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CERDEC S&TCD Investigations into Cognitive Radio Networking

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Tim Leising, Acting Chief Engineer Communication Networks & Networking Division - US Army RDECOM CERDEC S&TCD

Briefing Outline

- CERDEC S&TCD — Products / Services
- Cognitive Networking — S&TCD Activities
  - CNEDAT: Cognitive Network Design Toolset
  - Virtual Ad-Hoc Network (VAN) Testbed
  - Cognitive Network Radio Platform (CNRP)

S&TCD Products and Services

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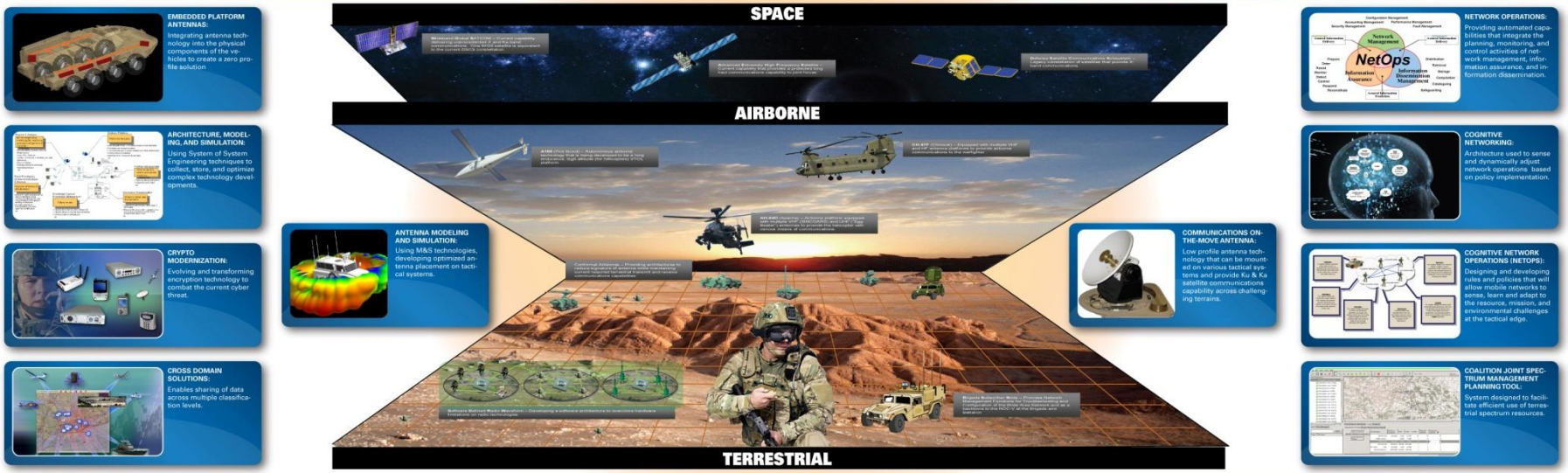

What We Do.

- *Develop and Transition Communication, Networking, and Cyber Security Technologies in Support of DoD Transformation*
- *Proactively Support LCMCs and Key Customers with Highly Qualified and Responsive Scientists and Engineers*
- *Provide System Engineering Capability (Integrated M&S, Architecture and Experimentation) to Support Current and Future Army and Joint Force Requirements*

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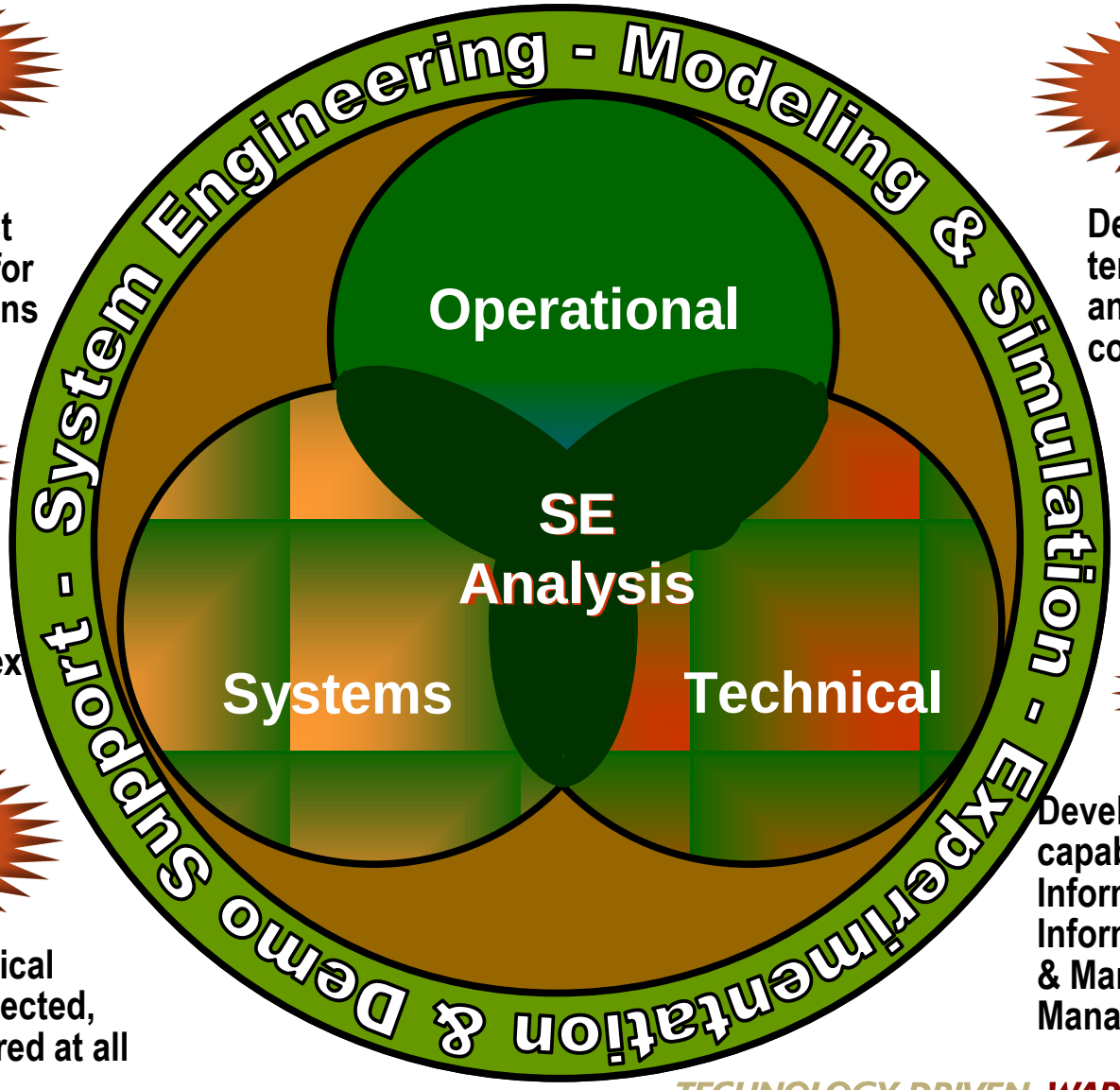
S&TCD Technology Thrusts



