Secondary User Monitoring in Unslotted Cognitive Radio Networks with Unknown Models

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Outline

- 1. **Background**
  - 1.1 Problem
  - 1.1 Challenges
  - 1.2 Related works
- 2. Motivation
- 3. Problem Formulation
- 4. Simulation
- 5. Conclusion & Future Work

1. Background

- Why & How to perform secondary user data capture in a Cognitive Radio Networks with sniffers?
- What is our goal and measurement?

1.1 Problem

- Monitoring the detailed characteristics of an operational cognitive radio network is critical
  - spectrum policy enforcement, wireless advisory
  - fault diagnosis, anomaly detection, attack detection
  - forensics, resource management
  - critical path analysis for network upgrades

1.1 Problem

- Very limited work has been done
- Efficient capture with limited number of monitors
- Customable capture

1.2 Challenges

- Secondary users' activities are unknown in priori
  - highly dynamic wireless network
- Monitor resource is limited
  - CRNs have much wider spectrum than traditional wireless networks
  - limitation of hardware technology
- Sniffer channel assignment
  - tradeoff : Exploration or Exploitation
- Customable capture
  - capture data of interested secondary users coexisting with PUs and unconcerned SUs

1.3 Related Work

- Multichannel Wireless Network Monitoring
  - Chhetri et al. MobiHoc’10 [7] - QoM
  - Arora et al. INFOCOM’11 [8] - MAB
- Cognitive Radio Network Monitoring
  - Chen et al. ICNP’11 [5] – SVR
- Opportunistic Spectrum Access
  - Tehrani et al. CAMSAP’11 [14] – Channel assignment

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2. Motivation

- Efficient capture with limited number of monitors
  - sharing information among sniffers
  - Tradeoff: exploration and exploitation
  - Dynamic assigning the sniffers
- Customable capture
  - Data from different users have priorities
  - Maximize the expected captured data of interested secondary users

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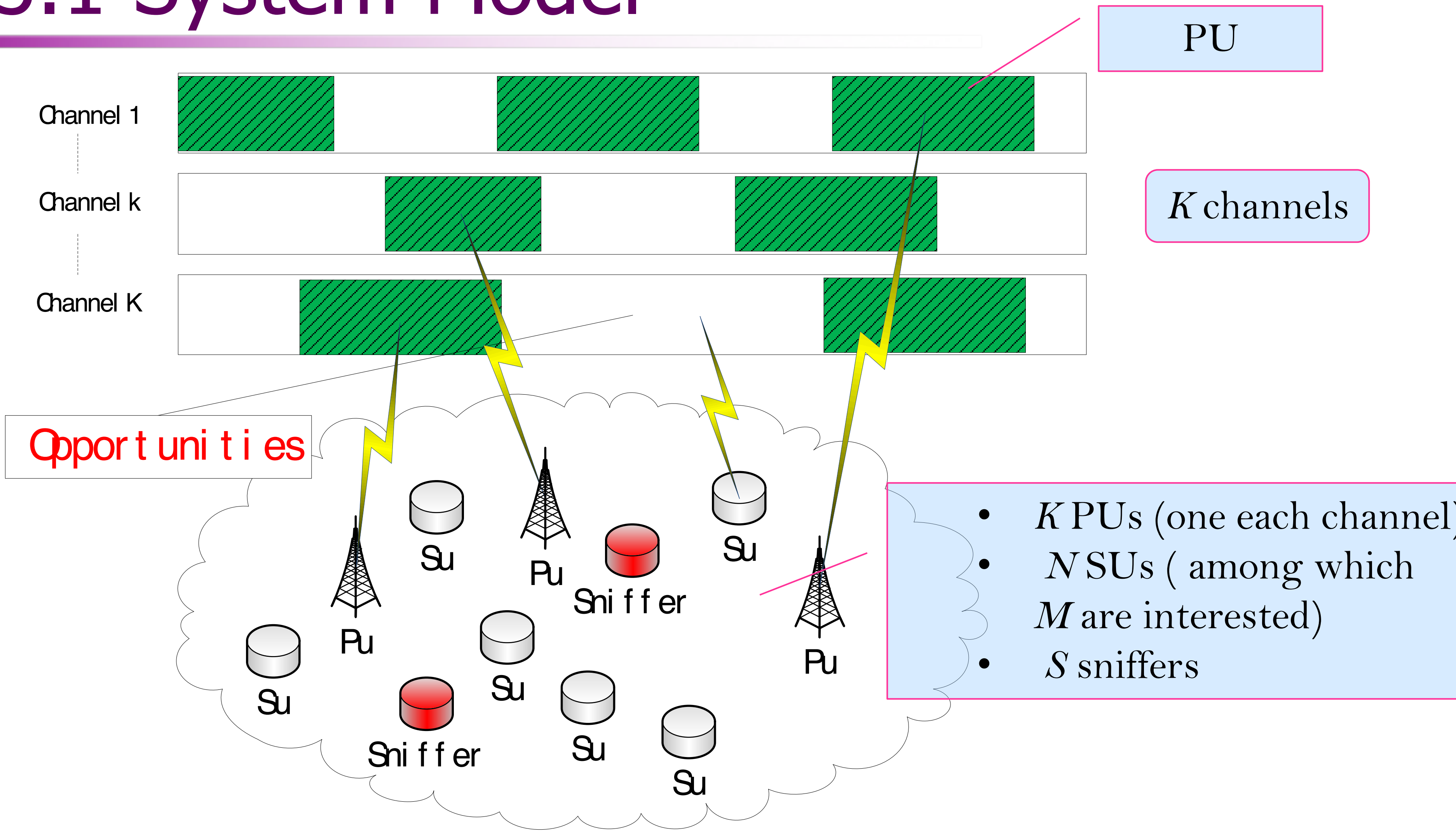
3. Problem Formulation

