CogNet

An Architectural Foundation for Experimental Cognitive Radio Networks within the Future Internet

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Wireless Networking Challenges

Why is wireless networking hard?

- Mobility is inherent with untethered
- Resources are constrained
  - Spectrum “scarcity” → bandwidth & delay issues
- Environment changes
  - Mobility → different surroundings (indoor, urban, rural)
- Varying physical properties
  - Wireless communication path changes over time

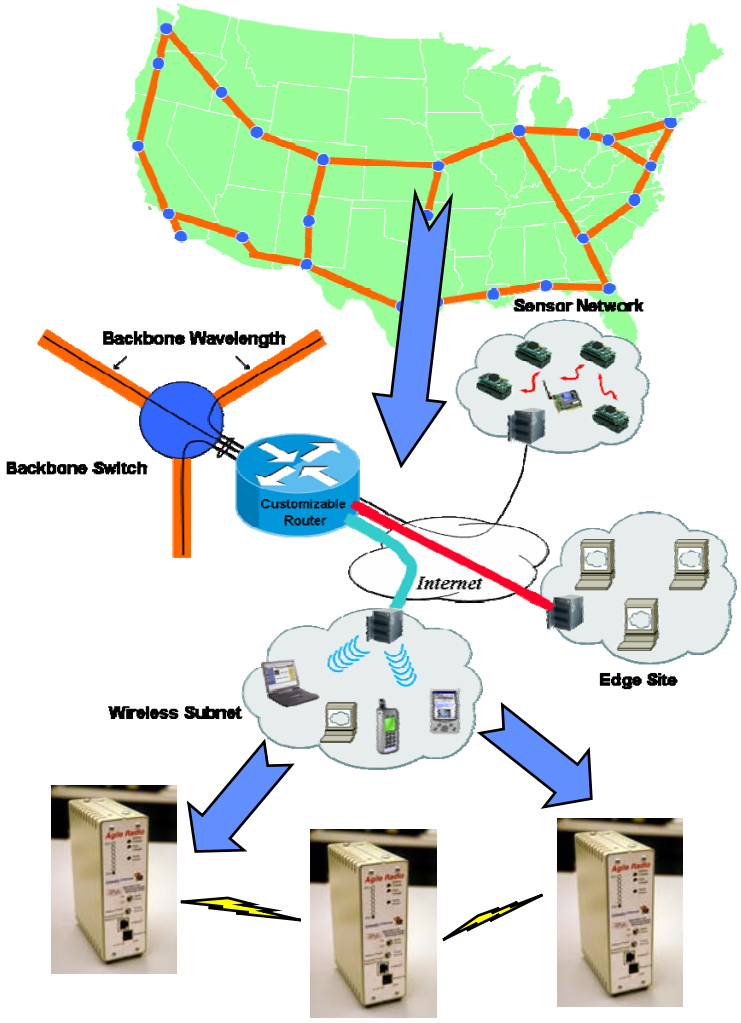
Cognitive Networking

Cognitive (from Wikipedia) – applying the experience gathered in one place by one being to actions by another being elsewhere

- Developing experimental protocol stack for cognitive *networks*, not just cognitive *radios*
- Scalable autoconfiguration & network management
- Dynamic network layer supporting tailored functionality (IP, group messaging, rich queries, etc.)
- Builds on the foundation of cognitive radios (e.g., Rutgers & GNU Radio, KU Agile Radio), but extends it further up the protocol stack, and explores across stack

CogNet in Perspective

- GENI (Global Environment for Network Innovations)
  - Global experimental facility that will foster exploration and evaluation of new networking architectures (at scale) under realistic conditions
  - Major infrastructure, expected to be $367 million
- FIND (Future Internet Network Design)
  - Requirements for global network of fifteen years from now - what should that network look like and do?
  - How would we re-conceive tomorrow's global network today, if we could design it from scratch?
  - Innovative ideas in broad area of network architecture, principles, and design
  - Research projects expected to be funded at $20 million per year in progressive phases
  - Provides experiments and architectures that will be pursued on the GENI infrastructure



