Context-Awareness and Intelligence in Cognitive Radio Networks: Design and Applications

Kok-Lim Alvin Yau
Supervisors: Peter Komisarczuk and Paul D. Teal

Communications Systems Research Group
School of Engineering and Computer Science
Victoria University of Wellington, New Zealand

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

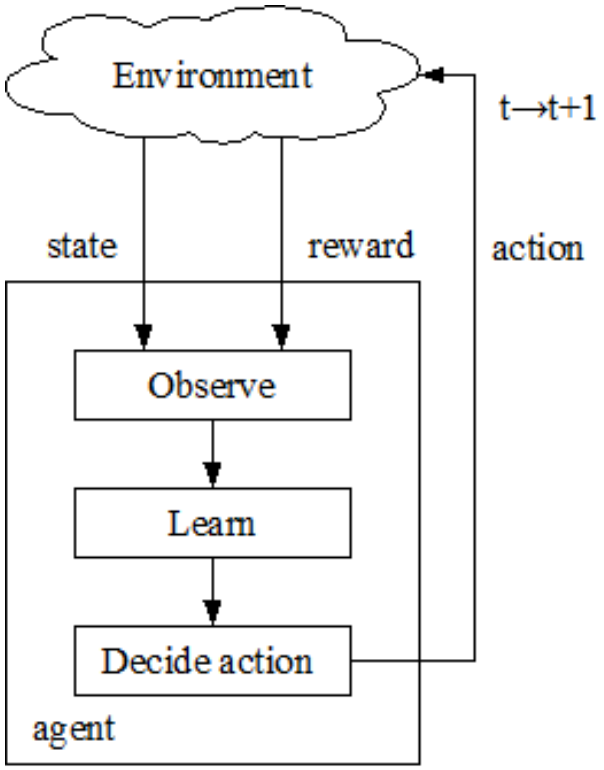
CAPITAL CITY UNIVERSITY

Seminar on Future Wireless Technologies, Ministry of Economic Development, August 24, 2009

Agenda

- **Overview of Cognitive Radio**
- **Research Outline**
- Network-level Cognition Cycle
- Node-level Cognition Cycle
- Conclusions
- Questions

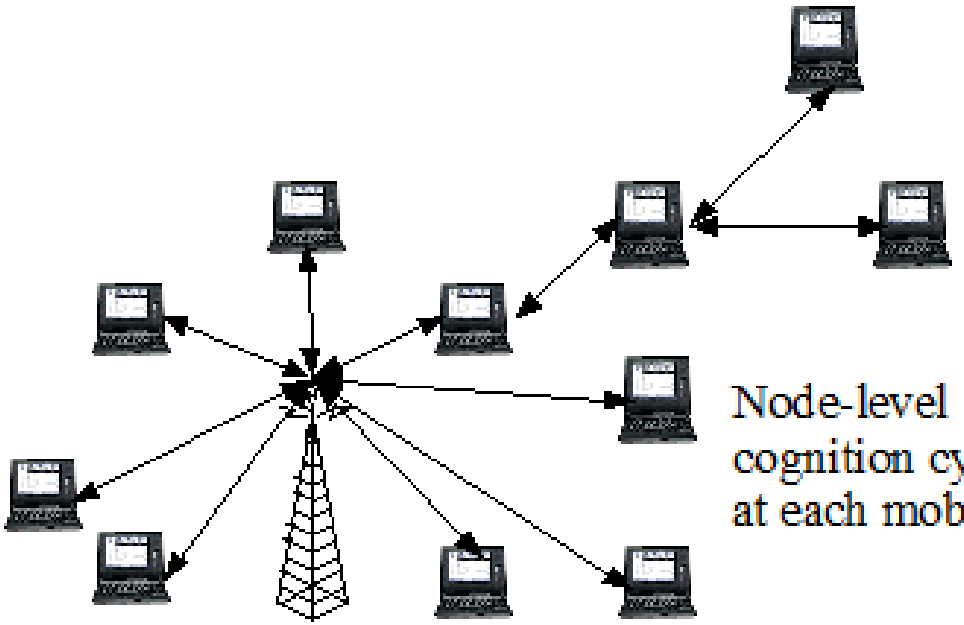
Overview of Cognitive Radio (1/2)
Cognition Cycle



- The key component in Cognitive Radio (CR) is the Cognition Cycle (CC)
  - Cognition cycle
    - Provides the capability to *observe*, *learn*, and *decide action* in an efficient manner with respect to its operating environment without adhering to a *strict and static* self-defined policy.
    - Achieves context-awareness and intelligence

Overview of Cognitive Radio (2/2)
Cognition Cycle

- Two levels of CC
  - Network-level for centralized networks
  - Node-level for distributed networks



