



Spectrum Collaboration Challenge (SC2) ***Colosseum***

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Where This Talk Fits in the Overall Workshop



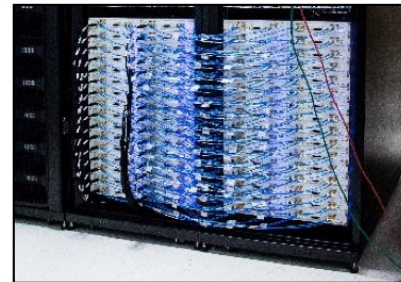
Spectrum Collaboration Challenge – Challenges

Collaborate Without Co-Design



Create radio networks that work with others without knowing how they "think"

Engineer Emergent Effects



Discover and solve issues that only arise in large-scale realistic settings

Communicate Without Constraints

too specific

too general

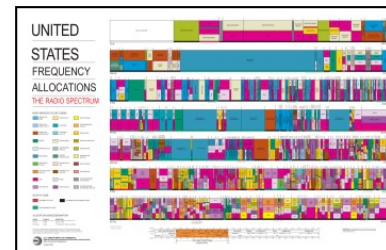


frame 15, slot 7



Create a protocol that supports evolving new forms of collaboration

Evolve The Ecosystem



Change radio design, applications, and spectrum management to enable and leverage collaboration.



Thumbs-up image source: <http://sr.photos3.fotosearch.com/bthumb/CSP/CSP880/k8803233.jpg>
Pencil image source: <http://www.pngall.com/wp-content/uploads/2016/03/Pencil-PNG.png>

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Colosseum – Motivation

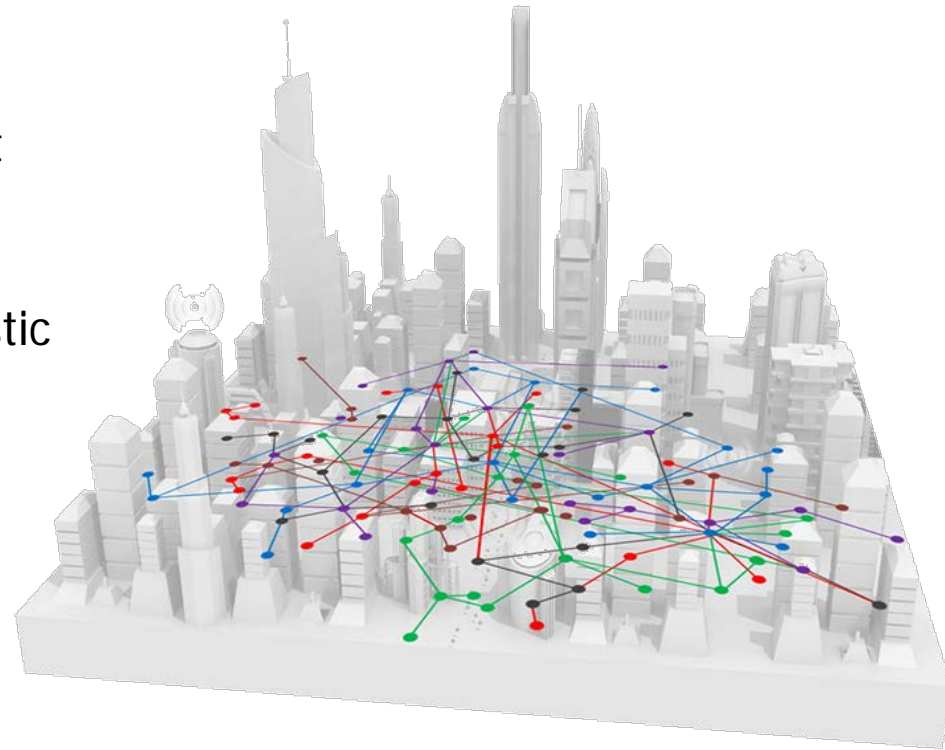
A Colossal research environment for next generation collaborative radio technology.