- 3.1 System Model
- 3.2 Traffic Model
- 3.3 Objective
- 3.4 Multi-Armed Bandit Problem
  - 3.4.1 Reward
  - 3.4.2 Regret
  - 3.4.3 Data Capture Policy

3.1 System Model



- K PUs (one each channel)
- N SUs (among which M are interested)
- S sniffers

3.1 System Model

- Behavior of sniffer
  - can only observe one channel at a time
  - can switch to other channel at anytime
  - Information is shared

- Behavior of SU
  - keep silent when the primary user shows up

3.2 Traffic Model

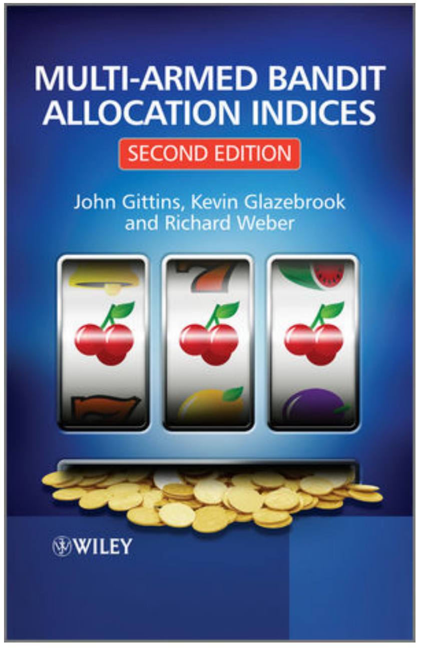
- The traffic of SU&PU is modeled as on-off renewal process.
  - The duration of state follows exponential distribution.
- Unslotted system
  - No need of time synchronization, no extra overhead
  - more common and adaptable
  - more complex due to the arbitrary starting and ending times of transmission.

