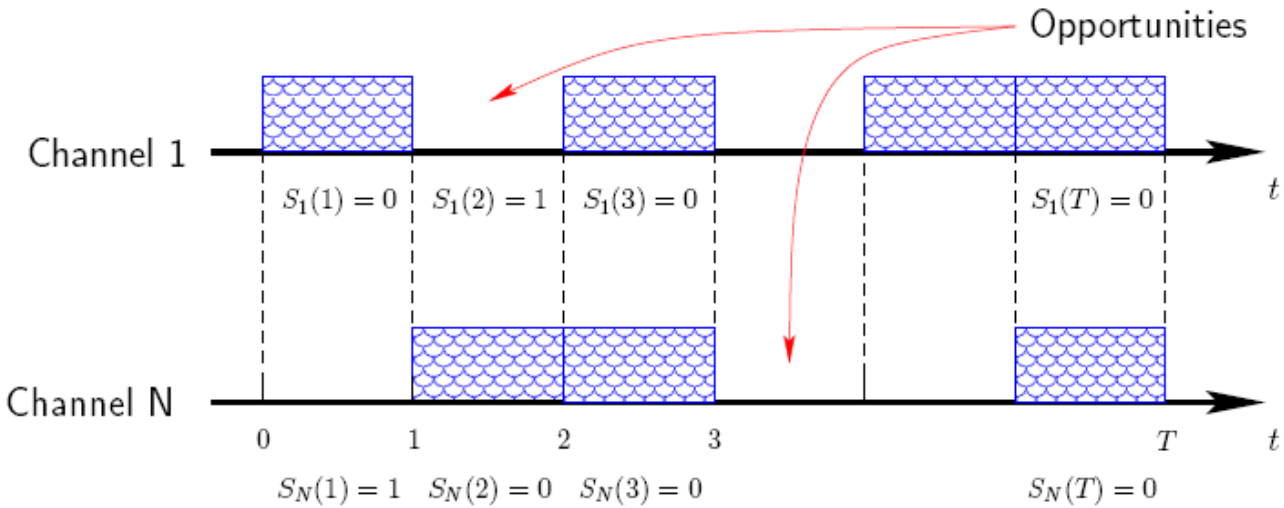
Sensing policy



Sensing policy: π_s

➢Choose the sensing action a (channel index) in each slot

Access policy



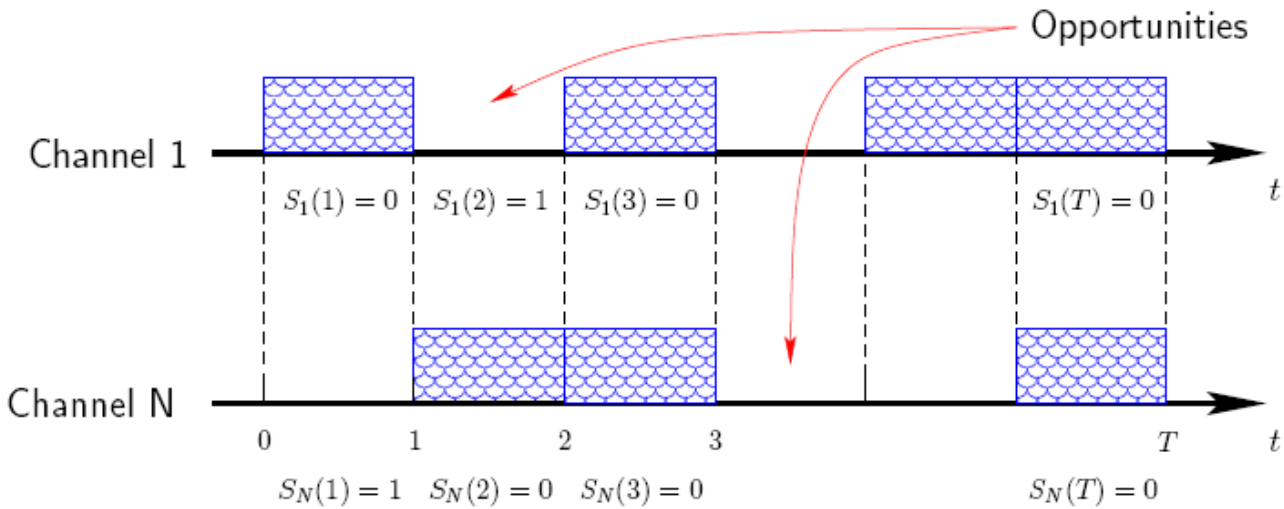
Access policy: Φ_a

(an example)

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

In this stage, we have combine PHY sensing with MAC sensing.

