An Architecture to Support Cognitive-Control of SDR Nodes

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Roles for AI in Networking

- Cyber Security
- Network Configuration (which modules to use)
- Network Control (which parameter settings to use)
- Policy Management
- Traffic Analysis

- Sensor fusion / situation assessment
- Planning
- Coordination
- Optimization
- Constraint reasoning
- Learning (Modelling)
  - Complex Domain
  - Dynamic Domain
  - ➢ Unpredictable by Experts

AI enables real-time, context-aware adaptivity

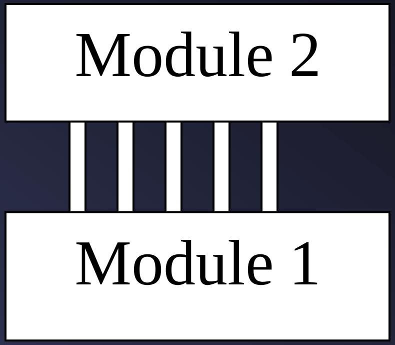
Network Control is ready for AI

- **Massive Scale**: ~600 observables and ~400 controllables *per node.*
- **Distributed:** each node must make its own decisions
- **Complex Domain:**
  - Complex & poorly understood interactions among parameters
  - Complex temporal feedback loops (at least 3: MAC/PHY, within node, across nodes); High-latency
- **Rapid decision cycle:** one second is a *long* time
- **Constrained:** Low-communication: cannot share all knowledge
- **Incomplete Observations:**
  - Partially-observable: some things can not be observed
  - Ambiguous observations: what caused the observed effect?

Human network engineers can't handle this complexity!

A Need for Restructuring

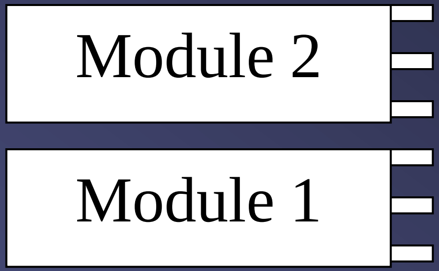
- SDR gives opportunity to create highly-adaptable systems, BUT
  - They usually require network experts to exploit the capabilities!
  - They usually rely on module APIs that are carefully designed to expose each parameter separately.



