Cognitive Radio Research at Virginia Tech

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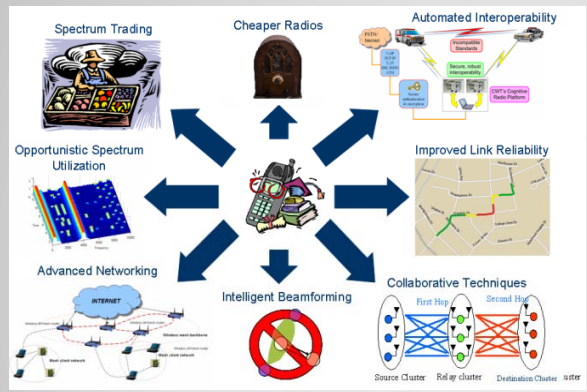
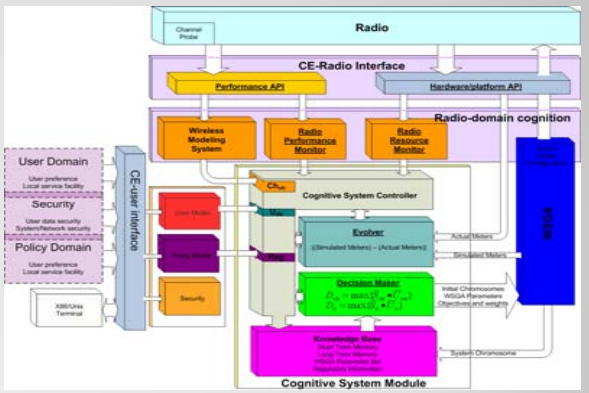




Wireless@Virginia Tech

ICTAS

VirginiaTech Invent the Future

Sponsors of Cognitive Network Research

- Army Research Office
- Air Force Research Laboratory
- BBN Technologies
- CAER
- CERDEC
- DARPA
- DISA
- ETRI
- ICTAS
- Intel
- National Science Foundation
- National Institute of Justice
- NGIA
- Office of Naval Research
- Qualcomm
- Rockwell Collins
- Tektronix
- Texas Instruments

Faculty

Jeff Reed
(Director)
Software Radio

Charles Bostian
RF Design,
Cognitive Engine

Allen MacKenzie
Cognitive Networks

Tamal Bose
(Assoc. Director)
Digital Signal Processing

Mike Buehrer
Cognitive MIMO

Jung-Min Park
Security

Claudio da Silva
Spectrum Sensing

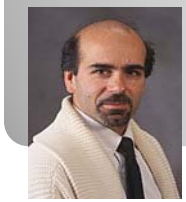
Tom Hou
Resource Management

Yaling Yang
Routing

Luiz DaSilva
Cognitive Networks

Michael Hsiao
Software Verification

Madhav Marathe
Modeling and Simulation



Peter Athanas
Reconfigurable Computing

Anil Vullikanti
Distributed and Mobile Computing

Special faculty: C. Dietrich, A. Amanna, S.M. Hasan, T. Newman, R. Thamvichai
Students: ~ 40 graduate students