Motivation:

- Can't test ensemble learning without deploying large scale networks
- Can't test emergent and learned behavior without a repeatable, realistic experimentation testbed
- Current state-of-the-art testbeds are geared toward handset/link testing

Colosseum Provides:

- World's largest channel emulator
- Extensive Software Defined Radio (SDR) resources
- Realistic Wireless Scenarios
- Robust testbed infrastructure



Source: courtesy of DARPA

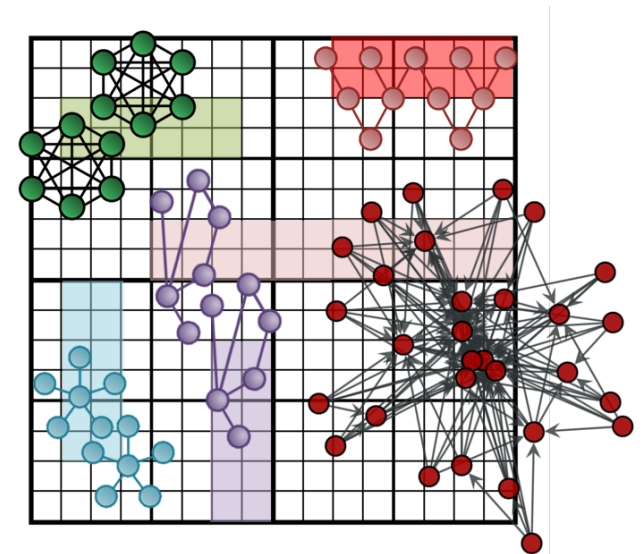
What does SC2 need from a Colosseum?

Channel Emulator Characteristics:

- Host a broad range of SDR designs
- Accommodate real radio hardware
- Provide repeatable environment (RF, traffic, etc.)
- Support large scale testing, e.g., lots of radio nodes
- Offer a variety of time-varying RF environments
 - Propagation: LOS, multipath, intermittent blockages
 - Interference: Noise, coexisting RF systems

