Cooperation in Cognitive Radio Networks

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Source: W. Saad and H. V. Poor, “Cooperation in Cognitive Radio Networks: From Monitoring to Access.” In *Mechanisms and Games for Dynamic Spectrum Allocation,* T. Alpcan, et al., Eds. (Cambridge University Press, 2014)

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Outline

1. Background and Motivation
2. Spectrum Sensing and Sharing
3. Spectrum Monitoring
4. Summary

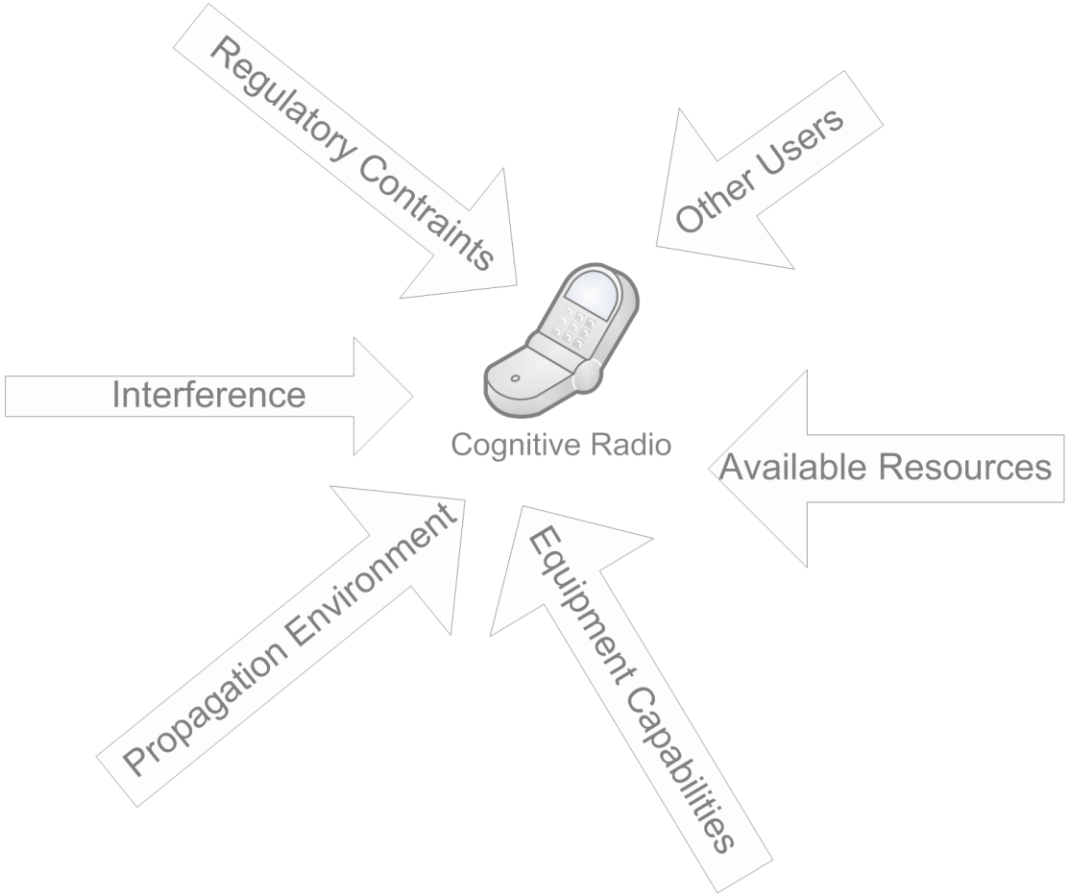
Background

And

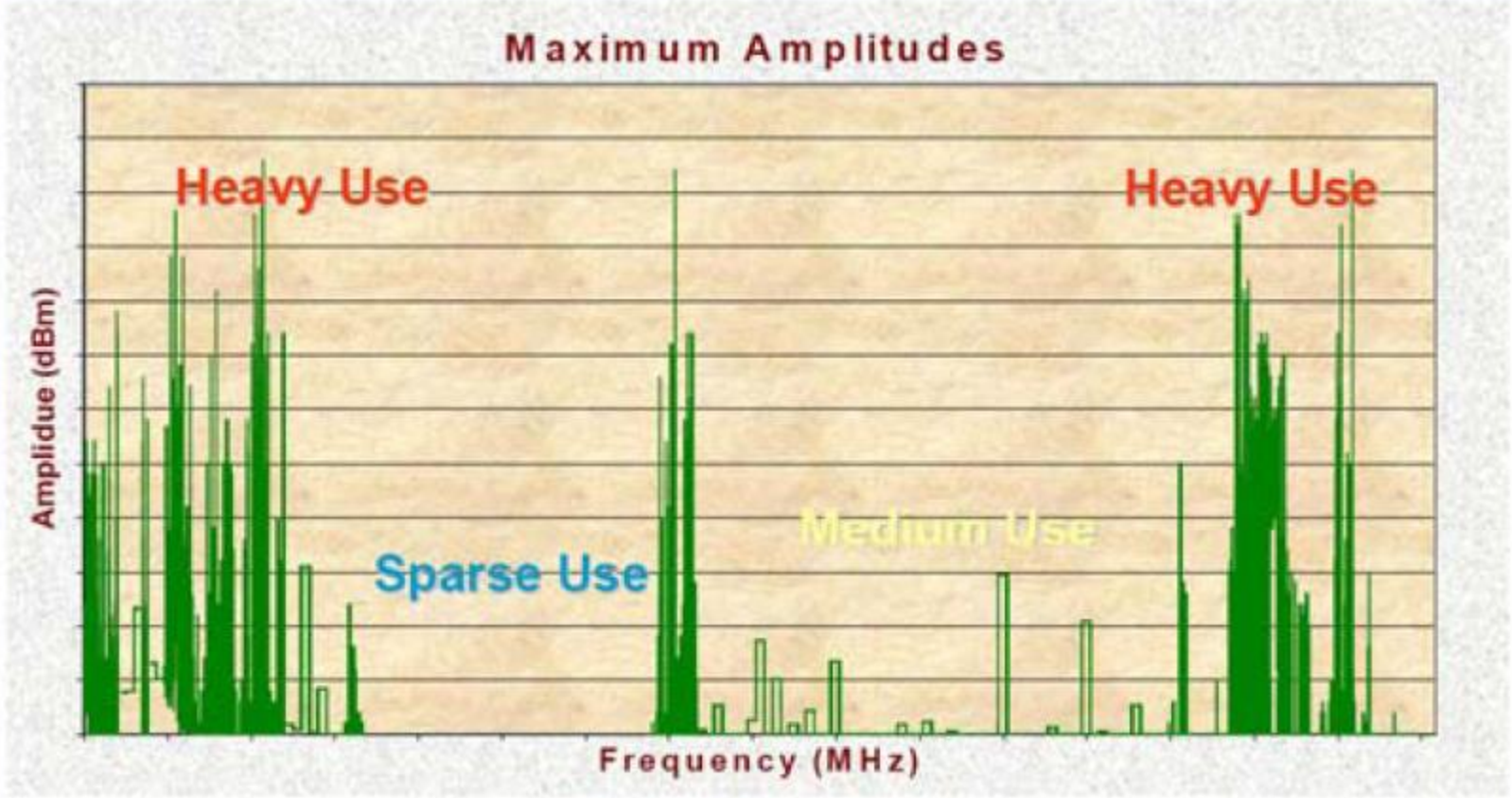
Motivation

Cognitive Radio

A cognitive radio is a radio that is able to sense, adapt and learn from its operating environment.

