Cognitive Radio: From Promise to Reality

José F. de Rezende
rezende@land.ufrj.br

LAND – Laboratory for Modelling, Analysis and Development of Networks and Computer Systems

Universidade Federal do Rio de Janeiro (UFRJ)

Cognitive Radio: Motivation

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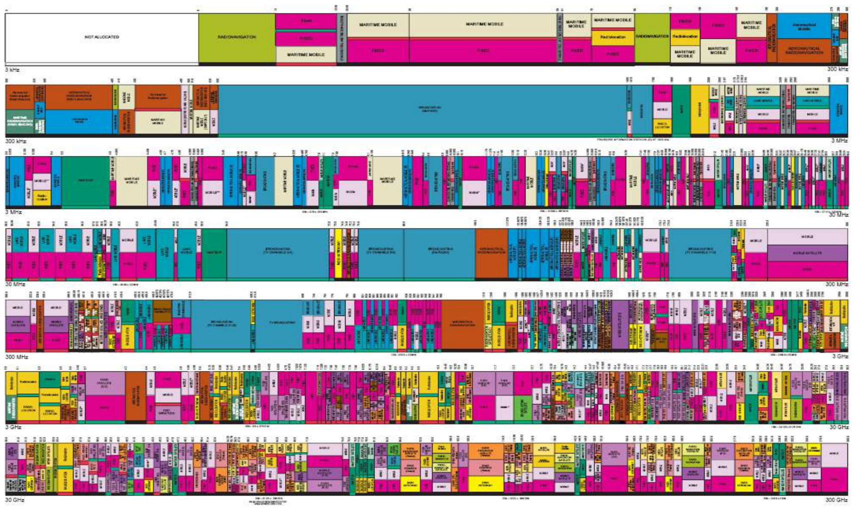
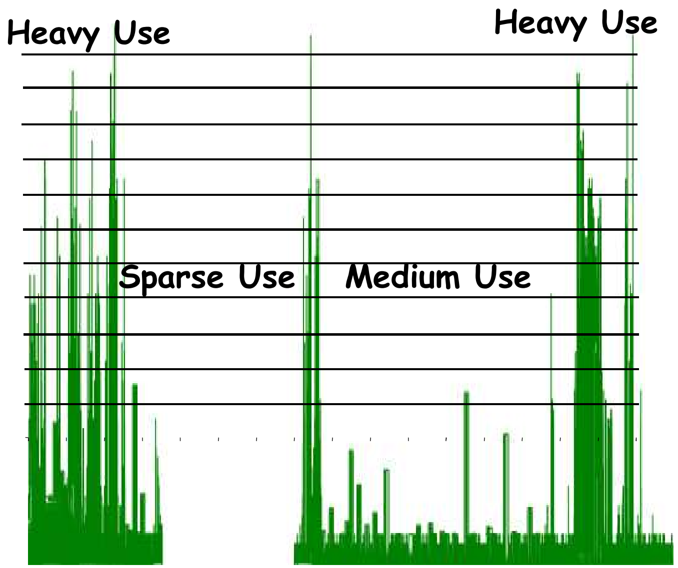
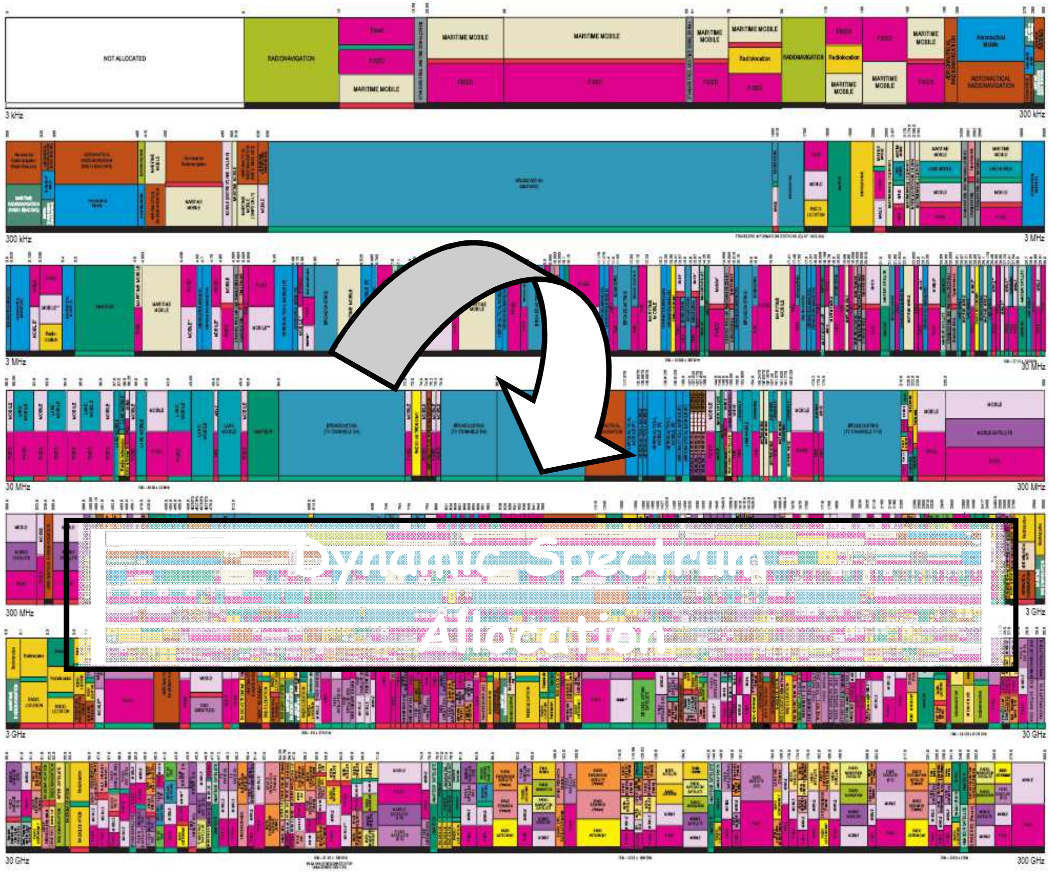