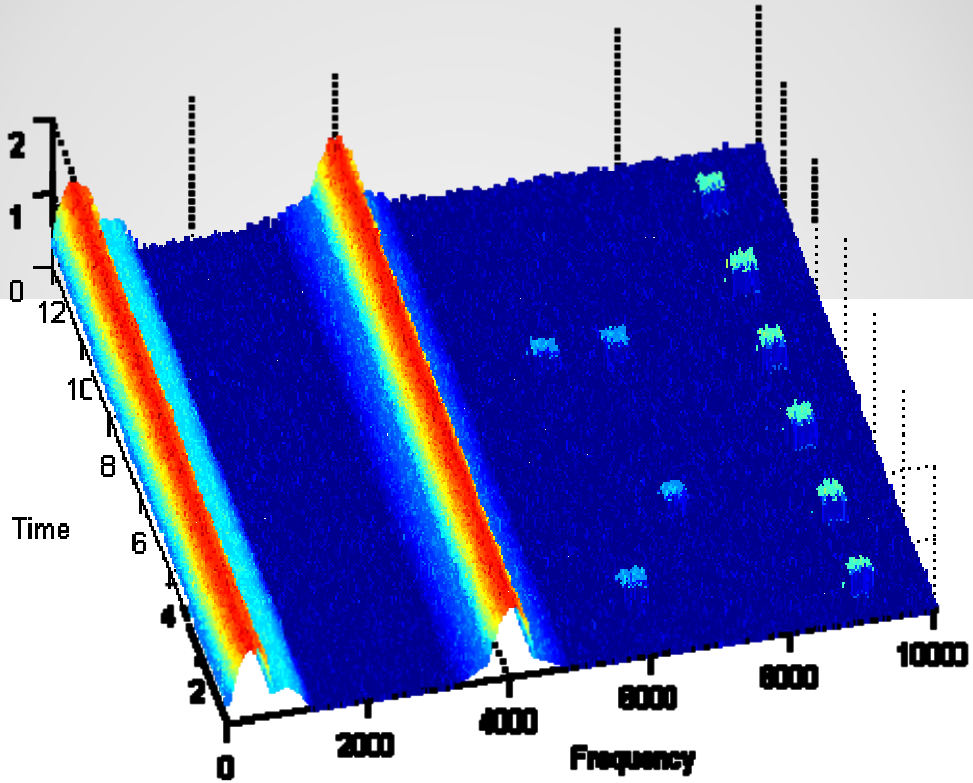
Revolutionary Applications

- *Femto cells and spectrum management*
- *Cognitive MIMO, e.g. learning the best spatial modes*
- *Collaborative Radio - Coverage and Capacity expansions*
- *Enhanced security*
- *Location dependent regulations*
- *Power Consumption Reduction*
- *Smart Antenna management*
- *Public Safety Interoperatibility*
- *Cellular Radio Resource Management*
- *Maintenance and Fault Detection of Networks*
- *Multibanding, e.g. mixing licensed and unlicensed spectrum or protected and unprotected*
- *Cognitive Routing and Prioritization*
- *Advanced Networking for QoS*
- *Emergency Rapid Deployment and Plug-and-Play optimization*
- *Anticipating user needs – intersystem handoff and network resource allocation*

Primary Cognitive Research Categories

- Signal Classification and Sensing for Cognitive Radio
- Cognitive MIMO Applications
- Cognitive Radio Network Modeling and Implementations
- Security Issues for Cognitive Radio Networks
- Power and Energy Applications for Cognitive Radio
- Cognitive Radio Network Deployments at Virginia Tech
- Cognitive Radio Network Testbed (CORNET)

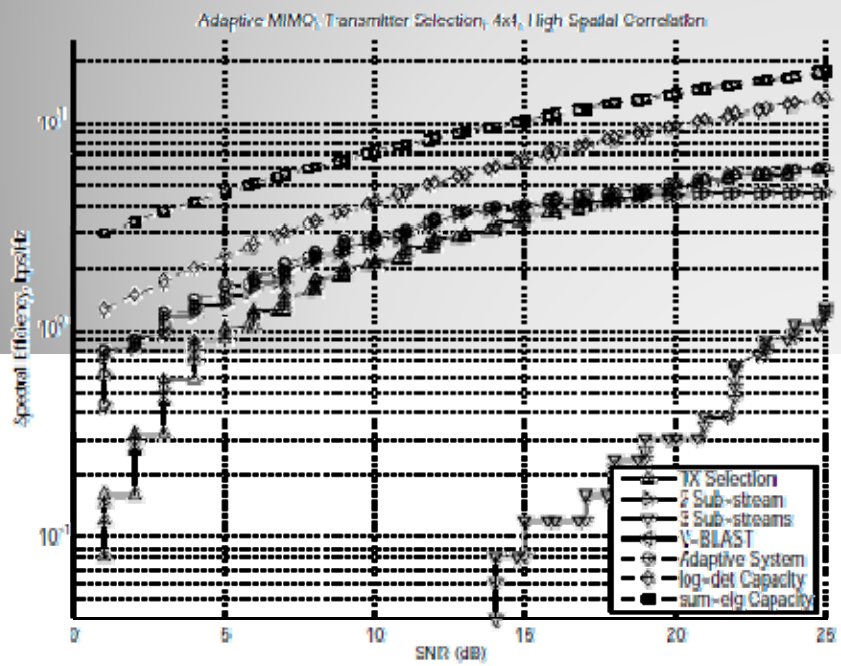
Signal Classification and Sensing for Cognitive Radio Networks