Immediate Reward



Immediate Reward:

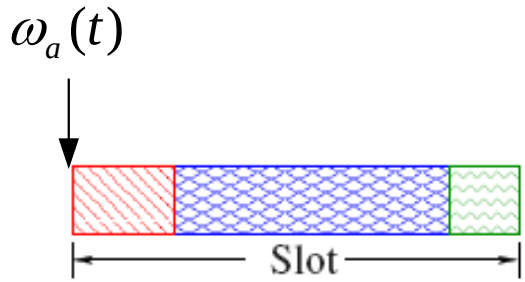
- If the chosen channel a is idle, a unit reward is accrued.
- If the chosen channel a is busy, no reward; wait until the next slot.

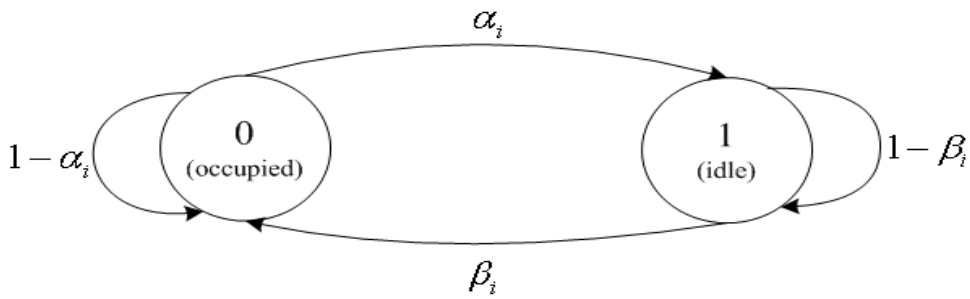
$$R(t) = S_a(t)\Phi_a(t)B_a$$

- Objective: choose sensing policy π_s to maximize Immediate Reward, throughput or others.

