Overview of Cognitive Radio Research at Victoria University

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

CAPITAL CITY UNIVERSITY

Agenda

- Introduction – who we are
- Context Aware and Intelligent CR Networks
  - Context-awareness, Intelligence and Reinforcement Learning
  - C^2Net
  - Dynamic Channel Selection
  - SDR-CR, Gnu Radio
- Future Work

Who are we?

- Distributed Systems Research Group (layer 2+)
- Faculty:
  - Layer 2+
    - Dr Peter Komisarczuk (cognitive MAC, QOS, wireless location determination, mobile Internet security)
    - Dr Qiang Fu (multi-hop wireless networks, transport protocols, QOS)
    - Dr Ian Welch (mobile games, mobile Internet security)
    - A. N. Other (arriving Q4/2009, wireless sensor networks)
    - A. N. Other (arriving Q4/2009) (cellular systems)
  - Students:
    - Kok-Lim Yau (Alvin) (PhD) Cognitive MAC and QOS

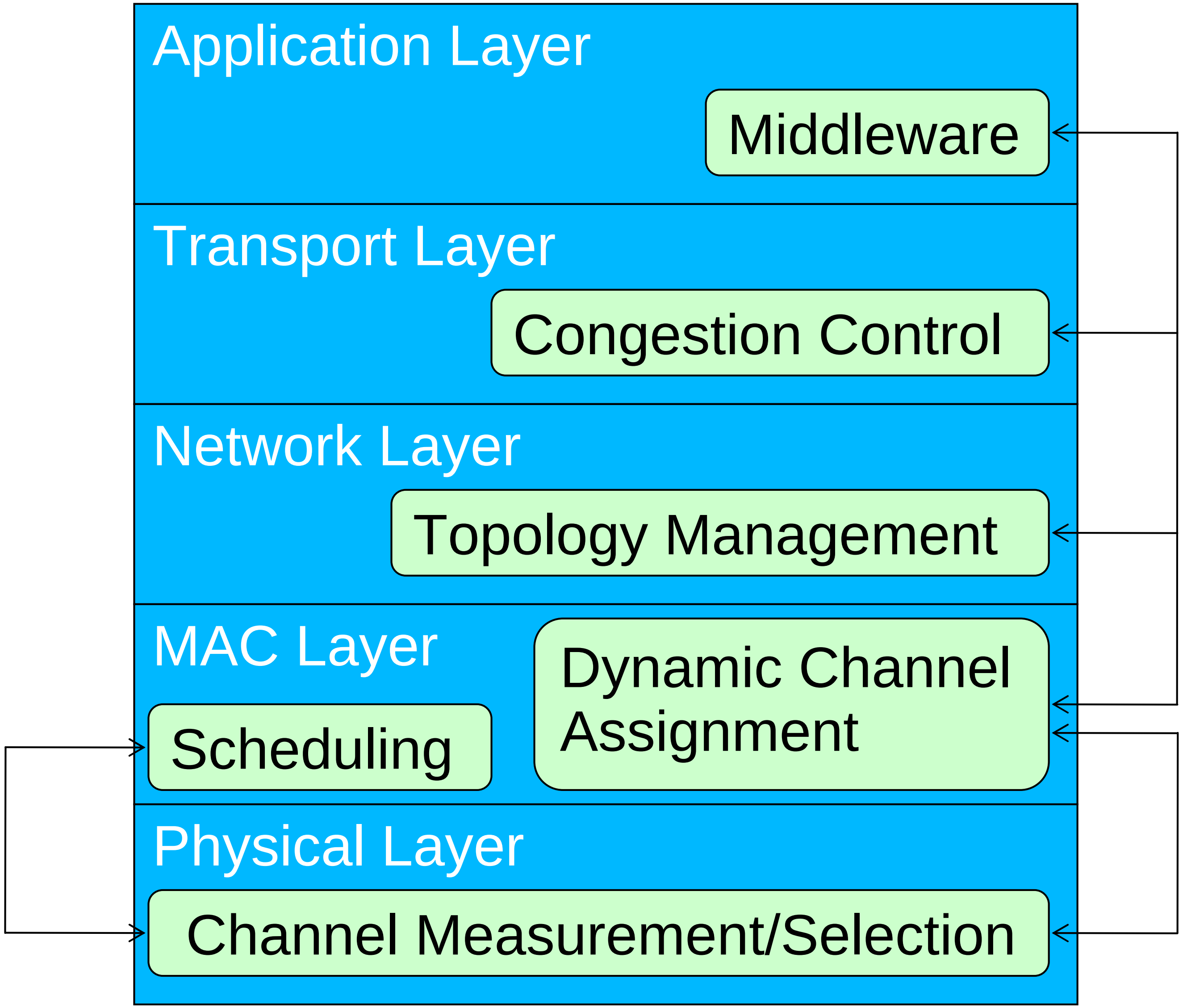
Who are we?

- Communication Systems Research Group (PHY, layer 1+)
- Faculty:
  - Layer 1+
    - Dr Paul Teal (Signal processing)
    - Dr Pawel Dmochowski (MIMO, information theory)
    - Adjunct Professor Mansoor Shafi (Telecom NZ)
- Students:
    - Ren Yu (Masters)
    - Harry Jones (Honours)
- Collaborations:
    - Peter Smith, University of Canterbury
    - Alan Coulson, Industrial Research Ltd

CR Projects

- **Interference** (Hanif, Smith, Shafi, Dmochowski)
- **SDR Channel Sounding** (Jones, Teal, Dmochowski, (Coulson))
- **Context Aware and Intelligent CR Networks** (Yau, Komisarczuk, Teal)
- **SDR-CR** (Yu, Komisarczuk, Dmochowski)