3.3 Objective

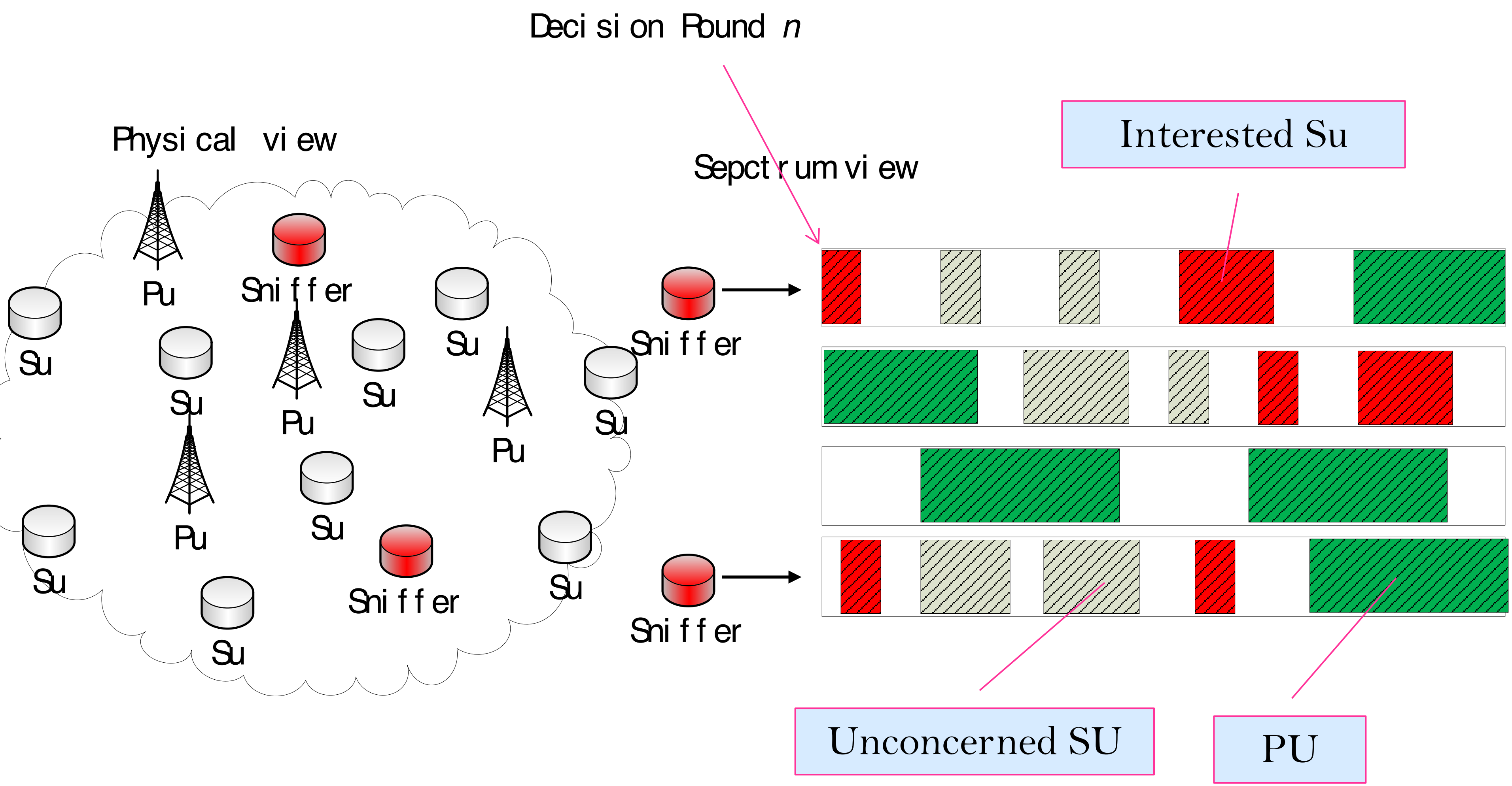
- Maximize the expected captured data of interested secondary users
  - unknown prior information
    - exploration or exploitation
  - limited monitoring resource
    - sniffer assignment