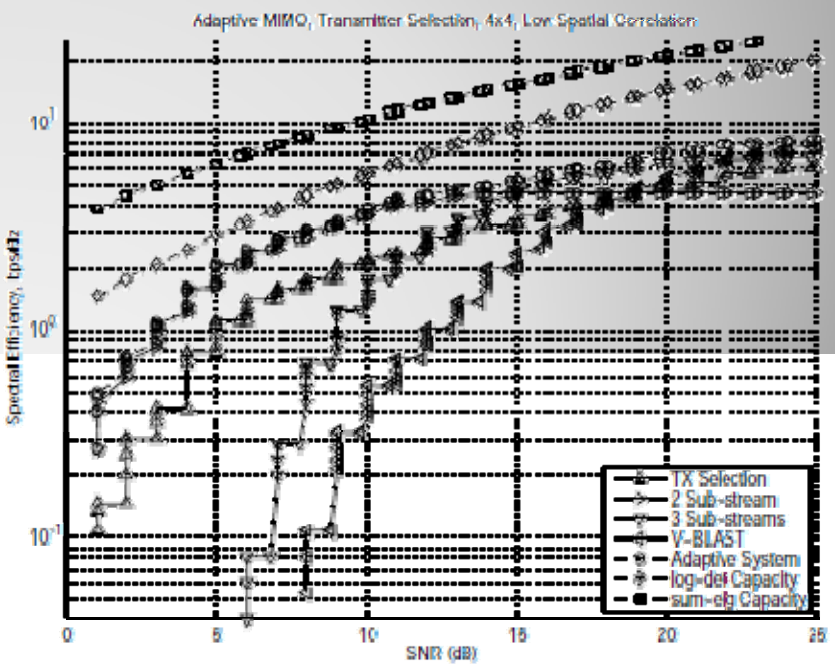
Signal Classification for Cognitive Radio Networks

- Universal Classification System (UCS)
  - Automatic signal recognition, synchronization, and provides necessary parameters for transceiver configuration and signal demodulation without any *a priori* knowledge of the signal.
- Robust Blind Equalization (EQ) and Automatic Modulation Classification (AMC)
  - Develop a cognitive receiver where performance of the AMC is also considered while designing the blind equalizer.
- Cyclostationary and collaborative techniques

