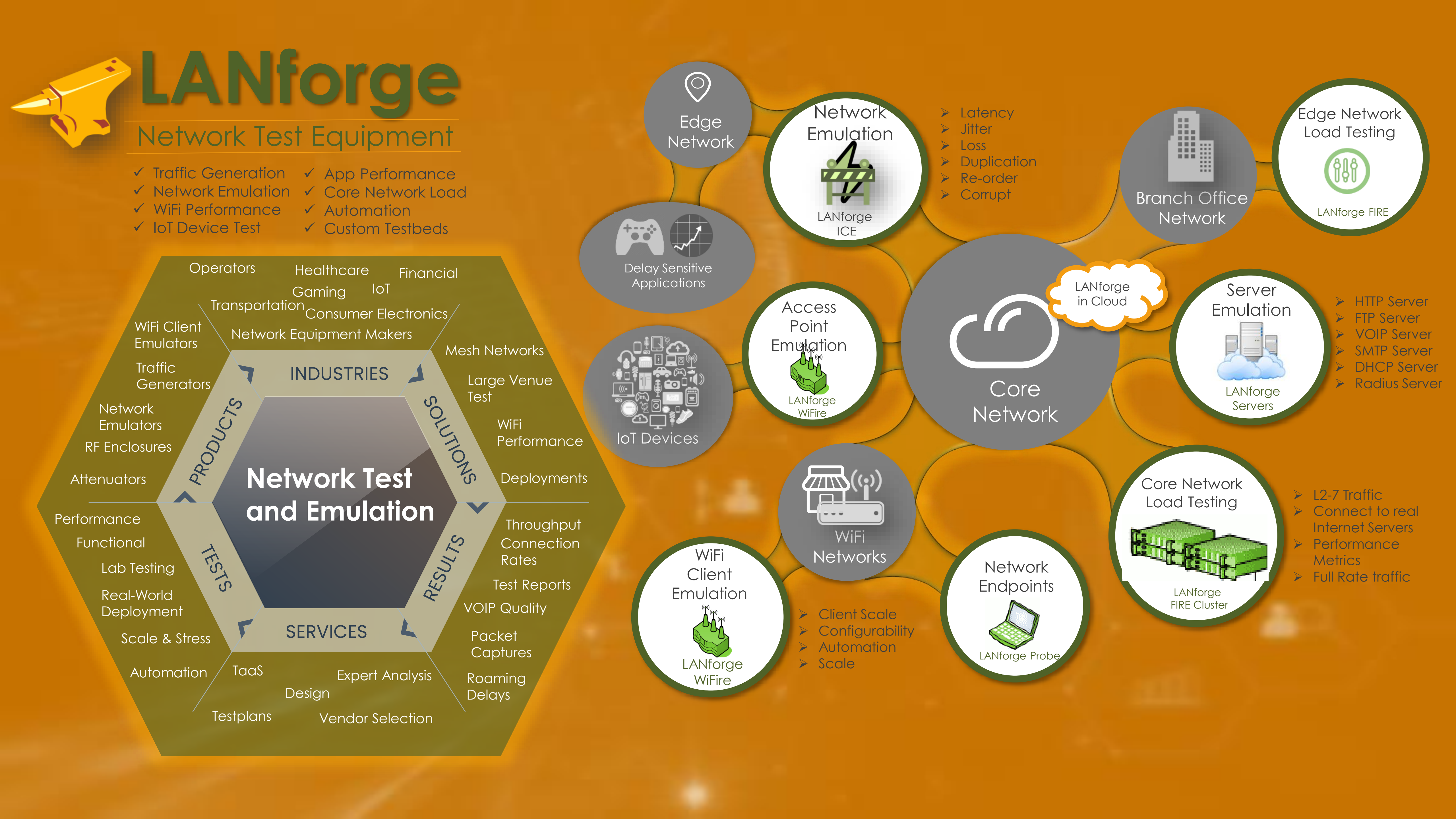
Network Testing & Emulation Solutions

- Founded in 2000
- Focus on Network testing and Emulation Solutions
- WiFi test solutions since 2006
- Team of Networking Technologies and Firmware Experts
- Helping over 200 customers, design, develop and deploy high quality networking products

sales@candelatech.com
1-360-380-1618

Candela Products & Solutions Overview


LANforge
Network Test Equipment
✓ Traffic Generation
✓ Network Emulation
✓ WiFi Performance
✓ IoT Device Test
✓ App Performance
✓ Core Network Load
✓ Automation
✓ Custom Testbeds
Operators
Healthcare
Financial
Gaming
IoT
Transportation
Consumer Electronics
Network Equipment Makers
WiFi Client Emulators
Traffic Generators
Network Emulators
RF Enclosures
Attenuators
Mesh Networks
Large Venue Test
WiFi Performance
Deployments
INDUSTRIES
PRODUCTS
SOLUTIONS
Network Test and Emulation
TESTS
RESULTS
SERVICES
Performance
Functional
Lab Testing
Real-World Deployment
Scale & Stress
Automation
Throughput
Connection Rates
Test Reports
VOIP Quality
Packet Captures
Roaming Delays
TaaS
Expert Analysis
Design
Testplans
Vendor Selection
Edge Network
Network Emulation
LANforge ICE
Latency
Jitter
Loss
Duplication
Re-order
Corrupt
Branch Office Network
Edge Network Load Testing
LANforge FIRE
Delay Sensitive Applications
LANforge in Cloud
Access Point Emulation
LANforge WiFire
Core Network
Server Emulation
LANforge Servers
HTTP Server
FTP Server
VOIP Server
SMTP Server
DHCP Server
Radius Server
IoT Devices
WiFi Networks
Core Network Load Testing
LANforge FIRE Cluster
L2-7 Traffic
Connect to real Internet Servers
Performance Metrics
Full Rate traffic
WiFi Client Emulation
LANforge WiFire
Client Scale
Configurability
Automation
Scale
Network Endpoints
LANforge Probe

SOME CUSTOMERS

Network Equipment Makers

Cisco, PacStar, meter, Relay2, altice labs, Mist (A Juniper Company), ekinops, Sequans Communications, Netgear, NetApp, Fortinet, alvarion (a SuperCom Company), Edgewater Computer Systems, Inc, Aricent, ABB, ZyXEL, Starry, Dejero, Davolink, cradlepoint, Brocade, eero, Ruckus (an ARRIS company), Nokia, SMART/RG (An ADTRAN Company), CommScope, ARRIS, Alcatel·Lucent, Huawei

IoT/Wireless Device Makers

dyson, Sony, Panasonic (Panasonic Avionics Corporation), Samsung, gogo, Dejero, iRobot, Innotech-Execaire Aviation Group, Jungo Connectivity, Thales, Motorola, Blizzard Entertainment, ndm systems, H&M (Henkels & McCoy), Dasan, Jet Aviation (A General Dynamics Company)

Chip/Module Vendors

Qualcomm, Compex, CSR, altair semiconductor, Askey, Huawei

Service Providers/Operators

TOT (Telecom of Thailand), Charter Communications, Telus, sky, Optus, true, Comcast, CenturyLink, Vidéotron, bright house networks, CableLabs, Rogers, Telefónica, Bell

Government and Large Enterprises

facebook, सी-डॉट C-DOT, United Airlines, Department of Defense United States of America, DCU, Daimler, 國立交通大學 National Chiao Tung University, Middlesex University London, VT Miltope, USI, University of Waterloo, Department of Justice, Varian medical systems, Communications Security Establishment Canada, EMS Technologies, arcadyan

Recent Customers

- Meta
- SpaceX
- Comcast
- Qualcomm
- Commscope
- Cisco
- QACafe
- Commscope
- Eero
- CACI
- Adtran
- Citrix
- NetApp
- Starry
- Sony-san-Diego
- Raytheon-IIS
- Sierra Wireless
- Telus
- Panasonic

- Charter
- Telnet networks
- Imco-manassas
- Qnet
- Haivision
- GogoAir
- Sony
- Net experience
- ViaSat
- Assured Networks
- Sterling
- Unwired
- Tessco
- Action
- smartrg.com
- Tactical Coms
- magic leap
- Brinker
- Oceaneering

- FCS
- LDC
- Cisco
- Ddsoftware
- Optus
- Palo Alto
- Casepoint
- Raytheon
- tierney-strachan.co.uk
- sos-software.com
- Matthew Shelden
- Rockstar games
- Nortek-control
- chevron.com
- Onemediallc
- sea-machines.com

- Sky UK
- Tele2
- Ekinops
- Samsung
- FreeBox
- Altice
- Samsung
- Vestifi
- smart-e-tech.de
- NordicLAN
- rdt.co.il
- Intel
- Intelsat
- Dyson
- Philips
- NetModule
- Deutsche Telekom
- Dekra

- Airtel
- Reliance
- Netgear
- Qualcomm
- Netgear
- Commscope
- Capgemini
- Cisco
- Relay2
- Comcast
- Technicolor
- NetApp
- HFCL
- CDOT
- Arista
- TataElxsi
- Thinkpalm

- Sony
- True Wireless
- TOT
- 3BB
- FPT
- Huawei
- Qualcomm
- LinkWen Electronics
- Commscope
- Belkin
- Optus

Over 350 customers in the last 10 years

Test Engineer

Key Careabouts

Comprehensive Test Coverage

Cover all tests in the WiFi test plan

Accurate Measurements

Accurate measurements with very little margin of error from the test tools.

Highly Repeatable Test Environments

Highly repeatable test results that can eliminate all variables except the DUT

High Degree of Automation

Run 100s of test cases fully automated at one push of a button.

Intuitive and Easy to Use Tools

Easy to configure and run tests, easy to interpret results.

Key Insights and Expert Analysis

Get key Insights and expert analysis and diagnostics when issues are found with the DUT.

WHY CANDELA?

Exceptional Support
Small team of product experts.
Support line goes directly to product developers.

Feature Velocity
Product design and architecture allows for super fast feature development
Developers work directly with the customers

Custom Solutions
Team can build any kind of custom solution the customer needs.
Most of we do is available for customers as open source to build on top of.

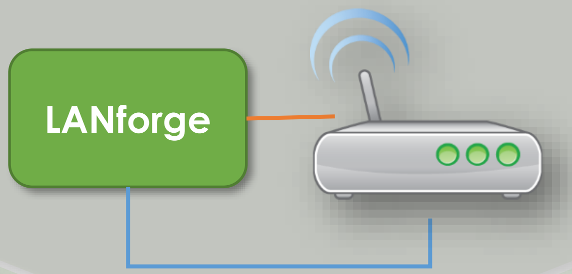
Technology Expertise
Team members have over 18 years experience in the WiFi Industry. You get not just good products, but solutions and domain/industry expertise.

Comprehensive Feature Set
A comprehensive set of features for functional, performance, interoperability, Proof-of-Concept, validation, regression and many forms of testing.

Highly Affordable
Offers the most affordable solutions in the market. Renting/Leasing/ Rent to own and other models available

WHAT CAN OUR PRODUCTS DO FOR YOU?

Test APs



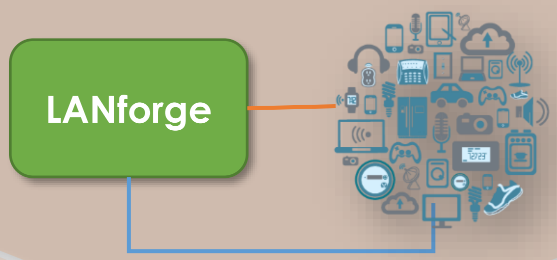
Use Cases

- ✓ AP Benchmarking
- ✓ Functional Testing
- ✓ Certifications
- ✓ Regressions
- ✓ Automation
- ✓ Proof of Concept
- ✓ Vendor Selection

Industries

- ✓ Equipment Makers
- ✓ ODMs/OEMs
- ✓ Chip vendors
- ✓ Operators
- ✓ MSOs
- ✓ Enterprises

Test Devices



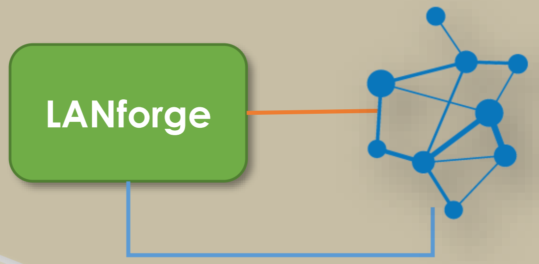
Use Cases

- ✓ Benchmarking
- ✓ Functional Testing
- ✓ Regressions
- ✓ Automation
- ✓ Proof of Concept
- ✓ Vendor Selection

Industries

- ✓ Computing
- ✓ Healthcare
- ✓ Retail
- ✓ Home Entertainment
- ✓ Industrial IoT
- ✓ Transportation
- ✓ Service Providers

Test Networks



Use Cases

- ✓ Performance
- ✓ Scale
- ✓ Functional Testing
- ✓ Real-World Simulation
- ✓ Monitoring
- ✓ Service Assurance

Industries

- ✓ Network Equipment Makers
- ✓ Enterprises
- ✓ Service Providers

Test Applications

Use Cases

- ✓ Application Performance
- ✓ Real-world scenarios
- ✓ End user Quality of Experience
- ✓ Scale
- ✓ Impairments

Industries

- ✓ Gaming
- ✓ Infotainment
- ✓ Hospitality
- ✓ Retail
- ✓ Home entertainment
- ✓ Transportation
- ✓ Healthcare

PRODUCT CATEGORIES

LANforge - FIRE

Network Traffic Generation

- Supports real-world protocols:
  - Ethernet, 802.1Q VLANs, MAC-VLANs, 802.11a/b/g/n/ac (wireless) ,Layer 3: TCP/IP,IPv6, UDP/IP, UDP Multi-cast, including TOS/QoS , Layer 4-7: FTP, HTTP, HTTPS, TELNET, PING, DNS, SMTP , G711, G729, SIP, SCP, iPerf3
- Capable of 140+ emulated VoIP phones per machine, capability to dial real phones, direct-dial mode and gateway mode.
- Comprehensive reporting of Call, RTP and RTCP statistics. PESQ automated voice quality reporting.
- Test routing protocols like OSPF, bridges, NAT etc…
- Emulates 1000+ unique networked devices per LANforge machine
- Comprehensive traffic reports include: Packet Tx/Rx rate, Packet drop, Tx/Rx bytes, Latency, jitter and many more statistics.

LANforge - ICE

WAN Emulation

- General purpose WAN and Network impairment emulator
- Simulate DS1, DS3, OC-3, OC-12, GigE, DSL, Cable-Modem, Satellite links and other rate-limited networks, from 10bps up to 10Gbps speeds (full duplex)
- Can modify various network attributes including: line-speed, latency, jitter, packet-loss, packet-reordering and packet-duplication.
- Supports Ethernet packet corruption with option to recalculate IP, UDP, and TCP checksums. Corruptions include bit flip, bit transpose, and byte over-write
- Supports 'WAN-Playback' allowing capture and replay

LANforge - WiFIRE

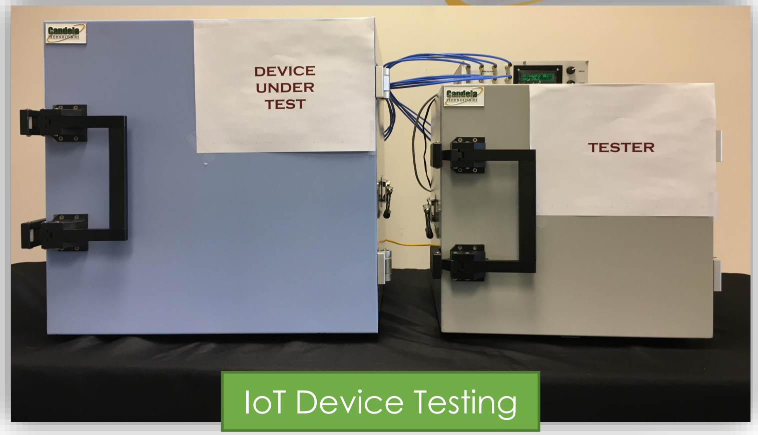
WiFi Device & AP Emulation

- All LANforge FIRE and ICE features
- Emulate 100s of 802.11a/b/n/ac WLAN STAs and APs
- All 2.4 and 5GHz channels supported
- 20/40/80/160 MHz channel BWs
- Most WLAN Security protocols.
- Modular platform that can house several radios .
- Hardware comes in many different form factors
- Per station MAC and PHY controls.
- Programmable Attenuation, Radar , Interference
- Signal, Noise Generation.
- Roaming/Range Testing, Fast Roaming
- Data plane performance testing
- Client scale/capacity testing
- Hotspot 2.0 / Captive Portal
- Voice/Video/Data traffic
- Mesh testing
- IoT Device Testing
- Mu- MIMO

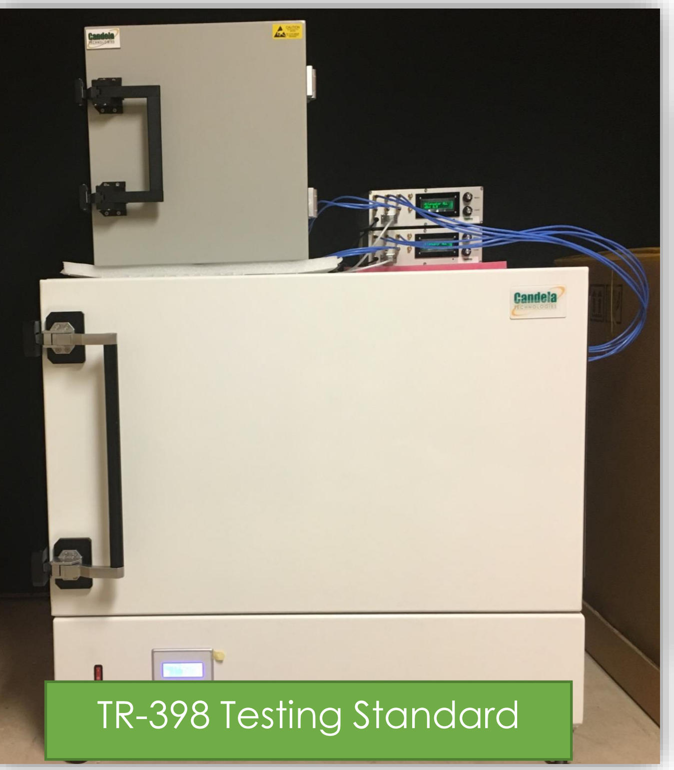
Some Testbed Pictures…

WiFi Mesh Networks

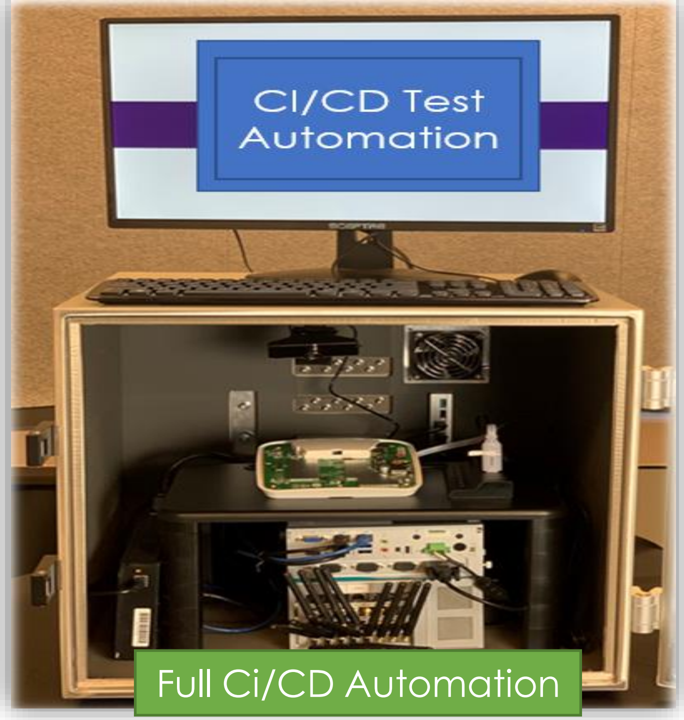
WiFi Transportation Networks



IoT Device Testing

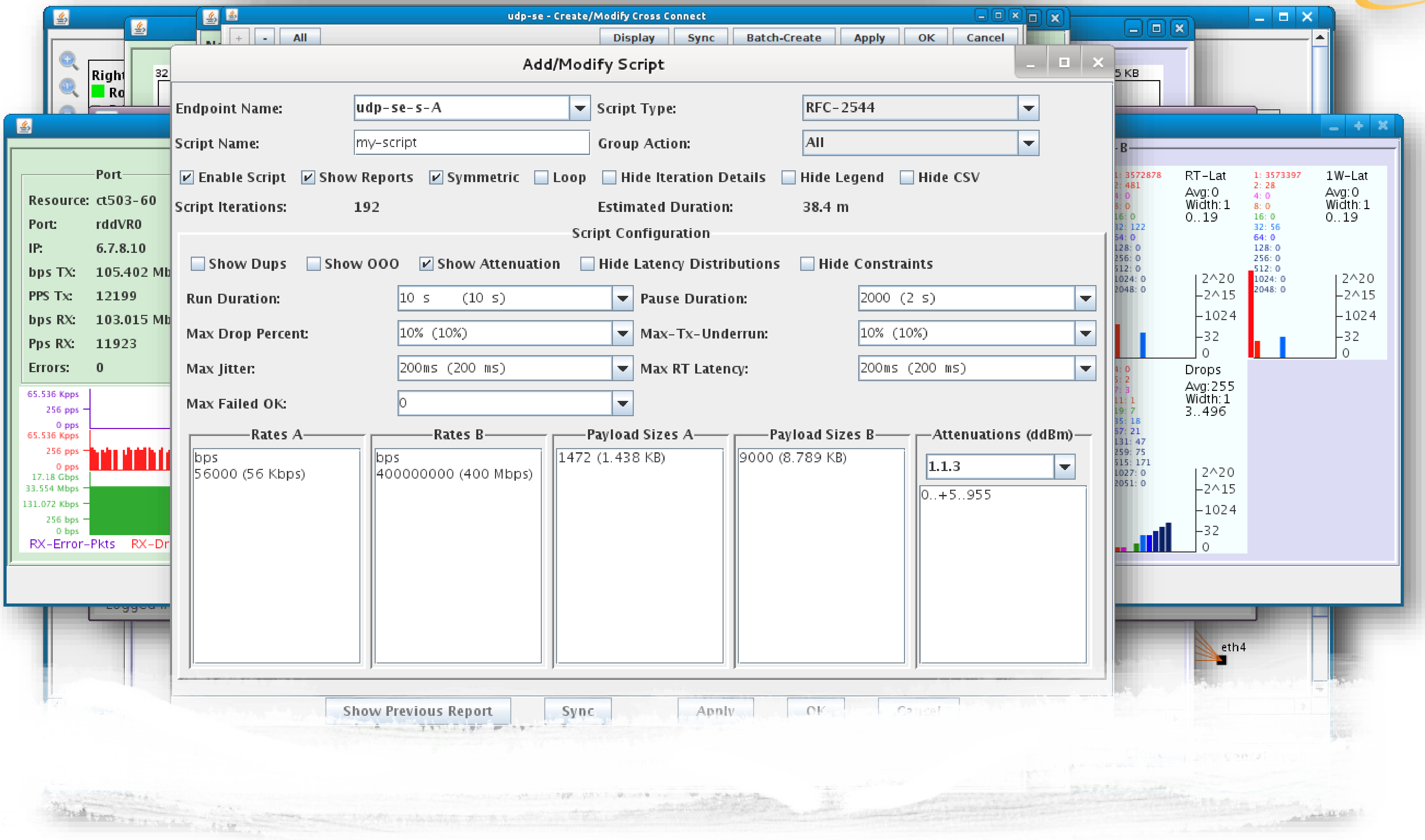

TR-398 Testing Standard

Gaming WiFi Applications

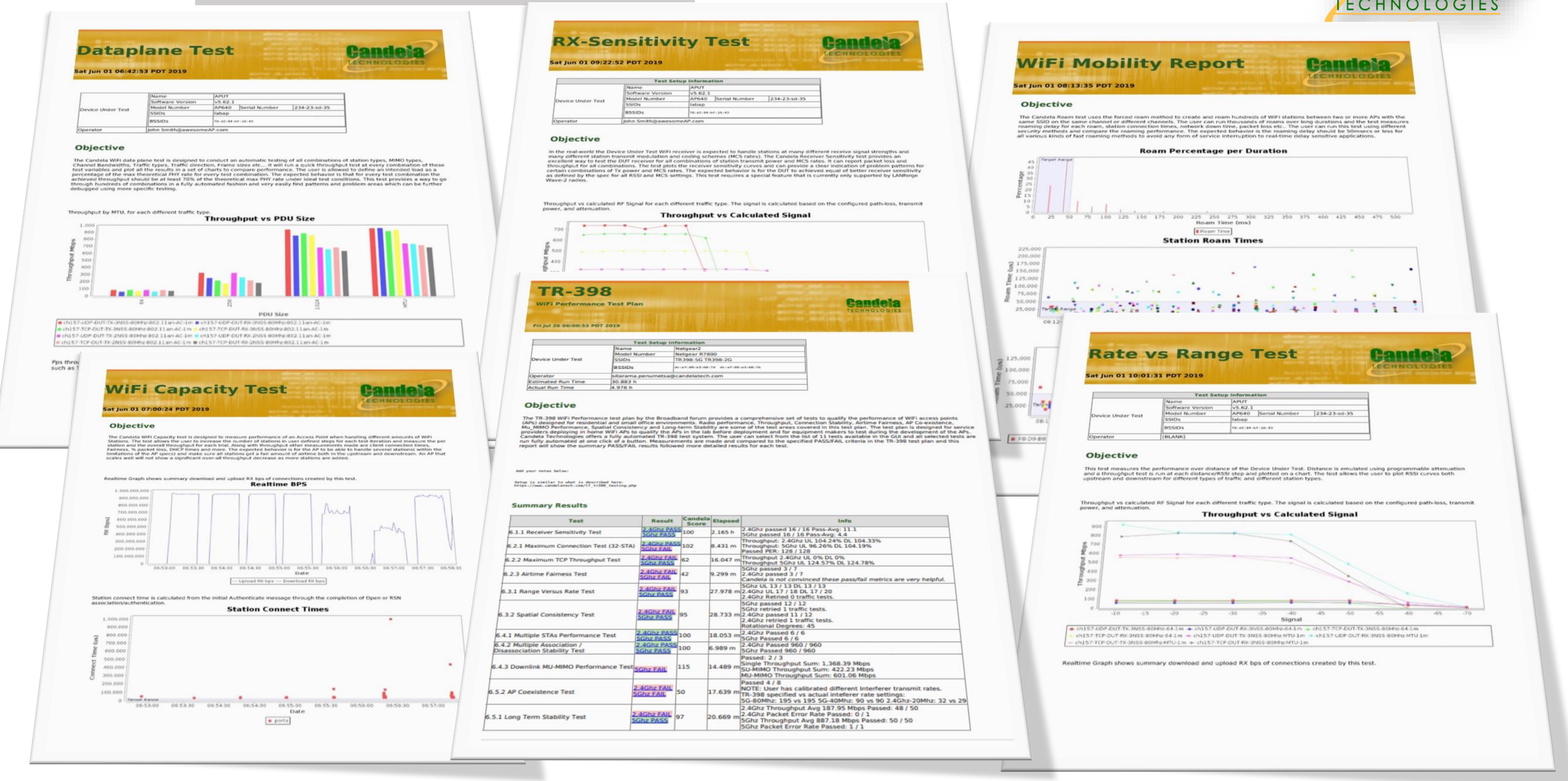


Full Ci/CD Automation

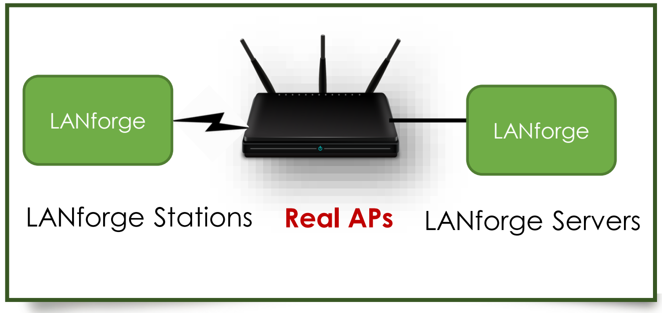
Lots of GUI controls and GUI based tests

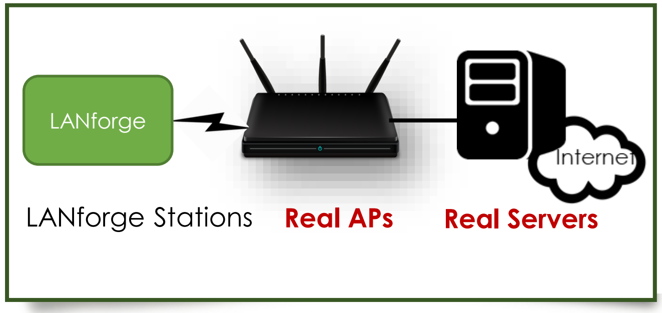


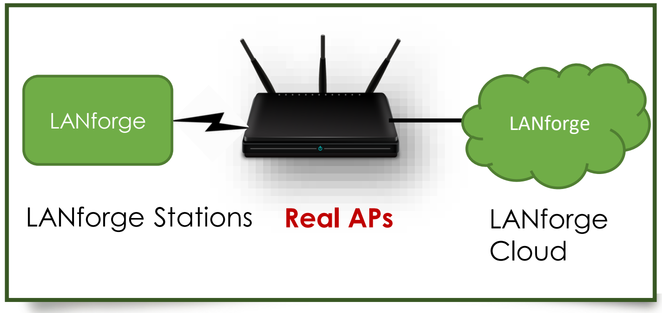
PDF TEST REPORTS

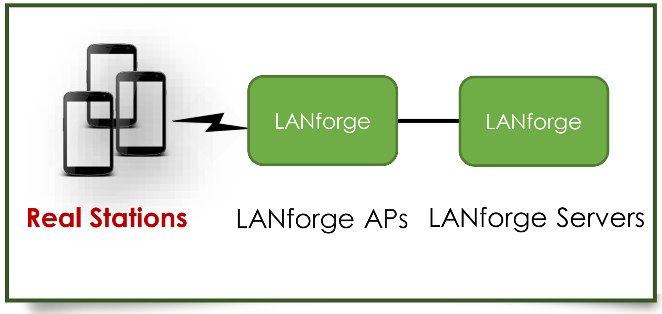


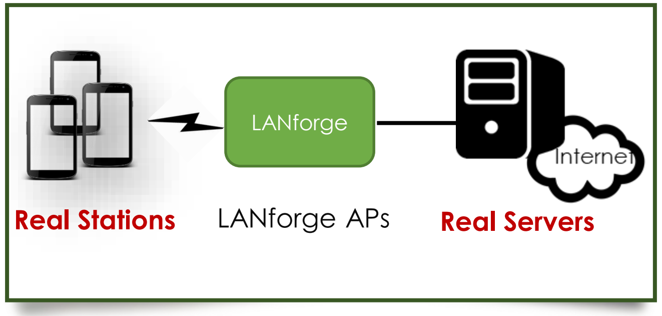
WiFi Test Topologies

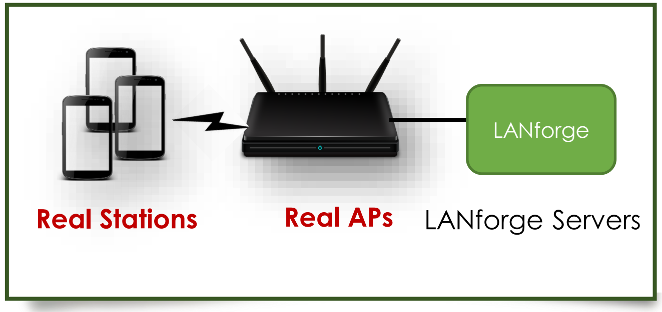


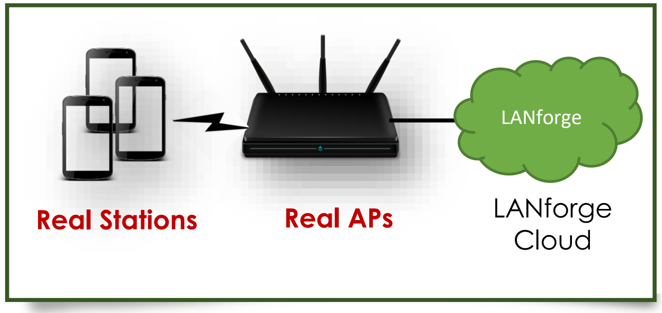


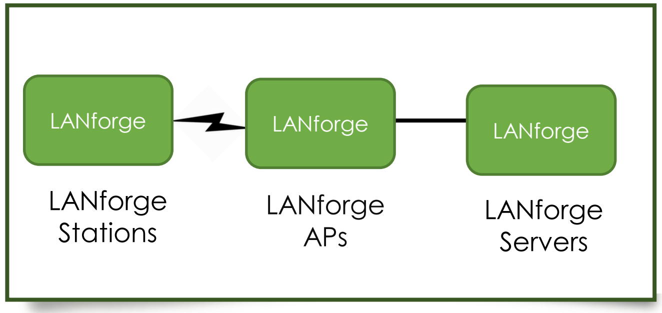


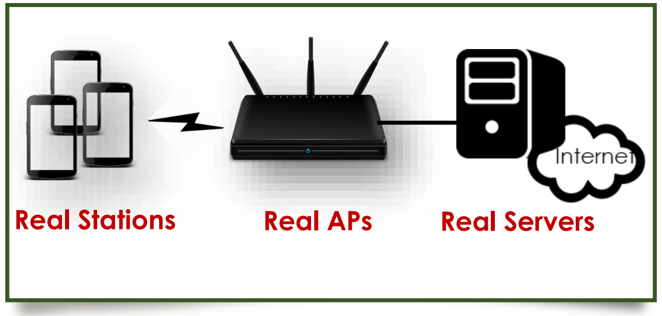












WiFi Test Ecosystem

Candela TECHNOLOGIES

Product Lifecycles

- Post Deployment
- Deployment
- Proof-of-Concept
- Manufacturing
- System QA
- Post Silicon System Test
- Pre-Silicon Design Verification

Customer Segments

- Government
- Enterprises
- Operators
- OEMs/ODMs
- Device Makers
- Network Equipment Makers
- Chip Vendors

Testing Requirements

- End User Quality of Experience
- Security
- Real-World Deployment Scenarios
- Stress & Performance
- System Test
- L2 - Signaling
- L1- Radio Quality

Candela Test Offerings

From Basic Manual Functional Testing to Full Lights Out CI/CD Automation and Everything in Between.

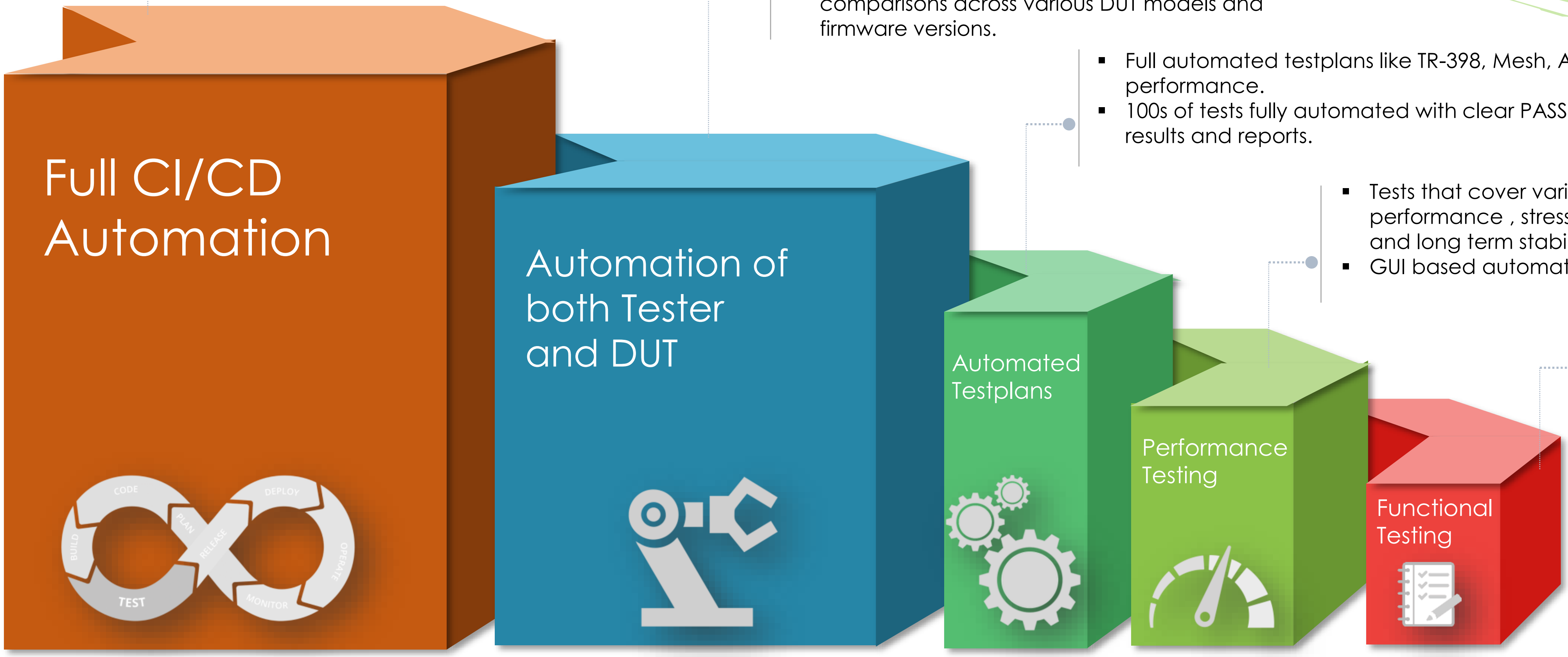
- Complete CI/CD Automation provides.
- Full automation to fetch and load builds on DUT, find the reserve testbeds, fetch and run test jobs, gather and analyze test results, export to result visualization tools.
- Integration with tools and platforms like Jenkins, Jira, GitHub, Testrail etc..

- Create 100s of fully automated test scripts that can automate both Tester and DUT controls.
- Create custom test reports and results comparisons across various DUT models and firmware versions.

- Full automated testplans like TR-398, Mesh, AP performance.
- 100s of tests fully automated with clear PASS/FAIL results and reports.

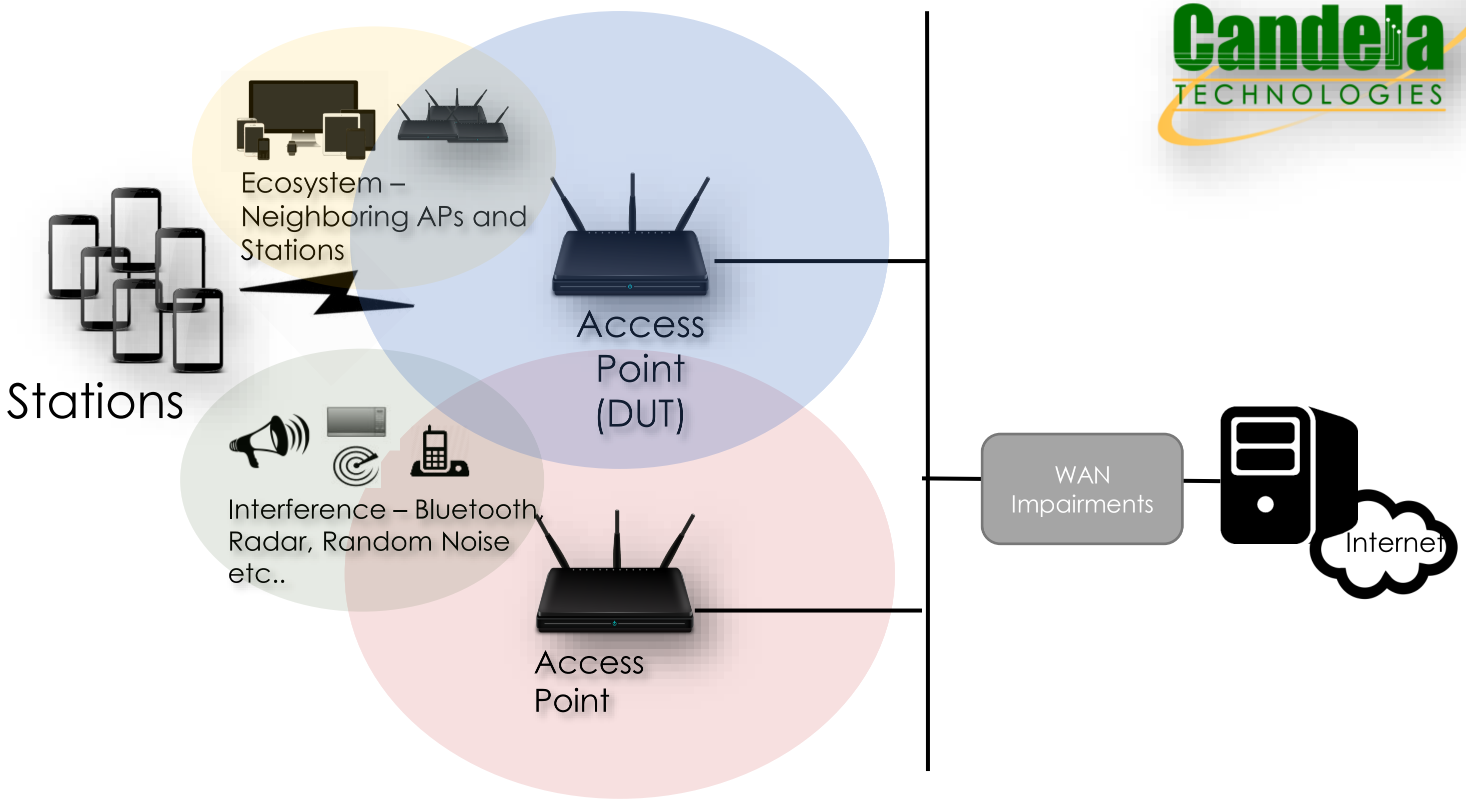
- Tests that cover various aspects of AP performance , stress, scale, real world scenarios and long term stability
- GUI based automated tests with test reports.

- Unit testing
- Test basic AP functions like connectivity, security, QoS, OFDMA, Mu-MIMO etc..
- Fully flexible GUI to create any type of test scenarios
- Ideal for Developer and early stage dev testing.



Testing Access Points

TESTING ACCESS POINTS



MOST DETERMINISTIC

Step1 : Benchmarking
- ✓ RF Performance
- ✓ Client Scale
- ✓ MAC Throughput
- ✓ Security
- ✓ Multi-Band/ multi-SSID Performance
- ✓ Mixed mode clients
- ✓ MU-MIMO
- ✓ Traffic Mix tests

\+

Step2 : Mobility
- ✓ Range
- ✓ Rate Scaling
- ✓ Roaming
- ✓ BSS Transition
- ✓ Neighbor APs
- ✓ Off Channel Scanning

\+

Step3 : Ecosystem
- ✓ Performance in the presence of co-channel/ adjacent channel interference
- ✓ Air time Fairness
- ✓ Medium Utilization
- ✓ QoS

\+

Step4 : Impairment
- ✓ Performance in the presence of RF Interference
- ✓ Radar compliance
- ✓ Performance with WAN impairments
- ✓ Defective Stations
- ✓ Rouge APs

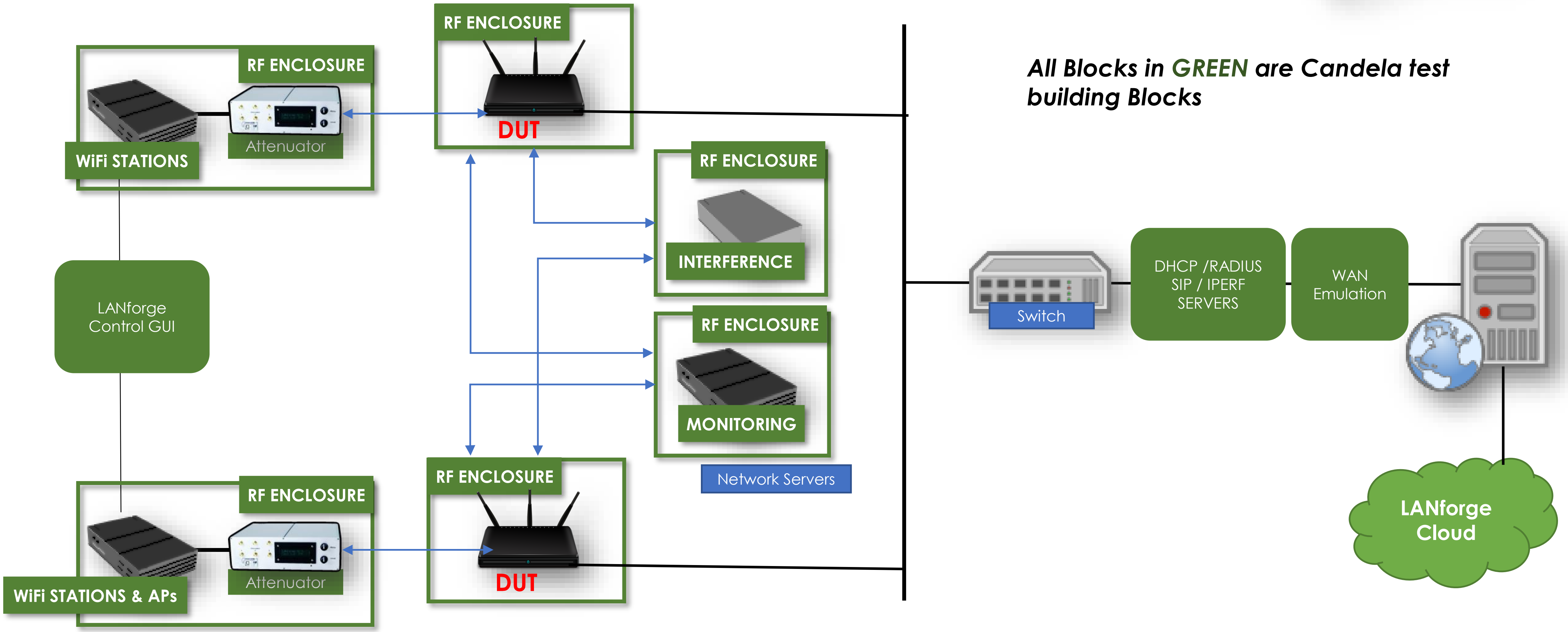
\+

Step5 : Real Applications
- ✓ HD video streaming
- ✓ FTP download
- ✓ VOIP Quality
- ✓ Real Application traffic performance for Application Specific Devices

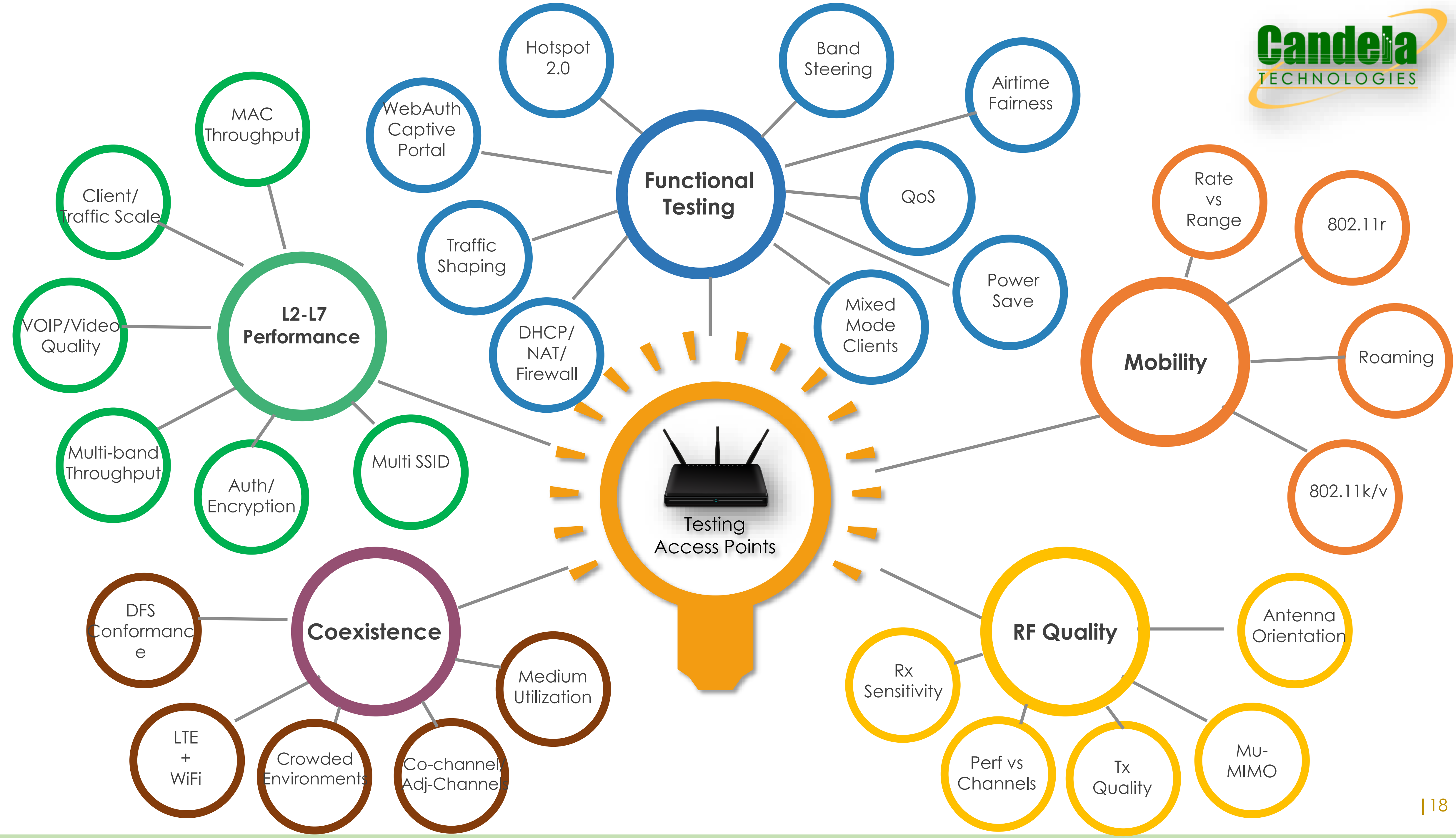
MOST REALISTIC

Control → Repeatability → Coverage → Automation → Scale → Expert Analysis → Executive Reports

TOPOLOGY – TESTING ACCESS POINTs



Control › Repeatability › Coverage › Automation › Scale › Expert Analysis › Executive Reports



Candela TECHNOLOGIES

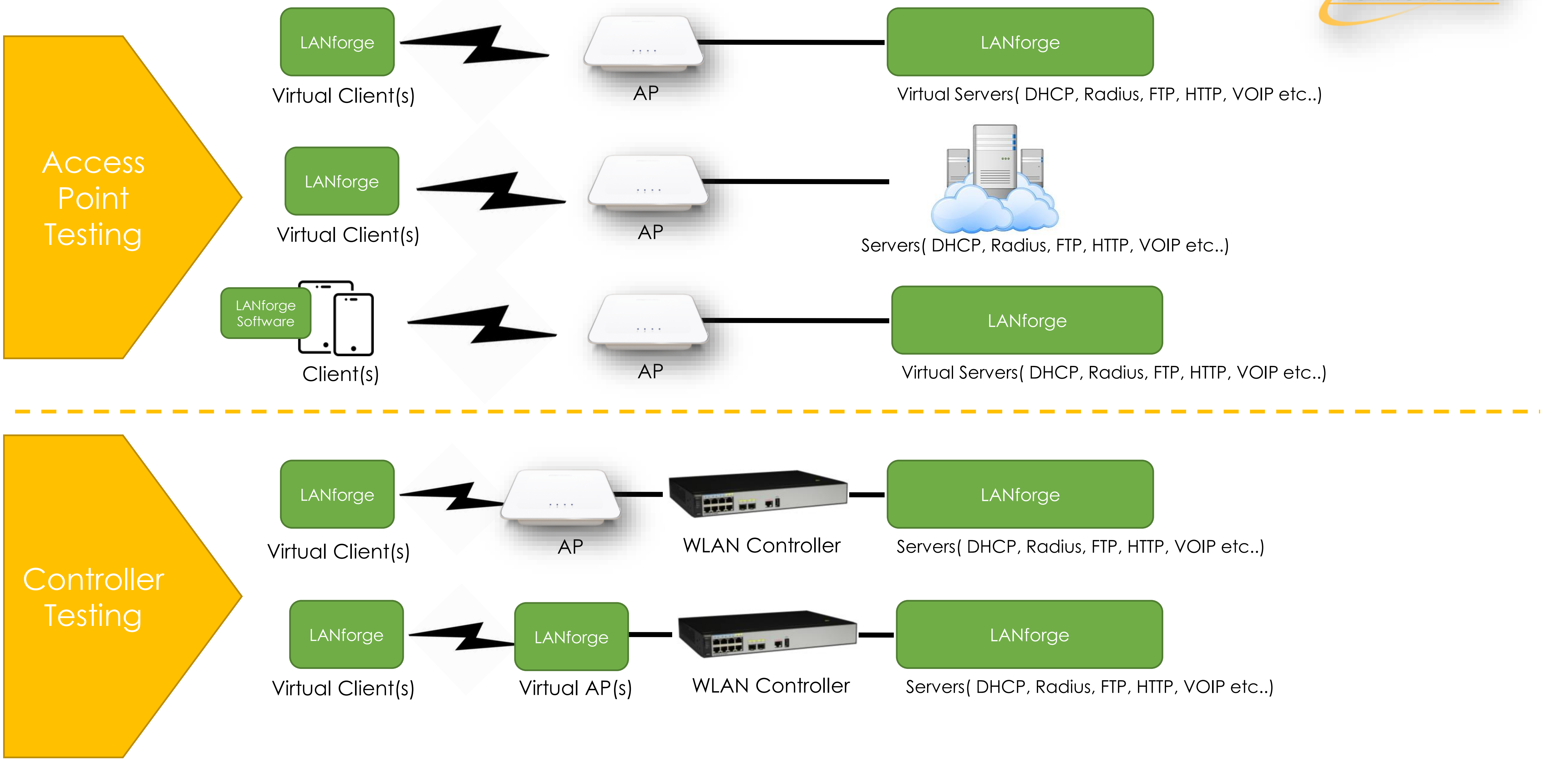
WiFi Access Point Tests

- Client Capacity Test
- Client Connection Test
- Clear Channel Assessment (CCA) Test
- Data Plane Throughput Test
- Traffic Mix Test
- Rate vs Range Test
- Receiver Sensitivity Test
- TX Power Test
- Roaming Test
- Multi-band Test
- Multi-SSID Test
- Airtime Fairness Test
- QoS Test
- Application Performance Test
- Load Balancing/Band Steering Test
- Mu-MIMO Performance Test
- OFDMA Performance
- Long Duration Stress Test
- Co-existence Test
- DFS Test
- Captive Portal Login Test
- Traffic Shaping/Policing Test
- Performance over Antenna Orientation Test
- Real-World Load Patterns Test

Access Point Testcases

Category	Sub-Category	Test Cases developed for
Command and Control	Firmware	Upgrades/Downgrades, AP boots/reboots, System resources
	Configuration & Communication	AP provisioning, ZTP, setting up networks/channels/profiles/APs, cloud connectivity, DHCP/Radius and other services, Alarms
	Operation Modes	Bridge/vlan/router modes,
	Physical & Virtual Interfaces	Basic functions of LAN/WAN/WLAN physical interfaces, indicators/LEDs, virtual interfaces (SSIDs/VLANs etc..)
	GUI/APIs	GUI settings (Read/Write) , API calls (Push/Pull)
Functional Testing	BSS Capabilities	Basic/Extended Capabilities, Security, QoS, RRM, DFS, 802.11a/b/g/n/ac/ax/k/v/r/i/u/w settings, reg domains etc..
	Connectivity & Security	Basic connectivity with all WPA/2/3 Personal/Enterprise, All EAP method, Passpoint. Captive Portal, WPS etc…
	Radio Resource Management	Load Balancing, Band Steering, Auto Channel Selection, DFS
	Smart WiFi	Role/User/Device/Network based policies, Traffic Shaping, Int Detection/Mitigation, DPI, threat detection, Location Services
	QoS & Mobility & Power Save	WMM, Fast Roaming, Open Roaming, Network assisted handoff, Legacy/WMM/MIMO Power Save
Performance Testing	Throughput Benchmark	Throughout for STA Modes/MIMO types/STA counts/BW settings/Traffic Types/Direction/Packet Sizes etc..
	Multiband Performance	Single/Dual/Tri band performance
	Mobility Performance	Rate vs Range, Rate vs Antenna Orientation, Roaming Delay, Roaming performance with different security types
	Radio Performance	Receiver Sensitivity, Transmitter Quality, Reg Domain TX power testing.
	Application Performance	VOIP Performance, Youtube/OTT Video Streaming, HTTP/FTP Performance, Social Media Apps performance
Stress and Endurance Testing	Day in Life Test	Mix of Stations/APs/SSIDs/Security Types/User Policies/Traffic/Device Load Patterns over time in a 10 hour day
	48-hour Stress Test	Full system load across all interfaces with maximum stations/traffic run for 48 hours
	Load Patterns #1,#2, #3	Various real world load patterns run over long durations.
Use Case Testing	Single AP SOHO	TR-398 or similar test plan for comprehensive single SOHO AP testing, Qualification/Badge Program
	SOHO Mesh	Throughput Per Hop, Mesh Failover, Roaming, Load Balancing, Qualification/Badge Program
	Med-Enterprise Network	Medium Size Enterprise Network Use cases, Qualification/Badge Program
	Multi Dweller Unit (MDU)	MDU Test plan with clear PASS/FAIL results , Qualification/Badge Program
	Campus Network/ LPV	Campus Network/Large Public Venue Test Plan/Operator Network, Qualification/Badge Program

Test Topologies



WiFi Access Point Test System Capabilities

Candela TECHNOLOGIES

Station Controls

- ✓ IP/MAC Address
- ✓ DHCP/IPV4/IPV6
- ✓ SSID/BSSID
- ✓ HT/VHT/20/40/80/160 MHz modes
- ✓ 802.11a/b/g/n/ac Modes
- ✓ Custom Information Elements
- ✓ Delay Handshake Responses
- ✓ Corrupt/Ignore frames in protocol handshakes
- ✓ Rate Adaptation / Retry Limits / Tx Rates
- ✓ Power Save Settings
- ✓ Band Steering Settings
- ✓ Passive/Active Scanning
- ✓ IBSS Mode/ Mesh Mode / WDS Mode
- ✓ Slot Times/Guard Intervals
- ✓ AMPDU/AMSDU settings

Traffic Controls

- ✓ Frame size/rate, traffic direction, CBR/VBR traffic rates
- ✓ IPv4/IPv6/TCP/UDP/VOIP
- ✓ All kinds of WiFi traffic
- ✓ Full iPerf and Native traffic Gen support
- ✓ Ping/Traceroute/DNS/SMTP/Telnet/Curl/Captive Portal
- ✓ IP ToS (QoS) supported per RFCs: 1349, 2474 and 2481
- ✓ SIP and H.323
- ✓ Real and emulated voice calls
- ✓ http:// and ftp:// URLs
- ✓ HTTP Authentication types (Basic, Digest, GSS, NTLM).
- ✓ POP3, P2P, iSCSI

Auth/Encryption Methods

- ✓ WPA
- ✓ WPA2
- ✓ WPA3
- ✓ OSEN
- ✓ WEP
- ✓ EAP-TLS
- ✓ EAP-TTLS
- ✓ EAP-MSCHAPV2
- ✓ EAP-MD5
- ✓ EAP-OTP
- ✓ EAP-GTC
- ✓ EAP-PEAP
- ✓ EAP-SIM
- ✓ EAP-AKA
- ✓ EAP-IKEV2
- ✓ EAP-FAST
- ✓ WFA-AUNAUTH-TLS
- ✓ WPA-PSK
- ✓ FT-PSK(11r)
- ✓ FT-EAP(11r)
- ✓ WPA-PSK-SHA256
- ✓ FT-SAE
- ✓ WPA-EAP-SUITE-B
- ✓ FILS-SHA256/384
- ✓ OWE

Protocols

- ✓ 802.11a/b/g/n/ac/ax/axe/be
- ✓ 802.11k
- ✓ 802.11v
- ✓ 802.11u
- ✓ Hotspot 2.0
- ✓ 802.11w
- ✓ WebAuth/Captive Portal

Tests

- ✓ Client Capacity Test
- ✓ Client Connection Test
- ✓ Clear Channel Assessment (CCA) Test
- ✓ Data Plane Throughput Test
- ✓ Traffic Mix Test
- ✓ Rate vs Range Test
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- ✓ Mu-MIMO Performance Test
- ✓ Long Duration Stress Test
- ✓ Co-existence Test
- ✓ DFS Test
- ✓ Captive Portal Login Test
- ✓ Traffic Shaping/Policing Test
- ✓ Performance over Antenna Orientation Test

Services

- ✓ Custom Test Automation
- ✓ Custom Testplan Development
- ✓ Restful APIs
- ✓ Text based APIs
- ✓ Full AP Performance Test as Service

Impairments

- ✓ 0 to 95dB Programmable Attenuation
- ✓ Most of the ETSI, FCC Radar Pulses
- ✓ Can modify various network attributes including: network-speed, latency, jitter, packet-loss, packet-reordering, and packet-duplication.
- ✓ Supports Packet corruptions, including bit-flips, bit-transposes and byte-overwrites
- ✓ WAN-capture Playback
- ✓ WiFi Impairments : Ignore % Rx Frames, Corrupt % Tx Frame, Duplicate % Tx Frames, Delay % Frame processing,
- ✓ RF Noise Generation
- ✓ Co-channel / Adjacent Channel Interference.
- ✓ Custom Payloads

Accessories

- ✓ RF enclosures
- ✓ Programmable Attenuators
- ✓ RF Noise Generators
- ✓ Channel Emulators
- ✓ Programmable Turntables
- ✓ RF Cables
- ✓ Splitter/Combiners
- ✓ Antennas

SYSTEM CAPABILITIES SUMMARY

Station/AP Controls

- ✓ IP/MAC Address
- ✓ DHCP/IPV4/IPV6
- ✓ SSID/BSSID
- ✓ Most Authentication & Encryption Methods
- ✓ HT/VHT/20/40/80/160 MHz modes
- ✓ 802.11a/b/g/n/ac Modes
- ✓ Advanced EAP Authentication
- ✓ 802.11u/ Hotspot 2.0
- ✓ Fast Reauth/ Fast Roaming
- ✓ 802.11k/v*
- ✓ 802.11w
- ✓ Custom Information Elements
- ✓ Delay Handshake Responses
- ✓ Corrupt/Ignore frames in protocol handshakes
- ✓ Rate Adaptation / Retry Limits / Tx Rates
- ✓ Power Save Settings
- ✓ Band Steering Settings
- ✓ Passive/Active Scanning
- ✓ IBSS Mode/ Mesh Mode / WDS Mode
- ✓ Slot Times/Guard Intervals
- ✓ AMPDU/AMSDU settings

Traffic Gen

- ✓ IPv4/IPv6/TCP/UDP/VOIP
- ✓ All kinds of WiFi traffic
- ✓ Full iPerf and Native traffic Gen support
- ✓ Ping/Traceroute/DNS/SMTP/Telnet/Curl/Captive Portal
- ✓ IP ToS (QoS) supported per RFCs: 1349, 2474 and 2481
- ✓ SIP and H.323
- ✓ Real and emulated voice calls
- ✓ allows http:// and ftp:// URLs to be accessed with multiple sessions
- ✓ HTTP Authentication types (Basic, Digest, GSS, NTLM).
- ✓ SSL/HTTPS certification
- ✓ Over 28,000 URLs per second per Resource
- ✓ Over 3000 HTTP simultaneous connections each with unique MAC and IP address
- ✓ Maximum aggregate download speed 9.74 Gbps on 10GE
- ✓ 2000 NFS Endpoint/clients per ressource
- ✓ POP3, P2P, iSCSI

Measurements

- ✓ IPv4/IPv6 Addresses
- ✓ Tx/Rx Mbps / Pps
- ✓ Rx/Tx Errors
- ✓ Tx/Rx PHY Rates
- ✓ Channel
- ✓ Access Point connected
- ✓ RSSI
- ✓ Noise Level
- ✓ Connection Time
- ✓ DHCP Handshake Time
- ✓ ANQP Time
- ✓ 4-way Handshake Time
- ✓ Last Connection Attempt Time
- ✓ WiFi Connection Time
- ✓ Disconnect Duration
- ✓ % Retry and Failed Retries
- ✓ Frame Sizes
- ✓ Failed Login Attempts
- ✓ PESQ / MoS /Voice Quality
- ✓ Jitter/Latency/Dropped Calls

Impairments

- ✓ 0 to 95dB Programmable Attenuation
- ✓ Most of the ETSI, FCC Radar Pulses
- ✓ Can modify various network attributes including: network-speed, latency, jitter, packet-loss, packet-reordering, and packet-duplication.
- ✓ Supports Packet corruptions, including bit-flips, bit-transposes and byte-overwrites
- ✓ WAN-capture Playback
- ✓ WiFi Impairments : Ignore % Rx Frames, Corrupt % Tx Frame, Duplicate % Tx Frames, Delay % Frame processing,
- ✓ RF Noise Generation
- ✓ Co-channel / Adjacent Channel Interference.
- ✓ Custom Payloads

802.11ac Access Point Test Plan - Overnight

Candela TECHNOLOGIES

Basic Client Connectivity

- Connect and Disconnect 20 clients each on 2.4Ghz and 5Ghz radios using Open, WPA-PSK, WPA-Enterprise methods, measure connecting times and connection drops.

Benchmark Throughput

- Run full line rate traffic with single client in 4x4 MIMO 80Mhz mode in 5GHz and 3x3 MIMO 40 Mhz in 2.4GHz. Measure and Benchmark maximum throughput.

Full System Performance

- Load all radios and ethnet interfaces simultaneously with full line rate traffic and measure the maxium achieved system throughput

Roaming Performance

- Create lots of clients and connect them to the AP and then cause lots of roams across various security types and measure romaing performance

Reciever Sensitivity

- Fix the MCS rates on the client and send traffic with same MCS rate but different transmit power values and measure receiver sensitivity at all power level. Run test at all MCS rates

Rate vs Range

- Measure performance over distance for various traffic types both Upstream and Downstream.

Client Capacity

- Run a throughput test with 1,2,5,10,20 and 40 clients. Repeat test on both 2.4GHz and 5GHz bands.

Mu-MIMO

- Create 3 STAs (1x 2x2 MIMO and 2x SISO) and measure the increase in troughput when Mu-MIMO feature is enabled.

Airtime Fairness

- Connect 1x 802.11ac client and 1x 802.11n client and 1x 802.11a client, run equal amount of traffic on all three clients and see if AP distributes airtime fairly.

QoS Performance

- Create different voice, video and data traffic streams with different DSCP settings and WMM settings and check to make sure the AP provides better throughput to high priority traffic.

DFS Conformance

- Generate different types of Radar Pulses and make sure the AP can detect Radar and move to a differen channel and stay off channel.

Lond Duration Stability

- Connect lots of clients and run traffic for a 24 hour period and look for any instability in the AP performance

Lights Out AP Testbed Setups

192.168.100.64/index.htm

Controller: TIP Testbed 1

Wed Jun 17 22:05:50 2020

Individual Control

#	Name	State	Action	
1	USB Hub	ON	Switch OFF	Cycle
2	Interior Lights	ON	Switch OFF	Cycle
3	Outlet 3	OFF	Switch ON	
4	Outlet 4	OFF	Switch ON	
5	Chamber Fans	ON	Switch OFF	Cycle
6	LANforge System	ON	Switch OFF	Cycle
7	DUT	ON	Switch OFF	Cycle
8	Outlet 8	OFF	Switch ON	

Master Control

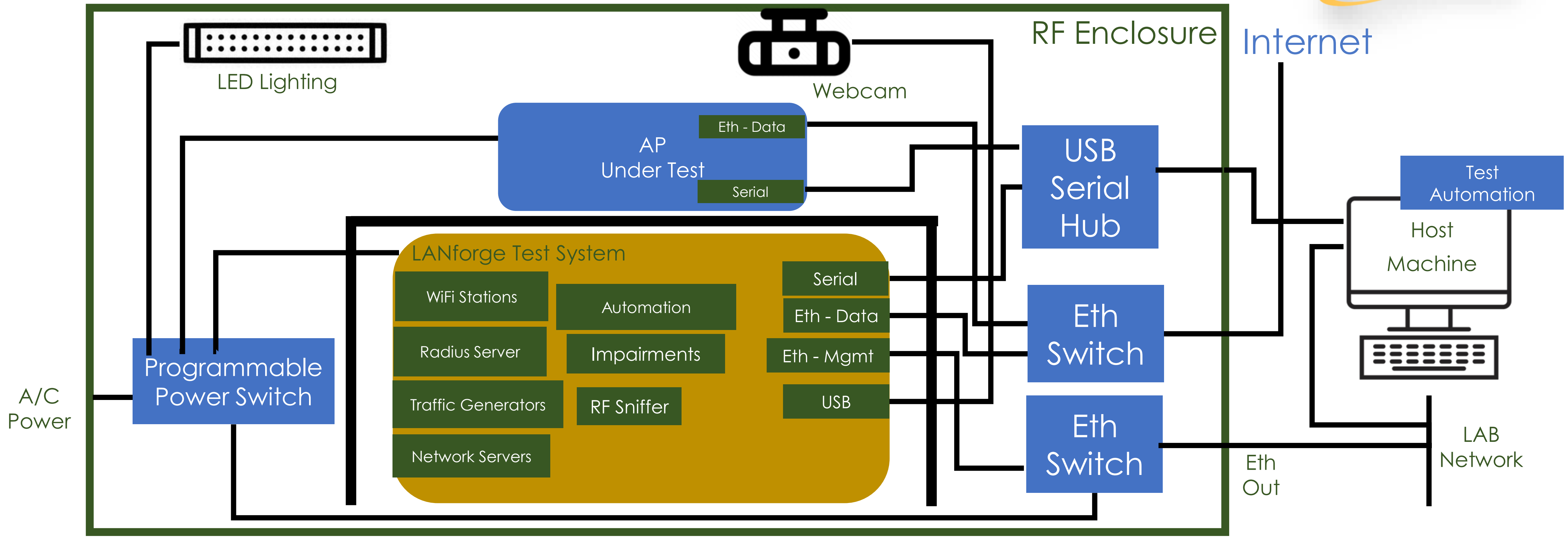
All Outlets OFF

All Outlets ON

Cycle all Outlets

Sequence delay: 10 sec.

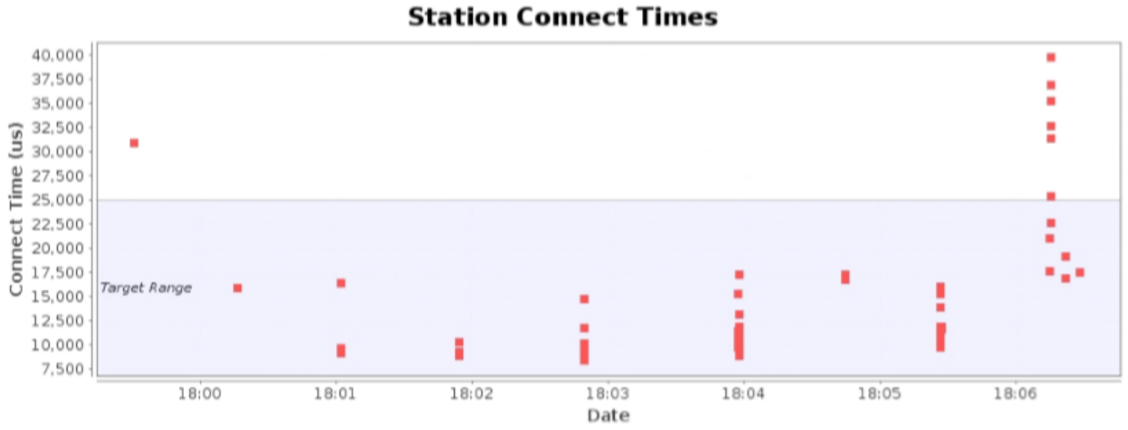
Fully Automated Basic AP Testbed

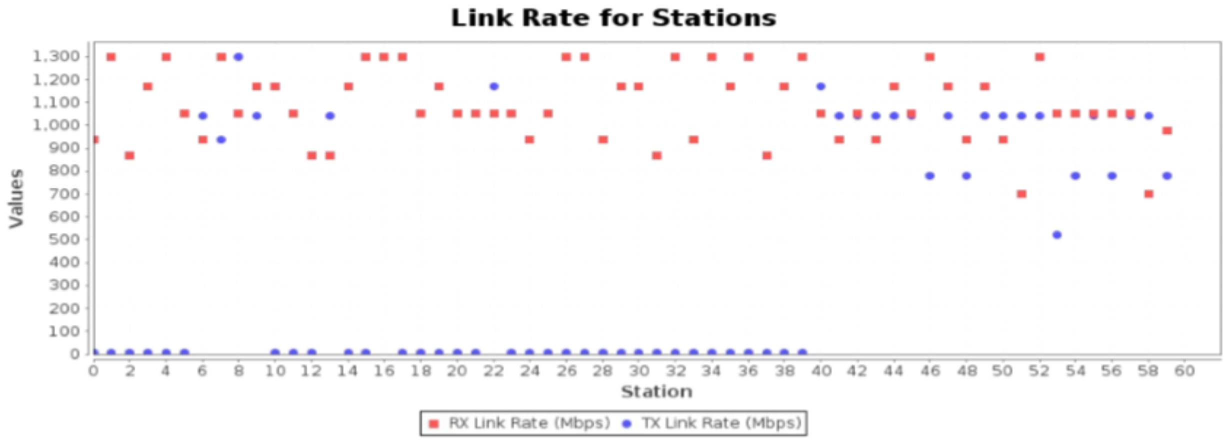


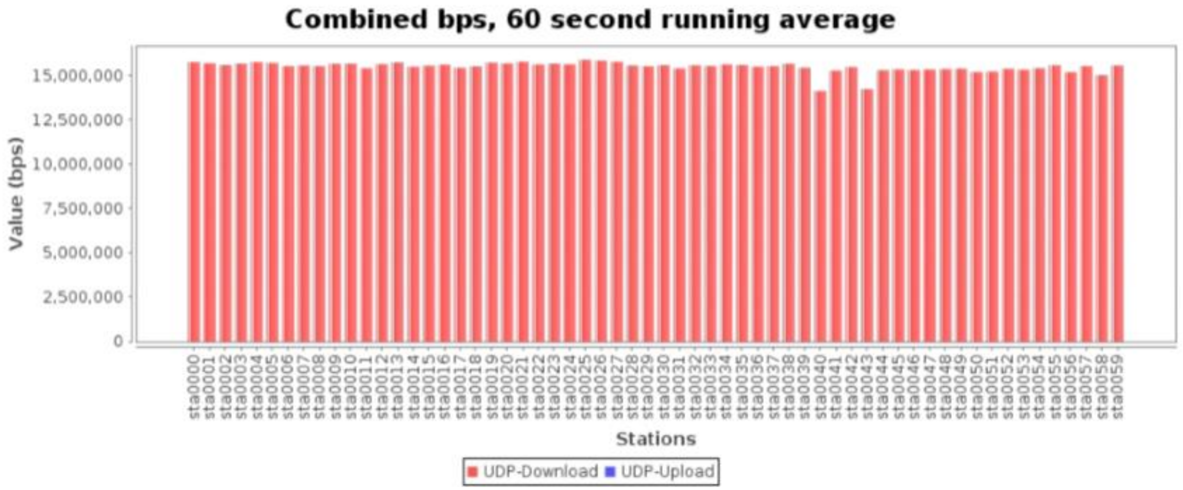
- Run 100s of tests fully automated without having to touch the testbed once setup with the DUT.
- Automate AP settings, upgrade and reboot APs through serial interface connected to LANforge system.
- Programmable Power Switch to power cycle all devices remotely.
- Can create any kind of custom test scripts.

WiFi Client Capacity Test

The Candela WiFi Capacity test is designed to measure performance of an Access Point when handling several WiFi Stations. The test allows the user to increase the number of stations in user defined steps for each test iteration and measure the per station and the overall throughput for each trial. Along with throughput other measurements made are client connection times, % packet loss, DHCP times and more. The expected behavior is for the AP should be able to handle several stations (within the limitations of the AP specs) and make sure all stations get a fair amount of airtime both in the upstream and downstream.