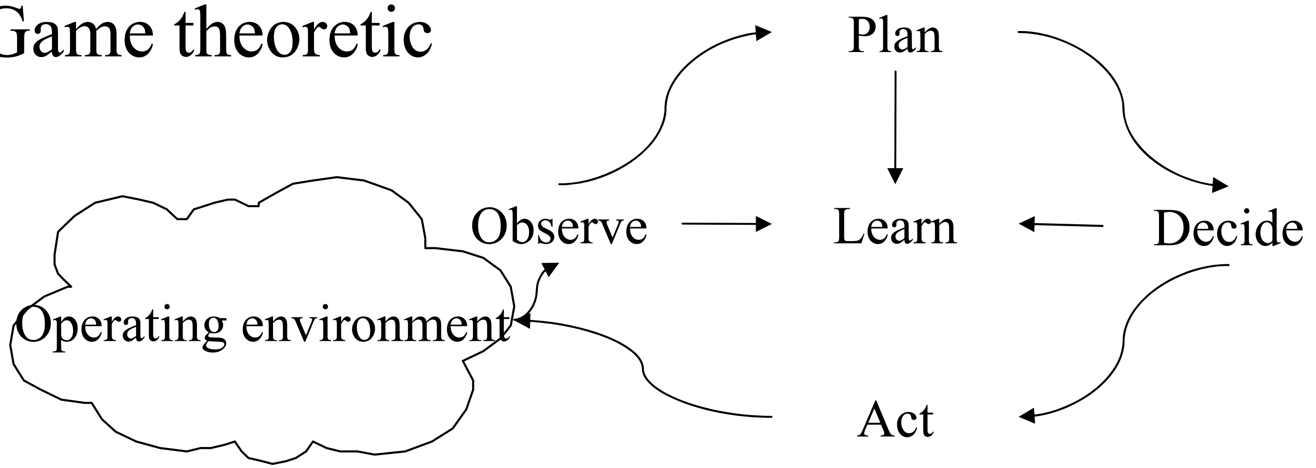
Cross Layer Cognition



Physical layer – multiple channels, agile/flexible

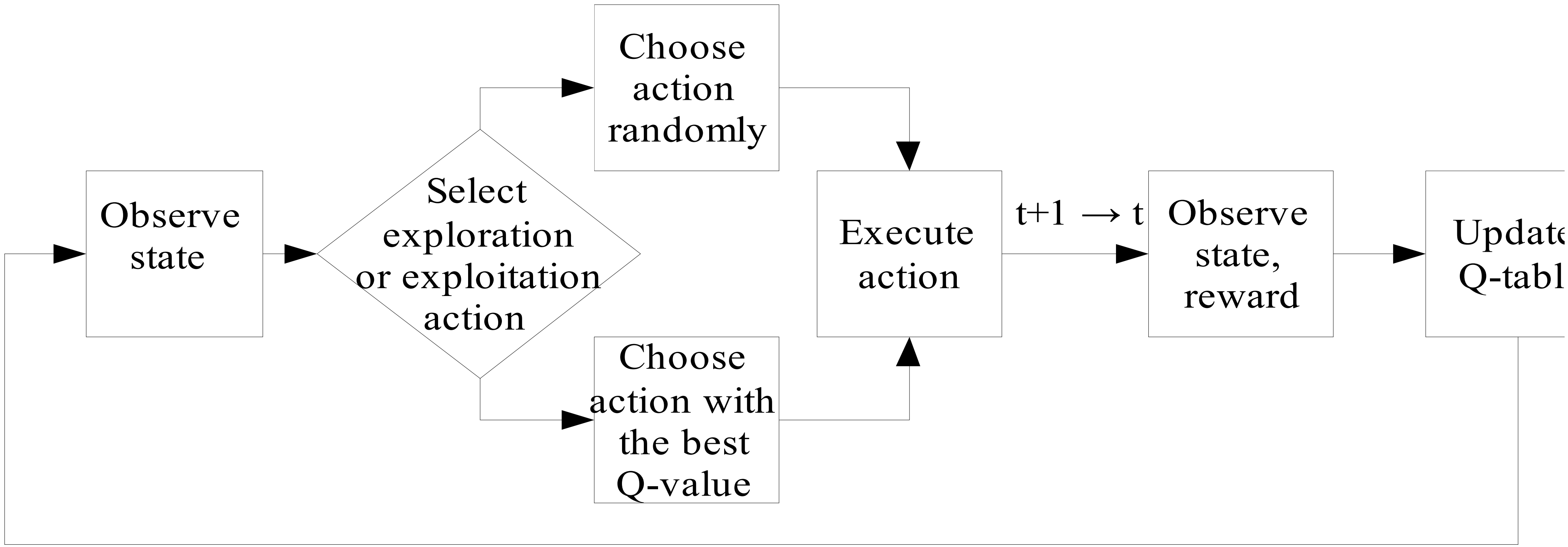
Context-awareness, Intelligence and Reinforcement Learning

- Context-awareness and intelligence
  - The capability to *sense*, *learn*, and *respond* in an efficient manner with respect to its operating environment without adhering to a *strict and static* self-defined policy.
- Reinforcement Learning => Q-learning
  - An on-line algorithm, Objective - determine an optimal policy that maximizes an agent's reward
  - Game theoretic

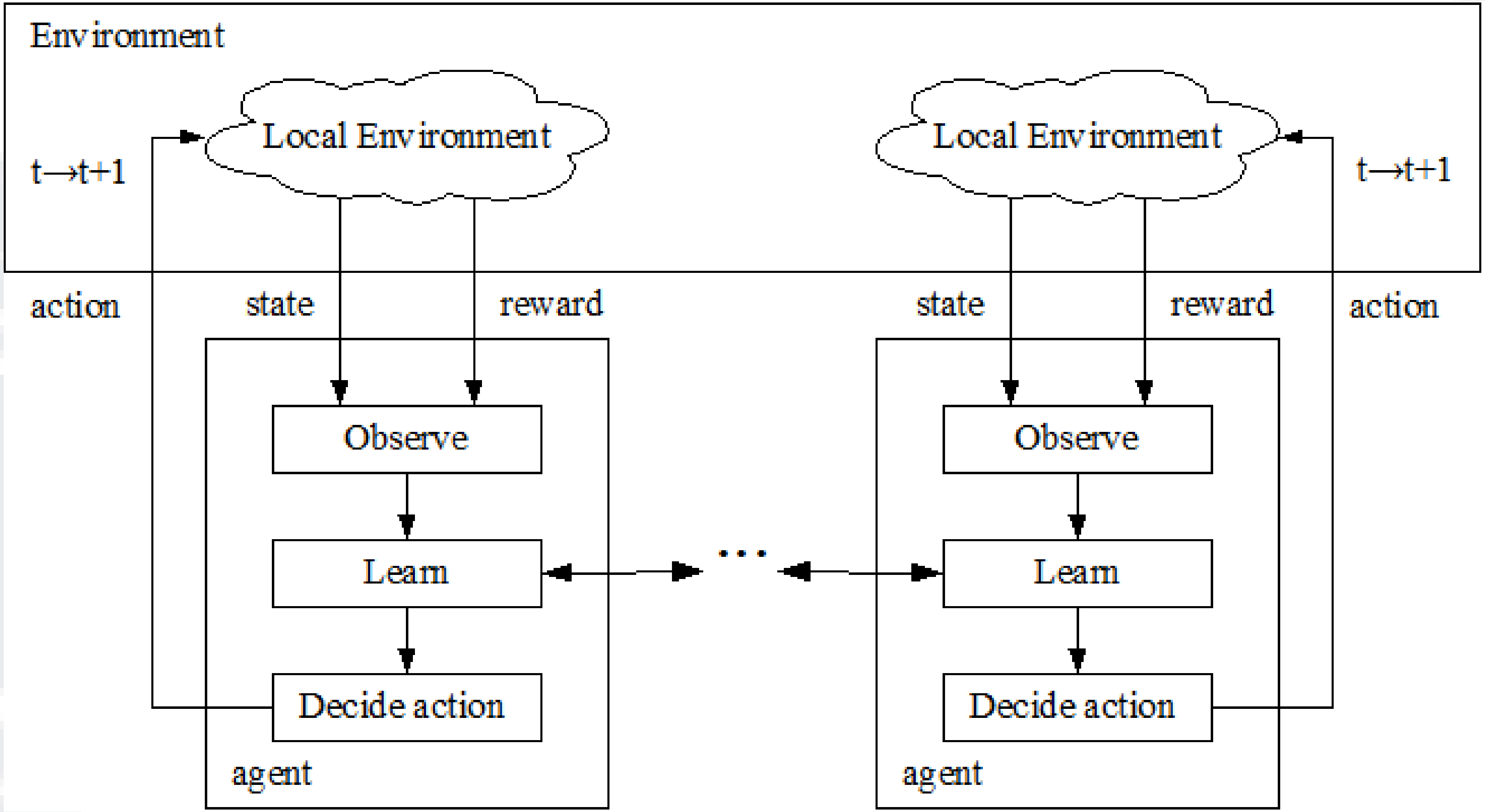


Reinforcement Learning

- Adaptation to dynamic and uncertain operating environment.
- Simple – detailed modeling of the operating environment and channel properties *are not necessary*.
- Node level and Network level optimisation