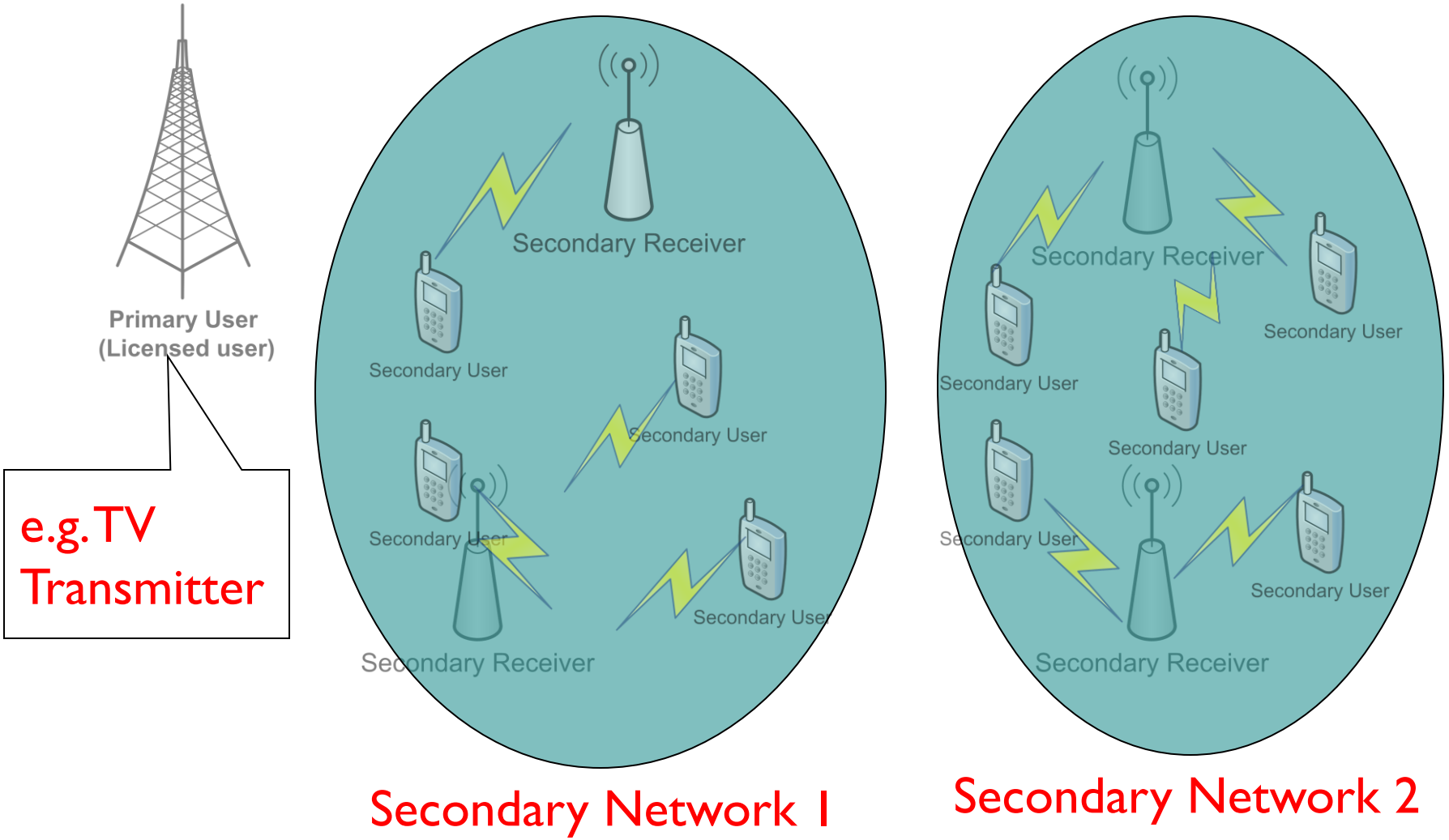


Spectrum Occupancy



Source: FCC, Spectrum Policy Task Force, Technology Advisory Council (TAC) Briefing (December 2002).

Cognitive Radio In a Nutshell



Secondary Network 1

Secondary Network 2

Cognitive Radio: Challenges

- Spectrum sharing
  - How to share the spectrum among the users?
  - Scheduling and resource allocation (e.g. channel allocation)
- Spectrum sensing
  - How to detect unused spectrum?
  - The spectrum sensing problem is basically a decision between two hypotheses: the primary user is absent/present
- Spectrum monitoring
  - How to generate models for the activity of the primary user?
  - Monitoring and evaluating the transmission patterns of primary users; machine learning

Spectrum Sensing

and

Sharing

Motivation and Model

- How can secondary users jointly sense and share the spectrum in a multi-channel cognitive network?
  - Sense to detect the best channel vs. time used for sensing
  - Accessing a vacant channel vs. waiting to find a better channel
  - Exploration vs. exploitation tradeoff
- Consider a multi-channel network with K PUs (channels) that are being sensed/accessed by N SUs:
  - Each PU channel is available with probability ϑ_k
  - An SU can only sense a subset of the K channels

Formalism

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Capacity achieved by SU *i* over channel k_j under "average" interference from other SUs

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Average sensing time with α being the fraction of time needed to sense one channel