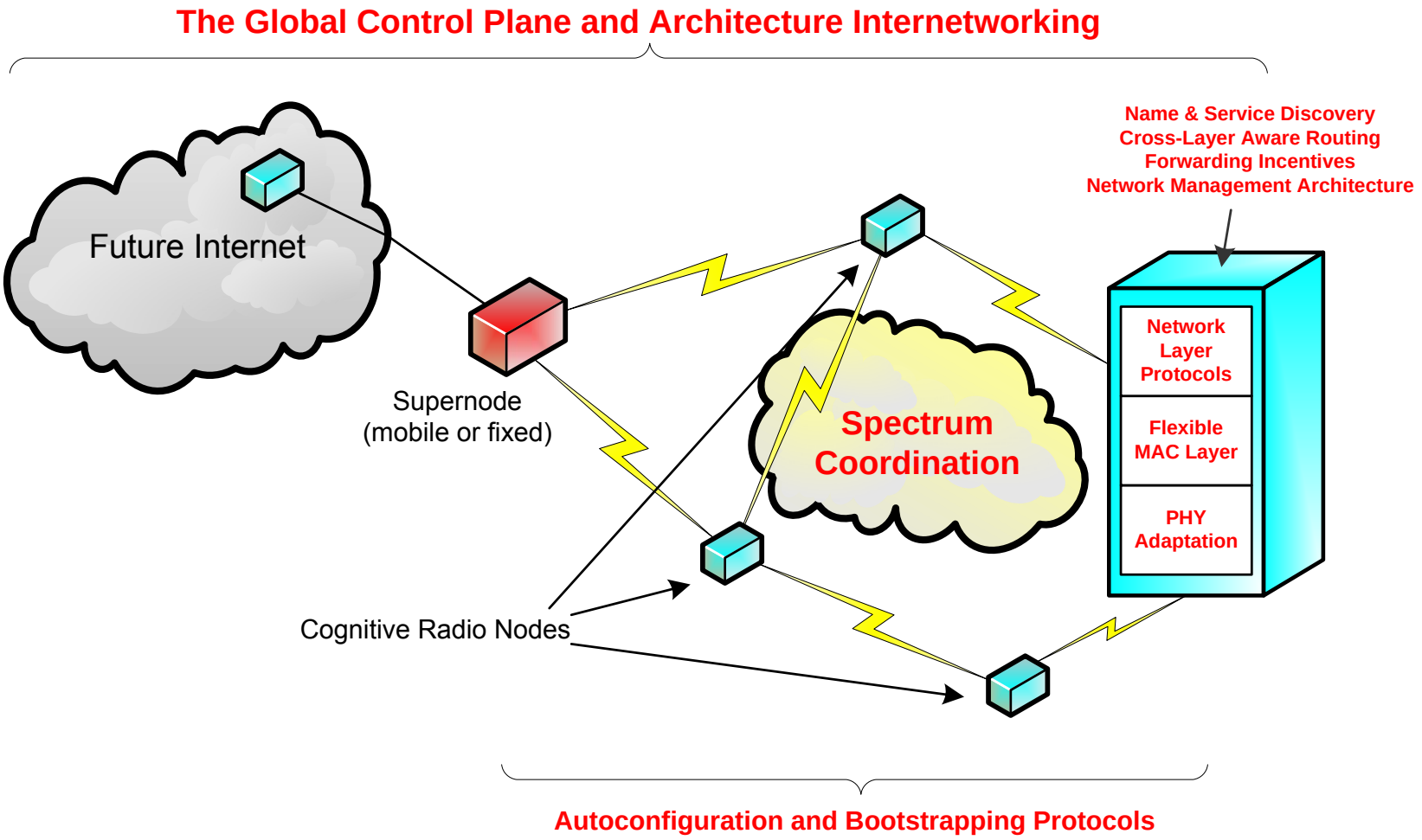
Cognitive / Agile Radio Platforms

- Flexible in RF carrier frequency
- Flexible in bandwidth
- Flexible in waveform
  - A/D and D/A driven
  - Generated/processed by programmable DSP and/or FPGAs
- Dials to observe
  - Traffic characteristics measured at network layer
  - Error rate & characteristics (BER and distribution)
    - MAC layer per packet error information
    - Network and transport layer per flow correlations
  - Receive characteristics
    - Physical layer – signal strength, interfering signals, background noise
    - MAC layer – transmit power, antenna in use
- Knobs to influence
  - Physical layer
    - Frequency & bandwidth
    - Transmit power
    - Beam width & direction
    - Data rate, code, & chipping rate
  - MAC protocol
    - FEC strength
    - Retransmit scheme
    - MTU size
    - Encryption & parameters
  - Network layer
    - Routing protocol
    - Addressing plan(s)
    - ACLs
- Interface framework with a flexible, usable set of scalable parameters
- Adapt to resource constraints, environment, varying physical conditions, application
- Capability to learn