Fixed Spectrum Assignment

Spectrum Utilization

Cognitive Radio: DSA Enabler



- J. Mitola III and G. Q. Maguire, Jr., "Cognitive Radio: Making Software Radios More Personal," *IEEE Personal Commun.*, vol. 6, no. 4, Aug. 1999, pp. 13–18.

What is a Cognitive Radio (CR)?

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- capability to use or share the spectrum in an opportunistic and intelligent manner
  - advantages:
    - allows for real-time spectrum management
    - significantly increases spectrum efficiency
- CR should be able to change (by software) its transmitter parameters based on interaction with the environment in which it operates
  - it senses the RF environment and modifies frequency, bandwidth, power or modulation

Cognitive Cycle

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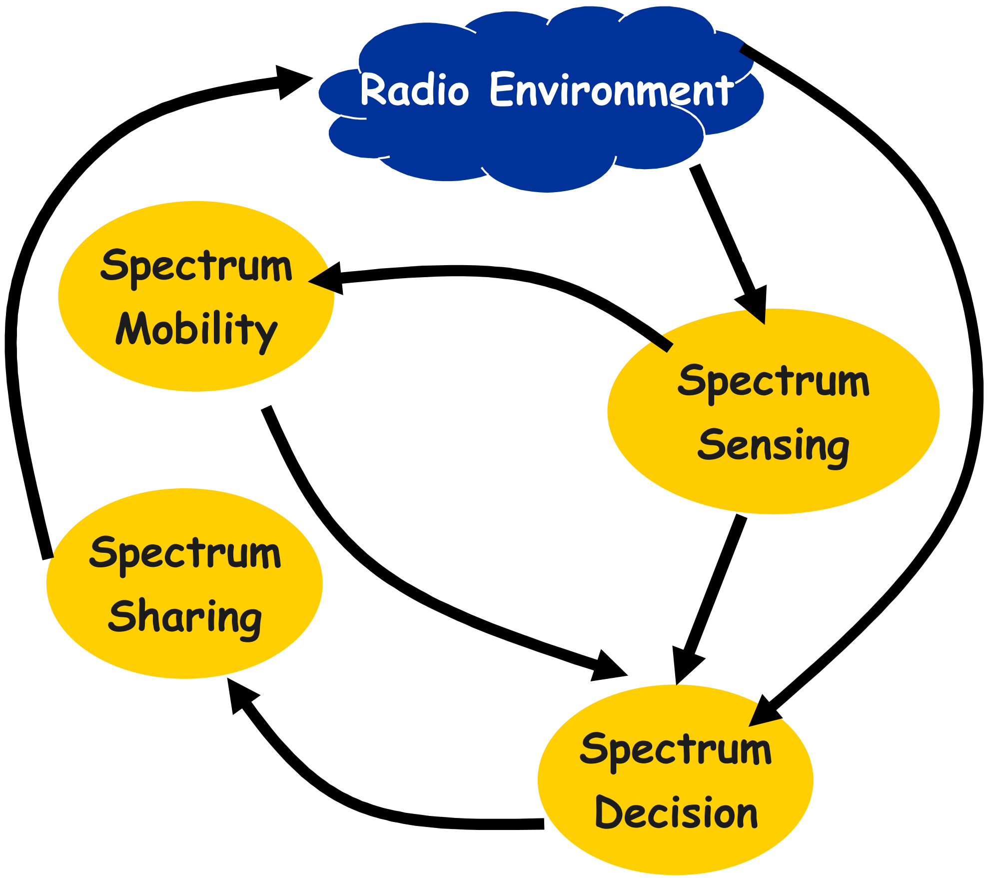
- determine which portions of the spectrum is available and detect the presence of licensed users (Spectrum Sensing)
- select the best available channel (Spectrum Decision)
- coordinate access to this channel with other users (Spectrum Sharing)
- vacate the channel when a licensed user is detected (Spectrum Mobility)