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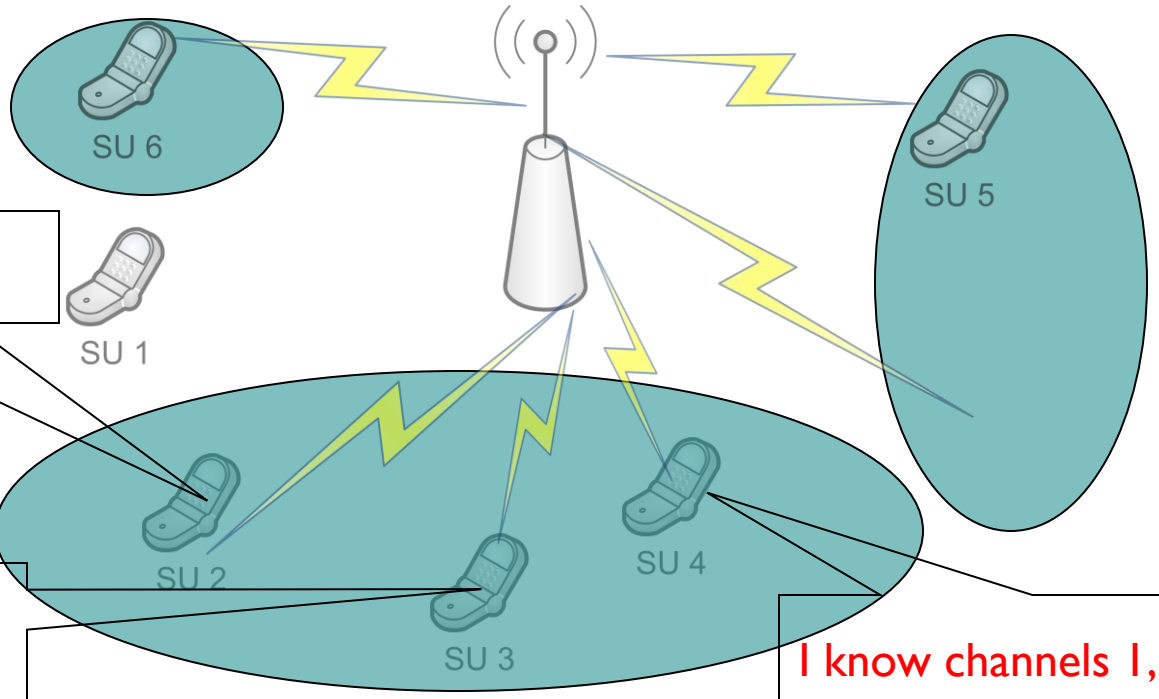
- Can SUs cooperate to reduce sensing time, and use/learn better channels?

Cooperative Sensing and Access

Cooperative spectrum sensing and access via coalition games.



I know channels 1 and 3

I know channels 2 and 5

I know channels 1, 6, and 8

Let's cooperate to enable:

- Spectrum sensing/exploration gains by sharing the statistics for the union of known channels
- Spectrum access (capacity) gains by reducing interference

Coalitional Games Preliminaries

- Coalitional game (*N,v*)
  - A set of players ***N,*** *a* ***coalition*** S is a group of cooperating players
  - Value (utility) of a coalition ***v*** and individual user payoff φ_i
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- Characteristic form vs. Partition form
  - When a coalition *S* forms or splits, does it affect the formation of the rest of the coalitions in the network?
  - ***YES => Partition form, NO => Characteristic form***