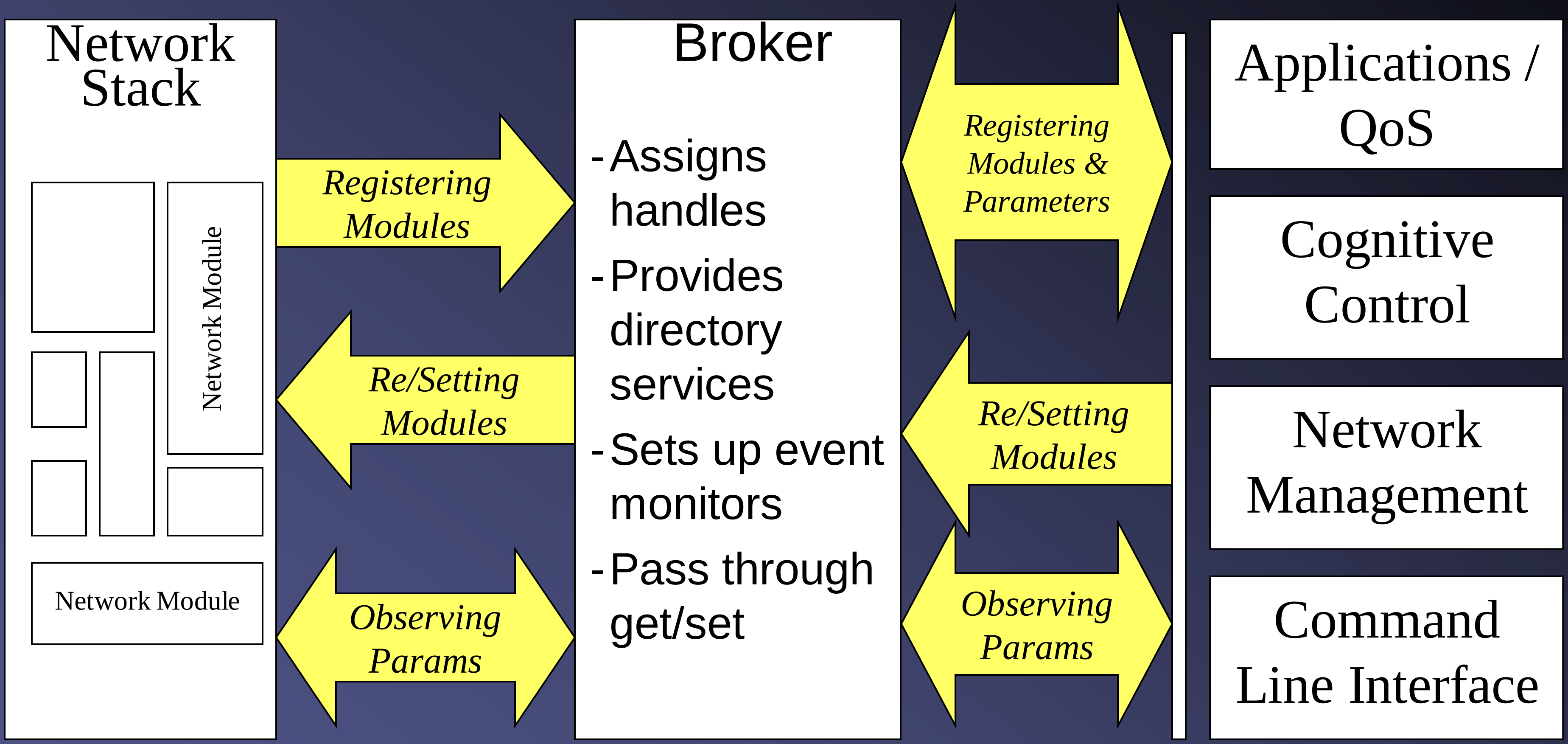
- This approach is not maintainable
  - e.g. as protocols are redesigned or new parameters are exposed.
- This approach is not amenable to real-time cognitive control
  - Hard to upgrade
  - Conflicts between module & AI

A Need for Restructuring

- We need one consistent, generic, interface for all modules to expose their parameters and dependencies.



A Generic Network Architecture



exposeParameter(*parameter_name*, *parameter_properties*)
setValue(*parameter_handle*, *parameter_value*)
getValue(*parameter_handle*)

Benefits of a Generic Architecture

- It supports network architecture design & maintenance
  - Solves the *nxm* problem (upgrades or replacements of network modules)
- It doesn't restrict the form of cognition
  - Open to just about any form of cognition you can imagine
  - Supports *multiple* forms of cognition on each node
  - Supports *different* forms across nodes

An example:

Adaptive Dynamic Radio Open-source Intelligent Team (ADROIT)