3.4 Multi-Armed Bandit Problem

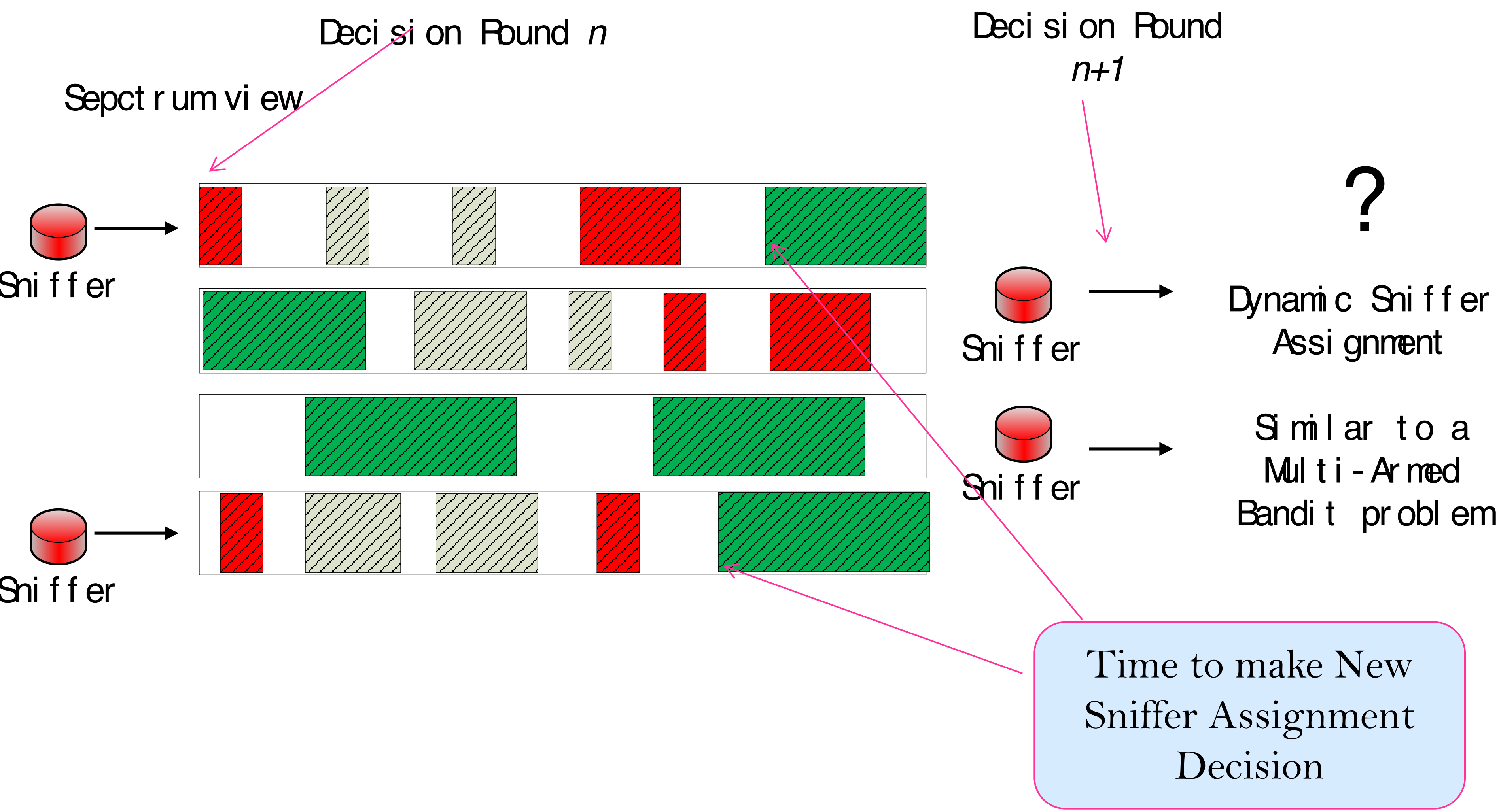
- N independent arms with Known states $x_1(t),\ldots,x_N(t)$
- At each time t
  - One arm is to be activated
  - Others are not
- Objective: maximize the expected reward



3.4 Multi-Armed Bandit Problem



3.4 Multi-Armed Bandit Problem



3.4 Multi-Armed Bandit Problem

- Player(Observer)
  - Sniffer
- Arm
  - Channel
- Reward
  - Valid captured data of SUs
- Data Capture Policy
  - channel assignment rule for sniffers

3.4.1 Reward

- The total captured data of sniffers

$$V_o(t - t_0) = \sum_{n(t_0)}^{n(t)} \sum_{k} \sum_{m} y^o_{k,m}(n)$$

Summed up by length of every captured data of all the interested SUs

- Virtual reward of channel *k*

$$V_k = \sum_{m} \frac{\hat{y}^o_{m,k}}{\hat{y}^o_{m,k} + \hat{x}^o_{m,k}} p^o_{m,k}$$

Summed up by average On/(Off+On) length ratio of all the interested SUs with weight value of the appearance probabilities of SUs

3.4.2 Regret

- Genie in MAB
  - Genie is ideal and omnipotent
  - Genie knows prior information
  - Genie always makes the right decision