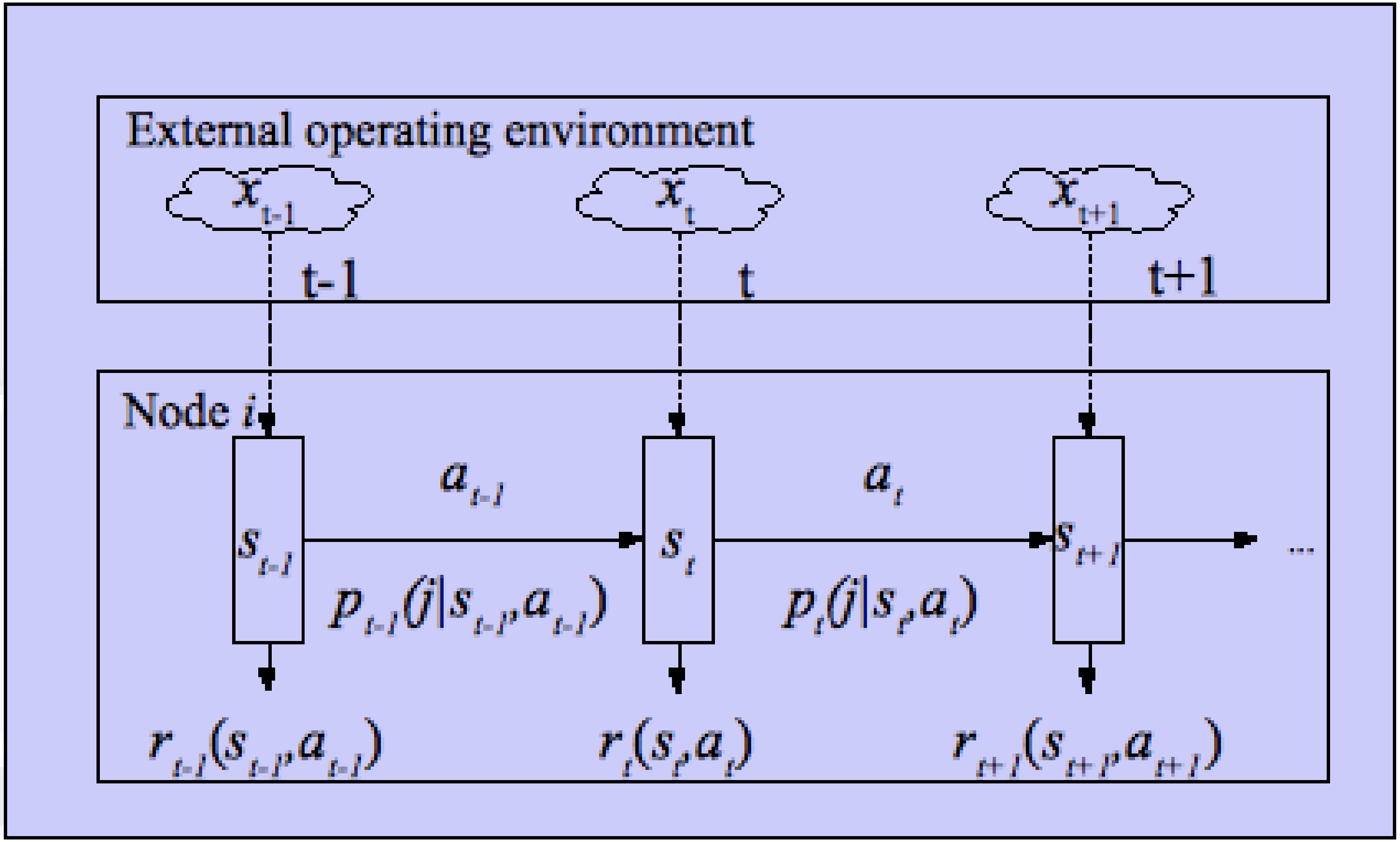


Context-Awareness and Intelligence in Cognitive Radio Networks



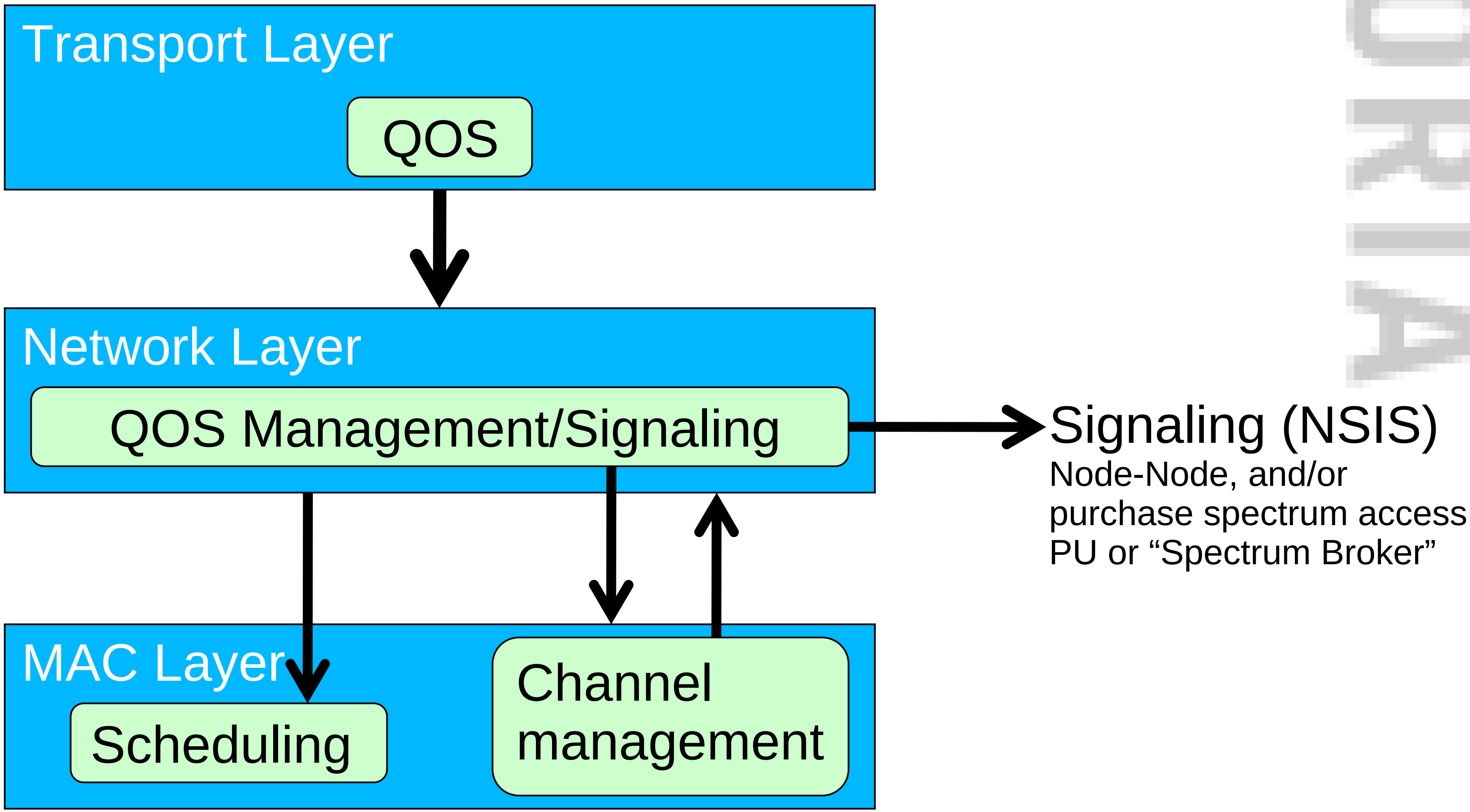
Node-level cognition cycle

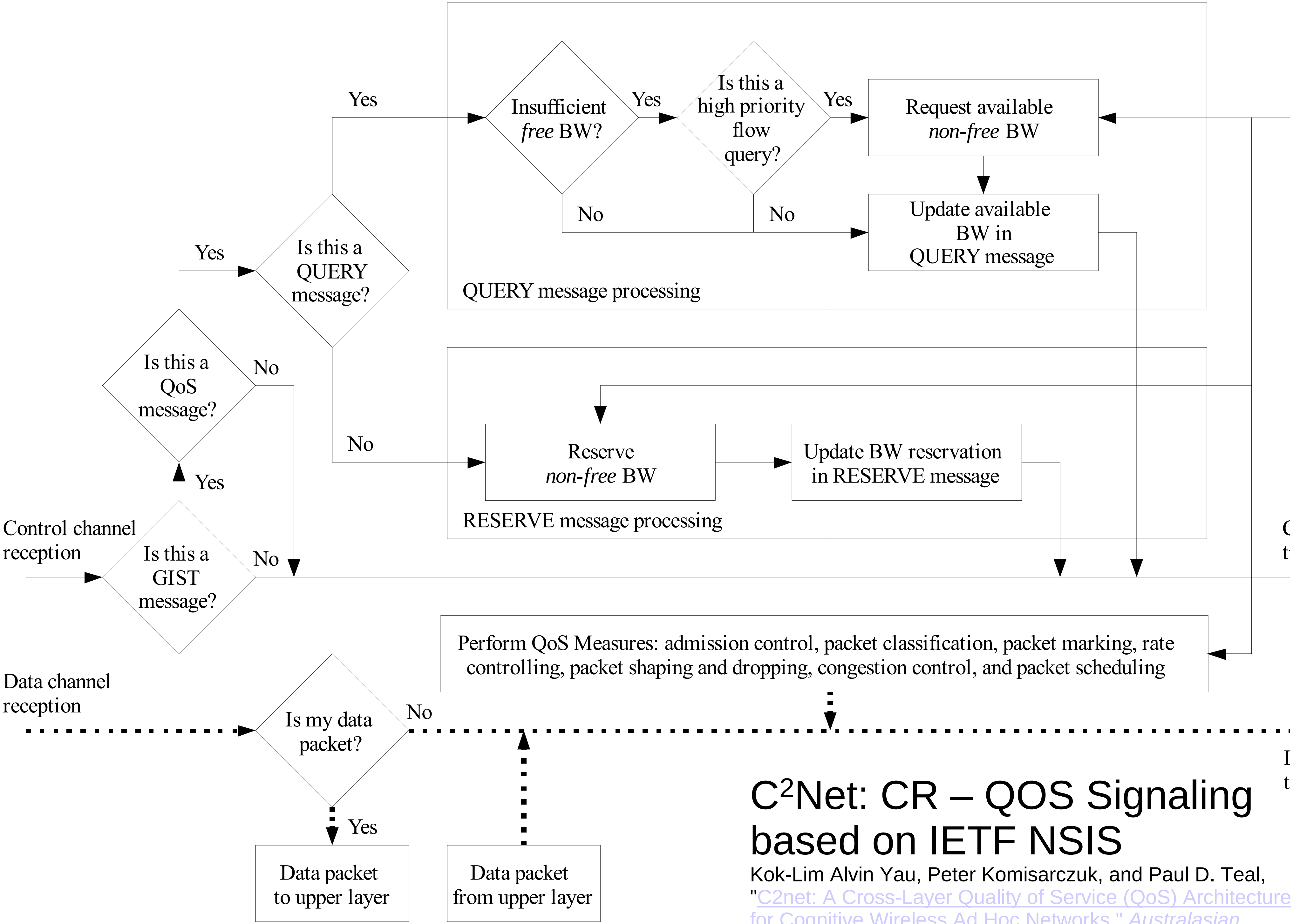
CR - Reinforcement Learning



CR QOS Management

Choosing and Provisioning Wireless Resources:

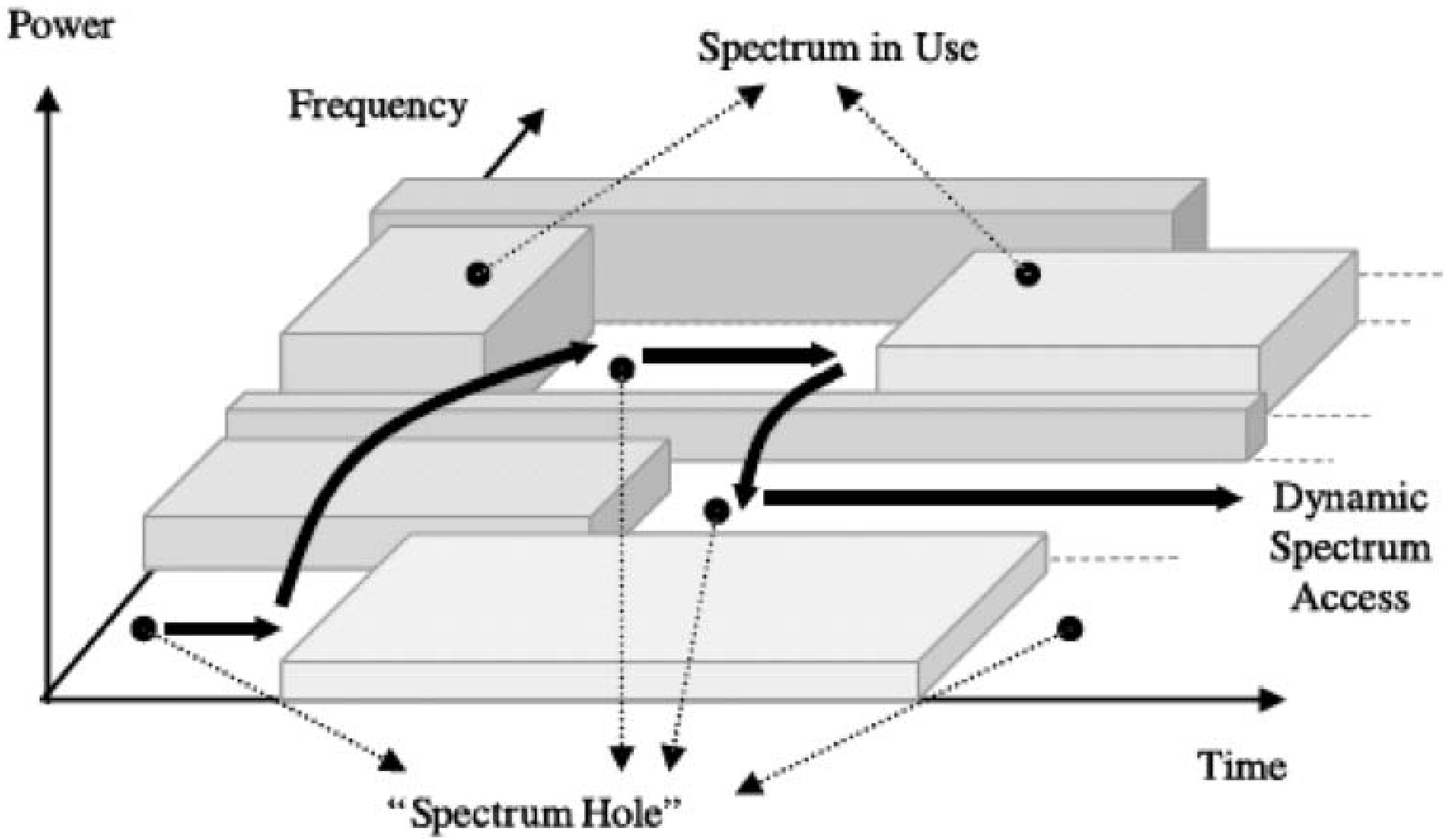




C²Net: CR – QOS Signaling based on IETF NSIS

Kok-Lim Alvin Yau, Peter Komisarczuk, and Paul D. Teal, "C2net: A Cross-Layer Quality of Service (QoS) Architecture for Cognitive Wireless Ad Hoc Networks," *Australasian Telecommunication Networks and Applications Conference (ATNAC'08) IEEE, Adelaide, Australia, December 2008.*