Cognitive MIMO Applications



(a) High Correlation



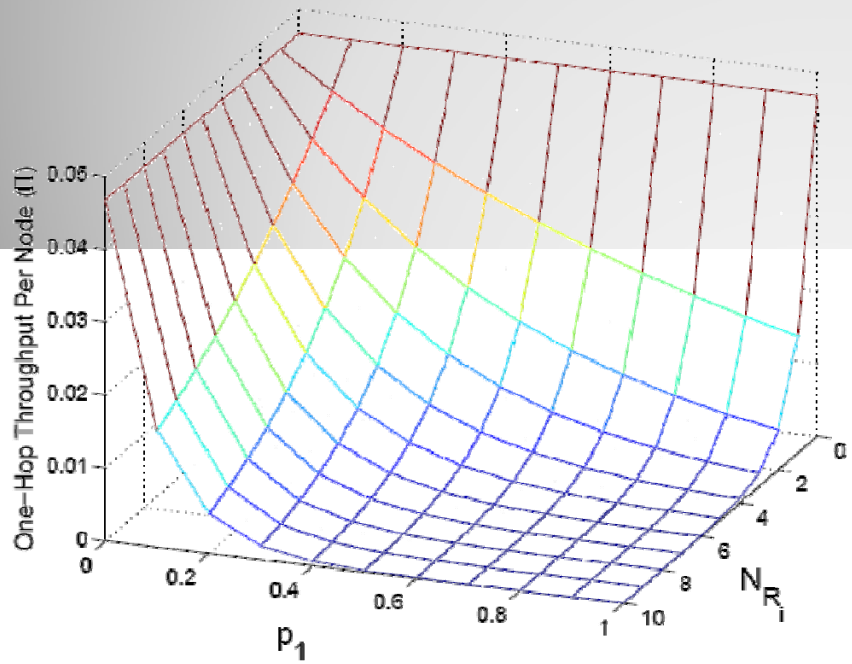
(b) Low Correlation

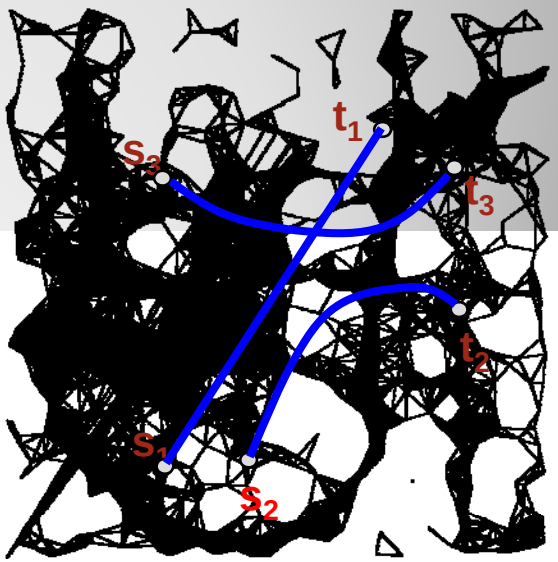
Key Issue: <u>Different algorithms and antenna configurations are required depending on the RF channel.</u>

Cognitive MIMO Applications

- Adapting Antenna Configurations
  - Dynamic topologies and data flows require greater agility from individual nodes to meet network-level objectives
- Cognitive Engine Design for Link Adaptation in Multi-Antenna Systems
  - Expand Cognitive Radio research to include multiple antenna systems
- Reductions in Power Consumption of RF
  - Cross optimize cross RF components and PHY and MAC layers
- Fundamental Capacity Limits
  - Determine maximum achievable capacity of Cognitive MIMO networks

Cognitive Radio Network Modeling and Implementations





Cognitive Radio Network Modeling

- Modeling Realistic Urban Scale Wireless-Social networks
  - Model realistic urban traffic and mobility models involving 10 million devices/individuals
- Testing and Verification for Cognitive Radio Components
  - Large number of multi-layer interactive components need to be accurately tested and validated
- Capacity estimation and cross-layer protocol design in cognitive networks
  - Develop a unified framework for capacity of ad hoc networks with a variety of models, constraints
- Multi-hop Networking with Cognitive Radios
  - Characterize and model cross-layer behavior for multi-hop cognitive radio networks
- Real world oriented design for Cognitive Radio Networks
  - Balancing cost and revenue for developing a financially feasible Cognitive Radio Network design

Security Issues for Cognitive Radio Networks

CR network security threats

Spectrum access-related security threats

Threats to incumbent coexistence mechanisms

- Spectral "honeypots"
- Sensory manipulation:
  - Primary user emulation
  - Geospatial manipulation
  - Chaff point attack
  - Spam point bias attack
- Obstruct synchronization of QPs

Threats to self-coexistence mechanisms

- Tx false/spurious inter-cell beacons (control messages)
- Exploit/obstruct inter-cell spectrum sharing processes

Radio software security threats

- Security threats to the software download process
  - Injection of false/forged policies
  - Injection of false/forged SW updates
  - Injection of malicious SW (viruses)
- Software IP theft
- Software tampering
  - Unauthorized policy changes
  - Tampering w/ CR reasoners (e.g., System Strategy Reasoner & Policy Reasoner)