Antennas and Spectrum

Develop a family of highly efficient, cost effective antennas for OTM communications

Mobile Networking

Provides assured mobile networks that work in complex terrains

Cyber Security & IA

Ensure mission critical information is connected, available, and secured at all times

Wireless Transport

Develop efficient terrestrial, airborne, and space communications

NetOps

Develop automated capabilities that integrate Information Assurance, Information Dissemination & Management, Network Management

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Cognitive Networking Technology

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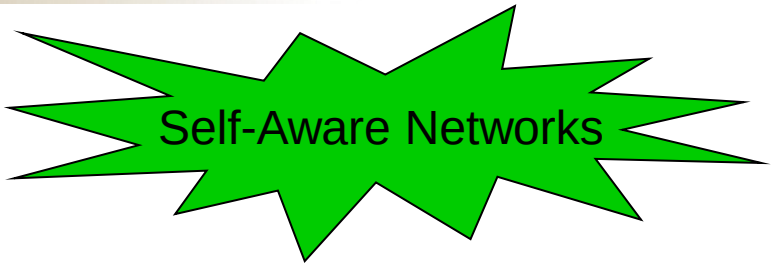
Network Design and Cognitive Networking Sciences VISION



- To employ Cognitive "***learning***" capabilities in both ***network management functions*** and software defined radios (***SDRs)*** to allow the tactical network to ***autonomously adapt*** to changing demands with ***less human intervention*** and provide a decisive tactical advantage to our warfighters
- To develop technical experts for developing cognitive capabilities that ***predict*** and ***optimize*** tactical ***network performance***

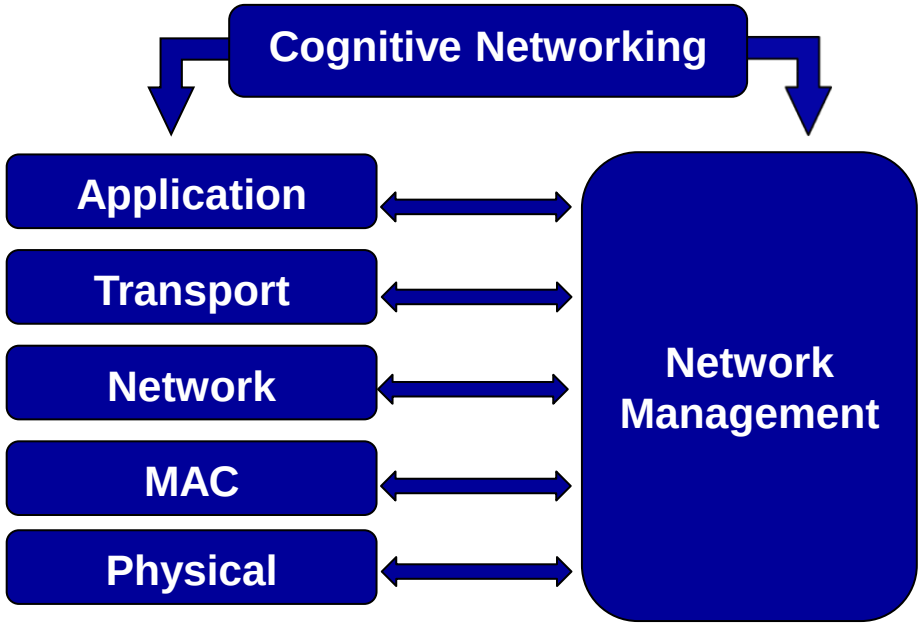
DOD's leading Cognitive Network Science Research, Development, Engineering and Technology Capability Provider

Cognitive Networking

- **Cognitive Networking Definition**: An application of **MACHINE LEARNING** algorithms to the communication network functions and protocols

Potential Cognitive Networking Functions

Application coding selection	MTU Size
Application Priority/ Precedence	Topology Control *
	QoS/Buffer Management
TCP connection management	TDMA Slot Assignment
Window Size/Flow Control	and Management
Network Routing *	Transmit Power *
Gateway Selection	DSA (Dynamic Spectrum Access)
Timer Management	Modulation/Coding/FEC
Neighbor Selection	
QoS Admission Control	
Estimation of delay, loss to be used with protocols	