A simple example: greedy approach

Channel a



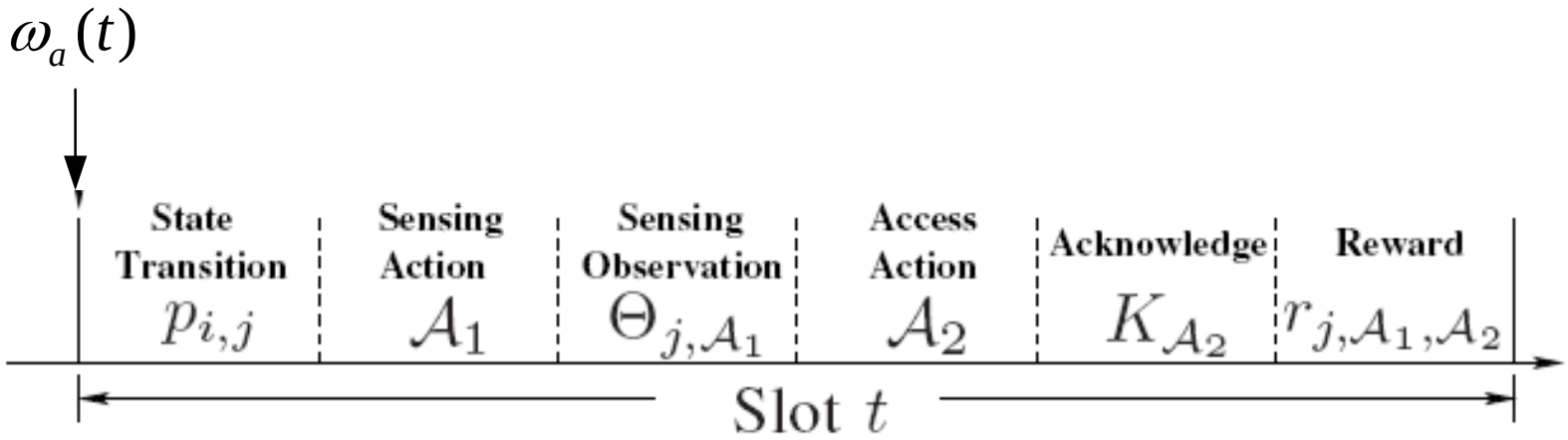


$$\Omega(t) = \left[\omega_1(t), \ldots, \omega_N(t)\right]$$

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

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

The sequence of operations in a slot



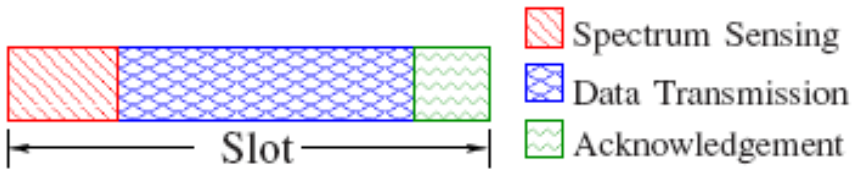
At the end of slot t, belief vector is updated based on action $a_*(t)$ and the observation $\Theta_{a_*}(t)$

$$\omega_i(t+1) = \begin{cases} 1 & \text{if } a_*(t) = i, \Theta_{a_*}(t) = 1 \\ 0 & \text{if } a_*(t) = i, \Theta_a(t) = 0 \\ \omega_i(t)\beta_i + (1-\omega_i(t))\alpha_i & \text{if } a_*(t) \neq i \end{cases}$$

How to introduce feedback

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

$$\begin{cases} \text{false alarm} & \varepsilon \\ \text{miss detection} & \delta \end{cases}$$



- Acknowledgement will be considered

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

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

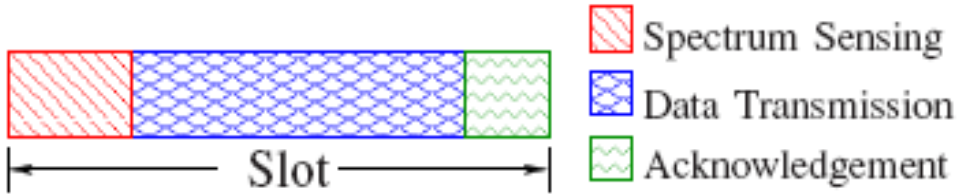
$$\left(\Pr\left[S_{a_*}(t)=1\middle|\Omega(t),K_{a_*}=0\right]\right)$$

What we can do

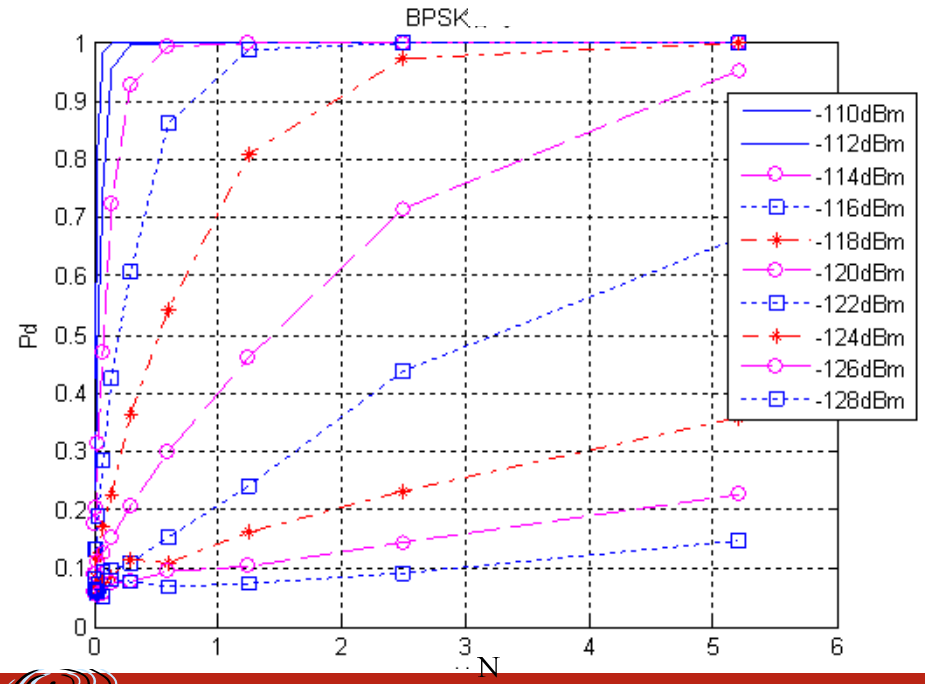
- You can design your own objective reward, your own sensing scheme, access scheme (including PHY sensing), even your own model, only if they are reasonable☺