CR Evolution

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- sensing based
  - regulator guidelines recommend a high sensitivity (-120 or -114 dBm)
    - increases the costs of the equipment
  - several blind and signal specific feature-based techniques
    - energy detector, spectral correlation, time-domain cyclostationarity, eigenvalue decomposition, pilot detection, high order statistics analysis
- geo-location based (White Space DB - WSDB)
  - the database determines the free channels for operation
    - cheaper cognitive radios (no sensing)
  - waste of temporal opportunities
    - more appropriate to TV bands (TVWS)
  - challenges on the database management, maintenance and information exchange
- hybrid: sensing + geo-location
  - database-aided sensing or sensing-aided database

Existing WSDBs

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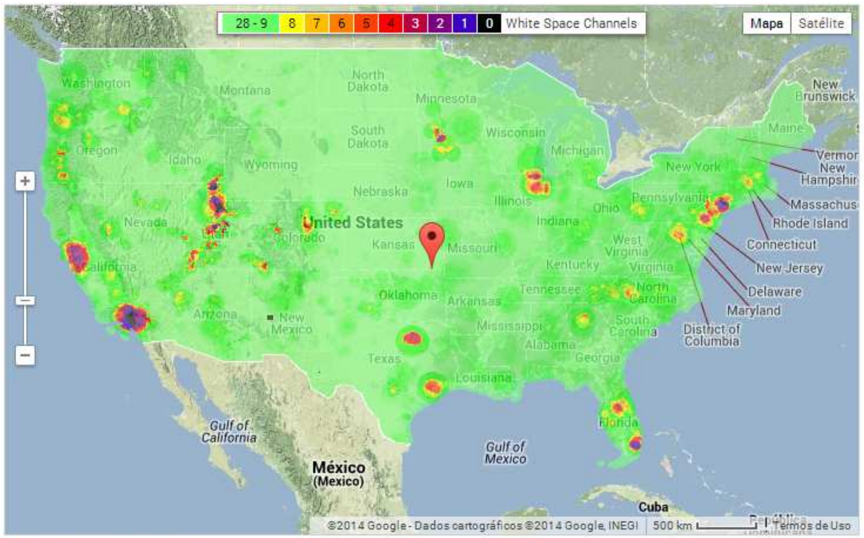
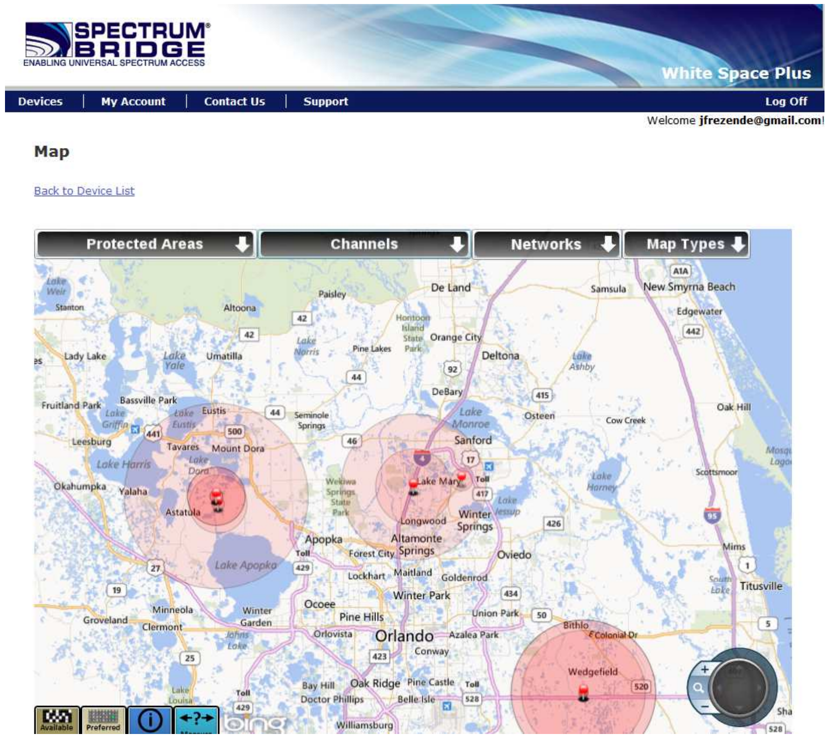
Google Spectrum Database