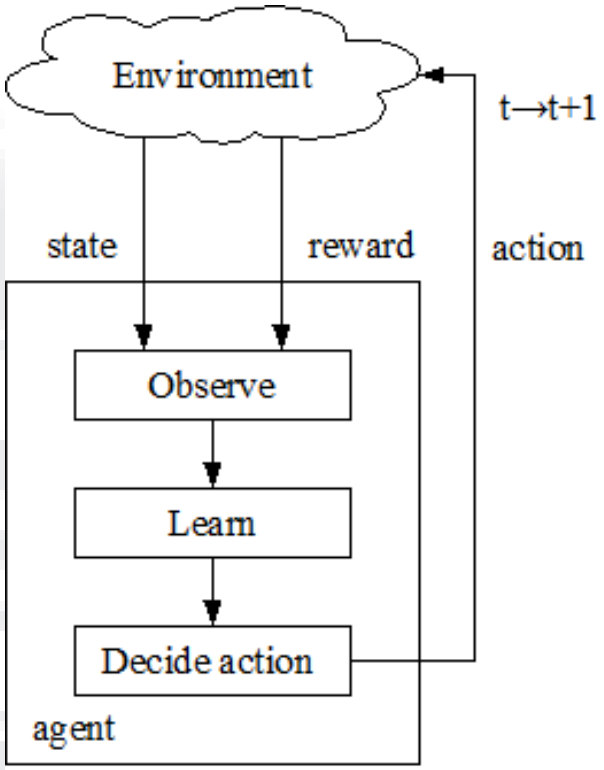
Research Outline

- Research question
  - How to achieve network-level and node-level CC in order to provide context-awareness and intelligence in CR networks?
- Research outcome
  - Implementations of the conceptual CC
  - Applications
    - Dynamic Channel Selection (DCS)
    - Scheduling
    - Congestion Control
    - Topology Management
    - CR-based Wireless Sensor Networks (CR-WSNs)

Agenda

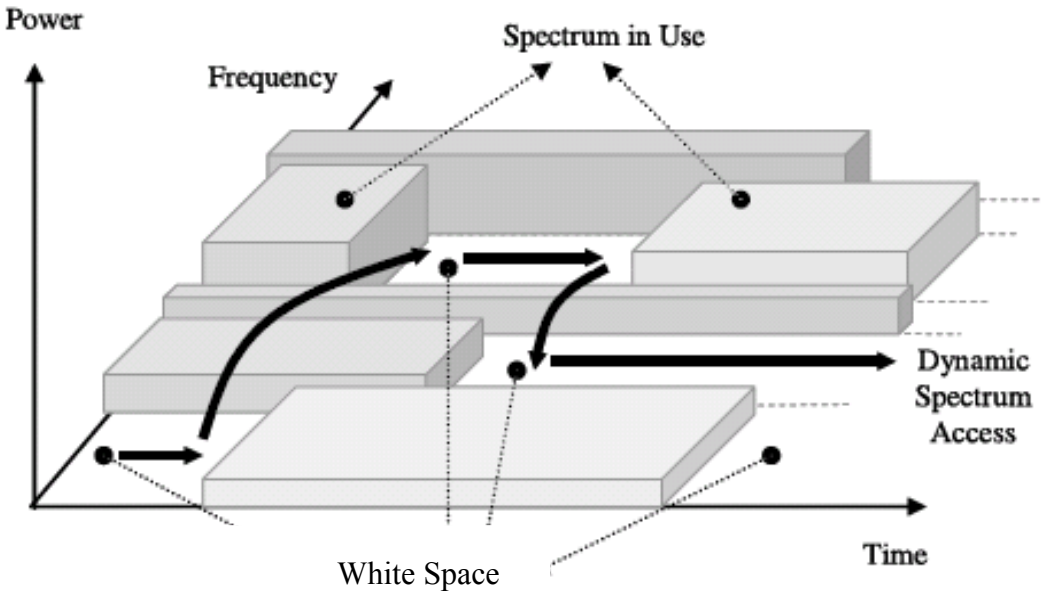
- Overview of Cognitive Radio
- Research Outline
- **Network-level Cognition Cycle**
- Node-level Cognition Cycle
- Conclusions
- Questions