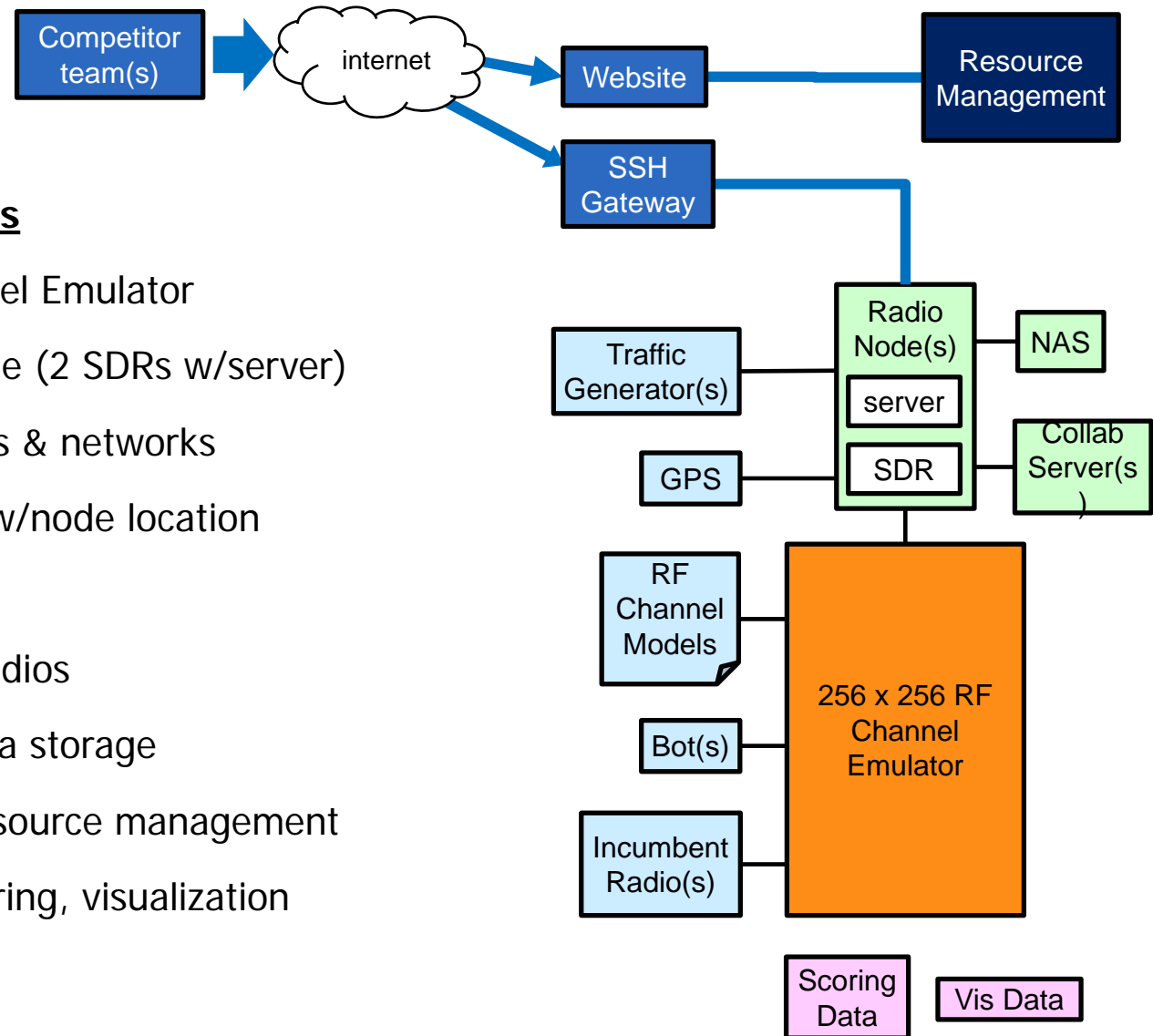
Concept of Operations: Remote shared access via internet to experiment at any time from anywhere without human intervention

- Self-contained, flexible radio definition
 - All layers, physical to application
 - Minimal constraints on design
- Broad range of experiment design choices
 - RF channels – user-designed or rich menu of pre-designed scenarios, fixed or mobile
 - Network size and complexity
 - IP traffic – menu of types and flows
 - Co-existing RF systems
 - Scrimmage partners (bots)



Source: courtesy of DARPA

RF Channel Emulator is Not Enough ...



Colosseum Functions

- 256 x 256 RF Channel Emulator
- 2x2 MIMO radio node (2 SDRs w/server)
- Collaboration servers & networks
- RF channel models w/node location
- IP traffic
- Bots & incumbent radios
- Experimentation data storage
- Remote access & resource management
- Event support – scoring, visualization

The Worlds Largest RF channel emulator

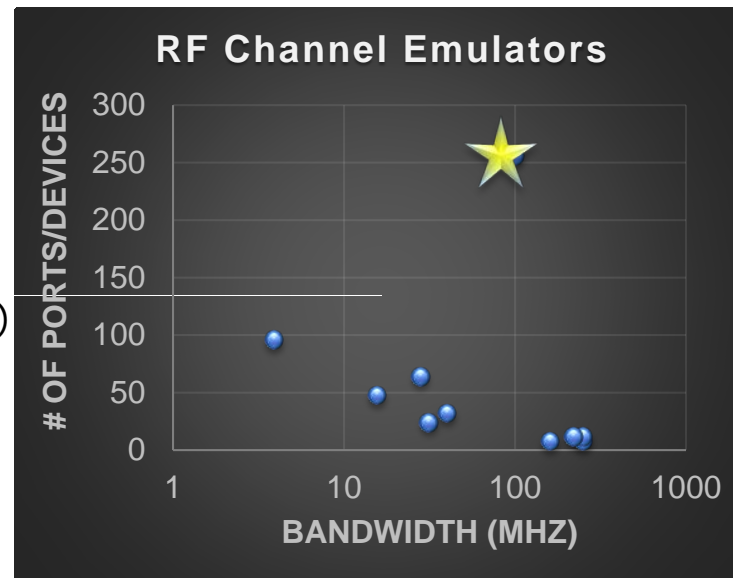
Massive Channel Emulator provided by Ettus Research, a National Instruments Company, with the largest number of ports of any emulator in the world.