Dynamic Spectrum Access

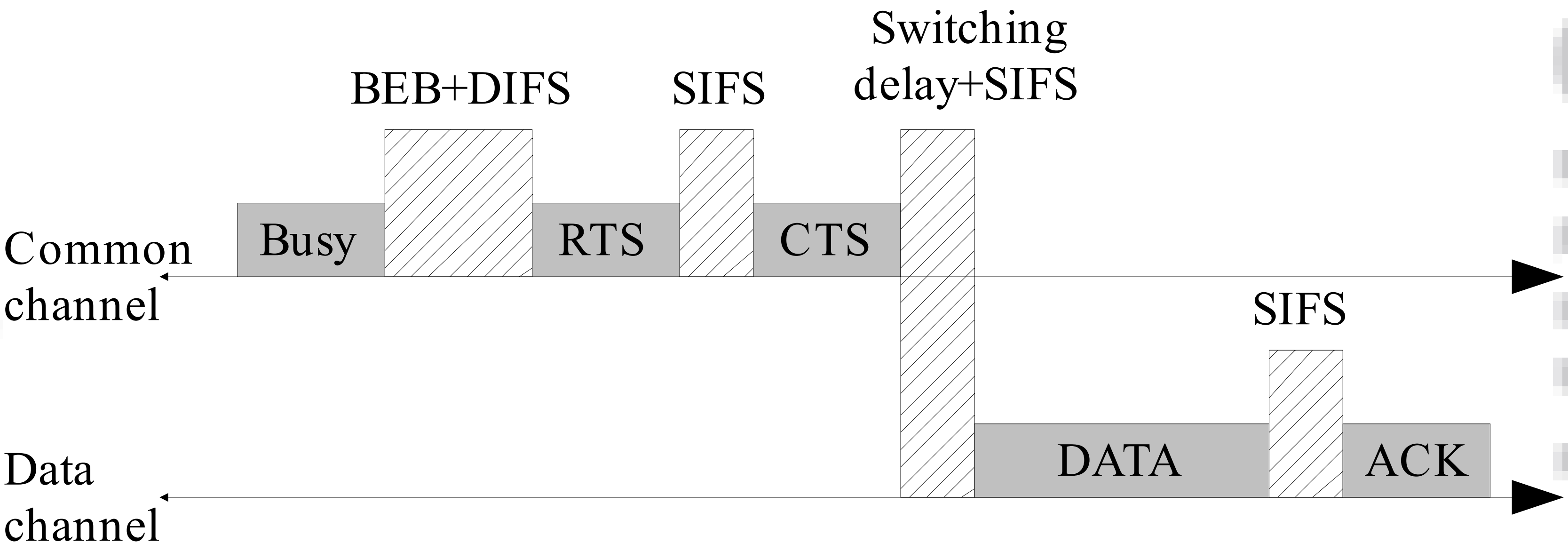


=> Context Awareness – white space and demand
=> Dynamic Channel Selection algorithms

Dynamic Channel Selection

- Channel condition is time-varying:
  - Channel heterogeneity
    - Channel distinctive properties
      - Channel characteristics/quality
      - Amount of white space
  - Other factors: Nodal mobility
- Dynamic Channel Selection Problem:
  - Objectives
    - Maximize CR throughput
    - Minimize CR delay (minimise channel switching)
  - How does a node choose its operating channel adaptively to enhance QoS (throughput and delay)?

CSMA-based Cognitive MAC Protocol



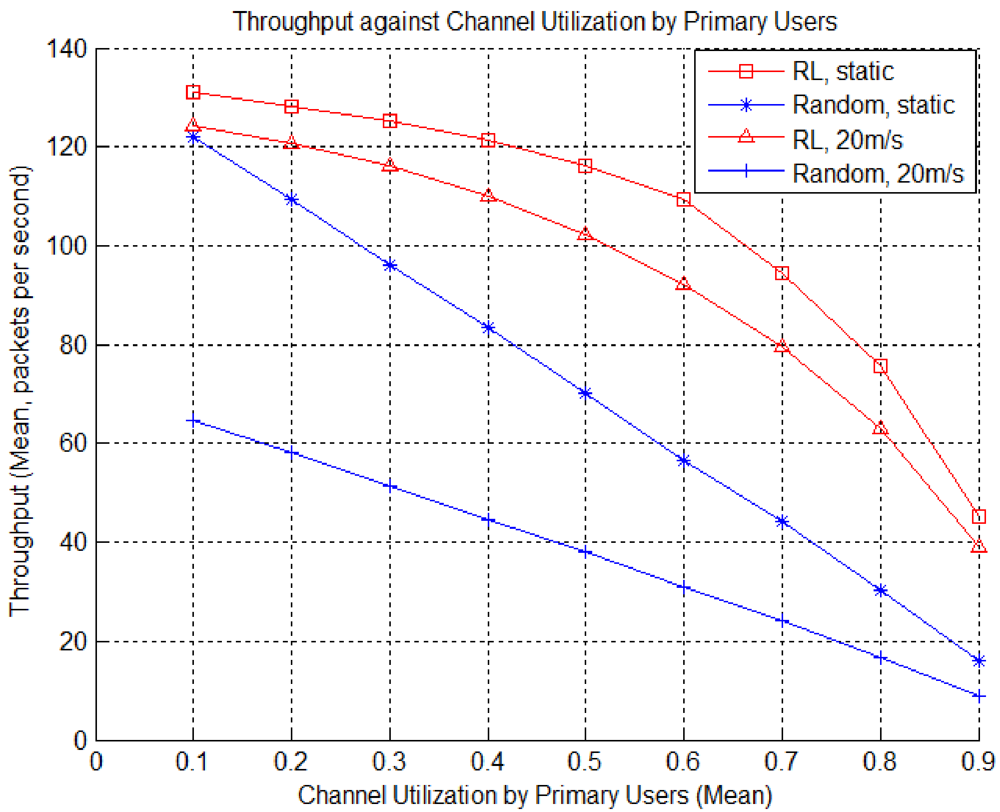
Basis for simulation (OMNET++)
Multiple channels with multiple PU – 3 used in simulations

CR – Simulation (OMNET++)

- Performance metrics
  - Throughput
  - Number of channel switches
- Graph ordinates
  - Channel utilization from PU
  - Packet error rate
  - Example
    - Channel utilization from PU = 0.8
      - [0.8,0.8,0.8]
      - [0.8,0.7,0.9]
      - [0.9,0.9,0.6]
- Simulation compares RL and Random scheme

Simulation Results (1/4)