Network-level Cognition Cycle (1/4)
Application on Dynamic Channel Selection

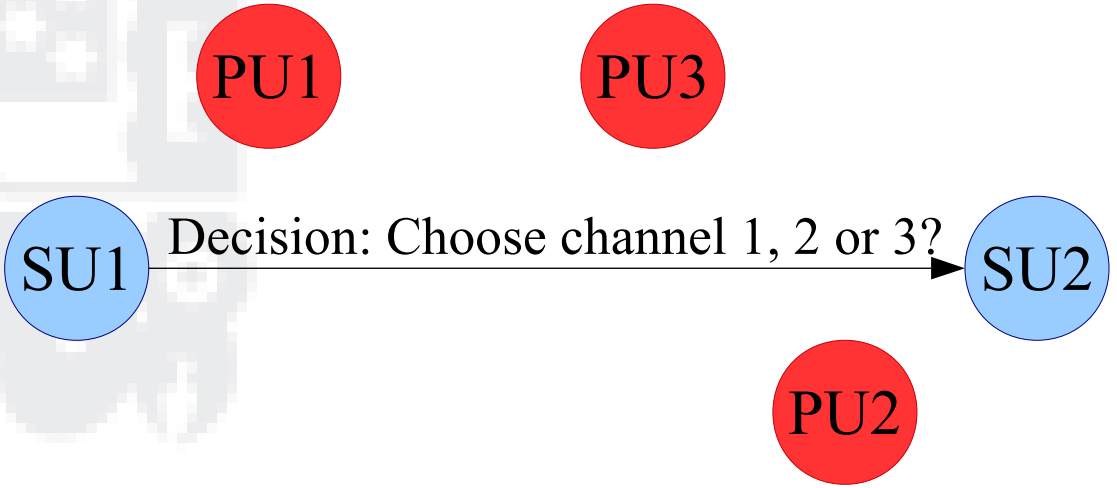


- Channel condition is time-varying because
  - Channel heterogeneity
    - Available channels share distinctive channel properties
      - Transmission range
      - Channel quality
      - Amount of white space
  - Nodal mobility
- Dynamic Channel Selection
  - How a node chooses its operating channel?
  - Objectives
    - Maximize throughput
    - Minimize delay (Number of channel switchings)
- Apply Reinforcement Learning (RL)

Network-level Cognition Cycle (2/4)
Application on Dynamic Channel Selection



- Consider this scenario

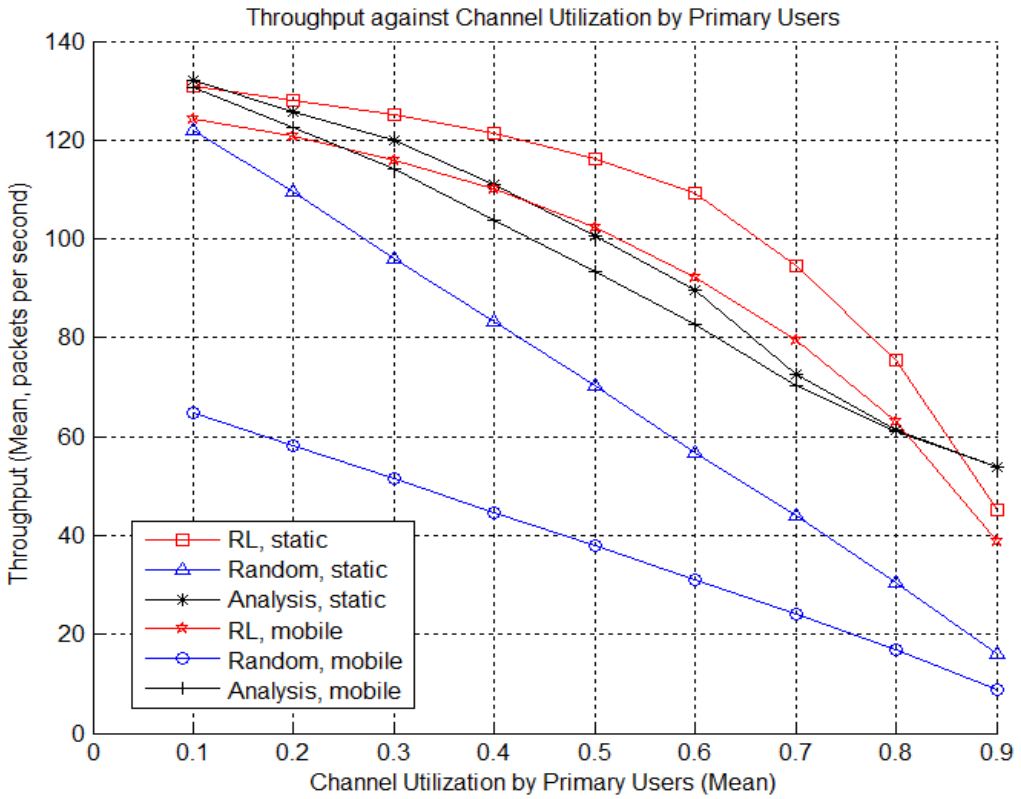


Channel	Channel properties
Channel 1	Less white space High channel quality
Channel 2	Out of transmission range
Channel 3	Many white space Low channel quality