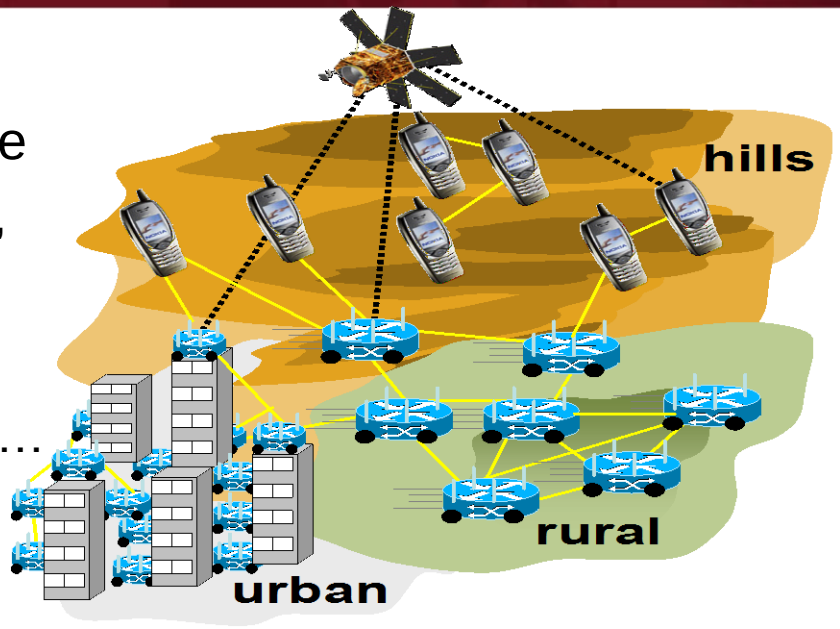


Learning algorithms can be applied to a component of an existing baseline protocol

* Prototyped and evaluated at E11

Problem Statement

- Future Force MANETs will be highly diverse
  - **Requirements**: capacity, survivability, loss, mobility, latency…
  - **Resources**: Radios, spectrum, energy, configurability,…
  - **Environments**: Urban, villages, rural, hills,…
  - **Protocols**: Traditional, Learning



- Need a capability to reduce complexity of designing robust network :
  - Optimize performance over mission phases
  - Provide rapid "what-if" analyses, prior to deployment
  - Exploits emerging cognitive (Learning) techniques to reduce Soldier Intervention
  - Reduce Time to Field and make efficient utilization of limited resources

CNEDAT: Cognitive Network Design Toolset

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Cognitive Network Engineering & Design Toolset Components

- Analytic Tool-Box
- Functional Models
- Learning
- Input Module
- Automated Design Manager
- Output Module

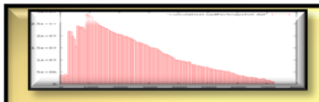
Inputs

Output

- Phase Transition Detection Module
- Subnet Design Module
- Waveform Assignment Module
- Capacity Estimation Module
- Topology Control (TC) Module
- Dynamic Spectrum Assignment Module
- Routing Module
- USAP MAC Module
- Automated Design Manager Module

Asset Info

Traffic & Mobility Info



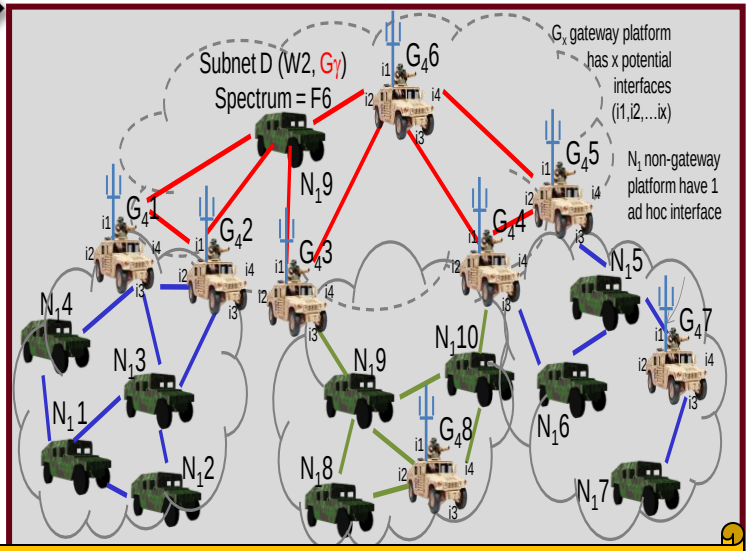
Design Objectives and Constraints

Interface to allow integration with DES, Emulation, Cognitive Radio

Cognitive Radios, DES**

madwifi project

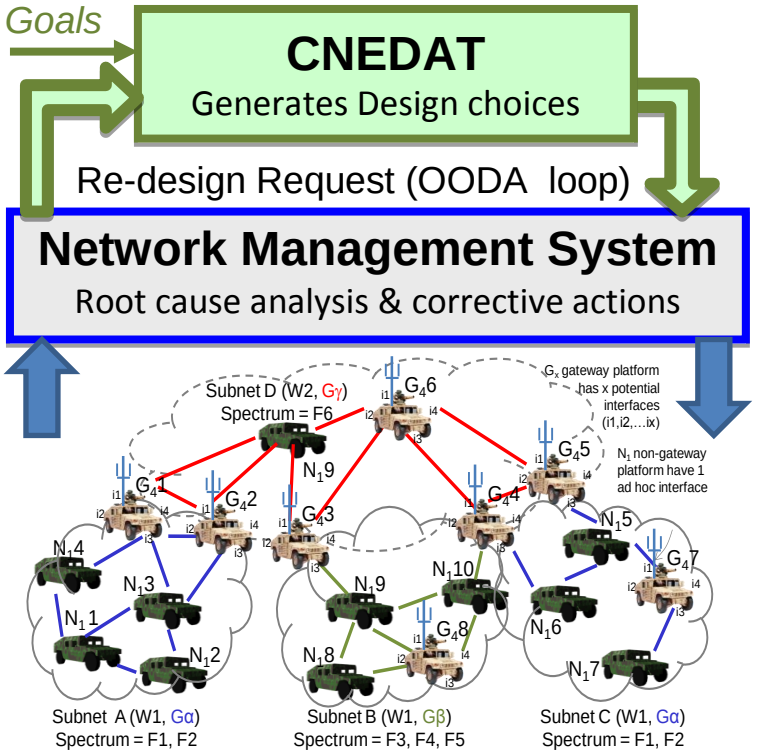
OPNET Making Networks and Applications Perform™