It's Really Big

- 26 GHz total instantaneous bandwidth
- 100MHz per channel X 256 X 256
- Full-mesh capable
- 52 TB/s of digital RF data
- 1.9 TB of RF scenario model data (30min)

Specifications

- 128 2x2 MIMO Tx/Rx Ports
- Phase Coherent
- Bandwidth: 80 MHz
- Tunable: 10 MHz to 6 GHz
- 4 tap PDP emulation
 - (10ns resolution, 5us max delay, 1 kHz update rate)



Source: courtesy of DARPA

**1 Quadrant
(32 Radios)**



Standard Radio Node (SRN) Overview

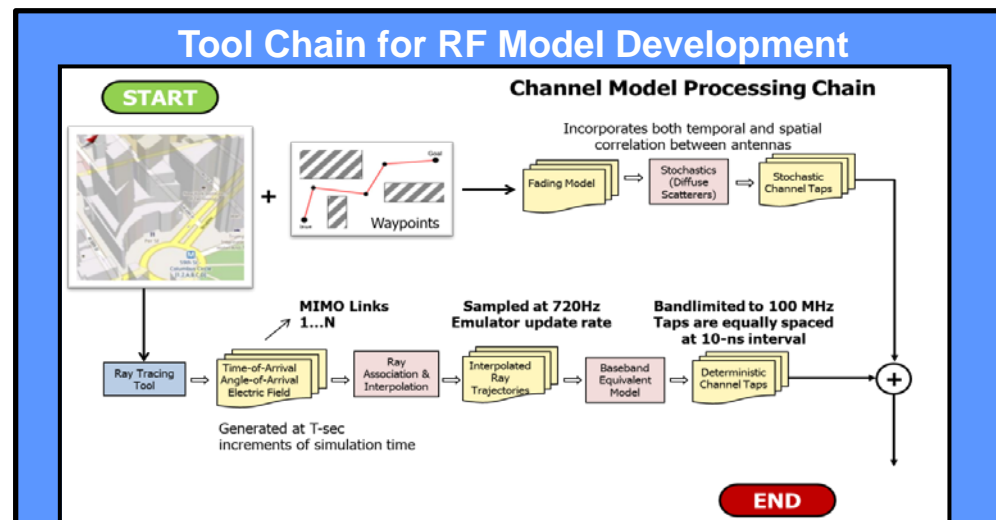
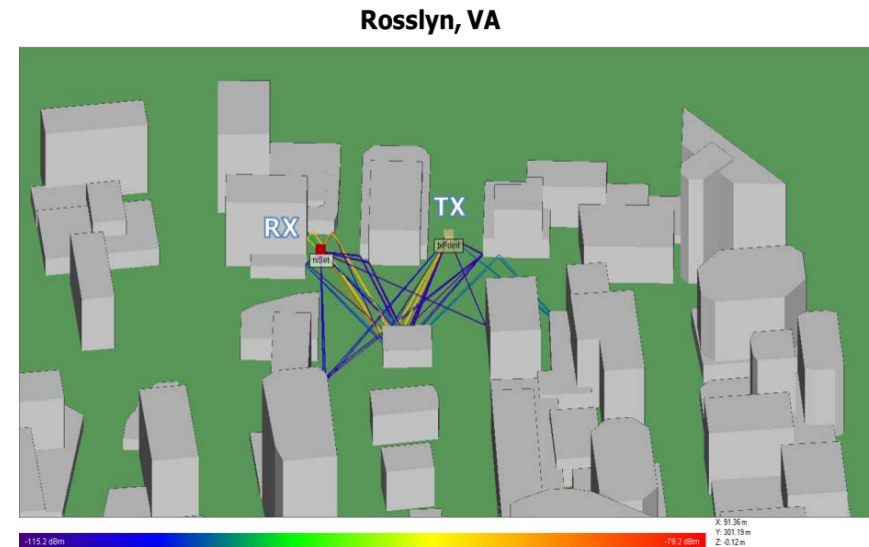
Standard Radio Node (SRN) provides ample heterogeneous computing environment platform for experimentation