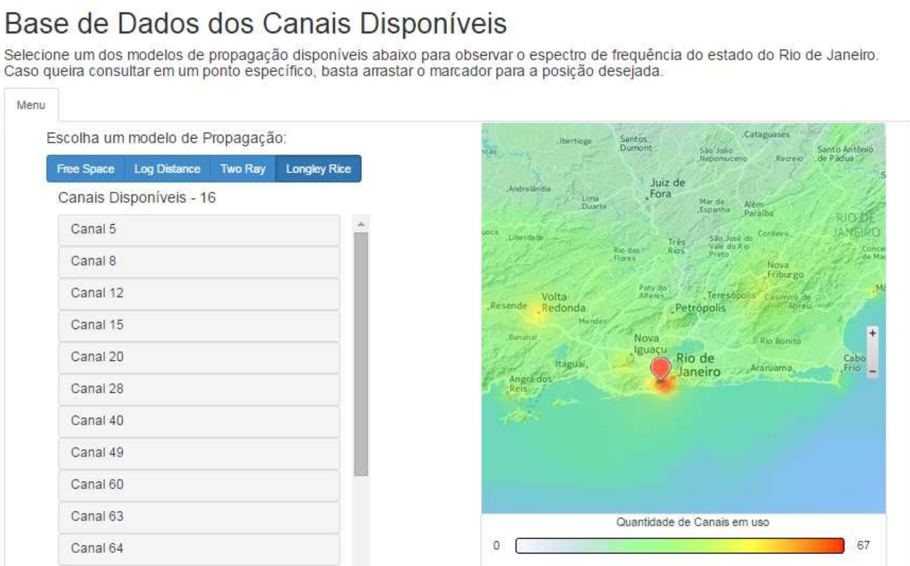
Spectrum availability (as of February 24, 2014)

Spectrum Bridge

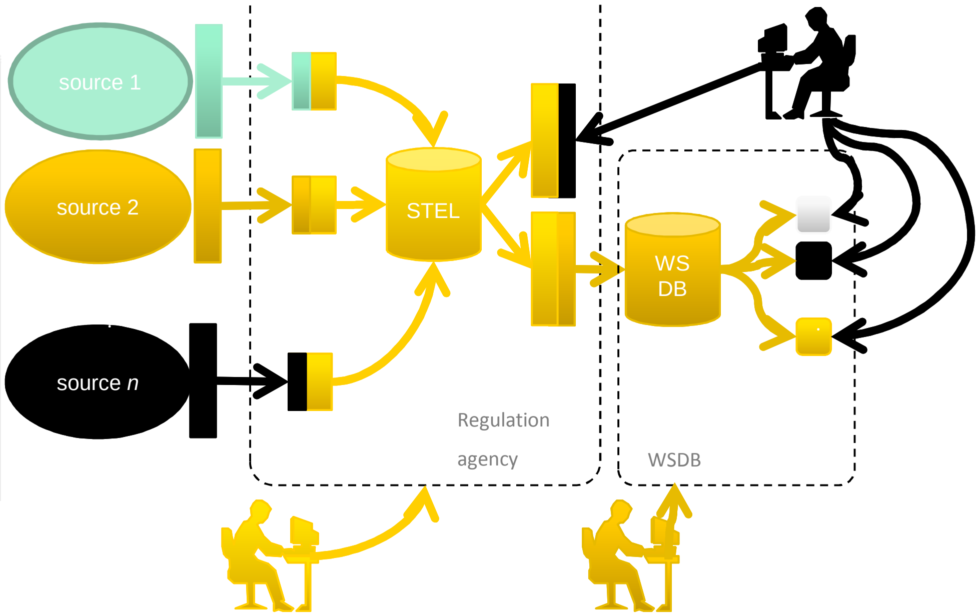


Existing WSDBs

- WSDB@UFRJ



- General Architecture



WSDB use cenarios

- Rural Broadband
  - 802.22 (Wi-FAR) and 802.11af
- IoT
  - Weightless, SigFox and 802.15.4m
- LTE femto cells
  - in the 3.5GHz radar band

Some Research Activities on CRs

- sensing
  - channel sensing order problem
  - proactive sensing for spectrum handoff
- DSA in the radar bands

Channel Sensing Order

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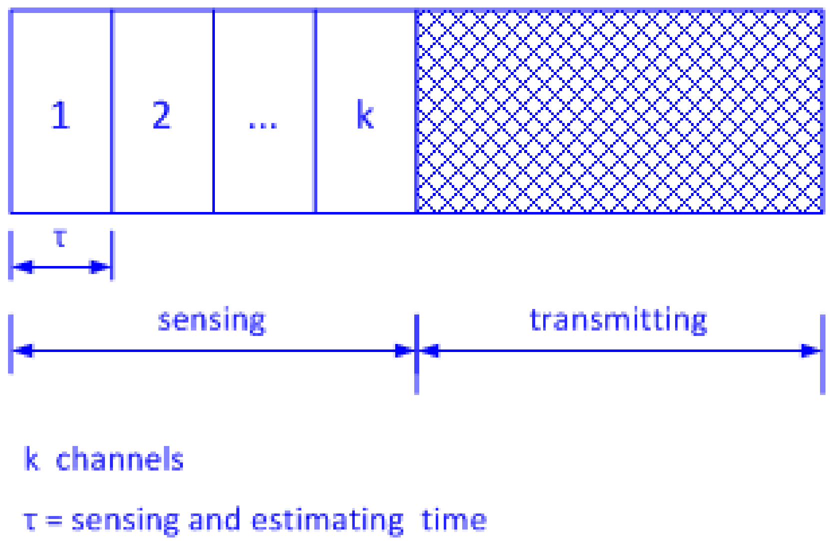
- single radio and multiple channels with temporal opportunities