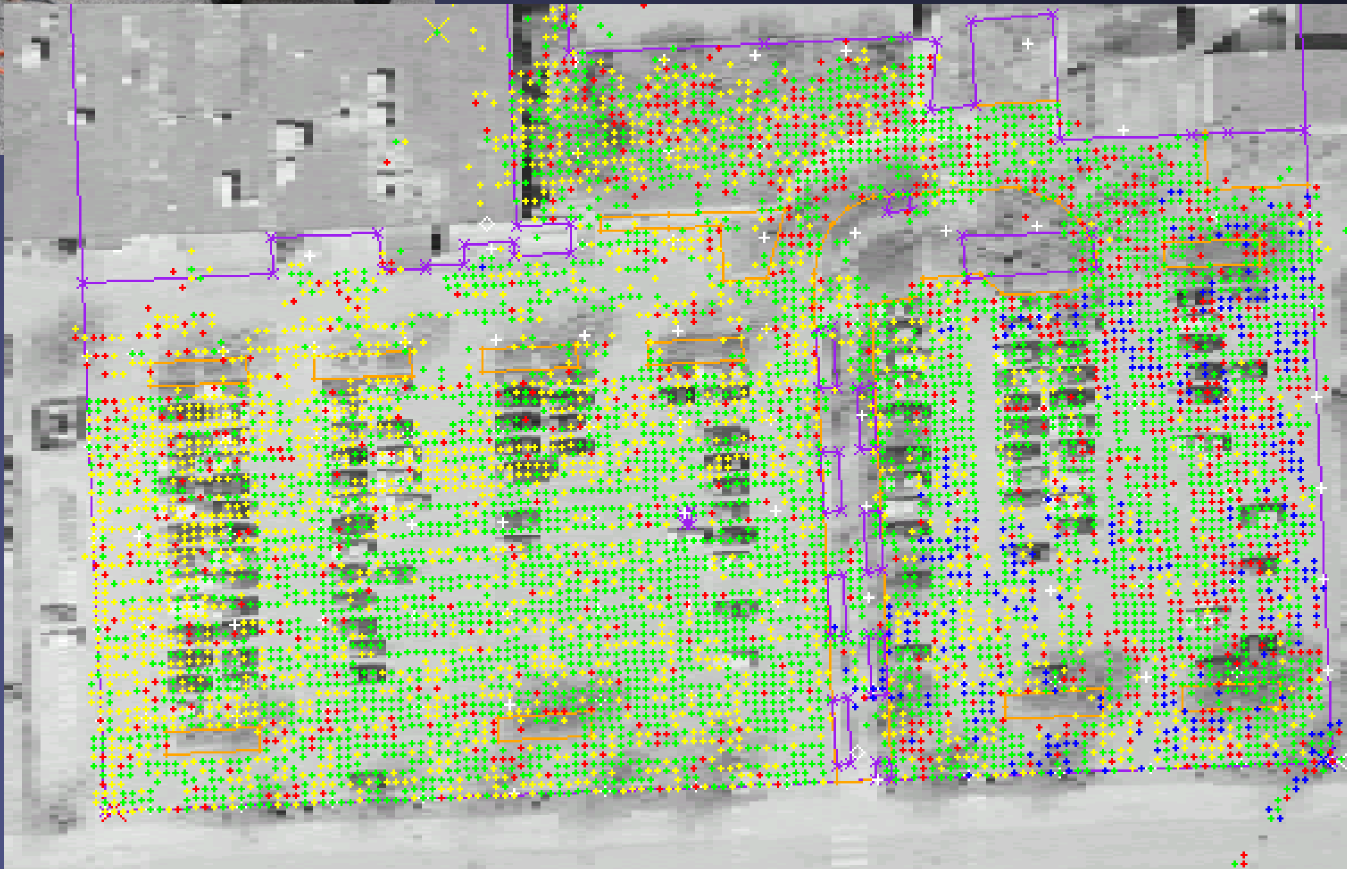
BBN, UKansas, UCLA, MIT

ADROIT's mission

- DARPA project
- Create cognitive radio teams with both *real-time composability* of the stack and *cognitive control* of the network.

- Recognize that the situation has changed
- Anticipates changes in networking needs
- Adapts the network, in real-time, for improved performance
  - Real-time composability of the stack
  - Real-time Control of parameters
  - On one node or across the network

Experimental Testbed



Maximize % of shared map of the environment

Experiment Description

- Maximize % of shared map of the environment
- **Goal:** Choose Strategy to maximize expected outcome given Conditions.
  - Each node chooses independently, so strategies must be interoperable
- Measure conditions
  - signal strength from other nodes
  - location of each node

Strategies:

- 2 binary strategy choices for 4 strategies

1. How to send fills to nodes without data?
   - multicast, unicast
2. When to send fills?
   - always
   - if we are farthest (and data is not ours), refrain from sending

Experimental Results

Training Run:

- In first run nodes learn about environment
- Train neural nets with (C,S)$\rightarrow$P tuples
  - Every 5s, measure and record progress conditions, strategy
  - Observations are local, so each node has different model!

Real-time learning run:

- In second run, nodes adapt behavior to perform better.
- Adapt each minute by changing strategy according to current conditions

Real-time cognitive control of a real-world wireless network

Observations from Learning

System performed better with learning

- Selected configurations explainable but not predictable
  - Farthest-refraining was usually better
    - congestion, not loss dominated
  - Unicast/Multicast was far more complex
    - close: unicast wins (high data rates)
    - medium: multicast wins (sharing gain)
    - far: unicast wins (reliability)

Overcoming Cultural Differences to Get a Good Design

Cultural Issues: But why?