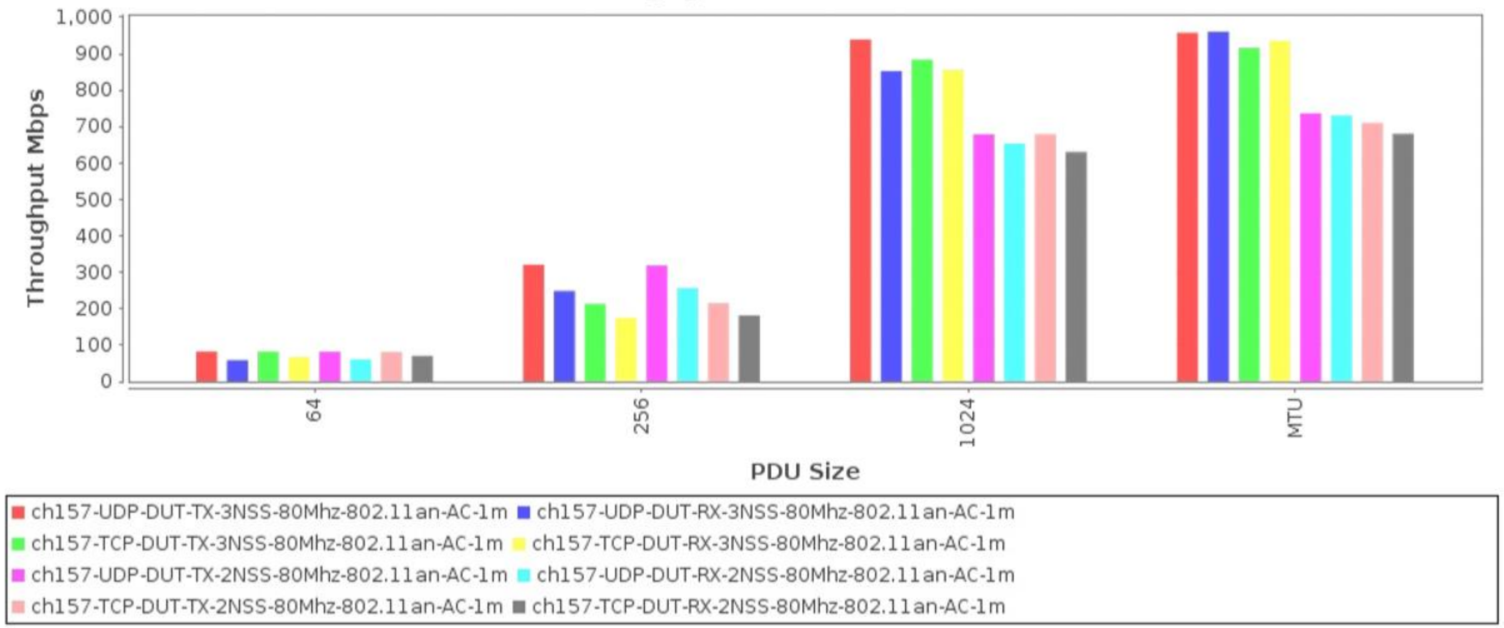


Dataplane Test

The Candela WiFi data plane test is designed to conduct an exhaustive walk through of all combinations of station types, MIMO types, Channel Bandwidths, Traffic types, Traffic direction, Frame sizes etc…and run a quick performance test at every combination of these test variables and plot all the result a chart to compare performance. The user is allowed to defined an intended load as a percentage of the max theoretical PHY rate for every test combination.

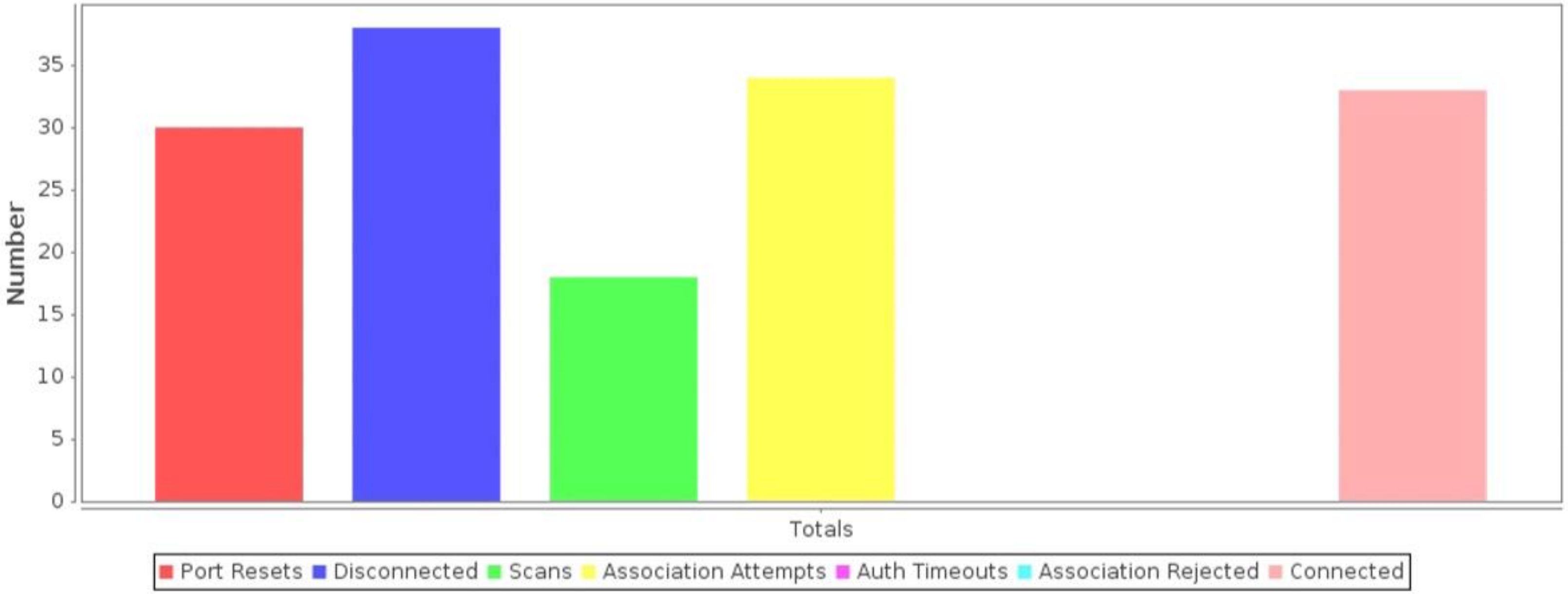
The expected behavior is that for every test combination the achieved throughput should be at least 70% of the theoretical max PHY rate under ideal test conditions. This test provides way to get through hundreds of combinations in a fully automated fashion and very easily find patterns and problem areas which can be further debugged using more careful testing.

Channel	Security	NSS	Mode	Bandwidth	PDU	Traffic-Type	Direction	Atten	Duration	Offered-1m	Rx-Bps	Rx-Bps-1m	Rx-Bps-3s	Theoretical	RSSI	Tx-Failed	Tx-Failed%	Tx-Rate	Rx-Rate	Mode
157	AUTO	3	802.11an-AC	80	64	UDP	DUT-TX	NA	10	375636278	82096786	82774154	82110085	1299900000	-35	0 / 7	0	585 Mbps	1.3 Gbps	802.11an-AC
157	AUTO	3	802.11an-AC	80	64	UDP	DUT-RX	NA	10	58675445	58487656	58669531	58822154	1299900000	-27	0 / 1146442	0	1300 Mbps	1.3 Gbps	802.11an-AC
157	AUTO	3	802.11an-AC	80	64	TCP	DUT-TX	NA	10	82612883	82081450	82754520	78784362	1299900000	-35	0 / 22627	0	1300 Mbps	1.3 Gbps	802.11an-AC
157	AUTO	3	802.11an-AC	80	64	TCP	DUT-RX	NA	10	68193119	67910744	68027524	67960029	1299900000	-35	0 / 1057056	0	1170 Mbps	1.3 Gbps	802.11an-AC
157	AUTO	3	802.11an-AC	80	256	UDP	DUT-TX	NA	10	794434891	318785180	32093006								
157	AUTO	3	802.11an-AC	80	256	UDP	DUT-RX	NA	10	248140311	247482798	24891779								
157	AUTO	3	802.11an-AC	80	256	TCP	DUT-TX	NA	10	214017649	213858800	21387888								
157	AUTO	3	802.11an-AC	80	256	TCP	DUT-RX	NA	10	176724557	173728847	17501814								
157	AUTO	3	802.11an-AC	80	1024	UDP	DUT-TX	NA	10	941816029	939300716	93953957								
157	AUTO	3	802.11an-AC	80	1024	UDP	DUT-RX	NA	10	852508903	852216421	85250637								
157	AUTO	3	802.11an-AC	80	1024	TCP	DUT-TX	NA	10	886778280	882152010	88431859								
157	AUTO	3	802.11an-AC	80	1024	TCP	DUT-RX	NA	10	857774487	853235642	85670856								
157	AUTO	3	802.11an-AC	80	MTU	UDP	DUT-TX	NA	10	968308432	956770180	95810850								
157	AUTO	3	802.11an-AC	80	MTU	UDP	DUT-RX	NA	10	1039199500	953035974	96055810								
157	AUTO	3	802.11an-AC	80	MTU	TCP	DUT-TX	NA	10	923497341	915752666	91680383								
157	AUTO	3	802.11an-AC	80	MTU	TCP	DUT-RX	NA	10	940290526	935195045	93578771								
157	AUTO	2	802.11an-AC	80	64	UDP	DUT-TX	NA	10	378401986	82020019	82367334								
157	AUTO	2	802.11an-AC	80	64	UDP	DUT-RX	NA	10	61030017	60627326	61031149								
157	AUTO	2	802.11an-AC	80	64	TCP	DUT-TX	NA	10	81180186	81178389	81185154								
157	AUTO	2	802.11an-AC	80	64	TCP	DUT-RX	NA	10	70477487	69807479	70360985								
157	AUTO	2	802.11an-AC	80	256	UDP	DUT-TX	NA	10	784572901	318743810	31905216								
157	AUTO	2	802.11an-AC	80	256	UDP	DUT-RX	NA	10	256922016	257099887	25718518								
157	AUTO	2	802.11an-AC	80	256	TCP	DUT-TX	NA	10	215336087	214365549	21550774								
157	AUTO	2	802.11an-AC	80	256	TCP	DUT-RX	NA	10	183800509	180087631	18128714								
157	AUTO	2	802.11an-AC	80	1024	UDP	DUT-TX	NA	10	855622771	674015653	67891515								
157	AUTO	2	802.11an-AC	80	1024	UDP	DUT-RX	NA	10	652023962	653432901	65393406								
157	AUTO	2	802.11an-AC	80	1024	TCP	DUT-TX	NA	10	677016512	680128387	68020774								
157	AUTO	2	802.11an-AC	80	1024	TCP	DUT-RX	NA	10	634571098	625403476	63027596								
157	AUTO	2	802.11an-AC	80	MTU	UDP	DUT-TX	NA	10	858893629	733473409	73660390								
157	AUTO	2	802.11an-AC	80	MTU	UDP	DUT-RX	NA	10	732609278	727490182	73119490								
157	AUTO	2	802.11an-AC	80	MTU	TCP	DUT-TX	NA	10	719999737	707701884	71061298								
157	AUTO	2	802.11an-AC	80	MTU	TCP	DUT-RX	NA	10	681104936	676757431	680691514	679484896	866600000	-36	0 / 615195	0	866.7 Mbps	866.7 Mbps	802.11an-AC



WiFi Client Reset Test

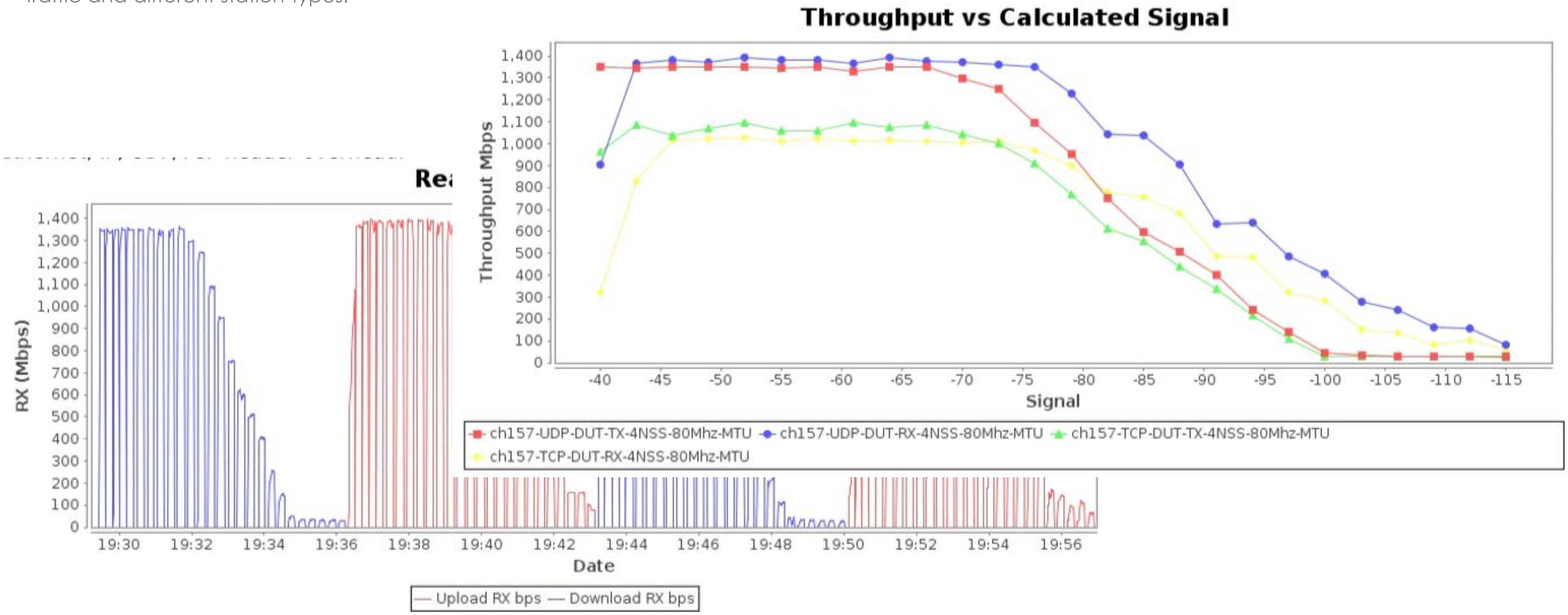
The port reset test allows user to create lots of WiFi stations and connect them the AP under test and then disconnect and reconnect a random number of stations at random intervals. The objective of this test is to mimic an enterprise/large public venue scenario where a number of stations arrive, connect and depart in quick succession. This test when run over a long duration can stress the various control and management aspects of the core Access Point functions and can often times find very interesting problems with the APs.



Testing WiFi networks in highly crowded environments with 1000s of WiFi clients Arriving and Departing.

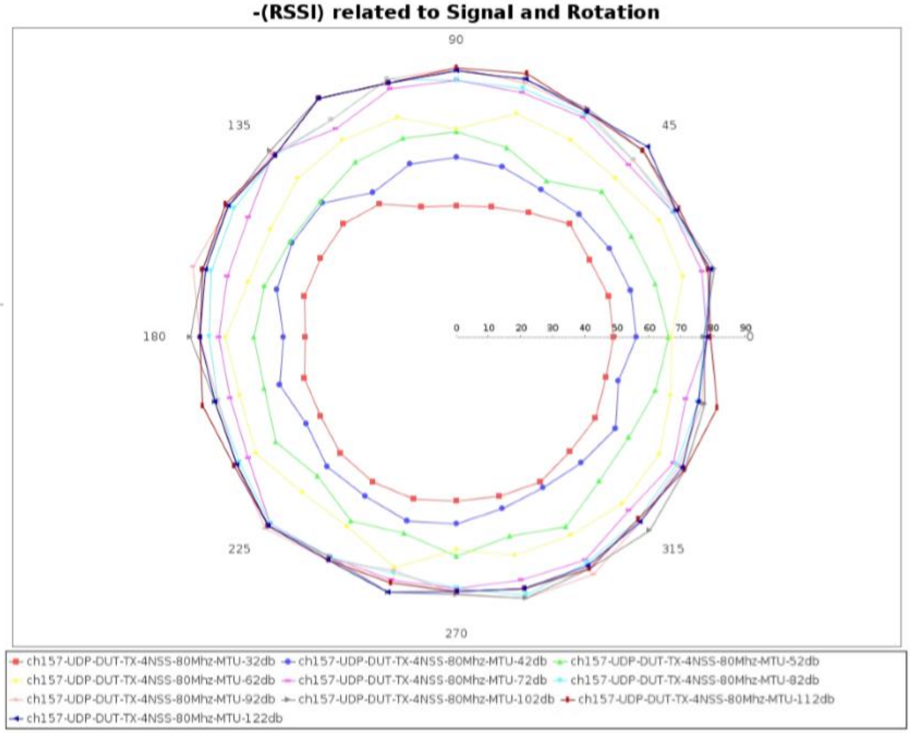
Rate vs Range Test

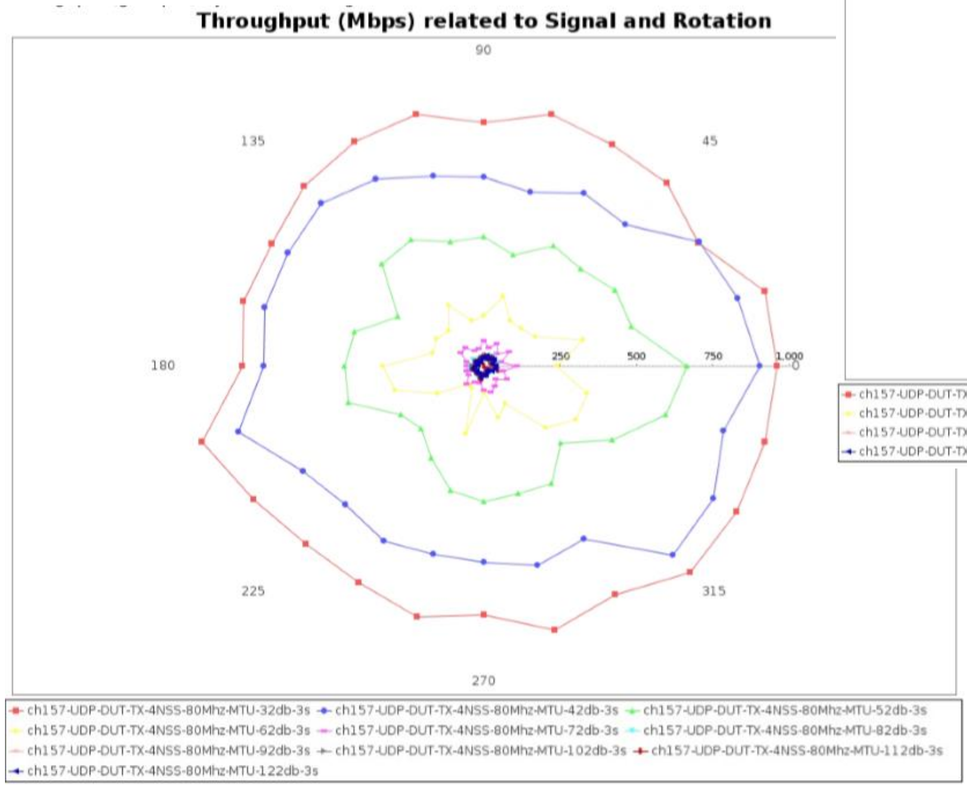
This test measures the performance over distance of the access point. Distance is emulated using programmable attenuation and a throughput test is run at each distance/RSSI step and plotted on a chart. The test allows the user to plot RSSI curves both upstream and downstream for different types of traffic and different station types.

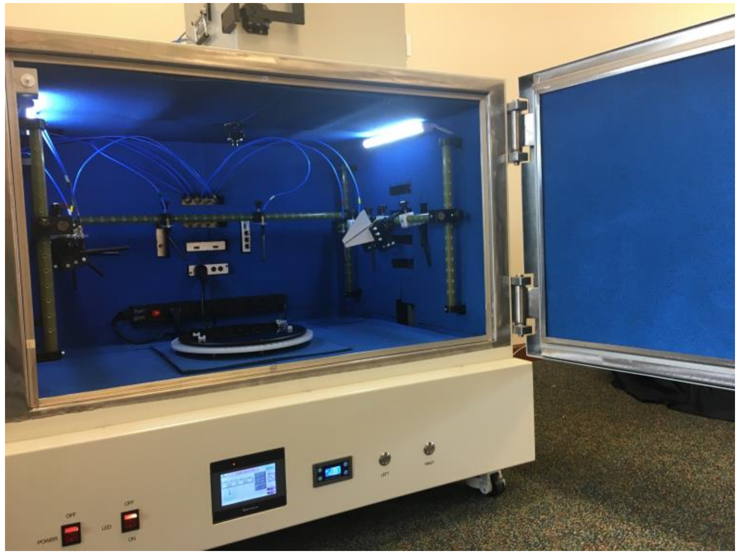


Throughput vs Antenna Orientation

This test measures the performance of the DUT at different antenna orientations. Different antenna orientations of the transmitter will respect to the receiver may results in huge variations of performance caused by antenna nulls and dead spots . Using a large chamber with a programmable turntable, the DUT is rotated to various angles and upstream/downstream throughput is measured at each orientation and the results are plotted on a polar plot.



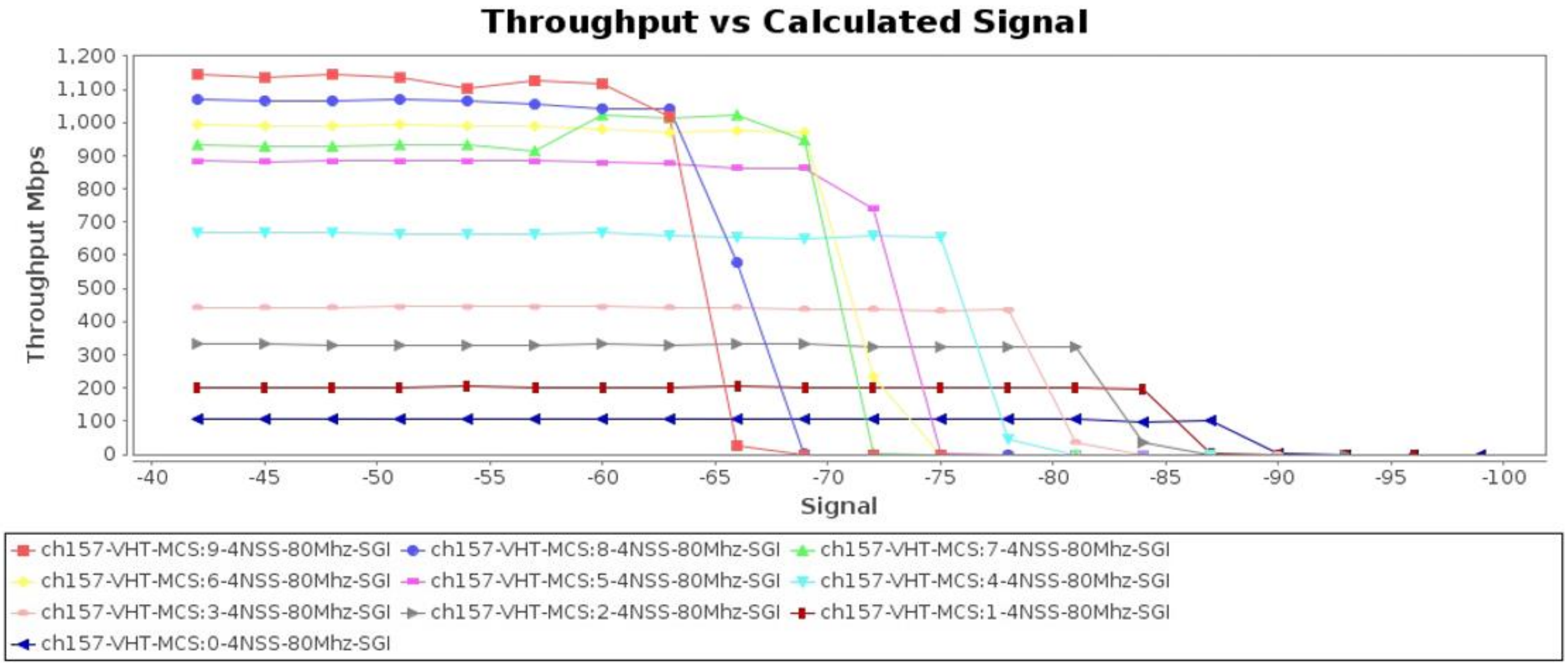




Receiver Sensitivity Test

In the real-world the Access Points receiver is expected to handle stations at many different receive signal strengths and many different stations transmit modulation and coding schemes (MCS rates). The Candela Receiver Sensitivity test provides an excellent way to test the AP receiver for all combinations of station transmit power and MCS rates and measure packet loss and throughput for all combinations.

The test plots the receiver sensitivity curves and can provide a clear indication of problem patterns for certain combinations of Tx power and MCS rates. The expected behavior is for the AP to achieved equal of better receiver sensitivity as defined by the spec for all RSSI and MCS settings.



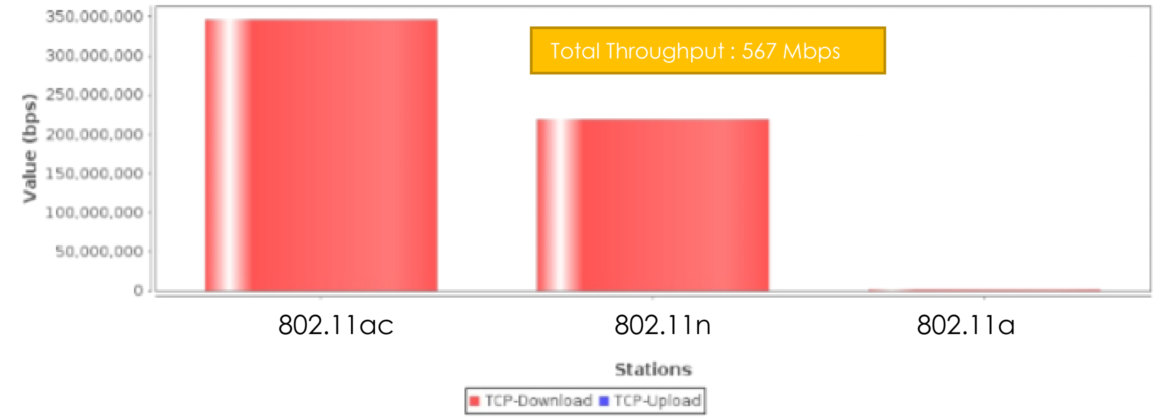
Airtime Fairness Test

Test Description

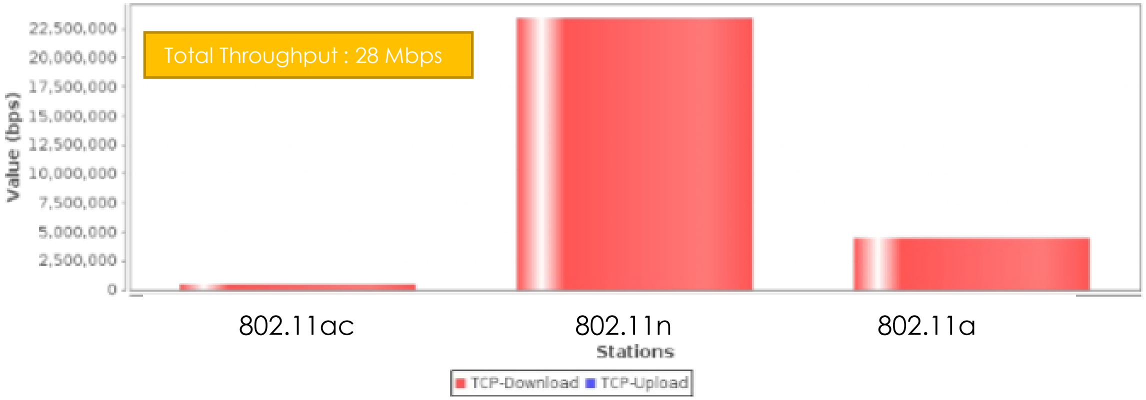
- ✓ Create 3 clients in the 5GHz band. Client1 : 11ac, Client2: 11n and Client3:11a.
- ✓ AP transmitting TCP traffic at full intended load to all three clients.
- ✓ Total throughput and throughput per station were measured.

Result Observations

- ✓ The expected result is that if airtime fairness is working the AP needs to evenly distribute the airtime between the 3 clients resulting in the highest throughput for 11ac and least(by non zero) throughput for 11a client .
- ✓ The Vendor A performed as expected, resulting in a very impressive total throughput of 567Mbps
- ✓ Vendor B performed very poorly and the 11n client performed better than the 11ac client, clearly showing airtime fairness is not working on both these APs.



Vendor A



Vendor B

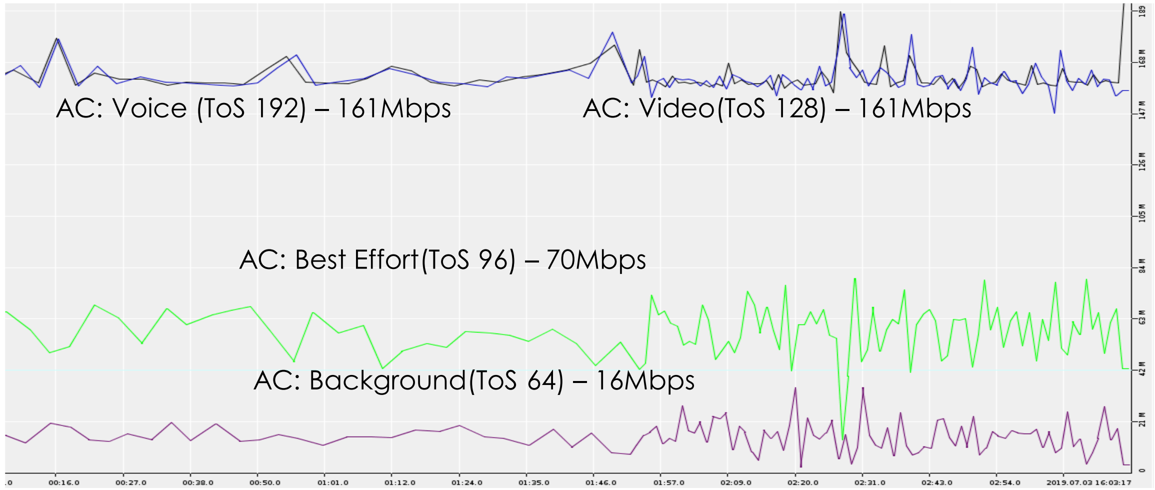
QoS Performance Test

Test Description

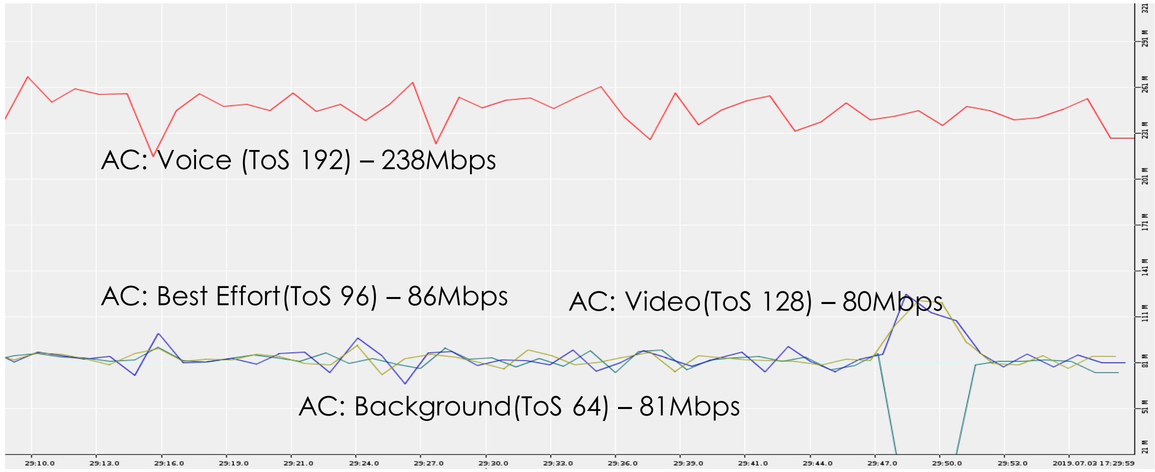
- ✓ Test run with 4 clients connected to the 5GHz radio of the AP under test.
- ✓ Downlink(AP to client) TCP traffic streams were set up to each client with different QoS access categories to each client (Client1: Voice, Client2: Video, Client3: Best Effort a Client4: Background
- ✓ All 4 traffic streams were run at full rate.

Result Observations

- ✓ The Vendor A AP provides similar throughput to Video and Voice traffic and the Best Effort traffic got lower throughput followed by Background with the lowest throughput, clearly showing that QoS works on this AP.
- ✓ The Vendor B AP provided better throughput to Voice traffic, but clearly provided the same amount of throughput for all the other access categories. It looks like this AP has only 2 priority queues instead of the usual 4.



Vendor A



Vendor B

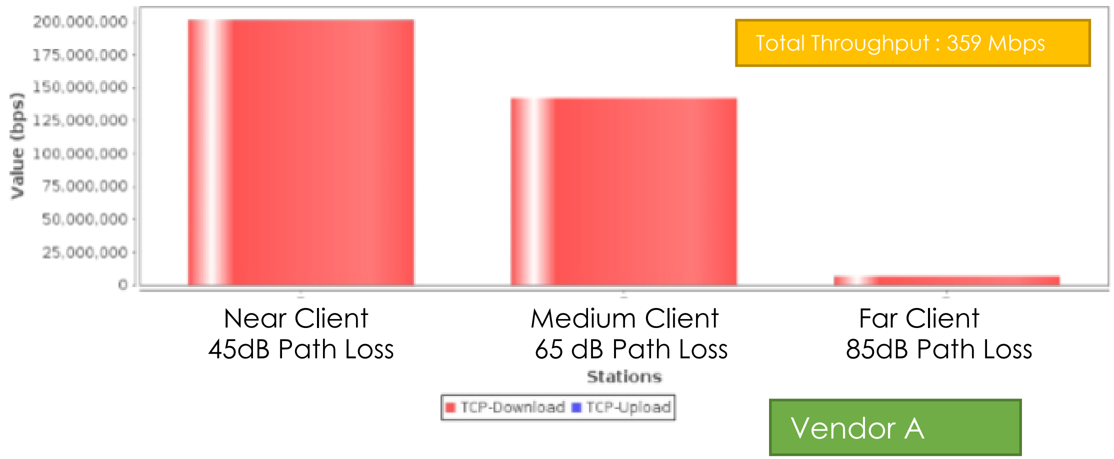
Near/Far Clients Test

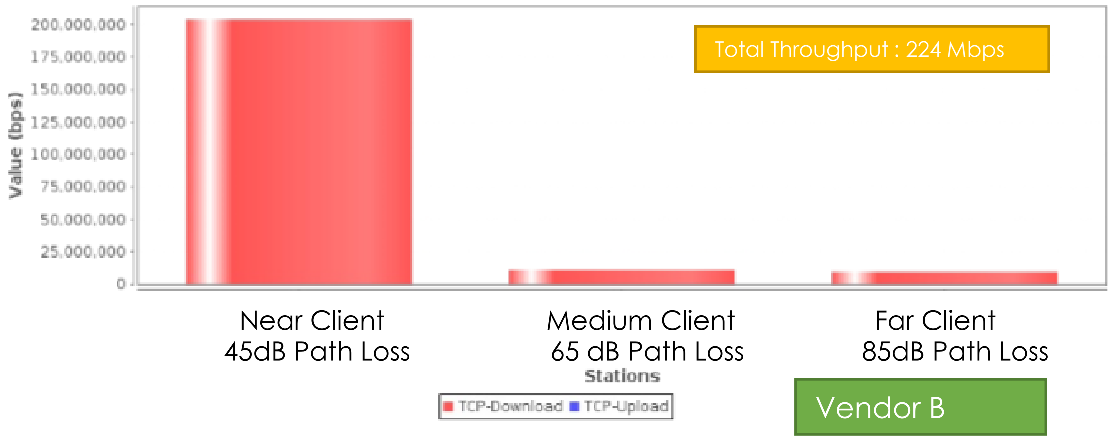
Test Description

- ✓ Three clients were created, one each on three different LANforge radios.
- ✓ Each client is connected to the DUT chamber through a different programmable attenuator allowing for different distances emulated for each client.
- ✓ The path loss created for the three clients was 45dB, 65dB and 85dB representing a Near, Medium Distance and Far Clients respectively.
- ✓ Test run at full rate TCP downstream from AP to all three clients and throughput is measured for each client.

Result Observations

- ✓ In the case of the Netgear AP, the performance was as expected, with the near clients achieving the most throughput with lesser throughput from the Medium and the Far clients.
- ✓ In the case of True APs the throughput dropped steeply for the Medium and the Far clients resulting in a smaller total throughput than the Netgear AP.





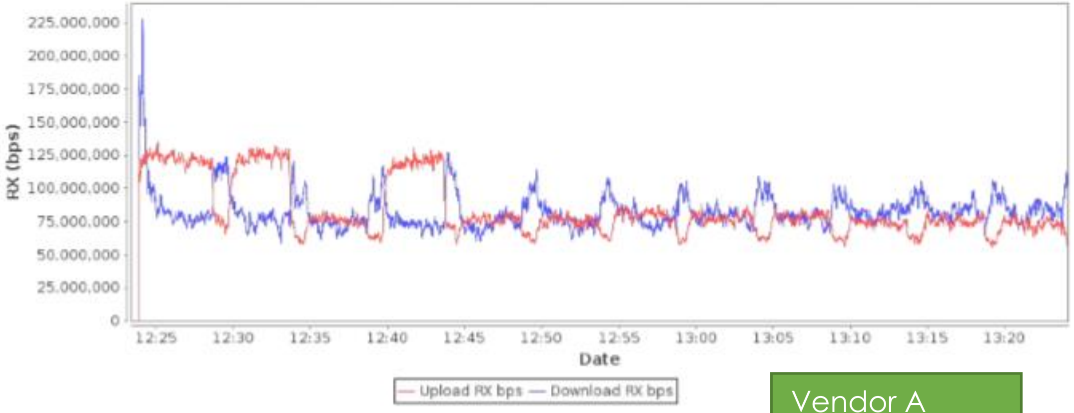
Long Duration Stability

Test Description

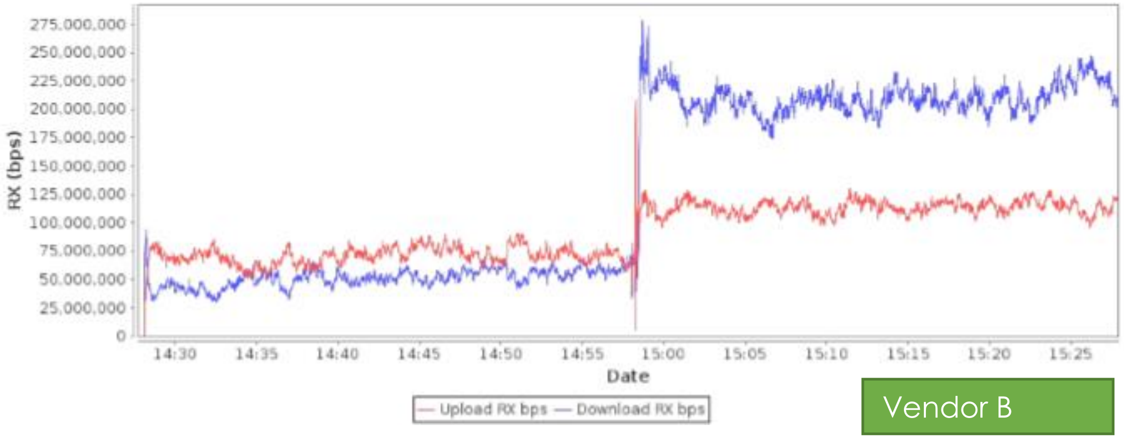
- ✓ This test was run with 32 clients each on both the radios with all client sending and receiving TCP traffic at full rate.
- ✓ The idea was to fully stress the AP for long test duration (in this case 1 hour, but the test should ideally be run for 24 hours).

Result Observations

- ✓ The Vendor A AP showed almost consistent performance all through the 1 hour test duration.
- ✓ The Vendor B AP for a large part of the test had very low throughput as none of the traffic flows on the 5GHz band were running properly. At around the halfway point of the test, the 5GHz traffic started to run and so increased the overall throughput.



Vendor A



Vendor B

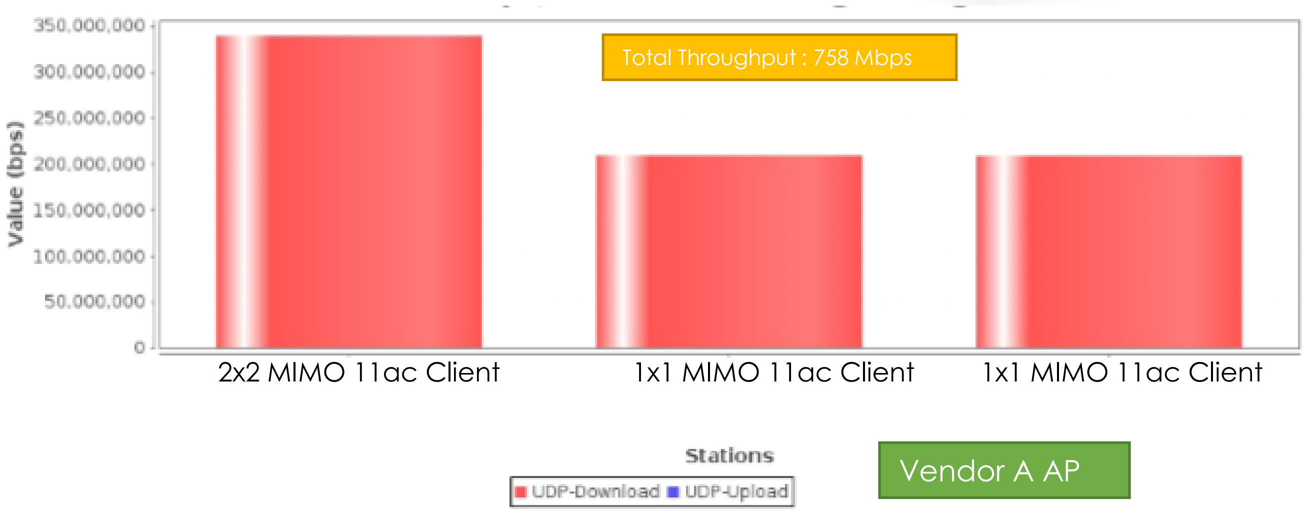
Mu-MIMO Performance Test

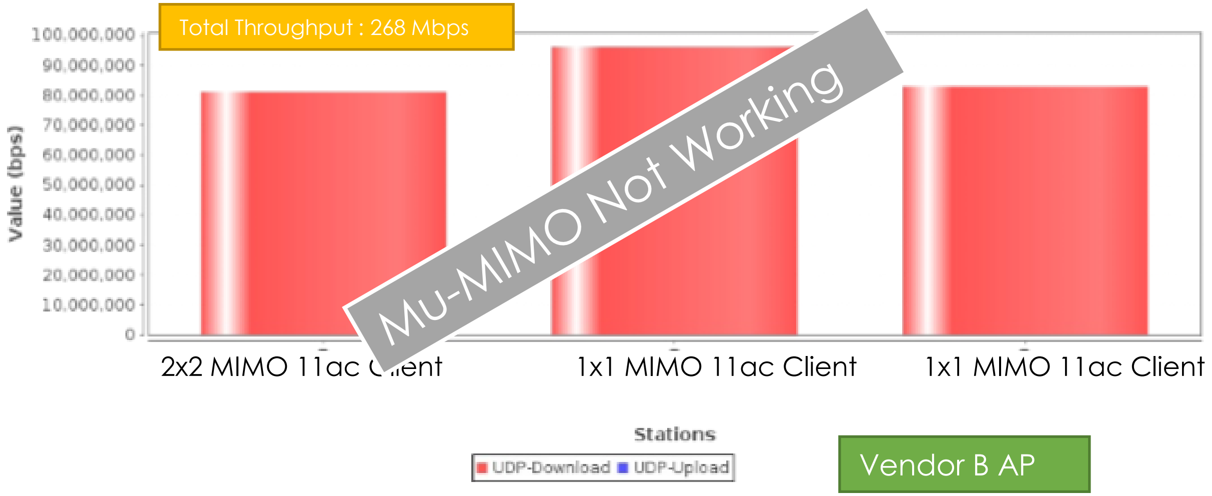
Test Description

- ✓ Test was run with 3 Mu-MIMO clients connected to the APs 5GHz radio. Client1 was set to 2x2 MIMO and Client2 and Client3 were set to 1x1 Mode.
- ✓ TCP traffic is run at full rate from AP to all three stations.

Result Observations

- ✓ The expected result is the 4x4 MIMO AP should be able to beamform simultaneously to all three stations.
- ✓ Vendor A AP performed excellently with 325Mbps throughput to the 2x2 client and 200 Mbps each to the two 1x1 clients, achieving a total of 758Mbps throughput .
- ✓ Mu-MIMO was not working at all on Vendor B AP. Because of this the total throughput was less than 300 Mbps for both the APs.





Day in the Life of a Coffee Shop Access Point

Candela TECHNOLOGIES

Visit date start	Visit date end	Download	Upload	Device	OS	Length of stay
7/10/2019 0:02	7/10/2019 0:04	351627.0 B	113419.0 B	Phone	Android	1m 53s
7/10/2019 0:04	7/10/2019 0:22	4.7105071E7 B	1859678.0 B	Phone	iOS	17m 44s
7/10/2019 0:05	7/10/2019 4:05	1.3008324E7 B	1701971.0 B	Phone	Android	3h 59m 58s
7/10/2019 0:21	7/10/2019 0:21	414.0 B	4179.0 B	Phone	Android	19s
7/10/2019 0:24	7/10/2019 0:26	1527739.0 B	243094.0 B	Phone	Android	1m 20s
7/10/2019 0:27	7/10/2019 0:44	5.9727372E7 B	2756779.0 B	Desktop	Windows NT	16m 52s
7/10/2019 0:31	7/10/2019 0:37	1190041.0 B	88373.0 B	Phone	iOS	6m 28s
7/10/2019 0:34	7/10/2019 1:08	8.5999986E7 B	3489004.0 B	Phone	iOS	33m 50s
7/10/2019 0:35	7/10/2019 0:38	1276129.0 B	852757.0 B	Phone	iOS	3m 7s
7/10/2019 0:36	7/10/2019 0:45	8020413.0 B	1023410.0 B	Phone	Android	9m 42s
7/10/2019 0:39	7/10/2019 0:44	733313.0 B	566094.0 B	Phone	iOS	5m 3s
7/10/2019 0:47	7/10/2019 2:29	2.8476303E8 B	1.1469431E7 B	Phone	Android	1h 41m 50s
7/10/2019 0:53	7/10/2019 0:58	2.11845603E8 B	1.0356751E7 B	Phone	iOS	5m 19s
7/10/2019 1:00	7/10/2019 1:36	4.455044E7 B	5108056.0 B	Phone	Android	35m 44s
7/10/2019 1:05	7/10/2019 1:51	2651742.0 B	728853.0 B	Phone	Android	46m 12s
7/10/2019 1:07	7/10/2019 1:08	3003403.0 B	208901.0 B	Phone	Android	33s
7/10/2019 1:11	7/10/2019 1:27	2.343592E7 B	2657370.0 B	Phone	iOS	15m 57s
7/10/2019 1:13	7/10/2019 4:55	5.3491009E8 B	3.6869387E7 B	Phone	Android	3h 41m 56s
7/10/2019 1:16	7/10/2019 4:34	1.43801092E8 B	6932686.0 B	Phone	Android	3h 18m 3s
7/10/2019 1:22	7/10/2019 5:22	2.11108569E8 B	2.9101562E7 B	Phone	Android	3h 59m 59s
7/10/2019 1:23	7/10/2019 5:23	5423068.0 B	4811633.0 B	Tablet	Android	3h 59m 59s
7/10/2019 1:24	7/10/2019 1:34	1121260.0 B	278450.0 B	Phone	Android	10m 4s
7/10/2019 1:29	7/10/2019 1:38	3.3440411E7 B	1482691.0 B	Phone	iOS	9m 36s
7/10/2019 1:32	7/10/2019 1:34	1528406.0 B	192901.0 B	Phone	iOS	1m 10s
7/10/2019 1:41	7/10/2019 2:40	7.342847E7 B	3158211.0 B	Phone	iOS	58m 50s
7/10/2019 1:52	7/10/2019 2:09	8598326.0 B	938985.0 B	Phone	iOS	16m 56s
7/10/2019 1:55	7/10/2019 1:58	1.5047469E7 B	1440084.0 B	Desktop	Mac OS X	2m 20s
7/10/2019 1:58	7/10/2019 2:10	1.69738271E8 B	4848470.0 B	Desktop	Mac OS X	11m 56s
7/10/2019 1:59	7/10/2019 2:15	5.156241E7 B	2562057.0 B	Phone	Android	15m 34s
7/10/2019 2:04	7/10/2019 2:05	3.3489639E7 B	1243454.0 B	Phone	iOS	1m 37s

Large Scale Client Testbed Requirements

- ✓ Emulate 2000 WiFi Stations
  - ✓ Mix of 11ax, 11ac and 11n stations
- ✓ Test 50 APs representing an entire campus.
  - ✓ APs across different channels, SSIDs, security types etc..
- ✓ Test with 1000s of real work traffic streams.
- ✓ Recreate various real work load scenarios in the lab.
  - ✓ University Campus
  - ✓ Small and Medium Enterprise
  - ✓ Shopping Mall
  - ✓ Small/medium/Large Hotel
- ✓ Create various types of roaming patterns.
- ✓ Create groups of APs to test for load balancing
- ✓ Create application layer traffic to test DPI, device profiling, traffic shaping/policing functions on the AP.
- ✓ Test insight Application.
- ✓ Automate 1000s of test cases and DUT configurations.

Example University Campus Test Profile

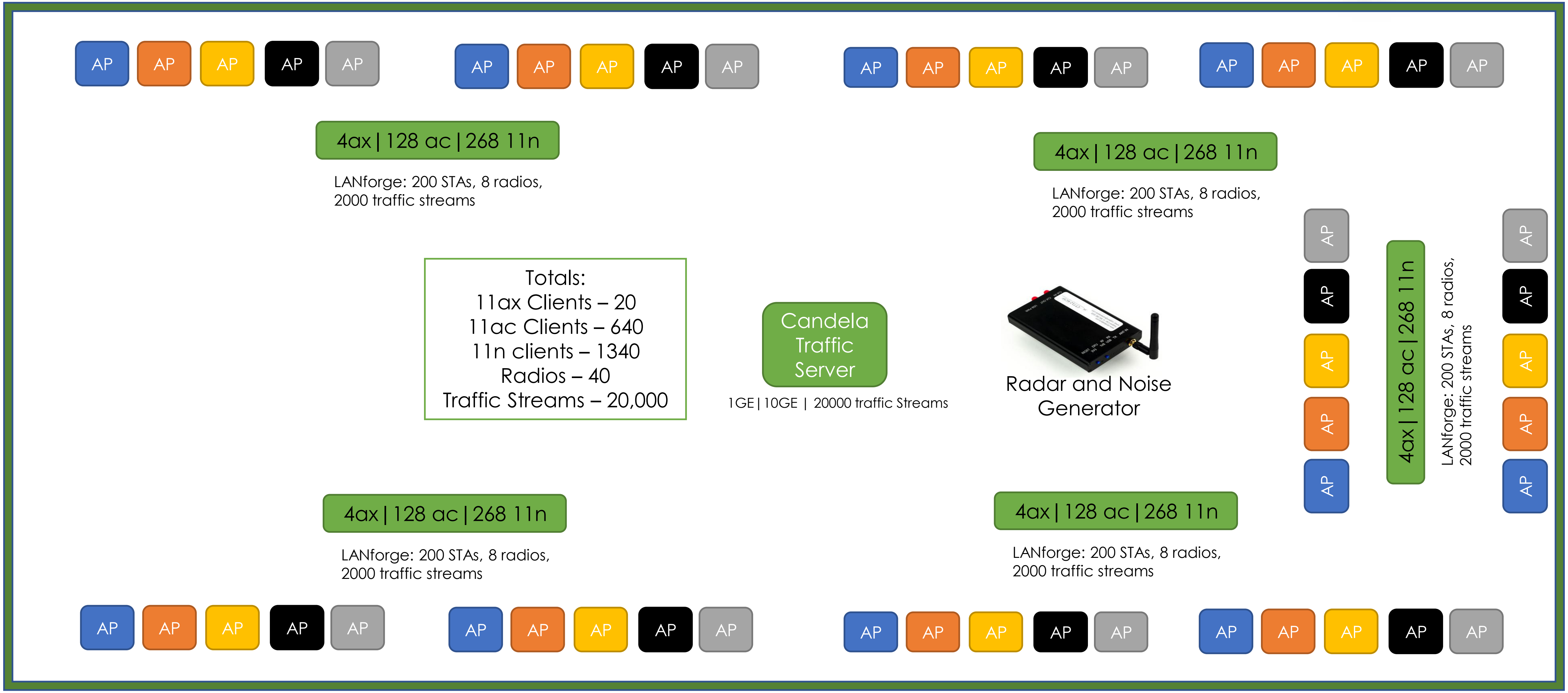
Day-in-the-Life of an University WiFi Network

- 08:00am – 12:00pm
  - ✓ 2000 devices connect to 50 APs across 25 classrooms.
  - ✓ 1000 students start browsing the internet for class research
  - ✓ 500 students watch online lectures
  - ✓ 500 university staff browse internet , place VOIP calls
- 12:00pm – 03:00pm
  - ✓ 1000 students move from classrooms to cafeterias and dorms causing lots of roams.
  - ✓ Students use their personal devices like smartphones and tablets of various kinds.
  - ✓ 200 devices of various kinds (POS terminals, scanners etc..) operate in the cafeterias.
- 03:00pm – 06:00pm
  - ✓ 500 students congregate in the indoor basket ball courts, watch real-time game scores and replays.
  - ✓ 200 students meet in the library and do online research for class projects.
  - ✓ Radar detected on some of the 5GHz channels.
- 06:00pm – 09:00pm
  - ✓ 1000 members are in the school theater participating in the school play and actively sharing details on social media.
  - ✓ 500 students participating in live voting and surveys for student body elections.
  - ✓ 500 students and staff watching soccer game and tweeting.

Key Performance Indicators

- ✓ Client Connection Times
- ✓ Connection Reliability / Uptime
- ✓ Performance over Distance
- ✓ Upload/Download Speeds
- ✓ Roaming Delays
- ✓ Network Latency
- ✓ File Download Times
- ✓ Voice Quality
- ✓ Video buffering and stalls
- ✓ Video streaming Quality
- ✓ Consistent quality over time.

Large Scale Campus Testing in the Lab



AP Auto Test Suite

Candela TECHNOLOGIES

Client Connectivity Test

Connect lots of clients across multiple bands using various security types and measure connection times and provide PASS/FAIL results

Throughput Test

Run a binary search mechanism to measure throughput of the DUT at various packet sizes, compare it with pass criteria and provide PASS/FAIL results

Long Term Stability Test

Create a mix of clients and traffic and run tests for long duration and measure if there is any performance degradation over time.

Dual band Performance Test

Run Throughput on one radio at a time on the AP and then run throughput test simultaneously on both bands (radios) and check if there is degradation in performance when both bands are used

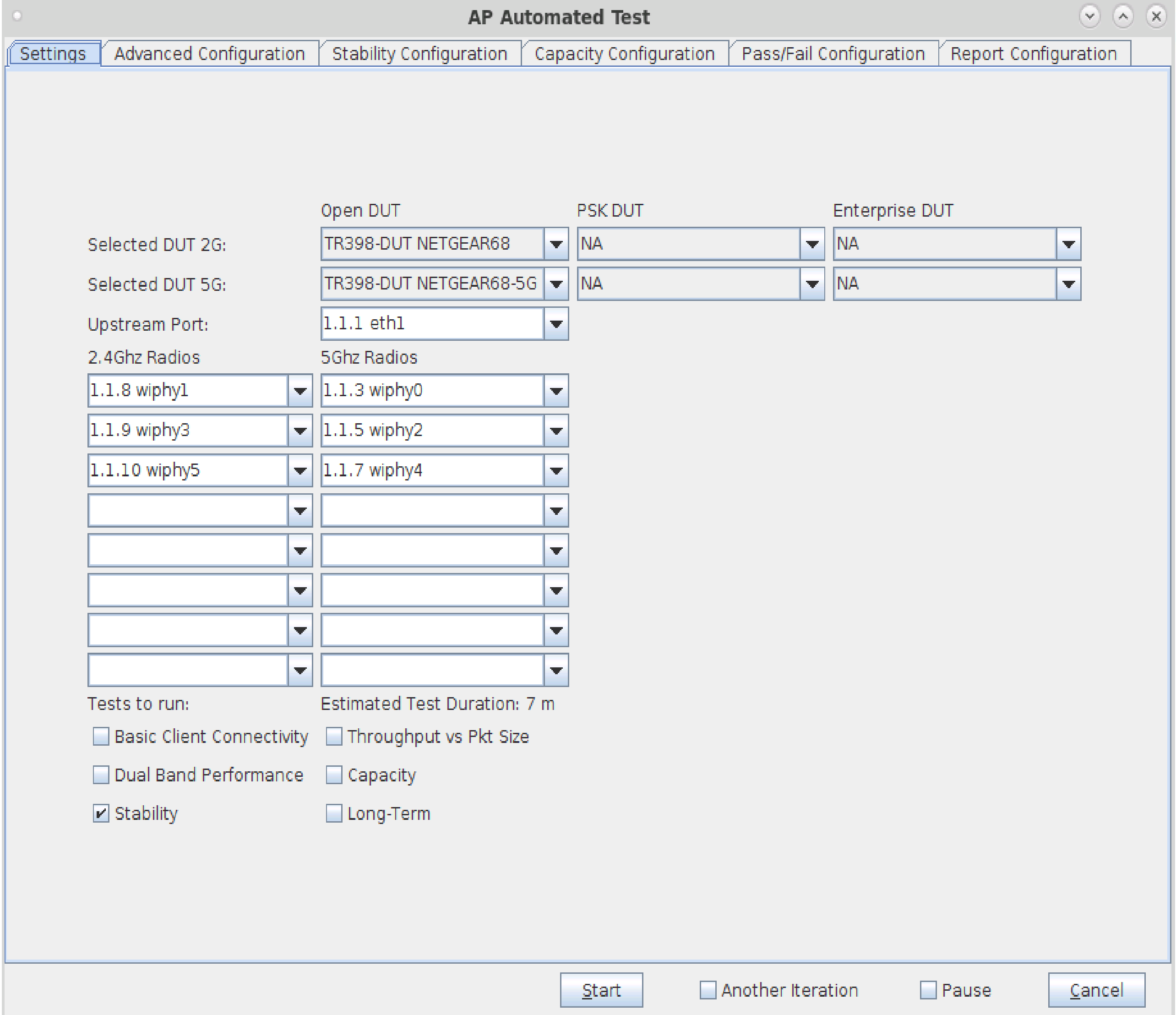
Mixed Stability Test

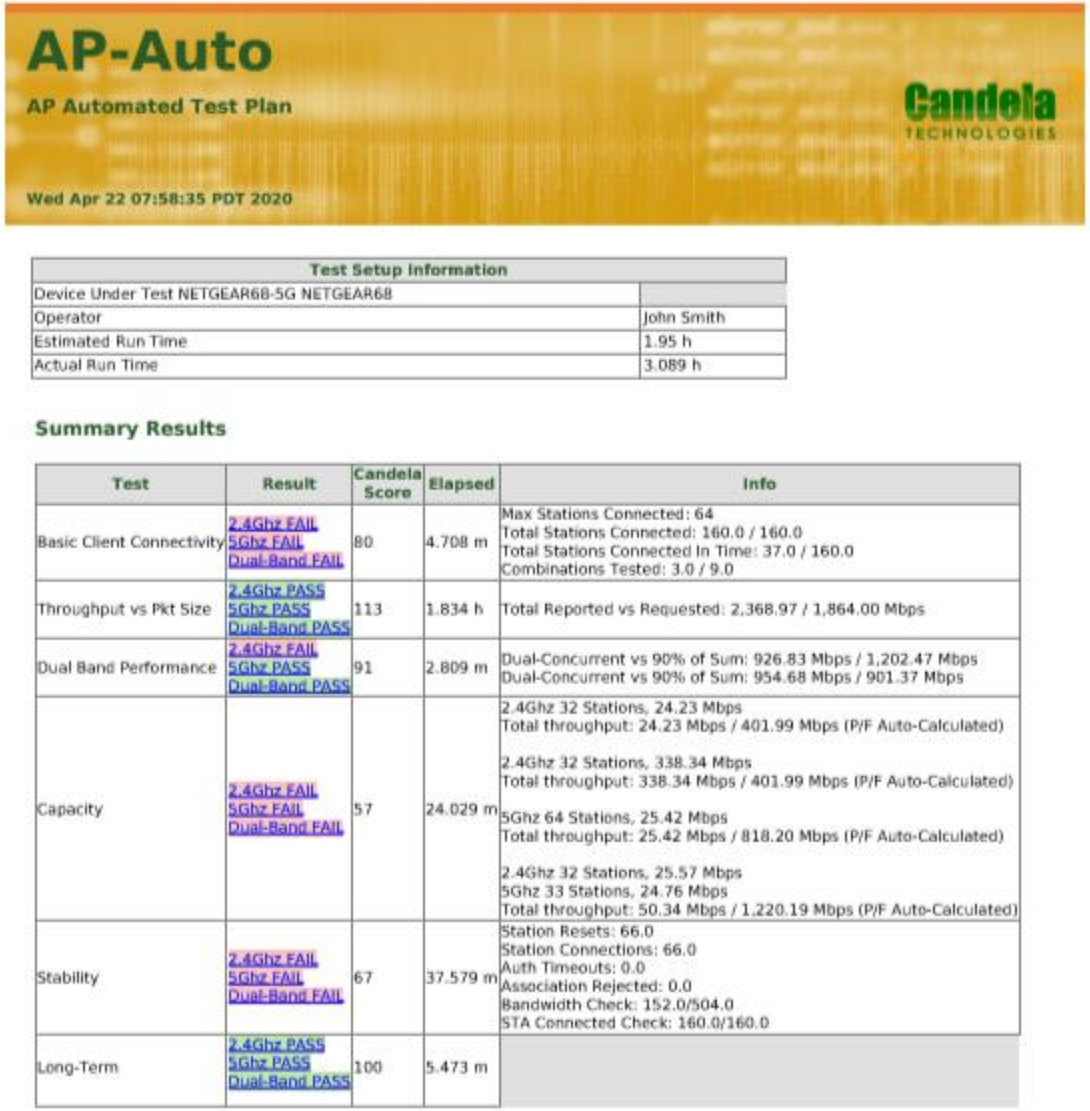
Allows the user to create a mix of voice, video and data traffic and run tests for long durations with a large number of clients to mimic real-world client and traffic load patterns.

Mixed Capacity Test

Allows the user to create a mix of voice, video and data traffic and run tests for long durations with a large number of clients while randomly disconnecting and reconnecting clients.

AP Auto Test Suite





AP-Auto

AP Automated Test Plan

Candela TECHNOLOGIES

Wed Apr 22 07:58:35 PDT 2020

Test Setup Information	
Device Under Test NETGEAR68-5G NETGEAR68	
Operator	John Smith
Estimated Run Time	1.95 h
Actual Run Time	3.089 h

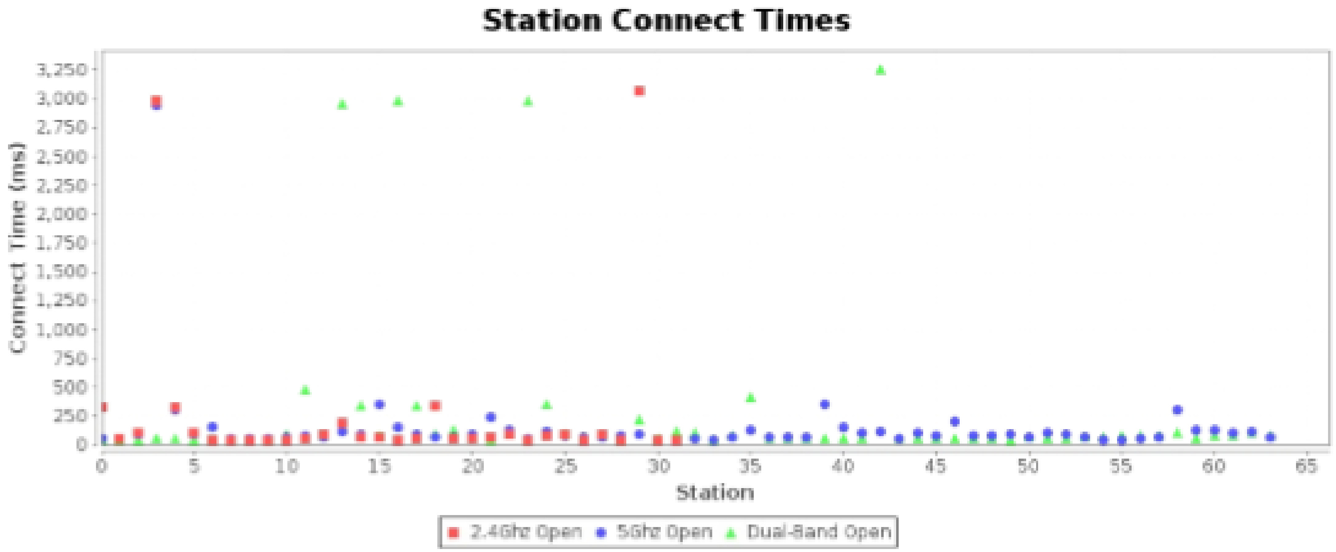
Summary Results

Test	Result	Candela Score	Elapsed	Info
Basic Client Connectivity	2.4Ghz FAIL 5Ghz FAIL Dual-Band FAIL	80	4.708 m	Max Stations Connected: 64 Total Stations Connected: 160.0 / 160.0 Total Stations Connected In Time: 37.0 / 160.0 Combinations Tested: 3.0 / 9.0
Throughput vs Pkt Size	2.4Ghz PASS 5Ghz PASS Dual-Band PASS	113	1.834 h	Total Reported vs Requested: 2,368.97 / 1,864.00 Mbps
Dual Band Performance	2.4Ghz FAIL 5Ghz PASS Dual-Band PASS	91	2.809 m	Dual-Concurrent vs 90% of Sum: 926.83 Mbps / 1,202.47 Mbps Dual-Concurrent vs 90% of Sum: 954.68 Mbps / 901.37 Mbps
Capacity	2.4Ghz FAIL 5Ghz FAIL Dual-Band FAIL	57	24.029 m	2.4Ghz 32 Stations, 24.23 Mbps Total throughput: 24.23 Mbps / 401.99 Mbps (P/F Auto-Calculated) 2.4Ghz 32 Stations, 338.34 Mbps Total throughput: 338.34 Mbps / 401.99 Mbps (P/F Auto-Calculated) 5Ghz 64 Stations, 25.42 Mbps Total throughput: 25.42 Mbps / 818.20 Mbps (P/F Auto-Calculated) 2.4Ghz 32 Stations, 25.57 Mbps 5Ghz 33 Stations, 24.76 Mbps Total throughput: 50.34 Mbps / 1,220.19 Mbps (P/F Auto-Calculated)
Stability	2.4Ghz FAIL 5Ghz FAIL Dual-Band FAIL	67	37.579 m	Station Resets: 66.0 Station Connections: 66.0 Auth Timeouts: 0.0 Association Rejected: 0.0 Bandwidth Check: 152.0/504.0 STA Connected Check: 160.0/160.0
Long-Term	2.4Ghz PASS 5Ghz PASS Dual-Band PASS	100	5.473 m	

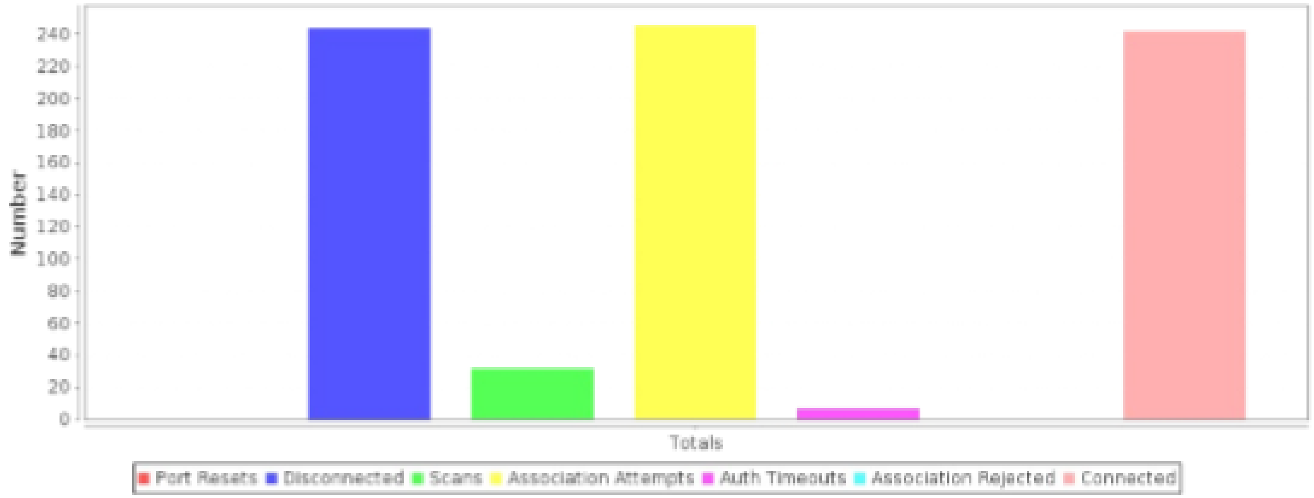
AP Auto : Client Connectivity Test

The client connectivity test is designed to check how well the AP can handle lots of clients trying to connect at the same time across both 2.4 and 5 GHz bands. The test systems creates and connects lot of clients and measures client connection times, number of scans, association attempts, Auth timeouts, Association rejections etc..

The test also lets the user define a PASS/FAIL criteria and the provides the user test results.



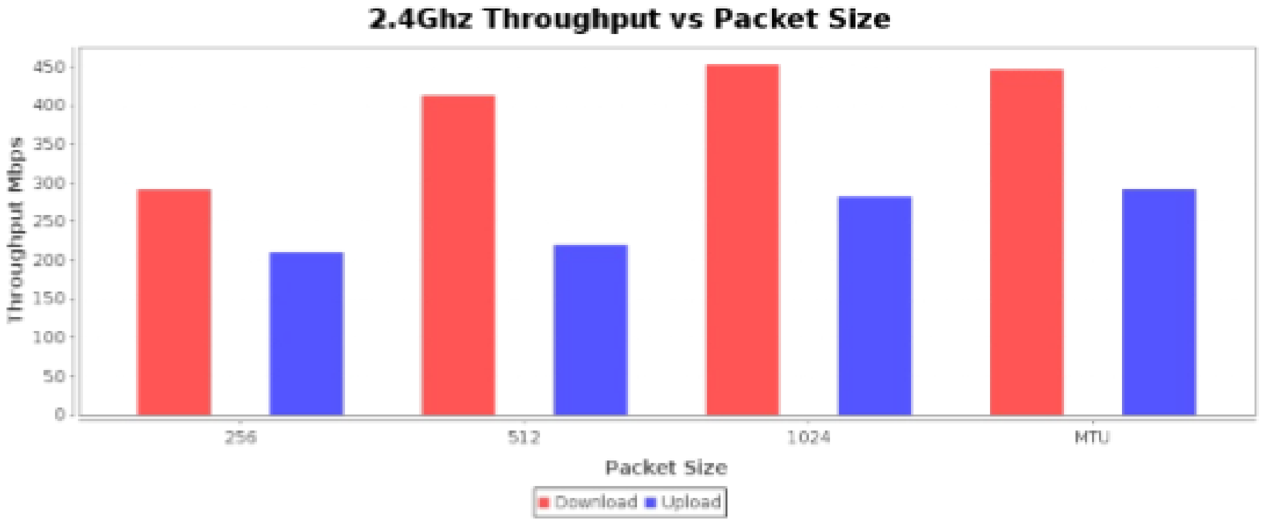
Type	Result	Notes
DUT: TR398-DUT NETGEAR68 CH 1 1.1.10 sta00500	FAIL	PSK DHCP: 14683ms Connect: 324 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.11 sta00501	FAIL	PSK DHCP: 10155ms Connect: 58 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.12 sta00502	FAIL	PSK DHCP: 8162ms Connect: 102 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.13 sta00503	FAIL	PSK DHCP: 3161ms Connect: 2984 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.14 sta00504	FAIL	PSK DHCP: 13416ms Connect: 334 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.15 sta00505	FAIL	PSK DHCP: 10179ms Connect: 107 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.16 sta00506	PASS	PSK DHCP: 7479ms Connect: 41 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.17 sta00507	PASS	PSK DHCP: 7448ms Connect: 41 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.18 sta00508	PASS	PSK DHCP: 7022ms Connect: 38 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.19 sta00509	PASS	PSK DHCP: 7623ms Connect: 39 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.20 sta00510	PASS	PSK DHCP: 7426ms Connect: 40 / 50 ms
DUT: TR398-DUT NETGEAR68 CH 1 1.1.21 sta01000	FAIL	PSK DHCP: 16181ms Connect: 61 / 50 ms

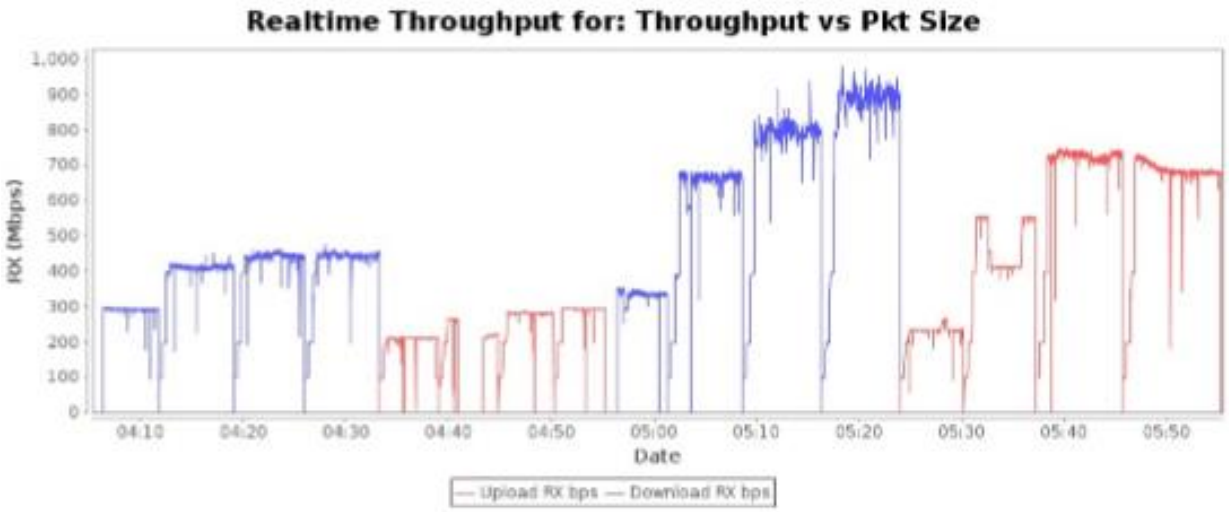


AP Auto : Throughput Test

The throughput test conducts a binary search and measures the maximum amount of traffic that can be forwarded at zero or acceptable packet loss. This procedure is repeated for each packet size and each frequency band.

Throughput is plotted for each frame size and PASS/FAIL results are provided based on the user defined criteria.