Throughput vs. Channel utilization by PU

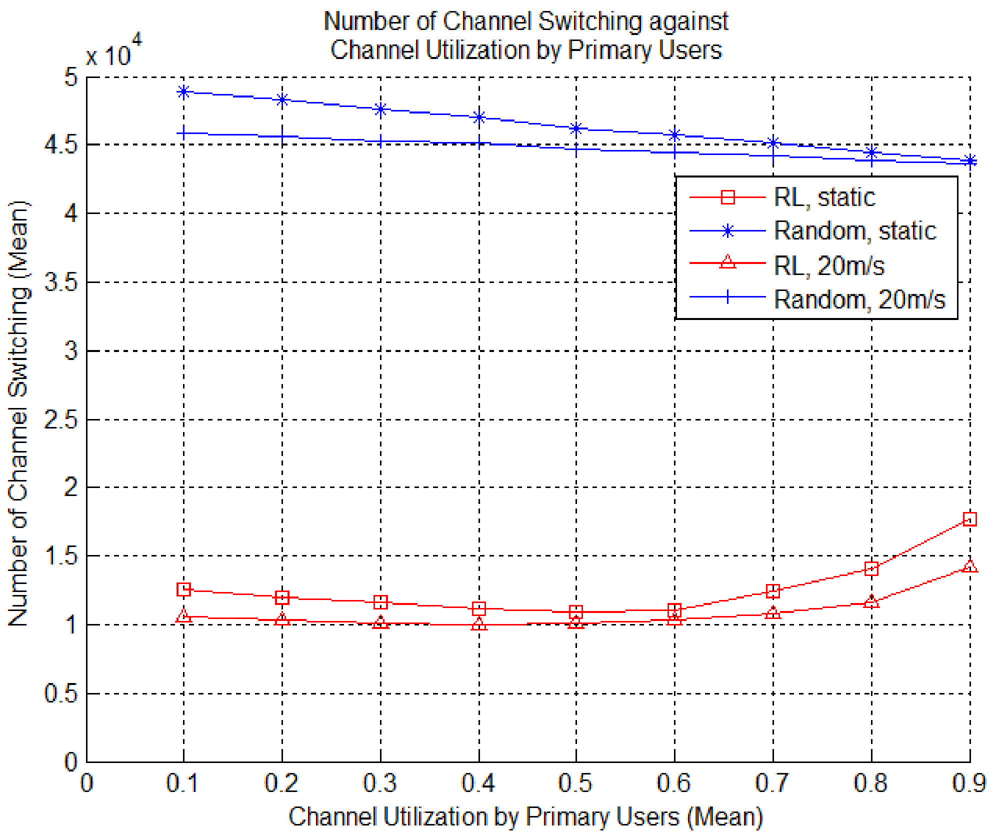


- Packet error rate for all channels = 0.1
- RL helps a CR host to choose a channel with low level of PU activity

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

Simulation Results (2/4)

Channel switching vs. Channel utilization by PU

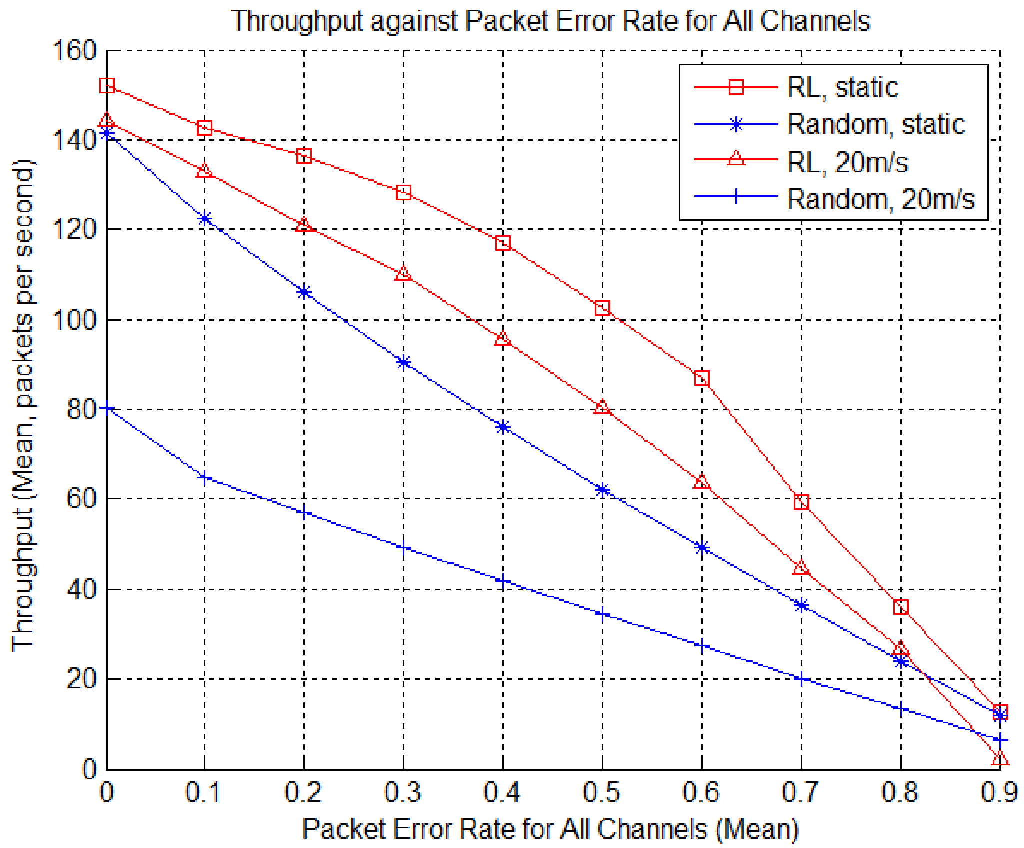


- Packet error rate for all channels = 0.1
- In RL, channel switching frequency dependent on ε.
- In RL, channel switching is lower compared to Random. Hence, it incurs lower delay.

Case	Random no. CS / RL no. CS
x = 0.5, static network	4.21
x = 0.4, mobile network	4.51

Simulation Results (3/4)

Throughput vs. Packet error rate for all channels

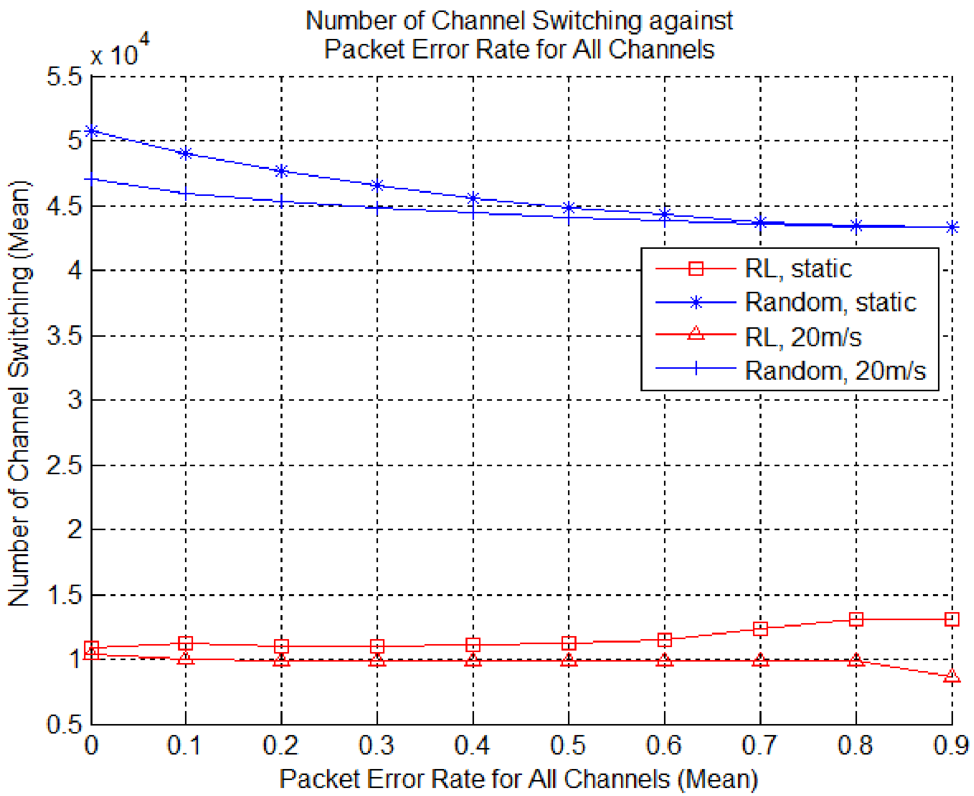


- Channel utilization by PU for all channels = 0.1
- RL helps a CR host to choose a channel with low packet error rate