- **High-capability radio computing**
 - National Instruments X310 SW Defined Radio (USRP)
 - Kintex 7 FPGA
 - 2 Channels x 160MHz Bandwidth
 - Dell R730 Server
 - Tesla K40M Graphics Processing Unit (GPU)
- **Safe development & experimentation**
 - LXC containerized environment isolates competitor from host OS
 - Simplifies application deployment - competitors upload containers with their code
- **Flexibility through rich set of provided development capabilities**
 - GNU radio
 - Freedom to use language of choice: C/C++, Python, GR, x86 assembly ...
 - Standard libraries for interfacing with the outside world

Design and run experiments via Scenarios

RF Channels Model

- Based on physical environment
 - Nodes – location and motion
 - Dynamic propagation environment – obstructions, multipath
- Site-specific channel models based on RF ray tracing
 - Incorporate node motion, obstructions
- Multipath fading incorporates temporal and spatial correlation between antennas
- Standardized format eases use in Colosseum



Design & run experiments via Scenarios Traffic, etc ...

GPS Location data

- Radio nodes receive GPS data streams consistent with motion seen in emulated RF channels

IP Network traffic generation

- Fully-scripted TCP & UDP traffic generation via NRL's MGEN emulate variety of applications – video, VoIP, internet browsing
- Controllable Quality of Service and traffic patterns
- Closed-loop performance measurement for self-eval and scoring

Incumbents

- Virtually any radio hardware can be integrated via simple RF interface
- SW defined incumbents provide variety of additional possibilities (e.g. LTE)

Bots

- SRN-hosted radio w/adaptive & collaborative capability facilitates practice

Collaboration Network

- Out-of-band back-channel for machine-machine spectrum coordination
- Incorporates impairments (throughput and latency) expected in real world
- Simultaneous instances to allow multiple matches