Throughput vs Pkt Size Results

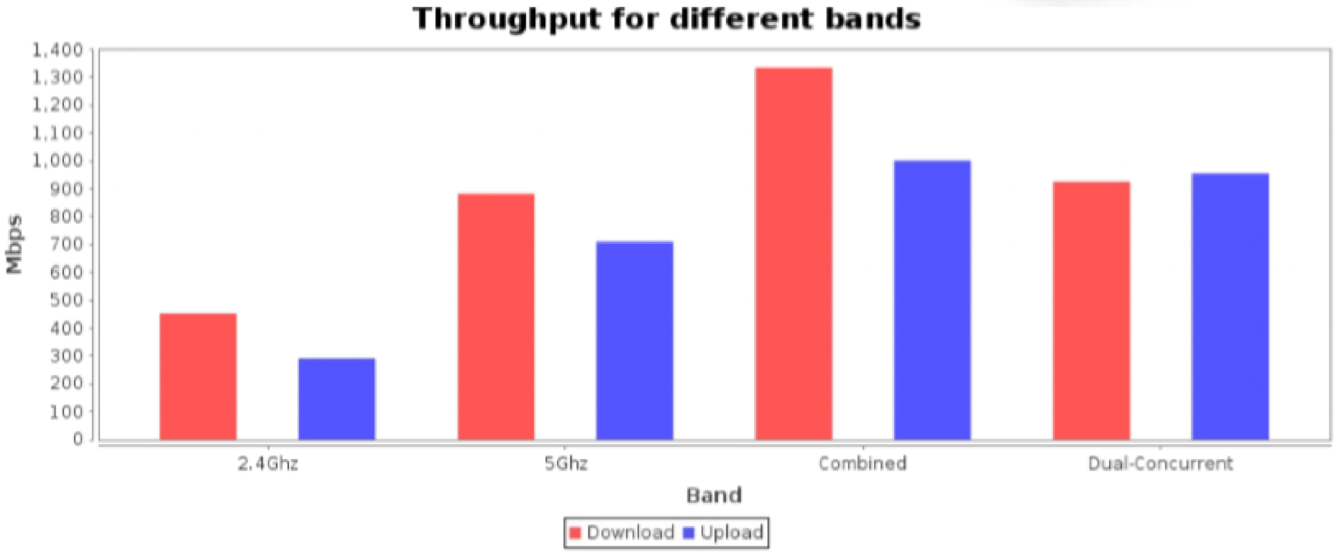
Type	Result	Notes
2.4Ghz Download 256	Info	291.59 Mbps PER: 0.63
2.4Ghz Download 512	Info	413.21 Mbps PER: 0.04
2.4Ghz Download 1024	Info	452.84 Mbps PER: 0.95
2.4Ghz Download MTU	PASS	446.66 / 282.00 Mbps PER: 0
2.4Ghz Upload 256	Info	210.02 Mbps PER: 0
2.4Ghz Upload 512	Info	219.85 Mbps PER: 0
2.4Ghz Upload 1024	Info	281.95 Mbps PER: 0
2.4Ghz Upload MTU	PASS	291.84 / 282.00 Mbps PER: 0
5Ghz Download 256	Info	332.36 Mbps PER: 0.76
5Ghz Download 512	Info	668.76 Mbps PER: 0.58
5Ghz Download 1024	Info	803.04 Mbps PER: 0.24
5Ghz Download MTU	PASS	909.11 / 650.00 Mbps PER: 0
5Ghz Upload 256	Info	260.56 Mbps PER: 0
5Ghz Upload 512	Info	551.01 Mbps PER: 0
5Ghz Upload 1024	Info	732.04 Mbps PER: 0
5Ghz Upload MTU	PASS	721.37 / 650.00 Mbps PER: 0

Throughput Test Result Analysis Example

	Traffic Type	Traffic Direction	STA Mode	Frame Size												
Channel BW =>					20 MHz				40 MHz				80 MHz			
MIMO Type =>					NSS1	NSS2	NSS3	NSS4	NSS1	NSS2	NSS3	NSS4	NSS1	NSS2	NSS3	NSS4
	TCP	DUT-RX	802.11a	142 Bytes	32%											
				256 Bytes	32%											
				512 Bytes	50%											
				1024 Bytes	63%											
				1518 Bytes	84%											
			802.11an	142 Bytes	44%	66%	73%	66%	48%	68%	60%	46%				
				256 Bytes	48%	66%	71%	72%	52%	71%	72%	40%				
				512 Bytes	62%	70%	76%	80%	68%	80%	81%	77%				
				1024 Bytes	68%	71%	75%	74%	73%	75%	74%	65%				
				1518 Bytes	75%	74%	84%	83%	77%	73%	88%	82%				
			802.11an-AC	142 Bytes									18%	35%	32%	27%
				256 Bytes									35%	39%	34%	30%
				512 Bytes									51%	64%	63%	55%
				1024 Bytes									62%	66%	71%	67%
				1518 Bytes									73%	62%	73%	79%
		DUT-TX	802.11a	142 Bytes	33%											
				256 Bytes	30%											
				512 Bytes	45%											
				1024 Bytes	55%											
				1518 Bytes	59%											
			802.11an	142 Bytes	40%	45%	33%	28%	37%	36%	27%	21%				
				256 Bytes	48%	51%	38%	32%	43%	42%	28%	32%				
				512 Bytes	71%	72%	50%	41%	64%	68%	49%	55%				
				1024 Bytes	88%	85%	56%	59%	79%	80%	64%	62%				
				1518 Bytes	89%	89%	55%	59%	86%	84%	68%	59%				
			802.11an-AC	142 Bytes									2%	32%	27%	23%
				256 Bytes									44%	36%	31%	27%
				512 Bytes									65%	56%	48%	43%
				1024 Bytes									78%	61%	40%	48%
				1518 Bytes									84%	62%	43%	57%

AP Auto : Dual Band Performance Test

The Dual band performance test is designed to check if the AP has any systems limitations with resources that are shared across multiple radios on the AP. The test runs traffic at full rate on the 2.4GHz first and then repeats the test in the 5 GHz band. Then the tests is run with full line rate traffic on both bands simultaneously. The combined throughput across both the bands when the tests are run separately are compared to the combined throughout when both the bands are loaded simultaneously . The PASS/FAIL criteria is determined based on how close the dual concurrent throughput is to the combined throughput.

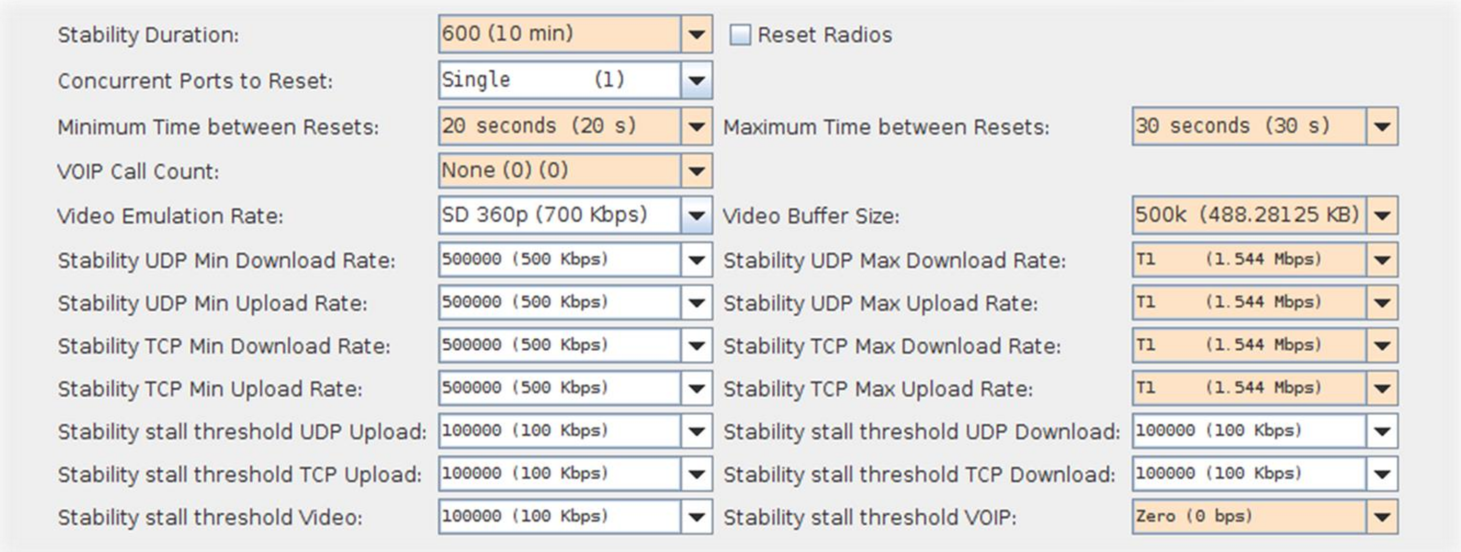


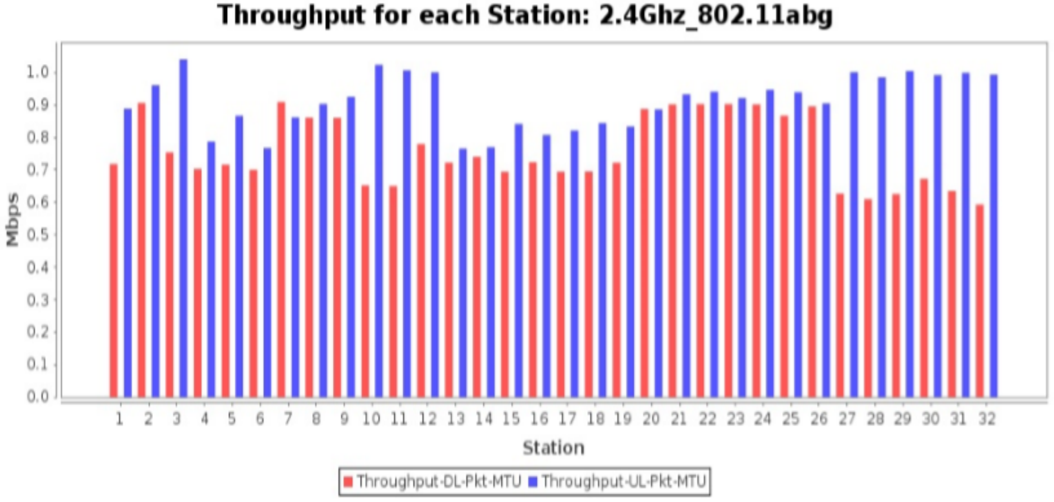
Dual Band Performance Results

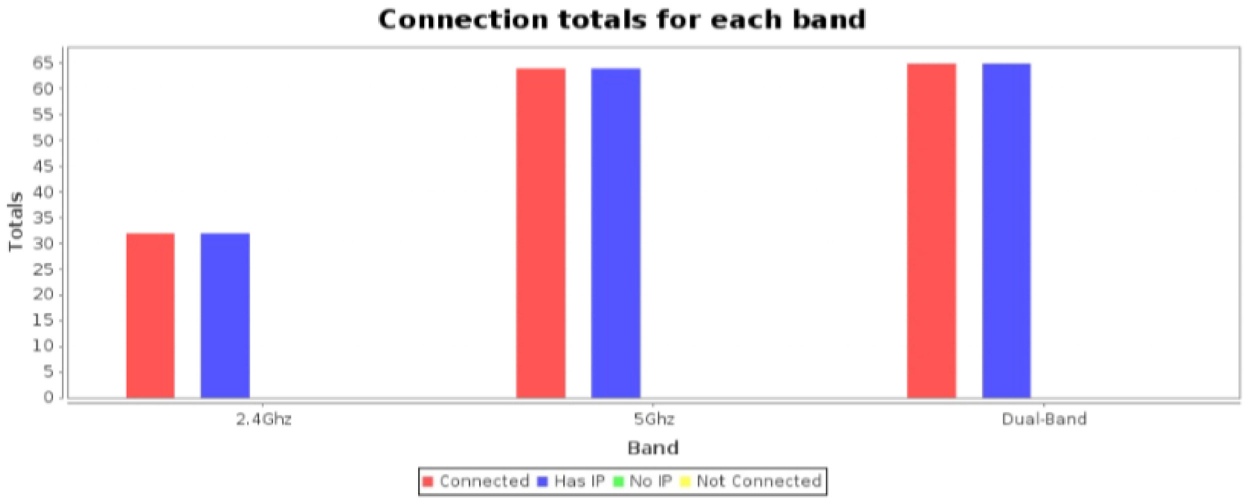
Type	Result	Notes
2.4Ghz Download	PASS	453.28 Mbps PER: 7.01
5Ghz Download	PASS	882.79 Mbps PER: 1.71
Dual-Concurrent Download	FAIL	926.83 Mbps PER: 2.16 Dual-Concurrent vs 90% of Sum: 926.83 Mbps / 1,202.47 Mbps
2.4Ghz Upload	PASS	292.03 Mbps PER: 0
5Ghz Upload	PASS	709.50 Mbps PER: 0
Dual-Concurrent Upload	PASS	954.68 Mbps PER: 0 Dual-Concurrent vs 90% of Sum: 954.68 Mbps / 901.37 Mbps

AP Auto : Mixed Stability Test

This test allows the user to create a number if real world test scenarios with a mix of voice, video and data traffic streams with lots of WiFi clients connecting and disconnecting to the WiFi network. This test is designed to bring more realism to testing in the lab and reproducing very interesting memory leaks, deadlocks and other AP performance problems that are missed in lab testing and only appear in the real when dealing with diverse client/load patters, stress, scale and long service hours.

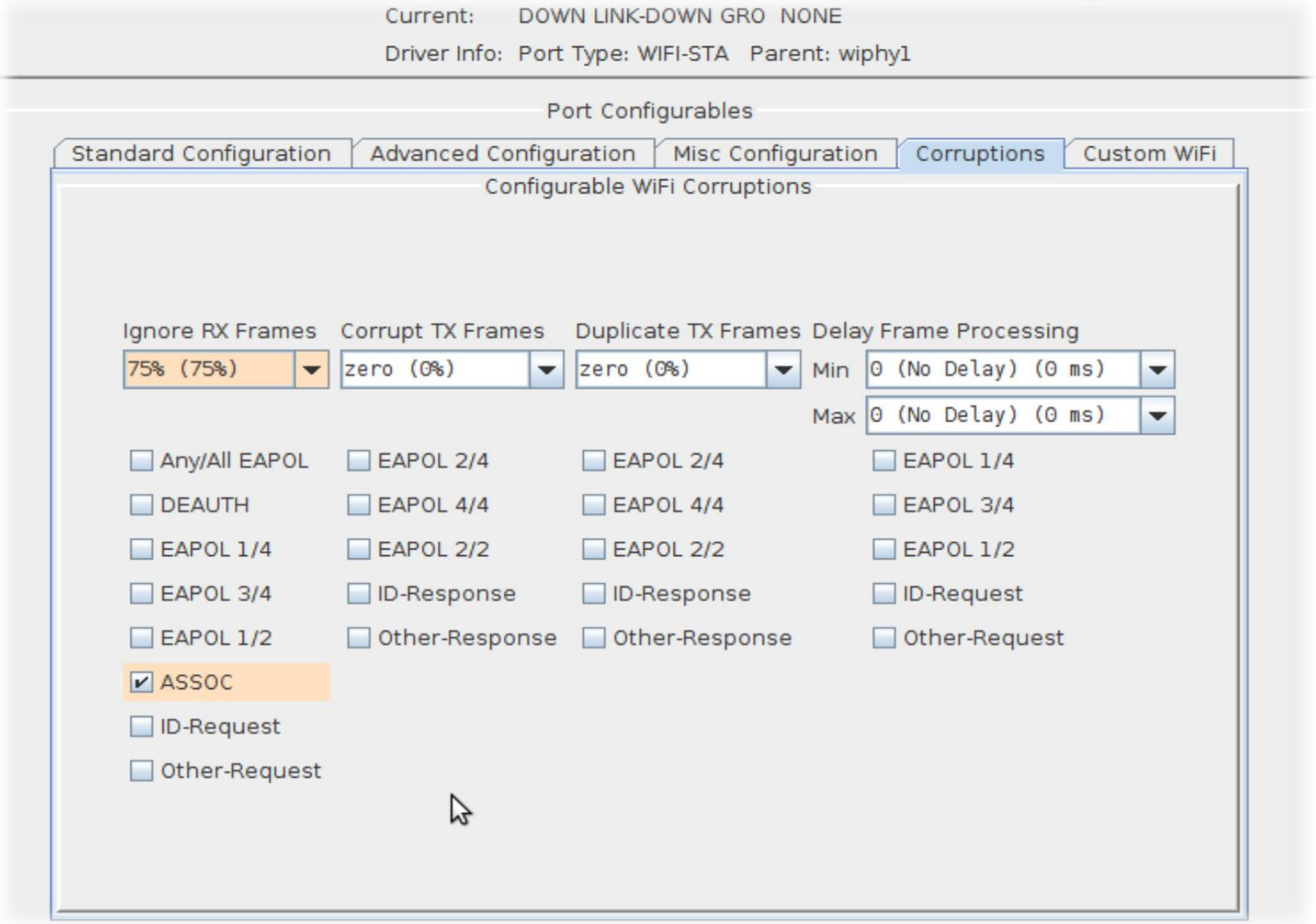






Emulating Misbehaving WiFi Clients

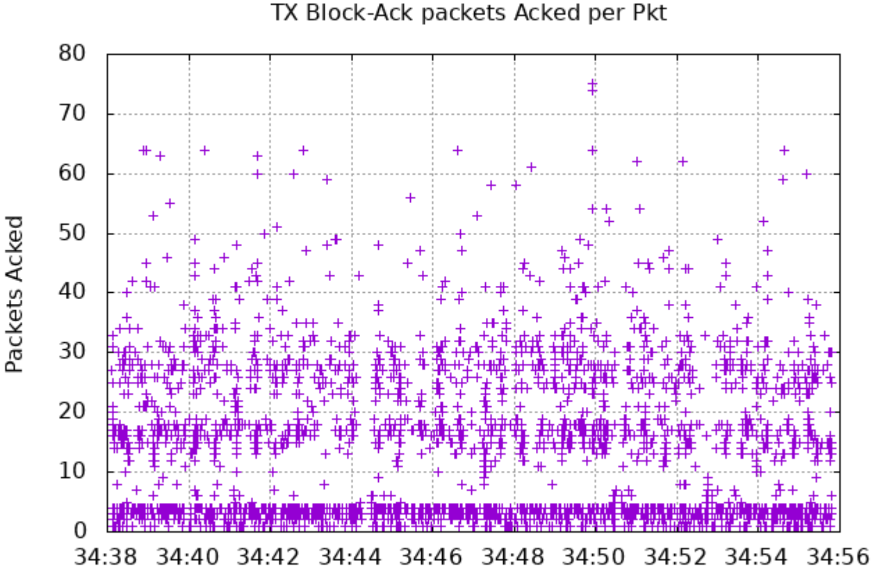
- Create misbehaving clients that can mimic real-world client behaviors.
- On a per client basis set the following on various management frames.
  - Ignore % RX Frames
  - Corrupt % TX Frames
  - Duplicate % TX Frames
  - Delay Frame Responses
- Select one or more types of frames to apply these corruptions.



Wireshark Capture File Analysis

RX (All) Retransmit percentage: 5197/78377 == 6.63077178253825
RX (Big) Retransmit count: 5197
TX (All) Retransmit percentage: 3/7108 == 0.0422059651097355
TX (Big) Retransmit count: 0
RX (All) no-ack-found: 56234
RX (Big) no-ack-found: 55705
TX (All) no-ack-found: 6
TX (Big) no-ack-found: 0
RX average gap between AMPDU frames (ms): 0.00344110614165813

RX average AMPDU chain time (ms): 0.0465246330408624
TX BA to RX AMPDU average gap (ms): 1.53520291279184
RX BA to TX AMPDU average gap (ms): 61.600923538208
Duplicate TX BA without AMPDU between them: 54
Duplicate RX BA without AMPDU between them: 32
WMM Info from DUT Beacon



TX Packet Type histogram

Type	Packets	Percentage
802.11 Block Ack (0x0019)	3657	51.449071
Acknowledgement (0x001d)	9	0.126618
Clear-to-send (0x001c)	3390	47.692741
QoS Data (0x0028) Best Effort (Best Effort)	51	0.717501
Request-to-send (0x001b)	1	0.014069

RX Packet Type histogram

Type	Packets	Percentage
802.11 Block Ack (0x0019)	51	0.065070
Beacon frame (0x0008)	68	0.086760
Data (0x0020)	2	0.002552
Probe Response (0x0005)	11	0.014035
QoS Data (0x0028) Background (Background)	7	0.008931
QoS Data (0x0028) Best Effort (Best Effort)	77121	98.397489
QoS Data (0x0028) Controlled Load (Video)	23	0.029345
QoS Data (0x0028) Excellent Effort (Best Effort)	1	0.001276
QoS Data (0x0028) Network Control (Voice)	5	0.006379
QoS Data (0x0028) Spare (Background)	9	0.011483
QoS Data (0x0028) Video (Video)	4	0.005104
QoS Data (0x0028) Voice (Voice)	8	0.010207
QoS Data + CF-Acknowledgment (0x0029) Best Effort (Best Effort)	2	0.002552
QoS Data + CF-Poll (0x002a) Best Effort (Best Effort)	3	0.003828
QoS Data + CF-Poll (0x002a) Controlled Load (Video)	1	0.001276
QoS Null function (No data) (0x002c) Best Effort (Best Effort)	3	0.003828
Request-to-send (0x001b)	530	0.676219
Unknown (0x002d) Best Effort (Best Effort)	1	0.001276
VHT/HE NDP Announcement (0x0015)	527	0.672391

RX AMPDU chain count histogram

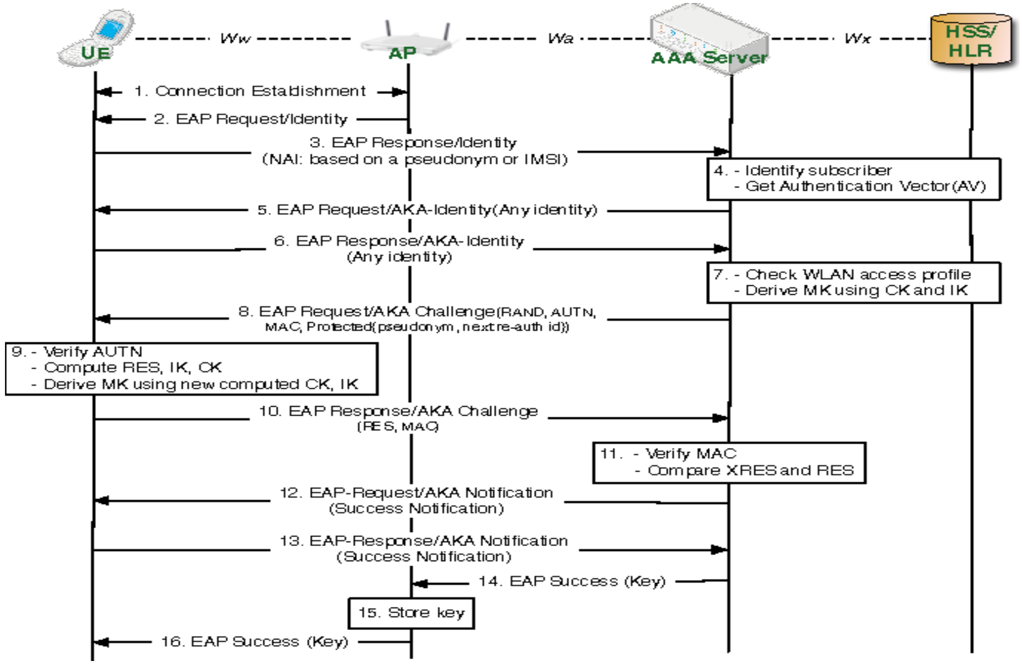
Average: 8.7571297481141

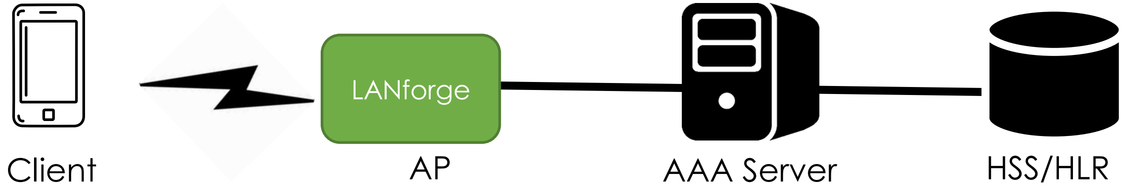
Chain Count	Packets	Percentage
2	43	1.977921
3	834	38.362466
4	726	33.394664
5	20	0.919963
6	32	1.471941
7	22	1.011960
8	5	0.229991
9	3	0.137994
10	1	0.045998
11	2	0.091996
12	4	0.183993
13	1	0.045998
14	5	0.229991
15	9	0.413983
16	5	0.229991
17	4	0.183993
18	2	0.091996
19	6	0.275989
20	8	0.367985
21	5	0.229991
22	18	0.827967

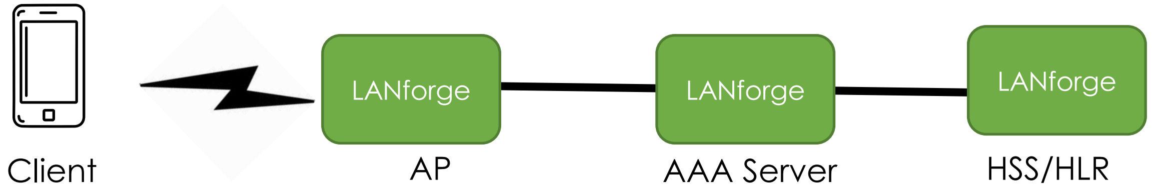
TX Encoding rate histogram.

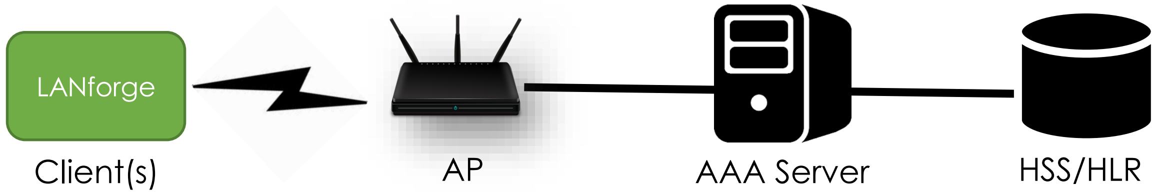
Rate Mbps	Packets	Percentage
6.0	3539	49.788970
12.0	9	0.126618
14.4	1	0.014069
24.0	3509	49.366911
28.8	1	0.014069
30.0	1	0.014069
45.0	1	0.014069
54.0	1	0.014069
58.5	1	0.014069
58.6	6	0.084412
60.0	1	0.014069
65.0	1	0.014069
87.9	12	0.168824
97.5	2	0.028137
117.0	2	0.028137
117.2	5	0.070343
130.0	2	0.028137
175.5	3	0.042206
195.0	1	0.014069
260.0	4	0.056275
263.4	2	0.028137
292.5	1	0.014069
390.0	1	0.014069
468.0	2	0.028137

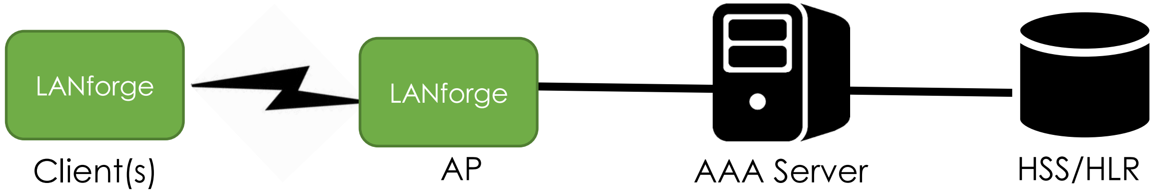
EAP-SIM and EAP-AKA Testing

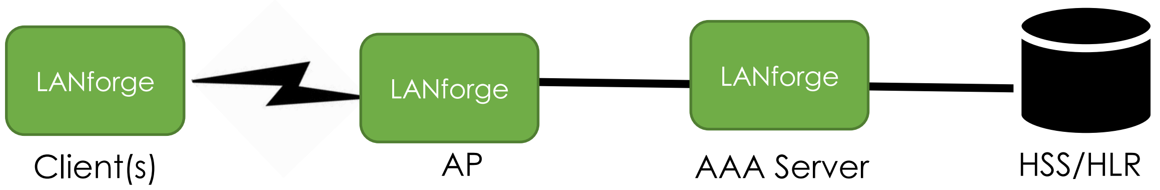


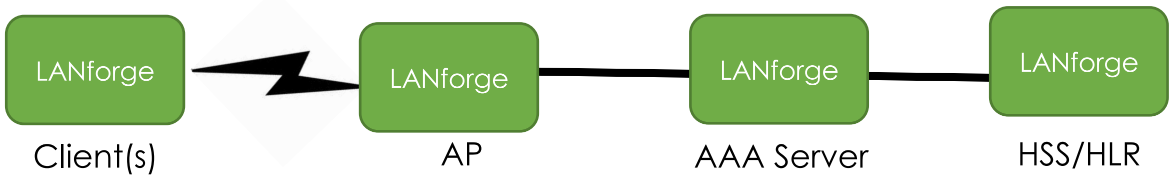






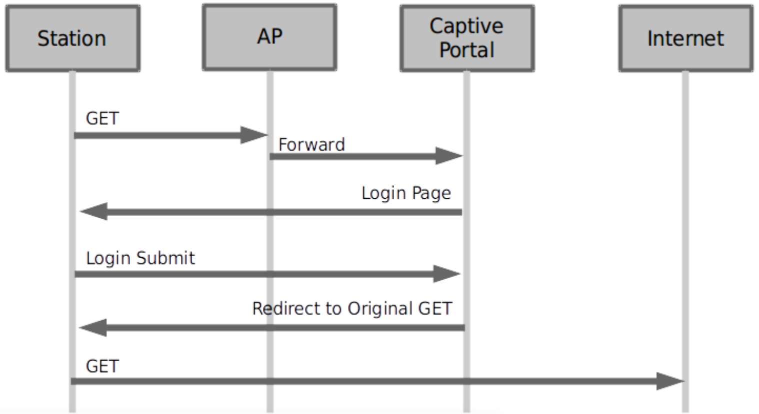




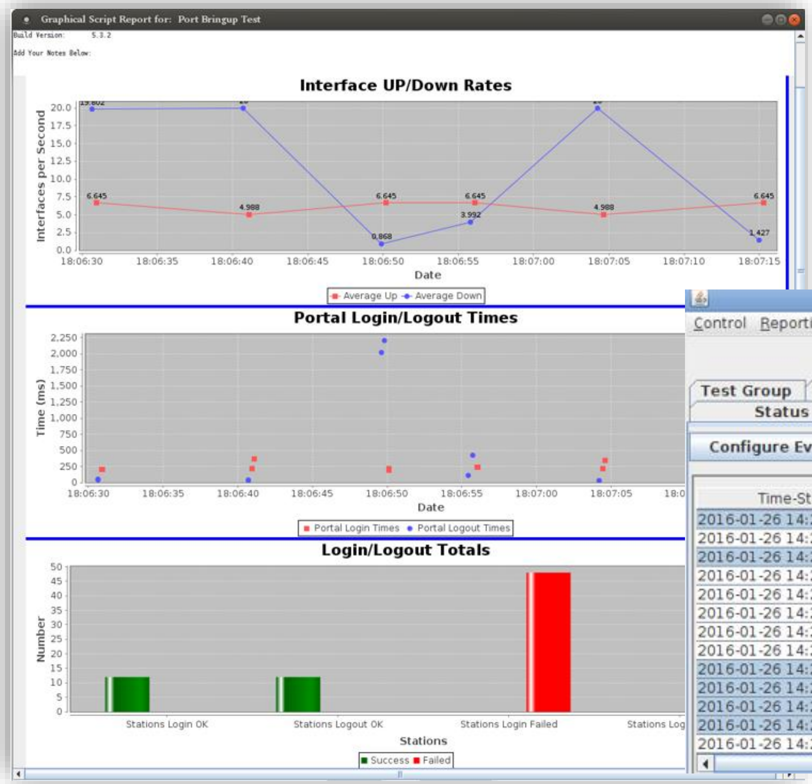


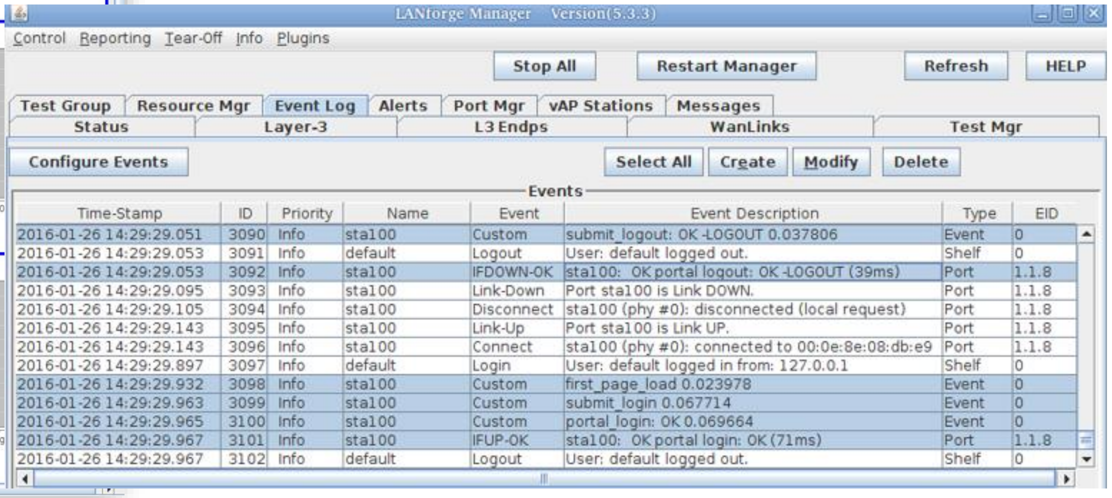
Captive Portal/Web Auth Testing

- Support various types of custom captive portal implementations.
- Can create custom scripts based on customer requirements.
- Can test with:
  - Redirects
  - Form posts
  - AJAX
  - Hidden fields
  - Cookies
  - Security headers
- Can scale to 1000s of captive portal logins.
- Can stress the DUT with lots of login attempts/sec from unique endpoints with different MAC addresses.
- Measure:
  - Time to receive the redirects
  - Time to Login page
  - Login Latency
  - Login Completion Rates




```
> curl -sqv http://basic-portal/start
* STATE: INIT => CONNECT handle 0x25bd9e8; line 1034 (connection #-5000)
* Added connection 0. The cache now contains 1 members
* STATE: CONNECT => WAITRESOLVE handle 0x25bd9e8; line 1071 (connection #0)
*   Trying 10.26.1.254...
* bind-local, addr: (nil)  dev: (nil)
* STATE: WAITRESOLVE => WAITCONNECT handle 0x25bd9e8; line 1151 (connection #0)
* Connected to basic-portal (10.26.1.254) port 80 (#0)
* Marked for [keep alive]: HTTP default
* STATE: WAITCONNECT => DO handle 0x25bd9e8; line 1229 (connection #0)
> GET /start HTTP/1.1
> User-Agent: curl/7.41.0-DEV
> Host: basic-portal
> Accept: */*
>
* STATE: DO => DO_DONE handle 0x25bd9e8; line 1314 (connection #0)
* STATE: DO_DONE => WAITPERFORM handle 0x25bd9e8; line 1441 (connection #0)
* STATE: WAITPERFORM => PERFORM handle 0x25bd9e8; line 1454 (connection #0)
* HTTP 1.1 or later with persistent connection, pipelining supported
< HTTP/1.1 302 Found
< Date: Fri, 04 Sep 2015 22:52:53 GMT
* Server Apache/2.4.7 (Ubuntu) is not blacklisted
< Server: Apache/2.4.7 (Ubuntu)
< Location: http://basic-portal/login.php
< Content-Length: 290
< Content-Type: text/html; charset=iso-8859-1
<
<!DOCTYPE HTML PUBLIC "-//IETF//DTD HTML 2.0//EN">
<html><head>
<title>302 Found</title>
</head><body>
<h1>Found</h1>
<p>The document has moved <a href="http://basic-portal/login.php">here</a>.</p>
<hr>
<address>Apache/2.4.7 (Ubuntu) Server at basic-portal Port 80</address>
</body></html>
```

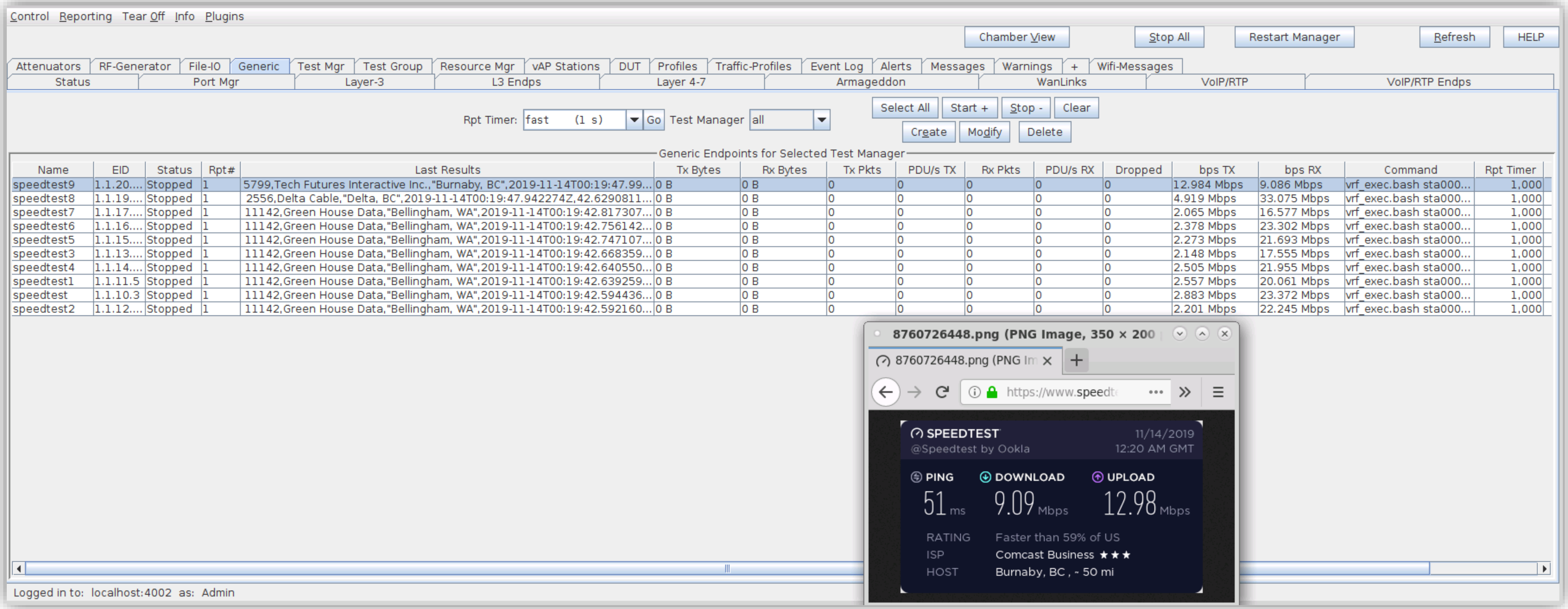




Time-Stamp	ID	Priority	Name	Event	Event Description	Type	EID
2016-01-26 14:29:29.051	3090	Info	sta100	Custom	submit_logout: OK -LOGOUT 0.037806	Event	0
2016-01-26 14:29:29.053	3091	Info	default	Logout	User: default logged out.	Shelf	0
2016-01-26 14:29:29.053	3092	Info	sta100	IFDOWN-OK	sta100: OK portal logout: OK -LOGOUT (39ms)	Port	1.1.8
2016-01-26 14:29:29.095	3093	Info	sta100	Link-Down	Port sta100 is Link DOWN.	Port	1.1.8
2016-01-26 14:29:29.105	3094	Info	sta100	Disconnect	sta100 (phy #0): disconnected (local request)	Port	1.1.8
2016-01-26 14:29:29.143	3095	Info	sta100	Link-Up	Port sta100 is Link UP.	Port	1.1.8
2016-01-26 14:29:29.143	3096	Info	sta100	Connect	sta100 (phy #0): connected to 00:0e:8e:08:db:e9	Port	1.1.8
2016-01-26 14:29:29.897	3097	Info	default	Login	User: default logged in from: 127.0.0.1	Shelf	0
2016-01-26 14:29:29.932	3098	Info	sta100	Custom	first_page_load 0.023978	Event	0
2016-01-26 14:29:29.963	3099	Info	sta100	Custom	submit_login 0.067714	Event	0
2016-01-26 14:29:29.965	3100	Info	sta100	Custom	portal_login: OK 0.069664	Event	0
2016-01-26 14:29:29.967	3101	Info	sta100	IFUP-OK	sta100: OK portal login: OK (71ms)	Port	1.1.8
2016-01-26 14:29:29.967	3102	Info	default	Logout	User: default logged out.	Shelf	0

SpeedTest.NET Testing

- Create lots of virtual wired and wireless clients to the network under test and a speed test to real Speedtest.net servers.
- Measure download and upload speeds.



6E Test cases Covered

6E Throughput Benchmark

This test gives the 6E performance with different packet sizes, channel BWs, traffic types, MIMO types.

Client Capacity

WiFi Capacity test is designed to measure performance of an Access Point when handling several 6E WiFi Stations.

Near/Far Clients, Band Steering

Measure the performance and stability of the 6E clients based on low and high RSSI levels

Tri-band Performance

Running traffic on 2.4, 5 & 6Ghz clients simultaneously.

6E RvR and RvO

This test measures the 6E performance over distance and different antenna orientation of the access point.

OFDMA Performance

This test gives the downlink and uplink OFDMA performance for the multiple 6E clients. Sizes of RUs allocated to different users

Latency

This test intends to verify latency under low, high and maximum AP traffic load with multiple stations

Airtime Fairness, QoS

Airtime Fairness Test intends to verify the capability of Wi-Fi device to ensure the fairness of airtime usage.

MU-MIMO

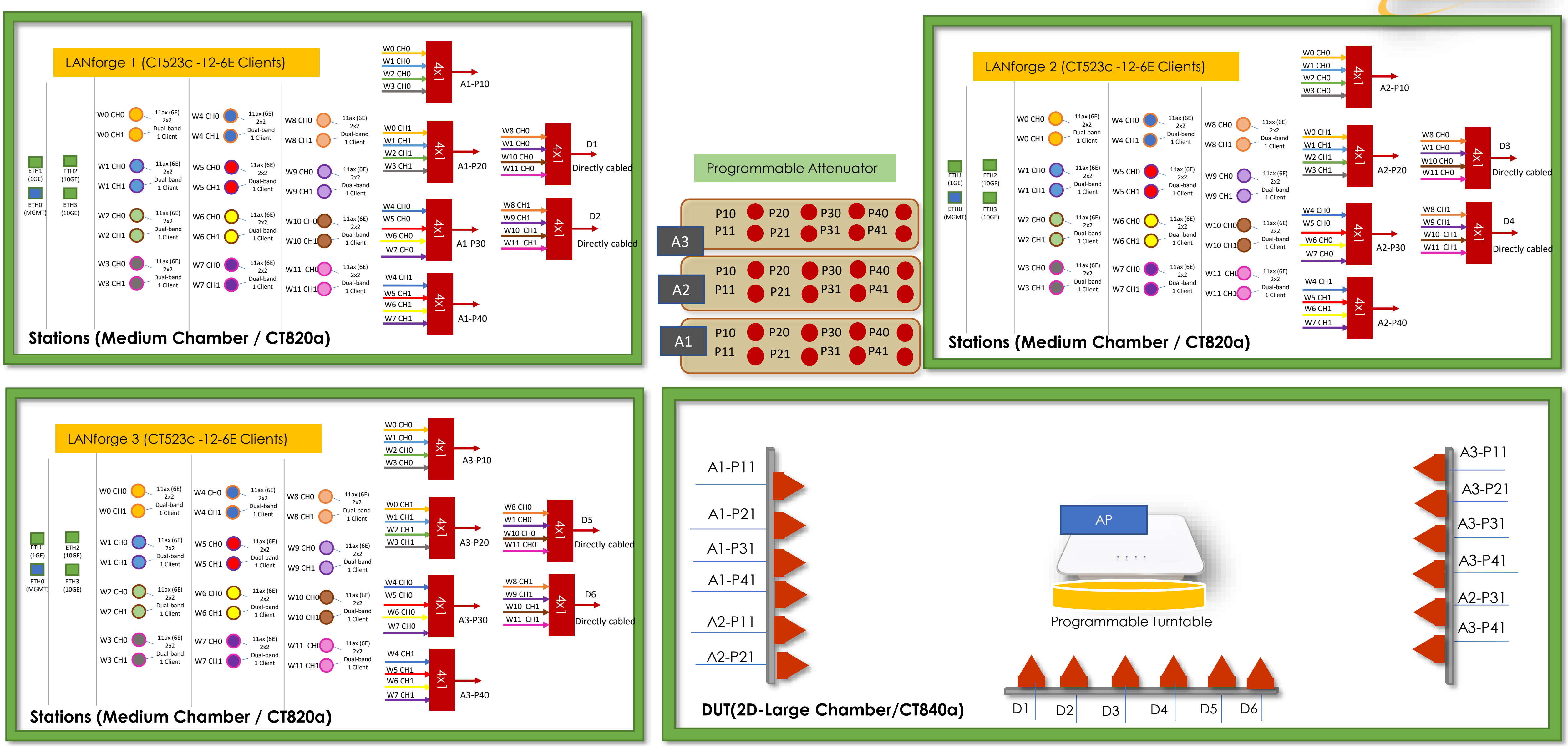
This test measures the 6E Downlink and uplink multiuser, multi input, multi output

6E Testbed Images

Outside

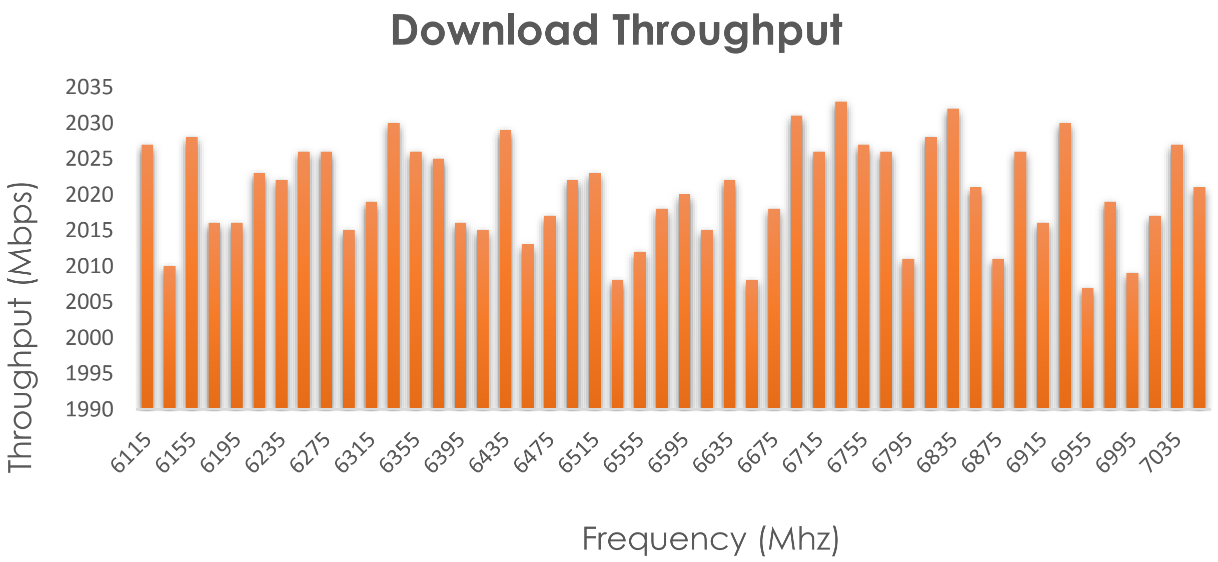
Inside

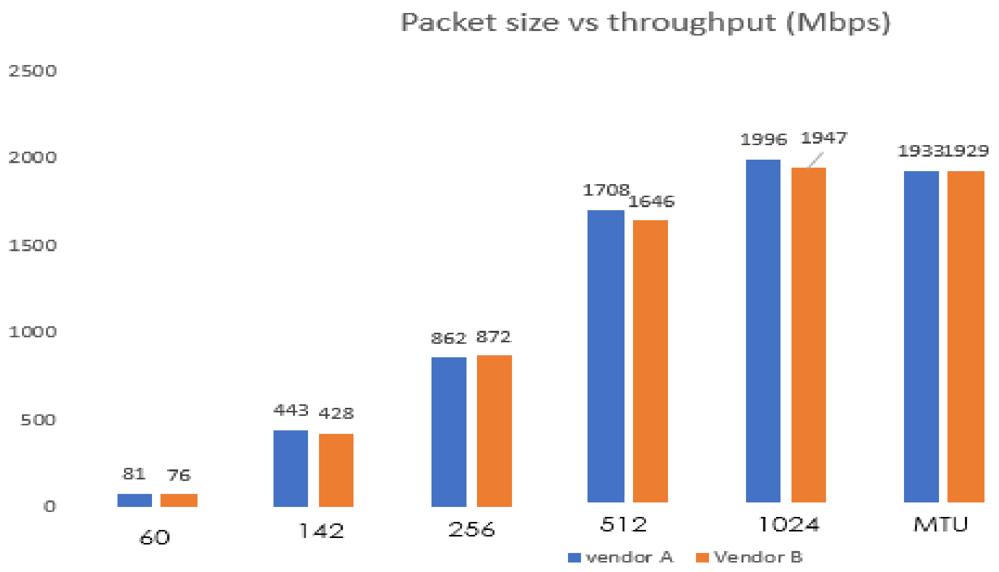
WiFi 6E Testbed Wiring Diagram



6E Throughput Benchmark

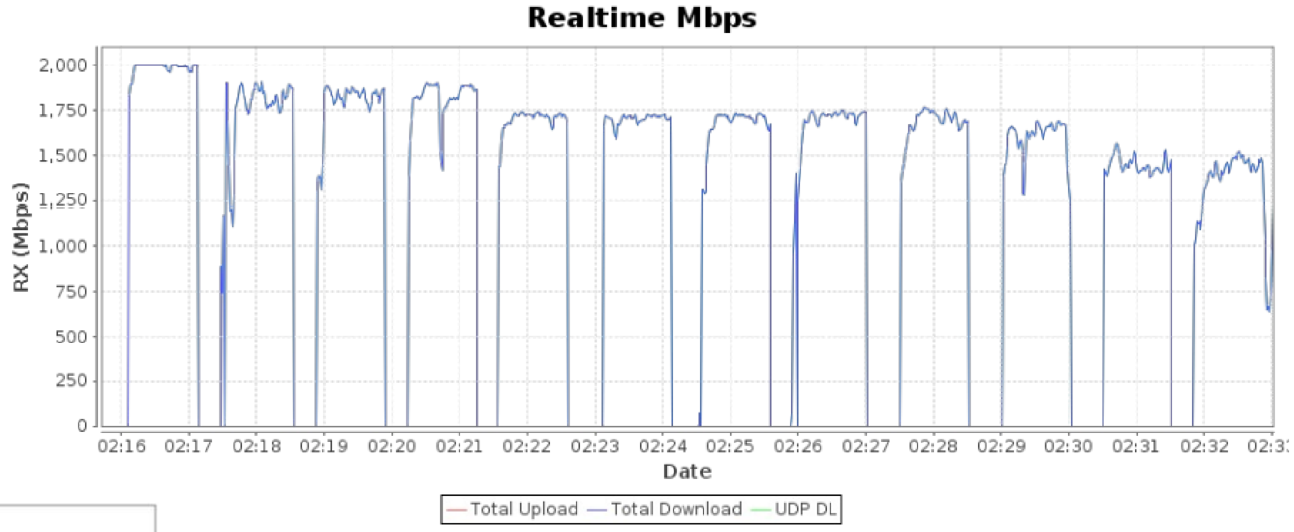
The Candela WiFi data plane test is designed to conduct an automatic testing of all combinations of station types, MIMO types, Channel Bandwidths, Traffic types, Traffic direction, Frame sizes etc… It will run a quick throughput test at every combination of these test variables and plot all the results in a set of charts to compare performance. The user is allowed to define an intended load as a percentage of the max theoretical PHY rate for every test combination. The expected behavior is that for every test combination the achieved throughput should be at least 70% of the theoretical max PHY rate under ideal test conditions. This test provides a way to go through hundreds of combinations in a fully automated fashion and very easily find patterns and problem areas which can be further debugged using more specific testing. The below chart shows the throughput with all the 6E channels

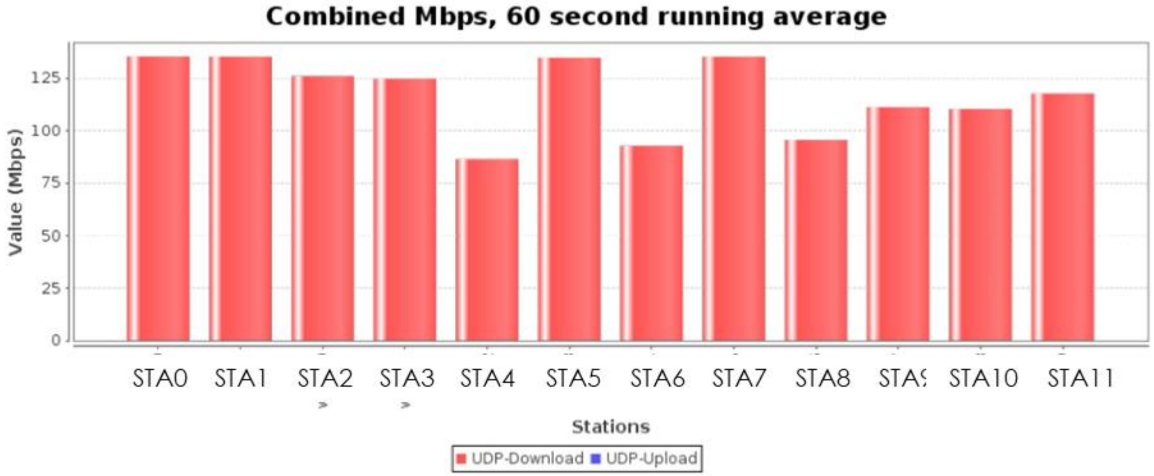




WiFi Capacity Test

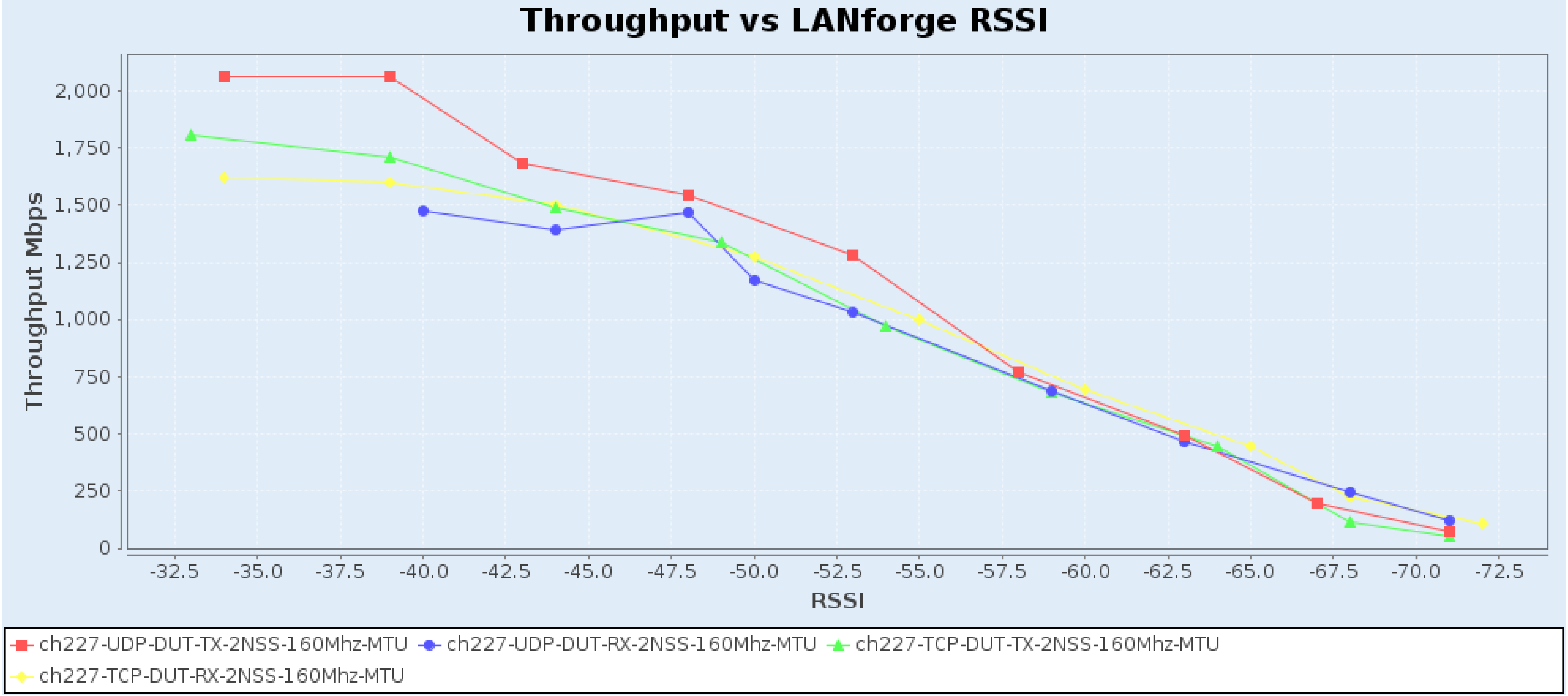
The Candela WiFi Capacity test is designed to measure performance of an Access Point when handling several 6E WiFi Stations. The test allows the user to increase the number of stations in user defined steps for each test iteration and measure the per station and the overall throughput for each trial. Along with throughput other measurements made are client connection times, % packet loss, DHCP times and more. The expected behavior is for the AP should be able to handle several stations (within the limitations of the AP specs) and make sure all stations get a fair amount of airtime both in the upstream and downstream.





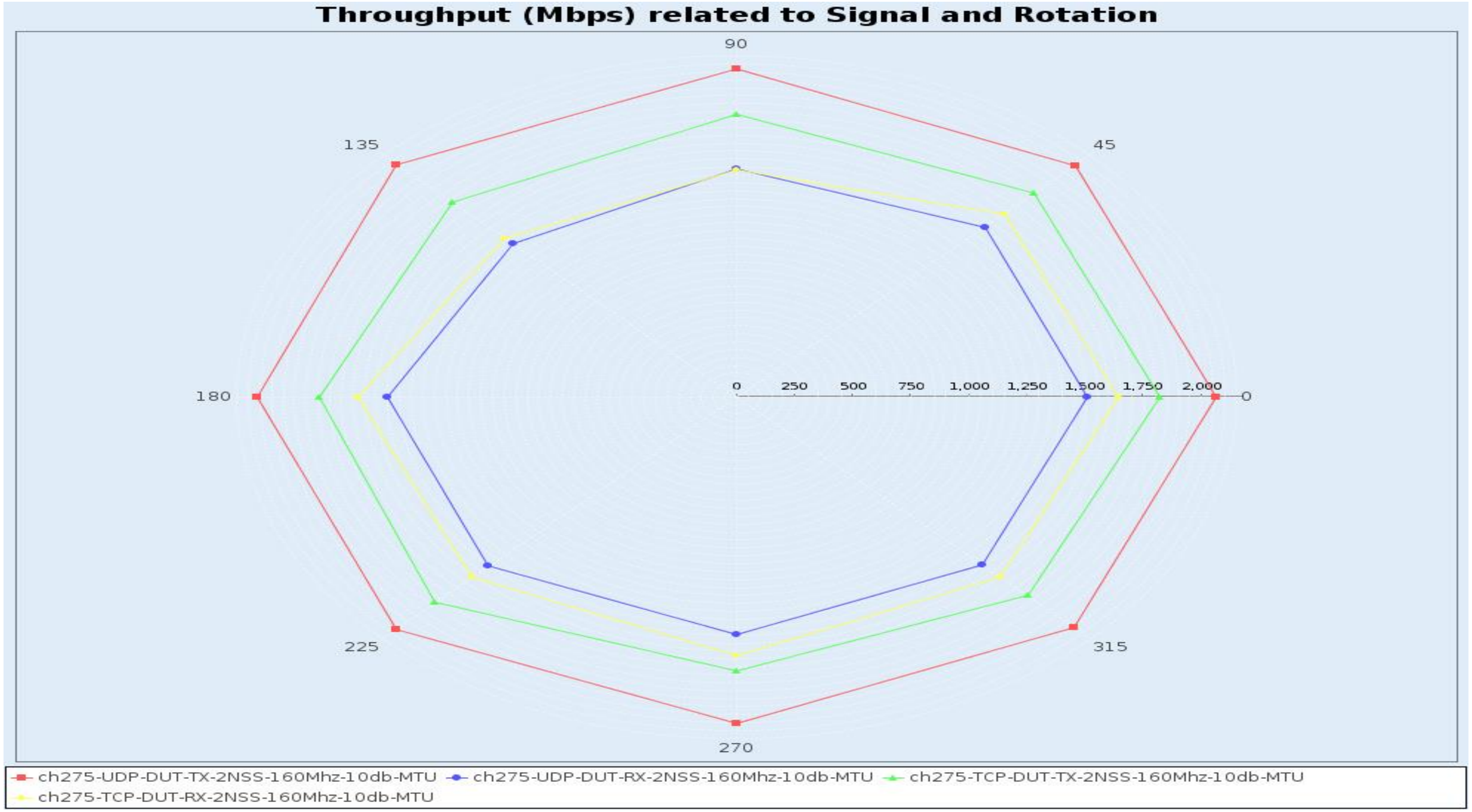
6E Rate vs Range Test

This test measures the performance over distance of the Device Under Test. Distance is emulated using programmable attenuation and a throughput test is run at each distance/RSSI step and plotted on a chart. The test allows the user to plot RSSI curves both upstream and downstream for different types of traffic and different station types. The below chart runs with the channel 227.



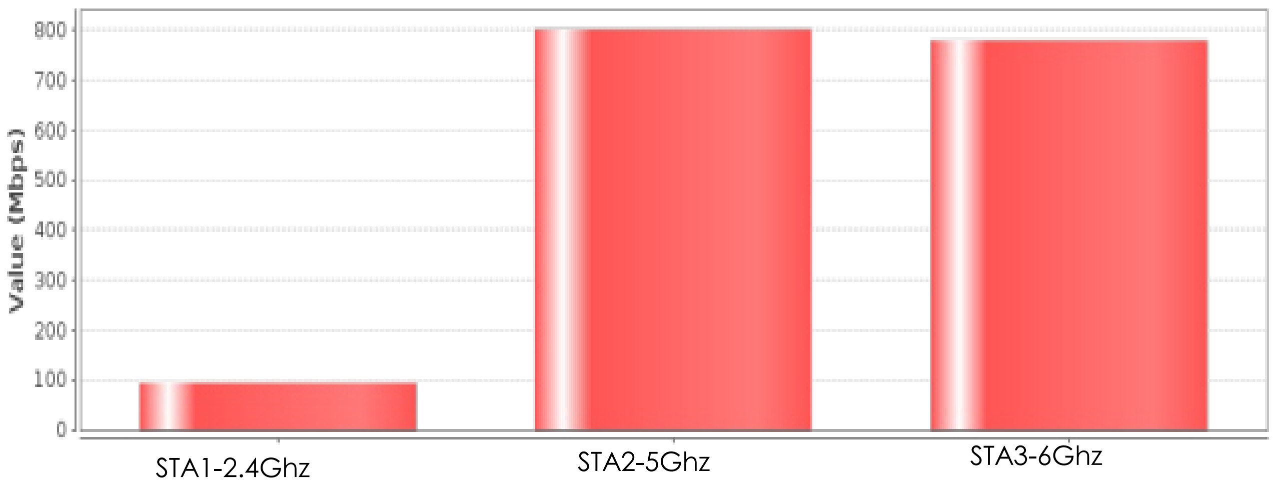
6E Rate vs Orientation Test

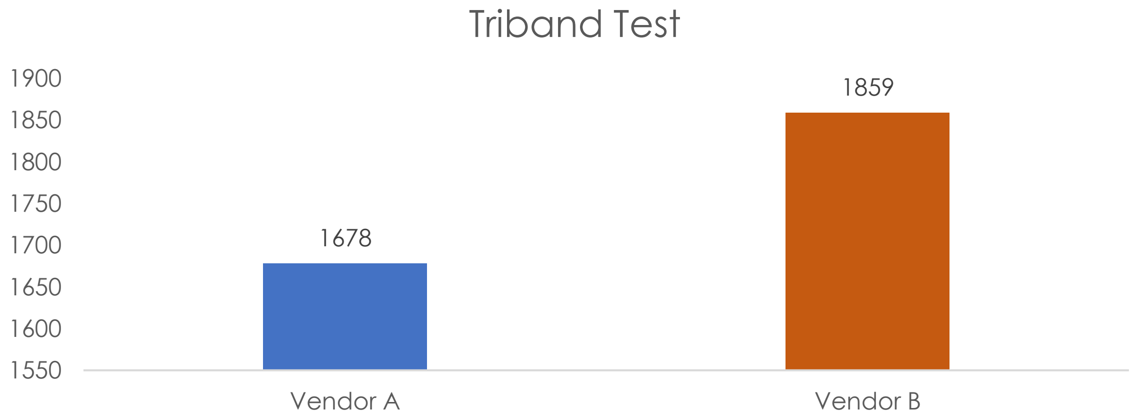
This test measures the performance of the DUT at different antenna orientations. Different antenna orientations of the transmitter will respect to the receiver may results in huge variations of performance caused by antenna nulls and dead spots . Using a large chamber with a programmable turntable, the DUT is rotated to various angles and upstream/downstream throughput is measured at each orientation and the results are plotted on a polar plot



Tri-Band Test

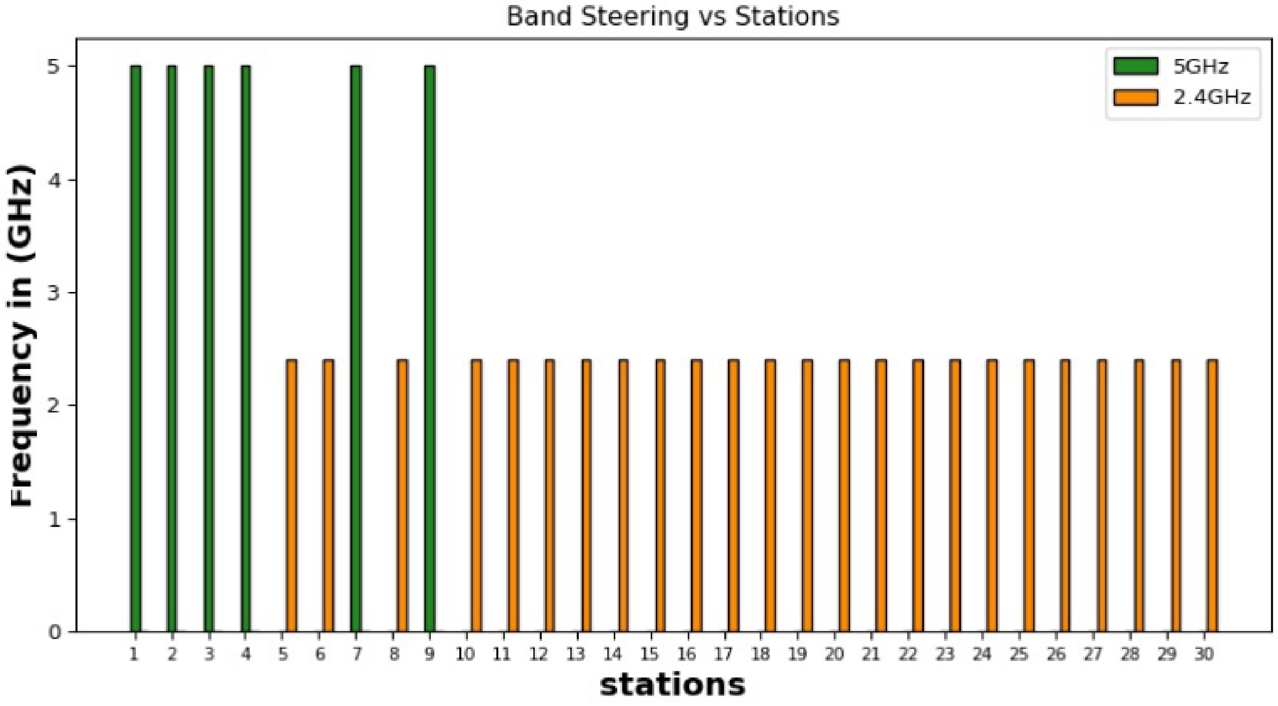
This test creates each client on 2.4, 5 and 6Ghz bands and run the traffic simultaneously. The Multi Band Performance test intends to verify that the Wi-Fi AP throughput with multiple bands active with a single station on each band. The configured speed will be 20% higher than the passing value for MTU sized frames in the throughput test. If the throughput test was skipped, then fixed values will be used.

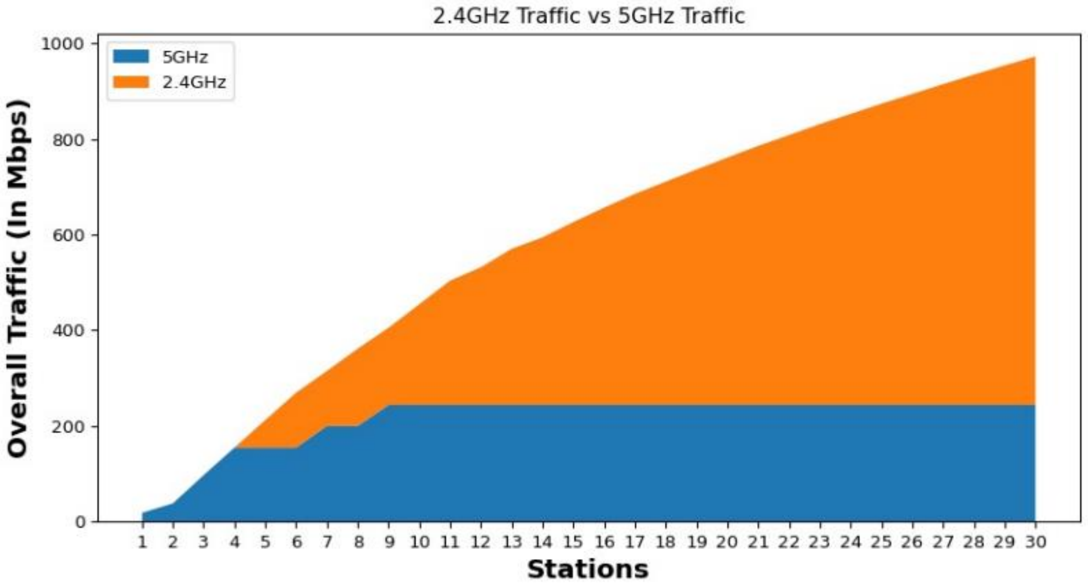




Band Steering Test

Through this test, clients get steered from one band to another based on RSSI levels or load based. The below chart shows the auto selected band of a station which is created on each iteration, Based on the overall load on the access point the next station will be created on a band which is having less load.

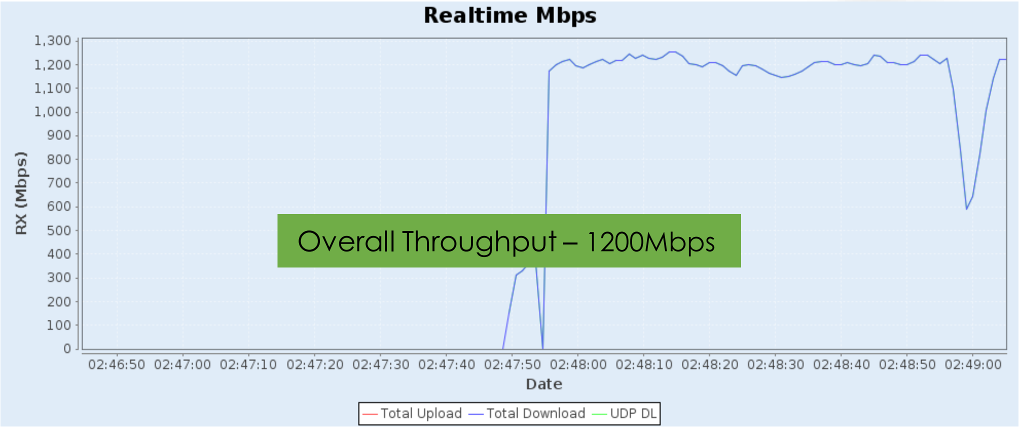




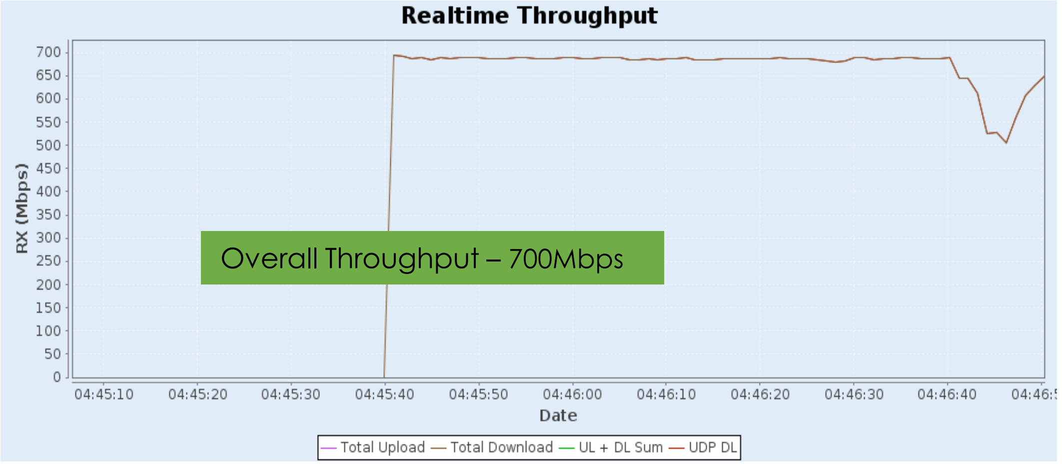
6E MU-MIMO Performance test

Test Description

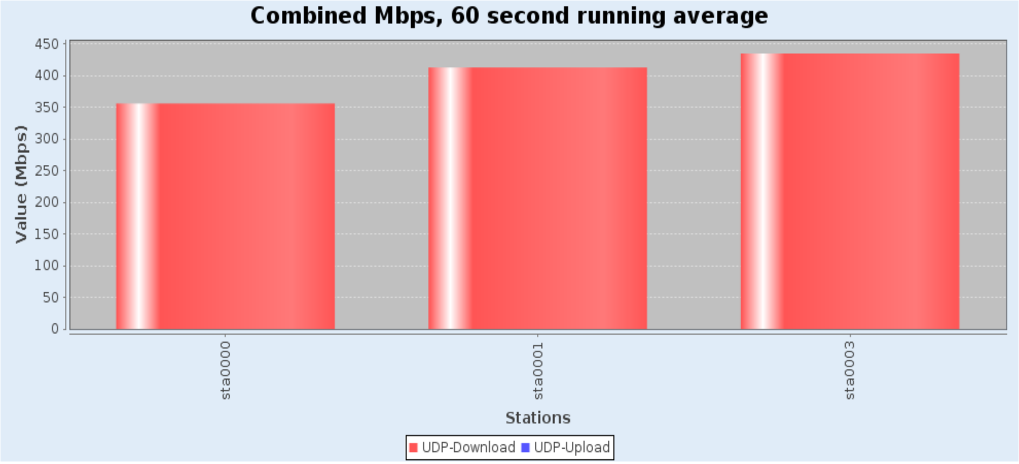
- Test was run with 3 MU-MIMO clients connected to the APs 6GHz radio. Client1 was set to 2x2 MIMO and Client2 and Client3 were set to 1x1 Mode.
- UDP traffic is run at full rate from AP to all three stations.



MU-MIMO Enable



MU-MIMO Disable

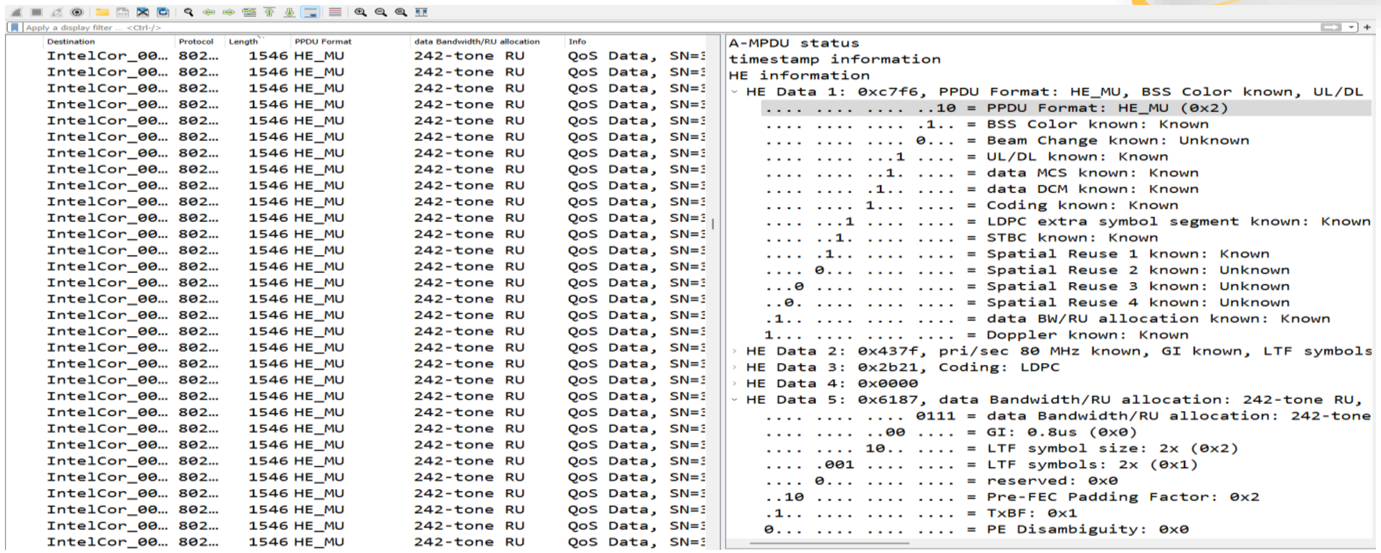


MU-MIMO Enable

6E OFDMA Performance test

Test Description

- Test was run with 4 clients connected to the APs 6GHz radio.
- Four 11ax stations each with a UDP download at 300B payload size which will show that the AP is using OFDMA.
- Packet capture on one of the STA shows AP using HE MU PPDU frame format for sending the QoS data and 242-tone RU is allocated.