Network-level Cognition Cycle (3/4)

Application on Dynamic Channel Selection

Throughput vs. Channel utilization by PU



- Packet error rate for all channels = 0.1
- RL helps a CR host to choose channel with low level of PU activity

Case	RL throughput / Random throughput
x = 0.1, static network	≈1
x = 0.9, static network	2.84
x= 0.1, mobile network	1.92
x= 0.9, mobile network	4.39

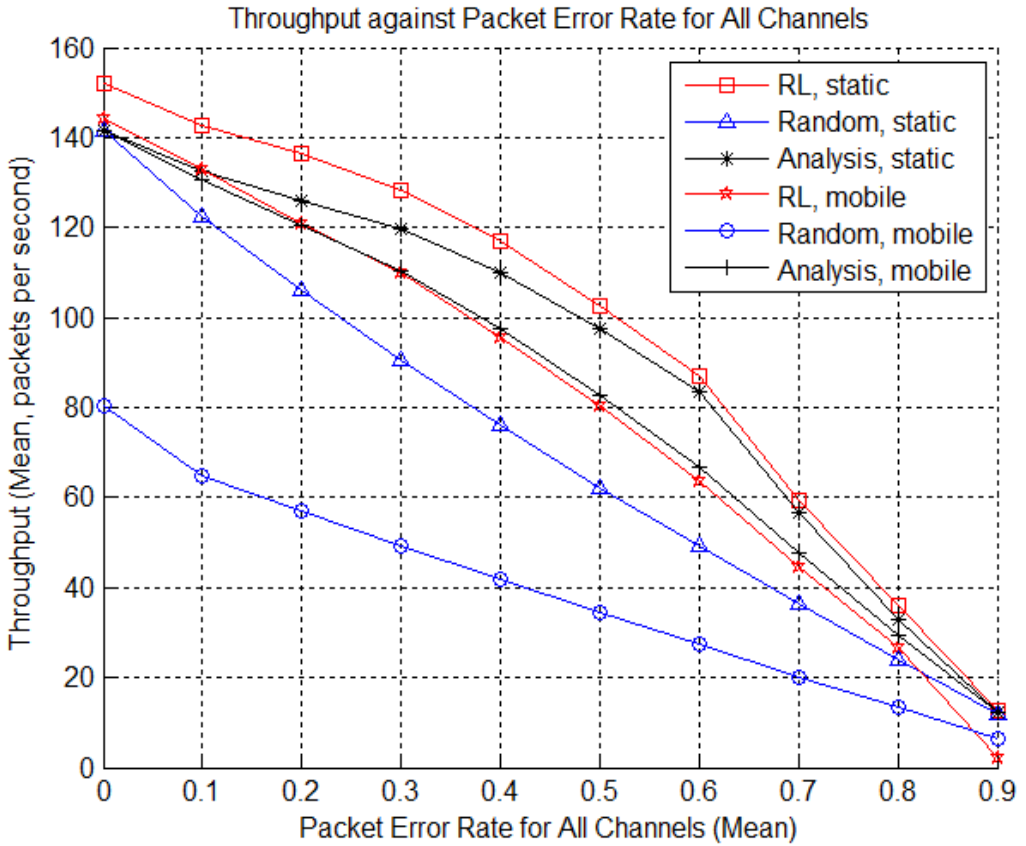
Selected Publications:

1. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "A Context-aware and Intelligent Dynamic Channel Selection Scheme for Cognitive Radio Networks," 4th International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM'09) IEEE, June 2009.
2. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Performance Analysis of Reinforcement Learning for Achieving Context-Awareness and Intelligence in Cognitive Radio Networks," 9th Intl. Ws. Wireless Local Nwk (WLN'09), IEEE, Oct. 2009.
3. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Achieving Context-Awareness and Intelligence in Cognitive Radio Networks using Reinforcement Learning," submitted to Journal of Computer Networks, Elsevier.