Competitor Support: Research and Practice

Reservation System allocates resources

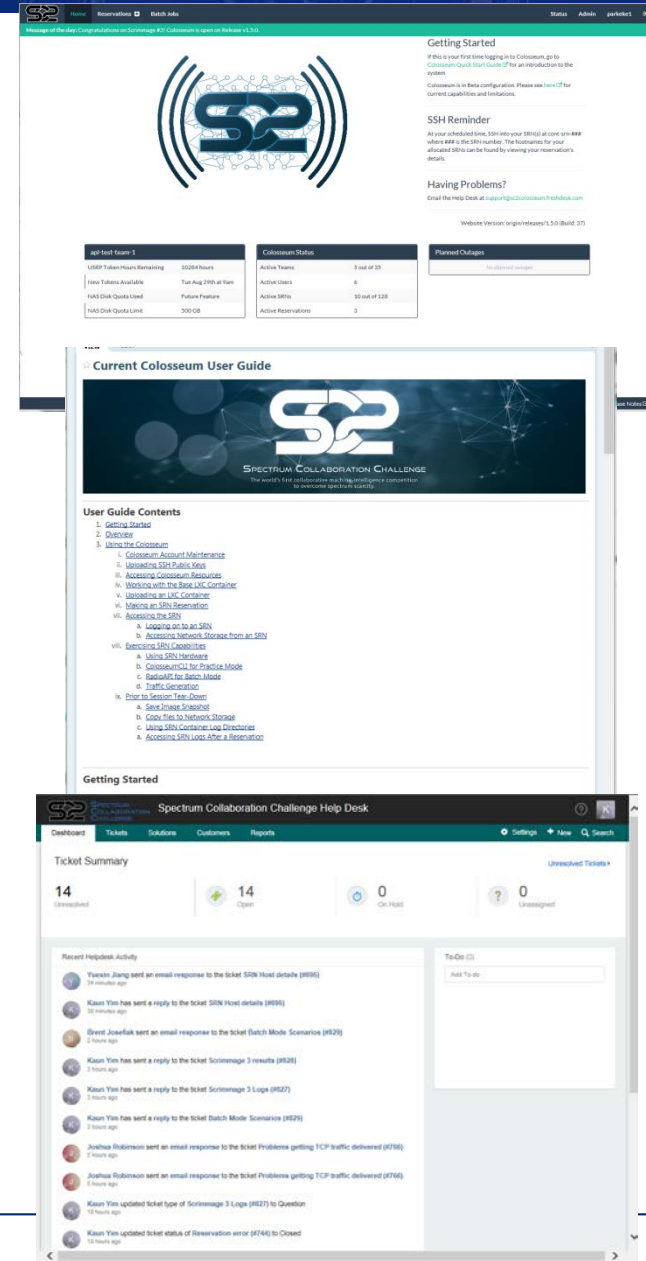
- Made through Colosseum website, specify number of nodes and scenario
- Each reservation results in unique physical nodes (SRNs), “cleaned” after each use
- Token-based for fair sharing, 24x7

Two Modes of Operation

- Development/Debug (Interactive mode)
 - Control experiment in real-time via command line interface with node(s) and Scenario
 - Automatic node shutdown & log storage at end of reservation
- Large scale testing (Batch mode)
 - Autonomously-run experiment with no operator involvement
 - Start time dictated by “fair” queue
 - Automatic node shutdown & log storage at end of test

Extensive on-line help & Reference

- Wiki pages
- Help Desk
- FAQ

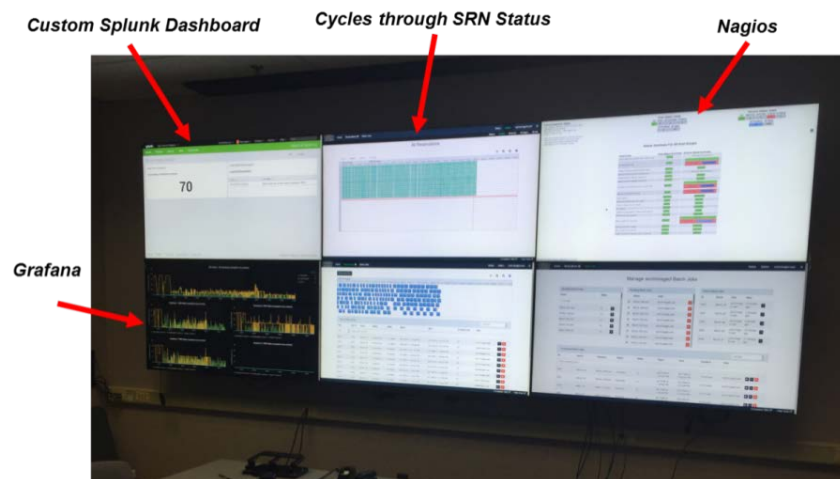


Operating 24 x 7 x 365

- Continuous Health & Status Monitoring
 - Hardware – power draw, fans, CPU utilization, disk space
 - Software services and applications
 - Competitor Operation
 - Website accessibility
 - “Canary” radio nodes to ensure RF flow
- Short weekly Maintenance Periods
 - Push new features & software patches
- UPS backup to sustain short power outages