Offers Systematic Way to Design, Analyze and Maintain Robustness of future force MANETS of types envisioned in the Network Centric Warfare (NCW) paradigm.

CNEDAT Usability

CNEDAT User	Required Network Expertise	Example Scenario
Network Designer	High (Guru)	Understand cost & performance tradeoffs of cognitive vs. non cognitive design options and quantities & types of radios
Radio Developer	Medium-High	Compare different radio design options (e.g., MIMO modes or different filters) in their impact on network performance.
Tester and Evaluator	Medium	Understand performance tradeoffs with several configuration options prior to expensive field testing and evaluation.
Mission Planner	Medium-Low	Network design for a mission constrained by limited radios, available spectrum, and protocol choices.
Network Manager (see Figure)	Low	Network alarm cannot be fixed with existing design options (e.g., add subnets if platform dynamics cause too much routing overhead).



CNEDAT supports users from protocol experts (tweaking protocol knobs) to personnel with limited protocol knowledge.

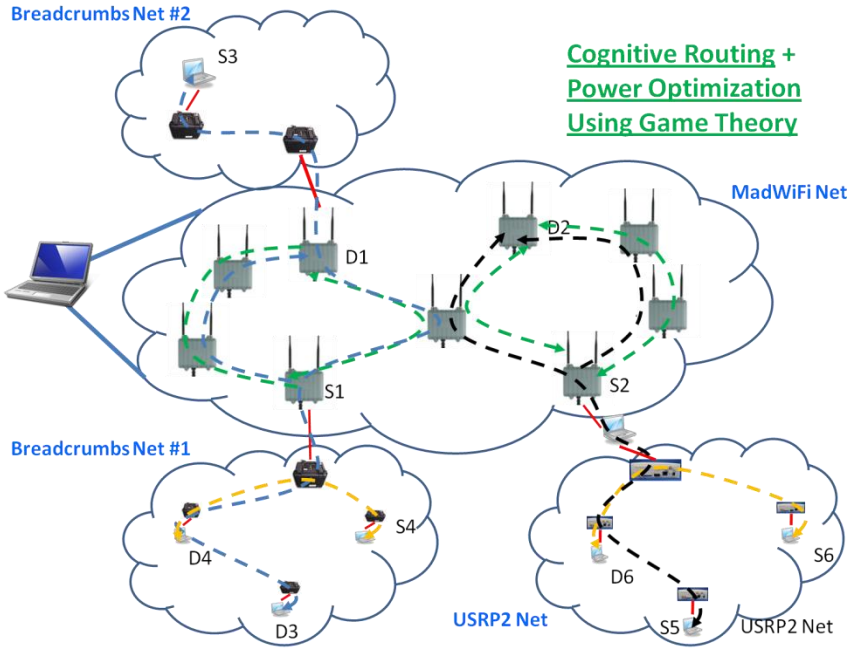
CANDE Experiment Overview

Objective

- Validate the predictions of key functions (Routing and Topology Control) of the CNEDAT tool with measured results from an outdoor environment

Network Architecture

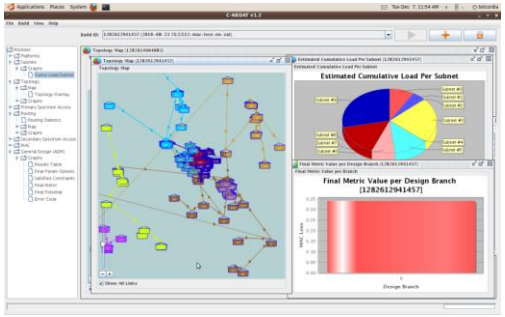
- CANDE experiment utilized 19 node network consisting of multiple subnets and radio types
- Various Load on the Network
- Different Network topologies



Network Architecture

Testing

- Cognitive Routing using Reinforcement Learning
- Cognitive Topology Control using Game Theory
- Non-cognitive implementations as well, i.e OLSR, and Load Aware Routing



Screenshot of CNEDAT

BC Node

Testing Area Range LZ3

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SPACE AND TERRESTRIAL COMMUNICATIONS DIRECTORATE
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Virtual Ad hoc Network (VAN) Testbed