- when channels have varying capacity and occupation
  - sensing order has a great impact in the performance

Channel Sensing Order

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- intuitive channel sequences
  - decreasing order of capacity/occupation
- the theory of optimal stopping can provide the best sequence to be followed
  - but requires a priori knowledge of the moments of the random variables that characterize the channels
  - and presents a high computational complexity
- our proposal uses a reinforcement learning (RL) machine
  - does not require any a priori knowledge about the channels
  - with a proper modeling we can
    - reduce the state space of the problem (Q-table)
    - achieve a performance close to the optimal

Results Normalized to the Optimal Sequence

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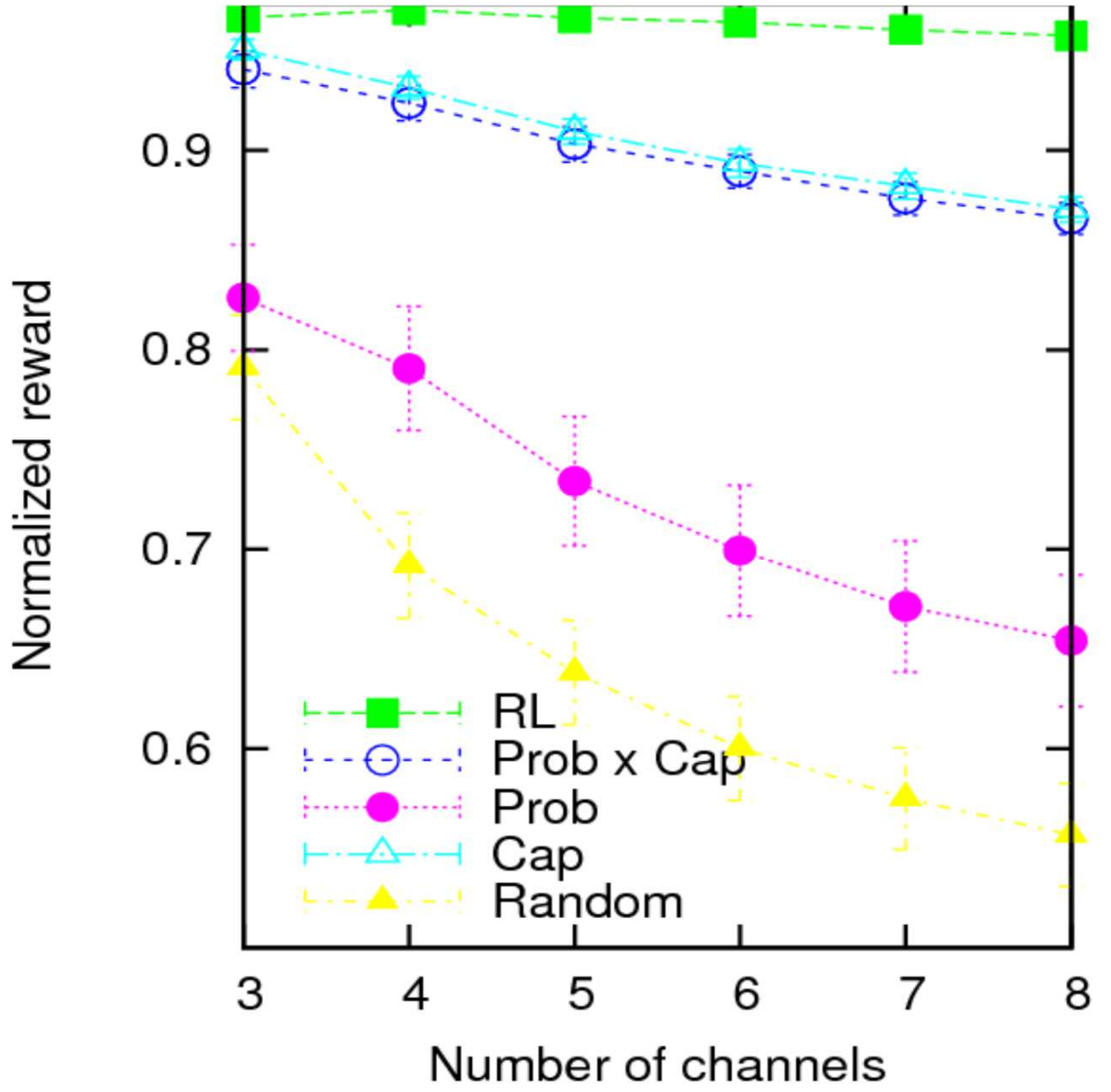

On-going Work on Channel Sensing Order

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- RL convergence problem
  - exploration x exploitation tradeoff

- multiple users
  - independent versus cooperative agent learners
    - spectrum utilization efficiency and fairness