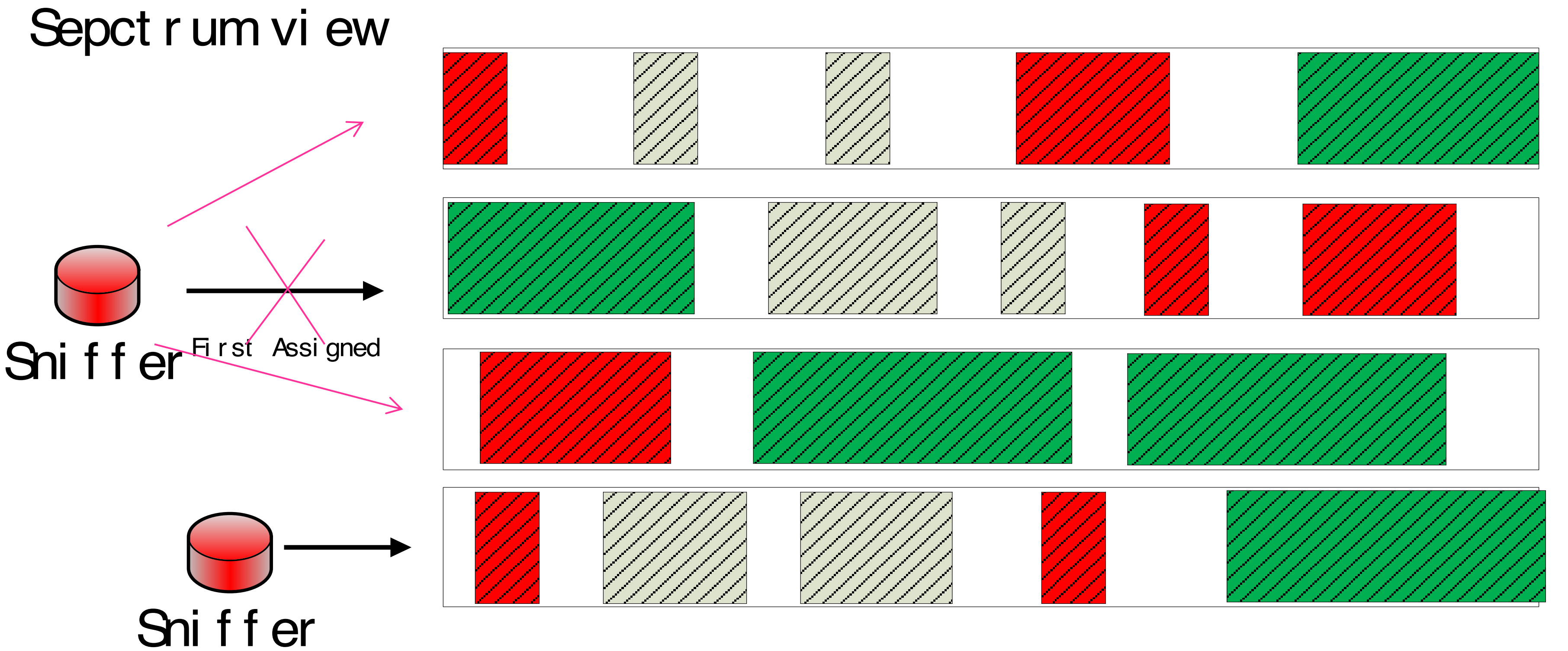
- Regret - Performance Measure

$$\mathbb{E}V^*(T) - \mathbb{E}V_o(T)$$

difference of expected value of gained reward between the “genie” and the proposed method

3.4.3 Data Capture Policy

- Monitor Rule
  - Random switching when a sniffer senses that the currently assigned channel is occupied by a primary user



3.4.3 Data Capture Policy

- UCB1 (Upper Confident Bound 1)

Deterministic policy: UCB1.
Initialization: Play each machine once.
Loop:

– Play machine j that maximizes $\bar{x}_j + \sqrt{\frac{2 \ln n}{n_j}}$, where $\bar{x}_j$ is the average reward obtained from machine j, n_j is the number of times machine j has been played so far, and n is the overall number of plays done so far.

Auer et al. Finite-time Analysis of the Multi-Armed Bandit Problem

3.4.3 Data Capture Policy

- Modified UCB1
  - Decision Index

$$I_k(t) = \overline{V_k}(t) + \sqrt{\frac{2\log(t)}{\sum_m n_{k,m}(t)}}$$

Average virtual reward from channel k

  - Update rule

$$\overline{V_k}(t+\Delta t) = \begin{cases} \frac{\overline{V_k}(t)+V_k(t,t+\Delta t)}{n_{k,m}(t)+1} & \text{if SU m is captured at channel k;} \\ \overline{V_k}(t) & \text{else} \end{cases}$$

$$n_{k,m}(t+\Delta t) = \begin{cases} n_{k,m}(t)+1 & \text{if SU m is captured at channel k;} \\ n_{k,m}(t) & \text{else} \end{cases}$$