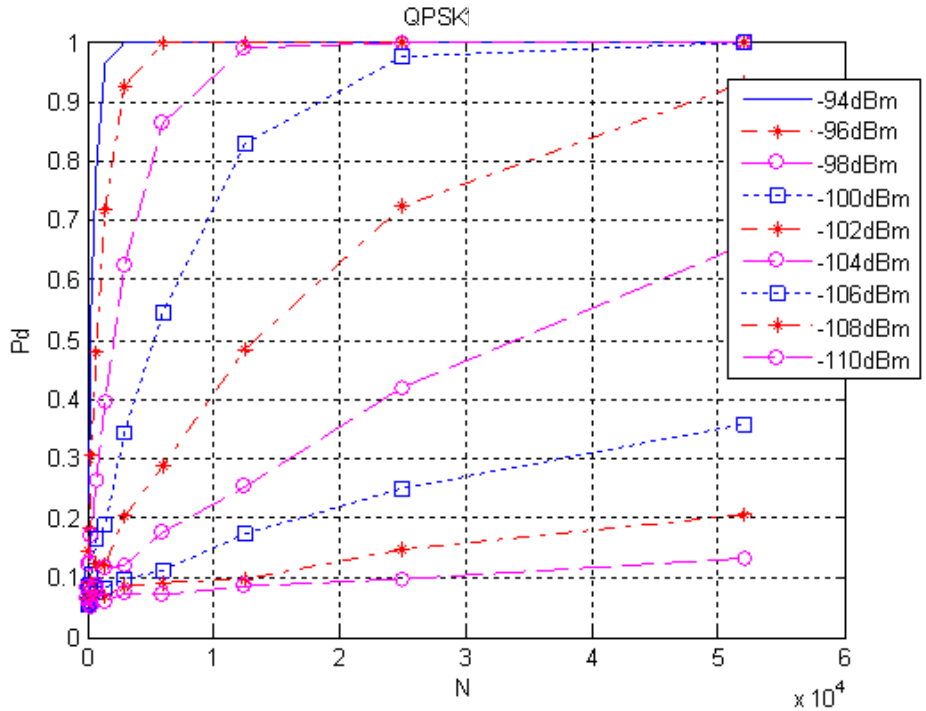
How to design a detailed slot structure(1)

- Within a slot, how many time shall we use for spectrum sensing?



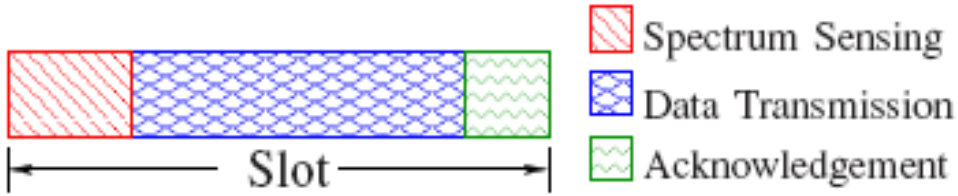
- Sensing error is a function of sensing time.





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?



reference

- Q. Zhao and B.M. Sadler, " A Survey of Dynamic Spectrum Access“, *IEEE Signal Processing Ma gazine*, vol. 24, no. 3, pp. 79-89, May, 2007
- Q. Zhao, L. Tong, A. Swami, and Y. Chen, "Decentralized Cognitive MAC for Opportunistic Spe ctrum Access in Ad Hoc Networks: A POMDP Framework“, *IEEE Journal on Selected Areas in C ommunications (JSAC): Special Issue on Adaptive, Spectrum Agile and Cognitive Wireles Netw orks* , vol. *25, no. 3, pp. 589-600, April, 2007.*
- *Y. Chen, Q. Zhao, and A. Swami,* "Joint Design and Separation Principle for Opportunistic Spec trum Access in the Presence of Sensing Errors“, *IEEE Transactions on Information Theory, vol. 54, no. 5, pp. 2053-2071, May, 2008*
- *Q. Zhao, B. Krishnamachari, and K. Liu, “*On Myopic Sensing for Multi-Channel Opportunistic Access: Structure, Optimality, and Performance" *iEEE Transactions on Wireless Communicati ons, vol. 7, no. 12, pp. 5431-5440, December, 2008.*

Thank you !