Joint Sensing and Access as a Game

- SUs are the players whose goal is to reduce sensing time and boost their capacity by cooperating (e.g., by coordinating interference and learning new channels)
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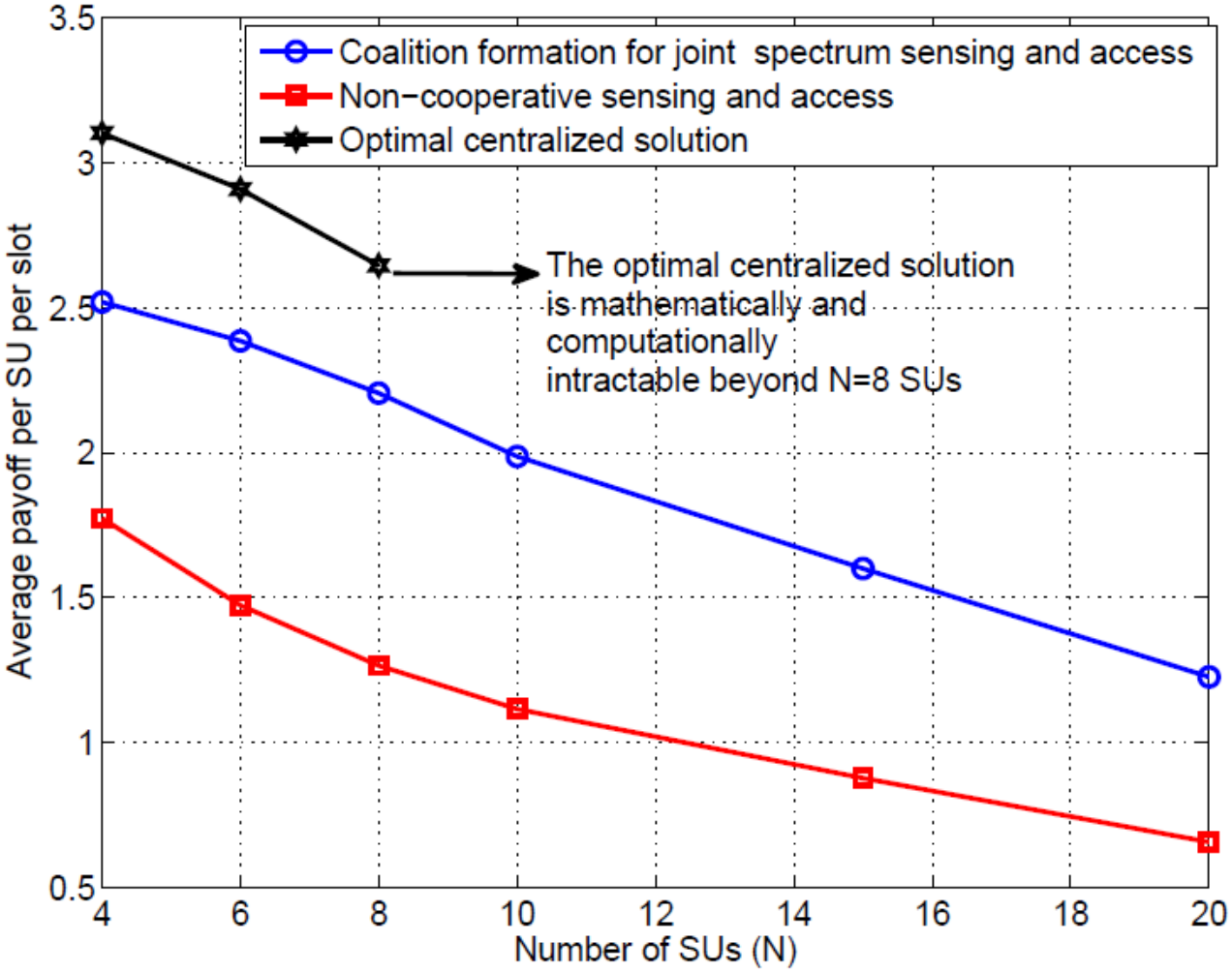
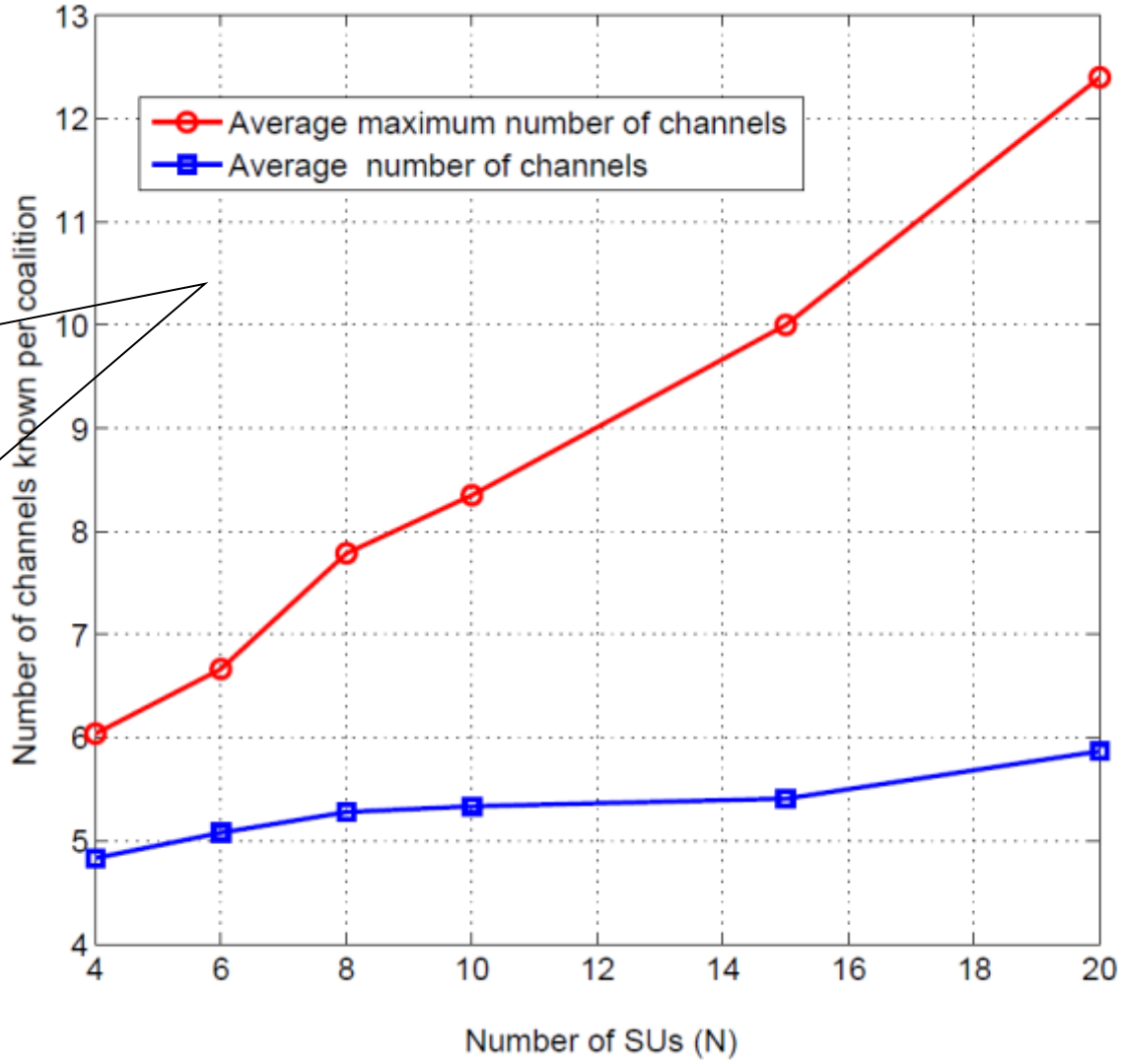
- Key results and observations
  - Utility depends on the entire partition => game has **partition form** and conventional coalition formation algorithms like merge/split do not work.
  - The game has NTU, since there is no transferable group utility.
  - An algorithm that is based on a "switch rule" whereby SUs change coalitions iteratively converges to a stable partition.
  - Stability in the Nash-sense: no SU has an incentive to leave current coalition