Proactive Sensing for Spectrum Handoff

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- spectrum handoff
  - in order to free the channel after PU arrival
    - i.e. reactive handoff
  - SU needs to sense other channels
    - sensing order matters
- however, by doing proactive sensing on the remaining N-1 channels, we can
  - estimate PU activity (i.e. two-state continuous-time Markov Chain)
  - gather channel state information, and then
  - determine a handoff sensing sequence that optimizes some criteria

Handoff Sensing Sequence

- the order in which channels are sensed matters
  - e.g. probability of being idle (P_{IDLE}): lesser time to handoff
  - e.g. expected transmission time (t_E): longer time before handing off again

- proposal
  - expected interference time (t_I): lesser interference to the PU
    - considering the misdetection probability (P_{MD})

Assessed Criteria

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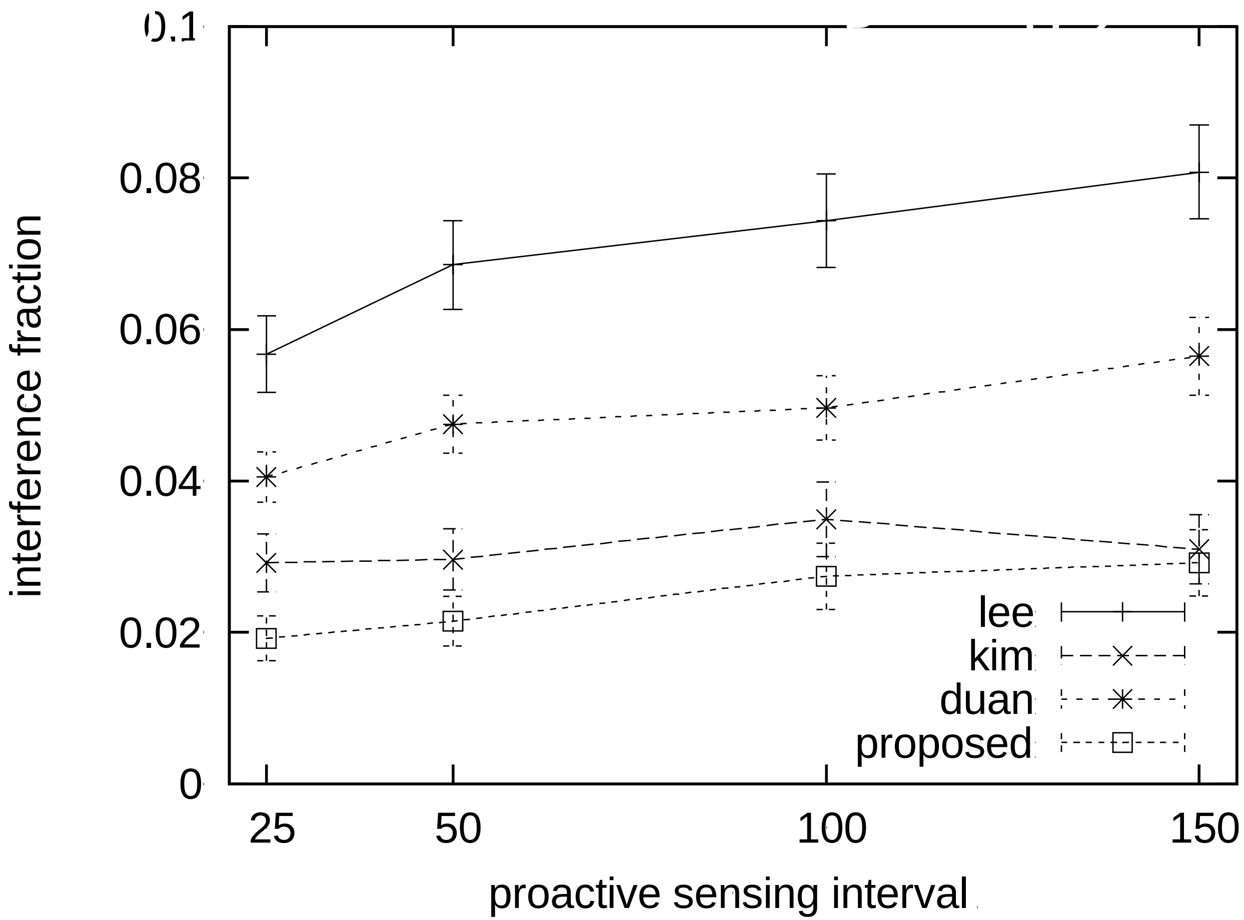
Name	Criterion	Reference
kim	P_{IDLE}	[Kim and Shin 2008]
duan	$P_{IDLE} \cdot t_E \cdot T_d(t_E)$	[Duan and Li 2011]
lee	t_E	[Lee and Akyildiz 2011]
proposed	$\frac{P_{IDLE} \cdot t_E}{t_I}$	[CrownCom 2012]