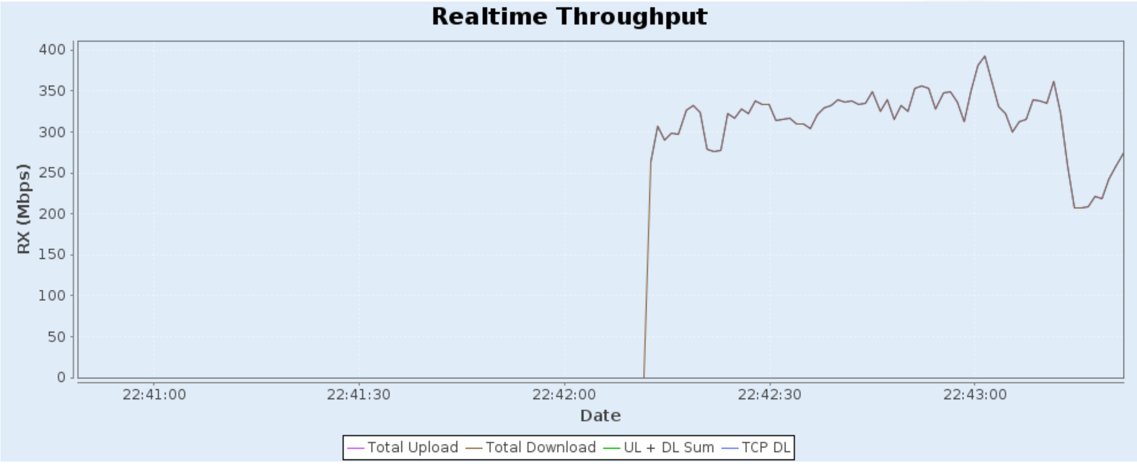


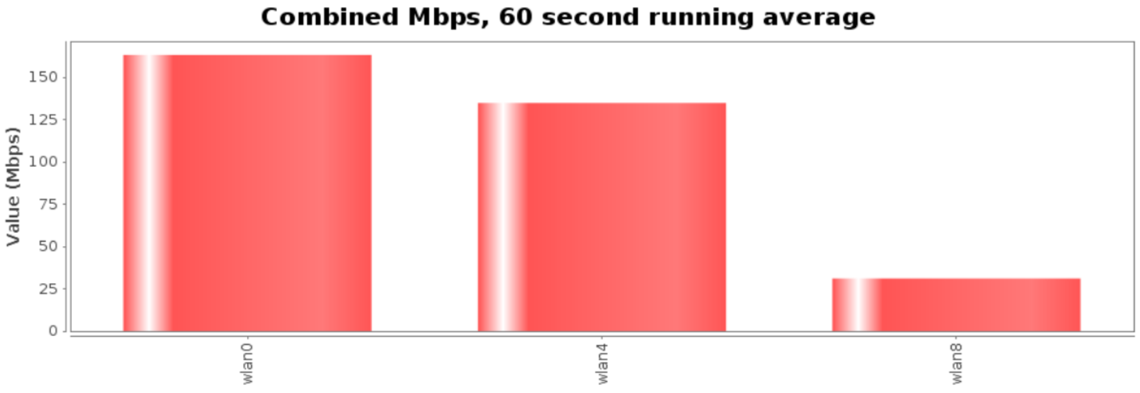
7C:50:79:3F:81:B2	1198.2	44.8	142.8%	24.9%	0.0%	80	11	2	98.4%	0.0%
(overall)	-	179.9	561.8%	-	-					
Station Address	PHY Mbps	Data Mbps	Air Use	Data Use	Retries	bw	mcs	Nss	ofdma	mu-mimo
7C:50:79:3F:8D:BF	1197.7	45.1	146.7%	25.1%	0.0%	80	11	2	99.5%	0.0%
40:1C:83:3C:75:C1	501.4	45.6	115.3%	25.3%	9.0%	80	9.3	1	90.3%	0.0%
14:18:C3:48:AE:77	1197.7	44.5	144.9%	24.8%	0.0%	80	11	2	98.8%	0.0%
7C:50:79:3F:81:B2	1197.4	44.7	141.9%	24.9%	0.0%	80	11	2	98.0%	0.0%
(overall)	-	179.9	548.8%	-	-					
Station Address	PHY Mbps	Data Mbps	Air Use	Data Use	Retries	bw	mcs	Nss	ofdma	mu-mimo
7C:50:79:3F:8D:BF	1196.0	45.2	152.5%	25.1%	0.0%	80	11	2	99.0%	0.0%
40:1C:83:3C:75:C1	479.1	45.4	122.1%	25.2%	7.6%	80	9.0	1	94.4%	0.0%
14:18:C3:48:AE:77	1196.1	44.6	152.3%	24.8%	0.0%	80	11	2	99.9%	0.0%
7C:50:79:3F:81:B2	1195.9	44.8	146.7%	24.9%	0.0%	80	11	2	99.1%	0.0%
(overall)	-	180.0	573.5%	-	-					
Station Address	PHY Mbps	Data Mbps	Air Use	Data Use	Retries	bw	mcs	Nss	ofdma	mu-mimo
7C:50:79:3F:8D:BF	1196.0	45.0	153.5%	25.1%	0.0%	80	11	2	99.2%	0.0%
40:1C:83:3C:75:C1	479.5	45.1	121.2%	25.1%	8.2%	80	9.0	1	94.9%	0.0%
14:18:C3:48:AE:77	1195.9	44.6	152.6%	24.9%	0.0%	80	11	2	99.1%	0.0%
7C:50:79:3F:81:B2	1195.9	44.7	147.0%	24.9%	0.0%	80	11	2	99.4%	0.0%
(overall)	-	179.4	574.3%	-	-					
Station Address	PHY Mbps	Data Mbps	Air Use	Data Use	Retries	bw	mcs	Nss	ofdma	mu-mimo
7C:50:79:3F:8D:BF	1195.1	44.8	155.5%	25.0%	0.0%	80	11	2	99.7%	0.0%
40:1C:83:3C:75:C1	479.4	44.8	120.3%	25.0%	9.7%	80	9.0	1	94.3%	0.0%
14:18:C3:48:AE:77	1195.1	44.7	155.1%	24.9%	0.0%	80	11	2	99.1%	0.0%
7C:50:79:3F:81:B2	1195.2	44.8	150.4%	25.0%	0.0%	80	11	2	99.6%	0.0%
(overall)	-	179.0	581.4%	-	-					
Station Address	PHY Mbps	Data Mbps	Air Use	Data Use	Retries	bw	mcs	Nss	ofdma	mu-mimo
7C:50:79:3F:8D:BF	1199.0	44.7	142.7%	25.0%	0.0%	80	11	2	99.3%	0.0%
40:1C:83:3C:75:C1	562.6	44.8	108.7%	25.1%	7.1%	80	10.4	1	87.1%	0.0%
14:18:C3:48:AE:77	1198.9	44.6	141.4%	24.9%	0.0%	80	11	2	99.0%	0.0%
7C:50:79:3F:81:B2	1198.9	44.8	135.1%	25.0%	0.0%	80	11	2	98.7%	0.0%
(overall)	-	178.9	527.9%	-	-					

6E Near/Far Clients test

Test Description

- Three clients were created, one each on three different LANforge radios.
- Each client is connected to the DUT chamber through a different programmable attenuator allowing for different distances emulated for each client.
- The path loss created for the three clients was 10dB, 25dB and 35dB representing a Near, Medium Distance and Far Clients respectively.
- Test run at full rate TCP downstream from AP to all three clients and throughput is measured for each client.





Near client
10dB Path loss

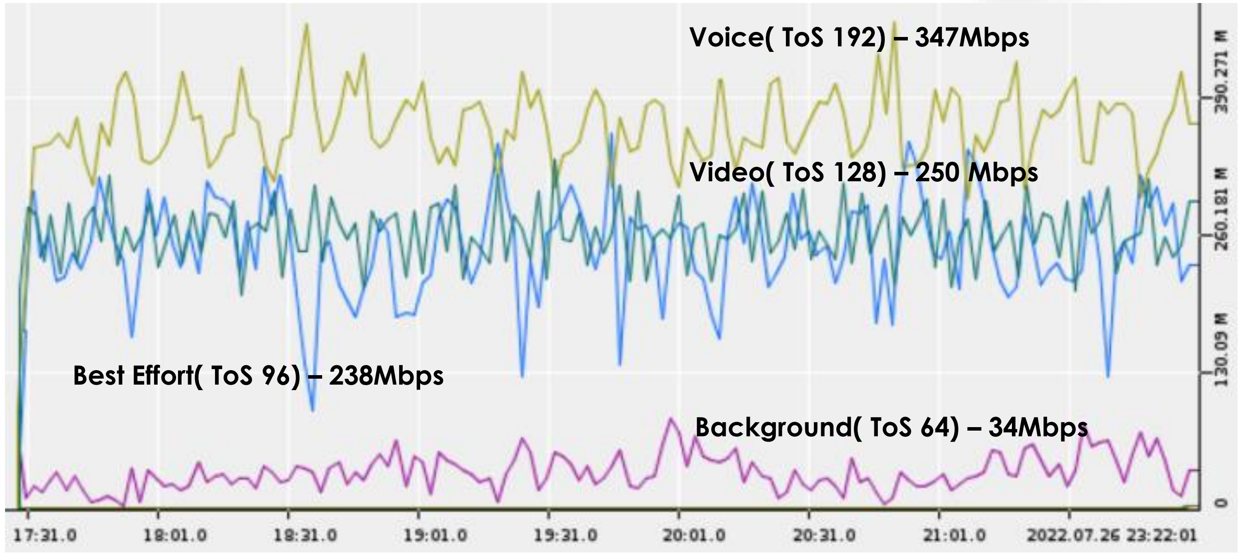
Medium client
25dB Path loss

Far client
35dB Path loss

6E QoS Performance test

Test Description

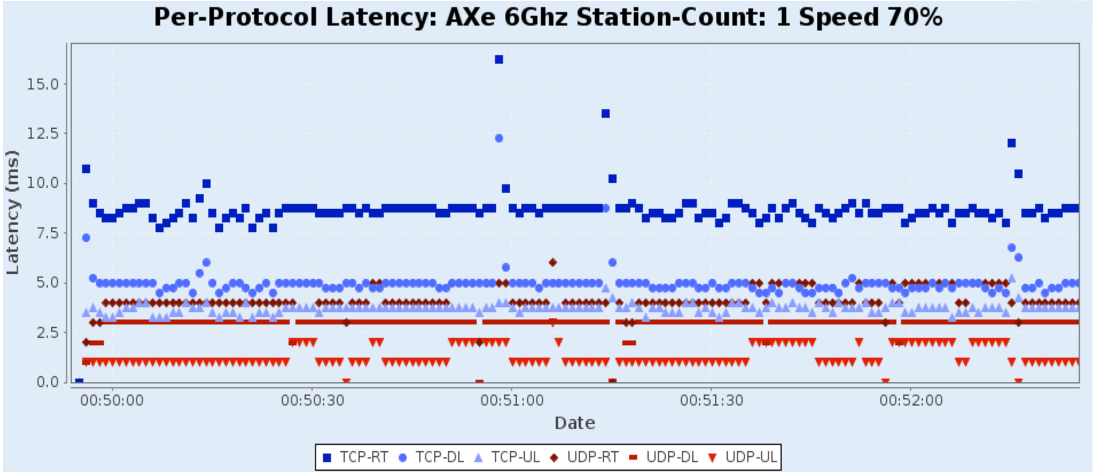
- Test run with 4 clients connected to the 6GHz radio of the AP under test.
- Downlink(AP to client) TCP traffic streams were set up to each client with different QoS access categories to each client Client1: Voice, Client2: Video, Client3: Best Effort , Client4: Background
- All 4 traffic streams were run at full rate.



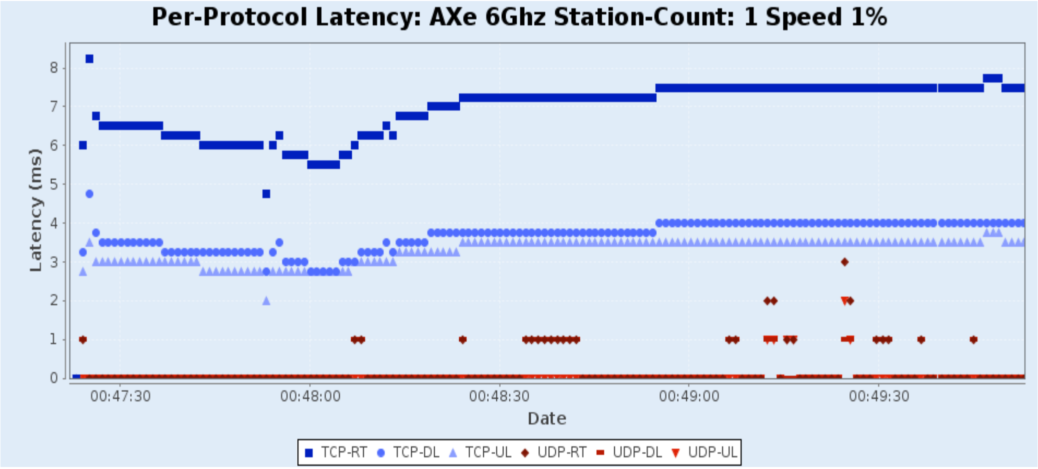
6E Latency test

Test Description

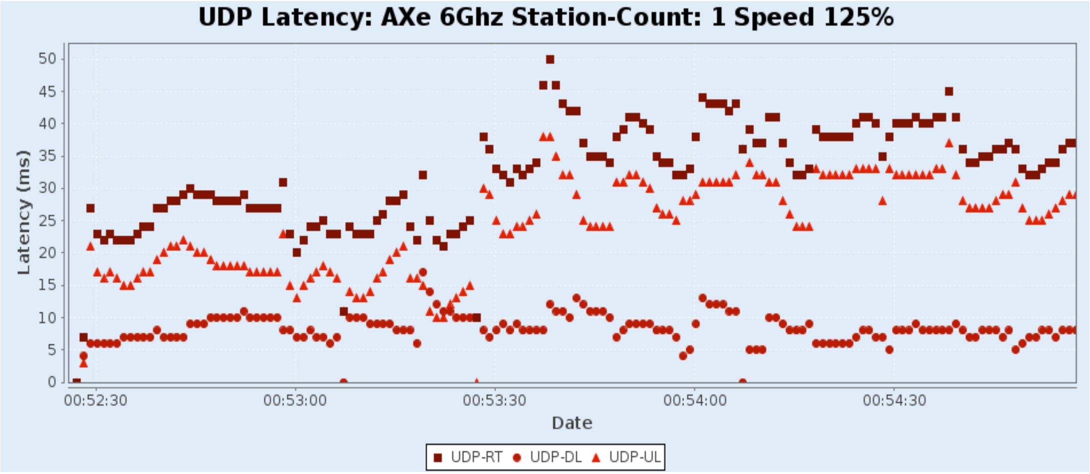
- The Latency test intends to verify latency under low, high, and maximum AP traffic load, with 1 stations. Traffic load is a 4 bi-directional TCP streams for each station, plus a low speed UDP connection to probe latency.
- Low load considered as 1% of max TCP throughput
- Medium load considered as 70% of max TCP throughput
- High load considered as 70% of max TCP throughput



Medium load

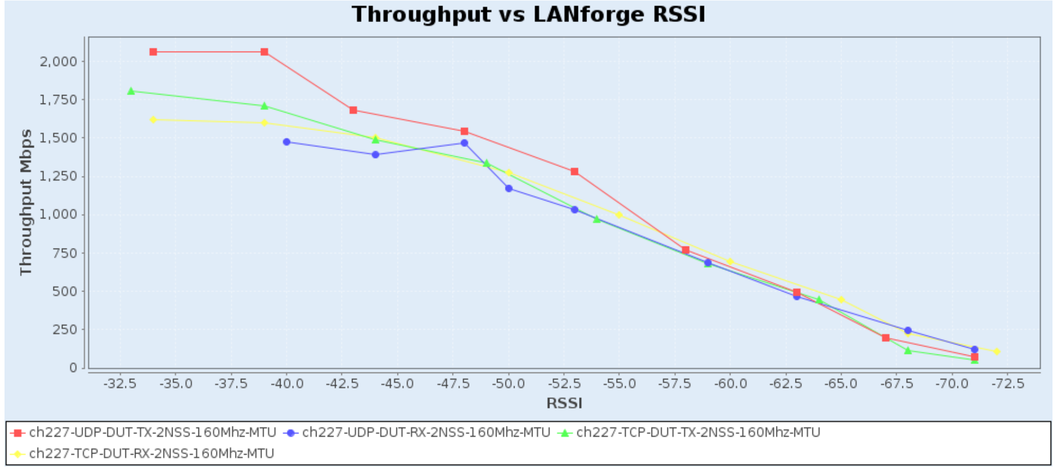


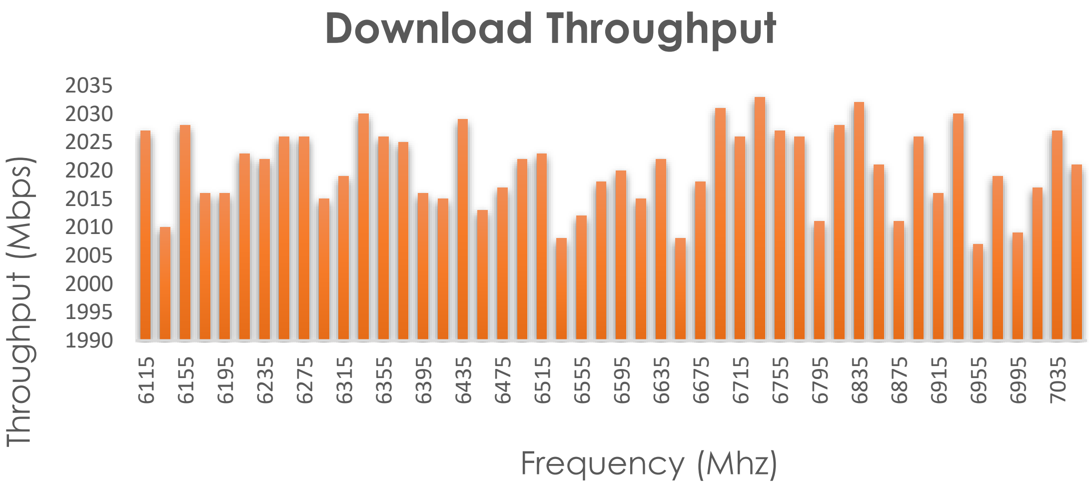
Low load

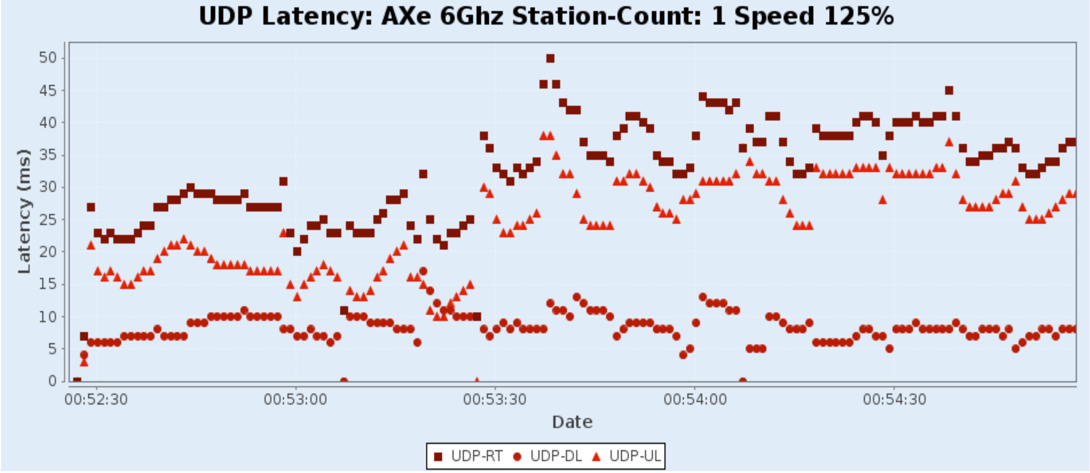


High load

Sample Results:





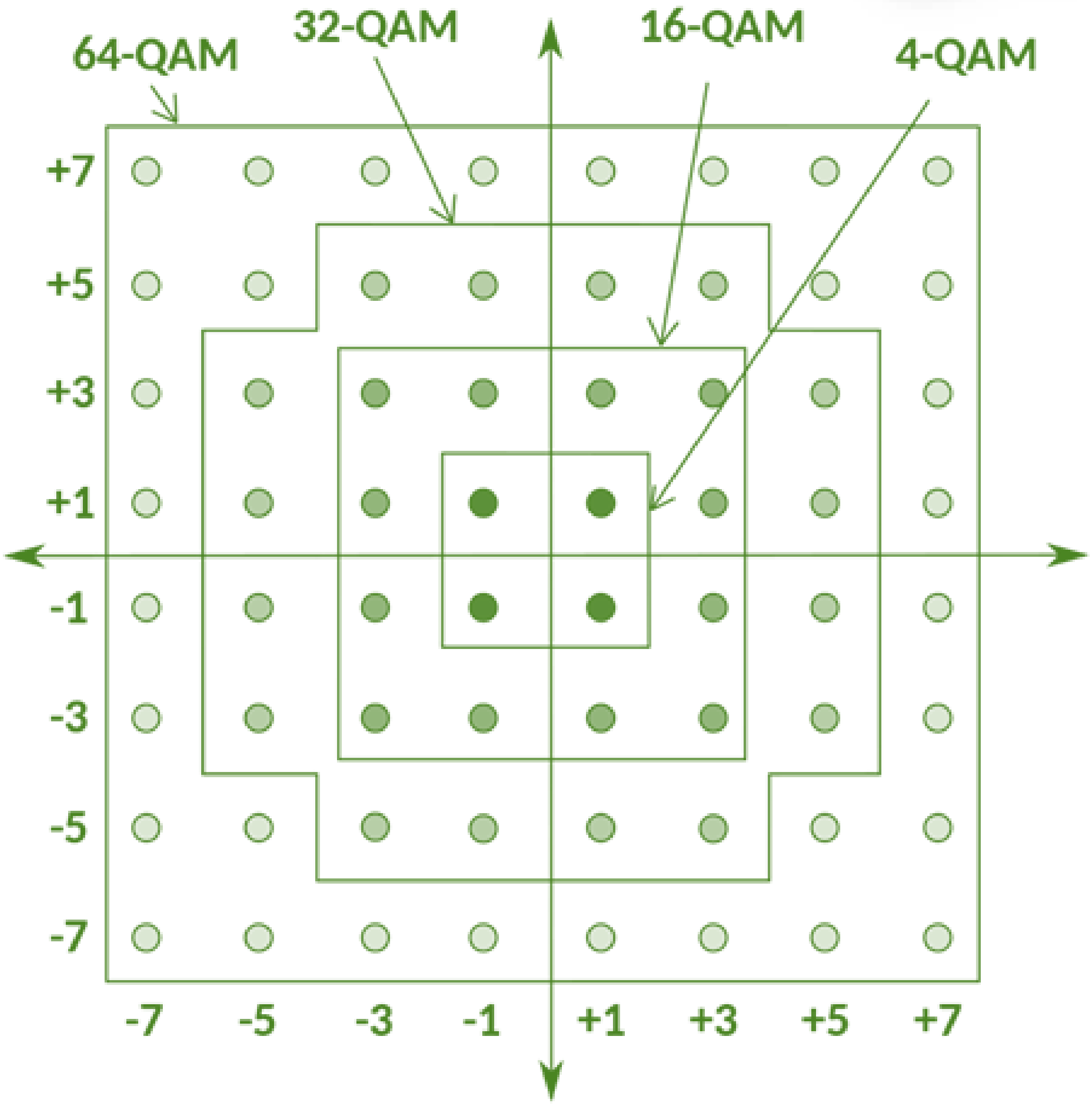


High load

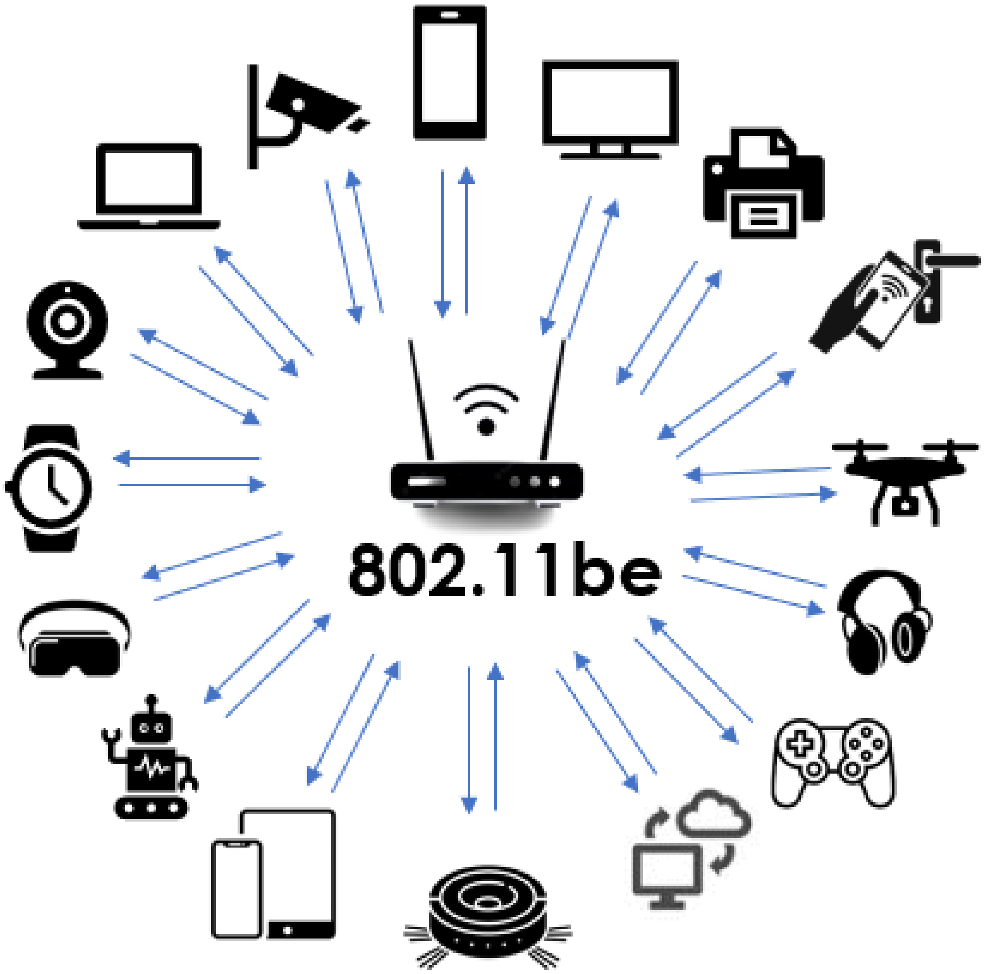
Wi-Fi7 Testing

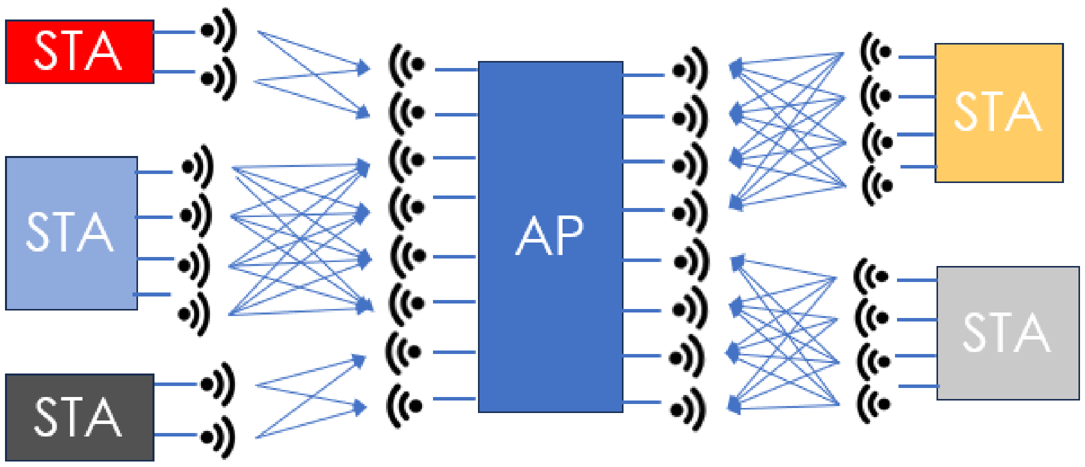
4096 QAM Modulation Scheme:

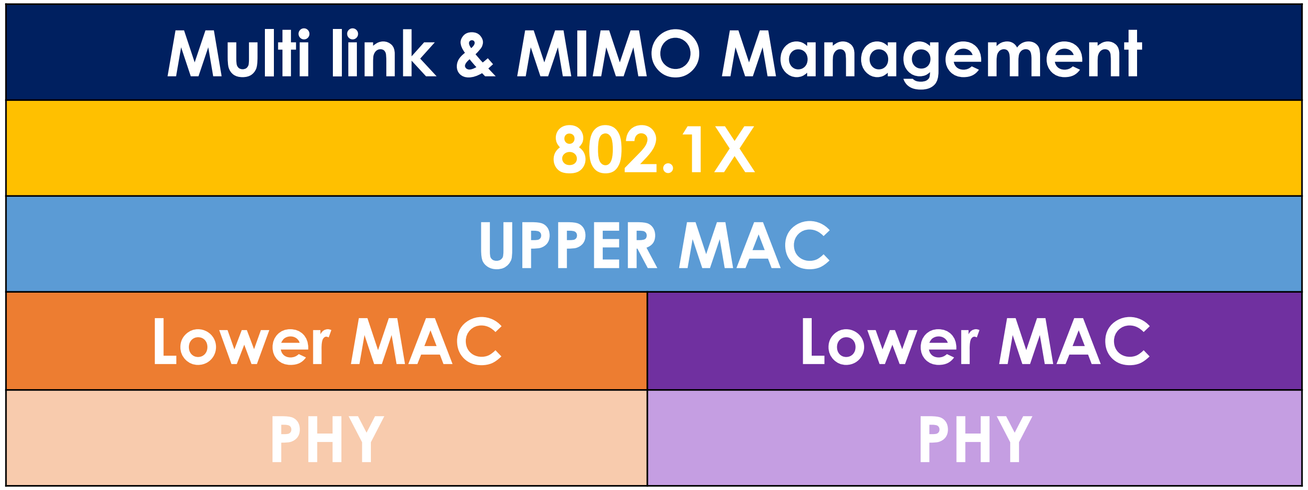
Bits per Symbol	Number of Symbols	QAM Modulation
4	$2^4 = 16$	16-QAM
6	$2^6 = 64$	64-QAM
8	$2^8 = 256$	256-QAM
10	$2^{10} = 1024$	1024-QAM
12	$2^{12} = 4096$	4K-QAM



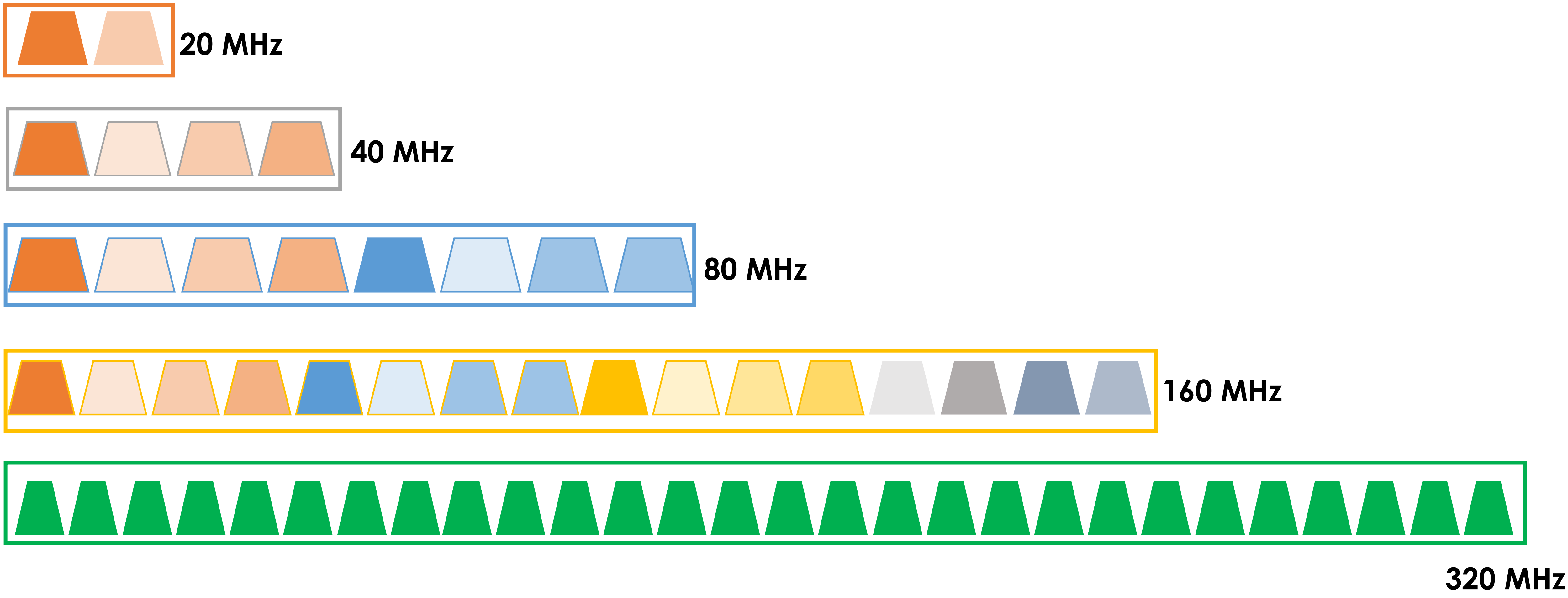
16 x 16 MU-MIMO and PHY Layer:







Wi-Fi 7 320 MHz Bandwidth:



MCS Table for Wi-Fi 7:

MCS index	Modulation type	Coding rate	Data rate (Mbit/s)														
			20 MHz channels			40 MHz channels			80 MHz channels			160 MHz channels			320 MHz channels		
			3200 ns GI	1600 ns GI	800 ns GI	3200 ns GI	1600 ns GI	800 ns GI	3200 ns GI	1600 ns GI	800 ns GI	3200 ns GI	1600 ns GI	800 ns GI	3200 ns GI	1600 ns GI	800 ns GI
0	BPSK	1/2	7	8	9	15	16	17	31	34	36	61	68	72	123	136	144
1	QPSK	1/2	15	16	17	29	33	34	61	68	72	122	136	144	245	272	288
2	QPSK	3/4	22	24	26	44	49	52	92	102	108	184	204	216	368	408	432
3	16-QAM	1/2	29	33	34	59	65	69	123	136	144	245	272	282	490	544	577
4	16-QAM	3/4	44	49	52	88	98	103	184	204	216	368	408	432	735	817	865
5	64-QAM	2/3	59	65	69	117	130	138	245	272	288	490	544	576	980	1089	1153
6	64-QAM	3/4	66	73	77	132	146	155	276	306	324	551	613	649	1103	1225	1297
7	64-QAM	5/6	73	81	86	146	163	172	306	340	360	613	681	721	1225	1361	1441
8	256-QAM	3/4	88	98	103	176	195	207	368	408	432	735	817	865	1470	1633	1729
9	256-QAM	5/6	98	108	115	195	217	229	408	453	480	817	907	961	1633	1815	1922
10	1024-QAM	3/4	110	122	129	219	244	258	459	510	540	919	1021	1081	1838	2042	2162
11	1024-QAM	5/6	122	135	143	244	271	287	510	567	600	1021	1134	1201	2042	2269	2402
12	4096-QAM	3/4	131	146	155	263	293	310	551	613	649	1103	1225	1297	2205	2450	2594
13	4096-QAM	5/6	146	163	172	293	325	344	613	681	721	1225	1361	1441	2450	2722	2882

Compressed Block Ack:[512,1024 MPDU’s]

802.11 a/b/g

RTS
CTS
QoS Data
Ack

802.11 n/ac

RTS
CTS
QoS Data
QoS Data
QoS Data
Block Ack

802.11 AX

RTS
CTS
QoS Data
QoS Data
QoS Data
QoS Data
QoS Data
Block Ack

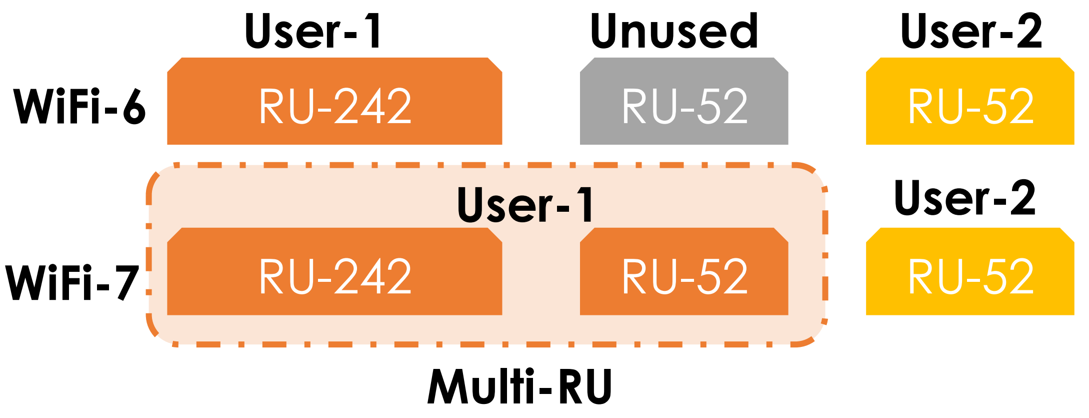
802.11 BE

RTS
CTS
QoS Data
QoS Data
QoS Data
QoS Data
QoS Data
QoS Data
QoS Data
Compressed BA

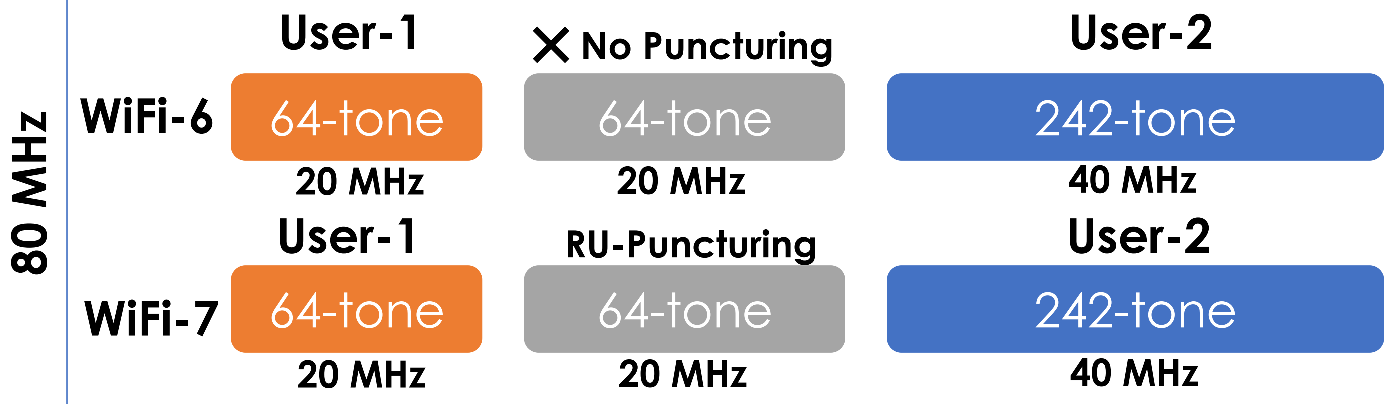
- **WiFi-7 forms larger aggregates when compared to its previous Wi-Fi standards.**
- **So, to acknowledged the QoS data frames, creating Block acks like WiFi-6 deployment might increase the Airtime overhead, because the Block operates at 24 Mbps PHY-rate.**
- **So, WiFi-7 has compressed Block Ack feature which acknowledge up to 512 &1024 MPDU’s.**

MU-OFDMA: [1024 Multi RU]

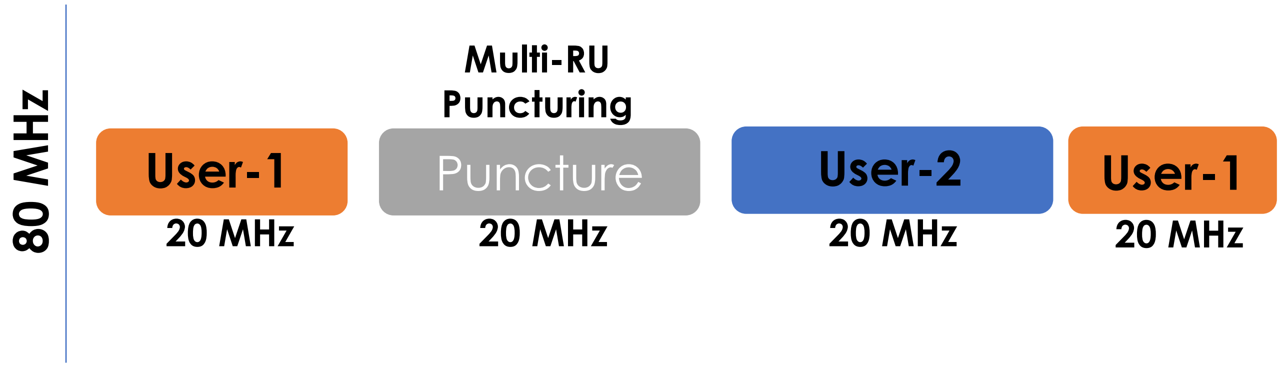
Multi RU



RU Puncturing



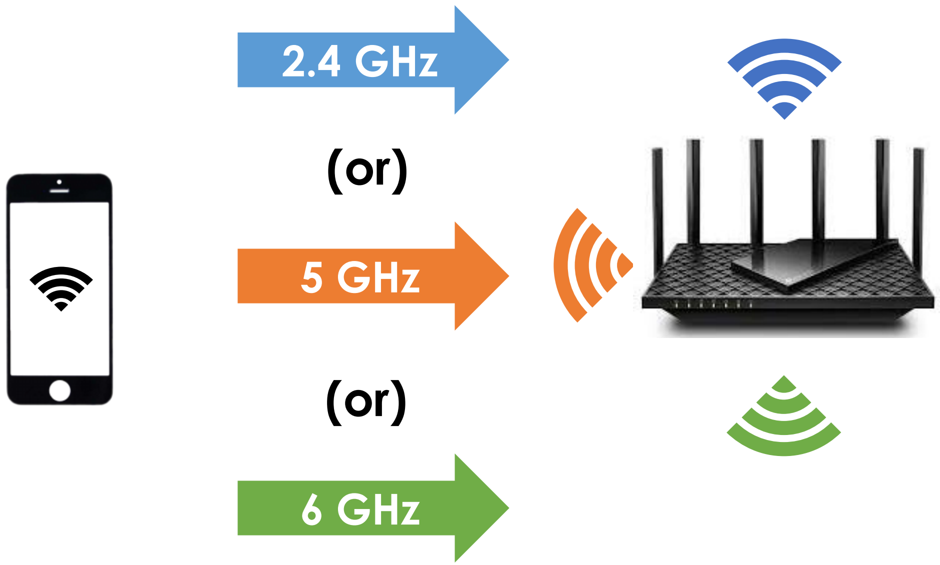
Multi-RU Puncturing in Wi-Fi 7:



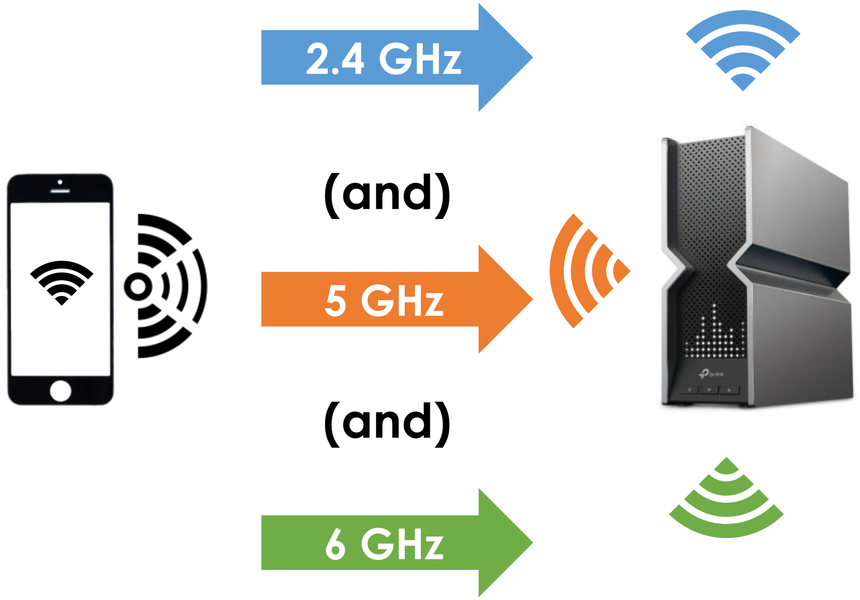
- There are some advancements in WiFi-7 based on OFDMA as there is a scope of communication in multiple channels.
- The clients also have the possibility of communicating in various Resource Units available such that it has more capacity for data exchange.

Multi-Link Operation MLO:

Wi-Fi 6E



Wi-Fi 7

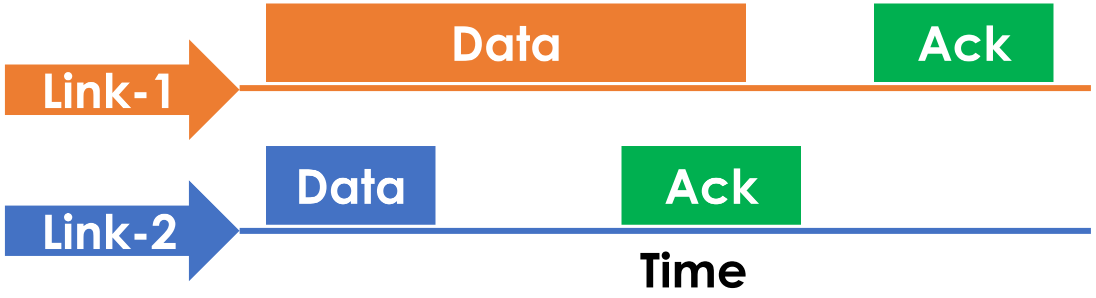


A Client can connect only to any of the single band of the AP which is available and may vary based on signal.

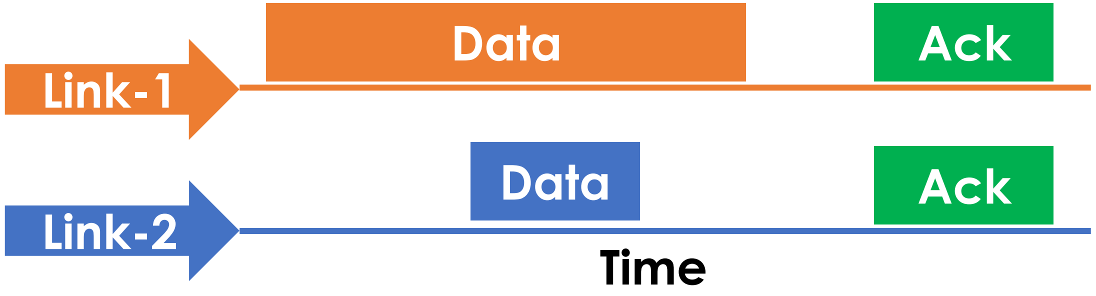
A Client can connect to any of the band based on the conditions of traffic and load on can get data.

Multi-Link Operation variants:

Asynchronous Multi-Link Operations:



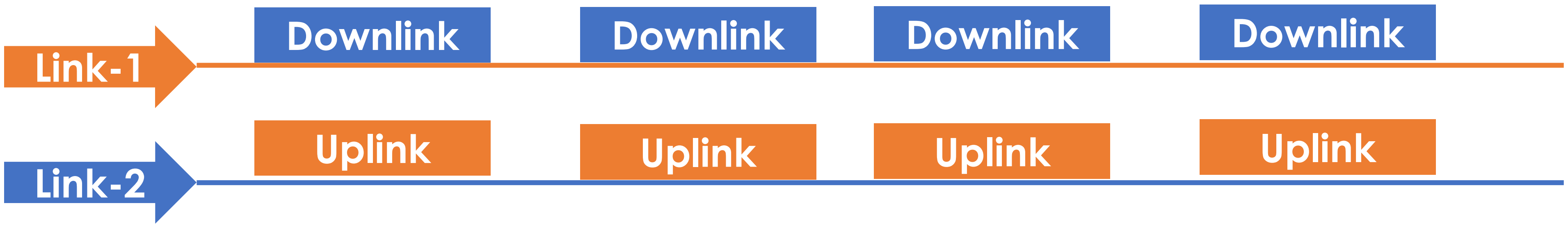
Synchronous Multi-Link Operations:



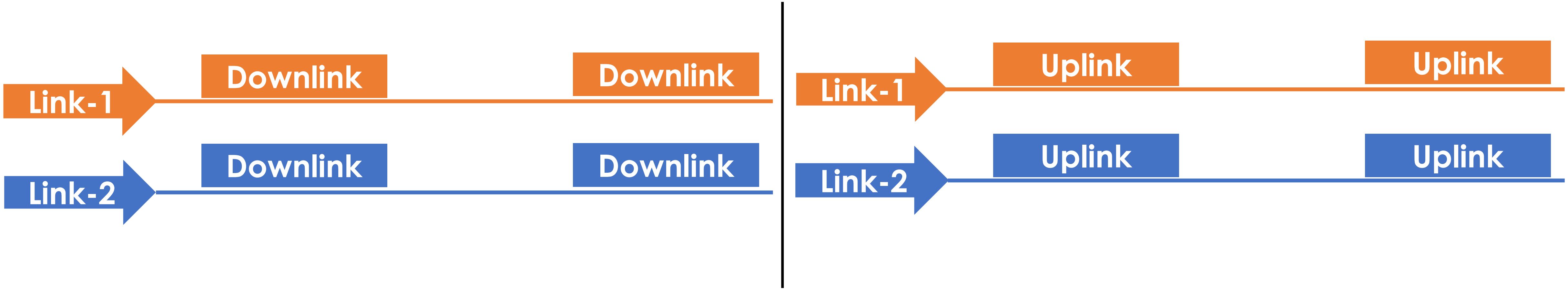
In this kind of MLO implementation, irrespective of data if both the links acknowledge the data at the same time, then it considered as Synchronous Multi-link operation, and if they are acknowledged at different times then it considered as Asynchronous Multi-link operation.

Multi-Link Operation variants:

STR Mode (Simultaneous Transmit and Receive Operation):

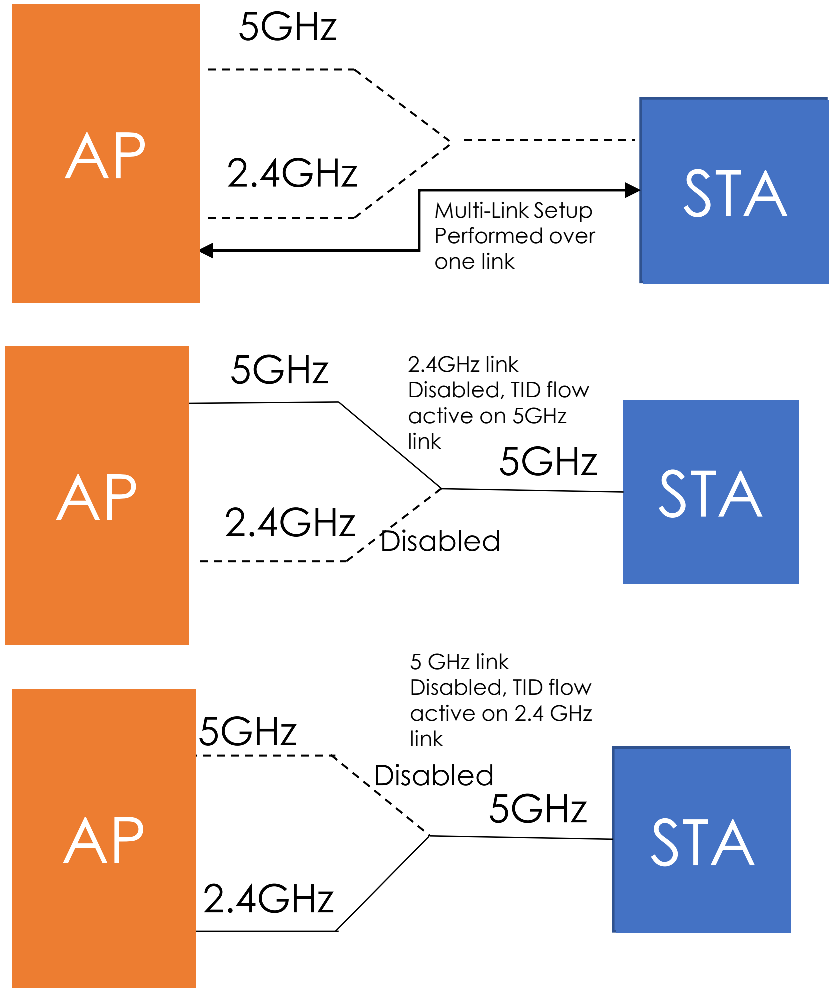


NSTR Mode (Non simultaneous Transmit and Receive Operation):

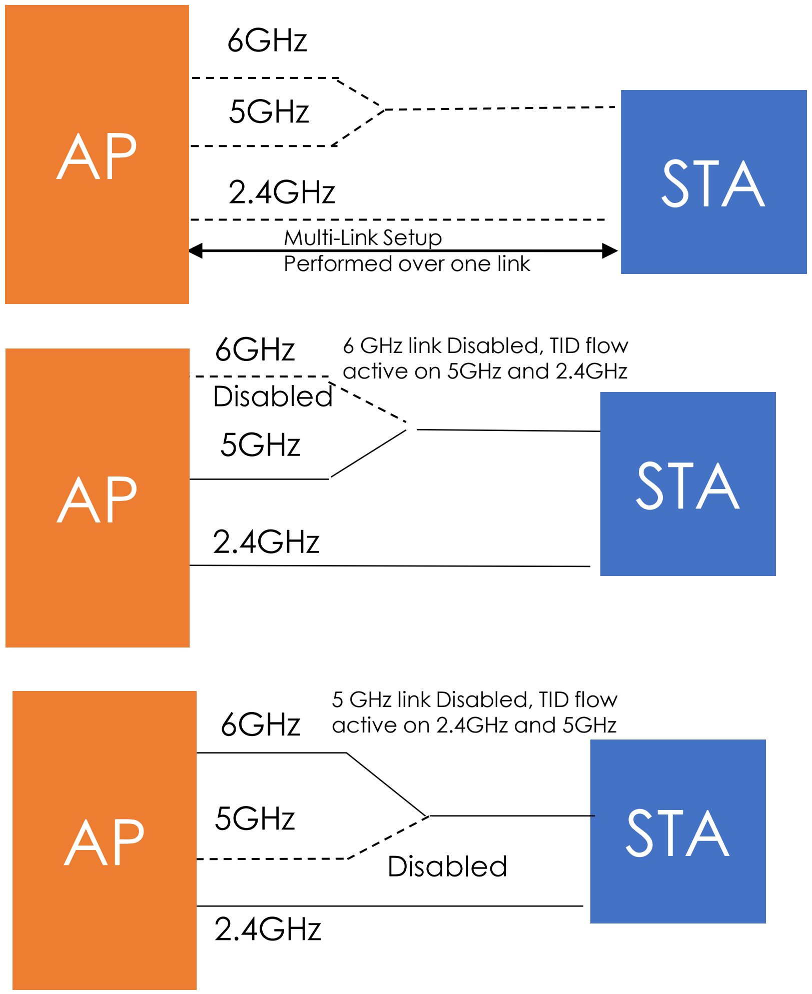


Types of Multi-Link Operation:

Multi-Link Single Radio[MLSR]

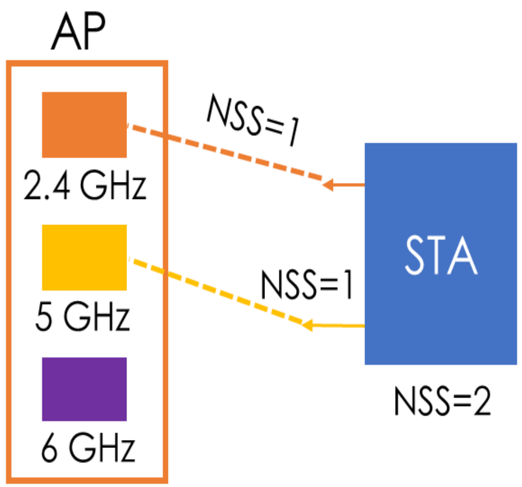


Multi-Link Multi Radio[MLMR]

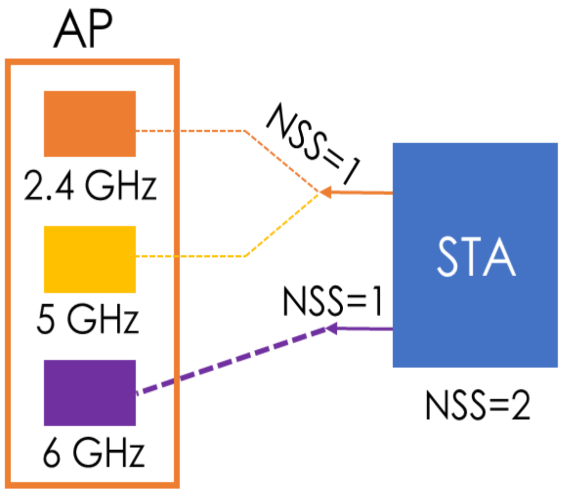


Multi-Link Operation variants [EMLSR]:

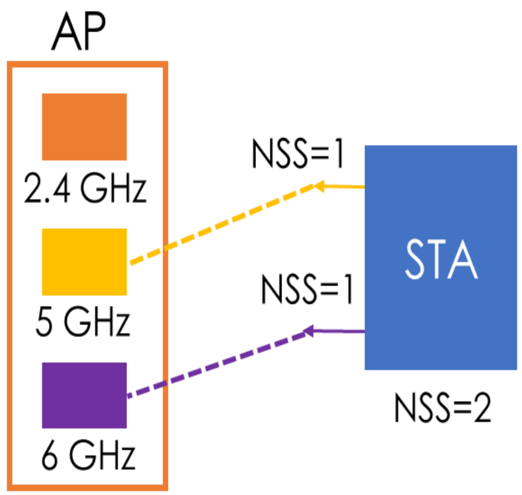
EMLSR [2-links] 2.4GHz and 5GHz



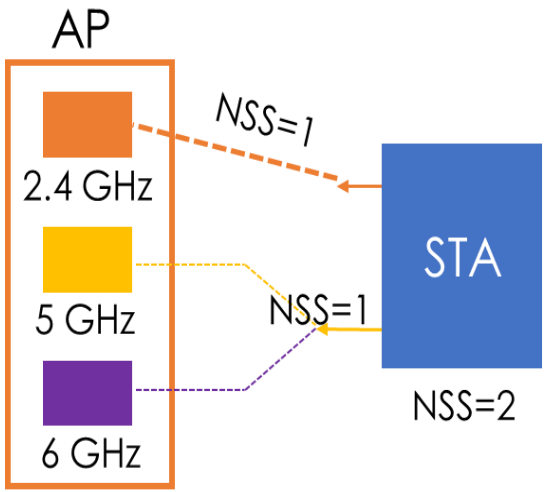
EMLSR [2-links] 2.4/5GHz and 6GHz



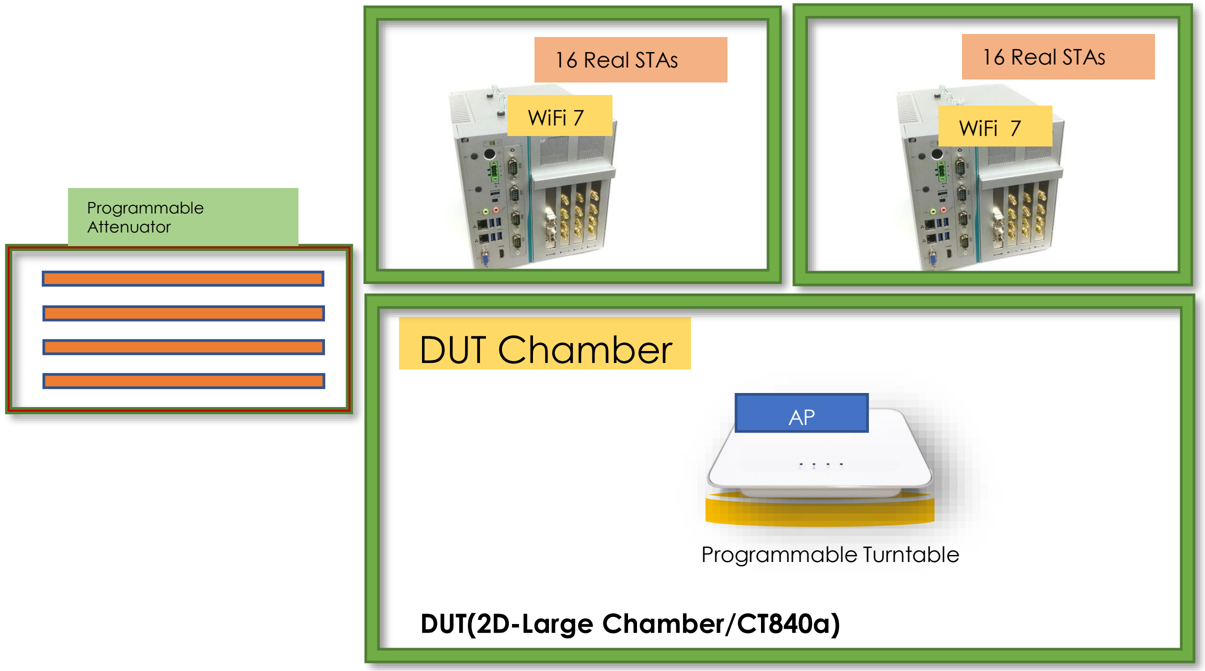
EMLSR [2-links] 5GHz and 6GHz



EMLSR [2-links] 2.4GHz and 5/6GHz



WiFi7 Test cases/Features Covered (802.11be):



Throughput Benchmark

This test gives the 6E performance with different packet sizes, channel BWs, traffic types, MIMO types.

Client Capacity

WiFi Capacity test is designed to measure performance of an Access Point when handling several 6E WiFi Stations.

Near/Far Clients, Band Steering

Measure the performance and stability of the 6E clients based on low and high RSSI levels

Wider Bandwidth -320Mhz

Supports Bandwidth upto 320Mhz

Rate vs Range vs Orientation

This test measures the 6E performance over distance and different antenna orientation of the access point.

4096 QAM

4096-QAM offers the potential for extremely high data rates, it also requires a high signal-to-noise ratio (SNR) for reliable communication

Latency

This test intends to verify latency under low, high and maximum AP traffic load with multiple stations

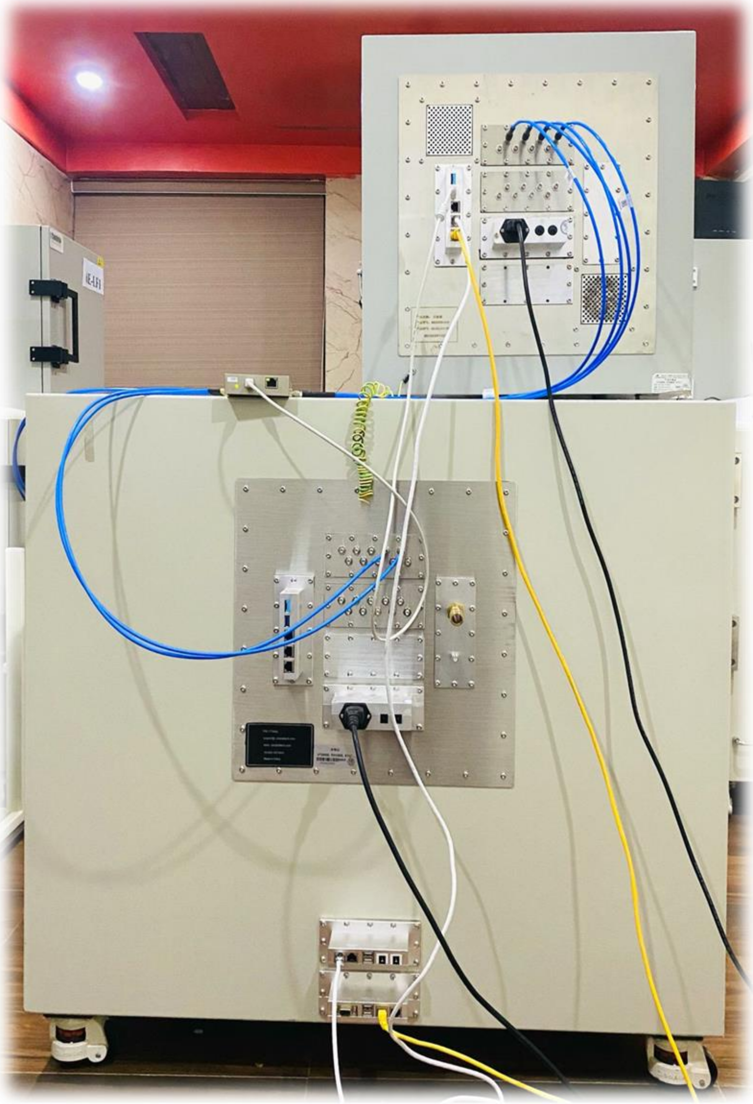
Airtime Fairness, QoS

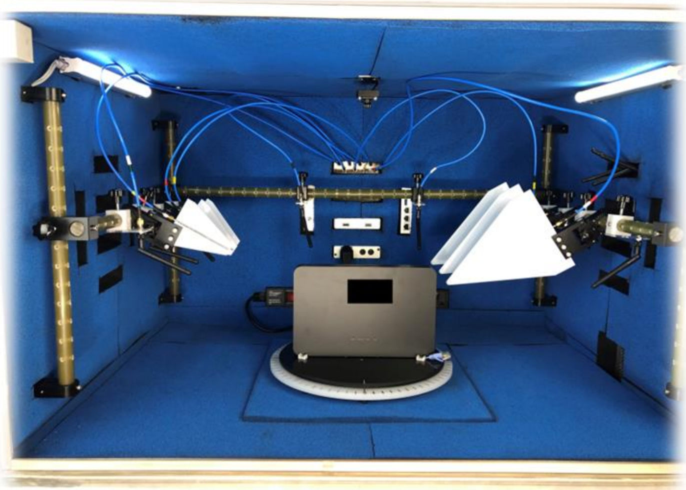
Airtime Fairness Test intends to verify the capability of Wi-Fi device to ensure the fairness of airtime usage.

MLO (Not Supported for now)

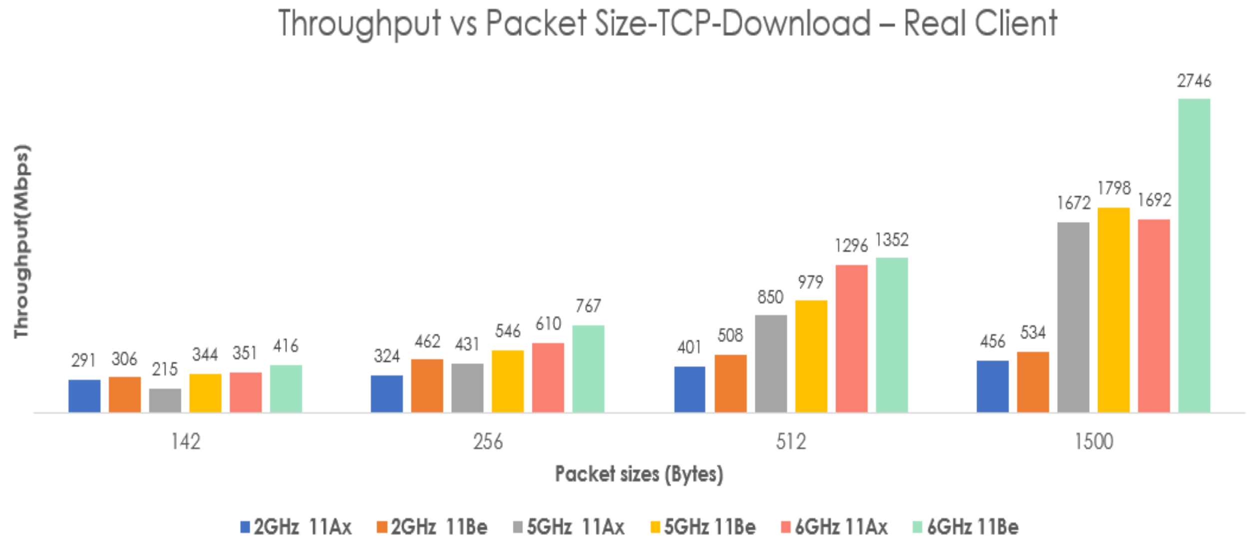
It enables devices to simultaneously send and receive data across different frequency bands and channels.

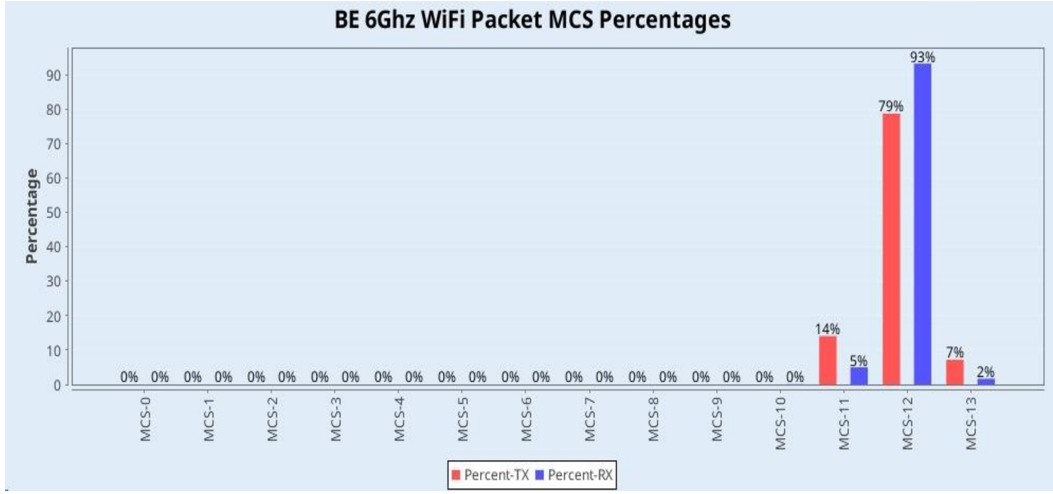
Testbed Images



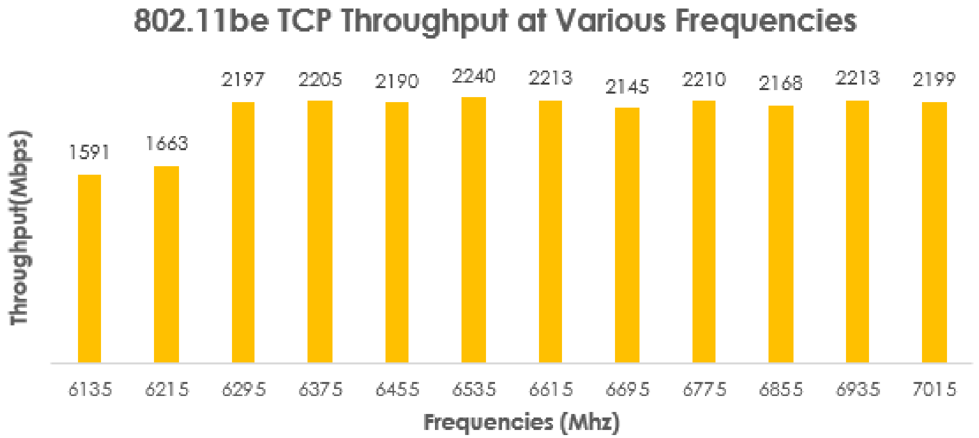


Wi-Fi 7 Throughput Benchmarking Test:

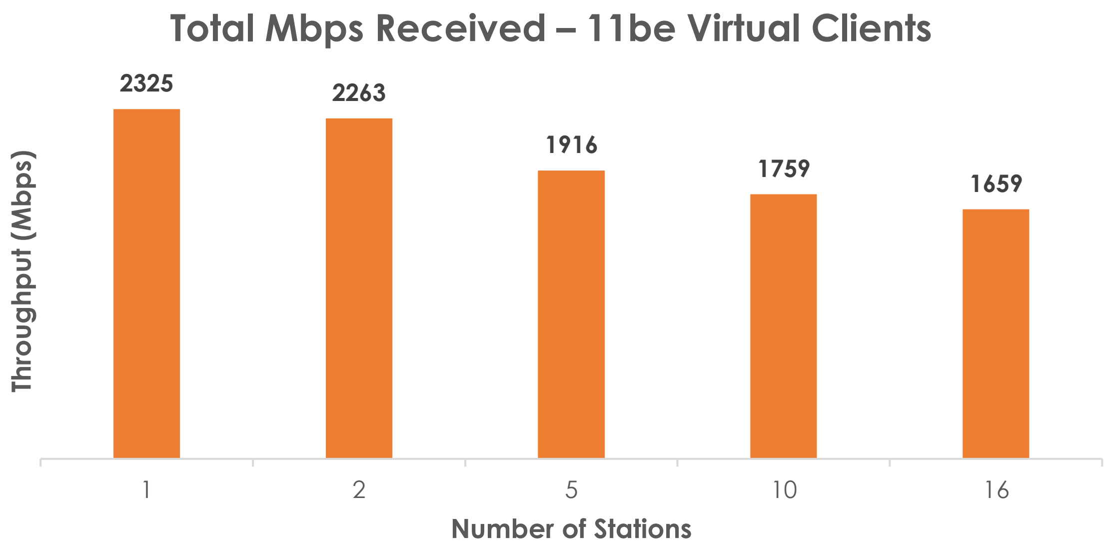


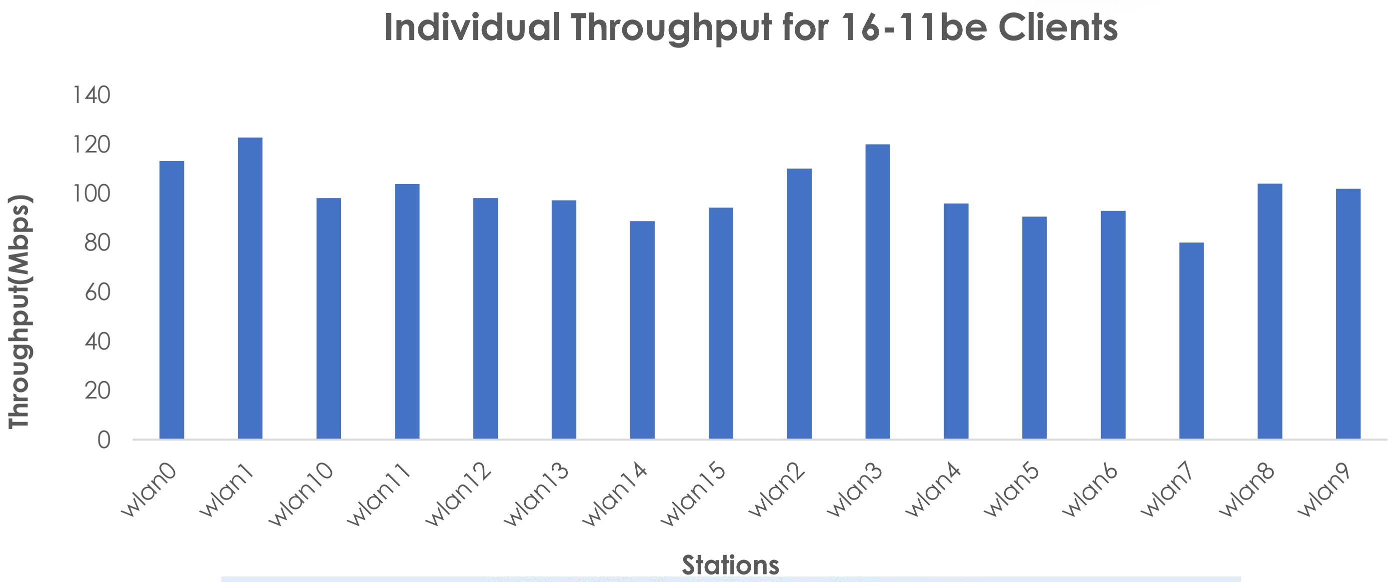


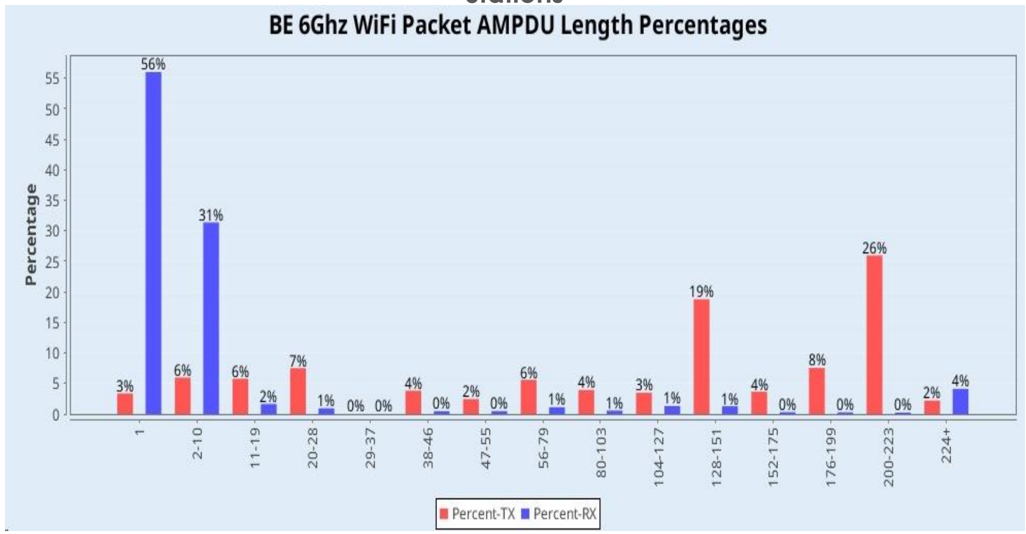
The Candela Wi-Fi data plane test is designed to conduct an automatic testing of all combinations of station types, MIMO types, Channel Bandwidths, Traffic types, Traffic direction, Frame sizes etc.… It will run a quick throughput test at every combination of these test variables and plot all the results in a set of charts to compare performance. The user is allowed to define an intended load as a percentage of the max theoretical PHY rate for every test combination. The expected behavior is that for every test combination the achieved throughput should be at least 70% of the theoretical max PHY rate under ideal test conditions. This test provides a way to go through hundreds of combinations in a fully automated fashion and very easily find patterns and problem areas which can be further debugged using more specific testing. The below chart shows the throughput with all the 6E channels.