Cognitive Radio Network Capabilities

- *Spectrum agility* and fast spectrum scanning over multiple frequency bands, providing local awareness of radio interference and the ability to change frequency bands on a per-packet basis
- *Fast PHY adaptation*, or the ability to change physical-layer waveforms on a per-packet basis and PHY collaboration modes such as network coding
- *Spectrum etiquette protocol* and dynamic spectrum policy implementation on a per-session basis
- Fully *programmable MAC layer*, with the option of dynamic adaptation to meet service needs
- *Cross-layer protocol implementation capabilities* based on integrated PHY, MAC, network algorithms
- *Ad hoc cluster formation*, involving multi-hop packet forwarding among peer groups of radio nodes

CogNet Vision

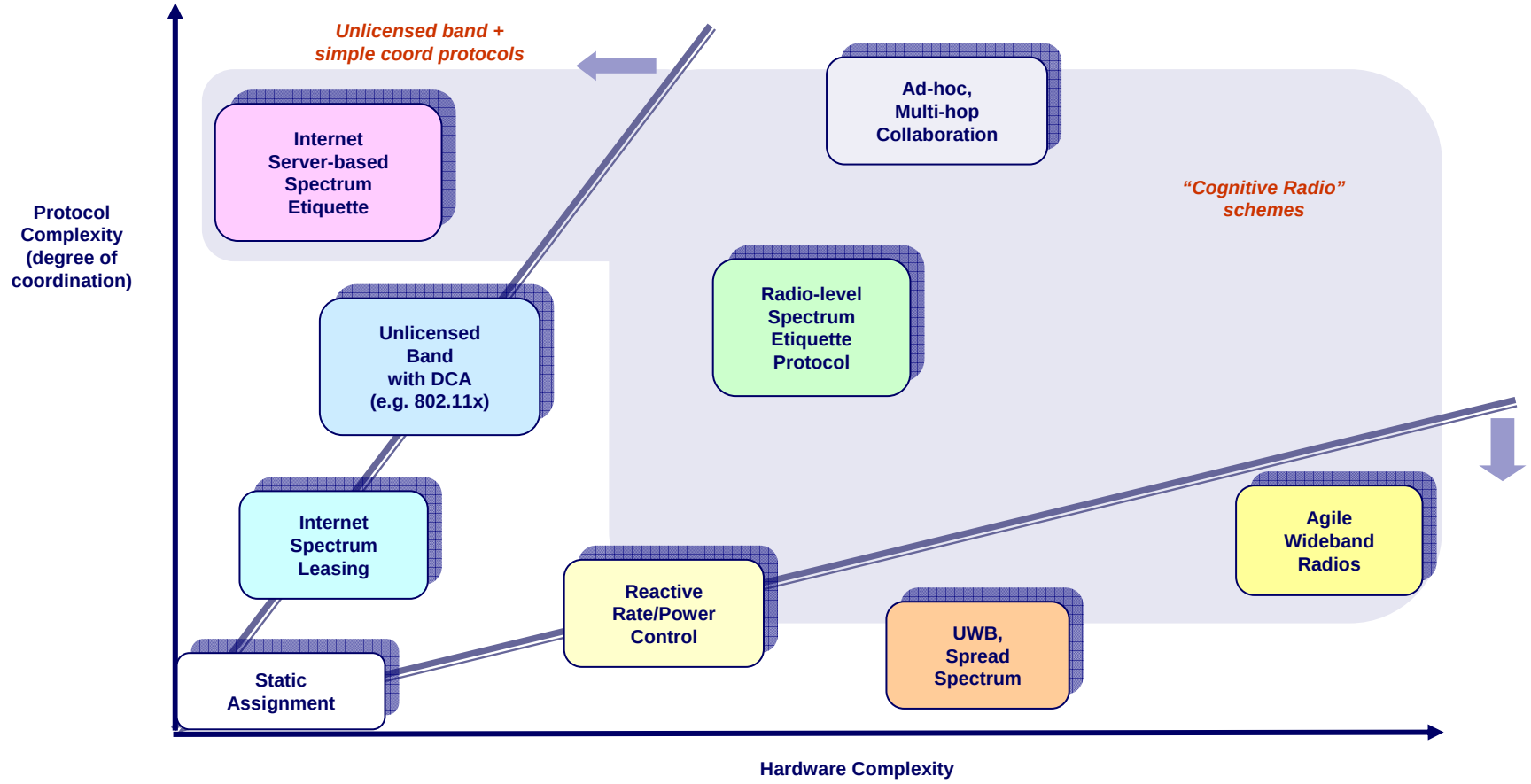


Build Architectural Foundations

- A *Global Control Plane (GCP)* implemented as a *cross layer network management overlay* that can interface with the network layer and can provide aggregated representations of the cognitive subnetwork state to the future Internet
- An *API for PHY layer adaptation* (e.g., agility, change of modulation waveform), and support for collaborative PHY via network coding
- Spectrum coordination protocols that facilitate dynamic sharing among radio nodes using mechanisms such as etiquette policies or spectrum server
- *Autoconfiguration* (e.g., bootstrapping and topology discovery) *protocols* that can be used to establish network connectivity after a cognitive radio device is turned on or enters a new service area
- *Flexible MAC framework* that permits programmable functionality capable of dynamic selection of channel sharing modes based on observed network conditions and traffic demands
- *Network layer protocols* that support service discovery, naming, addressing and routing in ad hoc wireless constellations, including features that provide economic incentives for collaboration