  - Index chosen rule

$$k = \arg\max_k I_k(t)$$

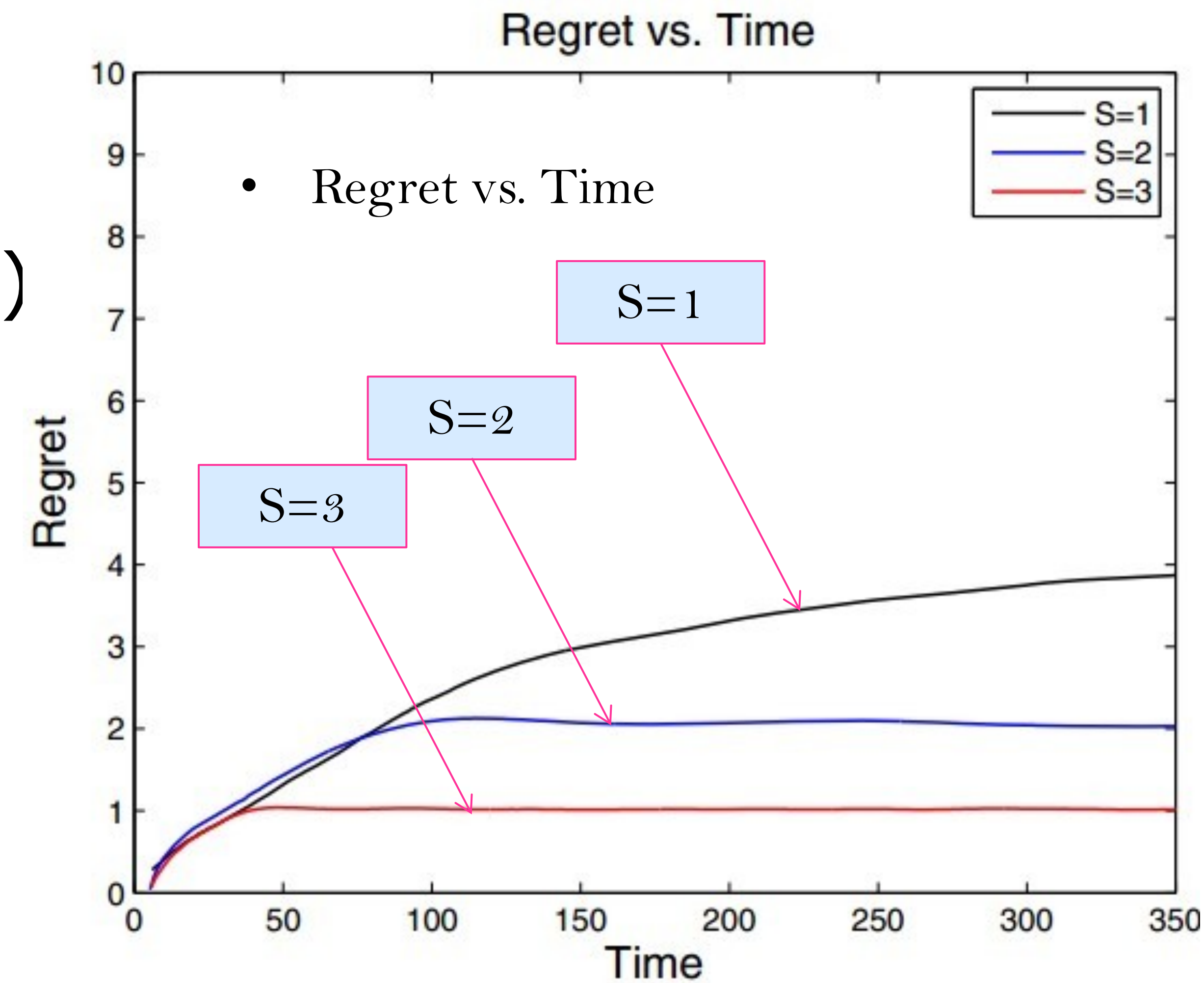
Outline

4.1 Simulation Setting

- Number of channels $K = 4$
- Number of interested SUs/SUs $M/N=[4, 8, 12]/12$
- Number of sniffers $S=[1, 2, 3]$
- busy/idle periods of users follow exponential distributions
- The appearance probabilities of SUs in channels are randomly generated