Network-level Cognition Cycle (4/4)

Application on Dynamic Channel Selection

Throughput vs. Packet Error Rate for all Channels



- Channel utilization by PU for all channels = 0.1
- RL helps a CR host to choose channel with low packet error rate

Case	RL throughput / Random throughput
$x = 0.6$, static network	1.76
$x = 0.6$, mobile network	2.33

Selected Publications:

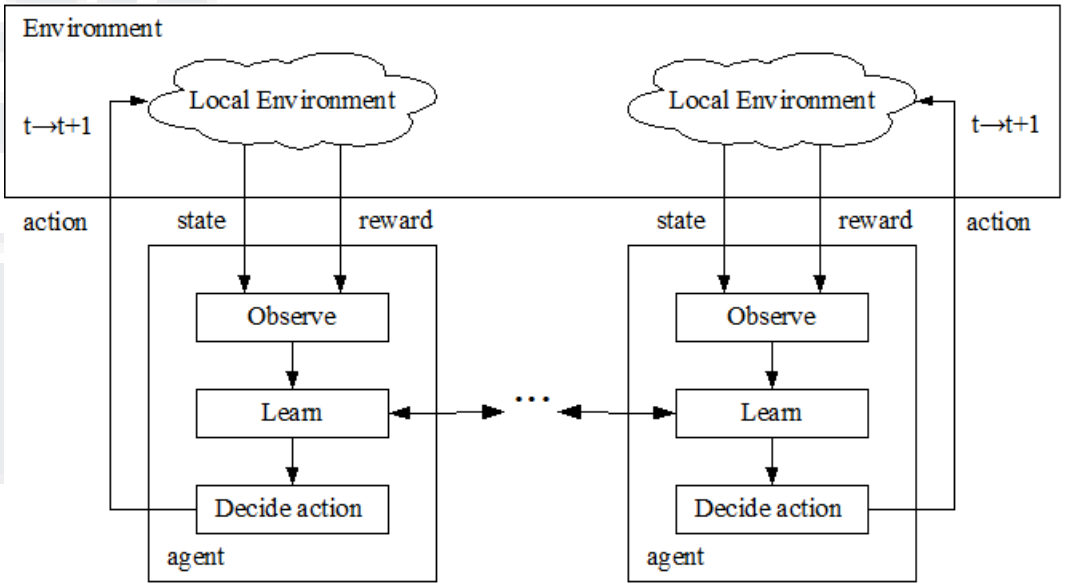
1. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "A Context-aware and Intelligent Dynamic Channel Selection Scheme for Cognitive Radio Networks," 4th International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM'09) IEEE, June 2009.
2. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Performance Analysis of Reinforcement Learning for Achieving Context-Awareness and Intelligence in Cognitive Radio Networks," 9th Intl. Ws. Wireless Local Nwk (WLN'09), IEEE, Oct. 2009.
3. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Achieving Context-Awareness and Intelligence in Cognitive Radio Networks using Reinforcement Learning," submitted to Journal of Computer Networks, Elsevier.

Agenda

- Overview of Cognitive Radio
- Research Outline
- Network-level Cognition Cycle
- **Node-level Cognition Cycle**
- Conclusions
- Questions

Node-level Cognition Cycle (1/4)
Introduction

- We address the drawbacks of the appliation of Game Theory in distributed CR networks.
- We apply Multi-Agent Reinforcement Learning (MARL) approach
  - Converge to optimal joint action in the presence of multiple optimal joint actions
  - Require low amount of information to compute optimal joint action
  - Adapt to changes in both the operating environment and the other SUs' actions
  - Allow the existence of heterogeneous learning agents
  - Robust to irrational SUs

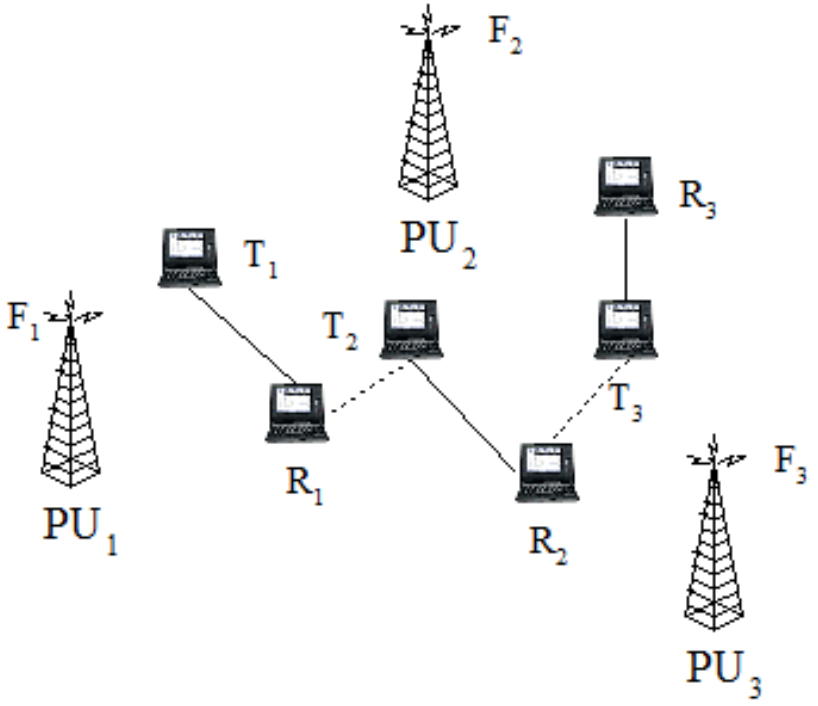


Selected Publications:

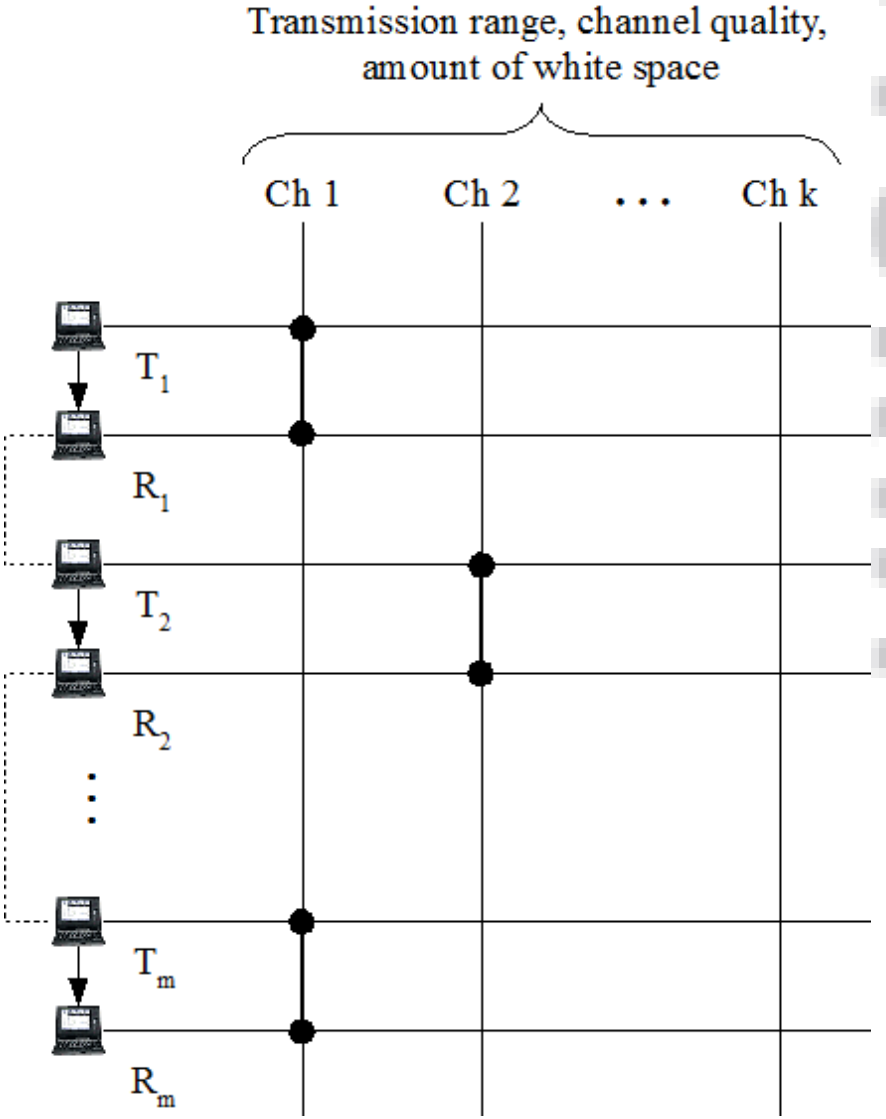
4. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Achieving Optimal Joint Action in Distributed Cognitive Radio Networks using Payoff Propagation," submitted to IEEE Communications Letters.

5. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Achieving Optimal Joint Action in Distributed Cognitive Radio Networks," submitted to Intl. Conf. on Comm. (ICC'10).