Proactive Sensing Interval Variation

- channel switching delay = 0.15 s
- P_{MD} = 0.01



P_{MD} Variation

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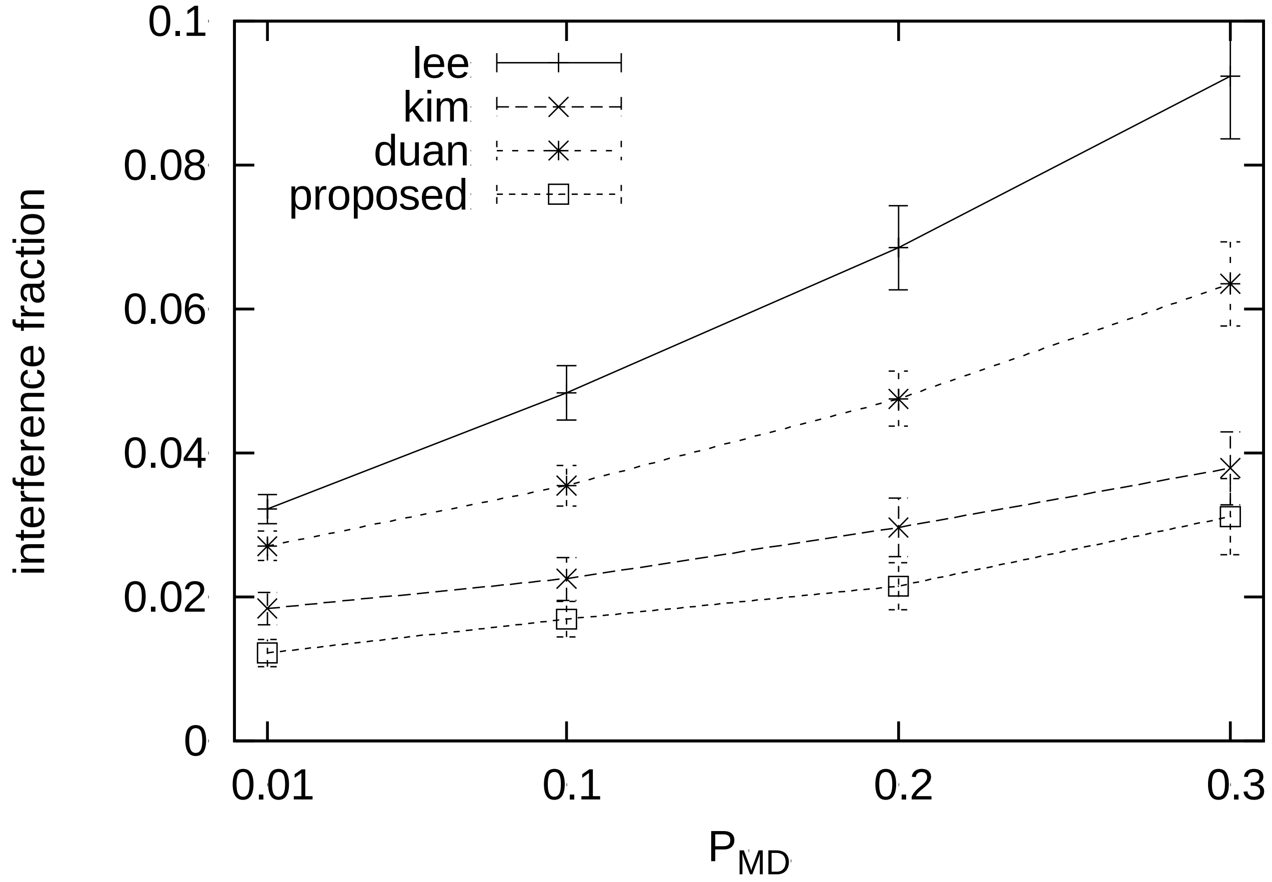
channel switching delay = 0.15 s
proactive sensing interval = 50 s