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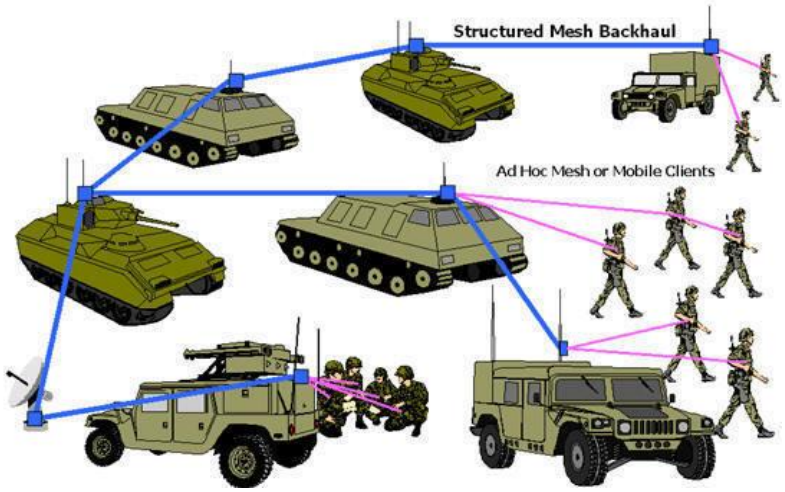
VAN Program Overview

- **V**irtual **A**d hoc **N**etwork (VAN) Testbed
  - Network virtualization via high fidelity simulation
  - Software is tested “as-is” without code modification
- VAN testbed R&D is funded by **OSD NCCP**
  - Started in 2008, intended for the R&D community
  - Army CERDEC S&TCD NetOps is PM
  - Telcordia is the contract performer
  - Two testbeds are up and running

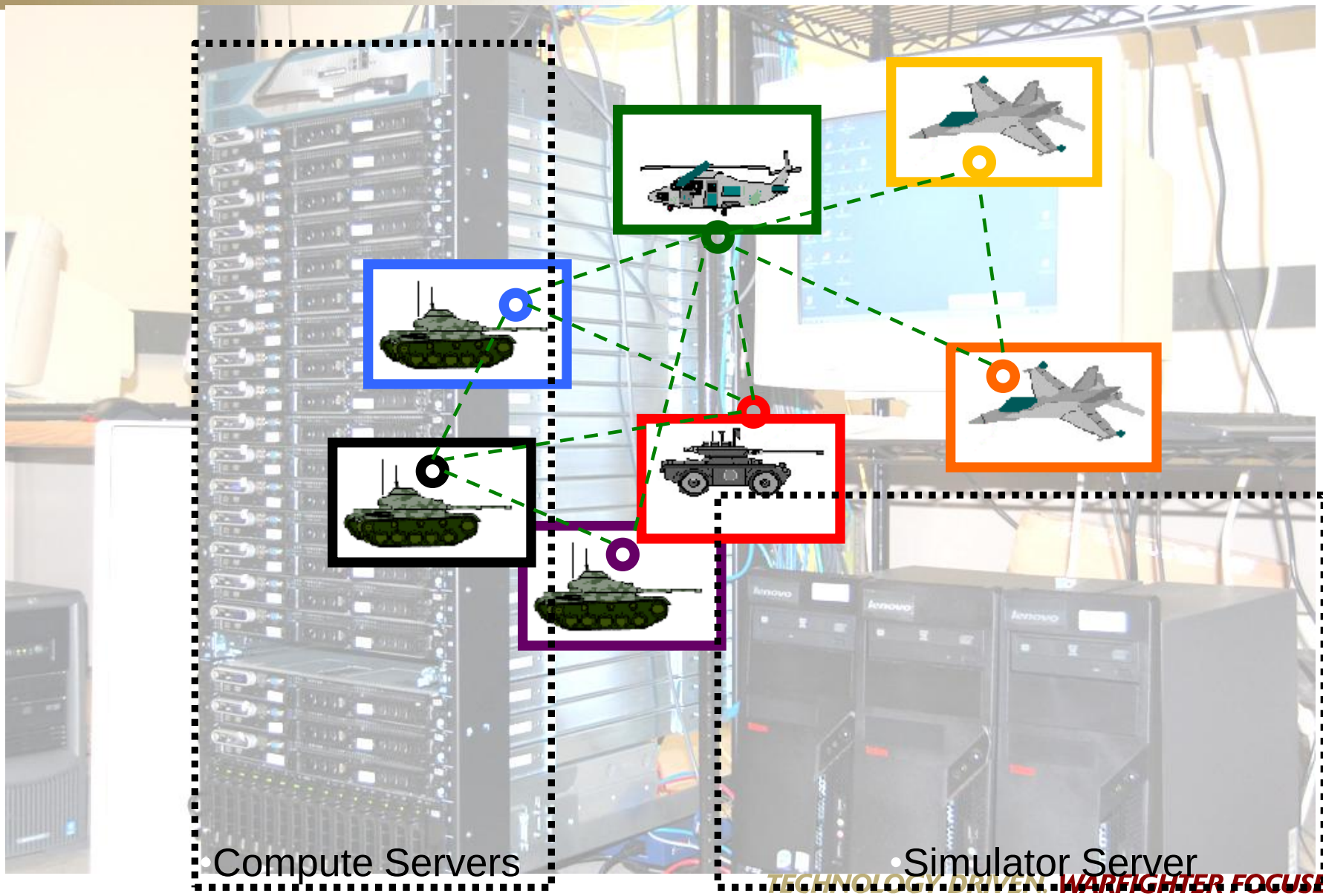
You are invited to join the VAN user community!