Wi-Fi 7 Client Capacity Test



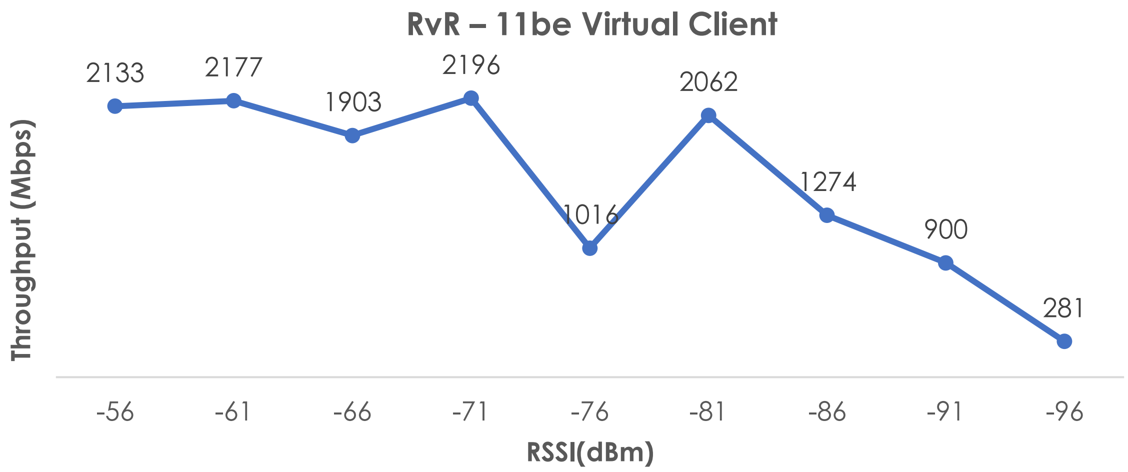


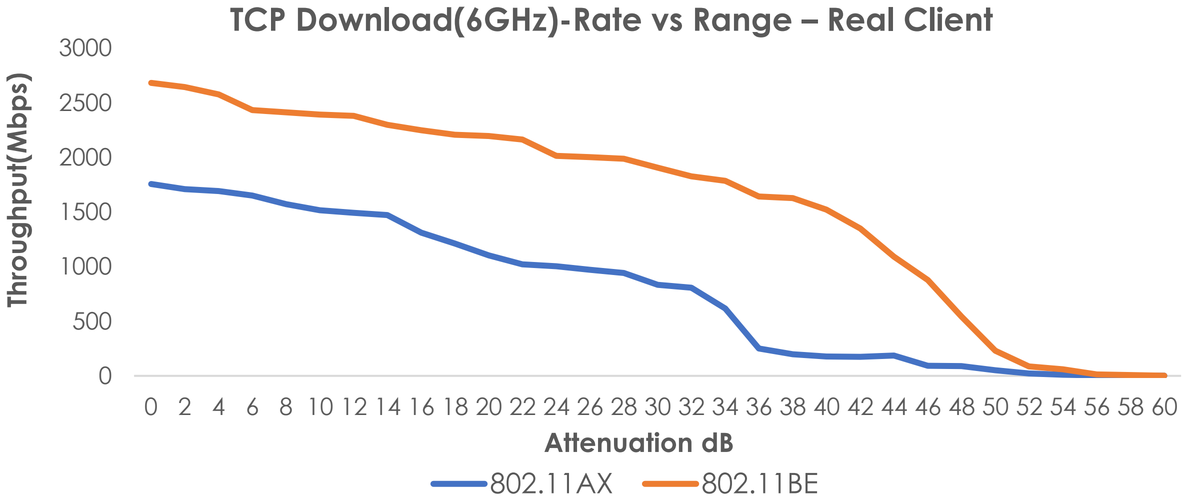


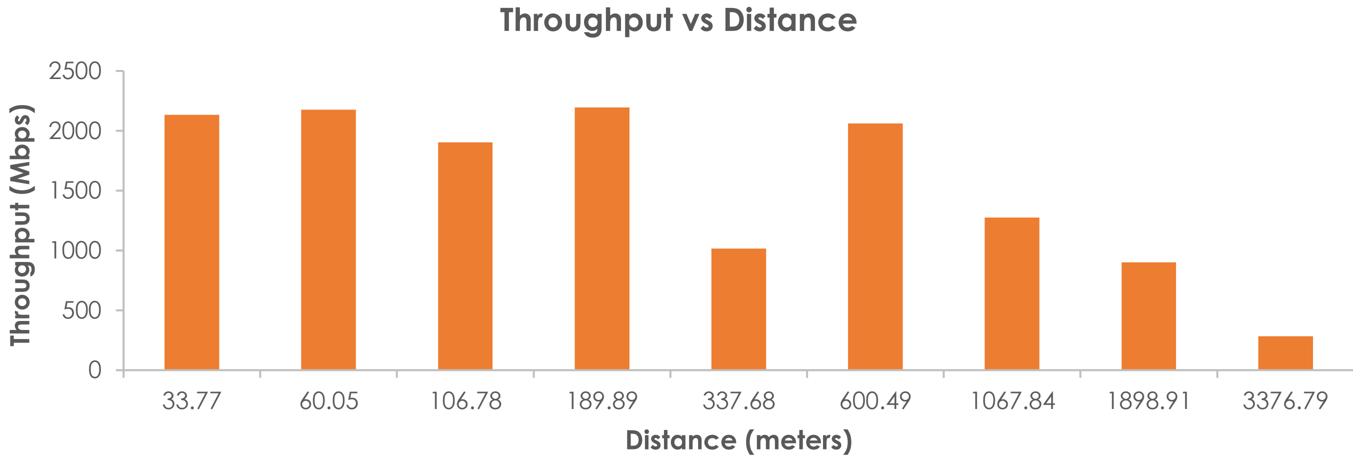
The Candela Wi-Fi Capacity test is designed to measure performance of an Access Point when handling several 6E Wi-Fi Stations. The test allows the user to increase the number of stations in user defined steps for each test iteration and measure the per station and the overall throughput for each trial. Along with throughput other measurements made are client connection times, % packet loss, DHCP times and more. The expected behavior is for the AP should be able to handle several stations (within the limitations of the AP specs) and make sure all stations get a fair amount of airtime both in the upstream and downstream.

Wi-Fi 7 Rate vs Range Test:

This test measures the performance over distance of the Device Under Test. Distance is emulated using programmable attenuation and a throughput test is run at each distance/RSSI step and plotted on a chart. The test allows the user to plot RSSI curves both upstream and downstream for different types of traffic and different station types.

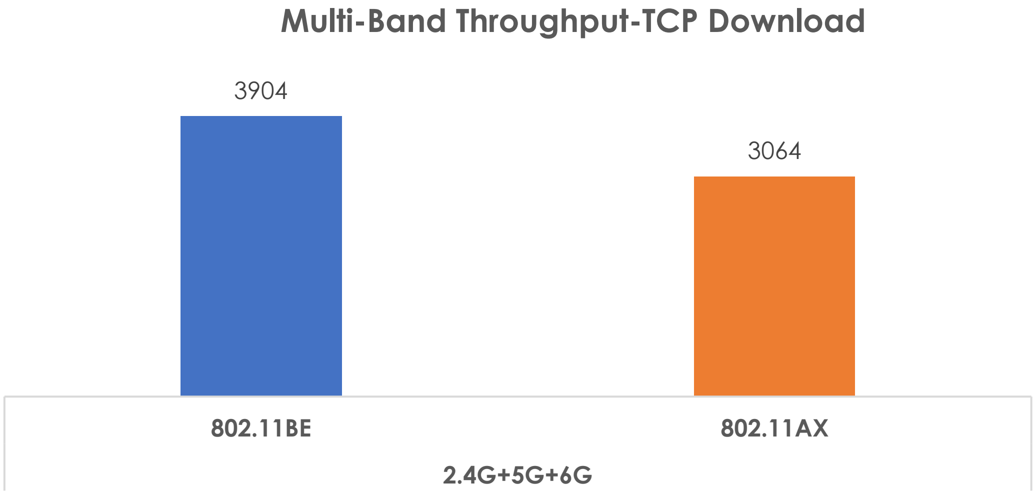


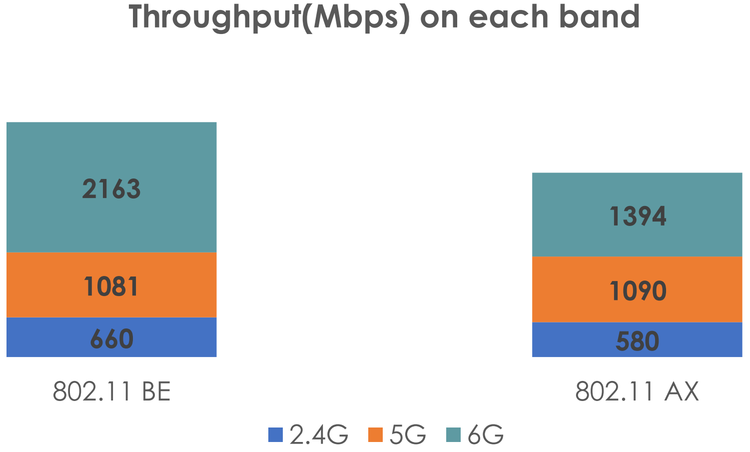


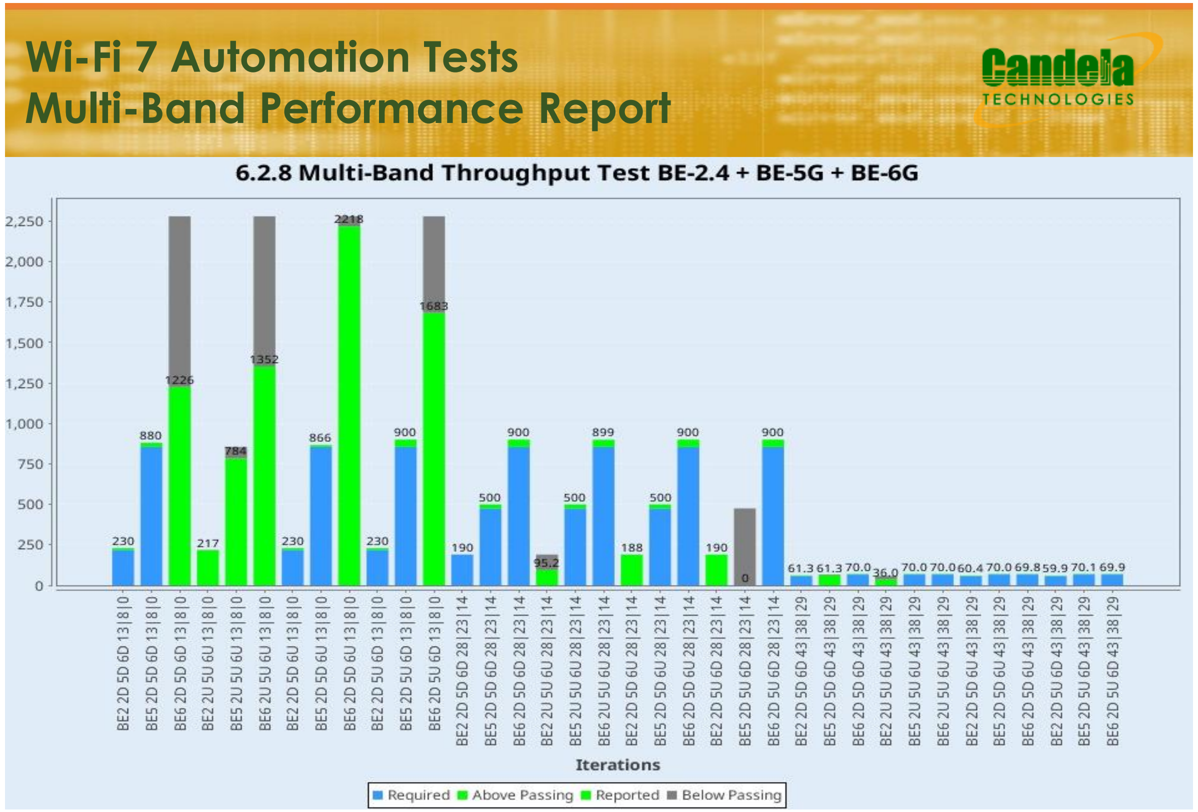


Wi-Fi 7 Multi-Band Throughput Test:

This test creates each client on 2.4, 5 and 6Ghz bands and run the traffic simultaneously. The Multi Band Performance test intends to verify that the Wi-Fi AP throughput with multiple bands active with a single station on each band. The configured speed will be 20% higher than the passing value for MTU sized frames in the throughput test. If the throughput test was skipped, then fixed values will be used.

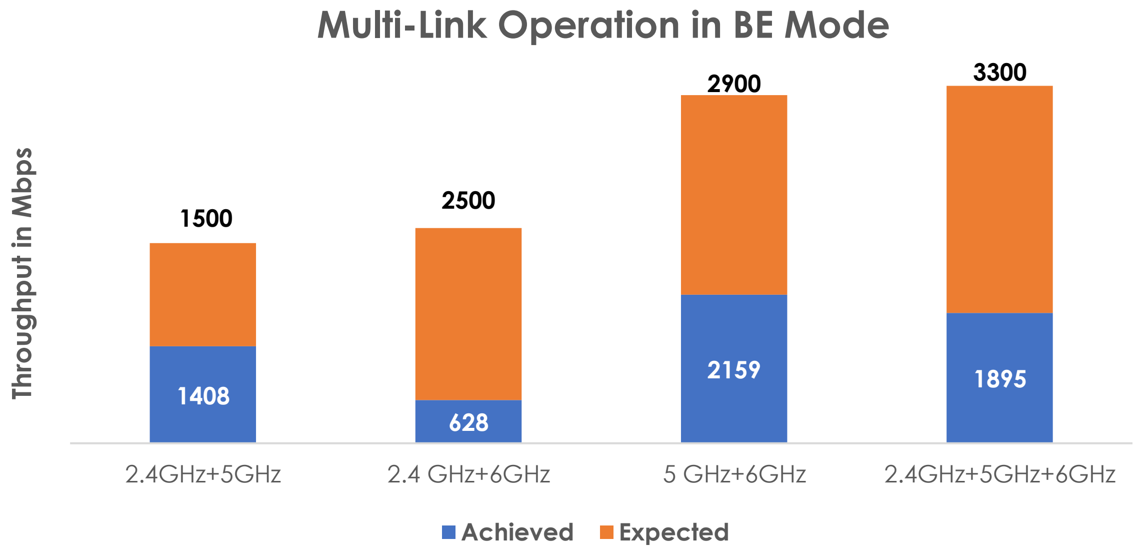






Multi-Link Operation:

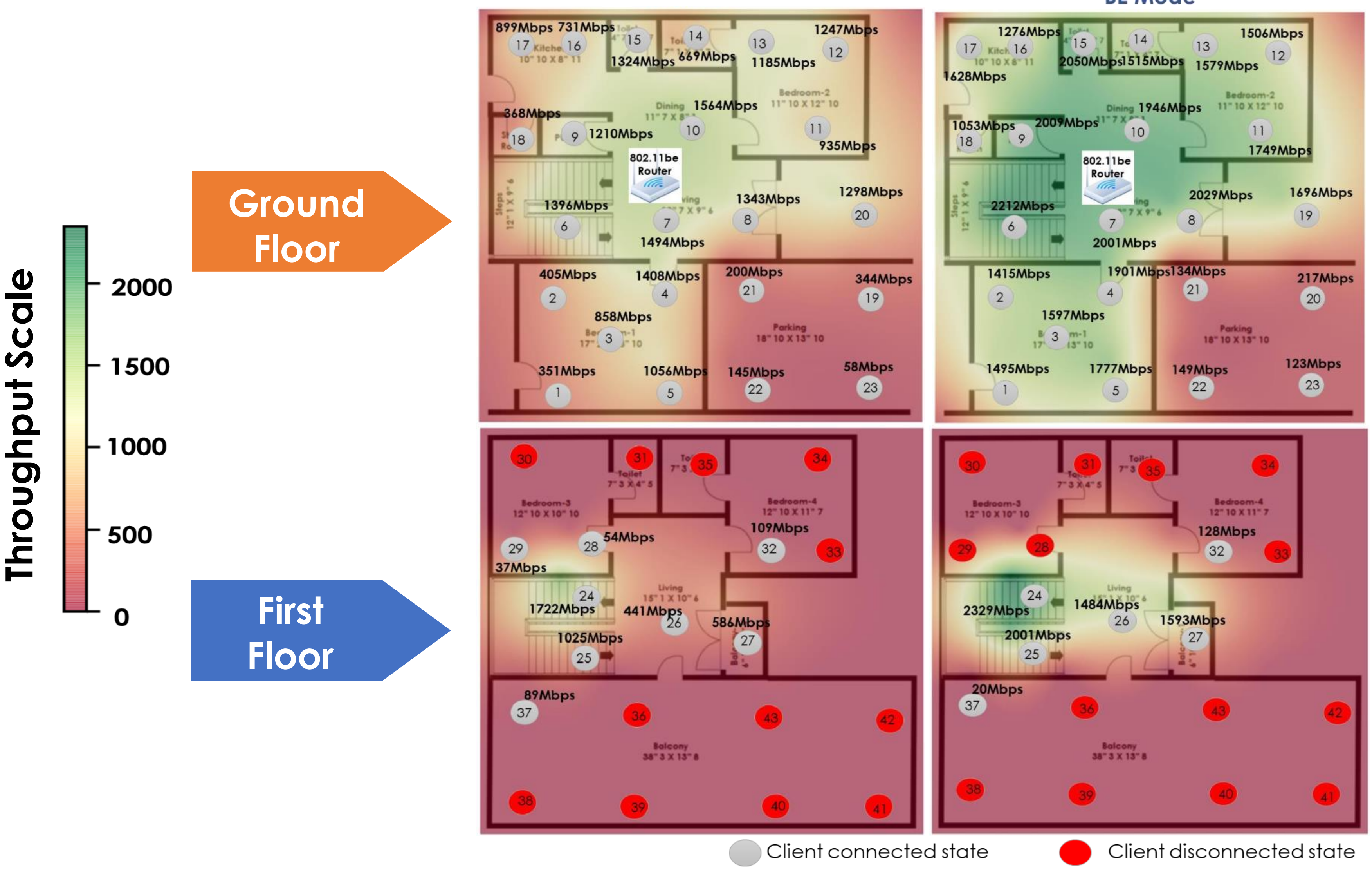
It enables devices to simultaneously send and receive data across different frequency bands and channels. With MLO, Wi-Fi 7 supports establishing multiple links between the Station (STA, such as your phone) and Wi-Fi access point (AP, such as your router). Connecting to the 2.4 GHz, 5 GHz, and 6 GHz bands simultaneously increases throughput, reduces latency, and improves reliability. It is ideal for emerging applications like VR/AR, online gaming, remote office, and cloud computing.



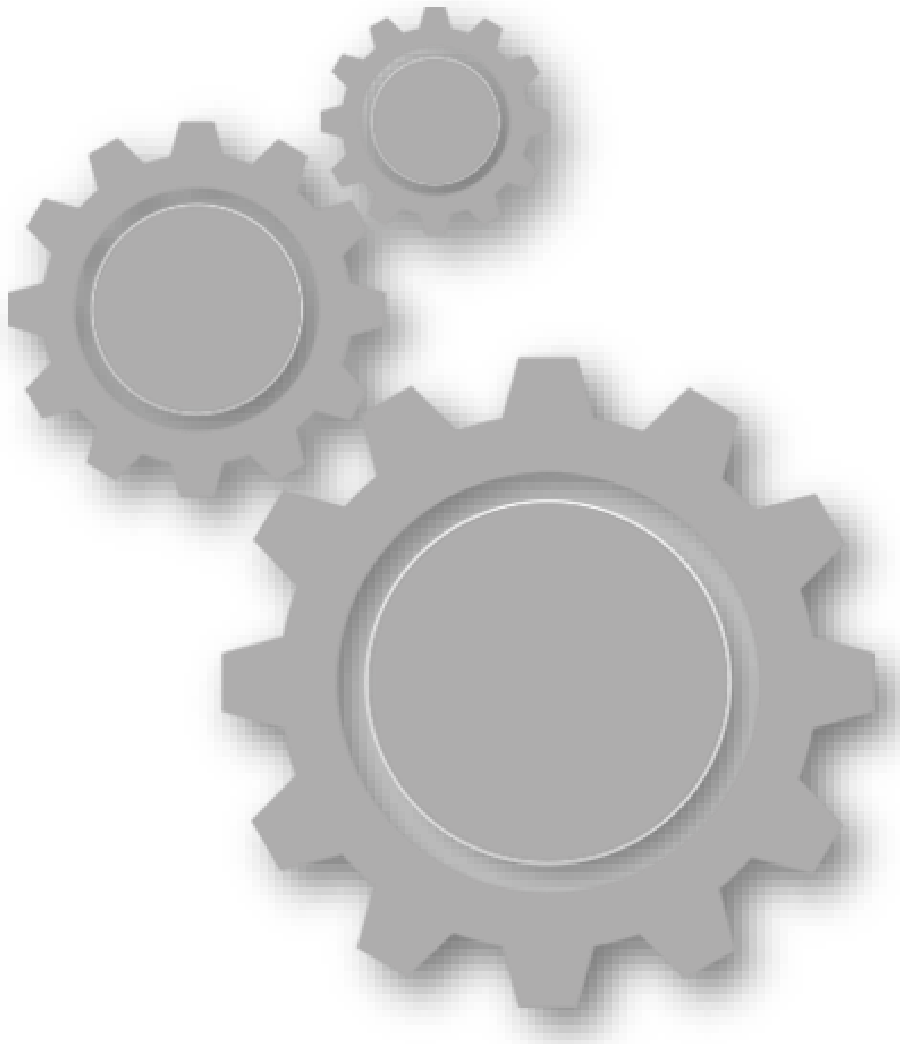
Band	Client Connected	MLO Enabled	MLO Working	Mode	NSS	MCS	Bandwidth	Channel	RSSI (dBm)	PHY-rate (Mbps)	TCP-DL Throughput (Mbps)	TCP-UL Throughput (Mbps)
2.4GHz + 5GHz	5GHz	Yes	Yes	BE	2	13	160	36	-30	2882	1408	1324
2.4GHZ + 6GHZ	2.4GHz, 6GHz	Yes	Yes	BE	2	9	320	1, 37	-19	1921, 3843	628	342
5GHz + 6GHz	5GHz	Yes	No	BE	2	12, 11	320	36	-29	5187, 4803	2.15 Gbps	2.43 Gbps
2.4GHz + 5GHz + 6GHz	6GHz	Yes	No	BE	2	13	320	1	-14	5764	1.89 Gbps	1.73 Gbps

802.11be Test-house Results:

Throughput in 6GHz band



Automation

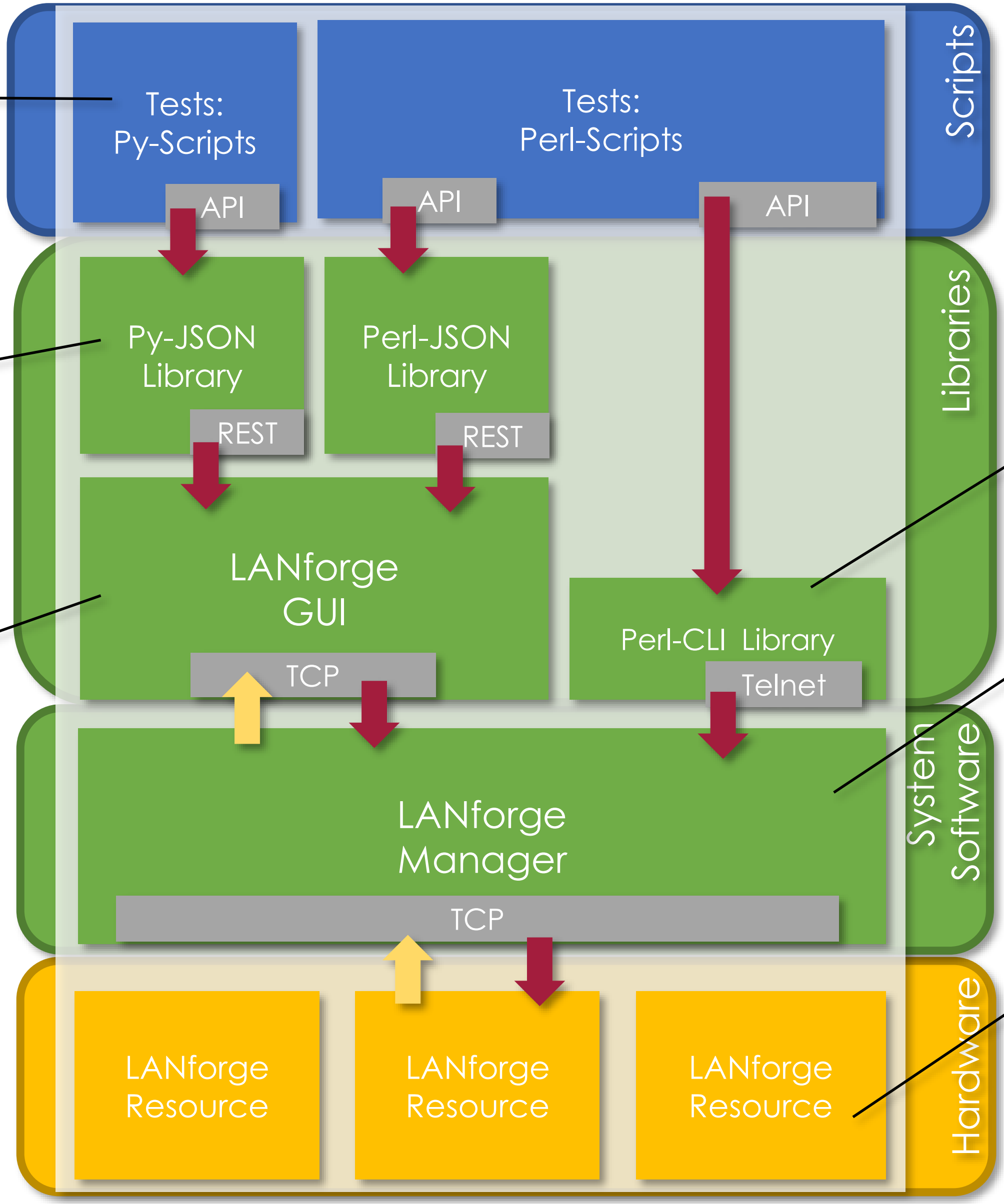


Candela Automation Architecture

- Test scripts for throughput, client capacity, roaming, range etc.. With minimum use of JSON API
- Structure for PASS/FAIL criteria and for CI/CD Automation

- Provide high level access to creating test scenarios
- Access to high level results
- Standard JSON results using REST API

- REST API Interface
- GUI Automation Interface
- Access to high level result calculations



- GUI Automation Interface
- Access to endpoint statistics
- Standalone scripts with mid level port and endpoint control.

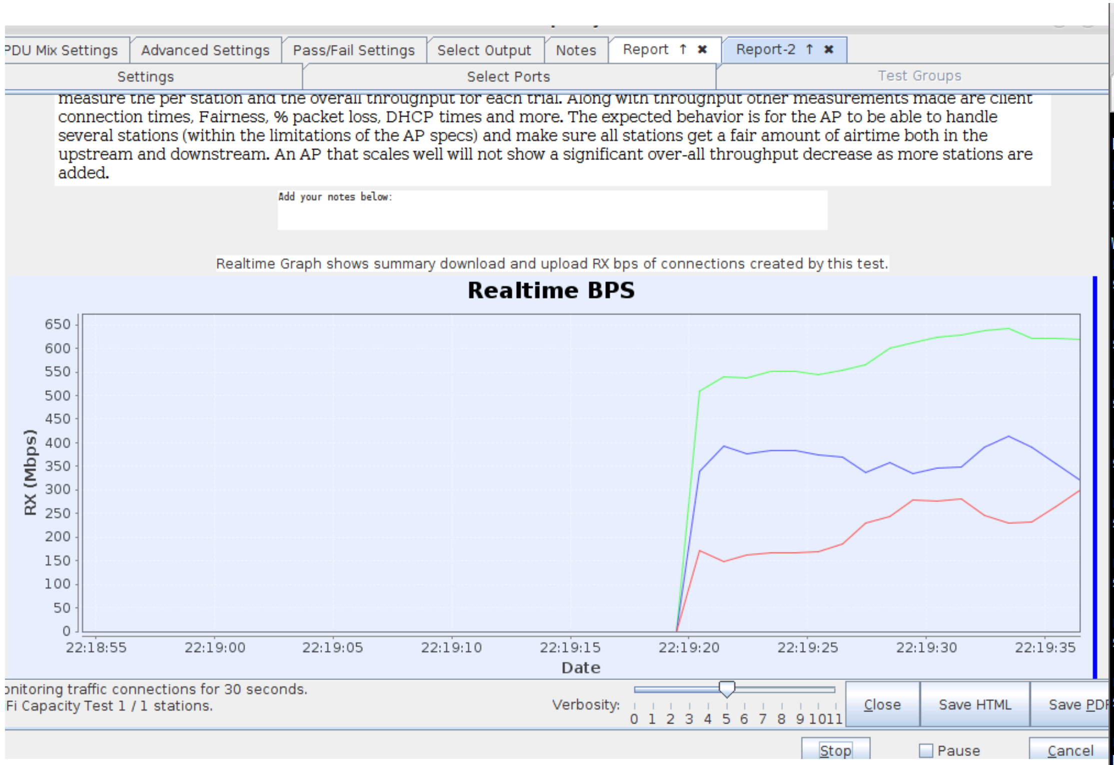
- LANforge Resource Management
- Manage third party resources (Attenuators, chambers etc..)
- Create clients/servers/traffic
- Consolidate and Present low level Statistics

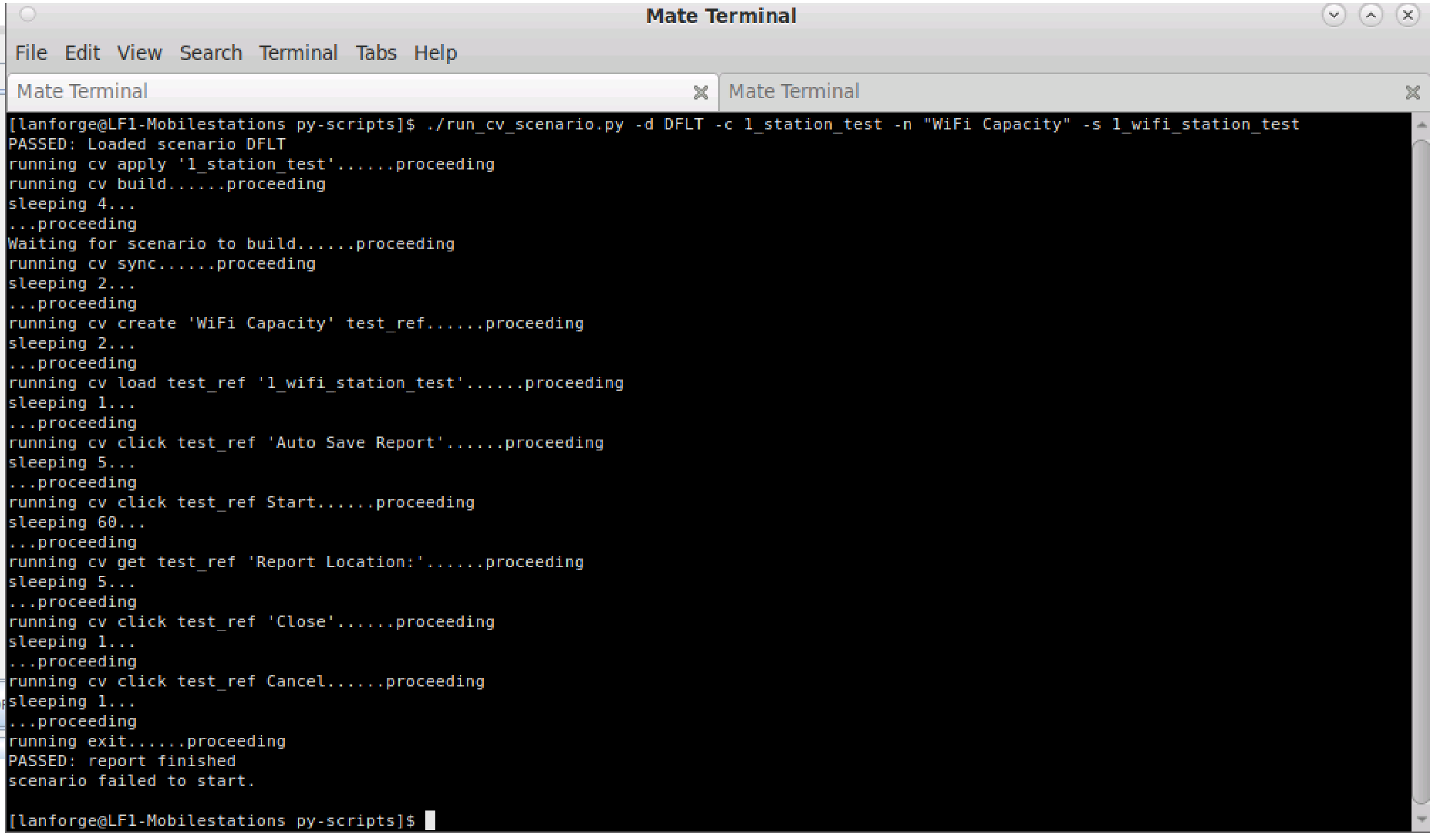
- Physical Network Ports
- Virtual WiFi Stations
- Virtual Access Points
- VLANs

Running GUI Tests from CLI

- Create test scenarios in the GUI and save the test configurations.
- Run the GUI created test configurations from the command line using "run_cv_scenario.py" script and passing the arguments with the Test name and the test profile name.
- Watch the test progress from the command line and also watch the test results in the GUI.
- The CLI based test run will save all the results and reports to the file system.

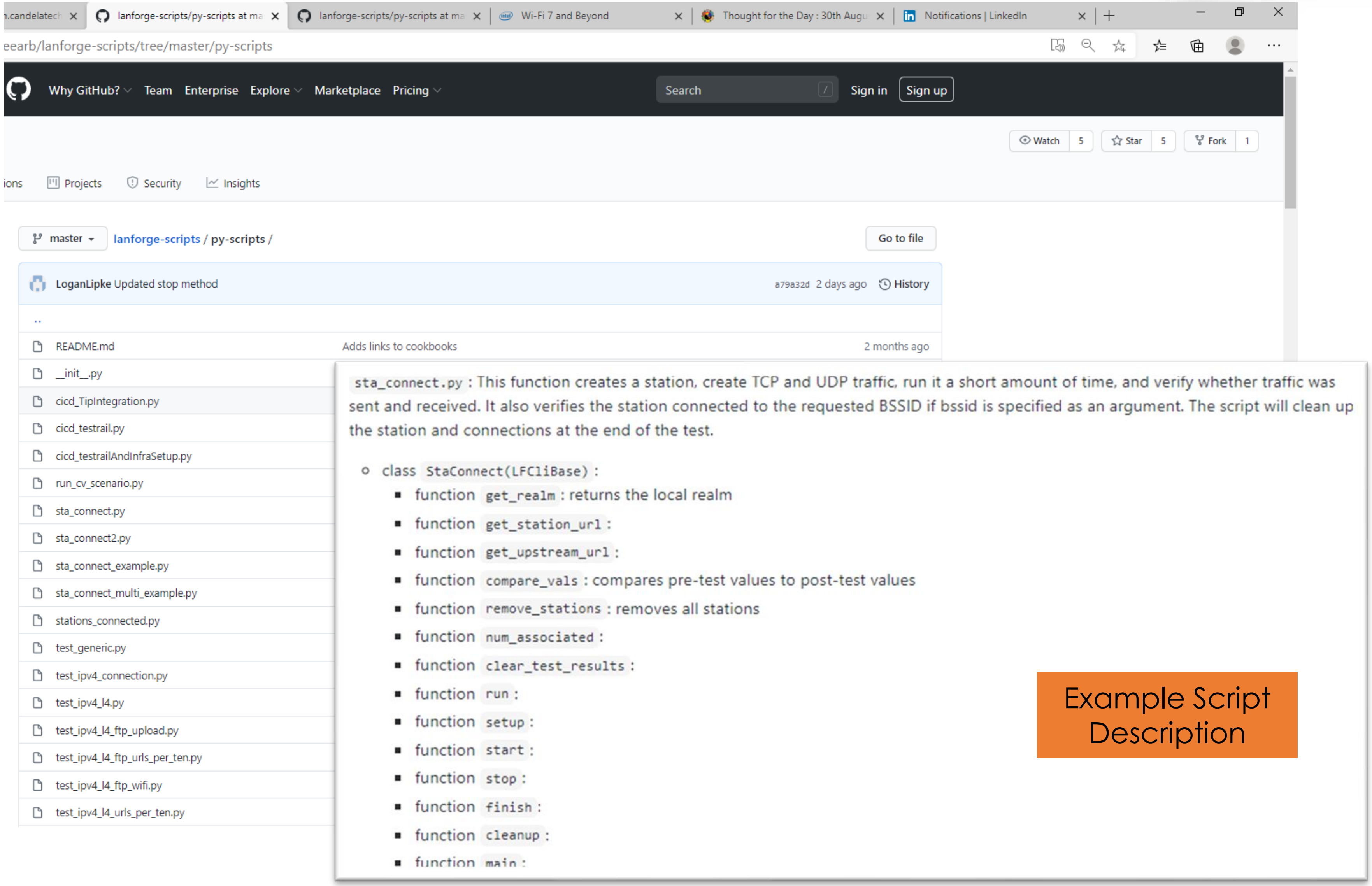
```
$ ./run_cv_scenario.py -d DFLT -c 1_station_test -n "WiFi Capacity" -s 1_wifi_station_test
```





Building from Existing Script Examples

- Libraries of scripts for various tests are available on GitHub: https://github.com/greearb/lanforge-scripts
- Generic set of scripts for simple test functions like creating WiFi stations and traffic and making measurements.
- Scripts available for more involved CI/CD automation to help automate command and controls for various CI/CD build and execution modules.
- Python modules to help create specific test scenarios like testing specific wireless security setting, traffic types, power save features etc.
- Perl scripts available for Captive Portal Login testing.



Low Level CLI Commands

add_arm_endp	Add an Armageddon (Kernel accelerated UDP) endpoint
add_cx	Add a cross-connect to a test-manager
add_cd	Add a Collision Domain (grouping of WanLinks)
add_cd_endp	Add an Endpoint to a Collision Domain
add_cd_vr	Add a Virtual Router to a Collision Domain
add_file_endp	Add a File endpoint to the LANforge Manager
add_gen_endp	Add a Generic endpoint to the LANforge Manager
add_l4_endp	Add a Layer-4 endpoint to the LANforge Manager
add_channel_group	Add a grouping of DS0 channels to be used by PPP
add_ppp_link	Add a PPP interface connection
add_t1_span	Add a T1/E1 SPAN to the LANforge Manager
add_voip_endp	Add a VOIP endpoint to the LANforge Manager
add_vr	Add or modify a Virtual Router object
add_vr_bgp	Add BGP configuration to a virtual router
add_bgp_peer	Add/Modify BGP peer configuration to a virtual router
add_vrcx	Add or modify a Virtual Router Connection Endpoint
add_vrcx2	Modify a Virtual Router Connection Endpoint object
set_vrcx_cost	Modify a Virtual Router Connection interface cost
add_endp	Add an endpoint to the LANforge Manager
add_event	Add a new event or modify an existing one
add_bond	Add a Linux Bond Device
add_br	Add a Linux Bridge Device
add_mvlan	Add a MAC based VLAN (Requires kernel support)
add_rdd	Add a Redirect-Device (Requires kernel support)
add_gre	Add a GRE Tunnel device
add_sec_ip	Add or update secondary IP Address(es)
add_vlan	Add an 802.1Q VLAN (Requires kernel support)
add_venue	Add/modify a Venue
add_sta	Add/modify a WIFI Virtual Station (Virtual STA) interface
add_vap	Add/modify a WIFI Virtual Access Point (VAP) interface
add_monitor	Add/modify a WIFI Montior interface
add_tm	Create and add a new test manager to the system
add_group	Create a new test group
add_tgcx	Adds CX to test group
add_wl_endp	Add a WanLink (ICE) endpoint to the LANforge Manager

add_wanpath	Add a WanPath (ICE) personality to a WanLink
admin	Various admin commands
apply_vr_cfg	Apply all of the virtual routing settings
cancel_vr_cfg	Cancel a virtual-router configuration process
clear_cx_counters	Clear counters for one or all cross-connects
clear_endp_counters	Clear counters for one or all endpoints
clear_cd_counters	Clear counters for one or all Collision Domains
clear_group	Clears all cross-connects in a test group
clear_port_counters	Clear one or all port counters or other items
clear_resource_counters	Clear counters on one or all resources
clear_wp_counters	Clear WanPath counters for one endpoint
discover	Force discovery of nodes on the management
diag	Get diagnostic information from the LANforge
notify_dhcp	Handle input from the DHCP client process
do_pesq	Start a PESQ calculation
file	Download files through LANforge API
gossip	Send a message to everyone else logged in
getintxrate	Get tx pps rate over the last 3 seconds
getinrxrate	Get rx pps rate over the last 3 seconds
getinrxbps	Get rx bpsrate over the last 3 seconds
gettxpkts	Get the total tx packets sent
getrxpkts	Get the total rx packets sent
getpktdrops	Get the total packets dropped
getavglatency	Get the average latency for an endpoint
getrxporterrpkts	Get the total error packets detected
getrxendperrpkts	Get the total error packets detected
getipadd	Get the IP for an endpoint
getmask	Get the IP Mask for an endpoint
getmac	Get the MAC address for an endpoint
?	Show help for command(s)
init_wiser	Initialize the Wiser NCW/HNW module
licenses	Print out license information. See also: set_license
load	Load a previously saved test database
login	Login as the client who's name you enter
create_client	Create a new client

log_level	Query or modify the logging level
motd	Get the message of the day (alerts
nc_show_endpoints	Non-Cached Show one or all endpoints
nc_show_pesq	Non-Cached Show PESQ results
nc_show_ports	Show one/all ports for one/all
c_show_ports	Show one/all ports for one/all resources
nc_show_channel_grps	Show one/all ChannelGroups for one/all resources
nc_show_spans	Show one/all Spans for one/all resources
nc_show_vr	Show one/all Virtual Routers for one/all resources
nc_show_vrcx	Show one/all Virtual Router Connections
nc_show_cd	Show one/all Collision Domains
nc_show_ppp_links	Show one/all PPP Links for one/all resources
probe_port	Probe & report low-level details for a port
probe_ports	Check for the existence of new (virtual) interfaces
port_reset_completed	notify LANforge the reset has completed
exit	Log out of the LANforge control server
report	Configure server-side reporting
reset_port	Reset an Ethernet port or ports
reset_serial_span	Reset a serial span
reboot_os	Restart the OS on a remote resource
rm_attenuator	Remove Attenuator
rm_cd	Remove a Collision Domain
rm_cd_endp	Remove an Endpoint from a Collision Domain
rm_cd_vr	Remove a Virtual Router from a Collision Domain
rm_endp	Remove one or all endpoints
rm_channel_group	Remove a channel group
rm_event	Remove one or more events from the event log
rm_group	Deletes a new test group
rm_threshold	Remove existing threshold-alert
rm_tgcx	Removes CX from test group
rm_venue	Remove a venue
rm_vr	Remove one or all Virtual Routers
rm_vrcx	Remove one or all Virtual Router Connections
rm_span	Remove a Serial Span
rm_ppp_link	Remove a PppLink

Running LANforge CLI Commands

- LANforge CLI commands are used by scripts and the GUI.
- Available Perl scripts can access the CLI commands directly.
- Python scripts talk to the GUI that issues CLI commands.
- Perl script debug mode can show all CLI commands being issued.

Create a Layer 4-7 Web Connection

Layer 4-7 connections are created with a one-sided technique, the curl command always operates on the **A-side** and the **B-side** is unmanaged. The endpoint and connection naming does not follow the Layer-3 convention.

Shell script:

```
./lf_vue_mod.sh --mgr jedtest --resource 2 --create_l4 --name yh200 --sta sta200 --url
http://www.yahoo.com/ --utm 2400 --log_cli /tmp/clilog.txt --quiet 1
```

Perl script:

Commands are set using `lf_firemod.pl --action do_cmd --cmd ...`

CLI commands:

```
add_l4_endp yh200 1 2 sta200 l4_generic 0 10000 2400 'dl http://www.yaho
set_endp_tos yh200 DONT-SET 0
set_endp_flag yh200 L4Enable404 0
set_endp_report_timer yh200 5000
set_endp_flag yh200 ClearPortOnStart 0
set_endp_quiesce yh200 3
add_cx CX_yh200 default_tm yh200
```

Command Composer [set_port]

This is the curl command:

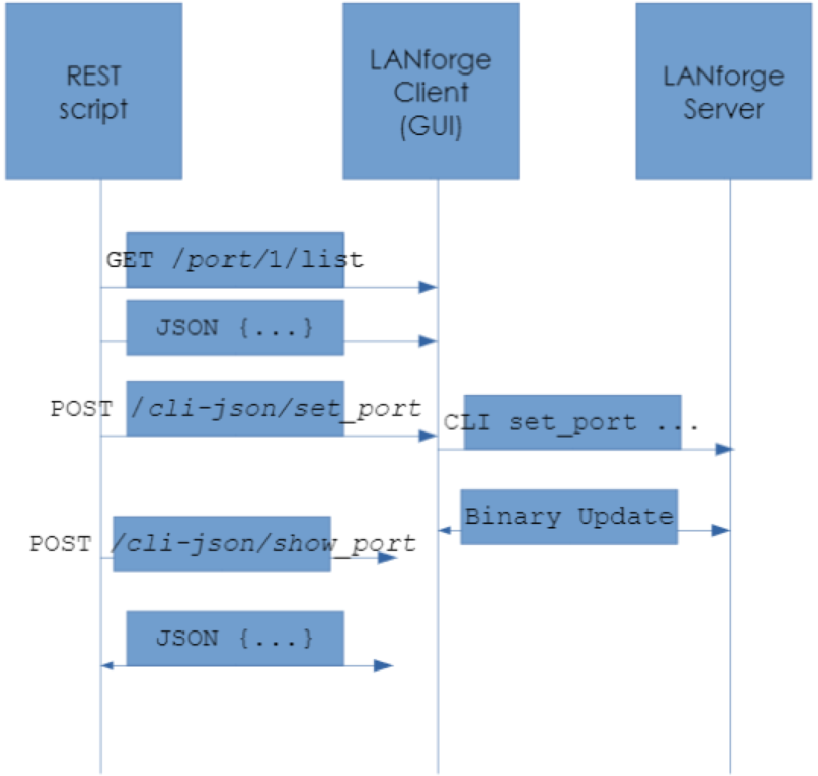
```
$ echo '' > /tmp/curl_data
$ curl -sqv -H 'Accept: application/json' -X POST -d '@/tmp/curl_data' http://atlas:8080/cli-form/set_port
```

This is the CLI command:

```
1 3 sta3000 NA NA NA NA 2147483649 NA NA NA NA 16384 3 NA NA NA NA NA NA NA NA NA
NA NA NA NA NA NA NA NA NA
```

REST APIs

- LANforge GUI contains an embedded webserver that processes REST requests.
- LANforge GUI can handle multiple REST requests at once.
- REST provides more information than available from CLI.
- REST APIs can be used from all programming language



Creating a WiFi Station

Please refer to the scripts `lf_associate_ap.pl` and `lf_vue_mod.sh` for examples of how to produce lists of CLI commands involved in creating stations. Please refer to:

1. Learn CLI Commands used to operate WiFi stations
2. and Changing Station WiFi SSID with the CLI API

These will provide ways of collecting the CLI commands in log files for you to place into the command `/help/` page.

- Use ssh to log into your LANforge manager. Use the `lf_vue_mod.sh` script to create a station:

```
$ cd scripts
$ ./lf_vue_mod.sh --mgr localhost --resource 3 --create_sta --name sta3101 \
  --radio wiphy1 --ssid idtest-1000-open --passphrase '[BLANK]' \
  --log_cli /tmp/clilog.txt

$ cat /tmp/clilog.txt
set_wifi_radio 1 3 wiphy1 NA -1 NA NA NA NA NA NA NA NA 0x1 NA
add_sta 1 3 wiphy1 sta3101 1024 idtest-1000-open NA [BLANK] AUTO NA 00:0e:8e:c1:df:45 8 N
set_port 1 3 sta3101 0.0.0.0 255.255.0.0 0.0.0.0 NA 2147483648 00:0e:8e:c1:df:45 NA NA NA
```

- Enter each command into the your browser toolbar by altering the command into a url:

1. `//localhost:8080/help/set_wifi_radio?cli=1 3 wiphy1 NA -1 NA NA NA NA NA NA NA NA 0x1 NA`

   Produces:

   ```
   $ echo 'shelf=1&resource=3&radio=wiphy1&channel=-1&flags=0x1' > /tmp/curl_data
   $ curl -sqv -H 'Accept: application/json' -X POST -d '@/tmp/curl_data' \
    http://localhost:8080/cli-form/set_wifi_radio
   ```

2. `http://localhost:8080/help/add_sta?cli=1 3 wiphy1 sta3101 1024 idtest-1000-open NA [BLAN`

   Produces:

   ```
   $ echo 'shelf=1&resource=3&radio=wiphy1&sta_name=sta3101&flags=1024&ssid=idtest-1000-ope
   $ curl -sqv -H 'Accept: application/json' -X POST -d '@/tmp/curl_data' \
    http://localhost:8080/cli-form/add_sta
   ```

3. `http://localhost:8080/help/set_port?cli=1 3 sta3101 0.0.0.0 255.255.0.0 0.0.0.0 NA 21474`

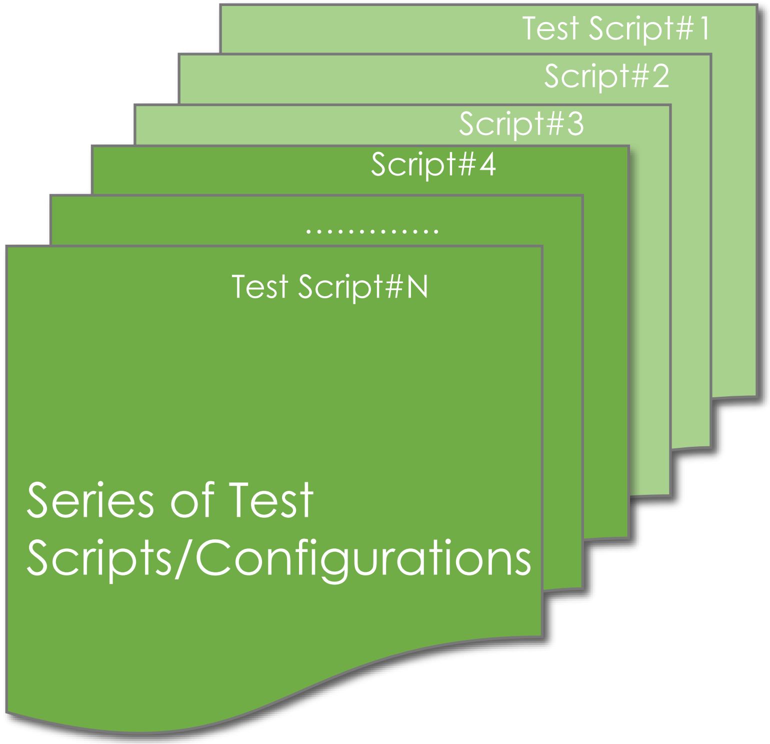
Running Groups of Tests

- Users can use scripts to load different test scenarios.
- Multi connections can be controlled via test groups.
- Reports can be generate at the end of a series of tests.
- Test groups can be integrated easily into any existing automation framework.

```
#!/bin/bash
cd /home/lanforge/scripts
./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "load tcp_thruput overwrite"
sleep 15
./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "start_group tcp_group1"
sleep 60
./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "quiesce_group tcp_group1"
sleep 5

./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "load udp_thruput overwrite"
sleep 15
./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "start_group udp_group1"
sleep 60
./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "quiesce_group udp_group1"
sleep 5

./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "load mcast_thruput overwrite"
sleep 15
./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "start_group mcast_group1"
sleep 60
./lf_firemod.pl --mgr localhost --action do_cmd \
 --cmd "quiesce_group mcast_group1"
sleep 5
```

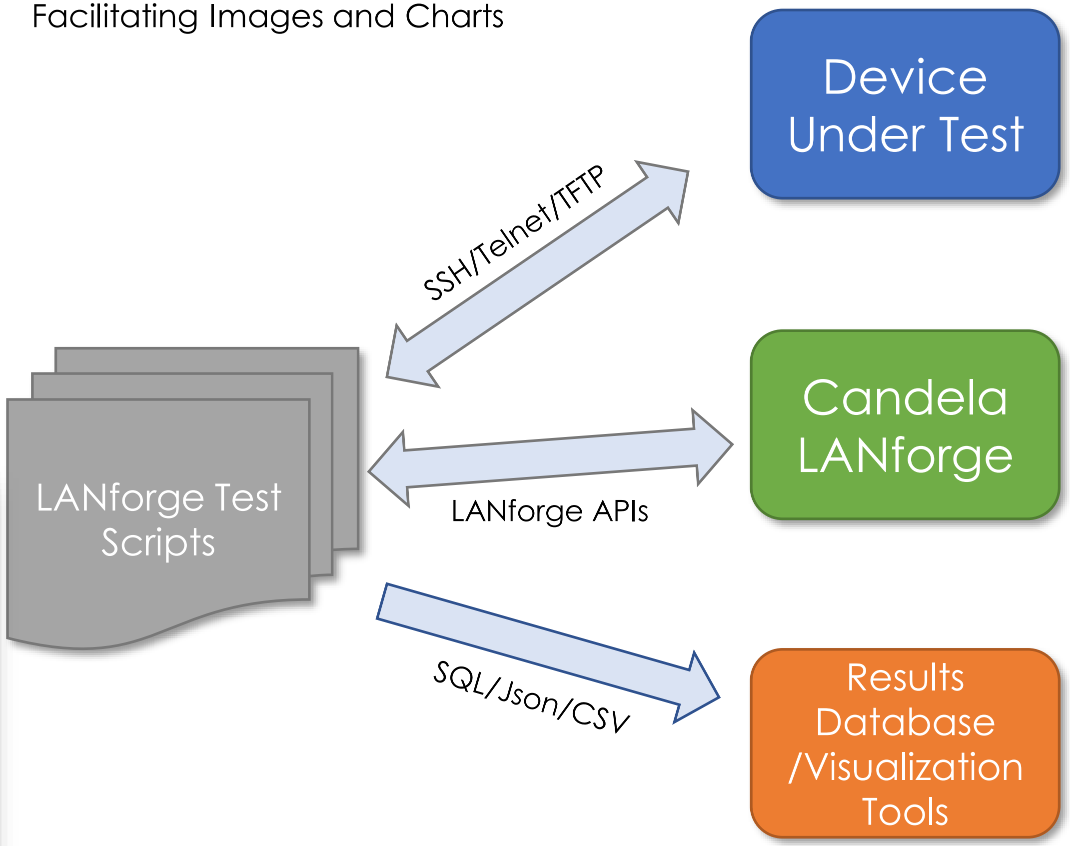


Scripting with Device Under Test Controls

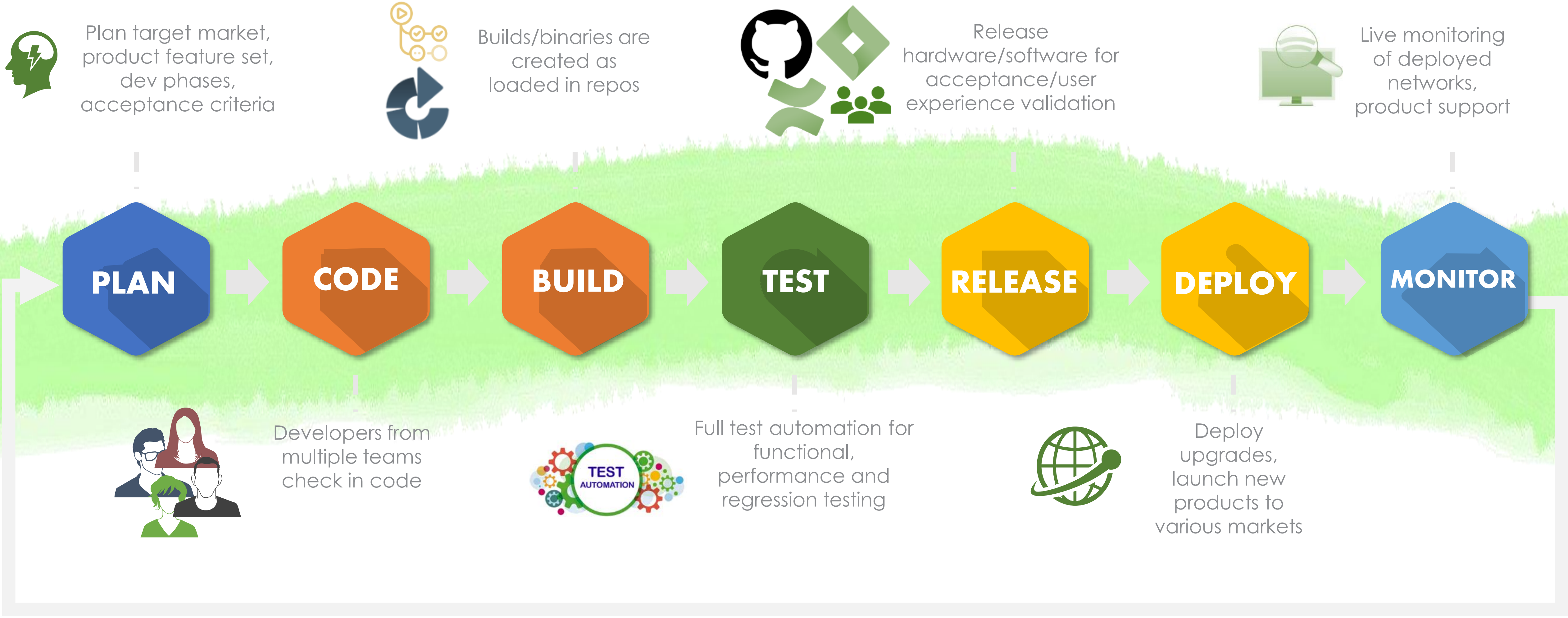
- Device Control
  - SSH: Commands
  - Telnet : Commands
  - TFTP : Firmware
- LANforge Control
  - Loading test scenarios
  - Creating traffic
  - Measuring Results
- Test Harness Interaction
  - Reporting PASS/FAIL results
  - Submitting test data
  - Facilitating Images and Charts

```
try:
    s = pxssh.pxssh()
    s.login(host2, user2, pwd)
    s.sendline('sysupgrade /tmp/openwrt-ipq40xx-generic-linksys_ea8300-squashfs-sysupgrade.bin')
    s.prompt()  # match the prompt
    print(s.before)  # print everything before the prompt.
    s.sendline('service opensync restart')
    s.prompt()  # match the prompt
    print(s.before)  # print everything before the prompt.
    s.logout()
    return "pass"
except pxssh.ExceptionPxssh as e:
    print("ALERT !!!!!! pxssh failed on login.")
    print(e)
```

```
  def run_opensyncgw_in_docker(self):
      #my_env = os.environ.copy()
      #my_env["userpass"] = user_password
      #my_command = 'python --version'
      #subprocess.Popen('echo', env=my_env)
      with open(local_dir +"docker_jfrog_login.log", "a") as output:
          subprocess.call("docker login --username" + cicd_user + "--password" + cicd_pw + " https://tip-tip-wlan-clou
                          stderr=output)
      with open(local_dir +"opensyncgw_upgrade.log", "a") as output:
          subprocess.call("docker pull tip-tip-wlan-cloud-docker-repo.jfrog.io/opensync-gateway-and-mqtt:0.0.1-SNAPSHO
                           stderr=output)
      with open(local_dir+"opensyncgw.log", "a") as output:
          subprocess.call("docker run --rm -i -p 1883:1883 -p 6640:6640 -p 6643:6643 -p 4043:4043 \
-v ~/mosquitto/data:/mosquitto/data \
-v ~/mosquitto/log:/mosquitto/log \
-v ~/wlan-pki-cert-scripts:/opt/tip-wlan/certs \
-v ~/app/log:/app/logs \
-v ~//app/config:/app/config \
-e OVSDB_CONFIG_FILE='/app/config/config_2_ssids.json' \
tip-tip-wlan-cloud-docker-repo.jfrog.io/opensync-gateway-and-mqtt:0.0.1-SNAPSHOT",shell=True, stdout=output,
                           stderr=output)
          print("opensync Gateway is running")
          return "pass"
```



CI/CD WiFi Pipeline



Continuous Integration(CI) / continuous Delivery(CD) Automation

Candela TECHNOLOGIES

03 Run Tests

Reboot/Reset DUT and Test system and other testbed components as needed. Pull information about test jobs to run, run the fully automated regression tests.

02 Load Builds

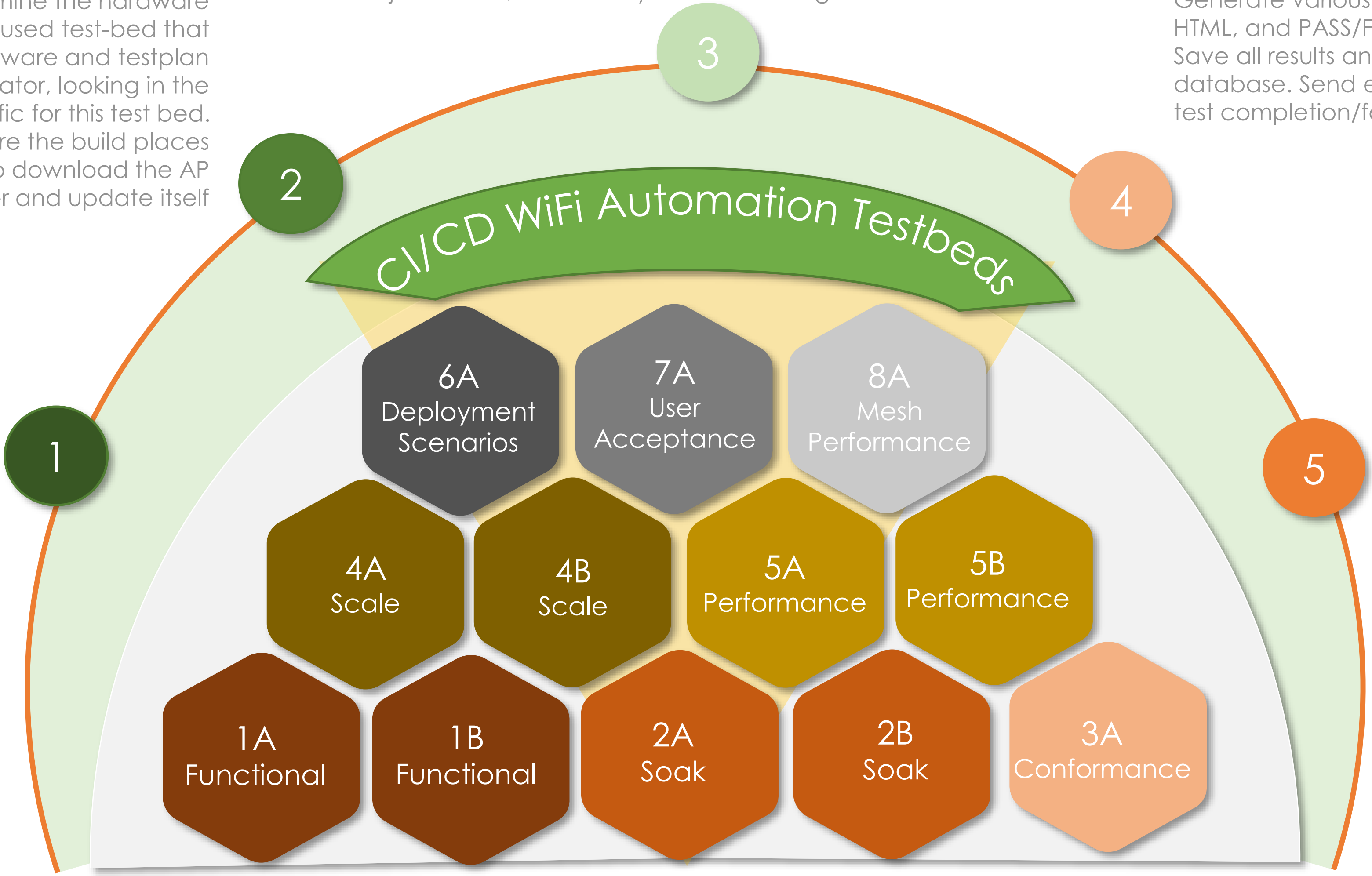
When new build is found, determine the hardware platform, and find the least-used test-bed that matches that DUT hardware and testplan schedule. Poll the Test Orchestrator, looking in the web folder specific for this test bed. Download AP image from where the build places it .Use serial port to ask the AP to download the AP image from the test controller and update itself

04 Generate Reports

Generate various forms of PDF, CSV, HTML, and PASS/FAIL reports. Save all results and logs in a database. Send emails/alert upon test completion/failures

01 Find Builds

Script polls a known URL, which provides a file listing. Parse that to find new builds



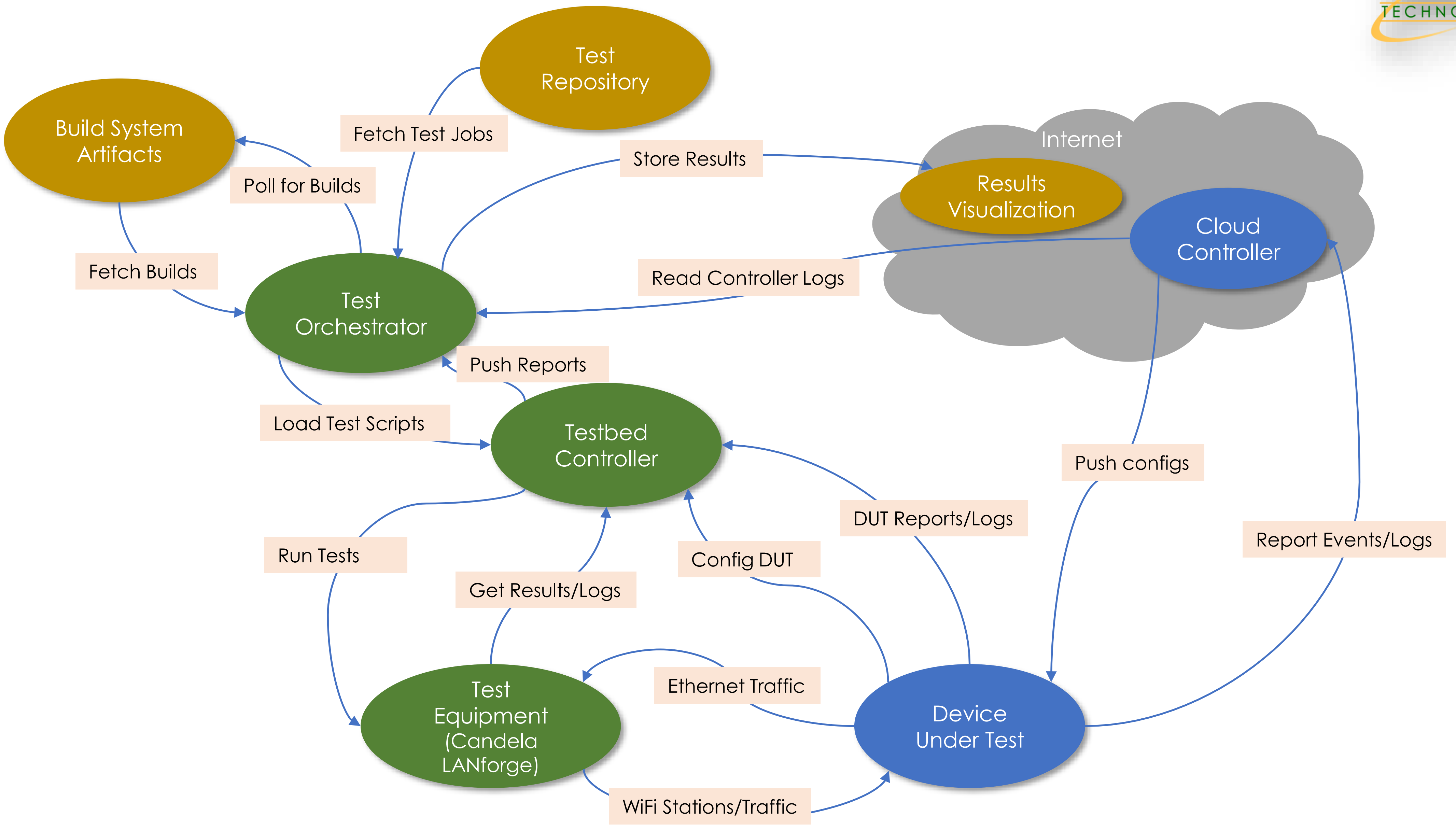
05 Compare/Analyze

Compare results across builds, DUT models, test setups etc…Presents performance trends and expert analysis.

Start

End

CI/CD Automation Work Flow

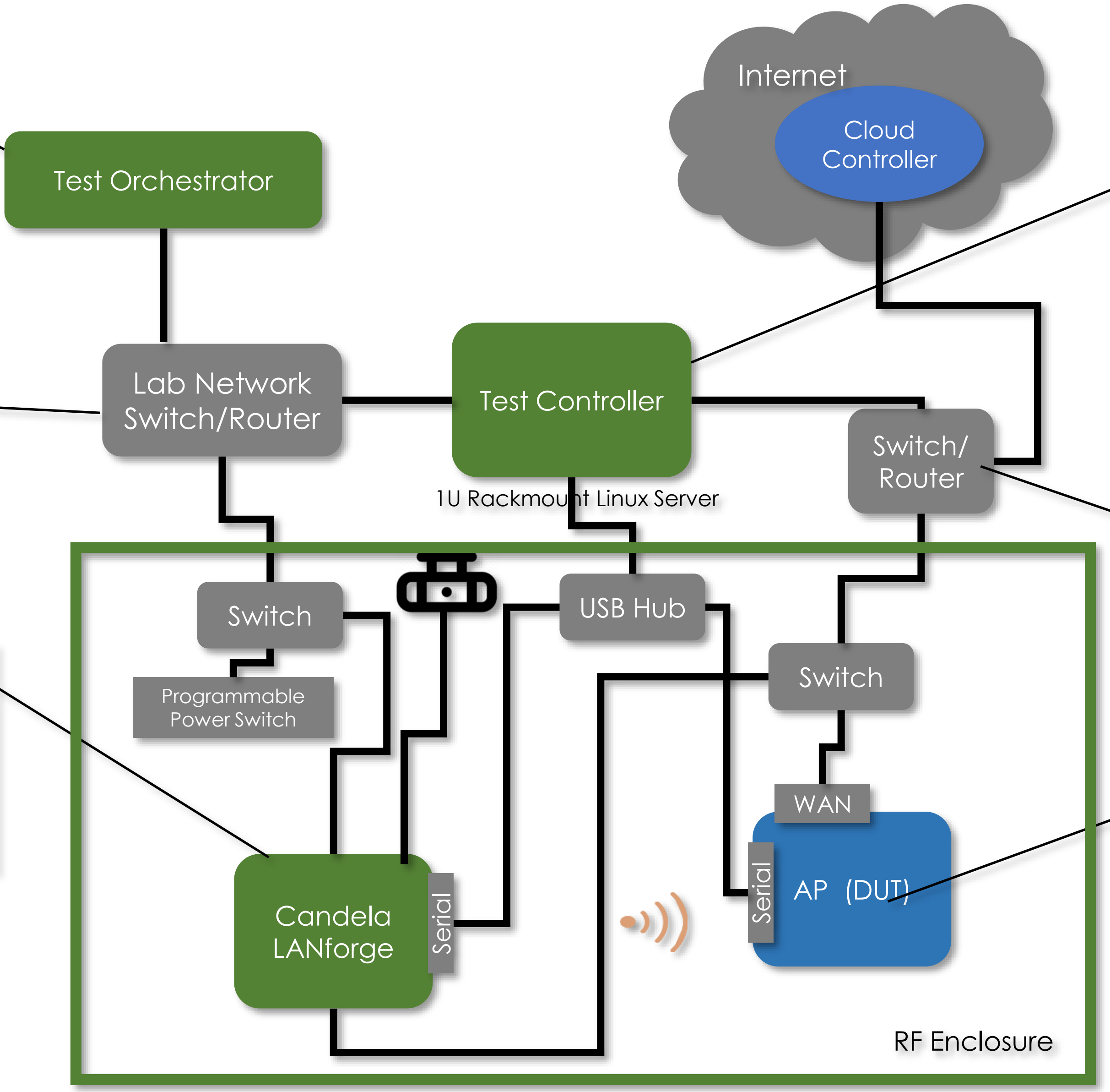


CI/CD Testbed Diagram

- Build Repos
- Test Orchestration Framework
- Build/Test Orchestration
- User/Account Management
- High level result/reporting database

- Lab Network VPN/Firewall/DHCP/NAT etc
- Provide network mgmt. and test orchestration. connectivity to LANforge and test Controller

- WiFi Client Emulation
- Test traffic generation& Analysis
- Control webcam
- Run Automated test suites
- Generate test results and reports in various formats.