4.2 Simulation Result

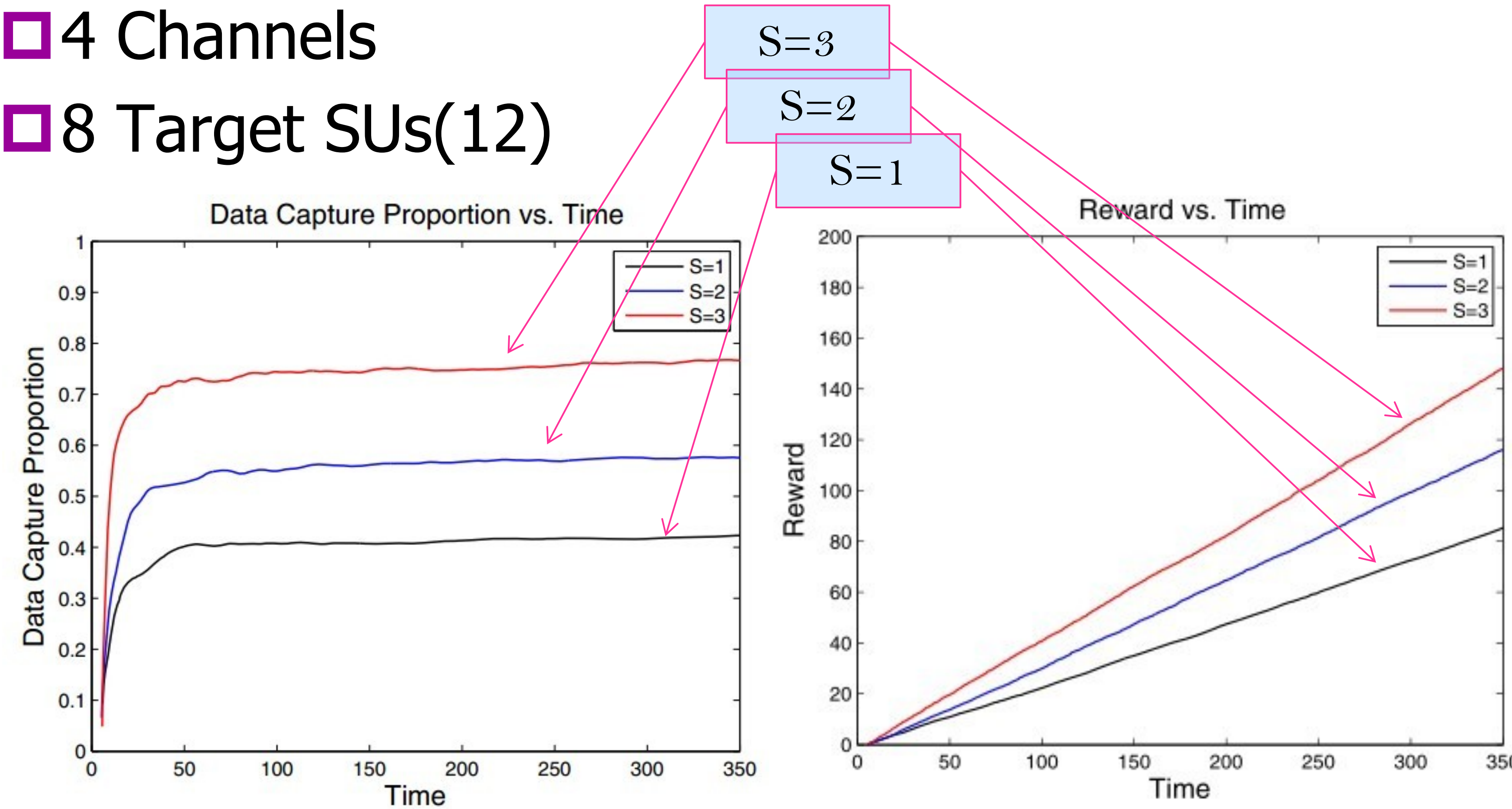
- Sniffer = [1,2,3]
- 4 Channels
- 8 Target SUs(12)



4.2 Simulation Result

- Sniffer = [1,2,3]
- 4 Channels
- 8 Target SUs(12)