Simulation Results (1)



Simulation Results (2)

Using coalition formation, each group of SUs now has a clearer view of the overall spectrum.



Spectrum Monitoring

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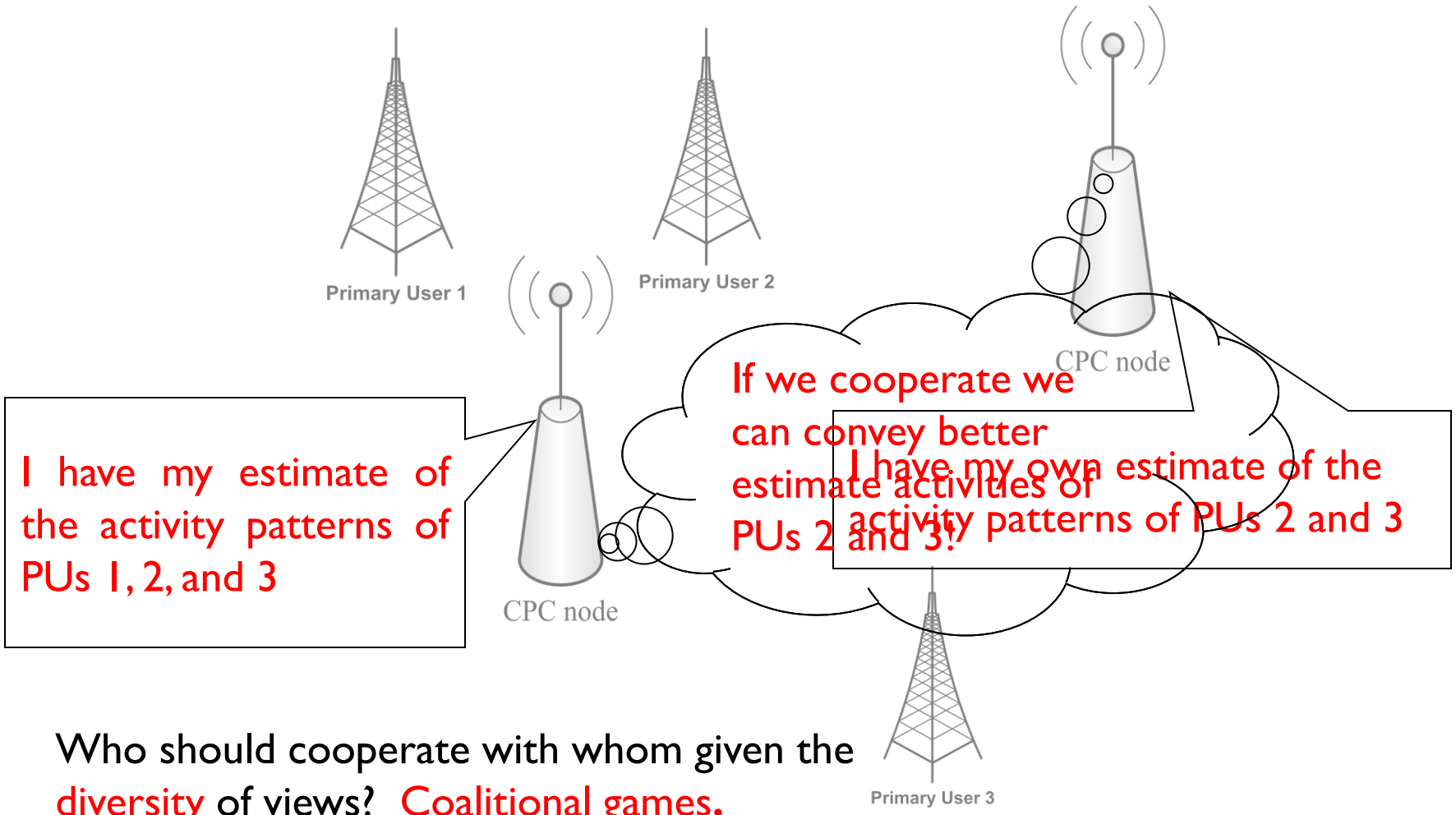
- Use a Cognitive Pilot Channel (CPC) carried by either a dedicated device (CPC node) or by SUs themselves:
  - Introduced for ensuring a conflict-free coexistence of SUs and PUs
  - A control channel that can carry information in a given area to assist cognitive users in their dynamic spectrum access
  - Assist SUs in their operation by identifying specific channels and operators for the SUs, providing a better view on spectrum utilization, or providing advance spectrum management strategies