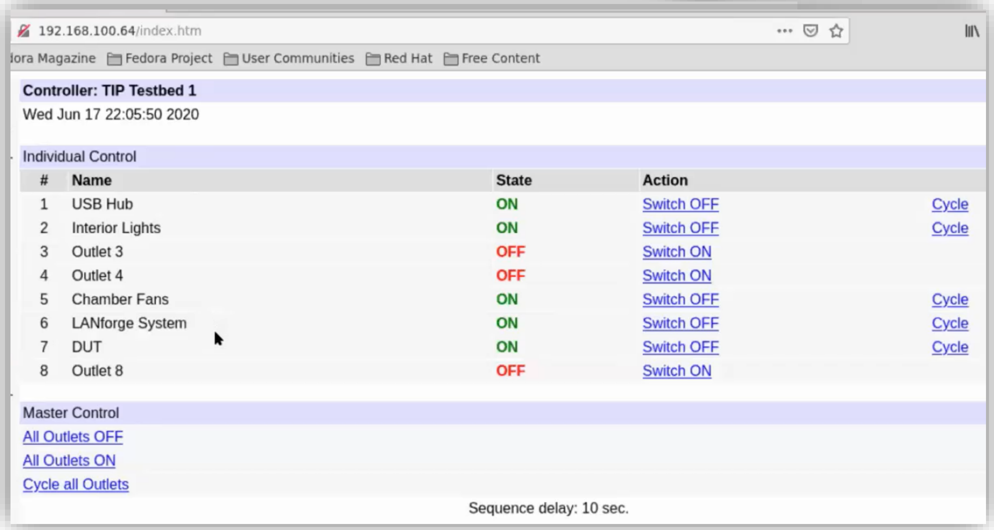


- Serial Connection to LANforge and DUT for debugging and resetting.
- Connection to AP and Cloud controller for remote control and firmware updates.
- Save session and debug logs
- Local database of detailed test results, logs, capture files, session data etc.
- Host Candela firmware/software repos and test script repos.

- Provide DHCP on the test network.
- NAT to Internet for AP to cloud controller connectivity and to run tests on the Datapath.

- Physical AP Hardware
- Assume WAN port can receive LANforge test traffic towards Wi-Fi interfaces.
- Assumed to have atleast 2 802.11a/b/g/n/ac/ax radios (2.4 and 5GHz)

Lights Out AP Testbed Setups


192.168.100.64/index.htm

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Controller: TIP Testbed 1

Wed Jun 17 22:05:50 2020

Individual Control

#	Name	State	Action	
1	USB Hub	ON	Switch OFF	Cycle
2	Interior Lights	ON	Switch OFF	Cycle
3	Outlet 3	OFF	Switch ON	
4	Outlet 4	OFF	Switch ON	
5	Chamber Fans	ON	Switch OFF	Cycle
6	LANforge System	ON	Switch OFF	Cycle
7	DUT	ON	Switch OFF	Cycle
8	Outlet 8	OFF	Switch ON	

Master Control

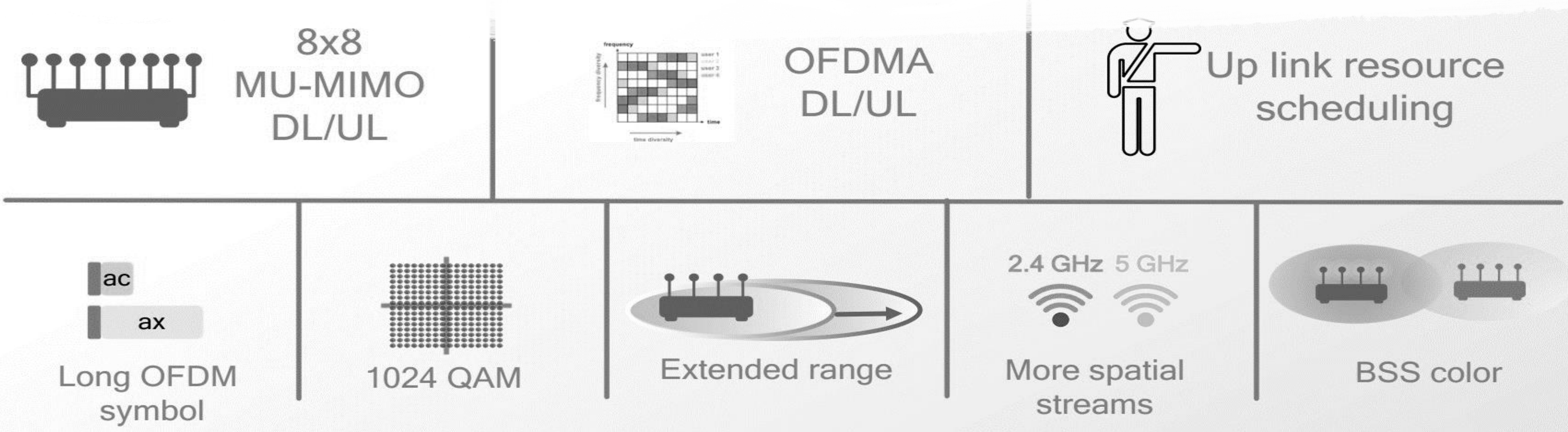
All Outlets OFF

All Outlets ON

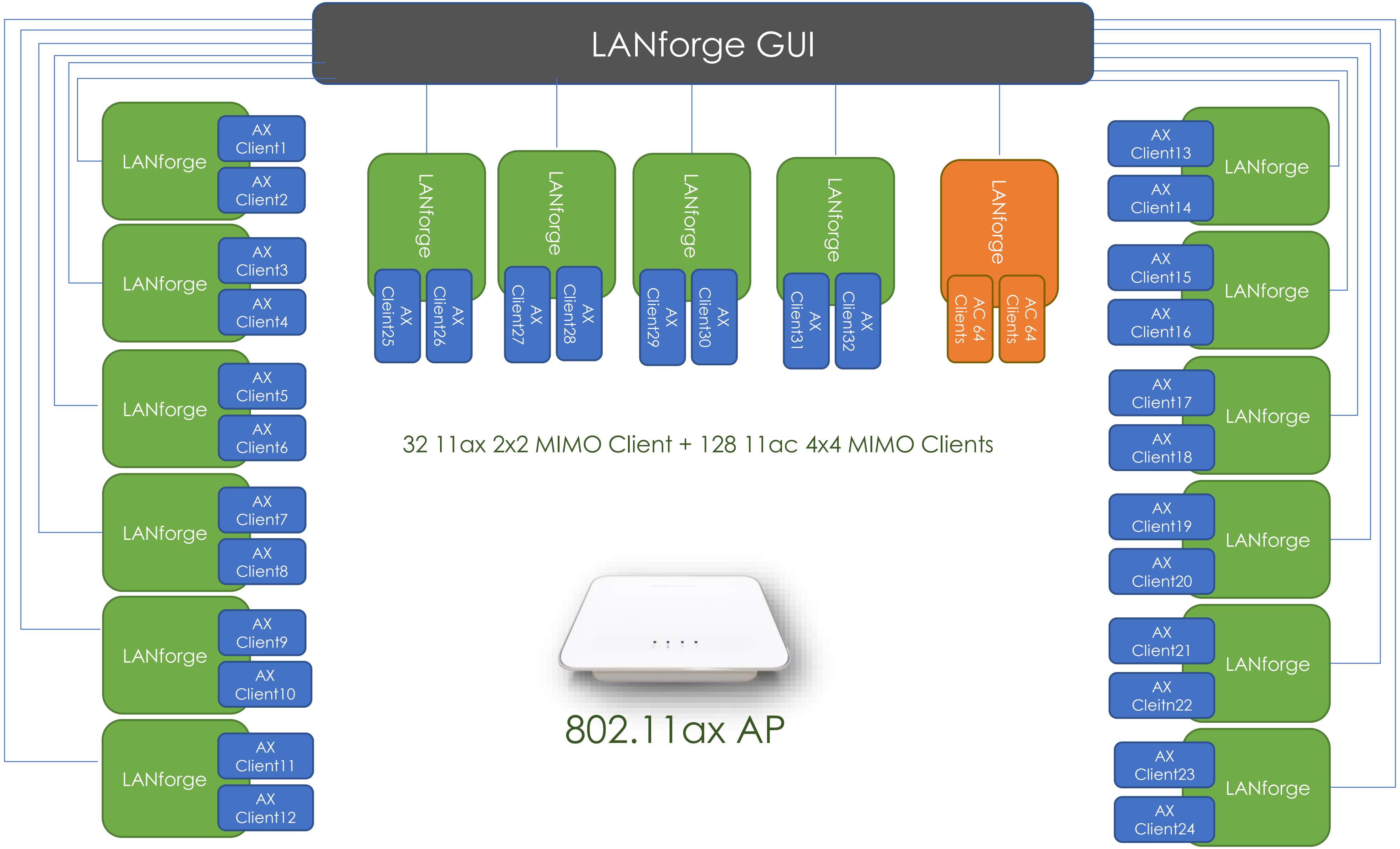
Cycle all Outlets

Sequence delay: 10 sec.

11ax Testing



32 11ax + 128 11ac Client Test Setup



- ✓ MCS 10,11
- ✓ UL/DL Mu-MIMO
- ✓ UL/DL OFDMA

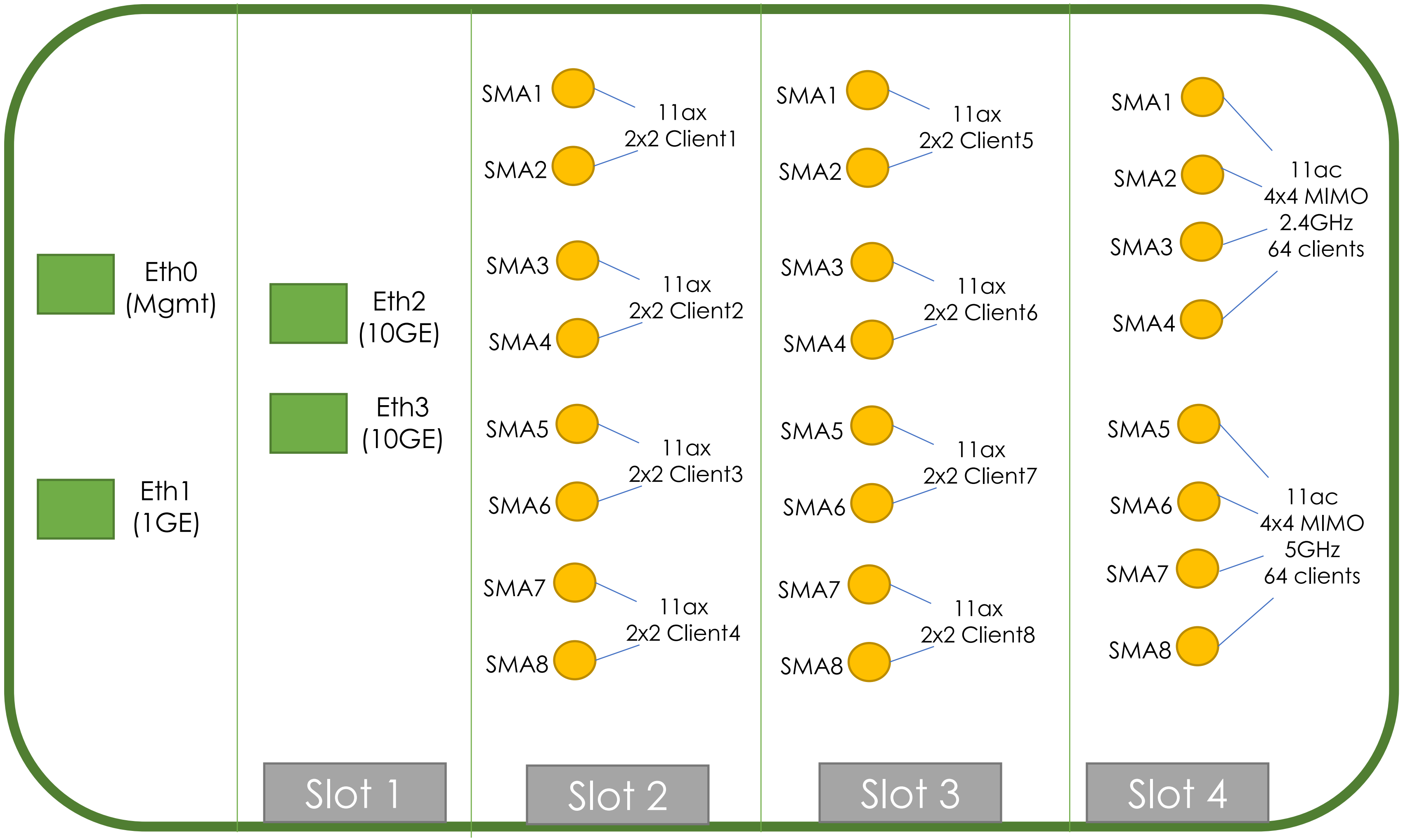
- Tests
  - ✓ Throughput
  - ✓ Client Connectivity
  - ✓ Range
  - ✓ Functionality
  - ✓ Airtime Fairness
  - ✓ Client Scale

CT-523c-8ax-ac2-db-10GE System

Interfaces:
- Slot0 :
  - Eth0 : Management
  - Eth1 : 1GE Traffic Port
- Slot1 :
  - Eth2: 1/2.5/5/10 Gig Ethernet
  - Eth3 : 1/2.5/5/10 Gig Ethernet
- Slot2 :
  - 4 units of 2x2 MIMO 11ax Radios
- Slot3 :
  - 4 units of 2x2 MIMO 11ax Radios
- Slot4 :
  - 1 unit of 4x4 MIMO 11ac 2.4Ghz radio
  - 1 unit of 4x4 MIMO 11ac 5GHz radio

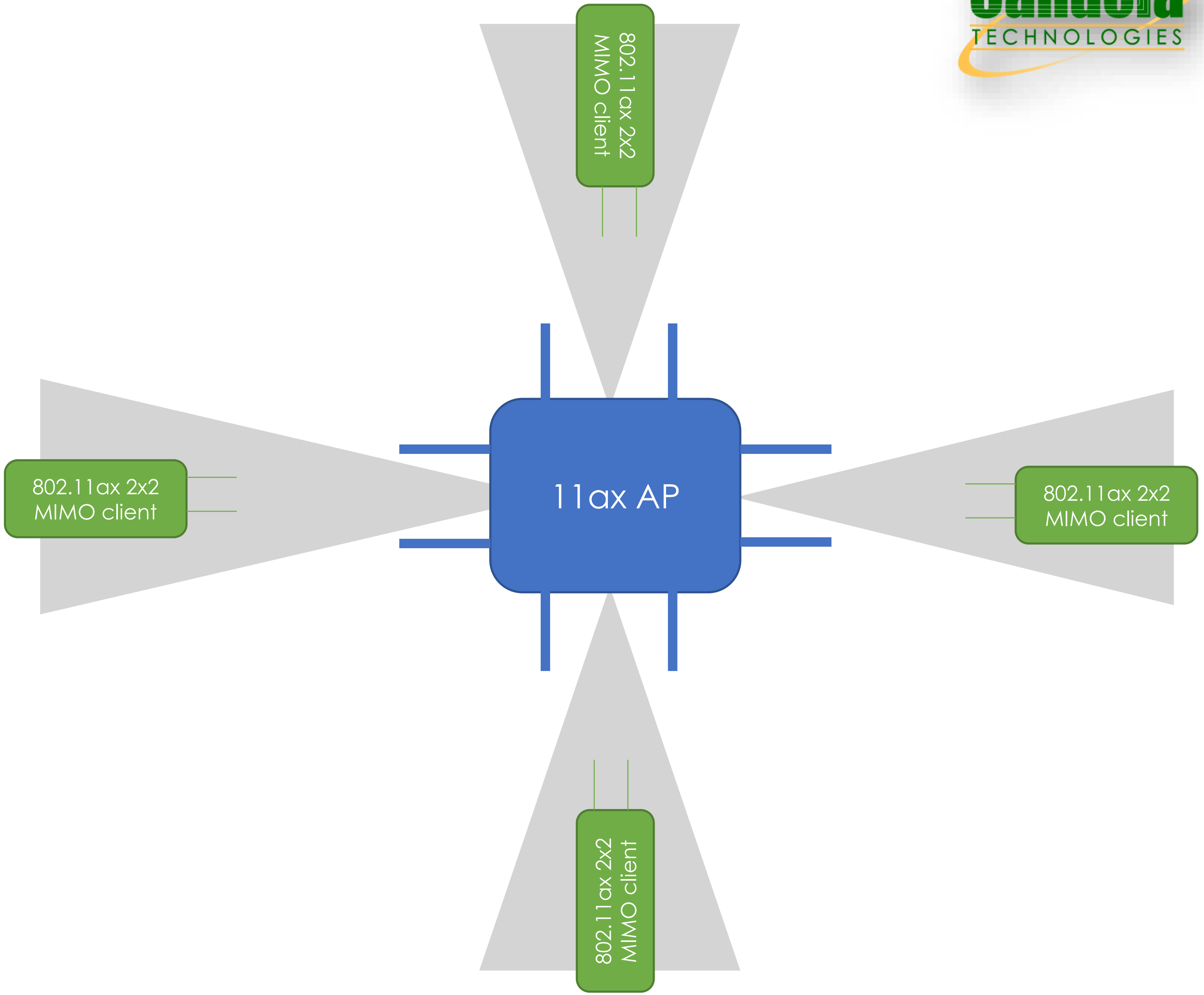
8 ax client + 128 11ac clients

- Tests
  - ✓ Throughput
  - ✓ Client Connectivity
  - ✓ Range
  - ✓ Functionality
  - ✓ Airtime Fairness
  - ✓ Client Scale
  - ✓ QoS
  - ✓ OFDMA Performance
  - ✓ Mu-MIMO Performance



Mu-MIMO Testing

➢ Test upto 8x8 MIMO 11ax AP, using Mu-MIMO for upto 4 2x2 MIMO 11ax clients



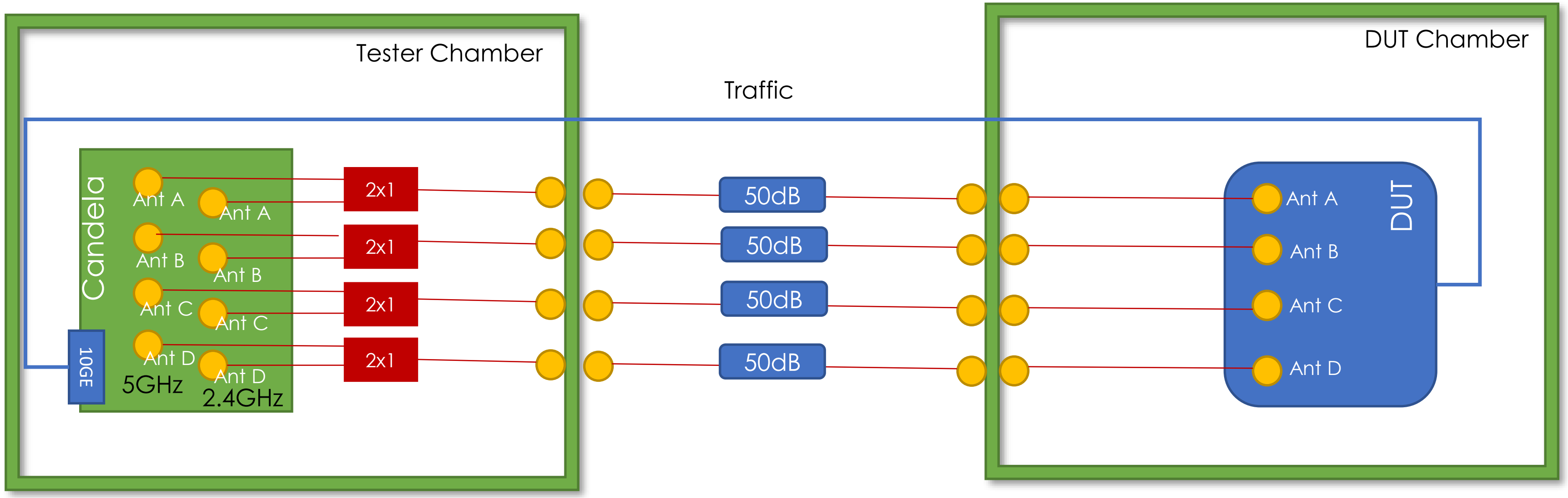
AP Tx Power Testing

9120AX-E TX Power Test 5GHz (B Domain - US)						
Channel	**BW**	**NSS**	**RSSI A (dB)**	**RSSI B (dB)**	**RSSI C (dB)**	**RSSI D (dB)**
36	20 MHz	4	-41	-41	-41	-39
36	20 MHz	4	-41	-42	-42	-41
36	20 MHz	4	-45	-45	-45	-44
36	20 MHz	4	-47	-47	-47	-45
36	20 MHz	4	-50	-51	-49	-50
36	20 MHz	4	-54	-54	-53	-52
36	20 MHz	4	-57	-57	-56	-56
36	20 MHz	4	-59	-60	-60	-59
36	40 MHz	4	-41	-40	-40	-40
36	40 MHz	4	-40	-41	-42	-40
36	40 MHz	4	-44	-44	-45	-44
36	40 MHz	4	-47	-47	-47	-45
36	40 MHz	4	-50	-50	-49	-48
36	40 MHz	4	-53	-53	-53	-52
36	40 MHz	4	-56	-56	-55	-56
36	40 MHz	4	-59	-59	-59	-57
36	80 MHz	4	-41	-40	-39	-40
36	80 MHz	4	-41	-40	-41	-40
36	80 MHz	4	-44	-43	-43	-43
36	80 MHz	4	-46	-46	-46	-46
36	80 MHz	4	-50	-49	-49	-49
36	80 MHz	4	-53	-52	-52	-52
36	80 MHz	4	-56	-55	-55	-55
36	80 MHz	4	-58	-58	-58	-59

AP Tx Power Measurement Testbed

Single Candela Unit does:

- WiFi Client creation
- Traffic Generation
- RSSI Measurements
- Control Settings on AP/Controller
- Host and Run automation scripts
- Create Test Reports.



Test Inputs:

- Channels : All 2.4 and 5GHz channels
- Power Levels : All power level setting supported on AP (1 through 8)
- MIMO Types: 1x1, 2x2, 3x3, 4x4
- Channel BWs : 20,40,80,160 MHz
- Regulatory Domains : Various country modes

Report:

- ✓ Test Inputs: Channel, Set Power, MIMO Type, BW, Reg Domain
- ✓ Measures Power (Antenna A,B,C and D)
- ✓ Calculated Tx Power(Antenna A,B,C and D)
- ✓ Offset Values (Antenna A,B,C and D) – PASS/FAIL results
- ✓ PDF/HTML test report with color coded results

Testbed Components:

- 1x Candela 523C Chassis
- 1x Candela 2.4GHz 4x4 MIMO Radio
- 1x Candela 2.4GHz 4x4 MIMO Radio
- 1x Candela 10GE Ports
- 2x Small RF enclosures
- 20x RF cables
- 6x 30dB fixed attenuators
- 6x Cat6 Ethernet Cables
- AP under Test
- AP Tx Power Measurement Automation Script


RIGOL DSA875
Spectrum Analyzer
RIGOL
Center Frequency
5.180000000 GHz
Frequency
FREQ
SPAN
AMPT

Example Measurements/Results

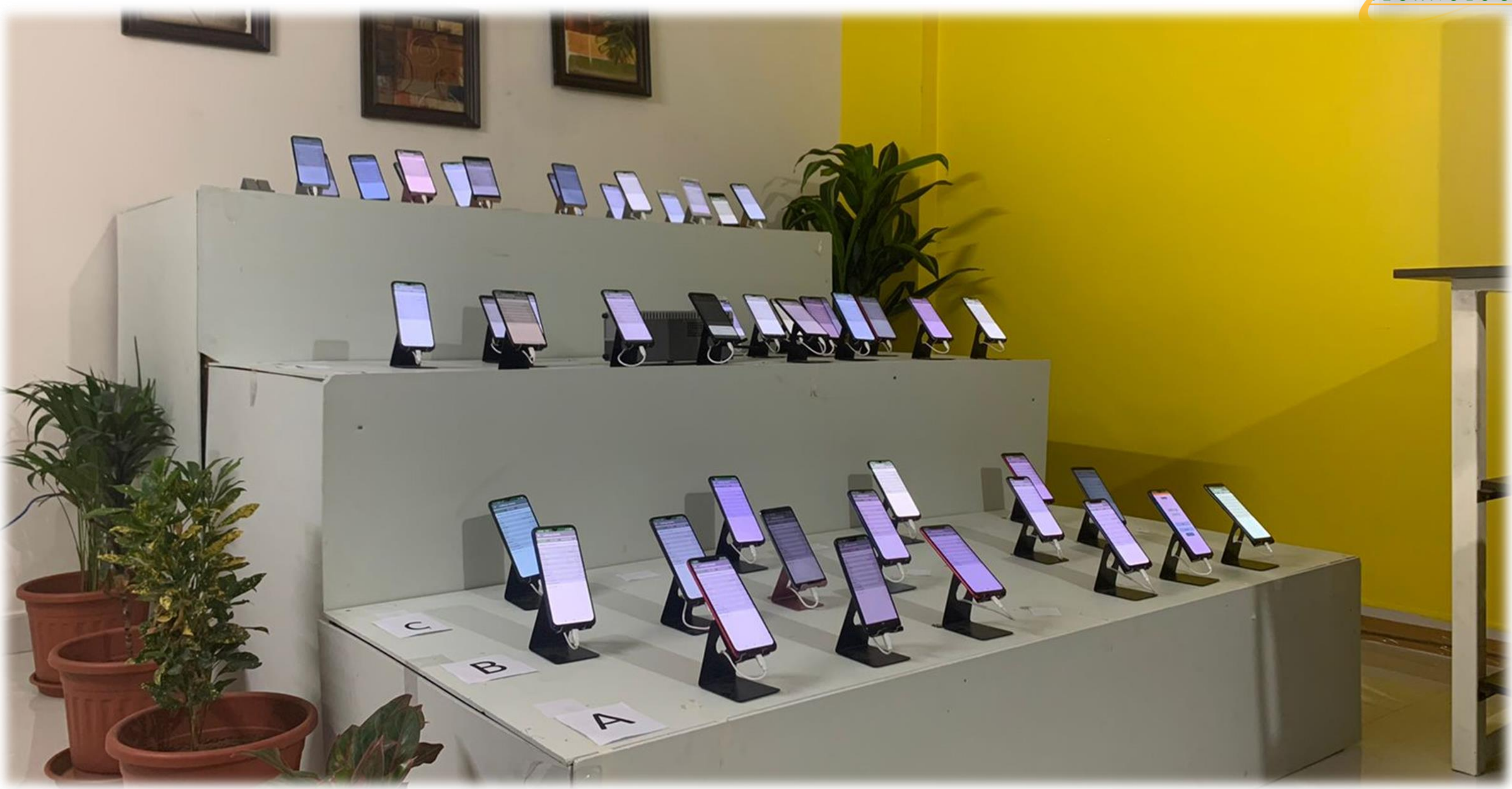
9120AX-E TX Power Test 5GHz (B Domain - US)																		
Channel	BW	NSS	Tx Power	Allowed Per-Path (dBm)	Path Loss (dBm)	RSSI A (dB)	RSSI B (dB)	RSSI C (dB)	RSSI D (dB)	Ant A (dBm)	Ant B (dBm)	Ant C (dBm)	Ant D (dBm)	Offset A (dB)	Offset B (dB)	Offset C (dB)	Offset D (dB)	Pass/Fail (+-3dB)
36	20 MHz	4	1	17	54	-41	-41	-41	-39	13	13	13	15	-4	-4	-4	-2	FAIL
36	20 MHz	4	2	14	54	-41	-42	-42	-41	13	12	12	13	-1	-2	-2	-1	PASS
36	20 MHz	4	3	11	54	-45	-45	-45	-44	9	9	9	10	-2	-2	-2	-1	PASS
36	20 MHz	4	4	8	54	-47	-47	-47	-45	7	7	7	9	-1	-1	-1	1	PASS
36	20 MHz	4	5	5	54	-50	-51	-49	-50	4	3	5	4	-1	-2	0	-1	PASS
36	20 MHz	4	6	2	54	-54	-54	-53	-52	0	0	1	2	-2	-2	-1	0	PASS
36	20 MHz	4	7	-1	54	-57	-57	-56	-56	-3	-3	-2	-2	-2	-2	-1	-1	PASS
36	20 MHz	4	8	-4	54	-59	-60	-60	-59	-5	-6	-6	-5	-1	-2	-2	-1	PASS
36	40 MHz	4	1	17	54	-41	-40	-40	-40	13	14	14	14	-4	-3	-3	-3	FAIL
36	40 MHz	4	2	14	54	-40	-41	-42	-40	14	13	12	14	0	-1	-2	0	PASS
36	40 MHz	4	3	11	54	-44	-44	-45	-44	10	10	9	10	-1	-1	-2	-1	PASS
36	40 MHz	4	4	8	54	-47	-47	-47	-45	7	7	7	9	-1	-1	-1	1	PASS
36	40 MHz	4	5	5	54	-50	-50	-49	-48	4	4	5	6	-1	-1	0	1	PASS
36	40 MHz	4	6	2	54	-53	-53	-53	-52	1	1	1	2	-1	-1	-1	0	PASS
36	40 MHz	4	7	-1	54	-56	-56	-55	-56	-2	-2	-1	-2	-1	-1	0	-1	PASS
36	40 MHz	4	8	-4	54	-59	-59	-59	-57	-5	-5	-5	-3	-1	-1	-1	1	PASS
36	80 MHz	4	1	17	54	-41	-40	-39	-40	13	14	15	14	-4	-3	-2	-3	FAIL
36	80 MHz	4	2	14	54	-41	-40	-41	-40	13	14	13	14	-1	0	-1	0	PASS
36	80 MHz	4	3	11	54	-44	-43	-43	-43	10	11	11	11	-1	0	0	0	PASS
36	80 MHz	4	4	8	54	-46	-46	-46	-46	8	8	8	8	0	0	0	0	PASS
36	80 MHz	4	5	5	54	-50	-49	-49	-49	4	5	5	5	-1	0	0	0	PASS
36	80 MHz	4	6	2	54	-53	-52	-52	-52	1	2	2	2	-1	0	0	0	PASS
36	80 MHz	4	7	-1	54	-56	-55	-55	-55	-2	-1	-1	-1	-1	0	0	0	PASS
36	80 MHz	4	8	-4	54	-58	-58	-58	-59	-4	-4	-4	-5	0	0	0	-1	PASS

LANforge Interop

100+ Real Device Testbed

Large Walk-in Chamber with 100+ Real Devices

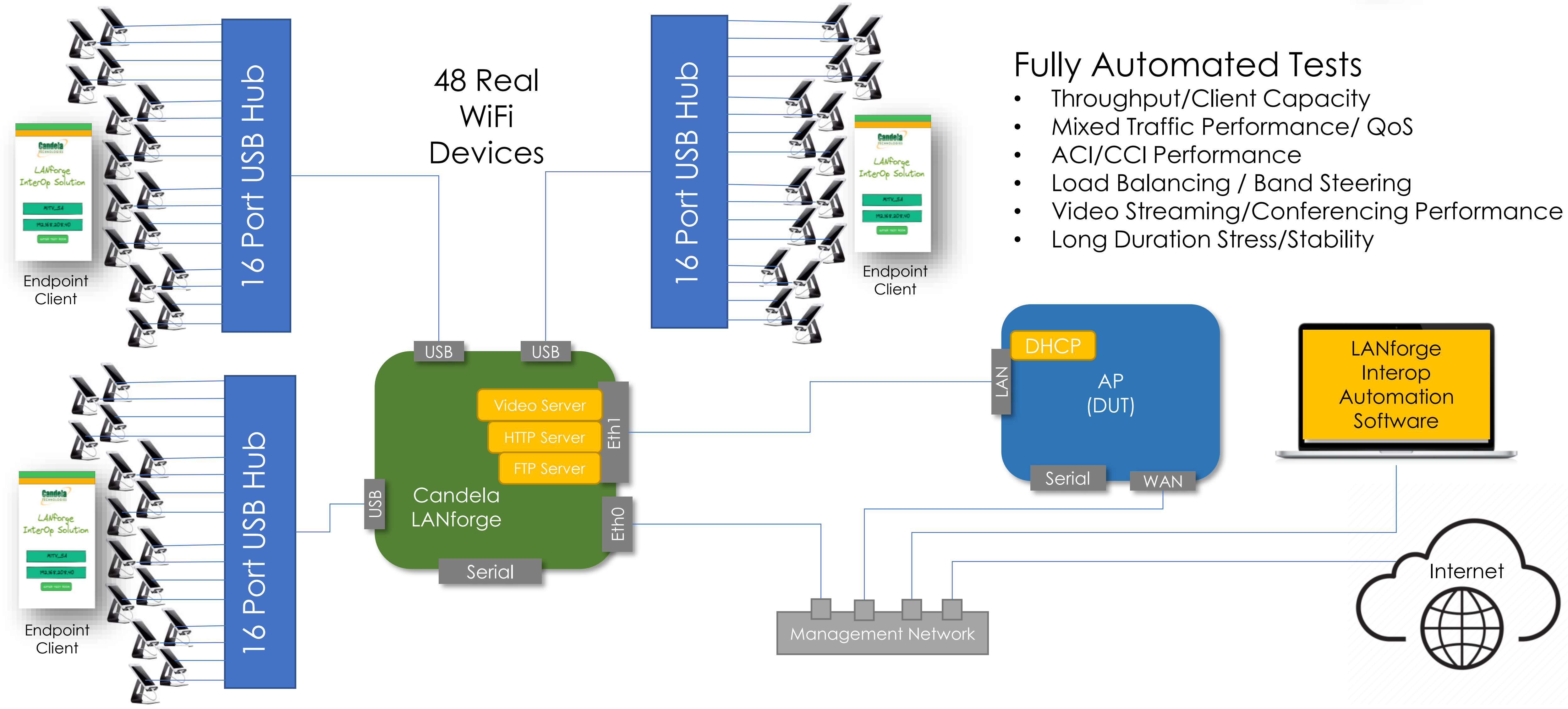
Interop Scale Testbed Topology



Interop Scale Testbed Topology

Fully Automated Tests

- Throughput/Client Capacity
- Mixed Traffic Performance/ QoS
- ACI/CCI Performance
- Load Balancing / Band Steering
- Video Streaming/Conferencing Performance
- Long Duration Stress/Stability

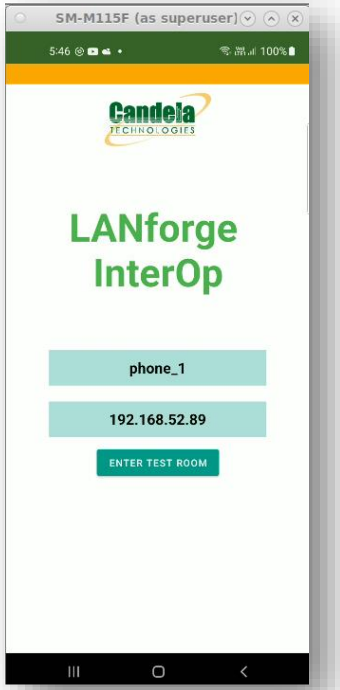


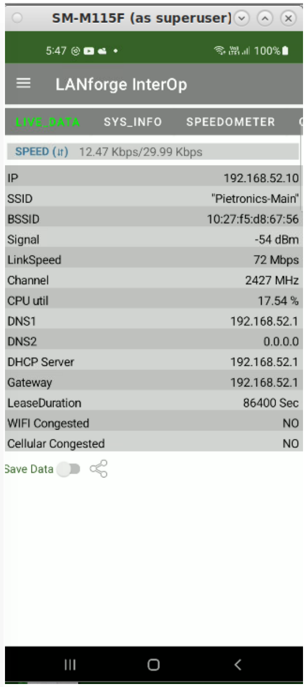
InterOp Test Application

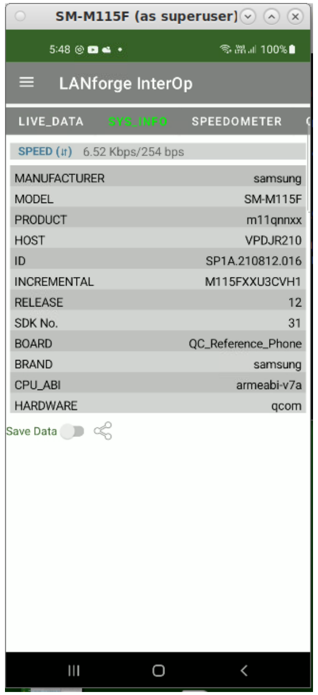
Control connecting/ disconnecting of real devices

Run many different types of data, voice, video traffic and collect metrics

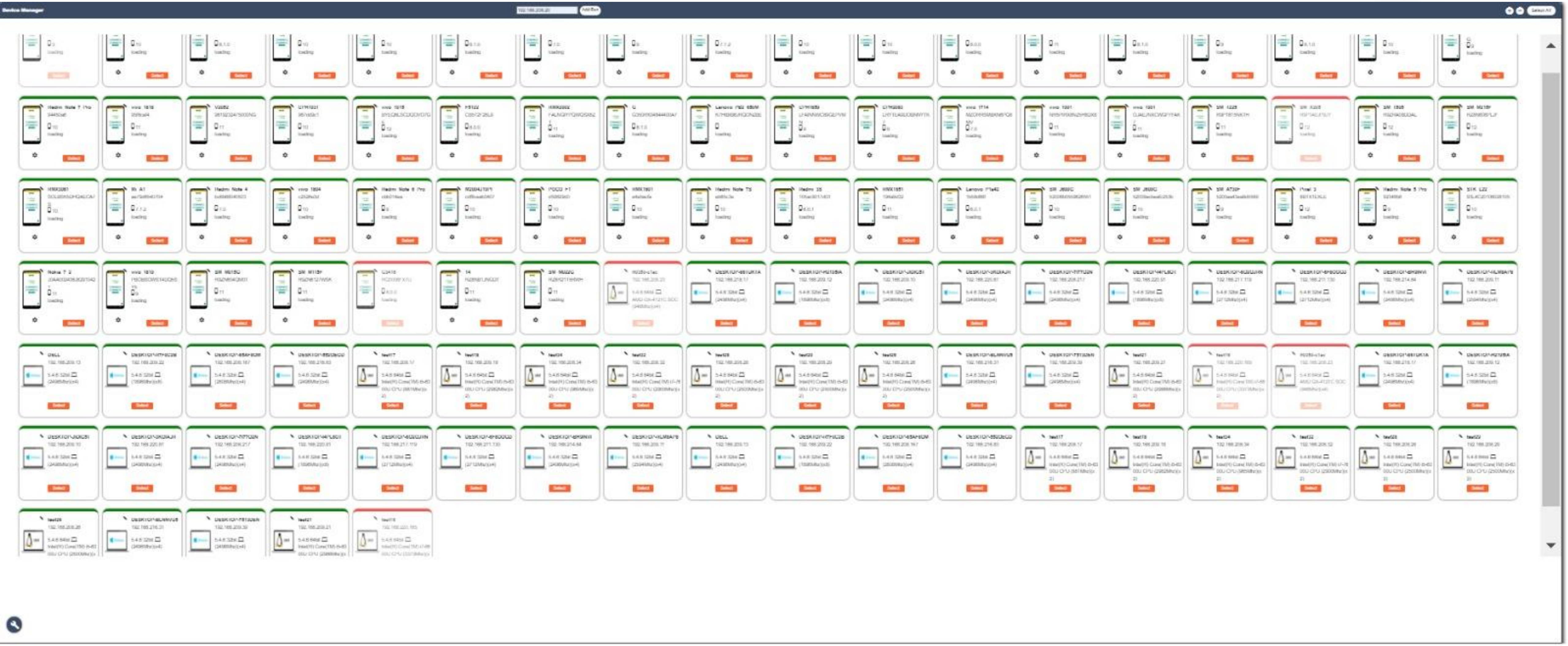
Run several automated tests, collect logs and create test reports

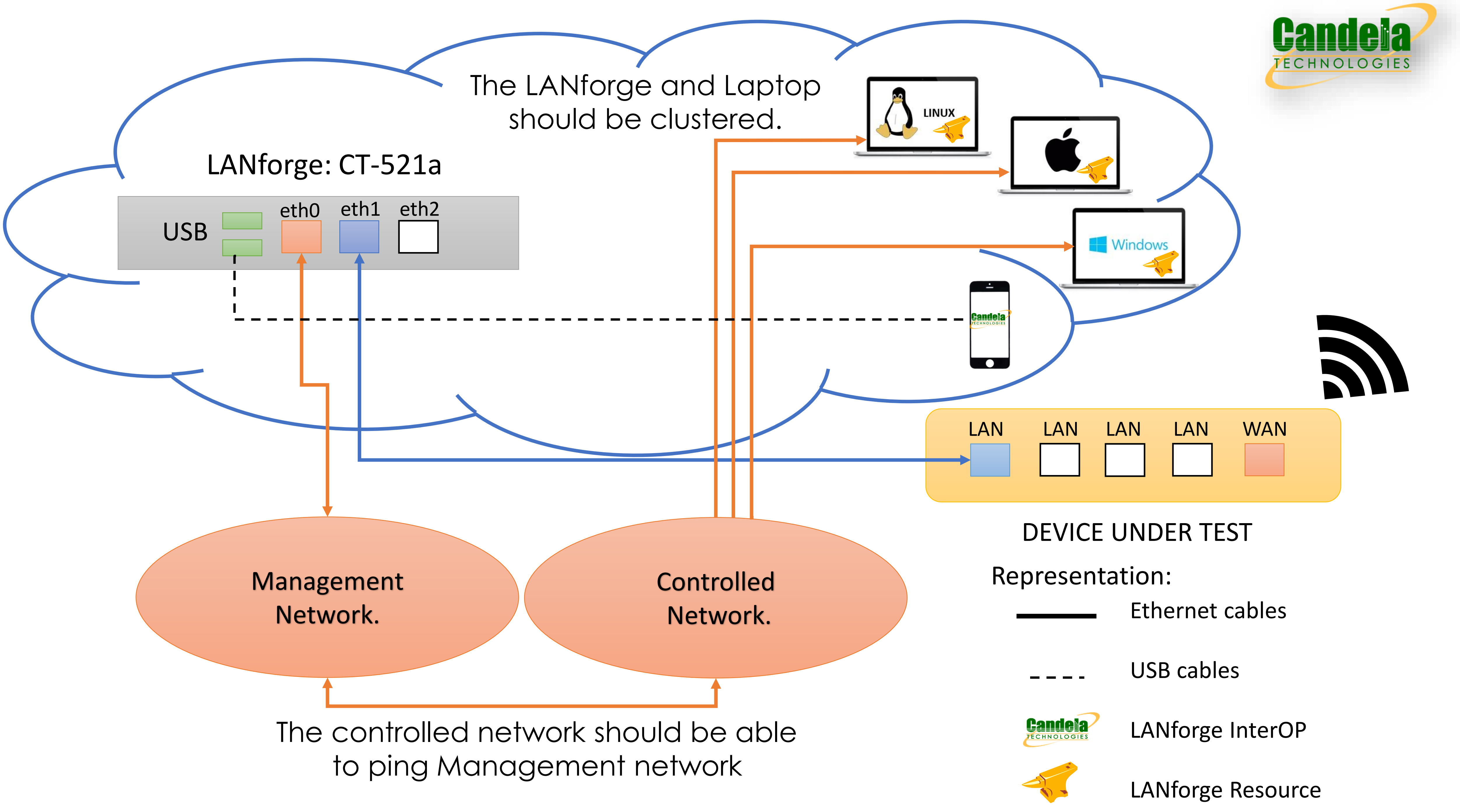






Devices Dashboard



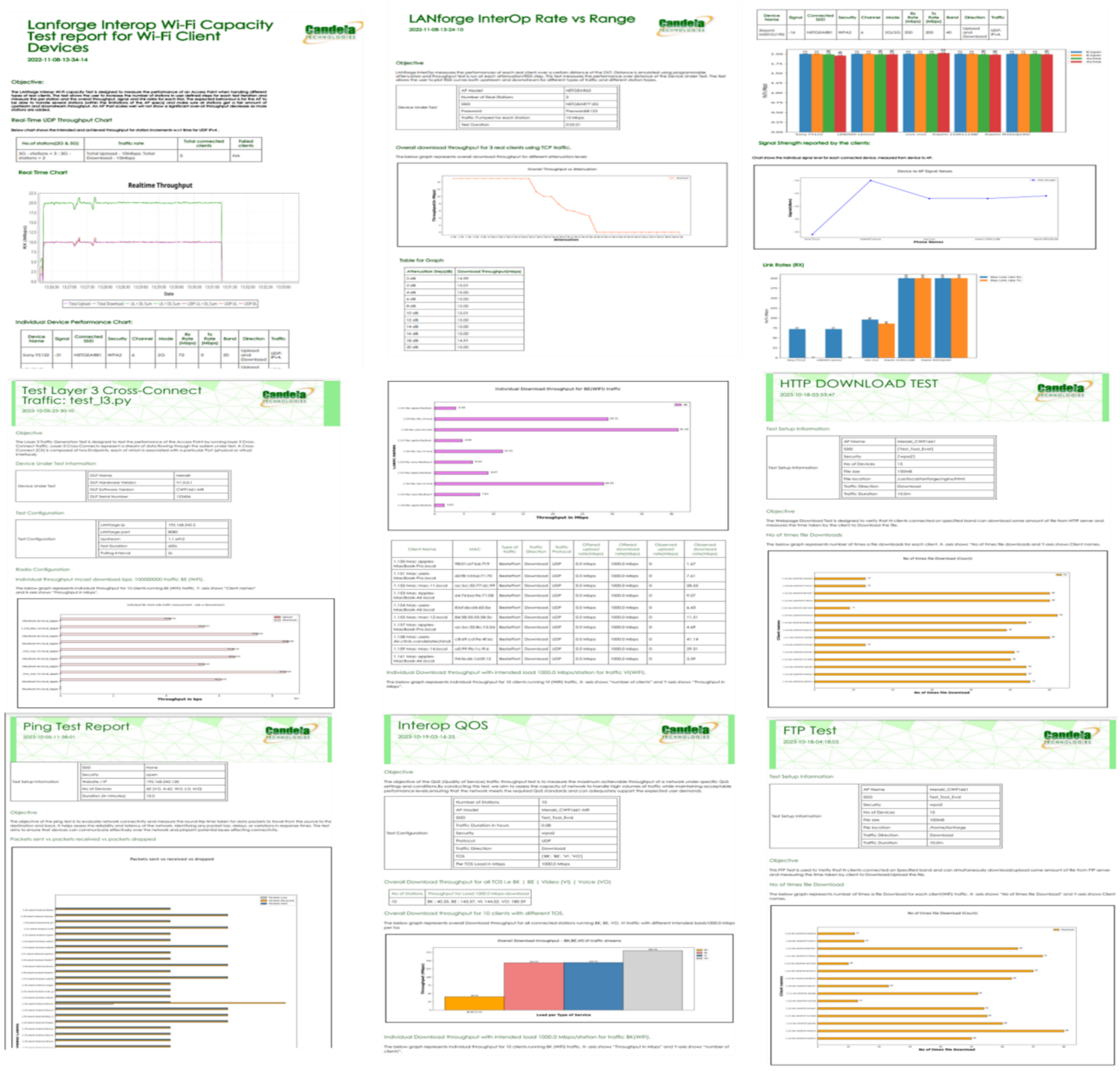


Candela TECHNOLOGIES
The LANforge and Laptop should be clustered.
LANforge: CT-521a
USB
eth0
eth1
eth2
LINUX
Windows
Candela TECHNOLOGIES
LAN
LAN
LAN
LAN
WAN
DEVICE UNDER TEST
Management Network.
Controlled Network.
The controlled network should be able to ping Management network
Representation:
Ethernet cables
USB cables
LANforge InterOP
LANforge Resource

Interop Solution Test Scenarios

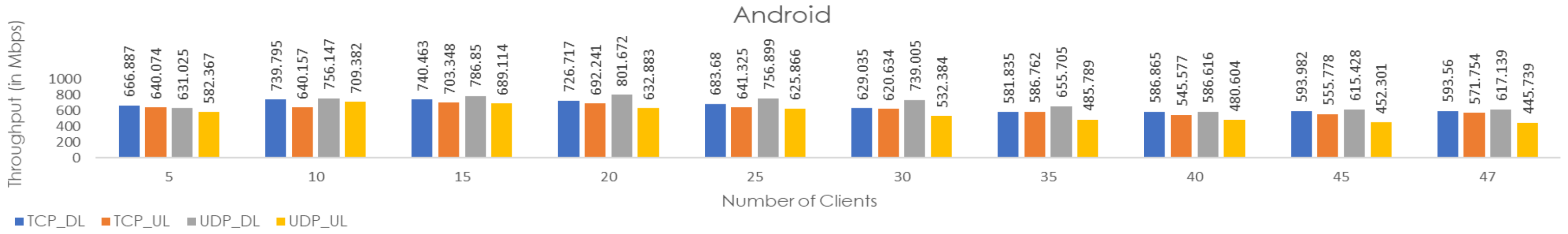
1. Performance Test
2. Ping Test
3. Web Browser Test
4. Video Streaming Test
5. FTP File Transfer
6. HTTP File Transfer
7. Mixed Traffic Test
8. QOS Test
9. Multicast
10. Rate Vs Range

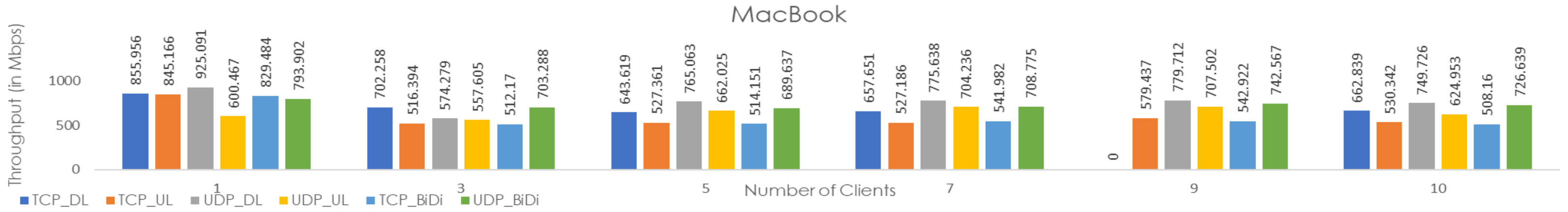
Automation Reports

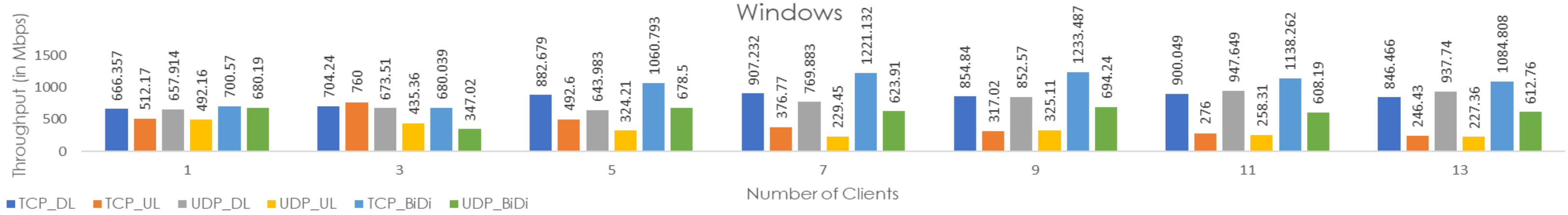


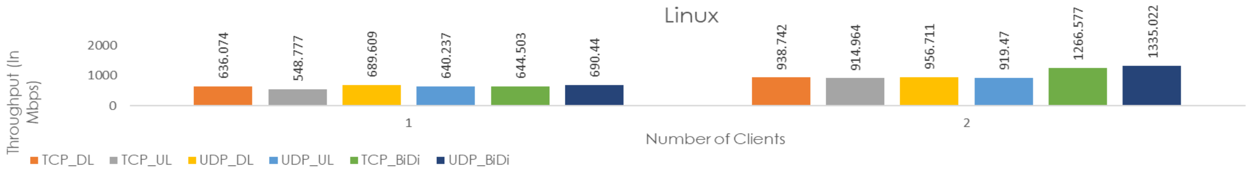
Performance Test

In this test, we'll link real clients from various operating systems to the Device Under Test (DUT) and apply the total intended load across different traffic directions and types. Our approach involves comprehensive monitoring and reporting, covering data rates, achieved throughputs, and per-client throughput distributions.



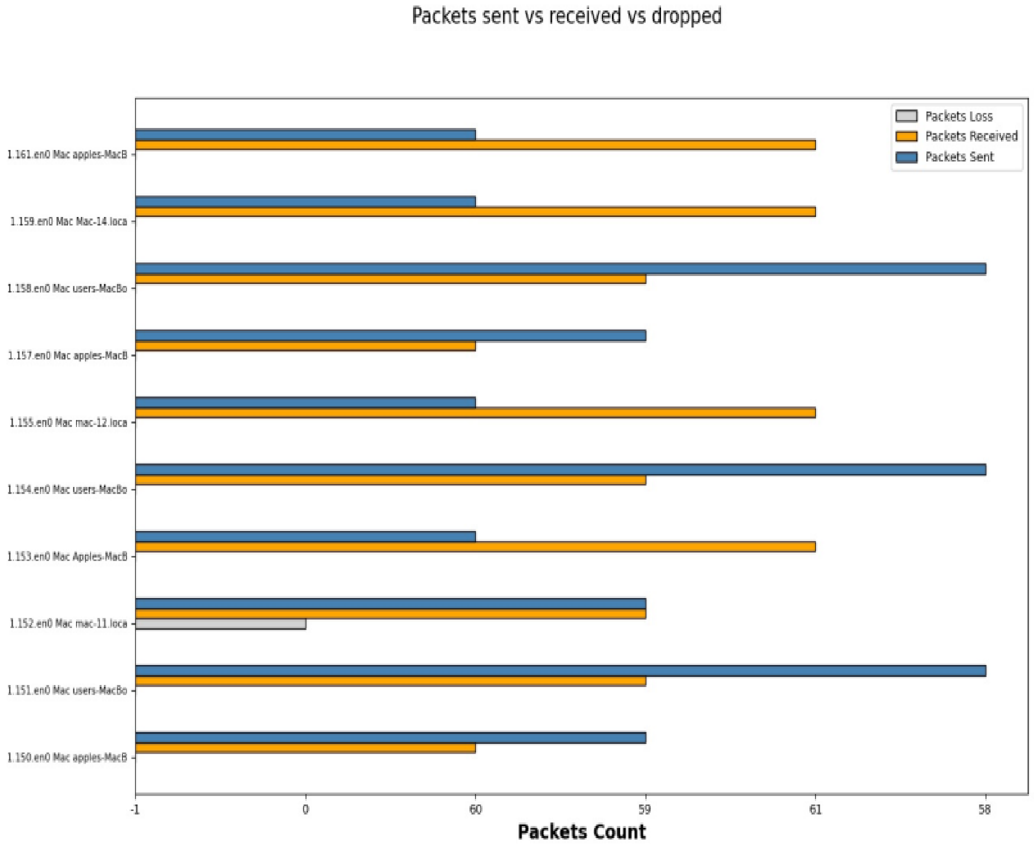


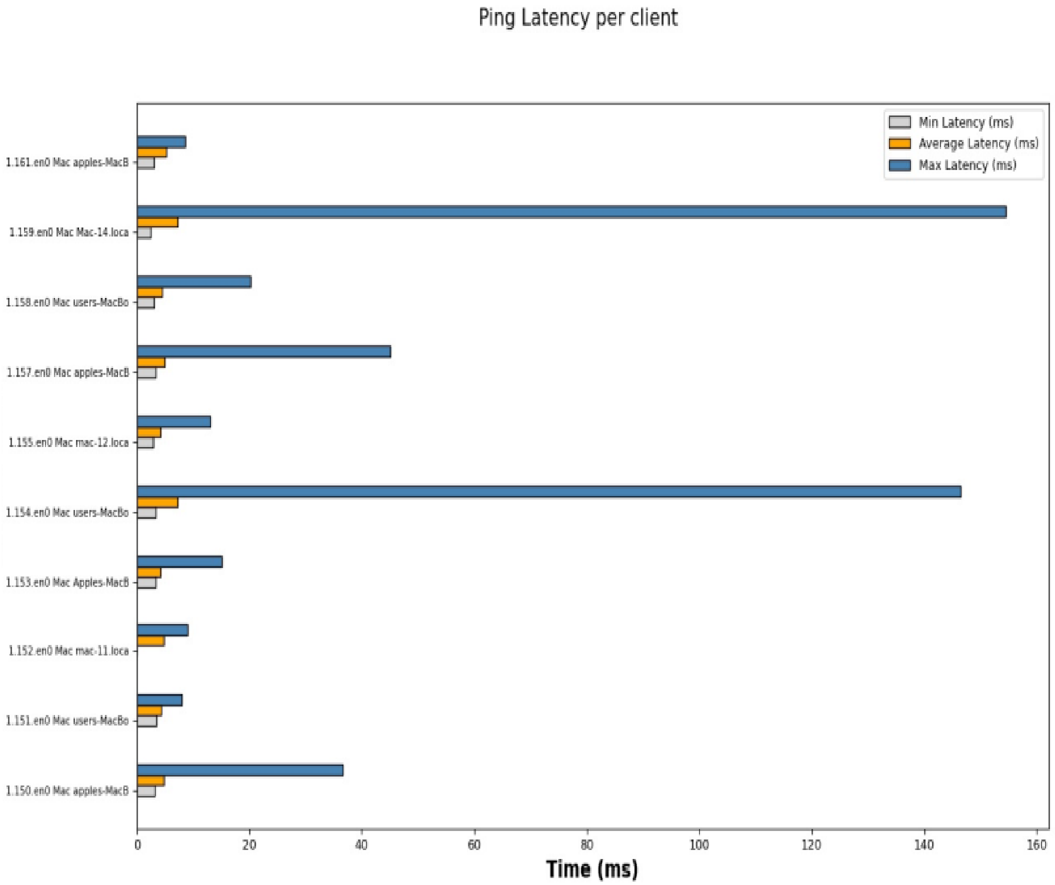




Ping Test

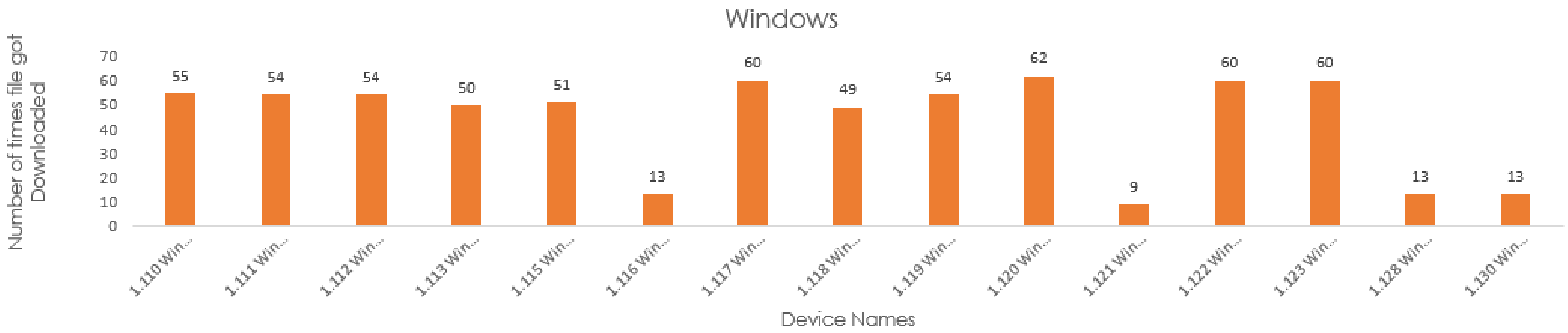
In this test we will connect multiple clients to any of the available SSID's and run PING sessions parallelly for all clients with various time intervals. Depending on the requirement we monitor and report the Packet loss and latency for ping test.

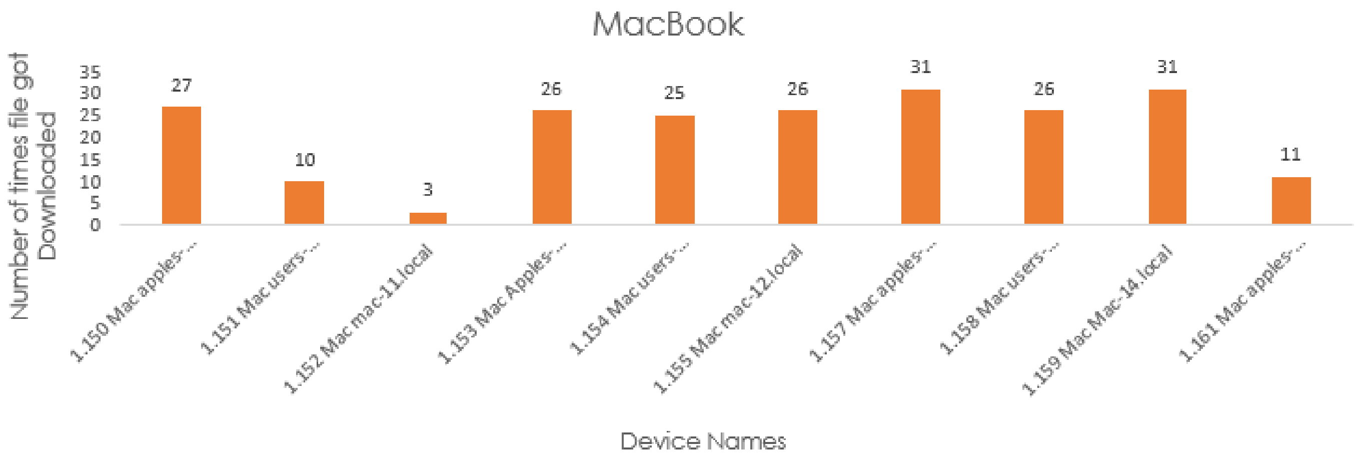


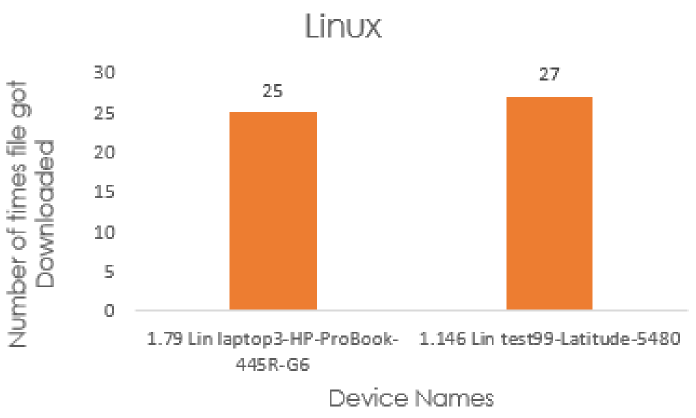


Web Browser Test

In this test we will try to reach any of the website based on the requirement and check how the user experience to reach the webpage is varying based on the number of real clients involved in the test.



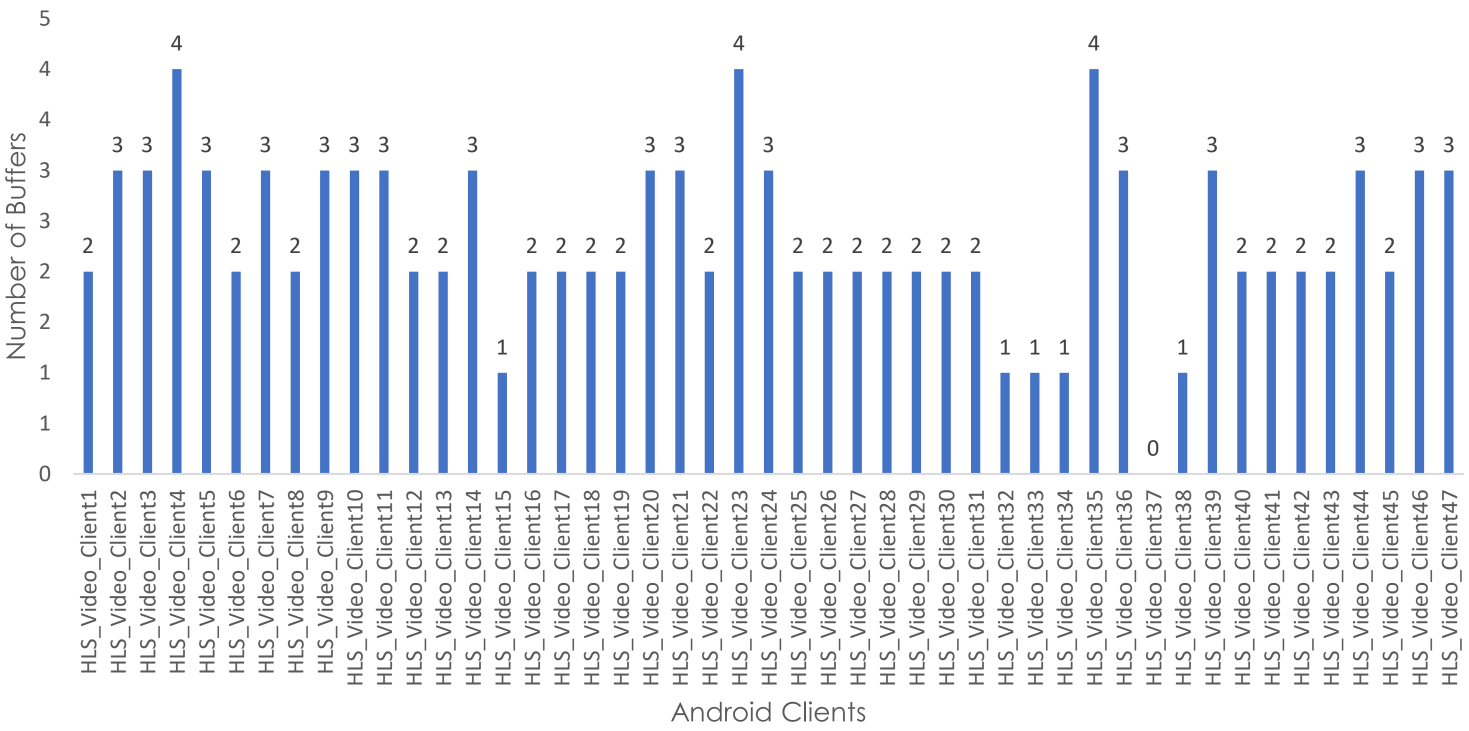


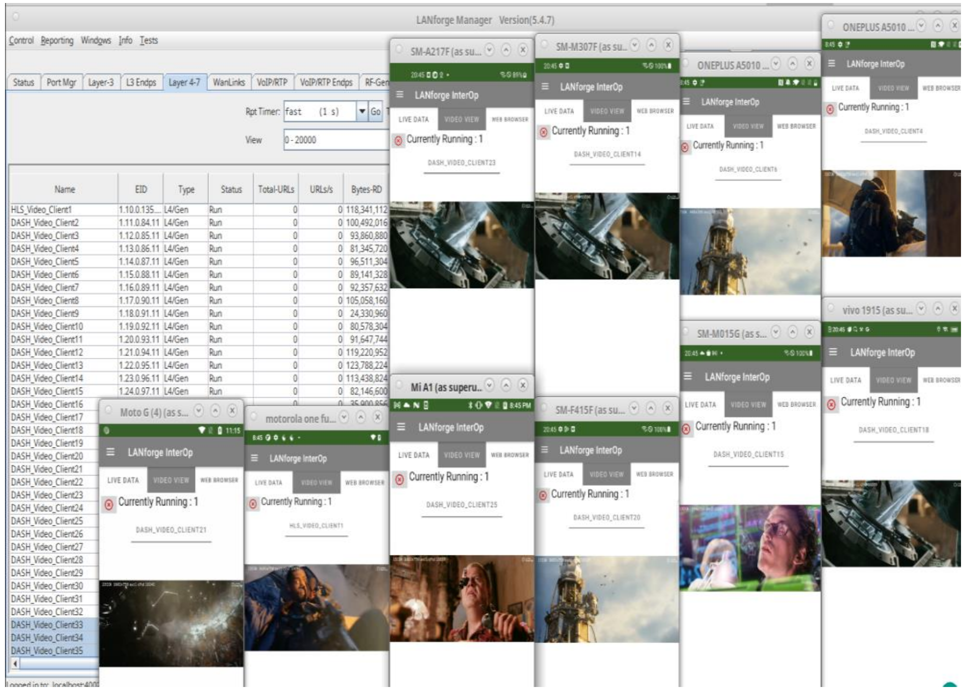


Video Streaming Test

In this test, we'll link all the actual clients to the Device Under Test (DUT) and stream videos on each client using various media sources such as DASH, HLS, Progressive, etc. Through this test, we can observe and track Total number of Buffers, Wait time, and other relevant parameters.

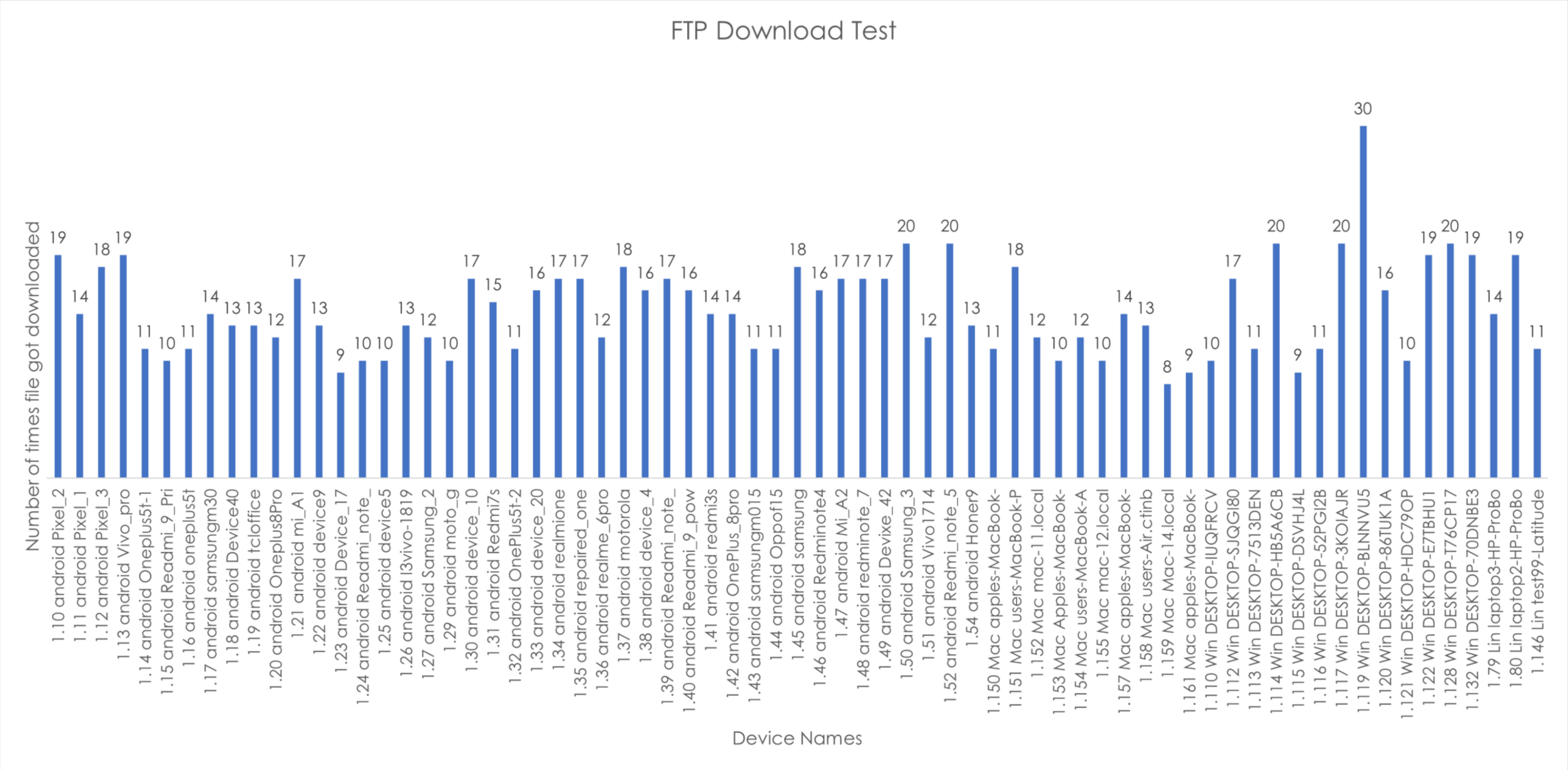
HLS - Total-Buffers for 1 Complete URL





FTP File Download Test

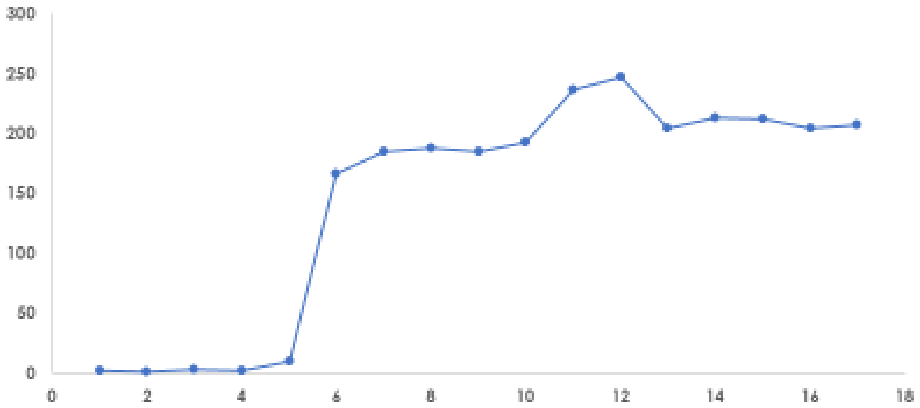
In this FTP test, we confirm that a specified number of clients connected to a particular band can download a file of various sizes from an FTP server simultaneously. We measure the time it takes for each client to complete the Download process and number of times the client downloaded the file in the given test duration.



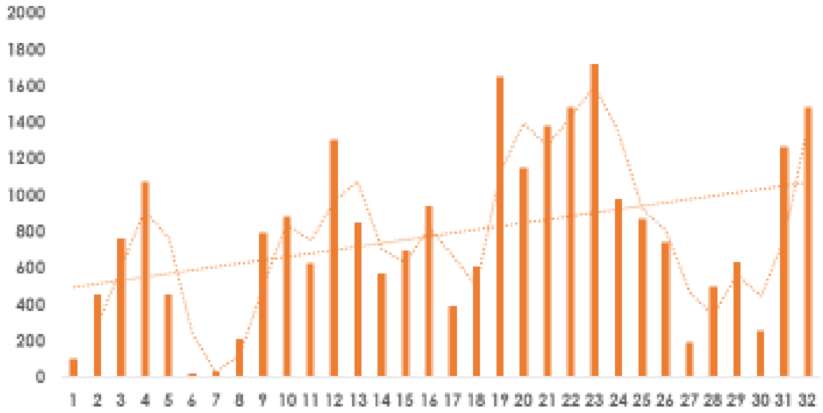
HTTP File Download Test

In this test we will try to download a file of various sizes based on our requirement and place them in HTTP server. We will try to download the file from the HTTP server with all the clients connected to it and monitor the Rx rate, RRT etc.