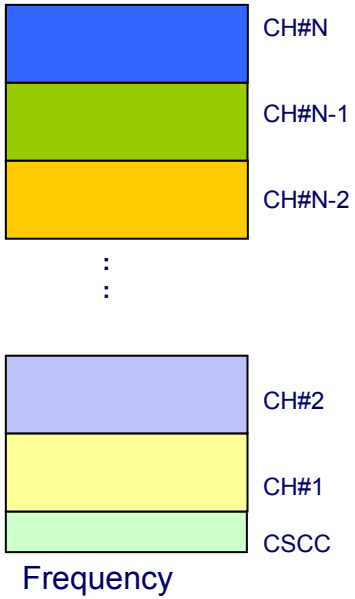
Spectrum Coordination Approaches

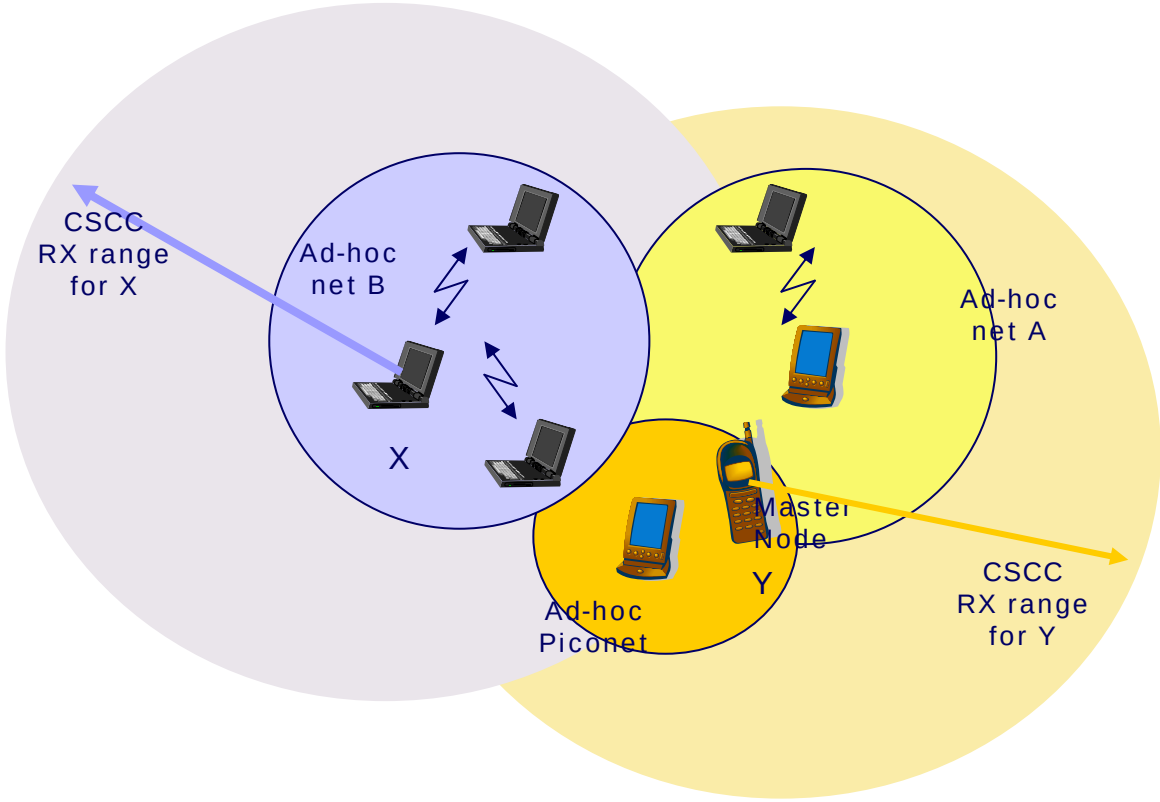
- Protocol & hardware complexity



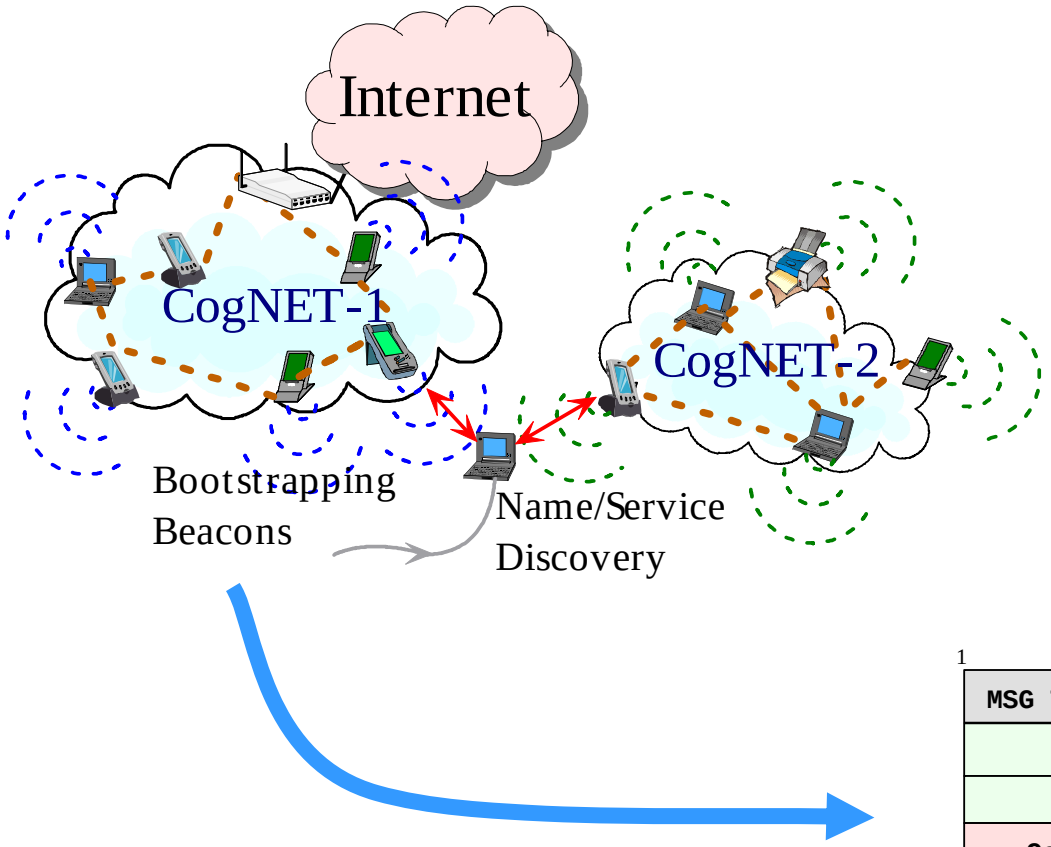
CSCC for Spectrum Coordination