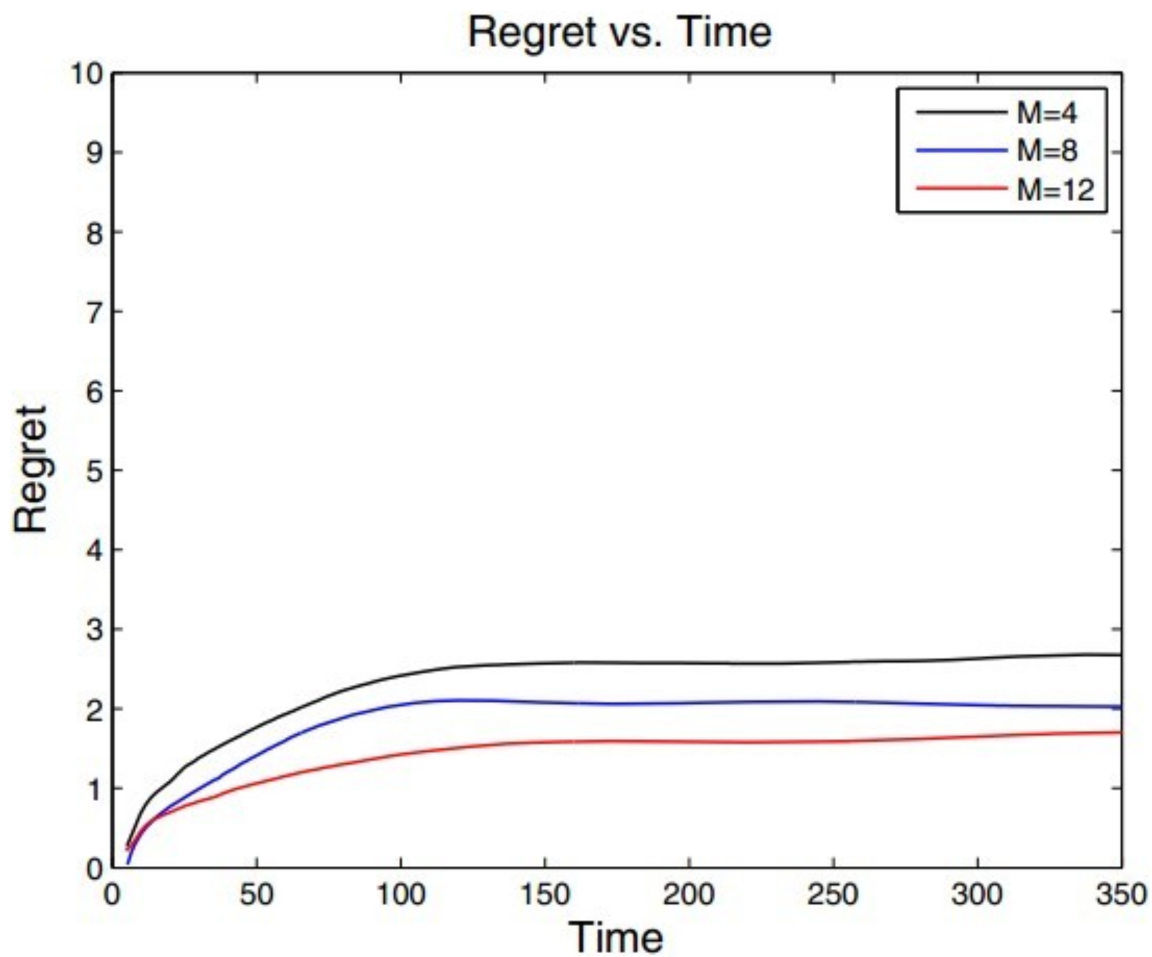
- Data Capture Proportion vs. Time
- Reward vs. Time



4.2 Simulation Result

- Interested SUs/SUs=[4,8,12]/12
- 2 sniffers
- 4 channels

• Regret vs. Time



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5.1 Conclusion

- Propose a secondary user monitoring problem in unslotted cognitive radio networks with unknown user traffic statistics
- Formulate the problem as a MAB problem with weighted virtual reward
- Apply UCB1 method to solve the proposed problem
- Simulation shows that the proposed policy can achieve a logarithmic regret with relative scalability

5.2 Future Work

- study the secondary user monitoring problem in more complicated scenarios
- considering secondary user channel switching and its influence on our policy design

Thanks!

Any Questions?