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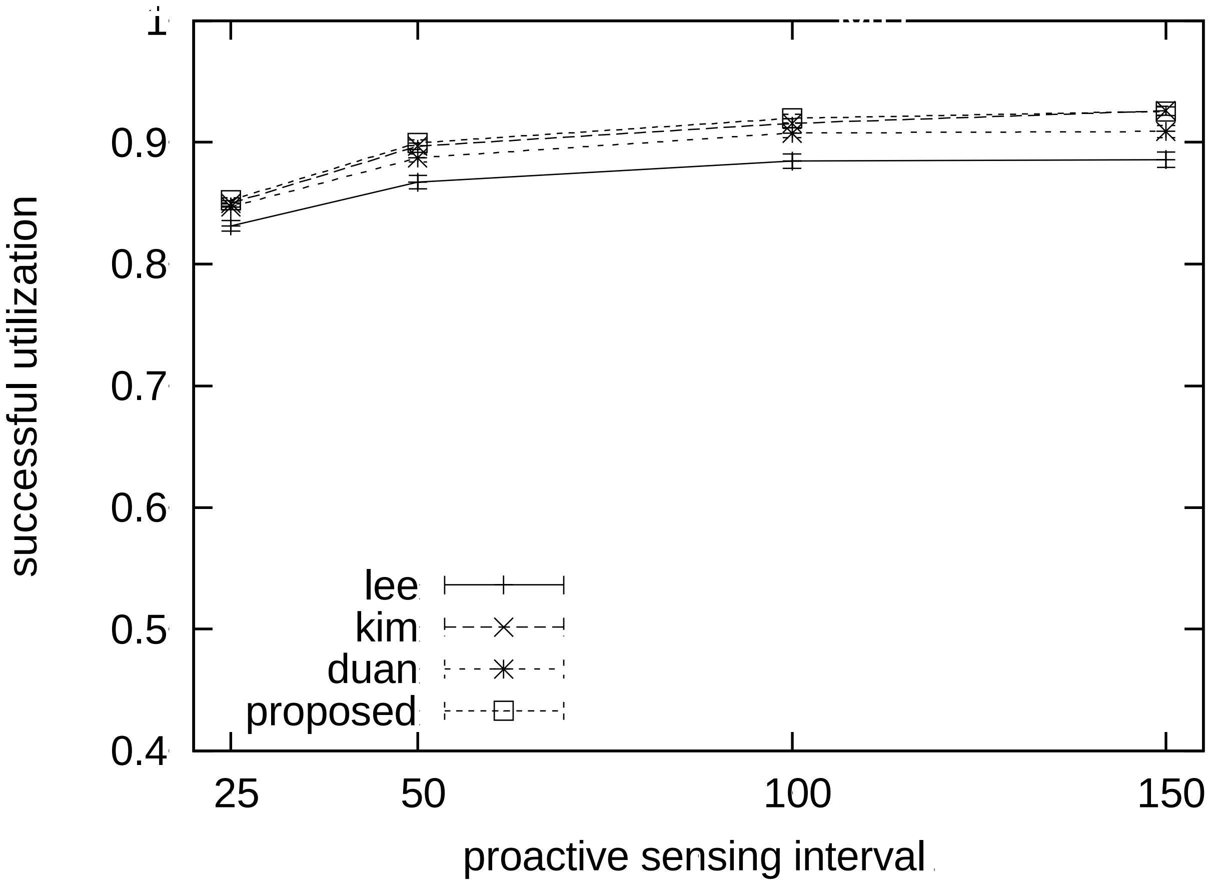

On-going Work on Spectrum Handoff

- proactive handoff
  - free the channel before the PU arrival

- eliminate unpredictable channels
  - use of entropy

- use spectrum measurement traces

Dynamic Spectrum Access in Radar Bands

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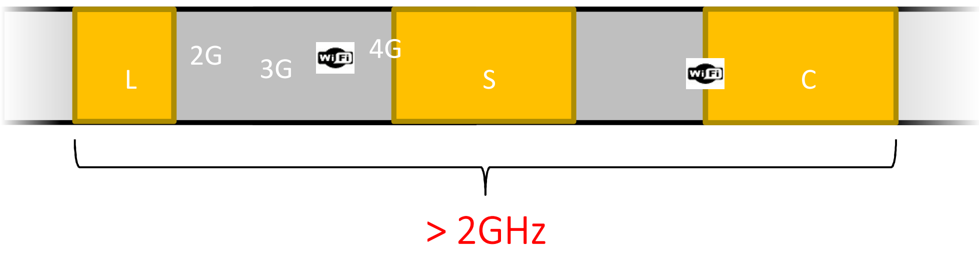
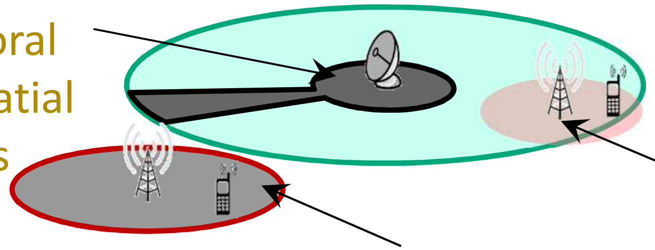
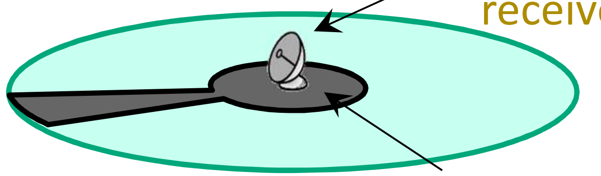
- huge space of opportunities



- spatial & temporal opportunities



- PU is easy to detect



The Aggregate Interference Problem

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- caused by multiple SUs
- static threshold
  - multiple interference is not considered
- proposal: a cooperative method between PU and SUs
  - combination of DFS-T: temporal & spatial opportunities
  - an additional mechanism to prevent Aggregate Interference (AI)
    - dynamic threshold which evolves with AI
    - cooperation between PU and SUs
      - PU measures the amount of interference and broadcasts new P_{thr}
      - SU updates P_{thr} information

References

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Thank You.

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