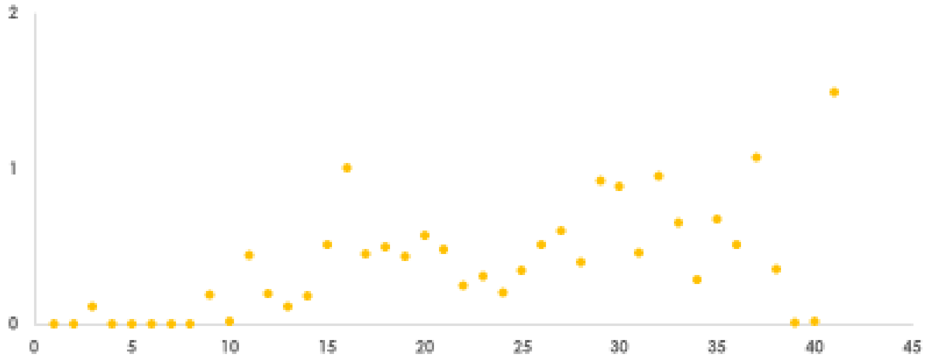
Realtime Throughput During the entire test



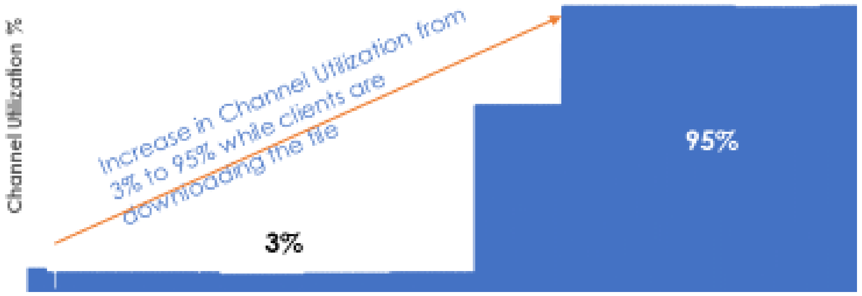
Average Rx-rate During the test



Round Trip Time During the test in (ms)

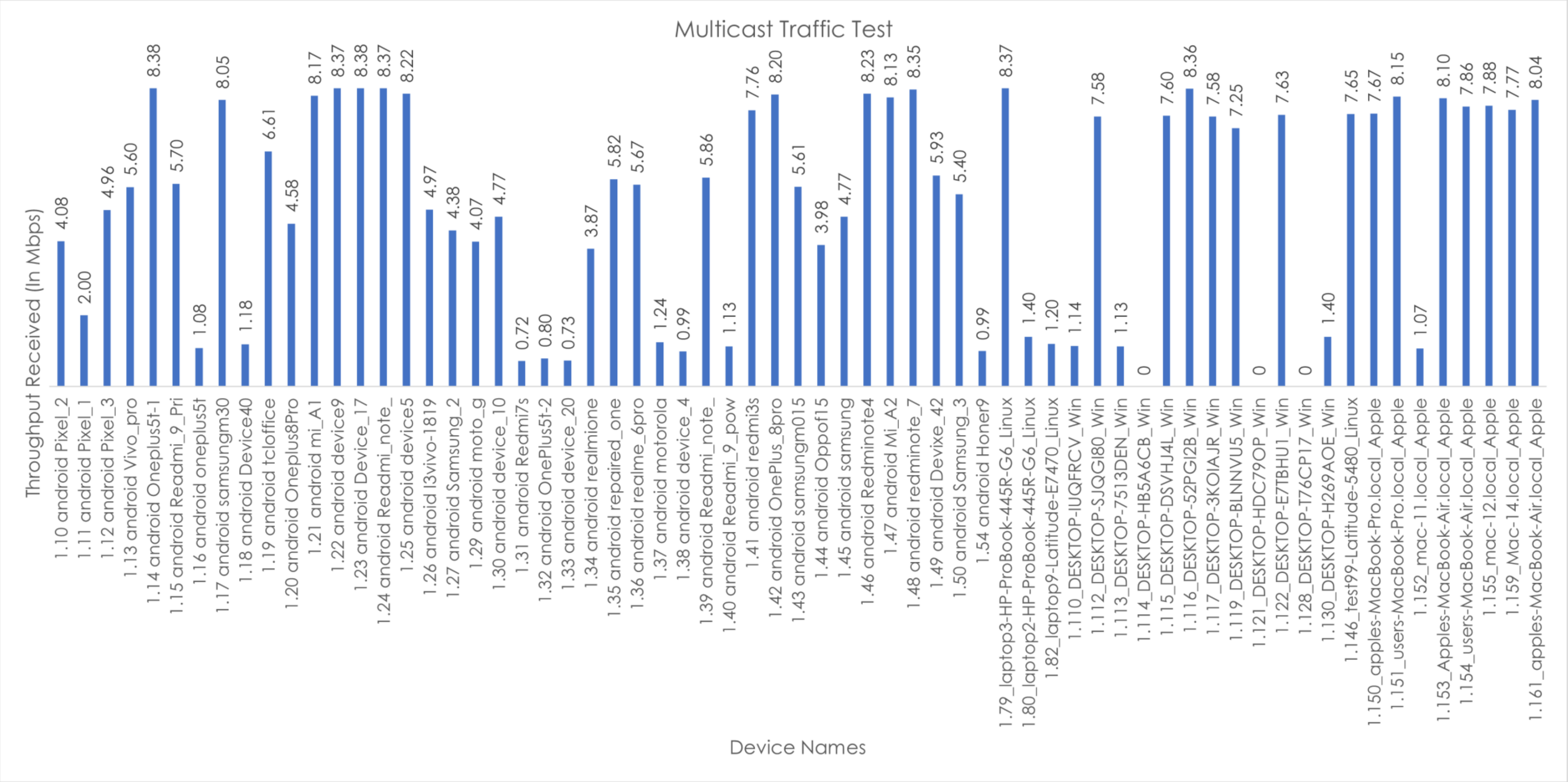


Channel Utilization



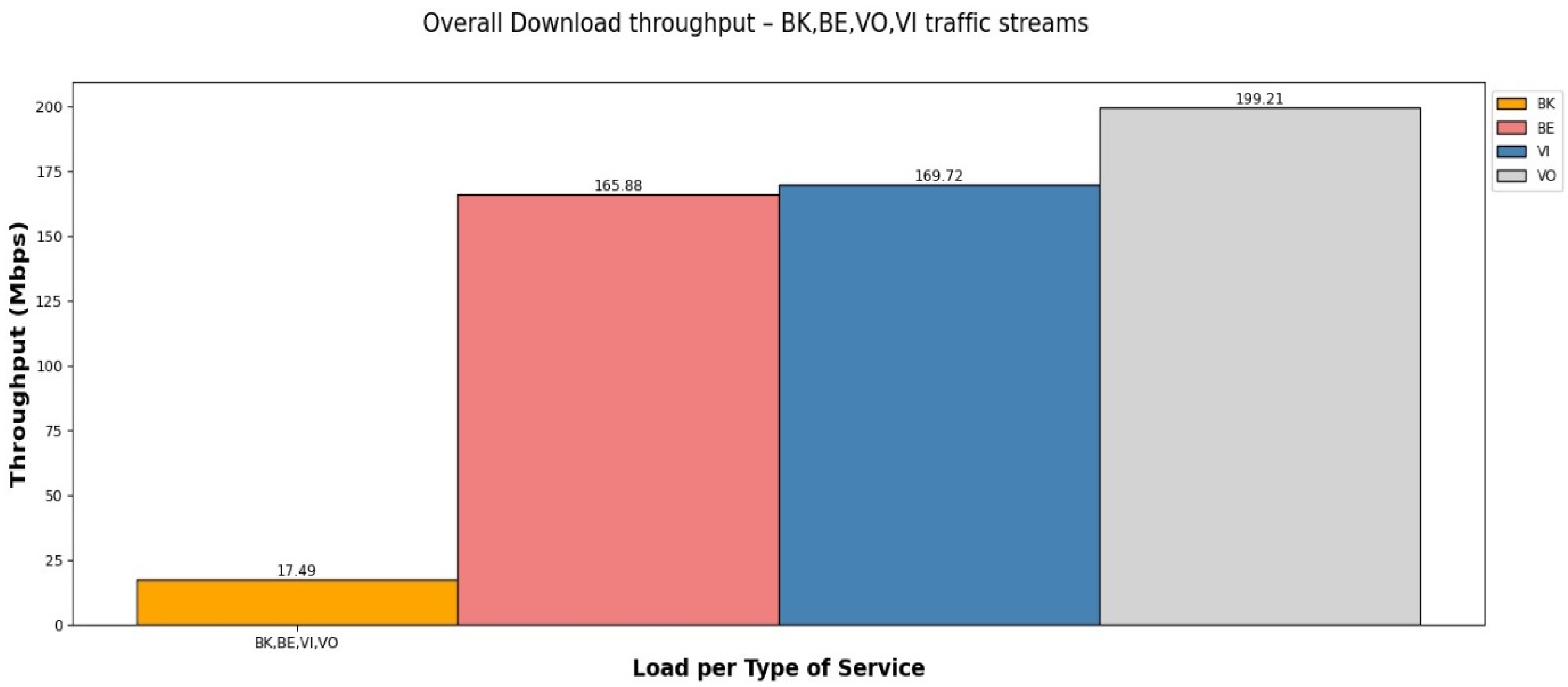
Multicast Test

In this test we create a multicast server on an Upstream interface and then initiate multicast sessions. Based on the number of clients we will try to send data to multiple clients from one server and record the packet loss and round-trip times.



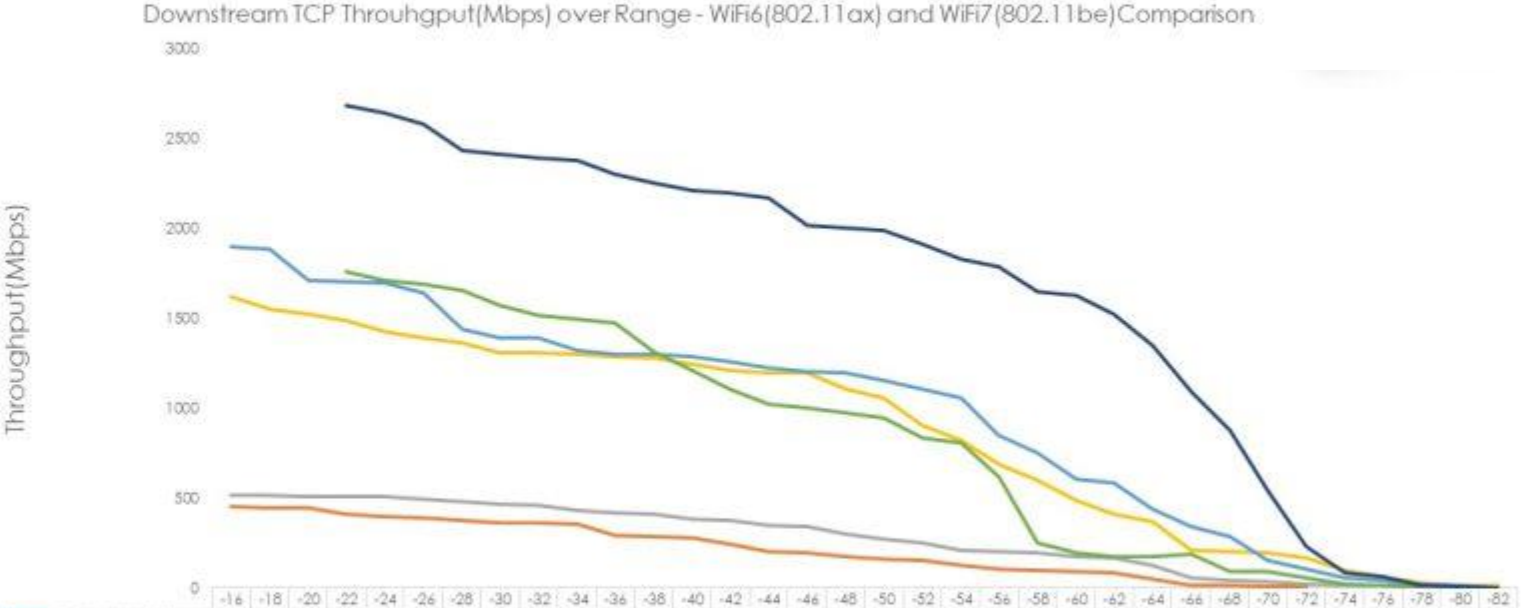
QOS Test

In this test we conduct QoS testing using various Differentiated Services Code Point (DSCP) values for Voice (VO), Video (VI), Best Effort (BE), and Background (BK) traffic and based on the number of clients involved we will try to check which ToS is getting the highest priority.



Rate vs Range Test (RVR)

In this test, we assess the performance of the Device Under Test (DUT) across varying distances. The distance is simulated using programmable attenuation, and we gauge the throughput at each distance/RSSI step.



	-16	-18	-20	-22	-24	-26	-28	-30	-32	-34	-36	-38	-40	-42	-44	-46	-48	-50	-52	-54	-56	-58	-60	-62	-64	-66	-68	-70	-72	-74	-76	-78	-80	-82
2.4GHz 20MHz BW - AX	453	441	440	407	398	387	371	362	359	351	290	281	276	245	201	196	175	161	153	127	106	98	91	83	47	16	11	9	7					
2.4GHz 20MHz BW - BE	515	511	509	509	503	489	476	461	457	429	417	408	384	371	344	336	298	271	247	204	199	192	174	169	125	52	41	37	21	13	11	8	3	1
5GHz 160MHz BW - AX	1617	1547	1522	1489	1426	1387	1359	1302	1302	1298	1284	1280	1245	1209	1192	1194	1101	1056	899	821	689	597	483	407	367	205	201	194	164	97	61	25	10	10
5GHz 160MHz BW - BE	1892	1879	1706	1701	1692	1641	1435	1391	1385	1321	1301	1297	1287	1256	1223	1203	1193	1154	1102	1056	849	746	601	584	436	336	285	149	106	56	40	21	10	2
6GHz 320MHz BW- AX				1756	1710	1690	1651	1572	1516	1491	1470	1310	1210	1102	1019	1002	972	941	832	807	617	251	196	176	174	185	91	89	51	23	11	4		
6GHz 320MHz BW- BE				2681	2642	2576	2431	2412	2391	2378	2298	2249	2207	2196	2164	2012	2001	1987	1906	1827	1784	1642	1627	1521	1348	1091	876	543	231	85	59	12	6	1

Client RSSI (in dBm)

Mixed Traffic Test

To Measure the Performance and Stability of an access point, we initiate this mixed traffic test by running multiple traffics (Ping, QOS, FTP , HTTP and Multicast) on all the Real devices (Android, Windows, Linux and MacBook) all at a time.

Mixed Traffic Test

2023-10-05-14-08-01

Test Setup Information

Overall Setup Info For all Tests	DUT Model	
	DUT Firmware	V1.0.0.10
	SSID	Test_Tool_Eval
	Security	wpa2
	No of Devices	41 (Virtual Clients: 0, Windows: 0, Linux: 0, Mac: 0, Android: 41)
	Test Duration (HH:MM:SS)	00:08:00

Objective

The Candela mixed traffic test is designed to measure the access point performance andstability by running multiple traffic on real clients like Android, Linux, Windows, and IOSconnected to the access point. This test allows the user to choose multiple types of traffic likeclient capacity test, web browser test, video streaming test ping test. Along with theperformance measurements are client connection times, Station 4-Way Handshake time, DHCPtimes, and more. The expected behavior is for the AP to be able to handle all types of traffic onthe several stations (within the limitations of the AP specs) and Make sure all clients can run alltypes of traffic.

Traffic Details

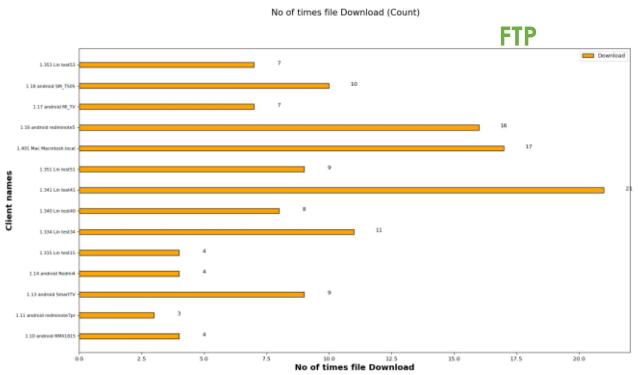
Sno	Test Cases	Test Duration
1	Ping Test	1 min
2	Quality Of Service(QOS) Test ['VI', 'VO', 'BK', 'BE']	4 min
3	FTP Test	1 min
4	HTTP Test	1 min
5	Multicast Test	1 min

1. Ping Test

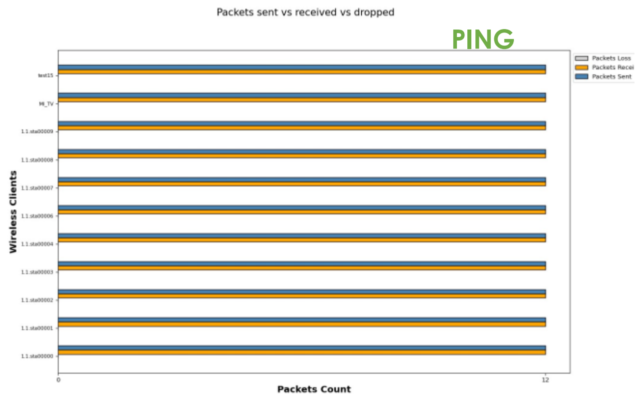
Test Configuration

Test Setup Information	IP / Website	192.168.242.128

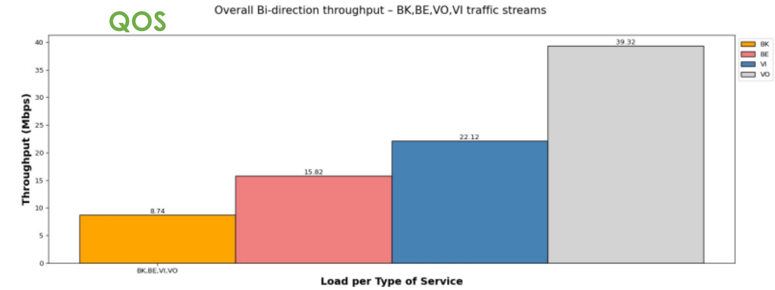
FTP



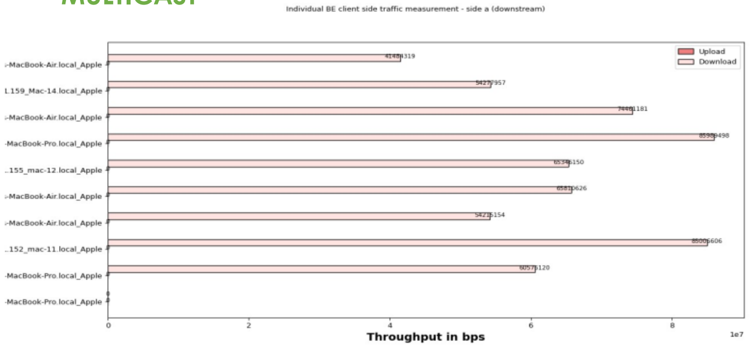
PING



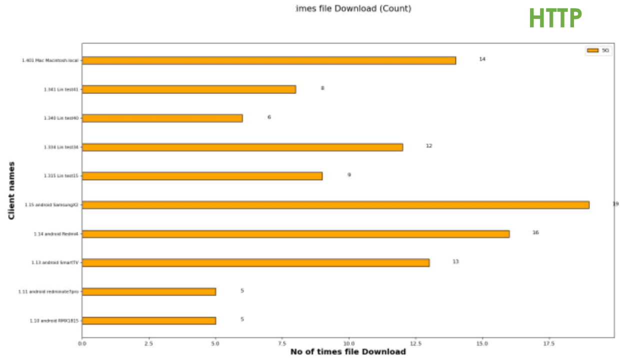
QOS



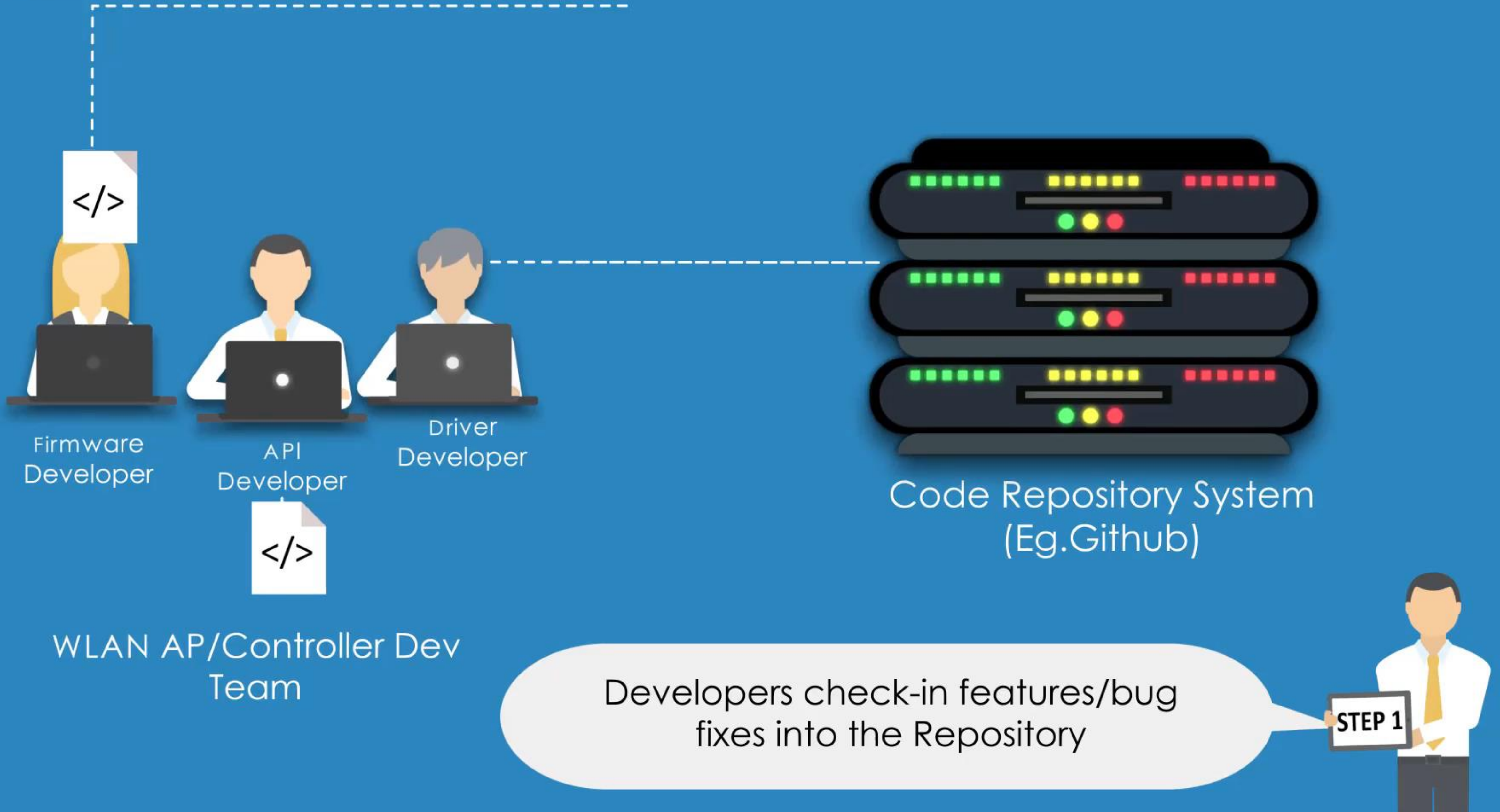
MULTICAST



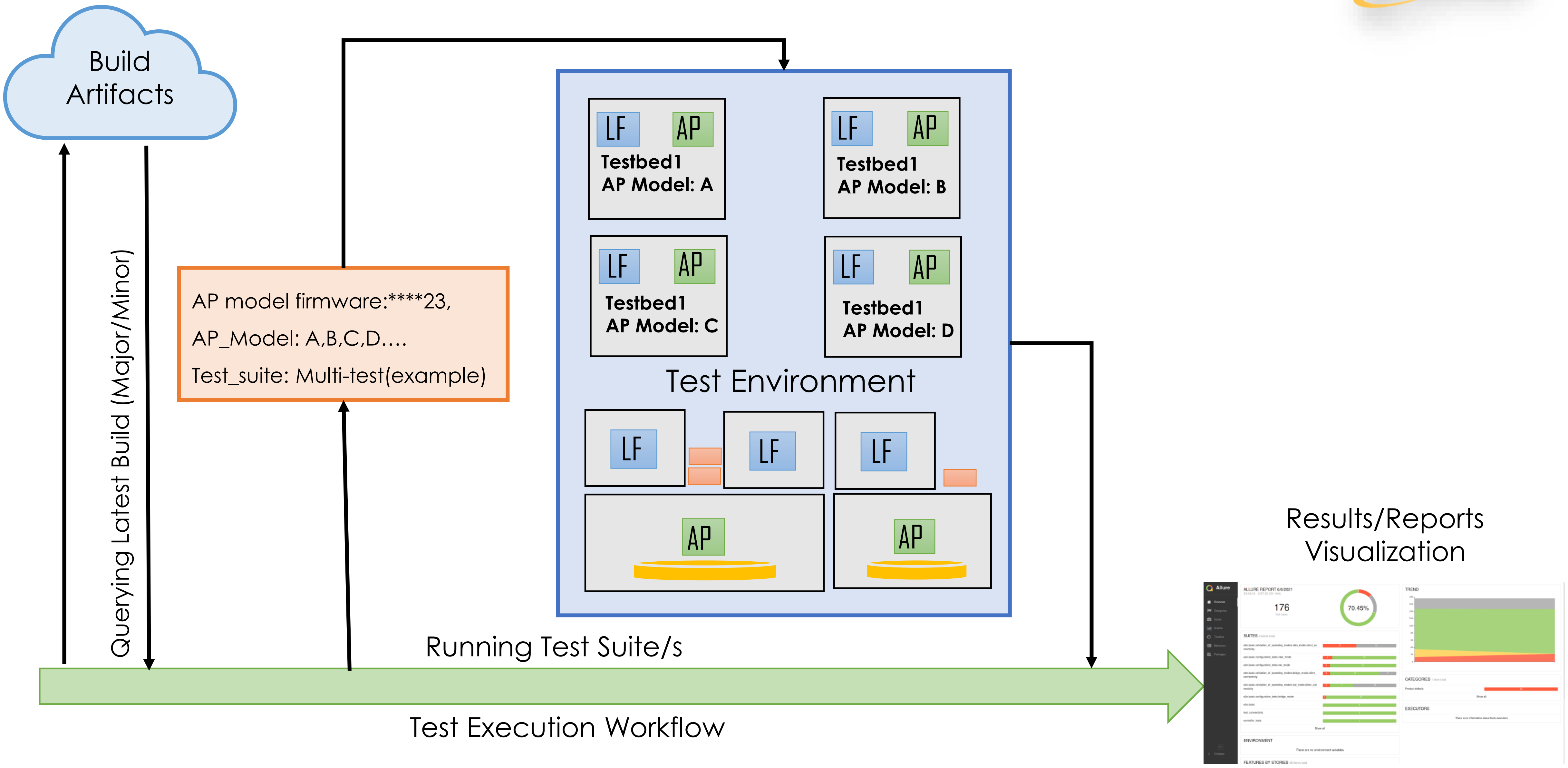
HTTP



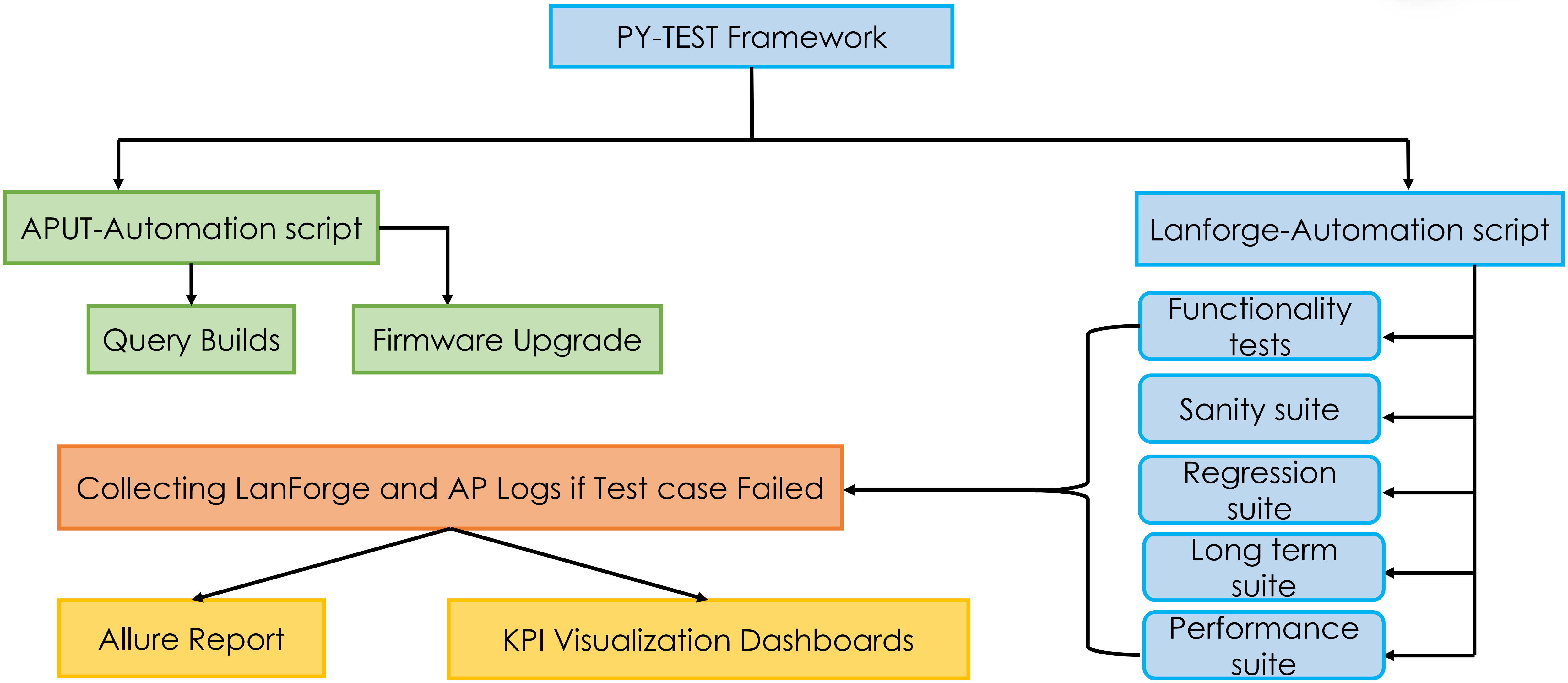
WiFi CI/CD Test Automation Framework



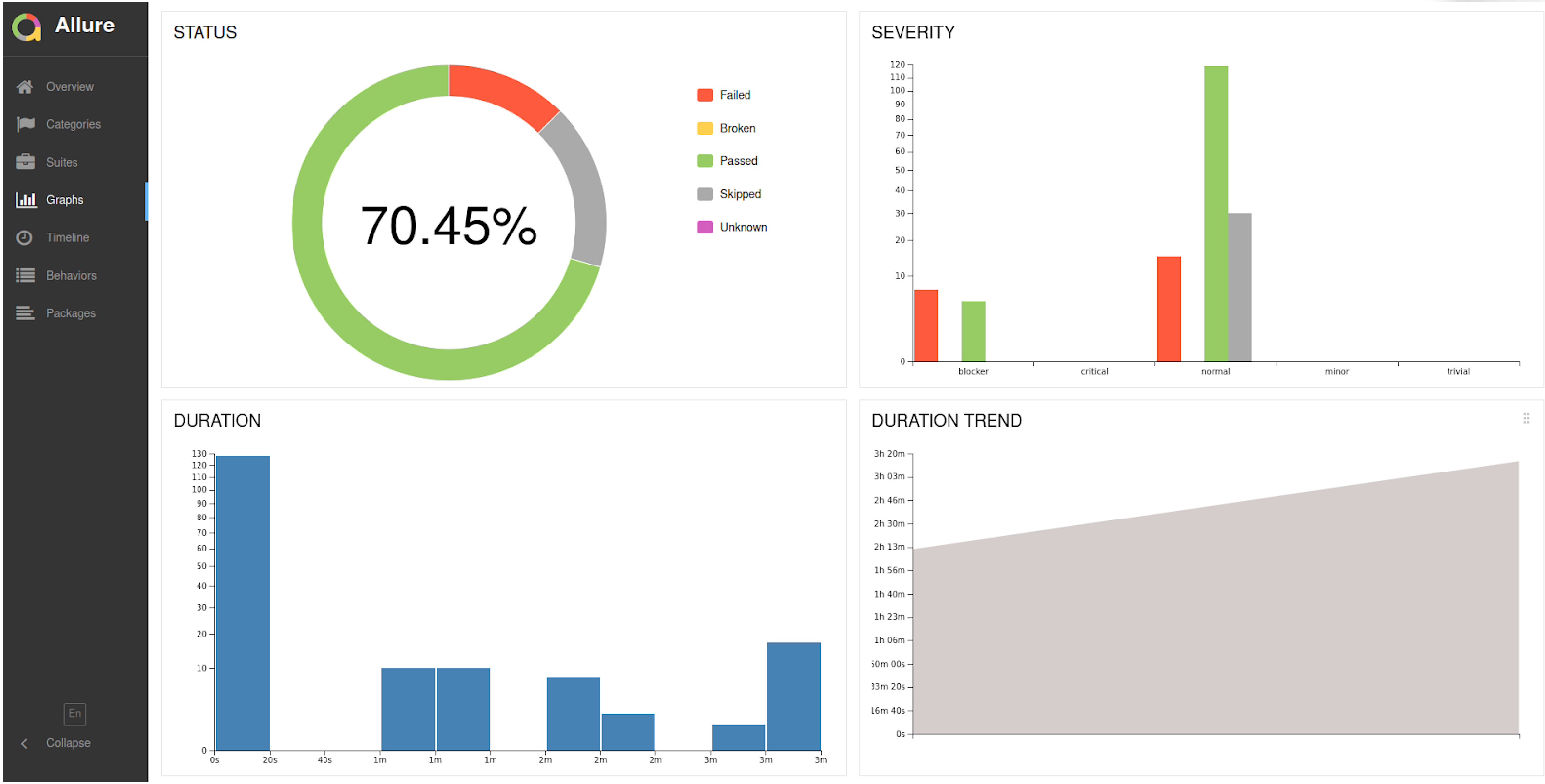
CICD workflow:



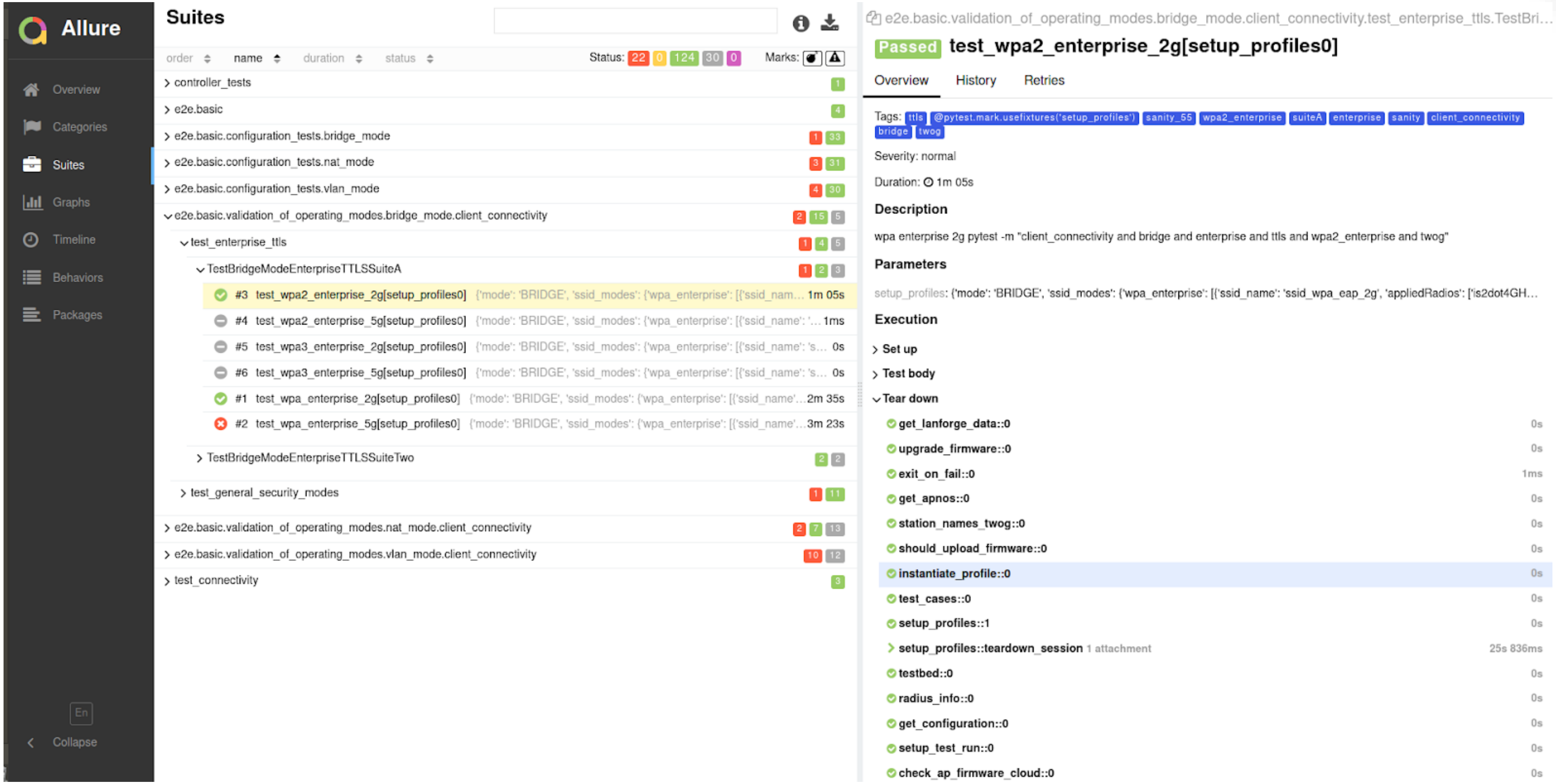
CI-CD framework Architecture:



Results and Report Visualization:



Results and Report Visualization:



TR-398

Wi-Fi In-Premises Performance Testing

(https://www.broadband-forum.org/download/TR-398.pdf)

TR-398 Test Plan Summary

Candela TECHNOLOGIES

6.1.1

Receiver Sensitivity Test

Test the Quality/Ability of the AP's receiver in being able to handle different coding schemes at different power levels .

6.2.1

Maximum Connection Test

The Maximum Connection test intends to verify that the Wi-Fi AP can support 32 STAs simultaneously connected with minimal packet loss and no disassociations taking place

6.2.2

Maximum Throughput Test

Test intends to measure the maximum throughput performance of the DUT.

6.2.3

Airtime Fairness Test

Verify the capability of Wi-Fi device to guarantee the fairness of airtime usage when handle a mix of clients using new and legacy 802.11 standards.

6.3.1

Range Versus Rate Test

Test measures the Throughput of the DUT with the station being at different distances from the AP.

6.3.2

Spatial Consistency Test

Test measures the performance of the AP at various antenna orientations with respect to the stations.

6.4.1

Multiple STAs Perf Test

Measure performance of the AP with multiple stations at different distances, to emulate the real world behavior.

6.4.2

Multiple Assoc/Disassoc Stability

In a multi client scenario, test if the AP throughput performance degrades with other clients connecting and disconnecting simultaneously

6.4.3

Downlink MU-MIMO Perf

Test to ensure the downlink throughput increases substantially with multiple clients and MU-MIMO enabled.

6.5.1

Long Term Stability

Test to make sure the AP can consistently achieve high throughput over a very long test duration.

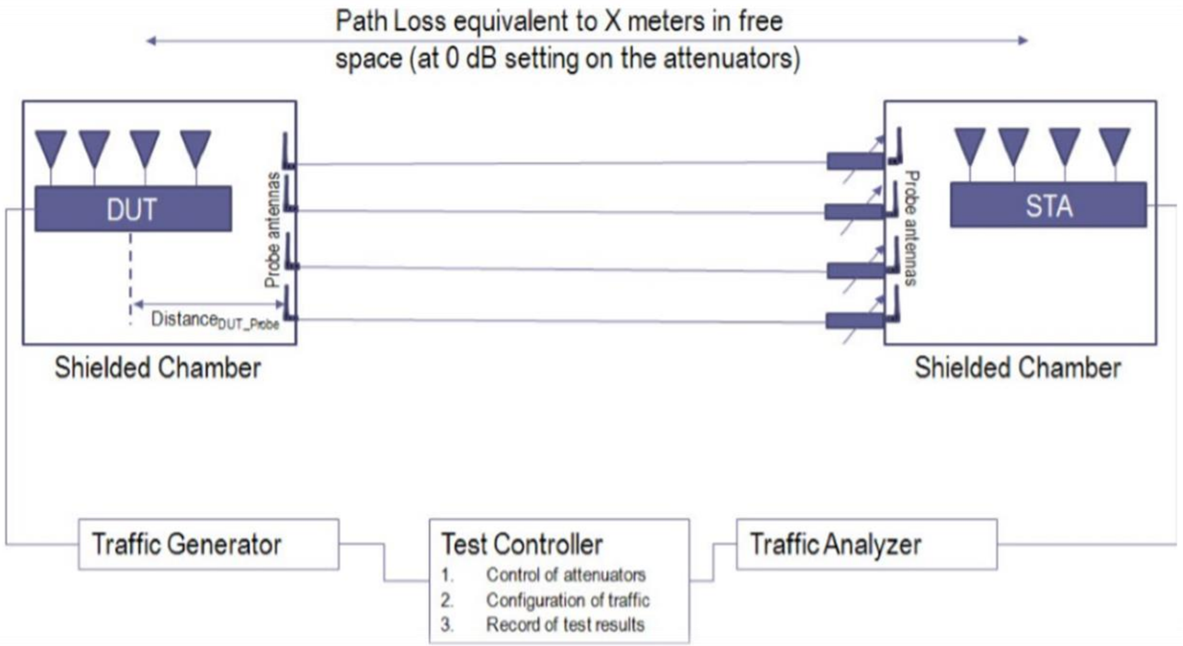
6.5.2

AP Coexistence

Test to make sure the AP can achieve good performance in the presence of other neighboring APs and clients

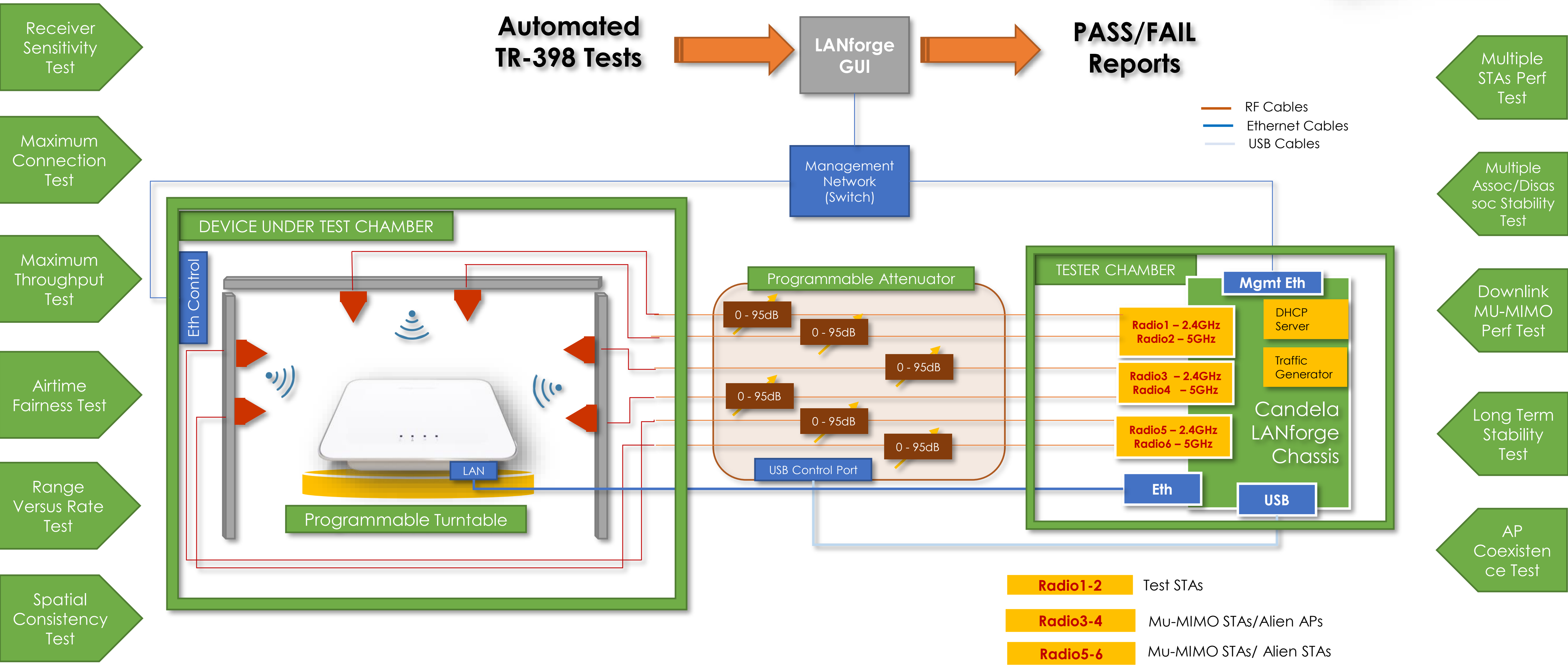
TR-398 Testbed Building Blocks

- ✓ Multi-station Emulator
- ✓ Traffic Generator
- ✓ Path Loss Emulator (Programmable Attenuator)
- ✓ Shielded Chambers / RF enclosures
- ✓ Programmable Turntable for Spatial Consistency Testing
- ✓ Mu-MIMO Station emulator for Mu-MIMO testing
- ✓ AP Emulator (to create Alien AP and Alien STAs for co-existence testing)
- ✓ Test Controller and Automation Test Software



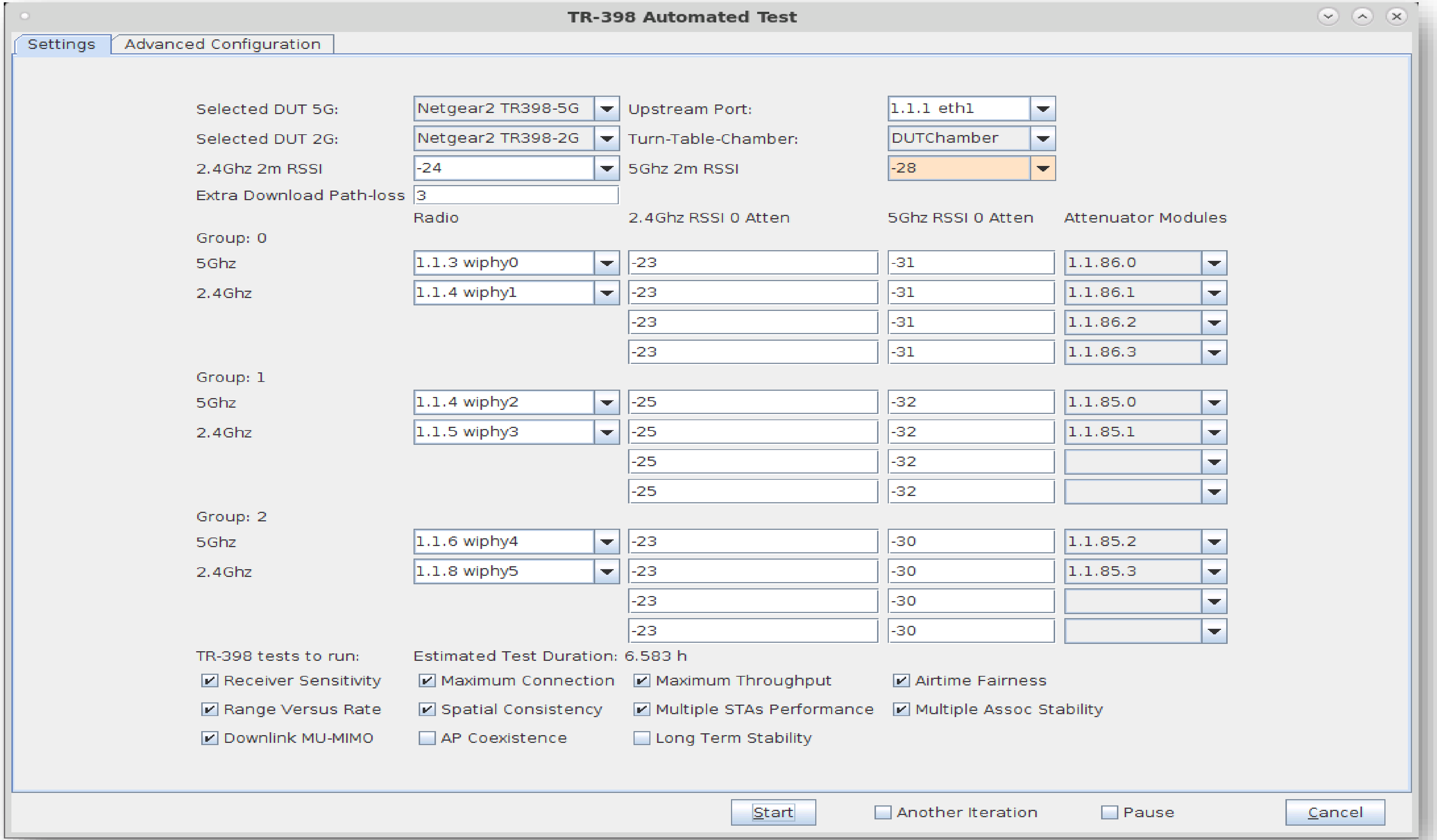
Candela Technologies offers a fully automated TR-398 Test suite with PASS/FAIL test results and all the testbed building blocks.

TR-398 Testbed Setup



TR-398 Testbed Pictures

TR-398 Automated Test GUI



Sample Test Results

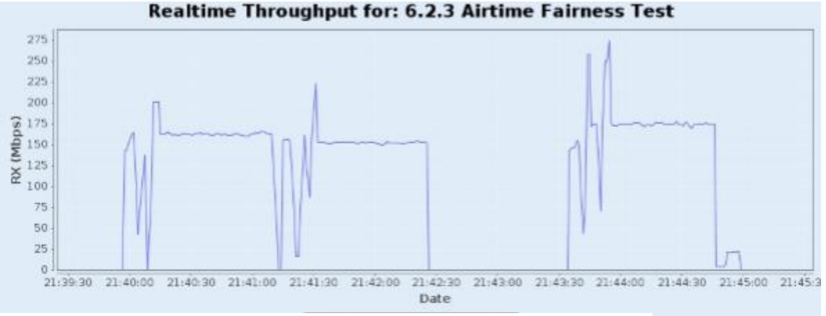
6.2.2 Maximum TCP Throughput Test Results

Type	Result	Notes
Total 2.4Ghz download throughput	PASS	Sum-total download: 114.46 Mbps Requires: 100Mbps STA-RSSI: -31 Rx-Rate: 144.4M Tx-Rate: 144.4M
Total 2.4Ghz upload throughput	PASS	Sum-total upload: 111.94 Mbps Requires: 100Mbps STA-RSSI: -30 Rx-Rate: 144.4M Tx-Rate: 144.4M
Total 5Ghz download throughput	PASS	Sum-total download: 696.93 Mbps Requires: 560Mbps STA-RSSI: -45 Rx-Rate: 866.7M Tx-Rate: 866.7M
Total 5Ghz upload throughput	PASS	Sum-total upload: 697.47 Mbps Requires: 560Mbps STA-RSSI: -44 Rx-Rate: 866.7M Tx-Rate: 866.7M

Comprehensive PDF Test Reports

Summary Results

Test	Result	Score	Elapsed	Info
6.1.1 Receiver Sensitivity Test	2.4Ghz PASS 5Ghz PASS	100.0	2.109 h	2.4Ghz passed 16 / 16 Pass-Avg: 10.9 5Ghz passed 16 / 16 Pass-Avg: 3.9
6.2.1 Maximum Connection Test (32-STA)	2.4Ghz PASS 5Ghz PASS	154.2	8.763 m	Throughput: 2.4Ghz UL 104.11% DL 104.39% Throughput 5Ghz UL 101.95% DL 104.34% Passed PER: 128 / 128
6.2.2 Maximum TCP Throughput Test	2.4Ghz PASS 5Ghz PASS	2.0	5.401 m	Throughput 2.4Ghz UL 1.12% DL 1.14% Throughput 5Ghz UL 1.25% DL 1.24%
6.2.3 Airtime Fairness Test	2.4Ghz FAIL 5Ghz FAIL	100.0	6.164 m	* Candela is not convinced these pass/fail metrics are very helpful.
6.3.1 Range Versus Rate Test	2.4Ghz FAIL 5Ghz PASS	83.6	34.083 m	5Ghz UL 13 / 13 DL 13 / 13 2.4Ghz UL 16 / 22 DL 17 / 23 2.4Ghz Retried 0 traffic tests.
6.3.2 Spatial Consistency Test	2.4Ghz PASS 5Ghz FAIL	93.8	44.3 m	5Ghz passed 11 / 12 5Ghz retried 1 traffic tests. 2.4Ghz passed 12 / 12 2.4Ghz retried 7 traffic tests.
6.4.1 Multiple STAs Performance Test	2.4Ghz PASS 5Ghz PASS	100.0	18.232 m	2.4Ghz Passed 6 / 6 5Ghz Passed 6 / 6
6.4.2 Multiple Association / Disassociation Stability Test	2.4Ghz PASS 5Ghz PASS	100.0	7.161 m	2.4Ghz Passed 960 / 960 5Ghz Passed 960 / 960
6.4.3 Downlink MU-MIMO Performance Test	2.4Ghz PASS 5Ghz FAIL	100.0	13.883 m	
6.5.2 AP Coexistence Test	2.4Ghz FAIL 5Ghz FAIL	62.5	17.533 m	Passed 5 / 8 NOTE: User has calibrated different Interferer transmit rates. TR-398 specified vs actual inteferer rate settings: 5G-80Mhz: 195 vs 195 5G-40Mhz: 90 vs 90 2.4Ghz-2
6.5.1 Long Term Stability Test	2.4Ghz FAIL 5Ghz PASS	91.0	54.568 m	2.4Ghz Throughput Avg 198.04 Mbps Passed: 46 / 5 2.4Ghz Packet Error Rate Passed: 0 / 5 5Ghz Throughput Avg 903.30 Mbps Passed: 50 / 50 5Ghz Packet Error Rate Passed: 5 / 5



6.3.2 Spatial Consistency Test Results

Type	Result	Notes
6.3.2 Assumptions	INFO	This test does not specify RSSI, so calibrating it is difficult. You may shift the attenuation by modifying the Attenuation Adjustment setting on the 'Advanced Configuration' screen.
Configuration NOTE	INFO	Attenuation Adjustment set to: 4
Configuration NOTE	INFO	Traffic duration is set to: 10s, default is 60s
Configuration NOTE	INFO	This test will retry below average tests: 3 times and record the best result.
5Ghz Avg DL Sig: 10	PASS	Avg download must be at least: 500Mbps, reported: 688.1
5Ghz Minimum DL Sig: 10	PASS	Min download: 623.9 must be at least 60%: 412.8 of the avg: 688.1Mbps

6.1.1 Receiver Sensitivity Test Results

Type	Result	Notes
6.1.1 Assumptions	INFO	This test does not specify RSSI, so calibrating it is difficult. You may change the attenuation by modifying the Attenuation Adjustment setting on the 'Advanced Configuration' screen.
Configuration NOTE	INFO	Attenuation Adjustment set to: 4
	PASS	5Ghz mcs: 0 BW: 80 rot: 0 last-atten-pass: 47 passing value: 46 STA RSSI: -60 Expected AP RSSI: -65
	PASS	5Ghz mcs: 9 BW: 80 rot: 0 last-atten-pass: 27 passing value: 21 STA RSSI: -38 Expected AP RSSI: -45
	PASS	5Ghz mcs: 0 BW: 80 rot: 45 last-atten-pass: 51 passing value: 46 STA RSSI: -61 Expected AP RSSI: -69
	PASS	5Ghz mcs: 9 BW: 80 rot: 45 last-atten-pass: 31 passing value: 21 STA RSSI: -40 Expected AP RSSI: -49
	PASS	5Ghz mcs: 0 BW: 80 rot: 90 last-atten-pass: 50 passing value: 46 STA RSSI: -62 Expected AP RSSI: -68
	PASS	5Ghz mcs: 9 BW: 80 rot: 90 last-atten-pass: 27 passing value: 21 STA RSSI: -38 Expected AP RSSI: -45
	PASS	5Ghz mcs: 0 BW: 80 rot: 135 last-atten-pass: 50 passing value: 46 STA RSSI: -61 Expected AP RSSI: -68
	PASS	5Ghz mcs: 9 BW: 80 rot: 135 last-atten-pass: 26 passing value: 21 STA RSSI: -36 Expected AP RSSI: -44
	PASS	5Ghz mcs: 0 BW: 80 rot: 180

6.4.2 Multiple Association / Disassociation Stability Test Results

Type	Result	Notes
2.4Ghz CX: cv_udp-1.1-1.sta0600--1.0.0 Steady-State	PASS	Requires: 3.96 Mbps Reported: 4.00 Mbps
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		
2.4Ghz CX: cv_udp-1.1-		

6.4.3 Downlink MU-MIMO Performance Test Results

Type	Result	Notes
6.4.3.4.3 SU-MIMO Sta-1 Baseline	INFO	Download Rate: 670.31 Mbps STA-RSSI: -45 Rx-Rate: 866.7M Tx-Rate: 866.7M
6.4.3.4.4 SU-MIMO Sta-2 Baseline	INFO	Download Rate: 347.54 Mbps STA-RSSI: -53 Rx-Rate: 433.3M Tx-Rate: 433.3M
6.4.3.4.5 SU-MIMO Sta-3 Baseline	INFO	Download Rate: 349.77 Mbps STA-RSSI: -49 Rx-Rate: 433.3M Tx-Rate: 433.3M
6.4.3.4.6 MU-MIMO Sta1 - 3 Total	INFO	Total Download Rate: 575.00 Mbps Sta-1 Download Rate: 300.15 Mbps STA-RSSI: -45 Rx-Rate: 32.6M Tx-Rate: 866.7M Sta-2 Download Rate: 274.85 Mbps STA-RSSI: -50 Rx-Rate: 32.6M Tx-Rate: 390M Sta-3 Download Rate: 0 Mbps STA-RSSI: -38 Rx-Rate: 433.3M Tx-Rate: 390M
6.4.3.4.7 SU-MIMO Sta1 - 3 Total	INFO	Total Download Rate: 575.00 Mbps Sta-1 Download Rate: 204.07 Mbps STA-RSSI: -45 Rx-Rate: 866.7M Tx-Rate: 866.7M Sta-3 Download Rate: 105.97 Mbps STA-RSSI: -49 Rx-Rate: 433.3M Tx-Rate: 390M Sta-3 Download Rate: 0 Mbps STA-RSSI: -38 Rx-Rate: 433.3M Tx-Rate: 390M
MU-MIMO-Throughput	FAIL	Requires: 615.43 Mbps Reported: 575.00 Mbps
6.4.3.5.B MIMO Throughput Comparison	PASS	SU-MIMO-Total: 419.52 Mbps MU-MIMO-Total: 575.00 Mbps

6.2.1 Maximum Connection Test (32-STA) Results

Type	Result	Notes
6.2.1 Assumptions	INFO	The spec is open to interpretation: Candela assumes stations can run at full available NSS and bandwidth.
6.2.1.5.A 2.4Ghz cv_udp-1.1-1.sta0600--1.0.0	PASS	Download-PER: 0STA-RSSI: -26 Rx-Rate: 600M Tx-Rate: 240M
6.2.1.5.A 2.4Ghz cv_udp-1.1-1.sta0601--1.0.0	PASS	Download-PER: 0STA-RSSI: -26 Rx-Rate: 600M Tx-Rate: 180M
6.2.1.5.A 2.4Ghz cv_udp-1.1-1.sta0602--1.0.0	PASS	Download-PER: 0STA-RSSI: -26 Rx-Rate: 600M Tx-Rate: 180M
6.2.1.5.A 2.4Ghz cv_udp-1.1-1.sta0603--1.0.0	PASS	Download-PER: 0STA-RSSI: -26 Rx-Rate: 600M Tx-Rate: 240M
6.2.1.5.A 2.4Ghz cv_udp-1.1-1.sta0604--1.0.0	PASS	Download-PER: 0STA-RSSI: -26 Rx-Rate: 600M Tx-Rate: 240M
6.2.1.5.A 2.4Ghz cv_udp-1.1-1.sta0605--1.0.0	PASS	Download-PER: 0STA-RSSI: -26 Rx-Rate: 600M Tx-Rate: 240M

TR-398

WiFi Performance Test Plan

Tue Jul 23 05:23:06 PDT 2019

Test Setup Information		
Device Under Test	Name	Netgear2
	Model Number	Netgear R7800
	SSIDs	TR398-5G TR398-2G
	BSSIDs	
Operator	sitarama.perumetsa@candelatech.com	
Estimated Run Time	30.883 h	
Actual Run Time	5.617 h	

Objective

The TR-398 WiFi Performance test plan by the Broadband forum provides a comprehensive set of tests to qualify the performance of WiFi access points (APs) designed for residential and small office environments. Radio performance, Throughput, Connection Stability, Airtime Fairness, AP Co-existence, Mu_MIMO Performance, Spatial Consistency and Long-term Stability are some of the test areas covered in this test plan. The test plan is designed for service providers deploying in home WiFi APs to qualify the APs in the lab before deployment and for equipment makers to test during the development of the APs. Candela Technologies offers a fully automated TR-398 test system. The user can select from the list of 11 tests available in the GUI and all selected tests are run fully automated at one click of a button. Measurements are made and compared to the specified PASS/FAIL criteria in the TR-398 test plan and this report will show the summary PASS/FAIL results followed more detailed results for each test.

Summary Results

Test	Result	Score	Elapsed	Info
6.1.1 Receiver Sensitivity Test	2.4Ghz PASS 5Ghz PASS	100.0	2.109 h	2.4Ghz passed 16 / 16 Pass-Avg: 10.9 5Ghz passed 16 / 16 Pass-Avg: 3.9
6.2.1 Maximum Connection Test (32-STA)	2.4Ghz PASS 5Ghz PASS	154.2	8.763 m	Throughput: 2.4Ghz UL 104.11% DL 104.39% Throughput 5Ghz UL 101.95% DL 104.34% Passed PER: 128 / 128
6.2.2 Maximum TCP Throughput Test	2.4Ghz PASS 5Ghz PASS	2.0	5.401 m	Throughput 2.4Ghz UL 1.12% DL 1.14% Throughput 5Ghz UL 1.25% DL 1.24%
6.2.3 Airtime Fairness Test	2.4Ghz FAIL 5Ghz FAIL	100.0	6.164 m	* Candela is not convinced these pass/fail metrics are very helpful.
6.3.1 Range Versus Rate Test	2.4Ghz FAIL 5Ghz PASS	83.6	34.083 m	5Ghz UL 13 / 13 DL 13 / 13 2.4Ghz UL 16 / 22 DL 17 / 23 2.4Ghz Retried 0 traffic tests.
6.3.2 Spatial Consistency Test	2.4Ghz PASS 5Ghz FAIL	93.8	44.3 m	5Ghz passed 11 / 12 5Ghz retried 1 traffic tests. 2.4Ghz passed 12 / 12 2.4Ghz retried 7 traffic tests.
6.4.1 Multiple STAs Performance Test	2.4Ghz PASS 5Ghz PASS	100.0	18.232 m	2.4Ghz Passed 6 / 6 5Ghz Passed 6 / 6
6.4.2 Multiple Association / Disassociation Stability Test	2.4Ghz PASS 5Ghz PASS	100.0	7.161 m	2.4Ghz Passed 960 / 960 5Ghz Passed 960 / 960
6.4.3 Downlink MU-MIMO Performance Test	2.4Ghz PASS 5Ghz FAIL	100.0	13.883 m	
6.5.2 AP Coexistence Test	2.4Ghz FAIL 5Ghz FAIL	62.5	17.533 m	Passed 5 / 8 NOTE: User has calibrated different Interferer transmit rates. TR-398 specified vs actual inteferer rate settings: 5G-80Mhz: 195 vs 195 5G-40Mhz: 90 vs 90 2.4Ghz-20Mhz: 32 vs 29
6.5.1 Long Term Stability Test	2.4Ghz FAIL 5Ghz PASS	91.0	54.568 m	2.4Ghz Throughput Avg 198.04 Mbps Passed: 46 / 50 2.4Ghz Packet Error Rate Passed: 0 / 5 5Ghz Throughput Avg 903.30 Mbps Passed: 50 / 50 5Ghz Packet Error Rate Passed: 5 / 5

6.1.1 Receiver Sensitivity Test

Summary

Receiver Sensitivity is a receiver's ability to receive and correctly demodulate weak signals. This test provides a simplified measurement of the receiver's sensitivity, relative to the total attenuation inserted between the DUT and the STA. As that attenuation is increased, the STA is limited to a single coding scheme, eventually causing the connection to degrade. The point at which the connection degrades represents the receiver's approximate sensitivity. This is an approximate measurement only, where a detailed receiver sensitivity measurement would typically be performed in a conducted test environment with calibrated transmitter power levels. The test is repeated with multiple coding schemes, ensuring the DUT should smoothly transition between coding

TR-398 Test Equipment and Components

- ✓ 3x 5GHz and 3x 2.4GHz NICs (4x4 Wave2)
- ✓ 2x 10GE Copper Port
- ✓ 64 STAs per Radio
- ✓ Background (Alien) APs and STA
- ✓ L2-7 traffic generation and monitoring

CT523c

LANforge Station Emulator/Traffic Generator

- ✓ Isolation: 75+ dB
- ✓ Frequency(GHz): 0.8 to 6GHZ
- ✓ Standard Interfaces: 16x SMAs, 2x USB 3.0, 2x 10G Ethernet, USB-C, 4K HDMI, RF Coax, Fiber, fan, DC power, universal A/C power strip. Other options available.
- ✓ In Dim(mm): 480(W) 490(D) 480(H)
- ✓ Out Dim(mm): 550(W) 650(D) 535(H)
- ✓ Weight: 30kg

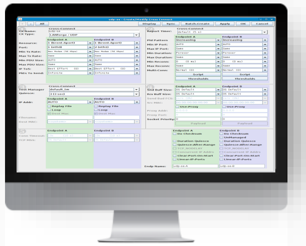
CT820a

Candela Medium RF Chamber

- ✓ Isolation: > 80 dB
- ✓ Frequency(GHz): 0.8 to 6GHZ
- ✓ Standard Interfaces: 16x SMAs, 2x USB 3.0, 2x 10GE, USB-C, 4K HDMI, RF Coax, Fiber, fan, DC power, universal A/C power strip.
- ✓ Programmable Turn Table
- ✓ In Dim(mm): 890 x 450 x495
- ✓ Out Dim(mm): 1060 x 770 x 880
- ✓ Weight: 90kg

CT840a

Candela Large RF chamber with 2D turntable



- ✓ LANforge TR-398 Automation Test Suite.
- ✓ PASS/FAIL Test Report

Software

Candela TR-398 Automation Test Suite

- ✓ Frequency Range:0.3 GHz – 6.0 GHz
- ✓ Attenuation Range:0 – 95.5 dB
- ✓ Attenuation Steps:0.5 dB increments
- ✓ Insertion Loss:8 dB nominal, 10 dB max
- ✓ Attenuation Accuracy:1-15 dB: ±1dB, 16+ dB: ±1.5dB or 4%

CT704b

Candela 4-port Programmable Attenuator

- ✓ Semi-rigid cable package included
- ✓ Splitter/Combiners
- ✓ Fixed Attenuators

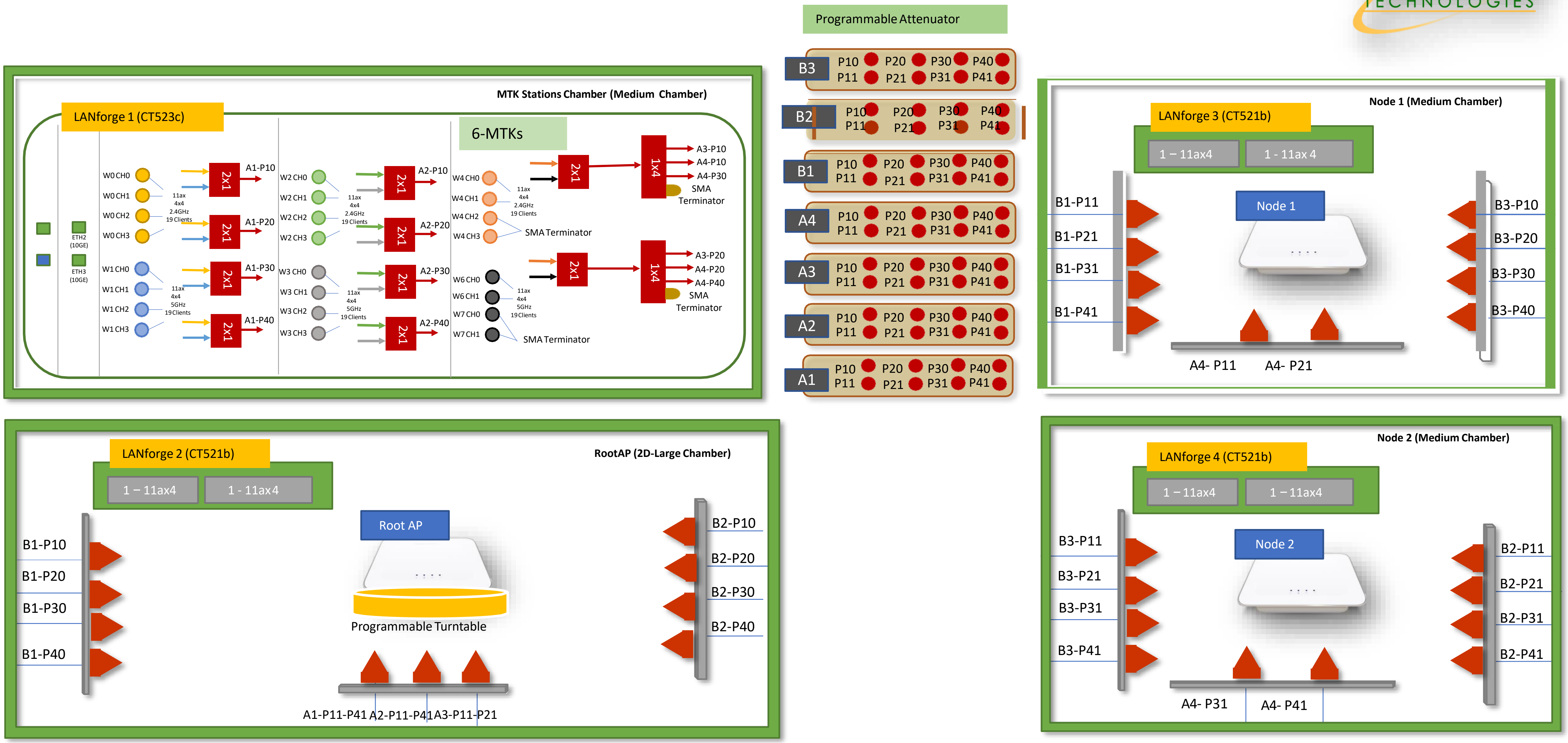
SMA Cable Bundle

TR-398 Issue 3 Test Cases

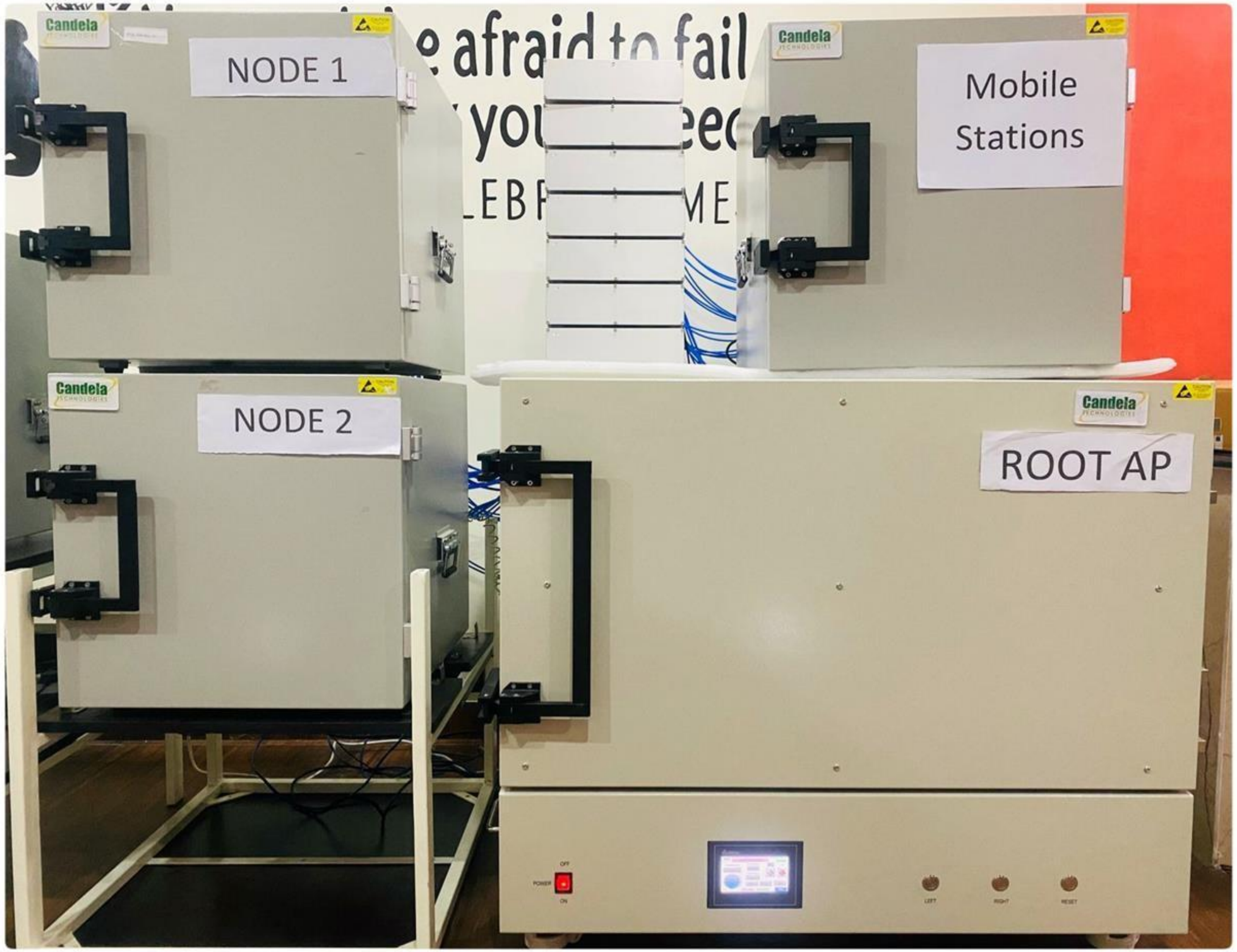
- 6.1. RF capability
  - 6.1.1 Receiver Sensitivity Test
- 6.2. Baseline Performance
  - 6.2.1 Maximum Connection Test
  - 6.2.2 Maximum Throughput Test
  - 6.2.3 Airtime Fairness Test
  - 6.2.4 Dual-band Throughput Test
  - 6.2.5 Bidirectional Throughput Test
  - 6.2.6 Latency under Load Test
  - 6.2.7 Quality of Service
- 6.3. Coverage
  - 6.3.1 Range Versus Rate Test
  - 6.3.2 Spatial consistency test -
  - 6.3.3 802.11ax Peak Performance Test
- 6.4. Multiple STAs Performance
  - 6.4.1 Multiple STAs Performance Test
  - 6.4.2 Multiple Association/Disassociation Stability Test
  - 6.4.3 Downlink MU-MIMO Performance Test
  - 6.4.4 Multicast Multi-Station
- 6.5. Stability/Robustness
  - 6.5.1 Long Term Stability Test
  - 6.5.2 AP Coexistence Test
  - 6.5.3 Automatic Channel Selection Test
- 6.6 Mesh Performance
  - 6.6.1 Mesh Backhaul RVR
  - 6.6.2 Mesh Backhaul Node2 RVR
  - 6.6.3 Mesh Roam Time

❖ The testcases in Orange colour represent new tests added in TR-398 Issue3

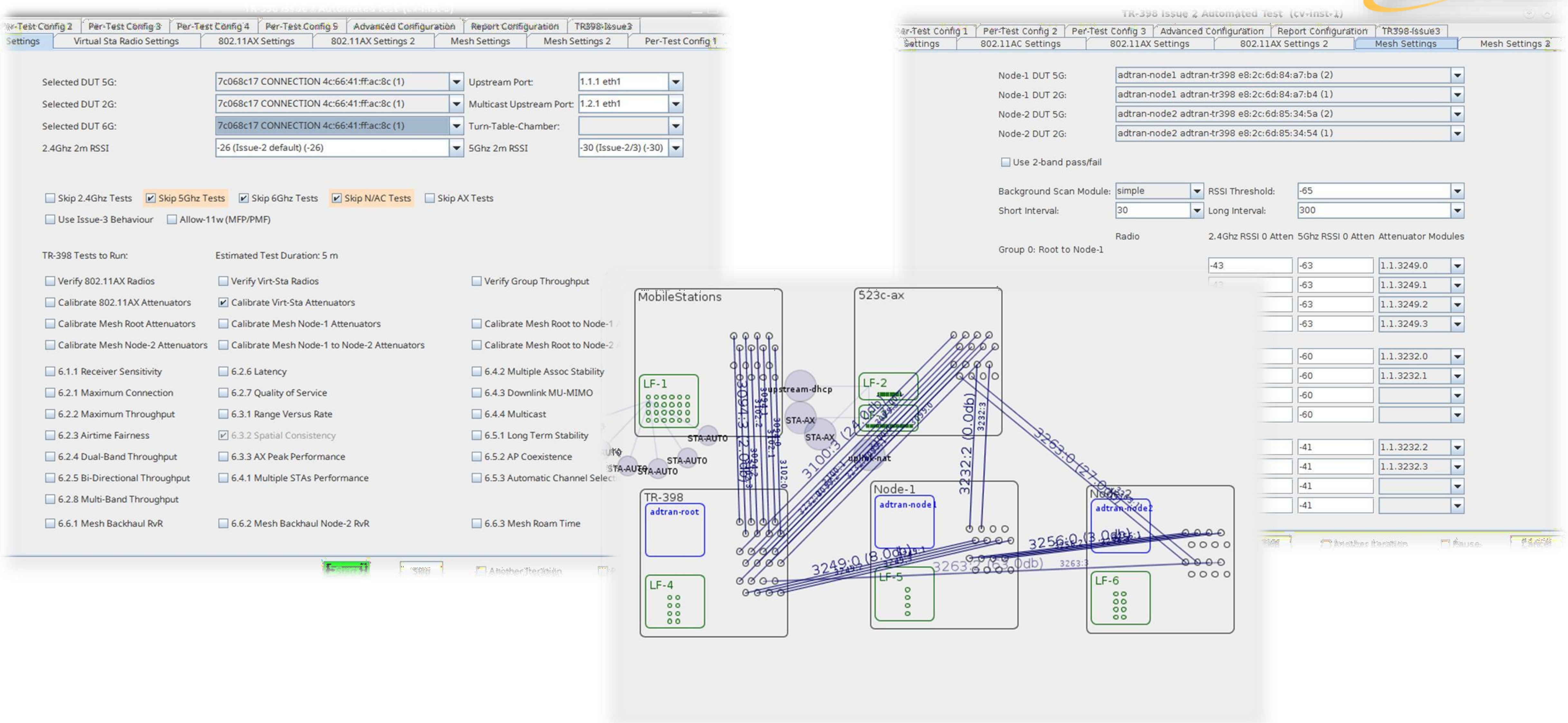
TR398 issue 3 +Mesh Wiring Diagram



TR-398 Issue 3+ Mesh Testbed Images



TR-398 Issue 3 GUI



TR-398 Issue3 Test Report

TR-398 Issue 2

WiFi Performance Test Plan

Tue Nov 15 09:45:35 IST 2022

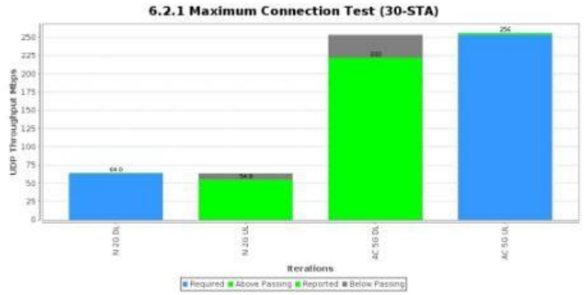
Test Setup Information		
Device Under Test	Name	DUT
	SSIDs	DUT_2G DUT_5G
	Passwords	
	BSSIDs	
	Notes	[BLANK]
Estimated Run Time	17.3 h	
Actual Run Time	13.011 h	

Objective

The TR-398 Issue 2 WiFi Performance test plan by the Broadband forum provides a comprehensive set of tests to qualify the performance of WiFi access points (APs) designed for residential and small office environments. Radio performance, Throughput, Connection Stability, Airtime Fairness, AP Co-existence, Mu_MIMO Performance, Spatial Consistency and Long-term Stability are some of the test areas covered in this test plan. The test plan is designed for service providers deploying in home WiFi APs to qualify the APs in the lab before deployment and for equipment makers to test during the development of the APs. Candela Technologies offers a fully automated TR-398 Issue 2 test system. The user can select from the list of tests available. Most tests can run fully automated, though some require user interaction. Measurements are made and compared to the specified PASS/FAIL criteria in the TR-398 Issue 2 test plan and this report will show the summary PASS/FAIL results followed more detailed results for each test.