- Benefits and scope of cross-layer design:
  - More than 2 layers!
  - More than 2-3 parameters per layer

  - ➢ Drill-down walkthroughs highlighted benefits to networking folks; explained restrictions to AI folks
  - ➢ Simulation results for specific scenarios demonstrated the power

- Traditional network design includes adaptation
  - But this works against cognition: it is hard to manage *global* scope
  - AI people want to control everything
  - But network module may be better at doing something focussed

  - ➢ Design must include *constraining* how a protocol adapts

Cultural Issues: But how?

- Reliance on centralized Broker:
  - Networking folks don't like the single bottleneck
  - ➢ Design must have fail-safe default operation

- Asynchrony and Threading:
  - AI people tend to like blocking calls.
    - e.g. to ensure that everything is consistent
  - Networking folks outright rejected it.
  - ➢ Design must include reporting and alerting

Cultural Issues: But it'll break!?!

- Relinquishing control outside the stack:
  - Outside controller making decisions scares networking folks
  - AI folks say "give me everything & I'll solve your problem"

  ➢ Architecture includes "failsafe" mechanisms to limit both sides

- Heterogenous and *non-interoperable* nodes
  - Networks usually have homogeneous configurations to maintain communications
  - AI likes heterogeneity because of the benefit
    - But always assumes safe communications!

  ➢ "Orderwire" bootstrap channel as backup

Cultural Issues: New horizons?

- Capability Boundaries
  - –Traditional Networking has very clear boundary between “network” and “application”
  - –Generic architecture blurs that boundary
    - AI folks like the benefit
    - Networking folks have concerns about complexity

➢ Removing this conceptual restriction will result in interesting and significant new ideas.

Conclusion

- Traditional network architectures do *not* support cognition
  - Hardware is doing that now (SDR), but the software needs to do the same thing

- To leverage the power of cognitive networking, both AI folks & Networking folks need to recognize and adapt