- Common Spectrum Coordination Channel





Bootstrapping and Discovery

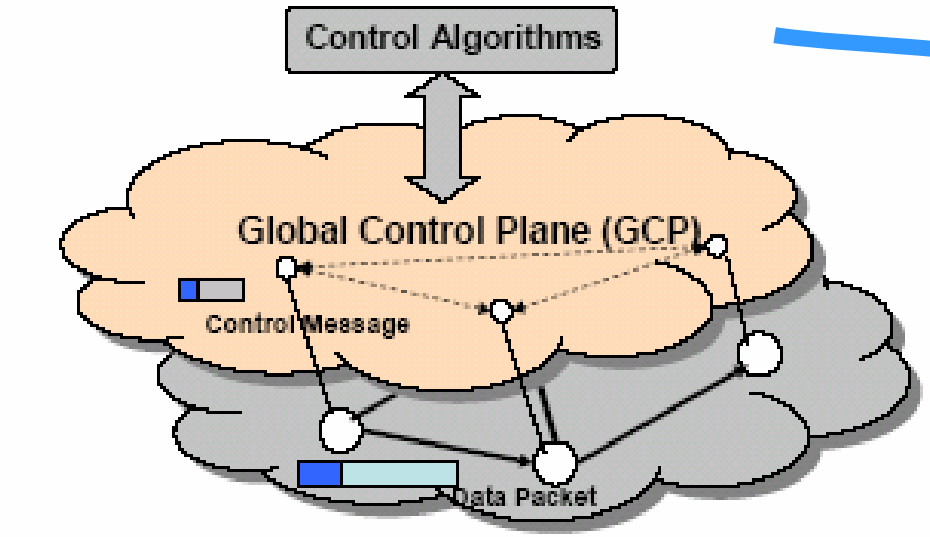


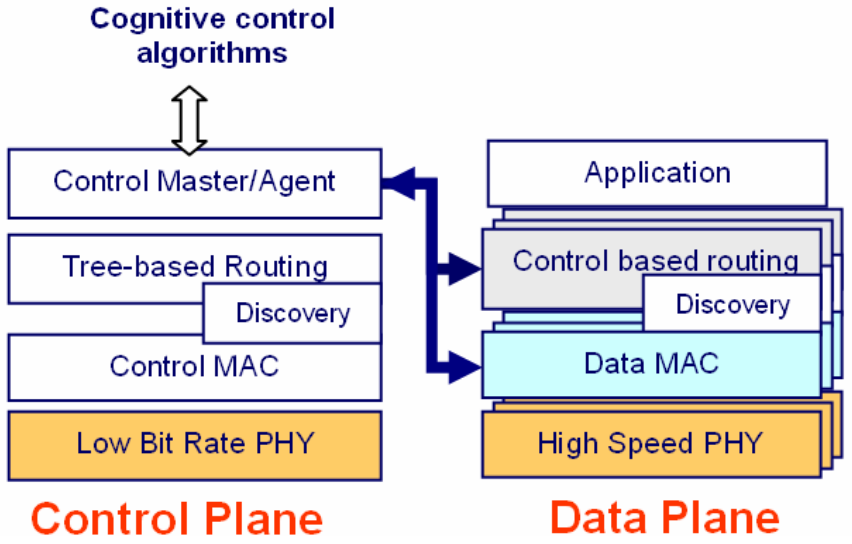
Establish network connectivity after a cognitive radio device is turned on or enters a new service area

Example Bootstrapping Beacon Format

1	8	16	24	32
MSG Type	Payload Length		Next Header	
Source Identifier				
Time Stamp				
Center Frequency			Power Level	Modulation /Coding
Bandwidth	Rate Level		Sub-Network Name	
Available Services				