Motivation

- Testing applications for mobile ad hoc networks (MANETs) is difficult because:
  - Mobile ad hoc networks are expensive and difficult to experiment with, due to mobility and network dynamics
  - Many military radios have either not yet been built or are not available for experimentation; however, high-fidelity simulation models of the waveforms do exist



Realizing Network Virtualization



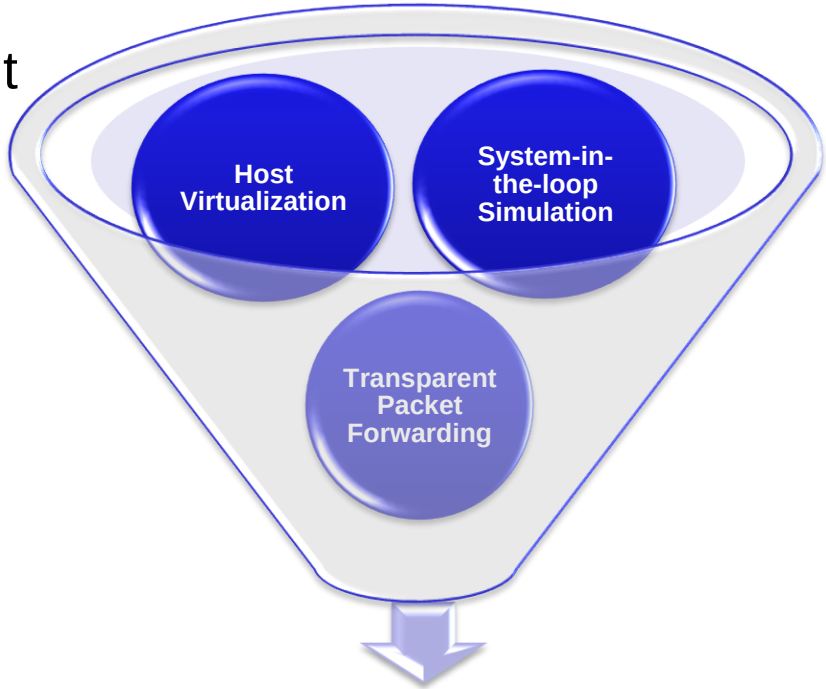
Major Innovations

- Extended concept of host virtualization to network virtualization
  - Create a high-fidelity virtual network test bed by enhancing Xen and system-in-the-loop simulation (OPNET & QualNet)
- Designed a seamless transparent packet forwarding mechanism
  - Gluing technologies together as a working solution
- Streamlined testbed management
  - Enhance resource utilization and reduce time needed for various testbed operations
- Large-scale testing support
  - Introduce a common virtual clock synchronizing time on all testbed components

Seamless Integration

Objective: **Test any application code as is on their native operating systems over a virtual mobile wireless (ad hoc) network**

- VAN represents a unique combination of technologies: host virtualization (XEN), SITL simulation, and transparent packet forwarding (Telcordia)
  - Host virtualization permits testing applications “as is”, allows flexible deployment and simple integration
  - SITL simulation permits use of arbitrary OPNET/QualNet simulation models for setting up test network scenarios
  - Transparent packet forwarding enables seamless conjunction of VMs with simulated nodes to construct a virtual network