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

Simulation Results (4/4)

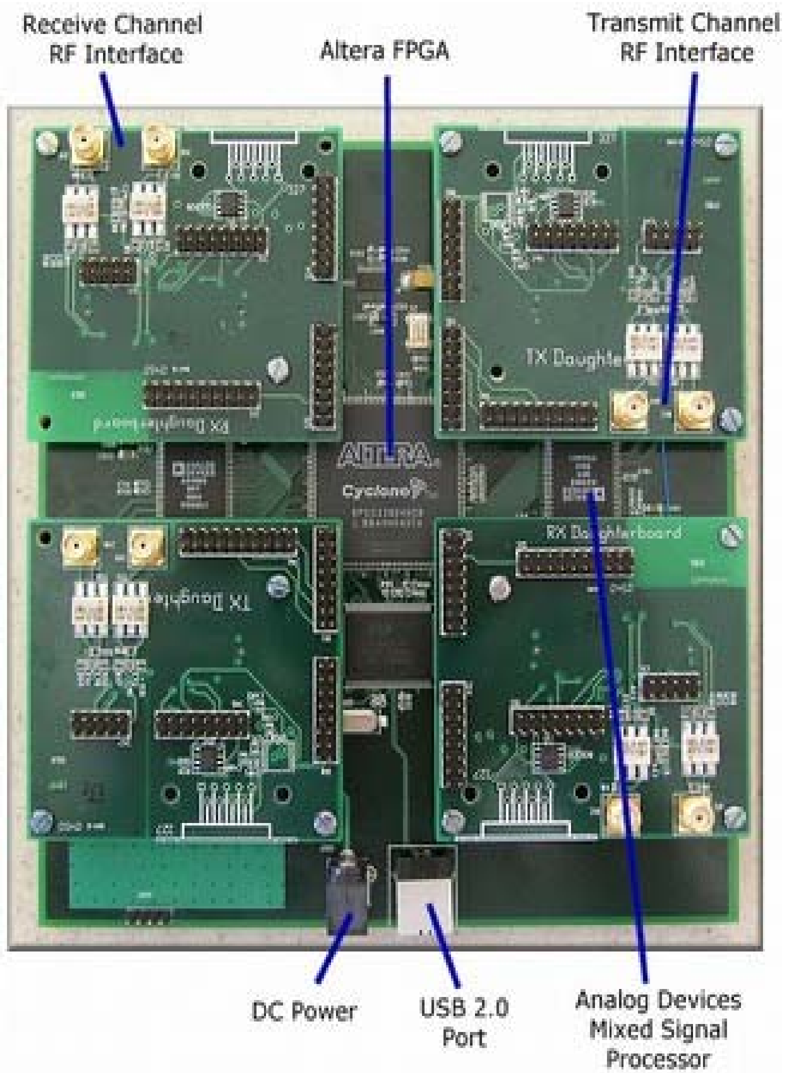
Channel switching vs. Packet error rate (all channels)



- Channel utilization by PU for all channels = 0.1
- In RL, the number of channel switches is dependent on ε

Case	Random no. CS / RL no. CS
x = 0.1, static network	4.35
x = 0.9, mobile network	4.4

SDR-CR => Gnu Radio



Implementing dynamic channel selection

- Gnu Radio: Ettus SDR kits
  - www.ettus.com
  - 12 motherboards, USRP
  - RF daughter boards: RFX2400 and LFTX/RX
- Ren Yu implementing cognitive MAC
  - Channel sensing, estimation and prediction

Conclusion

- Cross layer CR concepts
  - CR – network layer QOS signaling proposal => C^2Net
- Using RL and Game theory, we have shown
  - CR network optimisation => static/mobile networks
  - Context-aware, intelligent Dynamic Channel Selection scheme
    - Deals with channel heterogeneity characteristics
  - Convergence to optimal joint action in the presence of multiple optimal joint actions
  - Techniques require little information in order to compute optimal joint actions
  - Adaptive to changes in both PU and other SU actions
  - Allows for the existence of heterogeneous learning agents
  - Techniques show robustness to irrational SUs'
- Platform – Gnu Radio => SDR-CR

Future Work

- Continue exploration into Reinforcement Learning techniques and Game theory to CR
  - CR-MAC
  - CR aware network layer
    - C^2Net
  - Transport and Middleware adaptation to CR
- Platform implementation and verification
  - Gnu Radio based framework
    - Move to m-block support
- More collaboration – IRL, Canterbury, member of WUN CogCom group and exploring participation in COST Action IC0902

Questions?

For the latest on our work, please visit our research website at

http://ecs.victoria.ac.nz/Groups/DSRG/CognitiveRadioResearch

Appendices

Interference/CRI
CR - QOS Signaling
Simulation Parameters
References

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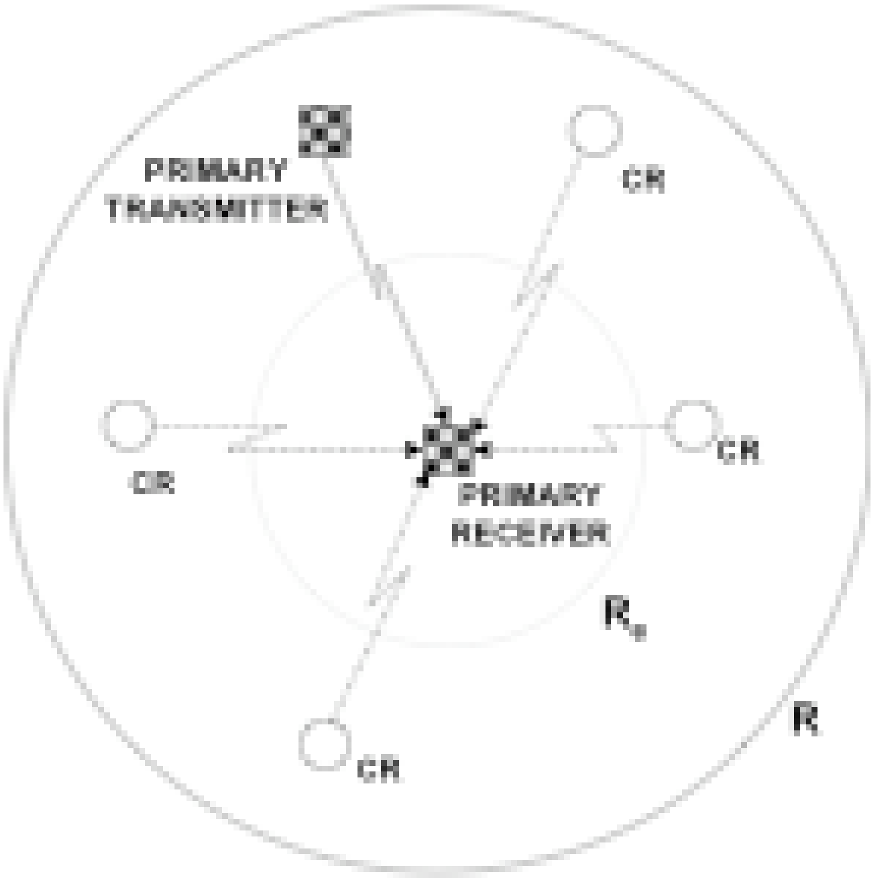
Modeling Interference – CR