Node-level Cognition Cycle (2/4)
Application on Dynamic Channel Selection

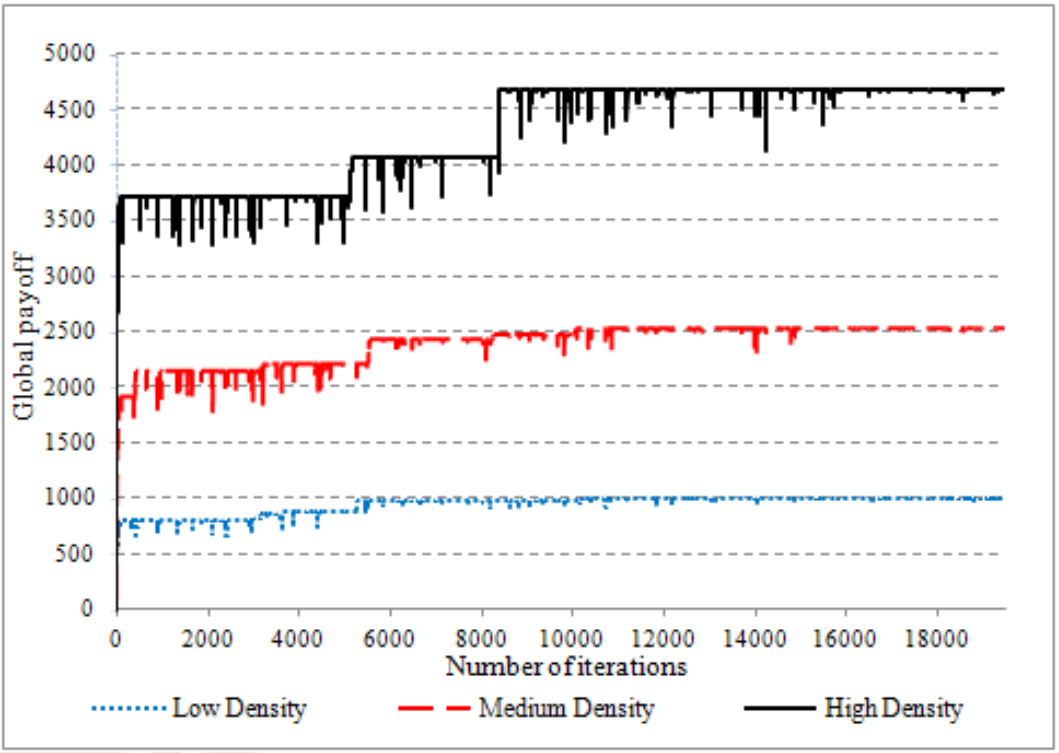


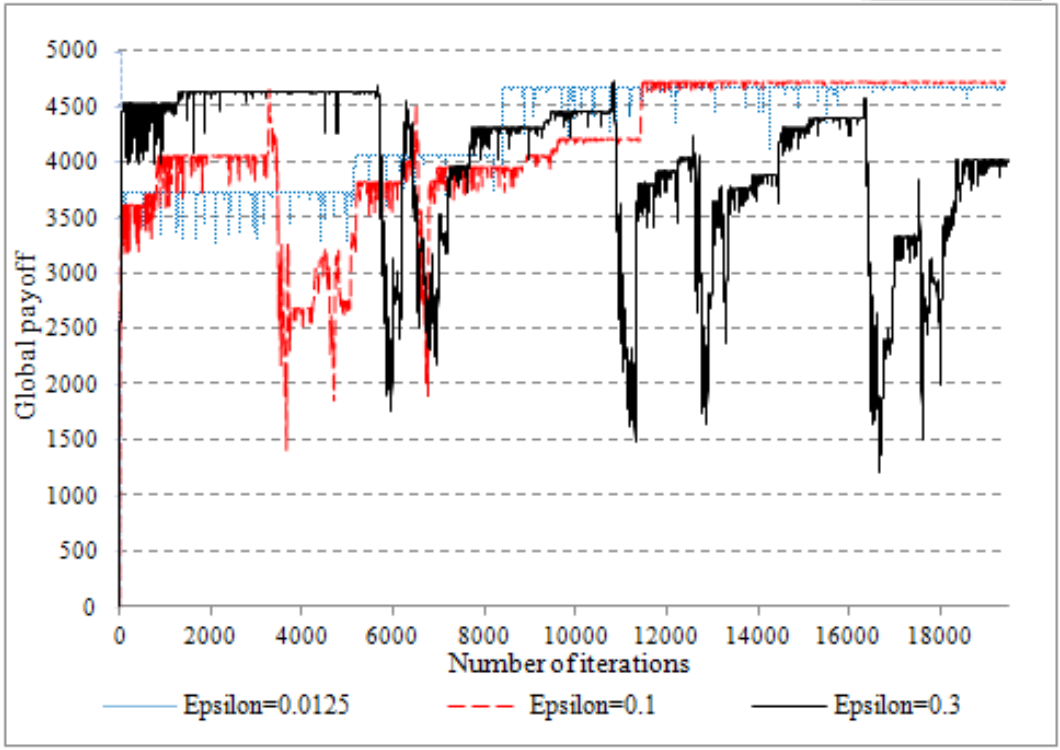
Scenario



Graphical representation

Node-level Cognition Cycle
Application on Dynamic Channel Selection (3/4)
Convergence of Global Payoff