VAN Testbed

Host Virtualization

A Quick Overview

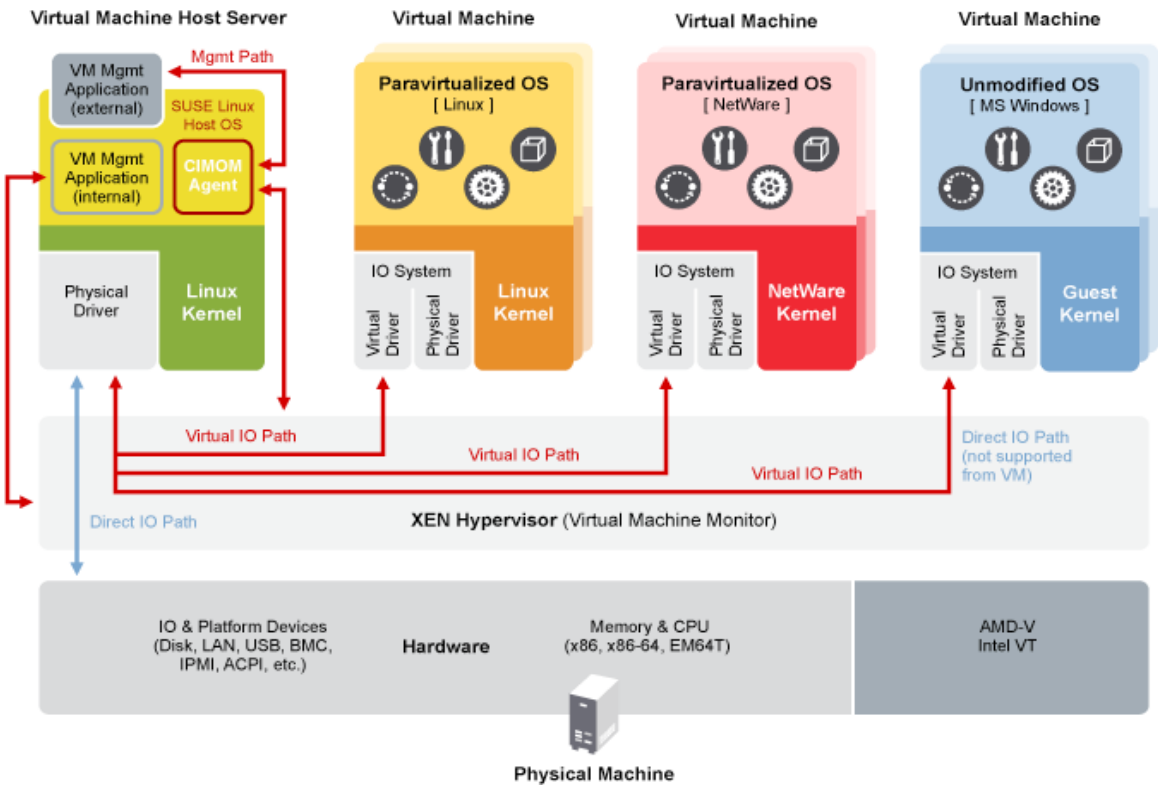
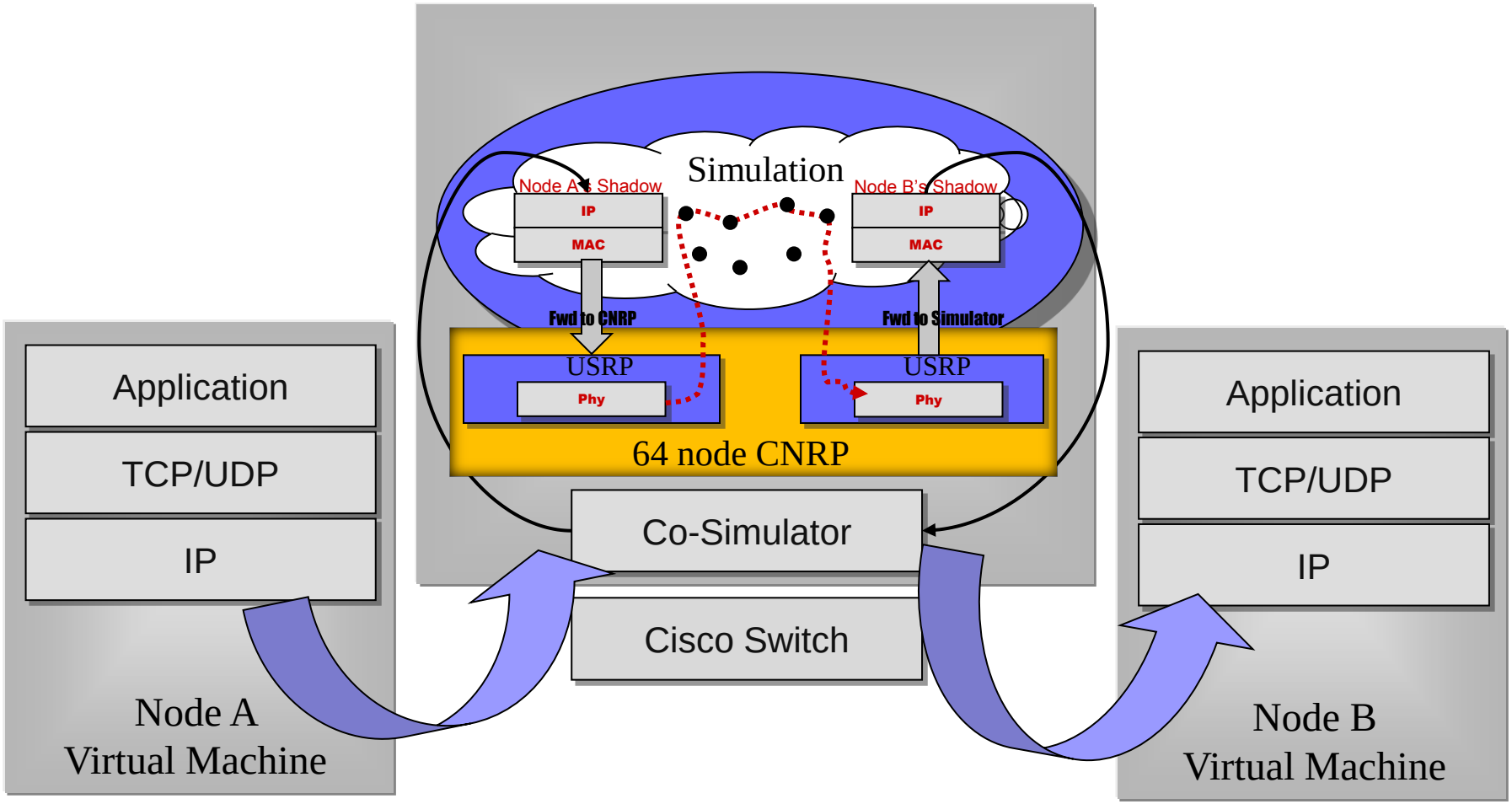


Illustration of XEN virtualization architecture
www.novell.com

- Host virtualization (e.g., Xen) enables simultaneous running of multiple OS virtual machines on single hardware
  - Each VM runs its OS over hypervisor, no different than directly running over its own physical machine
  - VMs share physical resources on their hosting machine
  - Enhances resource utilization
  - Enables remote hosting (cloud)
- **Although Xen provides a variety of configuration primitives, it lacks the ability to manage virtual network resources to enable network virtualization across Xen platforms**

Therefore, we developed a virtual network management solution on top of Xen.

Scaling VAN With Hardware in the Loop



Summary

- VAN testbed supports mobile ad hoc network application testing and evaluation by "***bring field environment characteristics into a laboratory testbed***"
- VAN has successfully been used for testing U.S. Army software such as ***FBCB2/JCR***
- For more information visit:
  - ***https://www.milsuite.mil/wiki/Virtual_ad_hoc_network***
  - ***https://www.intelink.gov/wiki/Virtual_ad_hoc_network***

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Cognitive Network Radio Platform (CNRP)

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Cognitive Networking Radio Platform (CNRP) Purpose

To develop a DSA / Cognitive Networking Radio Platform to promote research and development of Cognitive Networking technology to include algorithms, software, and devices by offering a host platform and test bed to facilitate rapid development and testing