Problem Statement



Who should cooperate with whom given the diversity of views? Coalitional games.

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- When cooperating, the CPC nodes must **jointly** estimate the distribution of the PU activity pattern but…
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  - A coalition uses such techniques cooperatively to get an estimate of the PU activity (viewed as a pdf over the probability with which a PU is active)
- In our (NTU, characteristic form) game, CPC node *i* in coalition *S* optimizes

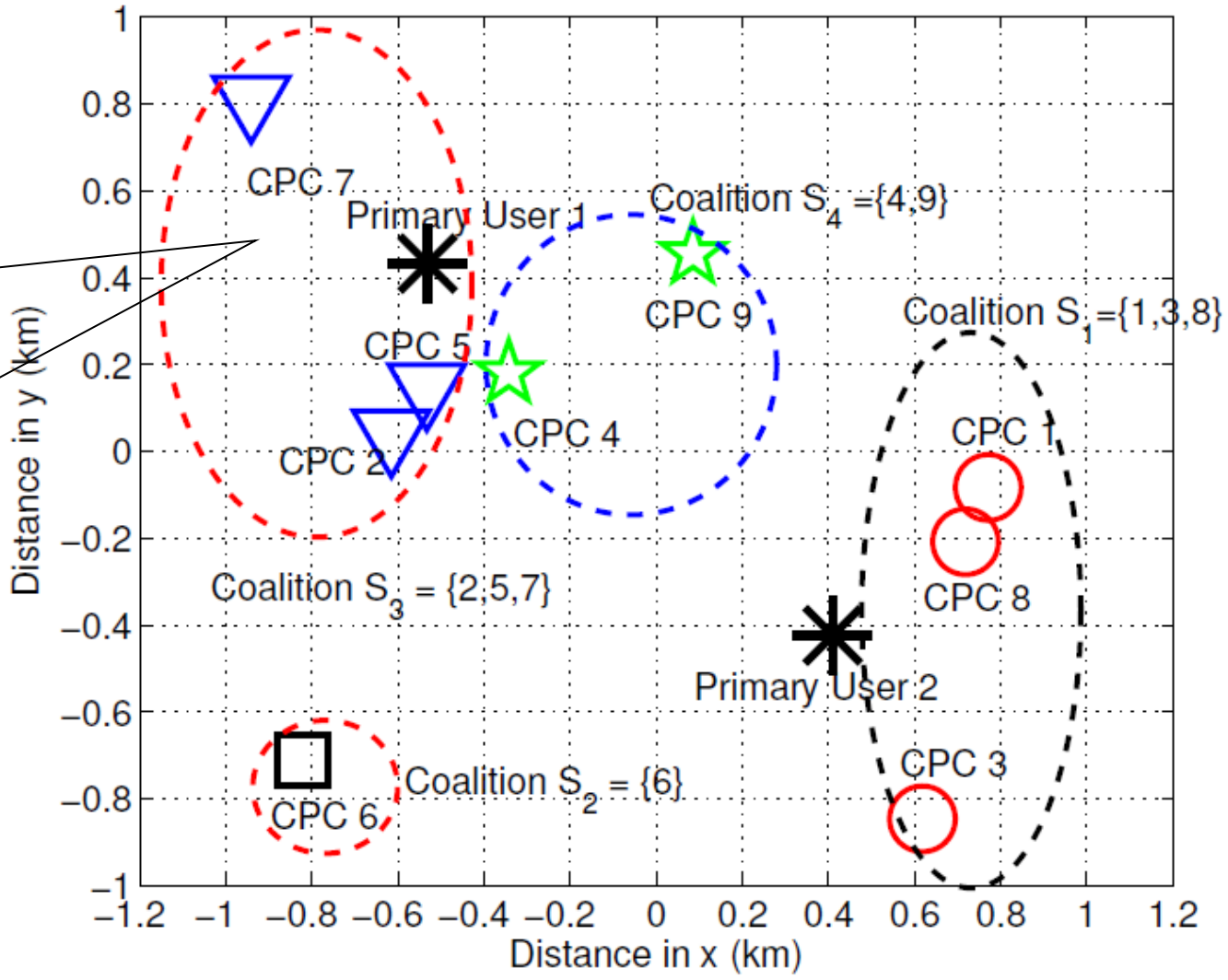
$$g_i(S) = \sum_{k \in \mathcal{K}} u_{ik}(S) - c(S)$$