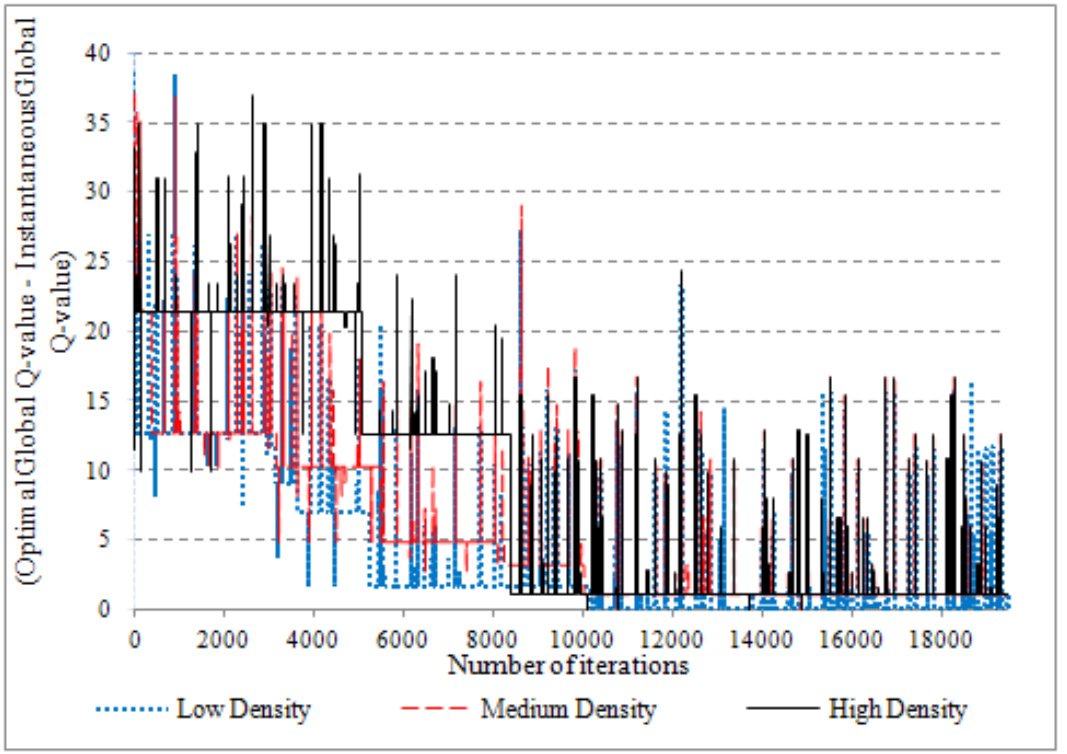
- Global payoff converges in low, medium and high density networks.
- Fast global payoff convergence is possible.

Selected Publications:

4. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Achieving Optimal Joint Action in Distributed Cognitive Radio Networks using Payoff Propagation," submitted to IEEE Communications Letters.

5. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Achieving Optimal Joint Action in Distributed Cognitive Radio Networks," submitted to Intl. Conf. on Comm. (ICC'10).

Node-level Cognition Cycle
Application on Dynamic Channel Selection (4/4)
Convergence to Optimal Joint Action



- Difference between instantaneous rewards and optimal rewards converge to zero value. This indicates the convergence to an optimal joint action.

Selected Publications:

4. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Achieving Optimal Joint Action in Distributed Cognitive Radio Networks using Payoff Propagation," submitted to IEEE Communications Letters.

5. Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "Achieving Optimal Joint Action in Distributed Cognitive Radio Networks," submitted to Intl. Conf. on Comm. (ICC'10).

Agenda

- Overview of Cognitive Radio
- Research Outline
- Network-level Cognition Cycle
- Node-level Cognition Cycle
- **Conclusions**
- **Questions**

Conclusion

- CC is a key component in CR
- Two levels of cognition cycle
  - Network-level
  - Node-level
- Previous work
  - Network-level CC
    - The RL approach achieves the expected performance
    - Current application: DCS
    - Possible applications: scheduling, congestion control, topology management, channel sensing, CR-WSNs
- Current and Future work
  - Node-level CC
    - The MARL approach achieves optimal joint action in distributed CR networks
    - Current application: DCS

Questions

For the most recent works, please visit our research website at http://ecs.victoria.ac.nz/Groups/DSRG/CognitiveRadioResearch

Thank you

For the most recent works, please visit our research website at
http://ecs.victoria.ac.nz/Groups/DSRG/CognitiveRadioResearch

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

CAPITAL CITY UNIVERSITY