Cognitive Radio Network Security

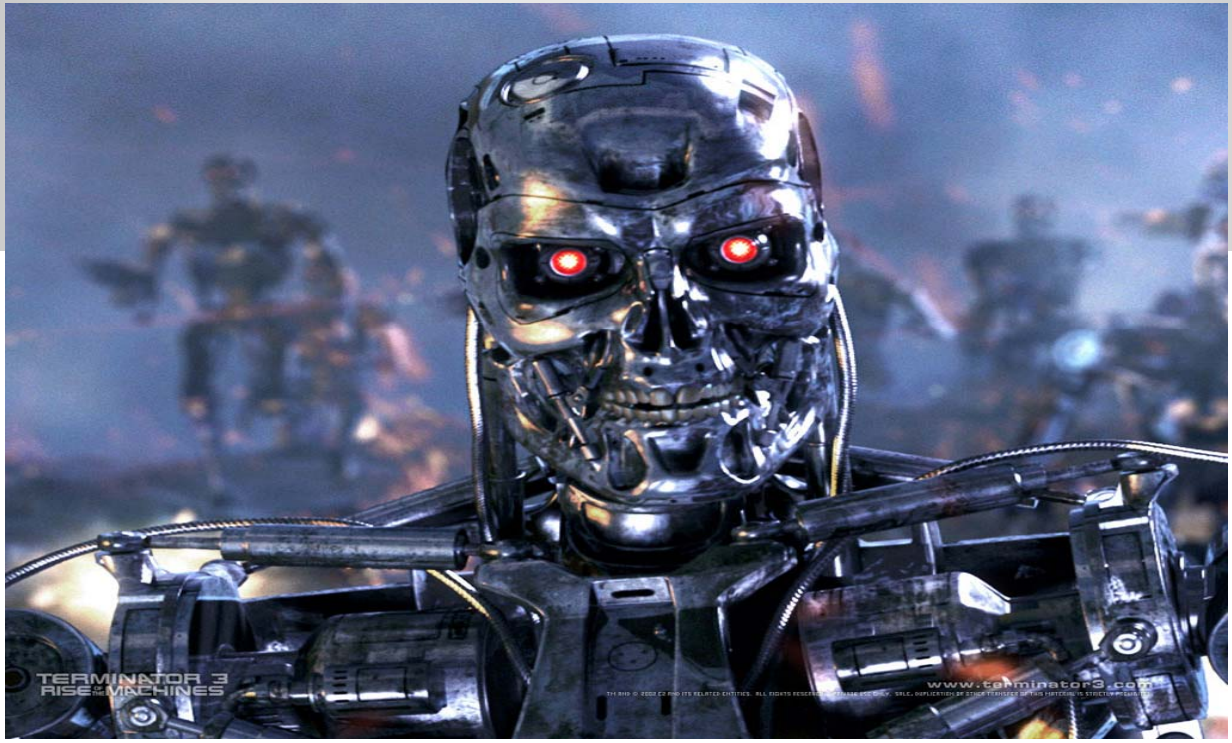
- Regulation of Cognitive Radio Behavior via the Policy Reasoner
  - Need to ensure that CR's transmissions conform to regulatory policies
- Threats against Incumbent Coexistence & Signal Classification
  - Analyzing new threats specifically to DSA primary user classification
- Jamming-Resistant Control Channels for Dynamic Spectrum Access
  - Develop robust control channel techniques for DSA
- Tamper Resistance for Software Defined & Cognitive Radio Software
  - Thwarting malicious software modifications to SDR components

Cognitive Radio Network Power and Energy Management Applications

Cognitive Radio Network Power and Energy Management

- Power and Energy Consumption Reduction Using CR
  - Develop CR framework for optimizing low level power and energy consumption
- Wireless Distributed Computing (WDC)
  - Develop WDC using Cognitive technology for distributing processing over multiple nodes
    - Distributed sensing
    - Geo-location
    - Coordinated jamming
    - Image processing
    - Cooperative MIMO
    - Direction finding
    - Secure systems