Simple cost, linear with coalition size

Negative of the KL distance between two nonparametric estimates of channel *k* with different # observations

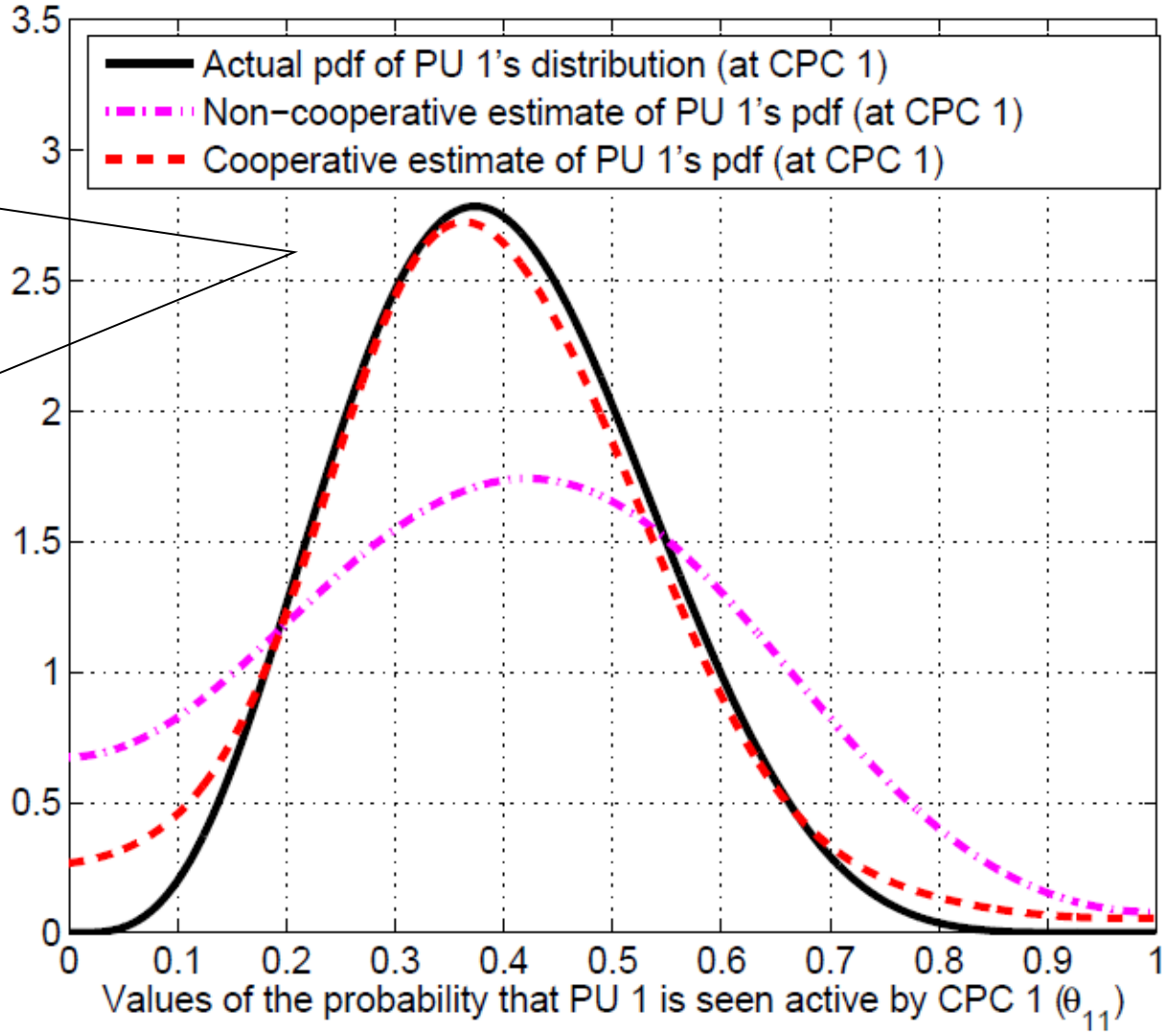
Simulation Results (1)

As per our intuition, CPC nodes that have overlapping PU views will cooperate.



Simulation Results (2)

Shows the accuracy of estimation using cooperation (this is CPC 1 from the previous slide).



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- Other areas of interest:
  - Cooperative communication among PUs (i.e., relaying)
  - Cooperation between PUs and SUs
  - Experimentation on testbeds – CorteXlab!


Thank You!