Backup

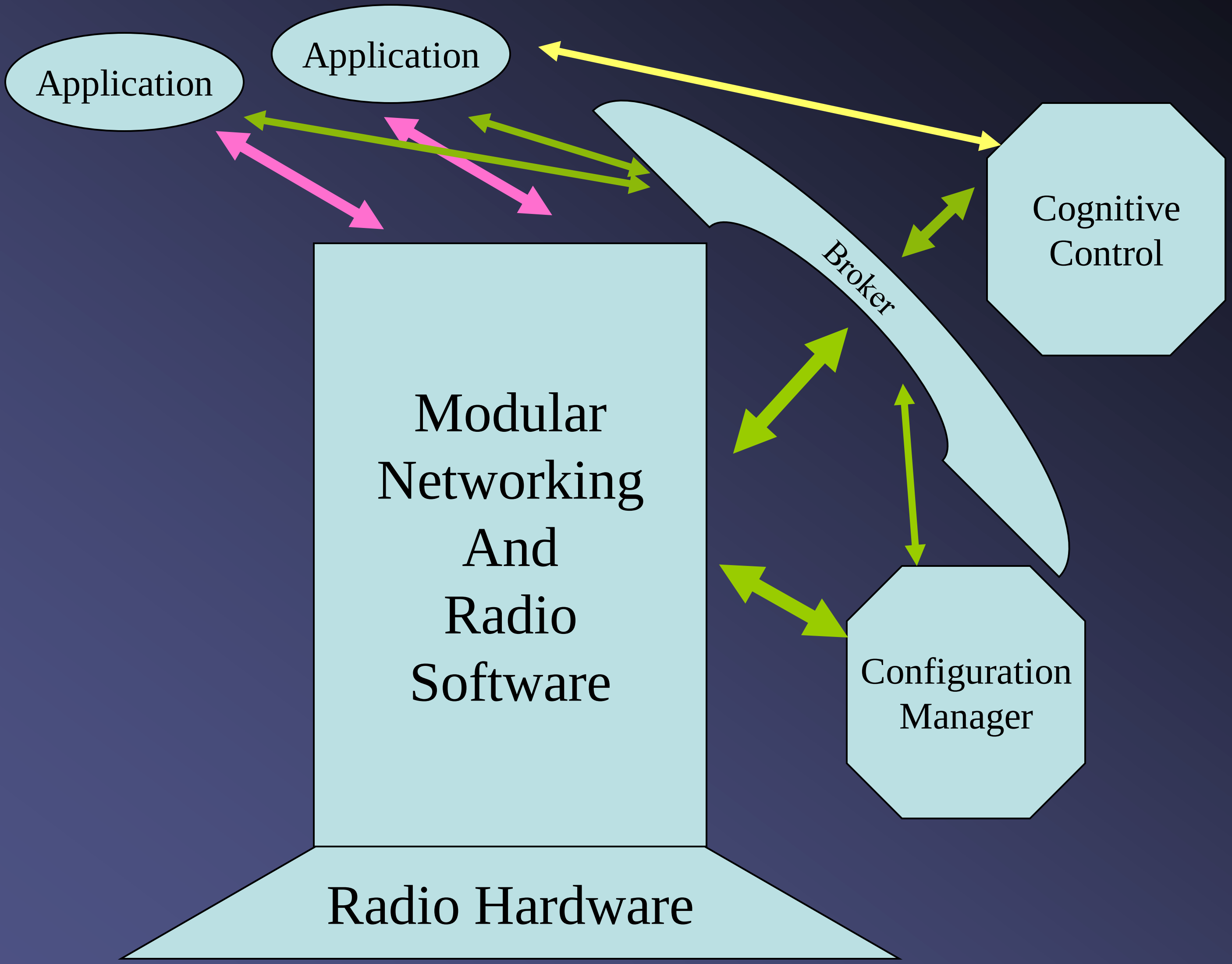
Environment Model

- Signal Strength
  - 12 cart-cart strengths
  - sorted to normalize
    - want to apply learning to similar situations with different cart numbering
- Position
  - seemed like a good idea (“use more information, let neural net sort it out”), but....
  - in testing, seemed more confounding than helpful
- On-line estimate required
  - operation uses environment

Configuration and Adaptation

- Configuration Manager
  - Determines what modules are currently running
  - Tracks what modules exists
  - Manager transitions from one configuration to another
  - Provides basic sanity check before enabling a new configuration
- Broker
  - Changes and monitors the state of active modules
  - Serves as a clearinghouse of information about all the modules in current configuration

ADROIT Big Picture



Managing Cognition

- ADROIT doesn't choose the form
  - Open to just about any form you can imagine
  - Multiple forms on each node, system wide
  - Operate via standard interface (broker)
- Coordination manager
  - Coordinates interactions among radios
  - Chooses local radio's external behavior taking into account needs of other radios in team and in region
  - Manages information sharing (keeps cognitive information exchanges within reasonable limits)

Modelling the Radio

- Need a way to model the radio for cognition
  - A chunk of code (module) is not expressive enough
  - At minimum, cognition needs to know what the chunk of code does
- A basic object model
  - Each module is an object
  - Two implementations of the same functionality are same object type, or inherit characteristics from the same object type
  - Pieces of hardware, etc, also viewed as objects

ADROIT resources

- Troxel et al. "Enabling open-source cognitively-controlled collaboration among software-defined radio nodes." *Computer Networks,* 52(4):898-911, March 2008.
- Troxel et al, "Cognitive Adaptation for Teams in ADROIT," in *IEEE Global Communications Conference*, Nov 2007, Washington, DC. **Invited**.
- Getting the ADROIT Code (Including the Broker)
  - https://acert.ir.bbn.com/
  - checkout instructions
  - GNU Radio changes are in main GNU Radio repository

Learning

- Karen Zita Haigh, Srivatsan Varadarajan, Choon Yik Tang, "Automatic Learning-based MANET Cross-Layer Parameter Configuration," in *IEEE Workshop on Wireless Ad hoc and Sensor Networks (WWASN)*, Lisbon, Portugal 2006.

ADROIT Team

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