Cognitive Radio Network Deployment

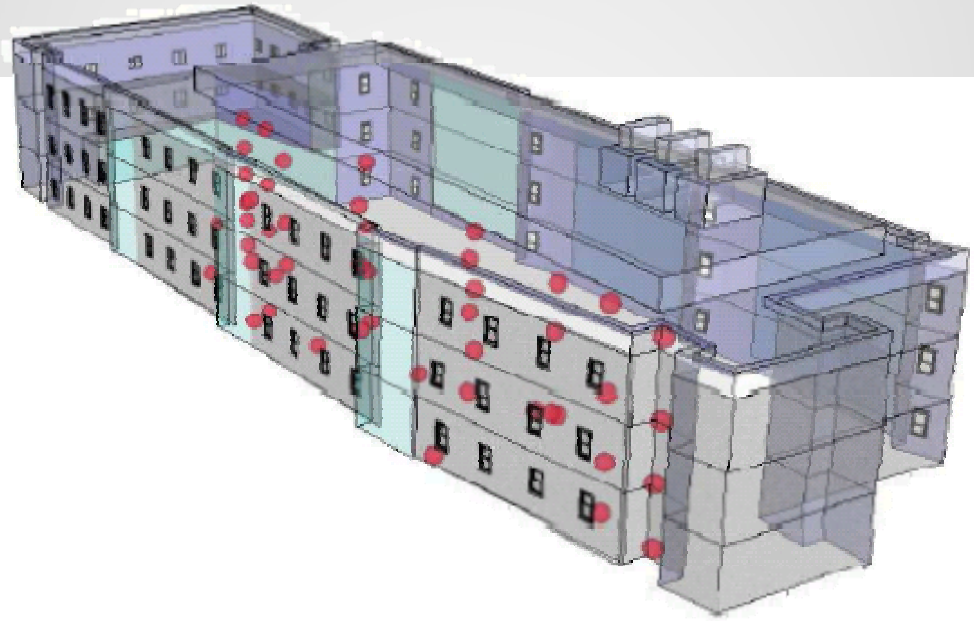


Cognitive Radio Network Deployment

- A Public Safety Cognitive Radio on a Digital Signal Processor Platform for Affordable Interoperability
  - Low-cost and low-power public safety Cognitive Radio platform
- Cognitive System Enabling Radio Evolution (CSERE)
  - Modular Cognitive Radio framework for integrating all components of a Cognitive Radio system
- Railway Cognitive Radio (Rail-CR)
  - Using Cognitive Radio for railway control systems
- Cognitive Gateway
  - CG can bridge the waveforms transmitted over different platforms, which include Walkie-talkies for family radio service (FRS), P25 radios, USRP boards, as well as commercial-off-the-shelf 802.11 WiFi chips, and 802.3 Ethernet adapters.
- Cognitive Radio Network Testbed (CORNET)

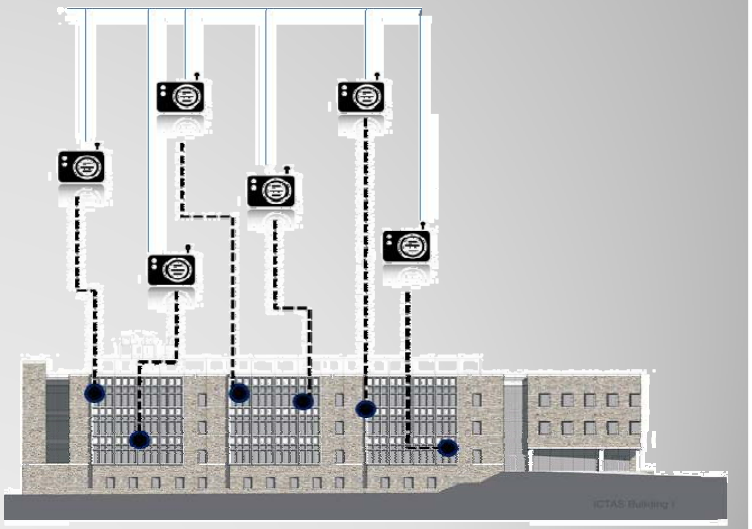
Cognitive Radio Network Testbed (CORNET)

Jeff Reed and Tamal Bose
Timothy R. Newman



Cognitive Radio Network Testbed

- Defense University Research Instrumentation Program (DURIP) grant for CR testbed equipment.
- Physical testbed deployed throughout a new campus building
- Total size of testbed is 48 nodes
  - 12 nodes per floor
- No restrictions on other wireless systems inside building