Collab with Canterbury (Hanif, Smith, Shafi, Dmochowski)



Model

- Random location of the PU TX in (R_0, R)
- Random number N and location of CR TX/RX pairs in (R_0, R), with varying coverage
- path loss and lognormal shadowing environment
- aggregate interference

$$I_N = \sum_{i=1}^{N} B_i L_i r_i^{-\gamma}$$

- Showed that aggregate interference statistics cannot be modeled accurately using common techniques
- Exploring shifted log normal distribution as a possible approximation technique

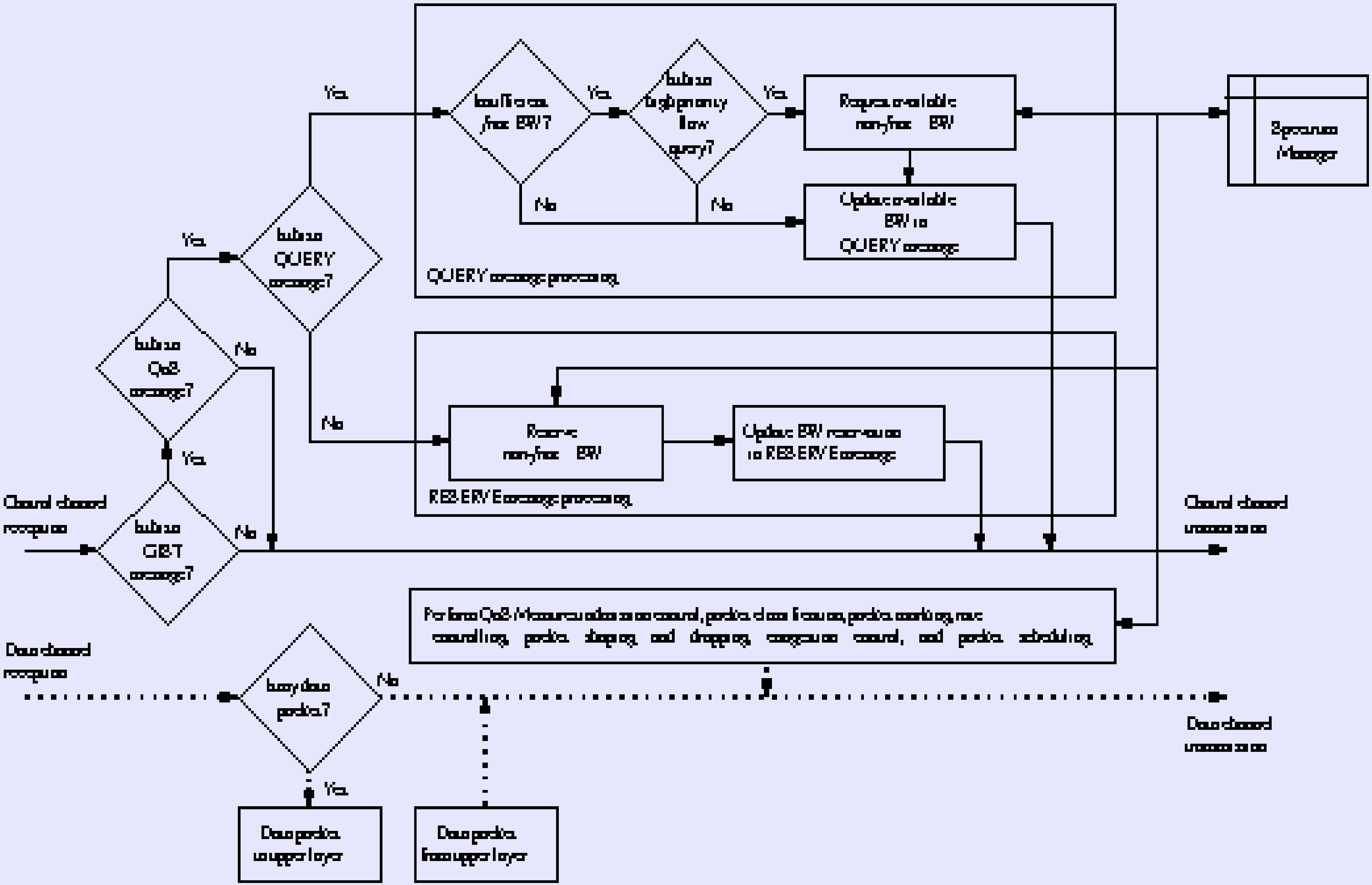
Interference – Deployment Issues

- Exclusion Zone Radius
  - how many CRs can we support if they are restricted to operation outside some region?
  - distance derived by amount of SINR 'hit' to Primary User
- Radio Environment Map
  - how many CRs can we support if we have knowledge of their interference level/statistics?
  - how do we go about administering the access (centralized vs decentralized)?

- M.F.Hanif, P.A.Dmochowski, M.Shafi and P.J.Smith, "Aggregate Interference Statistics of Cognitive Radio Systems in Shadowing Environments," submitted to IEEE Transactions on Wireless Communications.
- M.F.Hanif, P.J.Smith and M.Shafi, "Performance of Cognitive Radio Systems with Imperfect Radio Environment Map Information," in Proc. 9th Australian Communication Theory Workshop, Sydney, February 2008.
- M.F.Hanif, M.Shafi, P.J.Smith and P.A.Dmochowski, "Interference and Deployment Issues for Cognitive Radio Systems in Shadowing Environments," in Proc. IEEE International Conference on Communications (ICC 2009), Dresden, June 2009.

Channel State Information (CSI) - Imperfections

- What is the mean CR capacity if the CR is required to work under a peak interference constraint?
- How will the capacity degrade if the CSI on the CR-PU link is imperfect ?
- What happens if the CSI is also quantized?
- Given the above, what strategy should the PU adopt to protect itself from being over-interfered?



No
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Simulation Setup

Category	Details	Values
Initialization	Number of SU	2
	Number of available channels	3
	Center frequencies of available channels	{400MHz , 800MHz, 5.7GHz}
	Packet error rate of each available channel	[0, 0.9]
	Total simulation time	500s
Mobile Networks	Mean of speed	20m/s
	Standard deviation of speed	8m/s
Secondary user	Secondary user traffic model	Always backlogged
	Switching delay	100µs
Primary user	Primary user traffic model	Stochastic channels with exponentially distributed ON and OFF times, i.i.d
	Utilization of each PU traffic	[0.1, 0.9]
Q-learning	Learning rate of Q-learning	0.2
	Trade-off between exploration and exploitation	0.1
	Initial certainty values for all rules	1
	Reward	15
	Cost	5

Gnu Radio USRP* Specifications

	USRP(1)	USRP2
Interface	USB 2.0	Gigabit Ethernet
FPGA	Altera EP1C12	Xilinx Spartan 3 2000
RF BW to/from host	8 MHz @ 16bits	25 MHz @ 16bits
ADC	12-bit, 64 MS/s	14-bit, 100 MS/s
DAC	14-bit, 128 MS/s	16-bit, 400 MS/s
Daughter Boards (capacity)	2 TX, 2 RX	1 TX, 1 RX
SRAM	None	1 Megabyte
Other	-	MIMO support

USRP = Universal Software Radio Peripheral

GNU Radio

the gnu software radio

Signal processing ‘blocks’

- Implemented in C++
- Callable from python (SWIG framework)
- www.gnu.org/software/gnuradio/

Program development

- ‘Glue’ together existing blocks in python
  - https://radioware.nd.edu/documentation/a-dictionary-of-the-gnu-radio-blocks
- Stream oriented
  - m-block support for packet radio (v 3.2)
- Build your own blocks
  - https://radioware.nd.edu/documentation/advanced-gnuradio

References

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