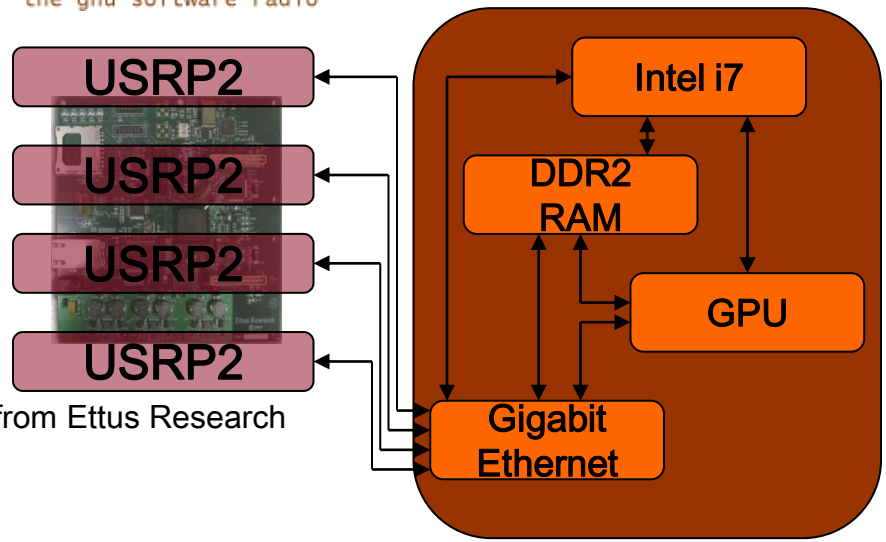
- Operation of DSA Radio systems using actual SDR Platforms
  - Validate or challenge modeling and simulation results
- Rapid prototyping development and test environment to enable performance evaluations of experimental algorithms
- Evaluation of a complete DSA or Cognitive Radio systems by operating one or several algorithms simultaneously to provide a full radio system
- Analyze DSA Radio network performance, scalability, and overhead when radio network sizes are increased up to 64 nodes
- Examine DSA co-existence impacts on radios and waveforms such as SRW, SINCGARS, EPLRS, and other tactical radio systems
- Establish remote management capabilities through the Defense Research Engineering Network (DREN) to allow remote and distributed tests with other organizations

64 Node GNU Radio Experimentation Platform

Advantages

- Rapid Prototyping Through Higher Level C Programming
- Spectrum Coverage from 50 MHz – 2.2 GHz with 25 MHz Wideband Channels
- Utilizes Conventional Desktop Computers for SDR Processing
- 64 Nodes Permit SDR/CR Network Simulations and Over the Air Realizations
- High Performance Processing Available from Graphics Processing Units
- Enables Spectrum Capture and Playback for repeatable tests
- Can be as RF Front End to COTS FPGAs/DSPs

GNU Radio
the gnu software radio



Leverages COTS Low Cost SDR Hardware

- Uses open source GNU Radio Software Environment
- Universal Software Radio Peripheral 2 (USRP2) SDR Platform from Ettus Research
- Conventional Desktop PCs
- Intel Core i7 With HyperThreading
- Dedicated 4 Port Intel Gigabit Ethernet NIC
- USRP2s in an RF Network Use Coaxial Cable and RF Combiners/Splitters

64 node GNU Radio Experimentation Platform

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64 node Platform Offers Advanced Wireless Communications Research through Over the Air Testing and Hardware In Loop Simulation

Accomplishments

- DARPA XG Dynamic Spectrum Access Algorithm Scalability Testing with John Hopkins University, Demonstrated a 3 Node Scenario
- 40 Node Wireless Network Using GMSK 1 Mbit/s links
- Developed Initial Control Application Operational Capability
- Client / Server Architecture through DREN Enables Remote Collaboration across CERDEC, NRL, and AFRL

Planned Experiments

- DARPA XG DSA Algorithm Scalability Testing Beyond 3 Nodes
- Cognitive Radio Reasoner Over the Air Network Tests
- Wireless Networking Up to 64 Nodes

Promotes Cognitive Networking and SDR Technology Research by leveraging flexible yet low cost GNU Radio software and hardware projects

DSA / Cognitive Radio Experimental Algorithms

DSA Algorithms

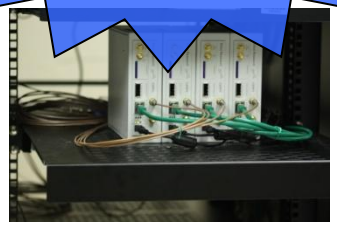
Spectrum Sensing Algorithms

Unified Cognitive Radio Architecture Specification

Learning Algorithms

Reasoning Algorithms

64 node GNU Radio Experimentation Platform



A standardized Cognitive Radio Platform to Host Developmental Algorithms for Evaluation and Demonstration

Enables Technical Comparisons of Third Party Algorithms From Industry, Government, and Universities

64 Node Experimentation Platform Hardware Installation

USRP2s Installed in the 64 Node Testbed

CNRP Rack

Cognitive Radio Testbed With Legacy Radio Systems

PRC-148s

DSA Enabled Radios

SSC DSA-2100s

PRC-152s

HF

Legacy Radios

EPLRs

SINCGARS

PRC-117Fs

64 node GNU Radio Platform

Evaluation of Dynamic Spectrum Access Systems Coexistence With Legacy Radios

CNRP Way Forward

Continue to establish a unified test platform for DSA / Cognitive Radio Technology development and testing

- Implement a TDMA MAC to augment the already available CSMA
- Identify performance relationship of various spectrum sensing methods when operating in varying sensing bandwidths, silence frame durations, and channel bin size
- Examine network scalability and overhead associated with a centralized Master / Subscriber DSA Radio Network
- Integrate legacy radio systems and characterize performance when co-exisiting with DSA / Cognitive Radio Systems
- Implement and identify Cyclostationary Feature detection performance vs. computational trade offs
- Expand 64 Node testbed to include distributed tests with other research organizations using network attached USRP2s to simulate separate subnets

Advancing Cognitive Radio through Continual Technology Insertion Enabled By Rapid Development and Testing