Physical Cognitive Radio Nodes

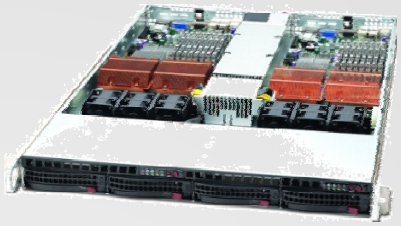
CR Testbed Hardware

Custom RF Daughterboard

- Motorola RFIC4
- 100 MHz – 4 GHz
- 20 MHz instantaneous BW
- Highly variable receive gain
  - 25 dB – 50 dB
- Multiple TX (3) and RX (5) paths
- Sideband Rejection
  - 40 dB - 60 dB

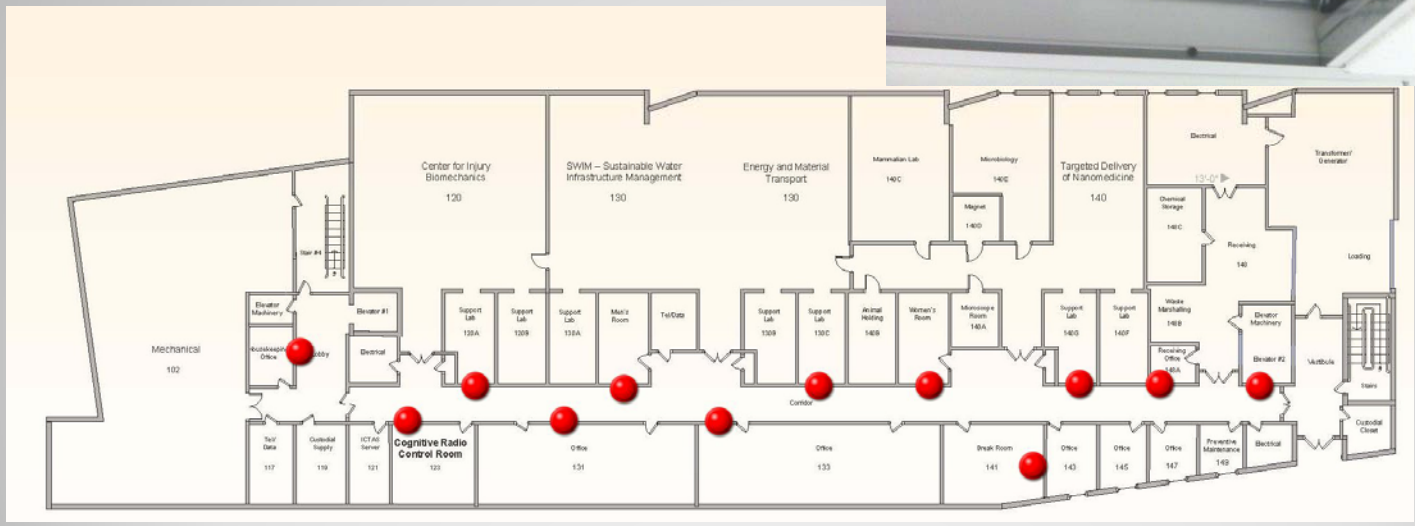
Host PC Servers

- Intel Xeon Quadcore 2.13 GHz
- 3 GB RAM, Gigabit Ethernet
- Upgradable to Intel Nehalem for future
- Much different from existing testbeds



Radio Node Locations

- RF portion is ceiling mounted in acrylic case
- Distributed above hallways in building



Testbed Applications

- Testbed Applications
  - Develop wireless systems on a practical medium size scale
  - Practical wireless environment -> Level past MATLAB
  - Emulate wireless systems and integrate new ones
    - Distributed CR operations
    - Spectrum Coordination
    - CR Network Security
    - Dynamic Spectrum Access Tests

Provides the platform for Rapid Prototyping Next-Gen CR Applications

Summary

- Adding simple intelligence to communications and networking enables a new set of capabilities.
- The impact is significant and has broad applicability across the OSI layers and hardware realization.
- Spectrum availability has dominated cognitive research to date, but automated radio resource management in general is the eventual "big payoff."