Global Control Plane

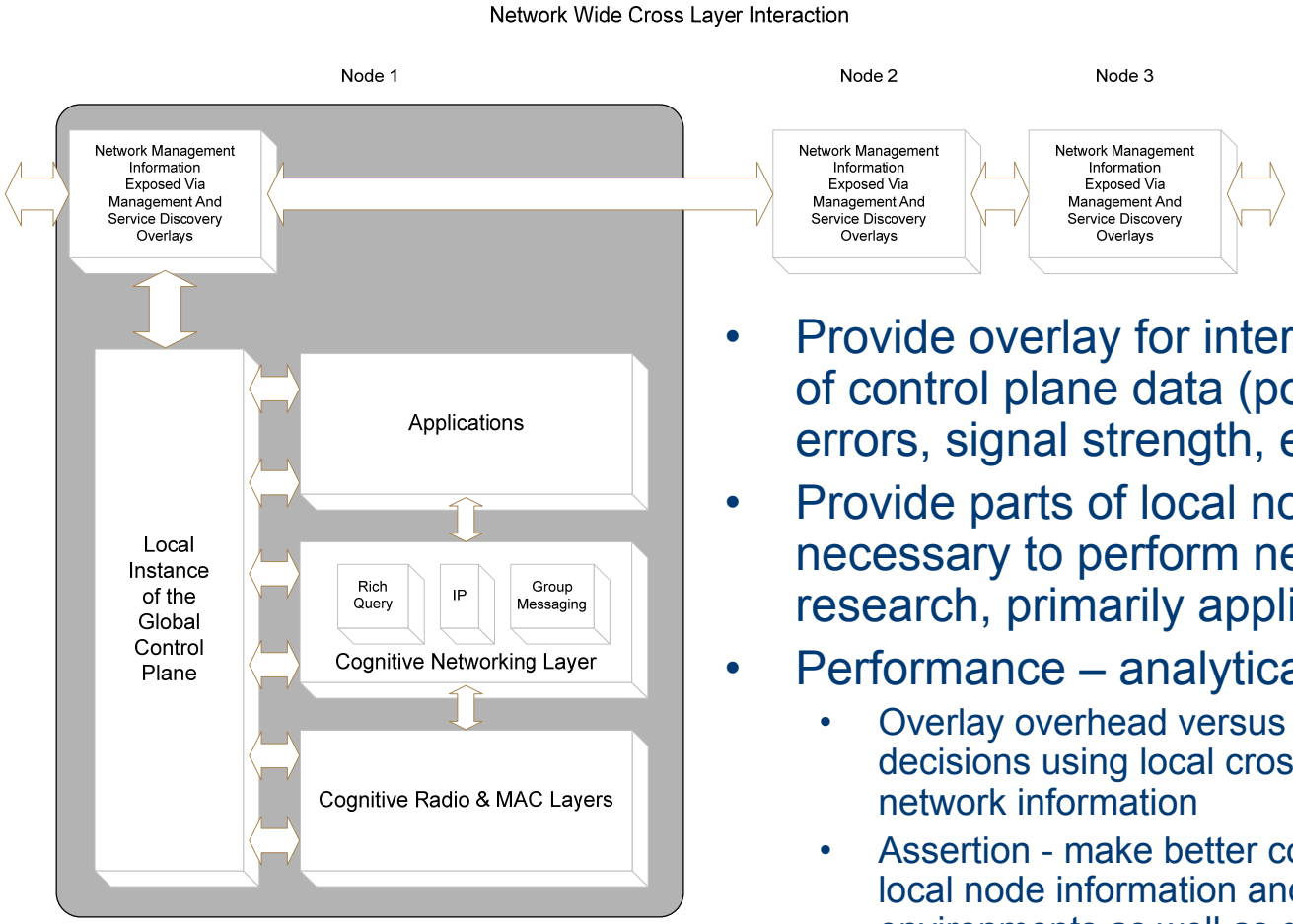




Global Control Plane (GCP)

- Cross layer network management overlay
- Interfaces with network layer
- Provides aggregated representations of cognitive subnet state to future Internet