Event Management & Execution

- Competitors submit radios (e.g., “containers”)
- Government plans matches – participants, scenarios, duration
- Colosseum operates normally EXCEPT when:
 - Web access cut-off from competitor teams
 - Automated process forms and runs (unattended) queue of successive batch tasks for predefined matches
- Visualization, scoring, and team data saved to NAS at end of each match
 - 6.6 TB for last scrimmage (220 matches, 16x16 nodes each)
- Competitor logs and results distributed later



Colosseum display wall provides SA on scrimmage execution

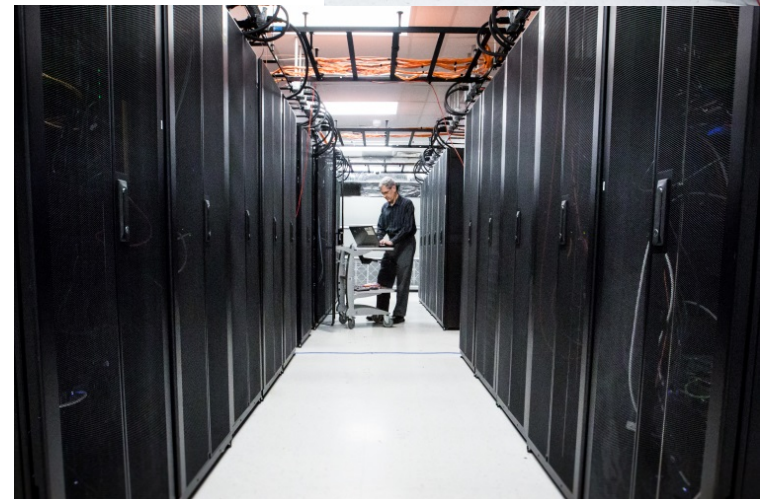
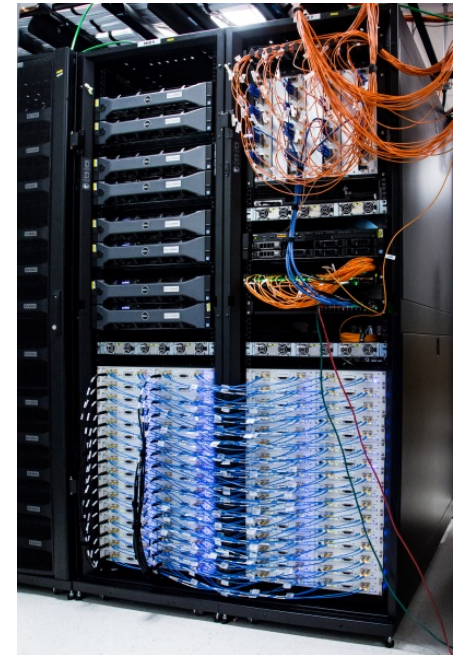
Summary

- World's largest RF testbed for large-scale network experimentation
 - Largest number of nodes
 - Wide channel bandwidth
- Rich set of capabilities supports repeatable, operationally-relevant experiments
 - High-capability Standard Radio Nodes for flexible SDR-based radio design
 - Realistic RF channel emulation based on physical environment
 - Variety of IP traffic models
 - Interference and incumbent systems for added realism
- Robust infrastructure enables experimentation 24 x 7 x 365 from anywhere via internet
 - Reservation-based interactive and batch operation
 - Extensive on-line help and reference

BACKUP

It Takes a Data Center ...

- Lots of hardware
 - 900 TB of Network Attached Storage (NAS)
 - 171 high-performance servers
 - 256 USRPs
 - 18 10G switches
 - 19 clock distribution systems
 - 100's high-speed optical connections
- Dedicated facility
 - 21 racks in 20'x40' equipment room
 - 40 ton HVAC
 - 65 kW, 208/120 VAC 3 phase for equip alone
- ~3 Full-time staff to operate
 - System administration/hardware maintenance
 - Monitoring and fault recovery
 - Manual intervention for special operations





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