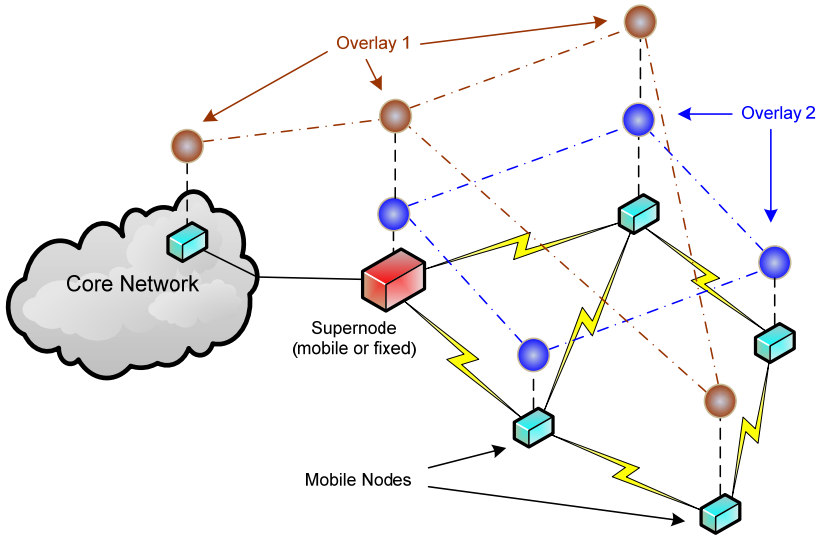
Network Management Architecture



- Provide overlay for inter-node transmission of control plane data (position, capabilities, errors, signal strength, etc.)
- Provide parts of local node control plane necessary to perform network layer research, primarily application and layer 3
- Performance – analytically & experiment
  - Overlay overhead versus better data for cognitive decisions using local cross-layer and global cross-network information
  - Assertion - make better cognitive decision knowing local node information and receiving node environments as well as details above any intermediate hops

Network Layer Overlays

- Overlay typically denotes an application layer network of semi-persistent links between participating nodes, that is used to forward messages between the distributed application elements
- Structured and unstructured P2P, DHT
- Services may map better to particular overlays – search, distributed file storage, load balancing, multicast messaging

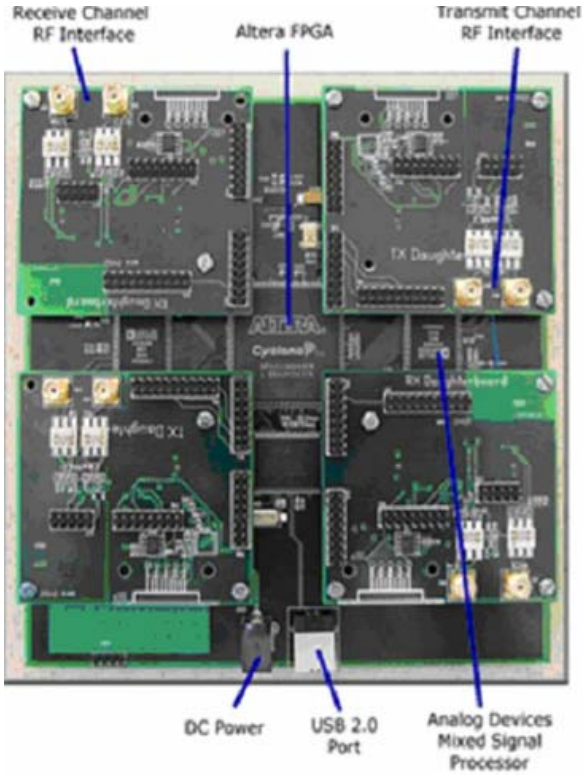


Network Layer Overlay Issues

- Feasible to use overlays for Layer 3 forwarding, e.g., Virtual Ring Routing? To provide new network layers?
- How would having tailored layer 3s, (IP, range-based overlays, multicast optimized overlays, etc.) may impact end-to-end network architecture for interoperating cognitive wireless subnets and the future Internet?
- How to use, position, and discover routers between the overlays themselves, and the Internet?
- How can applications decide which network layer to use?
  - Legacy approach manipulating resolver libraries
  - New approach by applications aware of the Global Control Plane (GCP)
- Explore performance tradeoffs (more overhead, etc. versus better utilization, etc.) in simulation and real cognitive radio network (KUAR or Rutgers/GNU Radio)

CogNet Protocol Stack Implementation

- USRP Software Radio Board



- KU Agile Radio (KUAR)

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