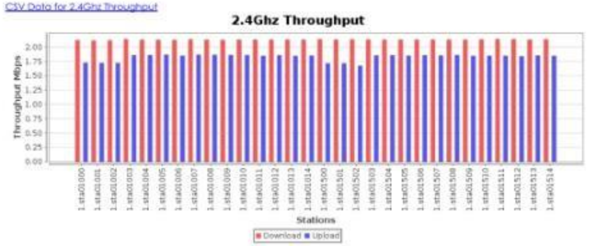
Summary Results

Test	Result	Candela Score	Elapsed	Info
Calibrate Mesh Zero Attenuation RSSI (STA to Node-1)	Skipped	0	0	
Calibrate Mesh Zero Attenuation RSSI (STA to Node-2)	Skipped	0	0	
6.1.1 Receiver Sensitivity Test	2.4Ghz FAIL 5Ghz PASS	41	2.505 h	N 2.4Ghz passed 2 / 16 N Fail-Avg: 10.1 N Pass-Avg: 13.0 N 2.4Ghz Failed-by-steps: 142.0 Passed-by-steps: 26.0 AC 5Ghz passed 16 / 16 Pass-Avg: 4.2 AC 5Ghz Failed-by-steps: 0.0 Passed-by-steps: 68.0 Internal ERROR: Rotation table failed to rotate.
6.2.1 Maximum Connection Test (30-STA)	2.4Ghz FAIL 5Ghz FAIL	95	12.159 m	Throughput: N 2.4Ghz UL 86.61% DL 101.03% Throughput: AC 5Ghz UL 101.02% DL 87.54% Passed PER: 116 / 120
6.2.2 Maximum TCP Throughput Test	2.4Ghz PASS 5Ghz FAIL	92	8.867 m	Throughput N 2.4Ghz UL 110.13% DL 108.31% Throughput AC 5Ghz UL 64.24% DL 86.36%
6.2.3 Airtime Fairness Test	2.4Ghz FAIL 5Ghz FAIL	0	32.324 m	AC 5Ghz passed 0 / 6 N 2.4Ghz passed 5 / 6
6.2.3 Issue-3 Airtime Fairness Test	Skipped	0	0	
6.4.4 Multiple STA Multicast Test	Skipped	0	0	
6.2.4 Dual-Band Throughput Test	2.4Ghz PASS 5Ghz FAIL	45	25.212 m	N 7 / 12 AC 4 / 12
6.2.5 Bidirectional UDP Throughput Test	2.4Ghz FAIL 5Ghz FAIL	50	36.453 m	N 2.4Ghz passed 1 / 3 AC 5Ghz passed 2 / 3
6.2.6 Latency Test	Skipped	0	0	
6.2.7 Quality of Service Test	Skipped	0	0	
6.3.1 Range Versus Rate Test	2.4Ghz FAIL 5Ghz FAIL	38	2.127 h	N 2.4Ghz UL 5 / 17 DL 3 / 17 AC 5Ghz UL 9 / 14 DL 6 / 14
6.3.2 Spatial Consistency Test	2.4Ghz PASS 5Ghz PASS	0	58.054 m	Internal ERROR: Rotation table failed to rotate. N 2.4Ghz passed 0 / 0 AC 5Ghz passed 0 / 0 AX 2.4Ghz passed 0 / 0 AX 5Ghz passed 0 / 0 AX 6Ghz-160 passed 0 / 0
6.3.3 AX Peak Performance TCP Throughput Test	Skipped	0	0	
6.4.1 Multiple STAs Performance Test	2.4Ghz FAIL 5Ghz FAIL	33	29.817 m	N 2.4Ghz Passed 4 / 6 AC 5Ghz Passed 0 / 6
6.4.2 Multiple Association / Disassociation Stability Test	2.4Ghz FAIL 5Ghz PASS	96	4.755 m	N 2.4Ghz Passed 15 / 16 AC 5Ghz Passed 16 / 16
6.4.3 Downlink MU-MIMO Performance Test	Skipped	0	0	
6.5.2 AP Coexistence Test	2.4Ghz FAIL 5Ghz FAIL	156	36.986 m	Passed 6 / 8 NOTE: Auto-Calibrated Interferer transmit rates: 5G-80Mhz-AC: 133.33 Mbps 5G-40Mhz-AC: 54.39 Mbps 2.4Ghz-20Mhz N: 23.40 Mbps
6.5.3 Automatic Channel Selection	Skipped	0	0	
8.1.1 Mesh Backhaul RvR	Skipped	0	0	
8.1.2 Mesh Backhaul Node-2 RvR	Skipped	0	0	
8.2.1 Mesh Roam Time	Skipped	0	0	



N 2.4Ghz Throughput (goodput) for each station.

CSV Data for 2.4Ghz Throughput

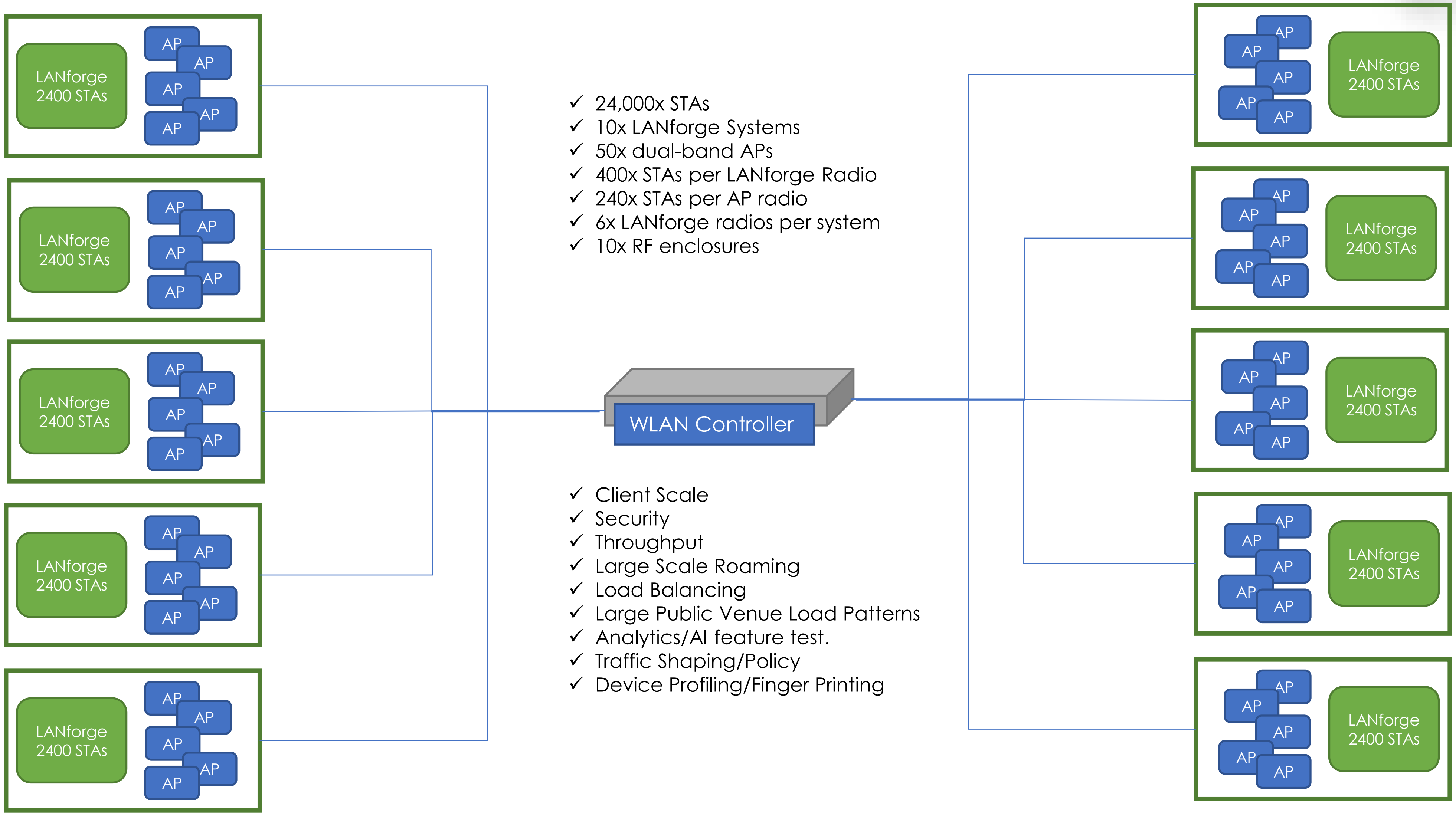


Max-Cx-Test: Snapshot N 2.4Ghz Download

Port	Tx-Bps 1m	Rx-Bps 1m	Tx-Fail %	Tx Link-Rate	Rx Link-Rate	Mode	Channel	Last CX-Time (ms)	RSSI (dBm)	AP	IP	MAC
1.1.10 sta01000	25 bps	2.195 Mbps	3.571	144.4 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	246	-26	78:97:41:DE:17:F9	192.168.29.188	00:0a:52:06:1a:2e
1.1.11 sta01001	25 bps	2.189 Mbps	7.143	117 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	256	-26	78:97:41:DE:17:F9	192.168.29.181	00:0a:52:06:06:2e
1.1.12 sta01002	25 bps	2.191 Mbps	10	144.4 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	311	-26	78:97:41:DE:17:F9	192.168.29.98	00:0a:52:06:3a:2e
1.1.13 sta01003	35 bps	2.203 Mbps	3.571	117 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	263	-26	78:97:41:DE:17:F9	192.168.29.32	00:0a:52:06:0e:2e
1.1.14 sta01004	35 bps	2.2 Mbps	15.625	144.4 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	252	-26	78:97:41:DE:17:F9	192.168.29.116	00:0a:52:06:01:2e
1.1.15 sta01005	35 bps	2.196 Mbps	4	130 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	279	-26	78:97:41:DE:17:F9	192.168.29.240	00:0a:52:06:1e:2e
1.1.18 sta01006	35 bps	2.194 Mbps	13.333	130 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	259	-26	78:97:41:DE:17:F9	192.168.29.59	00:0a:52:06:37:2e
1.1.19 sta01007	35 bps	2.203 Mbps	13.333	117 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	290	-26	78:97:41:DE:17:F9	192.168.29.33	00:0a:52:06:35:2e
1.1.20 sta01008	35 bps	2.2 Mbps	6.897	130 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	257	-26	78:97:41:DE:17:F9	192.168.29.78	00:0a:52:06:25:2e
1.1.21 sta01009	31 bps	2.19 Mbps	6.897	115.6 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	251	-26	78:97:41:DE:17:F9	192.168.29.201	00:0a:52:06:1b:2e
1.1.22 sta01010	31 bps	2.193 Mbps	3.571	144.4 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	271	-26	78:97:41:DE:17:F9	192.168.29.97	00:0a:52:06:13:2e
1.1.23 sta01011	39 bps	2.193 Mbps	6.897	130 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	260	-26	78:97:41:DE:17:F9	192.168.29.195	00:0a:52:06:2e:2e
1.1.24 sta01012	35 bps	2.192 Mbps	10.714	130 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	258	-26	78:97:41:DE:17:F9	192.168.29.7	00:0a:52:06:33:2e
1.1.25 sta01013	31 bps	2.198 Mbps	8	130 Mbps	144.4 Mbps	802.11bgn 20 2x2	2,437	195	-26	78:97:41:DE:17:F9	192.168.29.13	00:0a:52:06:20:2e

Controller Testing

WLAN Controller Testing – 24,000 11n STAs



- ✓ 24,000x STAs
- ✓ 10x LANforge Systems
- ✓ 50x dual-band APs
- ✓ 400x STAs per LANforge Radio
- ✓ 240x STAs per AP radio
- ✓ 6x LANforge radios per system
- ✓ 10x RF enclosures

- ✓ Client Scale
- ✓ Security
- ✓ Throughput
- ✓ Large Scale Roaming
- ✓ Load Balancing
- ✓ Large Public Venue Load Patterns
- ✓ Analytics/AI feature test.
- ✓ Traffic Shaping/Policy
- ✓ Device Profiling/Finger Printing

Control | Repeatability | Coverage | Automation | Scale | Expert Analysis | Executive Reports

Testing Stations (IoT Devices)

IoT DEVICE TEST REQUIREMENTS

Home

- ✓ HD Video Quality
- ✓ Tolerance to Interference
- ✓ Interoperability
- ✓ Crowded environment
- ✓ Client Connectivity
- ✓ Latency for Gaming
- ✓ Range & Roaming
- ✓ Security
- ✓ Mesh performance
- ✓ Battery Life
- ✓ Automation/Test Coverage

Healthcare

- ✓ Connection Reliability
- ✓ Mobility Performance
- ✓ QoS and consistent throughput
- ✓ Security
- ✓ Coexistence on hospital Wi-Fi networks
- ✓ Location Services
- ✓ Proper Device/Network Management
- ✓ Proof of Concept
- ✓ Vendor Selection
- ✓ Test Services/Consulting

Retail/Industrial

- ✓ Zero Downtime
- ✓ Range Performance
- ✓ Application throughput
- ✓ Low Latency
- ✓ Security
- ✓ Location Services
- ✓ Cellular and Wi-Fi Handover /Co-existence
- ✓ Proof of Concept /Vendor Selection
- ✓ Test Services/Consulting

Transportation

- ✓ Passenger Experience
- ✓ Zero Downtime
- ✓ Range Performance
- ✓ Video Performance
- ✓ Low Latency
- ✓ Security
- ✓ Location Services
- ✓ Cellular and Wi-Fi Handover /Co-existence
- ✓ Proof of Concept /Vendor Selection
- ✓ Test Services/Consulting

Module Vendors

- ✓ Radio Performance
- ✓ Protocol Compliance
- ✓ De-Sense Testing
- ✓ Manufacturing Test
- ✓ MAC Performance/ Throughput
- ✓ DFS testing
- ✓ Application Performance
- ✓ Roaming & Range
- ✓ Battery Life
- ✓ Security
- ✓ Automation/Test Coverage

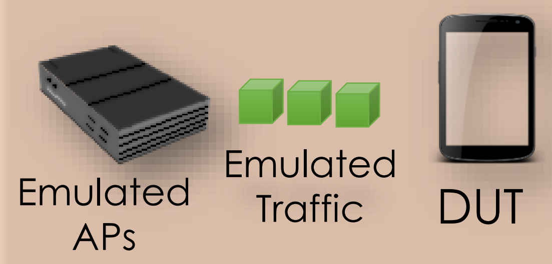
Service Providers

- ✓ Vendor Selection
- ✓ Proof of Concept
- ✓ Mesh Performance
- ✓ Video Performance
- ✓ Throughput
- ✓ Cellular and Wi-Fi Co-existence
- ✓ DFS testing
- ✓ Application Performance
- ✓ Roaming / Range
- ✓ Battery Life
- ✓ Security
- ✓ Automation

Medical Device Testing Scenario

SUPPORTED OPTIONS

Candela TECHNOLOGIES



Emulated APs / Emulated Traffic

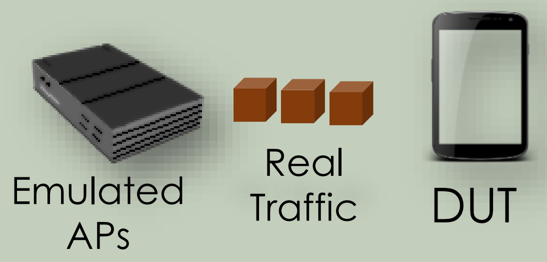
- Provides the most automated, repeatable, configurable and comprehensive test coverage.
- Ideal for early stage dev/QA, benchmarking and comparative testing

BENCHMARKING

Real APs / Emulated Traffic

- For interoperability testing with a known good golden AP from a partner.
- Still provides a high degree of test coverage and automation.
- Ideal for pre-deployment testing

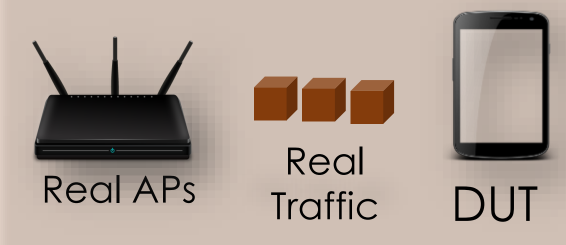
INTEROPERABILITY



Emulated APs / Real Traffic

- Testing scenarios where emulated traffic cannot represent real-traffic.
- Can provide medium level of control but a higher level of realism
- Ideal for testing application specific devices

APP PERFORMANCE



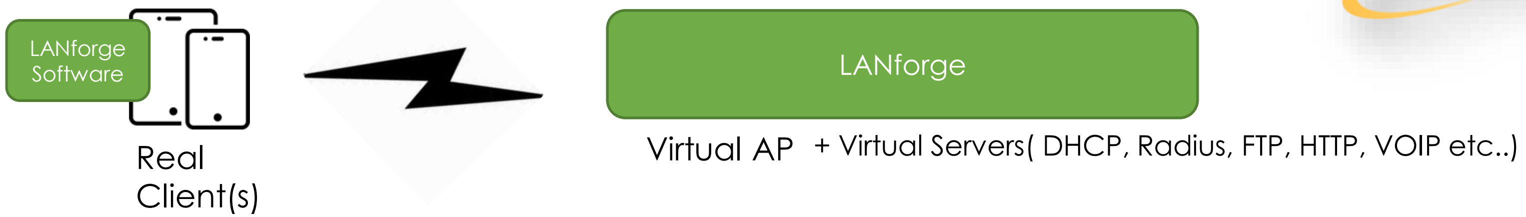
Real APs / Real Traffic

- The most realistic way of testing
- Provides the least amount of control, automation and repeatability.
- Ideal for pre-deployment testing of application specific devices operating on vendor specific networks

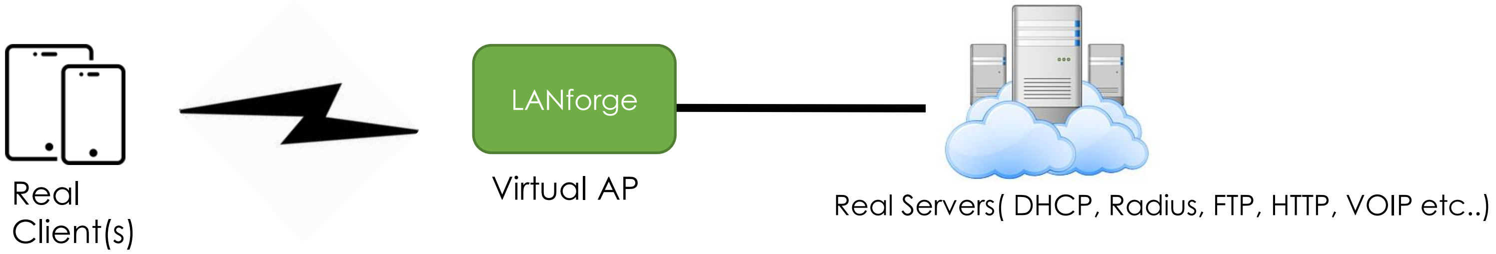
END USER EXPERIENCE

Some Test Topologies

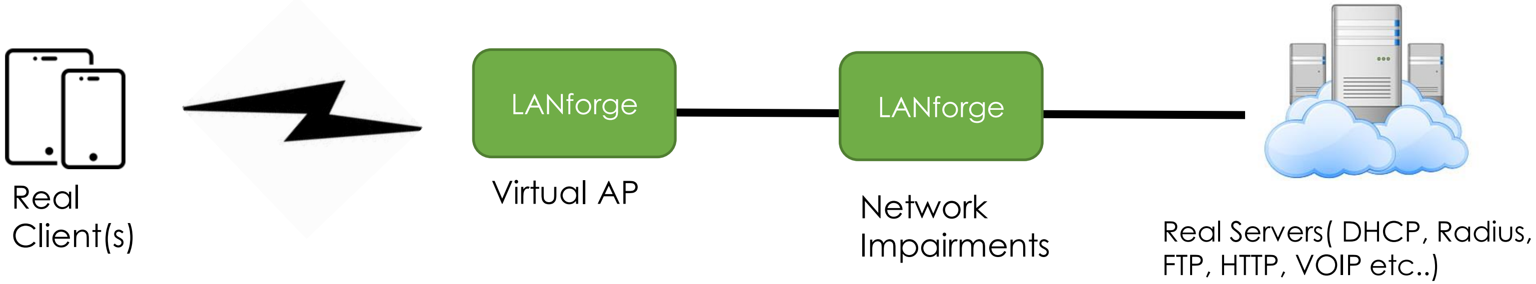
Testing real client (DUT) with LANforge acting as the AP, traffic generator and all the network servers behind the AP. Use iPerf or LANforge endpoint software on the DUT.



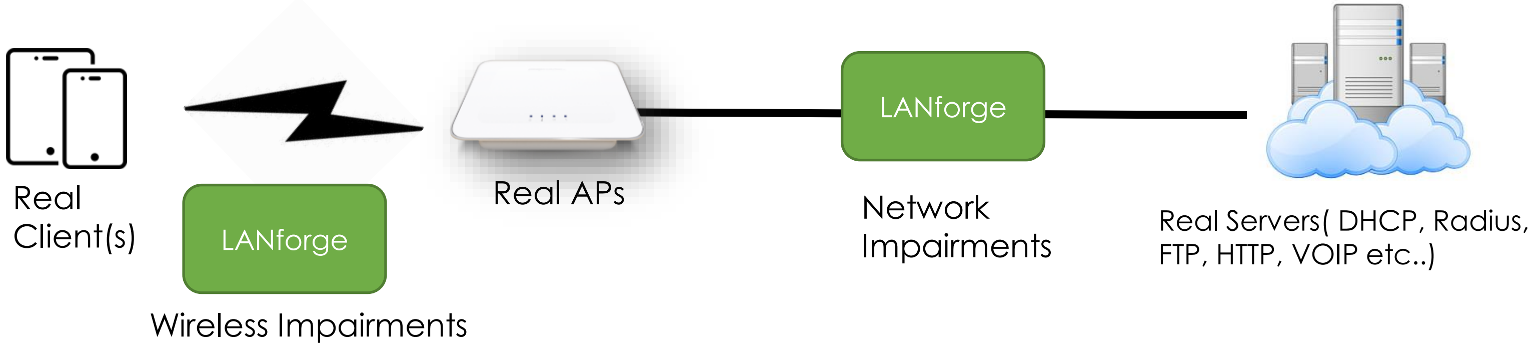
Testing real client (DUT) with LANforge acting as the AP, but connecting to real network servers. The traffic between DUT and servers can be real application traffic and LANforge will automate creation of may different types of emulated APs an test scenarios



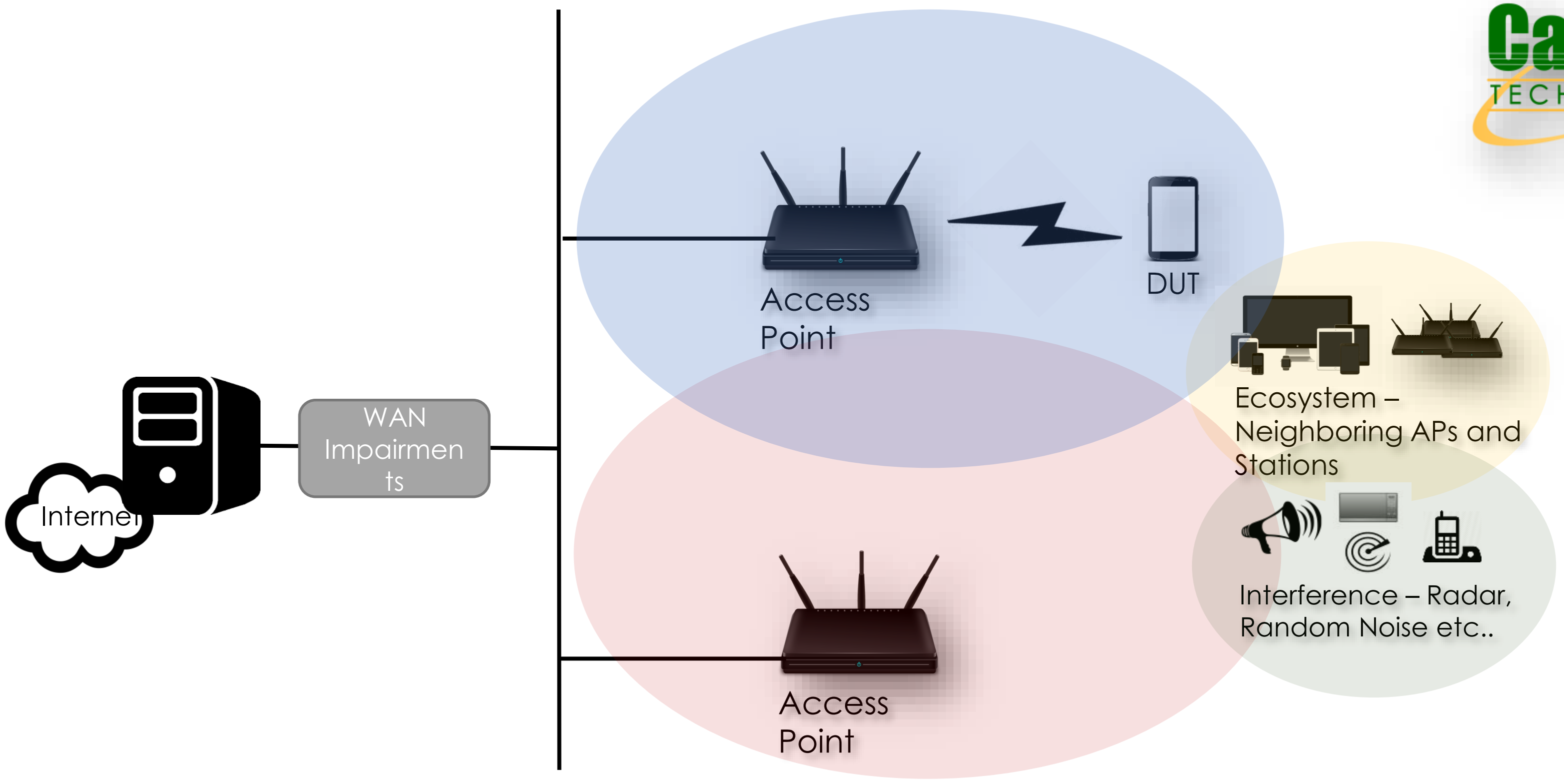
Same scenario as above, but in this case LANforge can also add various network impairments on the wired network between the virtual APs and the real network servers to test the effects of various network conditions on applications.



Testing real client (DUT) connected to real APs and real network servers. LANforge can create various wireless impairments (like co-channel/adjacent channel interference, emulated distance, noise, roaming et..) and also various impairments on the wired network (loss, jitter, packets errors etc..) and test effects on application traffic.



TESTING STATIONS



MOST DETERMINISTIC

- ✓ RF Performance
- ✓ General Connectivity
- ✓ MAC Throughput
- ✓ Security
- ✓ QoS
- ✓ Battery Life
- ✓ MU-MIMO
- ✓ Antenna Orientation

Step1 : Benchmarking

+

- ✓ Range
- ✓ Rate Scaling
- ✓ Roaming
- ✓ BSS Transition
- ✓ Neighbor APs
- ✓ Off Channel Scanning

Step2 : Mobility

+

- ✓ Performance in the presence of co-channel/ adjacent channel interference
- ✓ Air time Fairness
- ✓ Medium Utilization
- ✓ QoS

Step3 : Ecosystem

+

- ✓ Performance in the presence of RF Interference
- ✓ Radar compliance
- ✓ Performance with WAN impairments
- ✓ Rouge APs

Step4 : Impairment

+

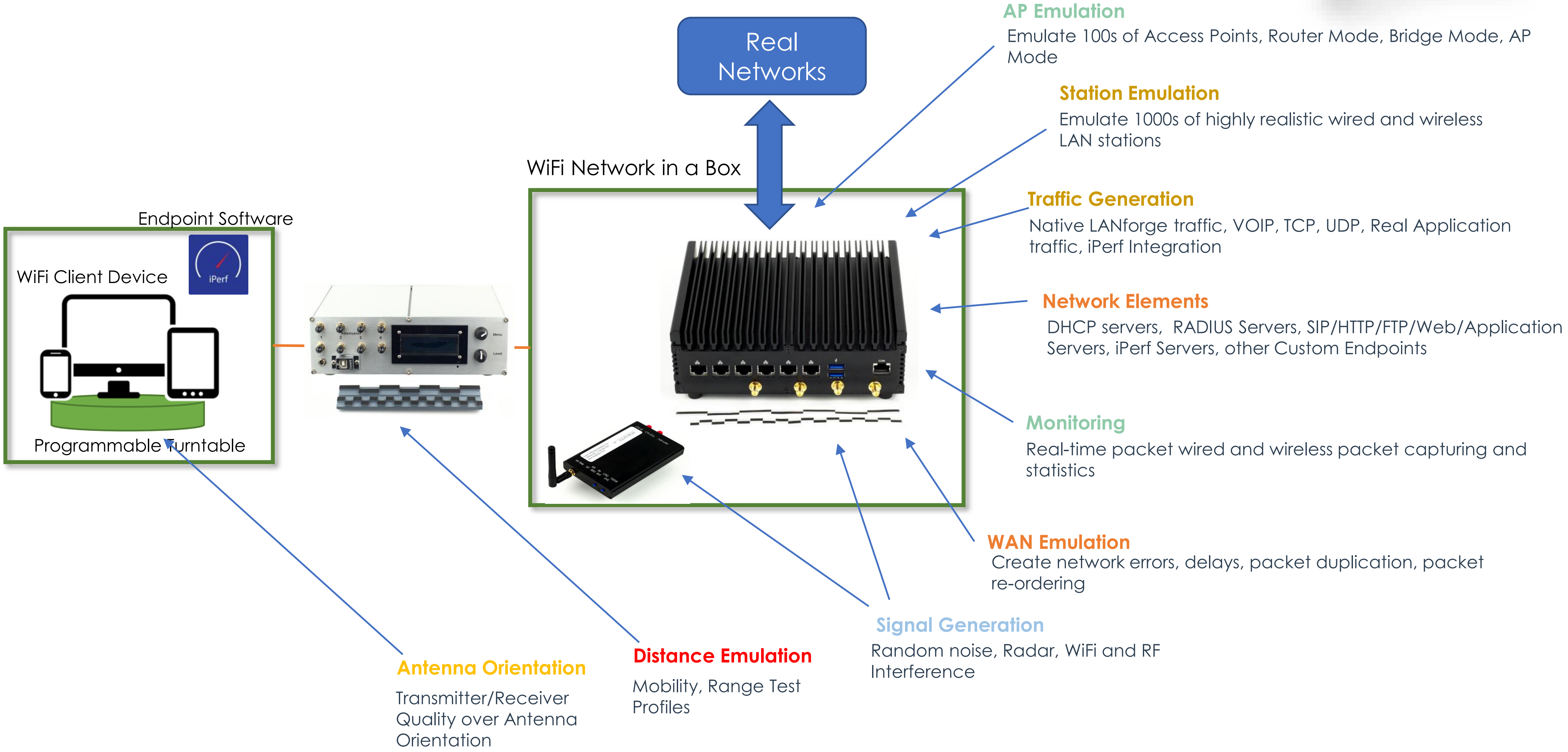
- ✓ HD video streaming
- ✓ FTP download
- ✓ VOIP Quality
- ✓ Real Application traffic performance for Application Specific Devices

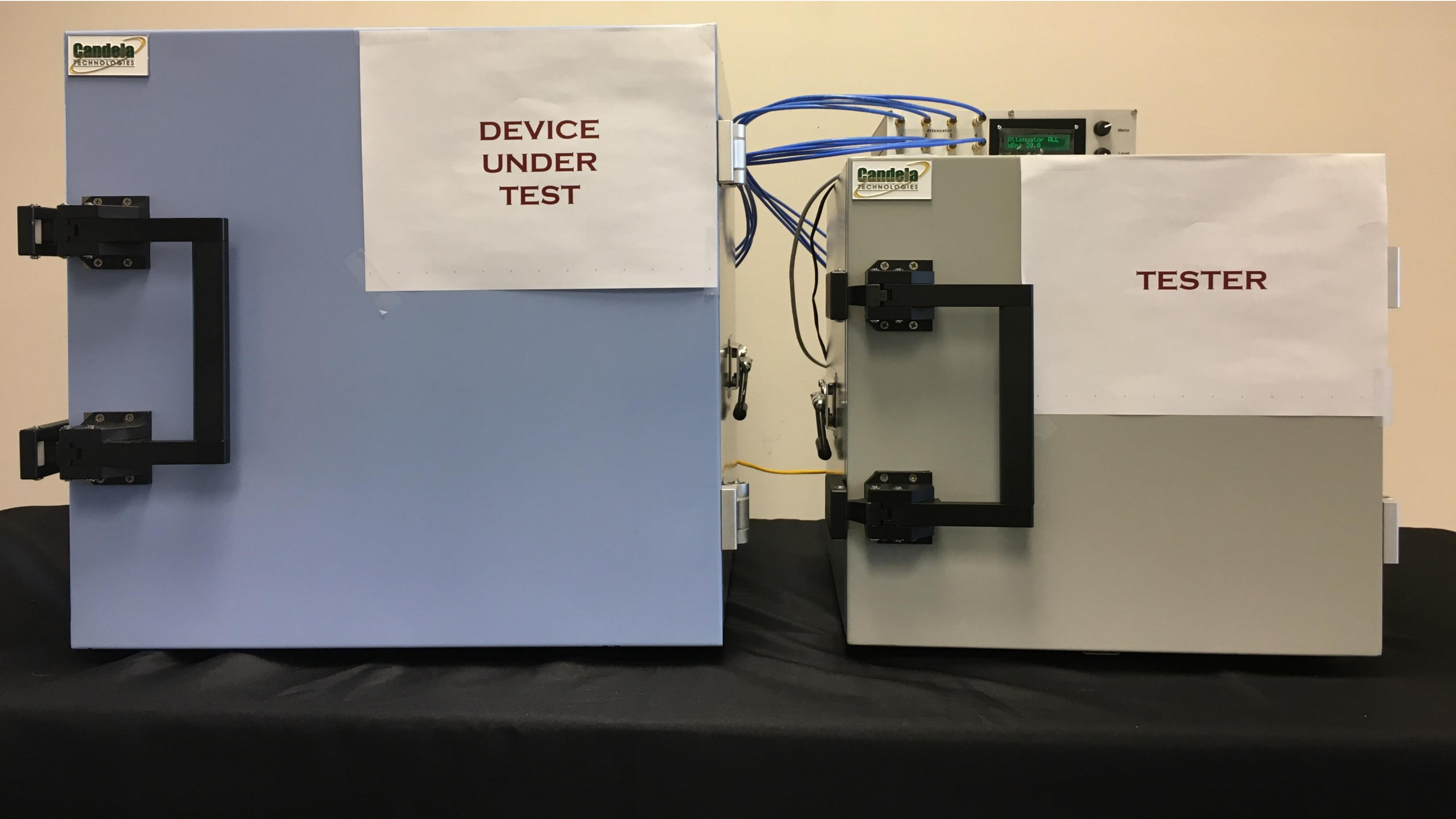
Step5 : Real Applications

MOST REALISTIC

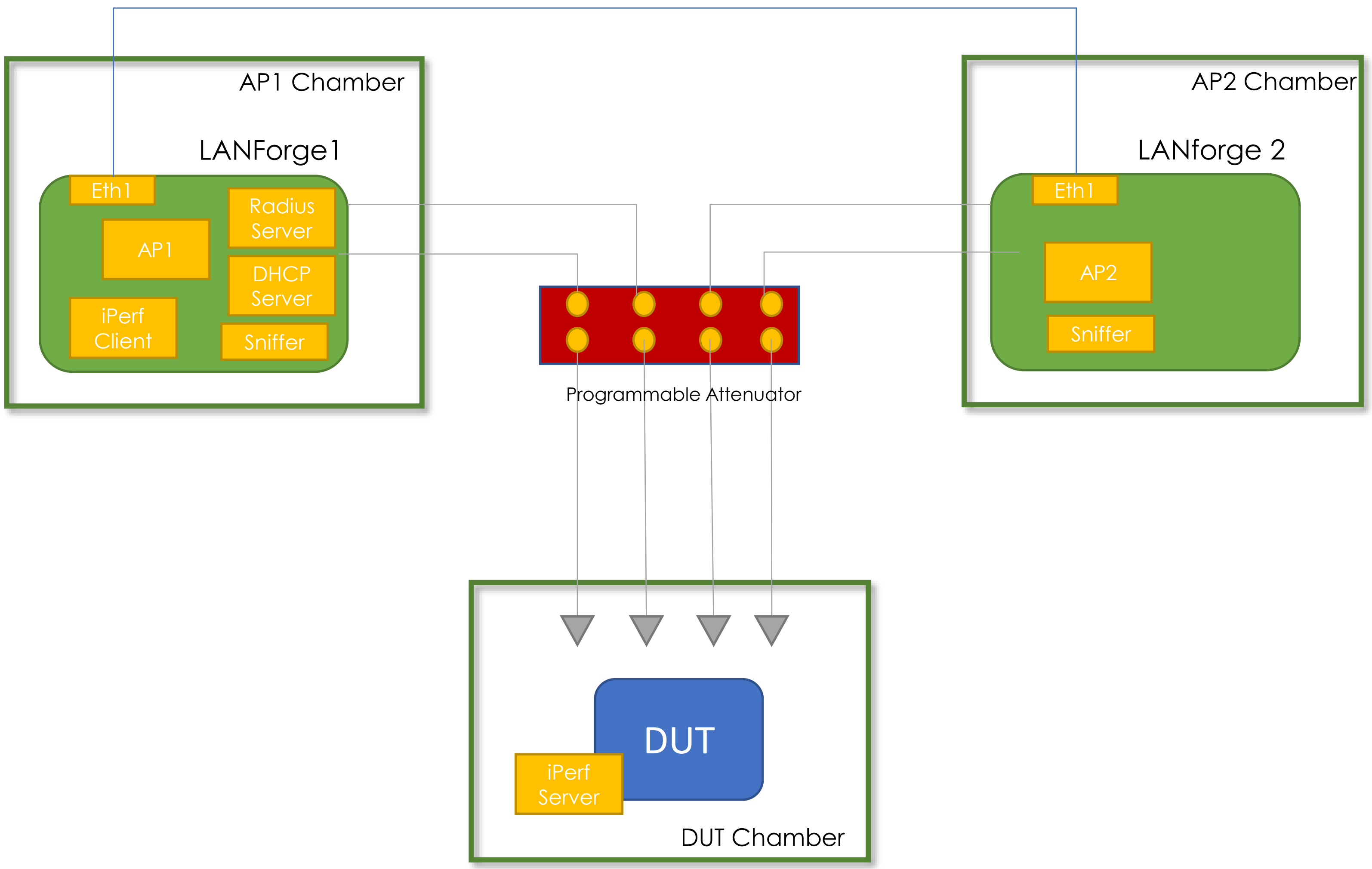
Control › Repeatability › Coverage › Automation › Scale › Expert Analysis › Executive Reports

LANforge WiFi Network Emulation

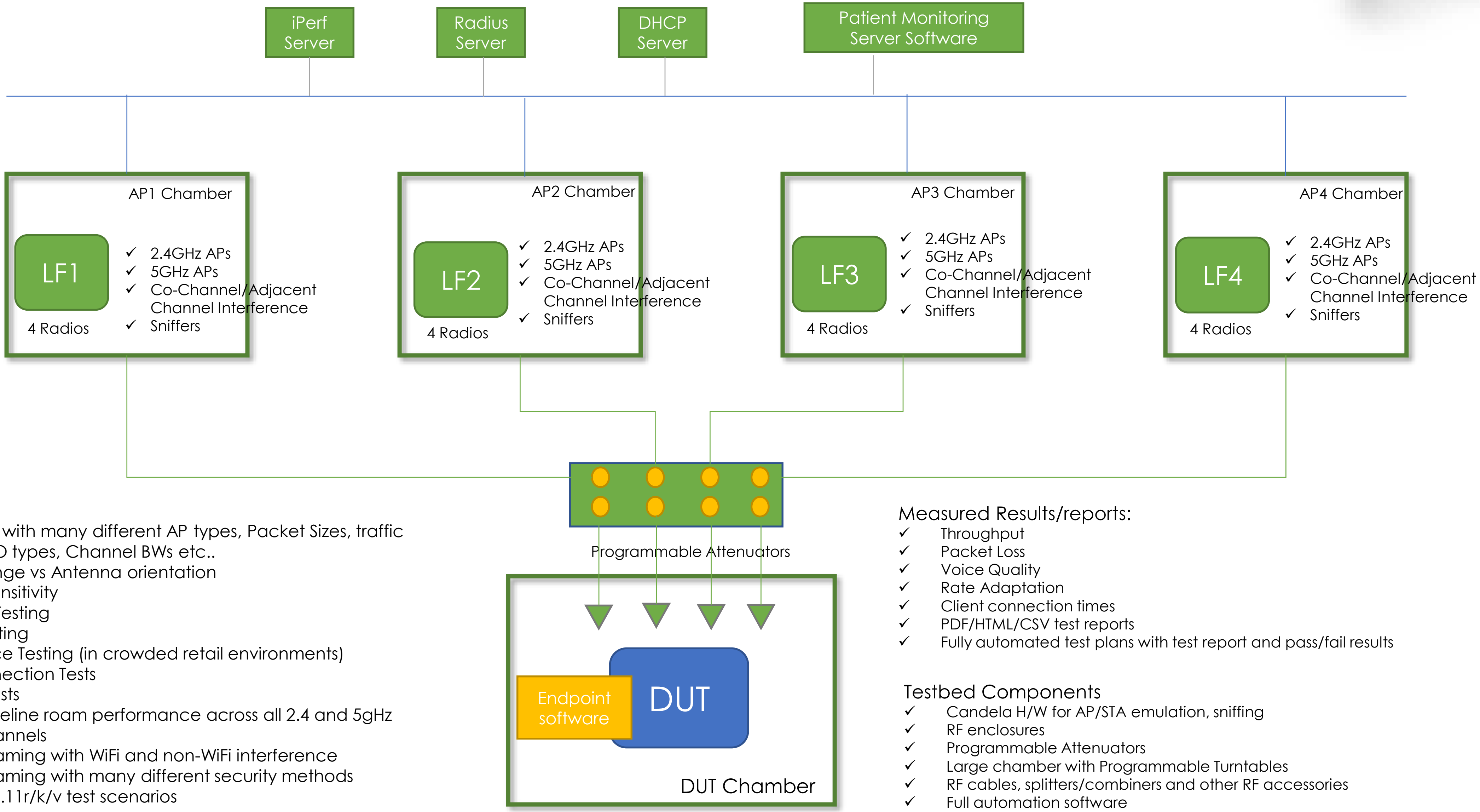



Candela
TECHNOLOGIES
DEVICE
UNDER
TEST
Candela
TECHNOLOGIES
TESTER

Simple Client Roaming Test Setup



Candela WiFi Client Testbed



Tests:

- ✓ Throughput with many different AP types, Packet Sizes, traffic types, MIMO types, Channel BWs etc..
- ✓ Rate Vs Range vs Antenna orientation
- ✓ Receiver Sensitivity
- ✓ Functional Testing
- ✓ Security Testing
- ✓ Co-existence Testing (in crowded retail environments)
- ✓ Client Connection Tests
- ✓ Roaming Tests
  - ✓ Baseline roam performance across all 2.4 and 5gHz channels
  - ✓ Roaming with WiFi and non-WiFi interference
  - ✓ Roaming with many different security methods
  - ✓ 802.11r/k/v test scenarios
- ✓ DFS Testing

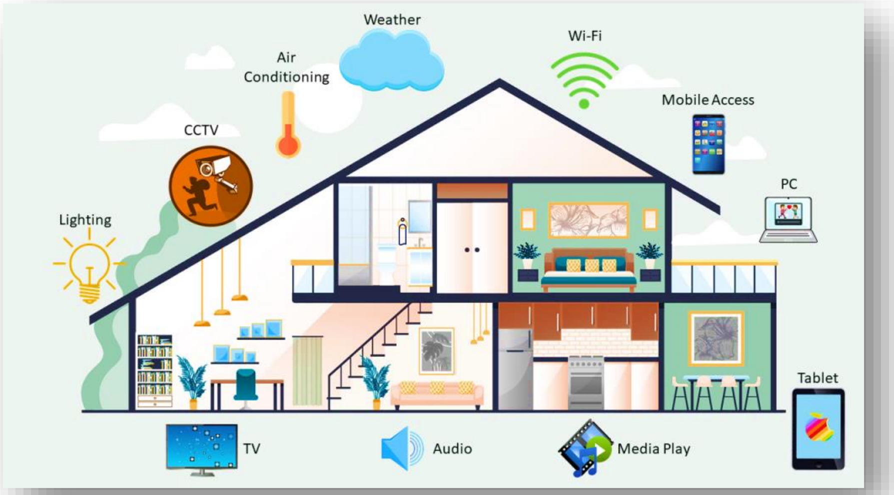
Measured Results/reports:

- ✓ Throughput
- ✓ Packet Loss
- ✓ Voice Quality
- ✓ Rate Adaptation
- ✓ Client connection times
- ✓ PDF/HTML/CSV test reports
- ✓ Fully automated test plans with test report and pass/fail results

Testbed Components

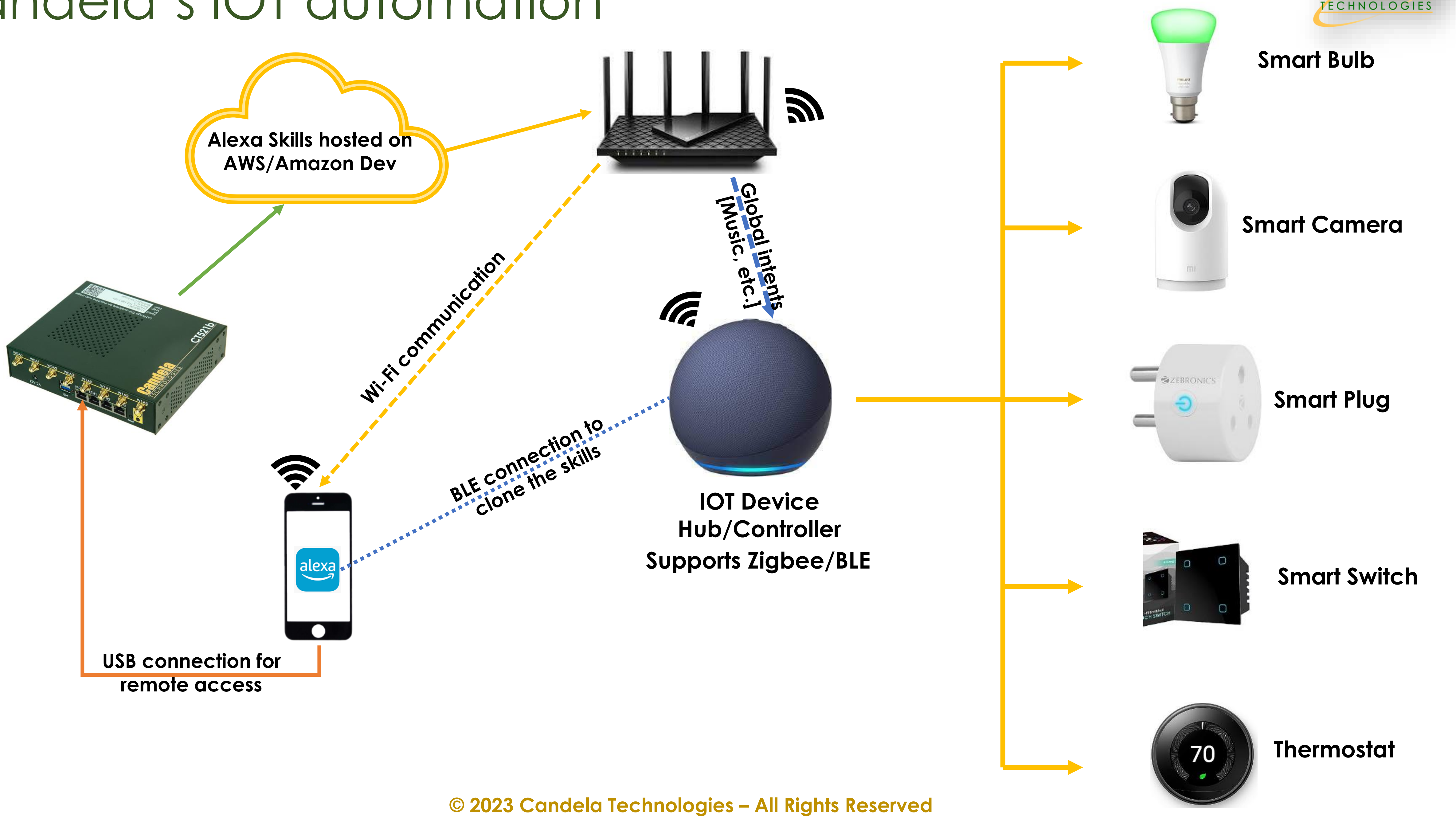
- ✓ Candela H/W for AP/STA emulation, sniffing
- ✓ RF enclosures
- ✓ Programmable Attenuators
- ✓ Large chamber with Programmable Turntables
- ✓ RF cables, splitters/combiners and other RF accessories
- ✓ Full automation software
- ✓ Radius/VOIP/DHCP/iperf/Application Servers created on Candela H/W

Candela's IOT automation

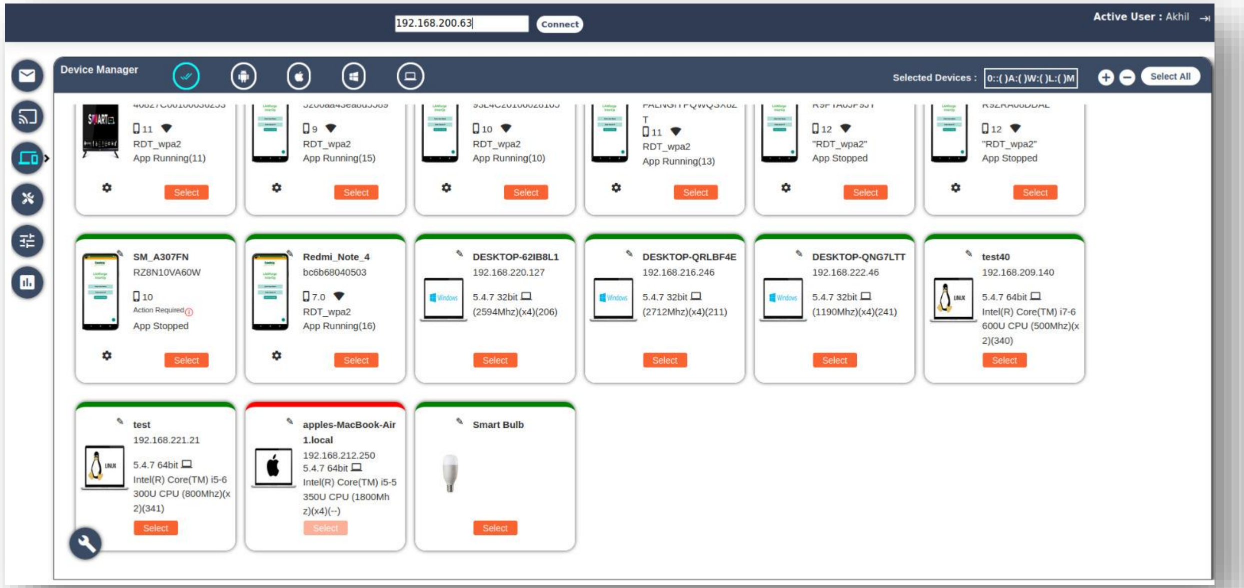


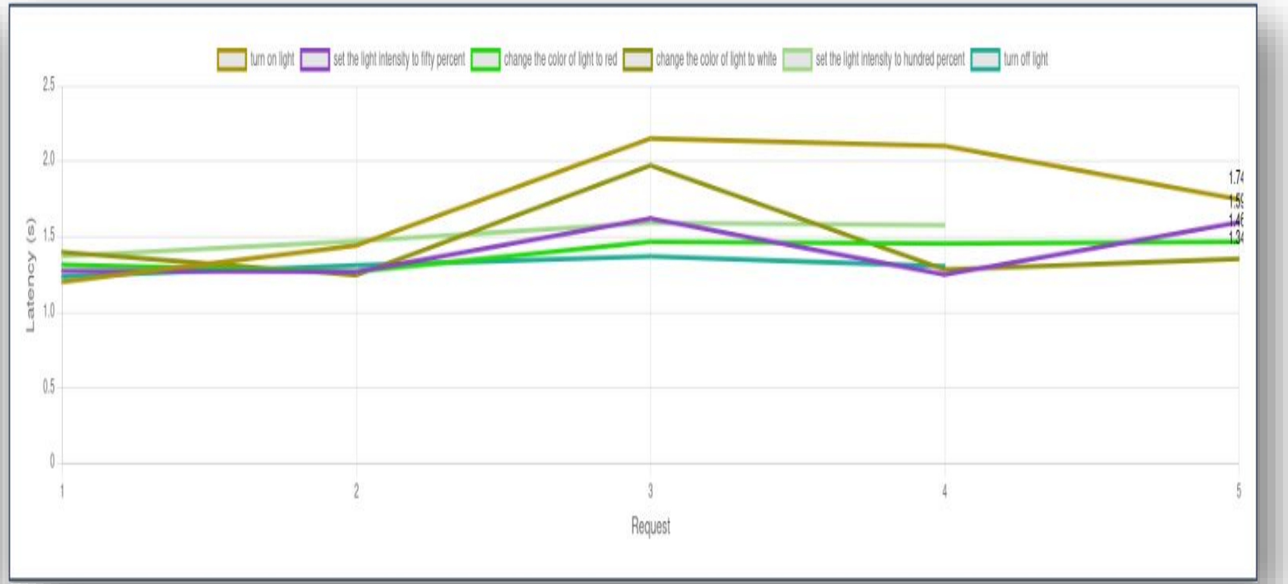
- We have automated various IOT controllers like Alexa, Google nest such that with a single click we would be able to give actions for various devices which are present in an ideal home.
- Using this automation, we can try to validate the latency of the IOT devices which have got invocations from the IOT controller through the Access Point.
- We report the performance of the bulb in long durations with repetitive change in the actions that triggered like change in brightness, changing the color, etc..
- Using our Web-UI you can have the test triggered with a less manual intervention.
- A detailed test report is generated after the test is completed with various kinds of information like API's initiated and delay responses, along with log files such that we can easily narrow down to the problem.

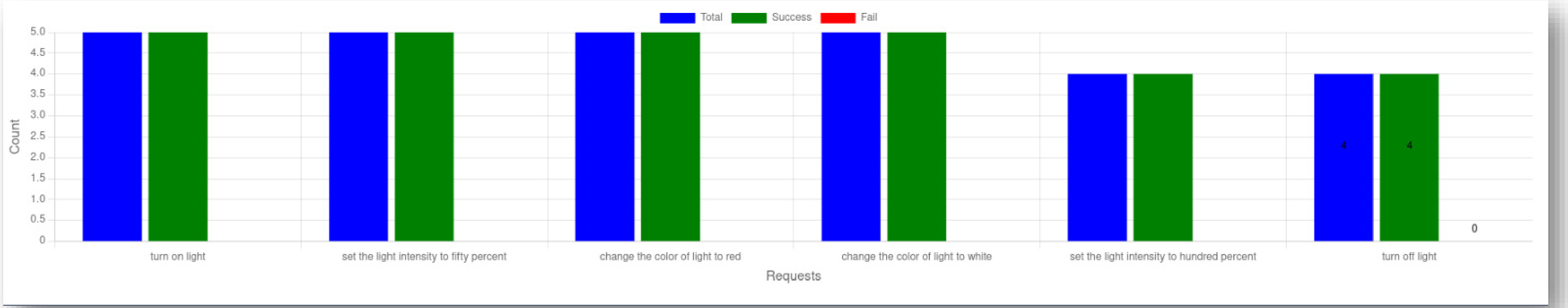
Candela's IOT automation



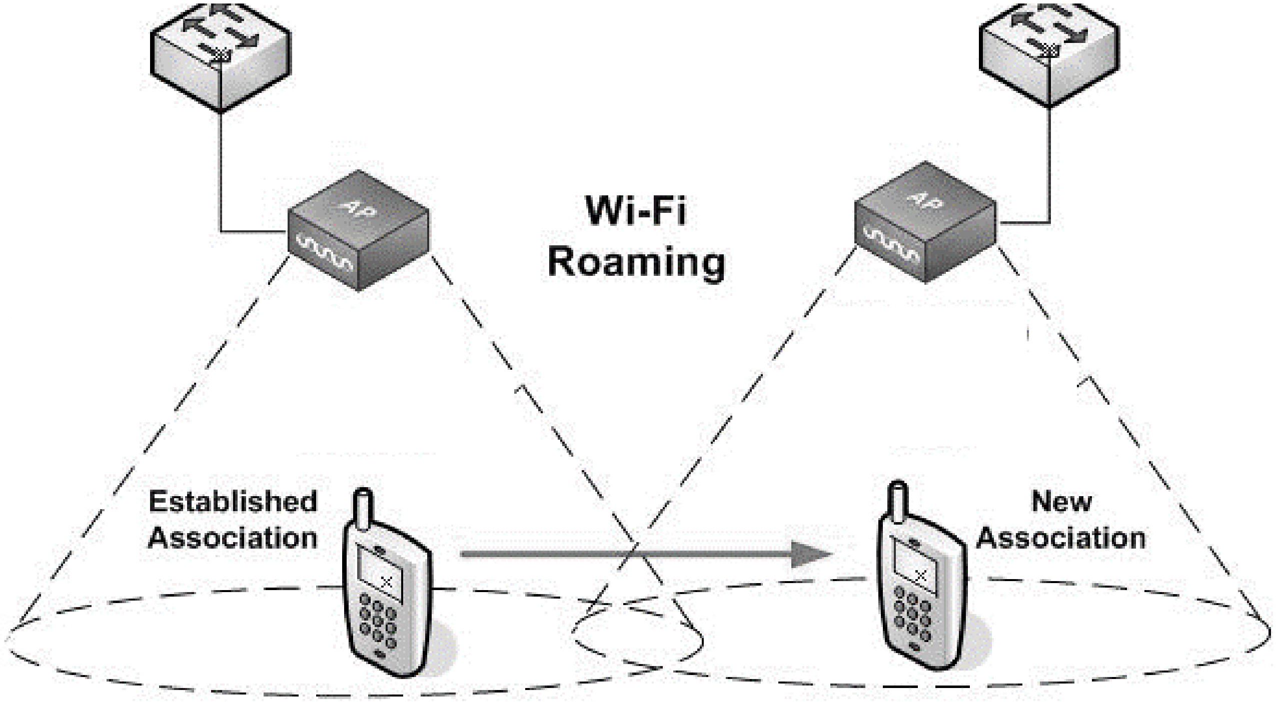
Candela's IOT automation







Roaming Testing



ROAMING PROCESS

Roam Initiation

- Measure RSSI, Packet Loss, Reties etc..
- Off Channel Scanning
- Create Neighbor AP lists
- Opportunistic Key Caching

Roam Decision

- Check if RSSI, Loss, Retry Thresholds are hit.
- Monitor AP assisted handoff commands.
- Look for loss of connectivity/service disruption of any kind

Roam Execution

- Disconnect with old AP.
- Initiate 802.11 connection with new AP.
- 802.1x Authentication Handshakes
- Session Key generation.
- Routing traffic through new AP.

ROAMING TEST METHODS

Walk Tests

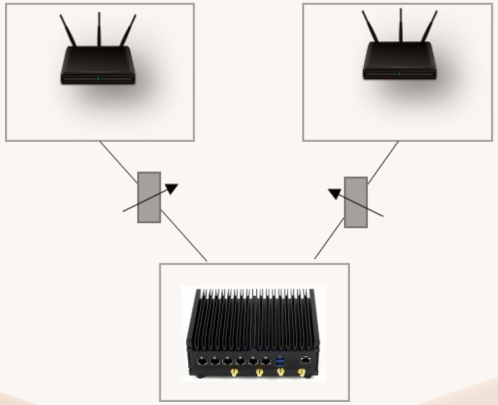
Pros

- ✓ Highly realistic.
- ✓ Can test Interoperability with most popular stations.
- ✓ Can test all three steps of roaming (initiation, decision and execution)

Cons

- ✓ Not Scalable
- ✓ Not Repeatable
- ✓ Not Automatable
- ✓ Extremely time consuming
- ✓ Extremely hard to debug issues

Using Attenuators



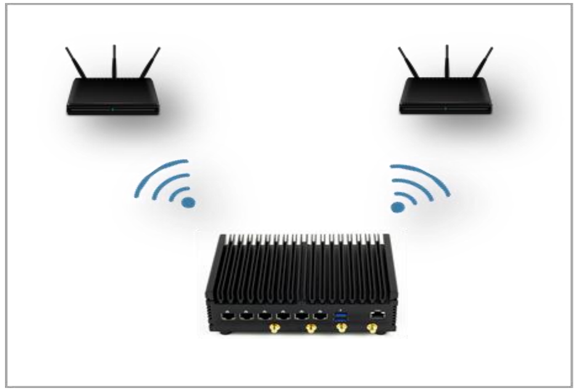
Pros

- ✓ Reapable
- ✓ Automatable.
- ✓ Can test all three steps of roaming (initiation, decision and execution)

Cons

- ✓ Not Scalable
- ✓ Expensive setup
- ✓ Not easy to measure roaming delays and debug issues.
- ✓ Not easy to isolate AP issues from station issues.

Forced Roaming



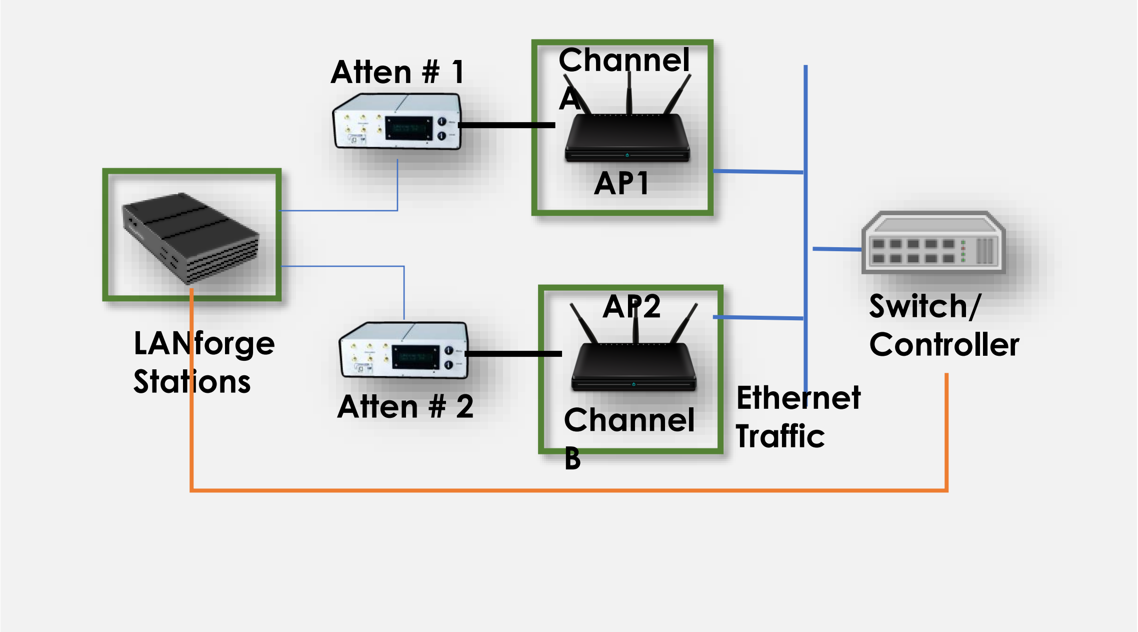
Pros

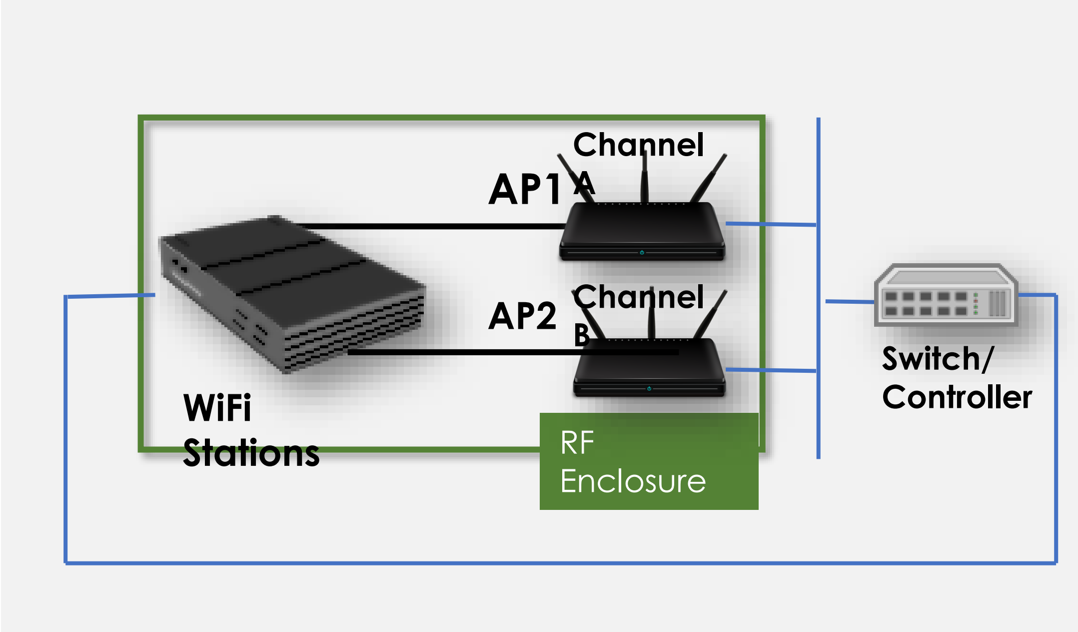
- ✓ Can scale to 1000s of roams for many hours and the only way to find issues related to scale.
- ✓ Can run tests very fast.
- ✓ Fully Automatable, Controllable and Repeatable
- ✓ Cost per roam the lowest

Cons

- ✓ Can only test Roam execution.
- ✓ Cannot test improvements in execution because of steps taking during roam initiation.
- ✓ Not very real-world

TEST SETUP

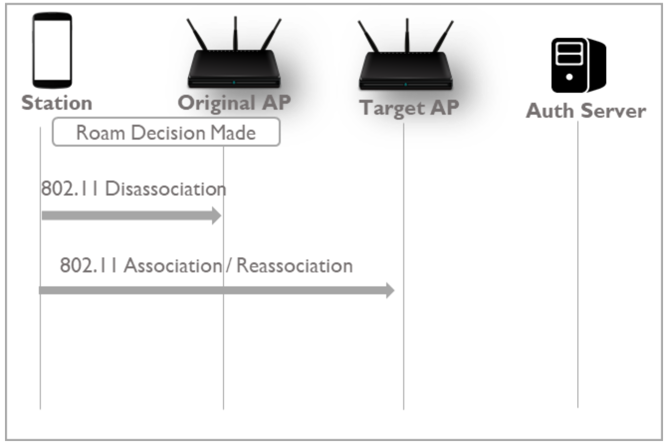




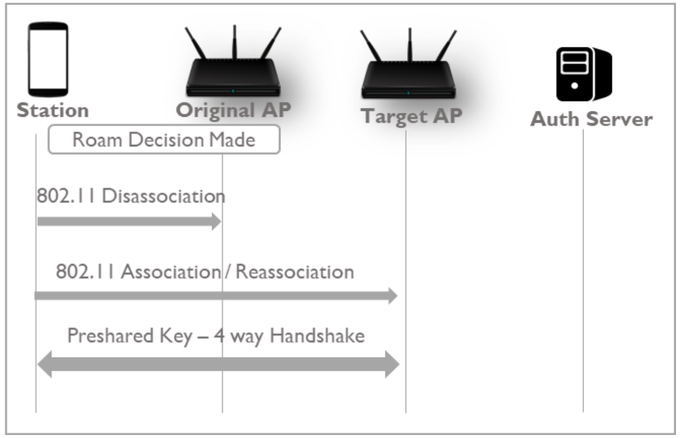
ROAM USING ATTENUATION

FORCED ROAM METHOD

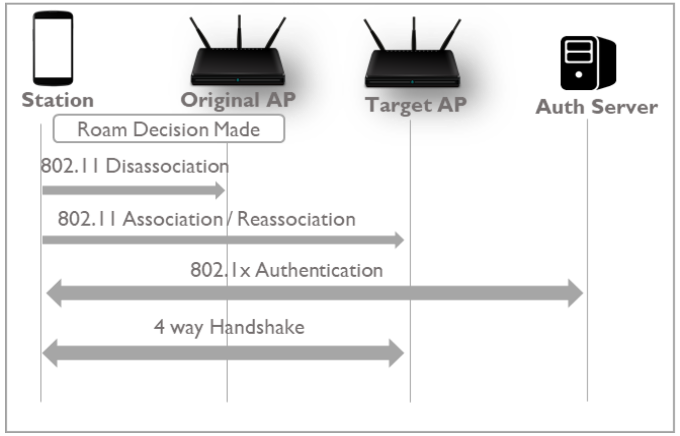
ROAM EXECUTION METHODS



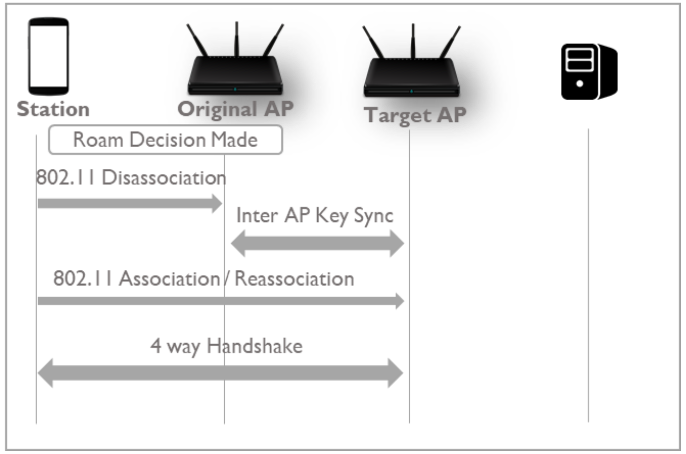
Open Authentication



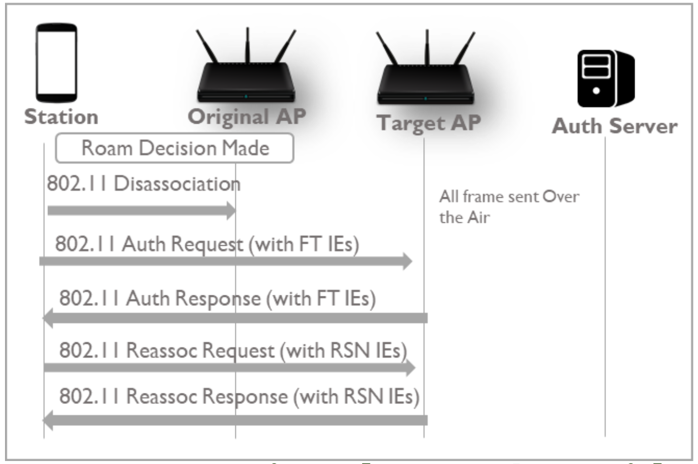
WPA-PSK



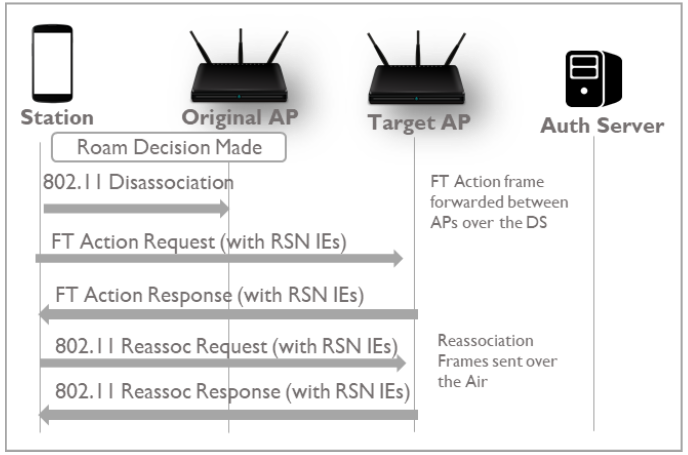
WPA-Enterprise (no Key Caching)



WPA-Ent (with Key Caching)

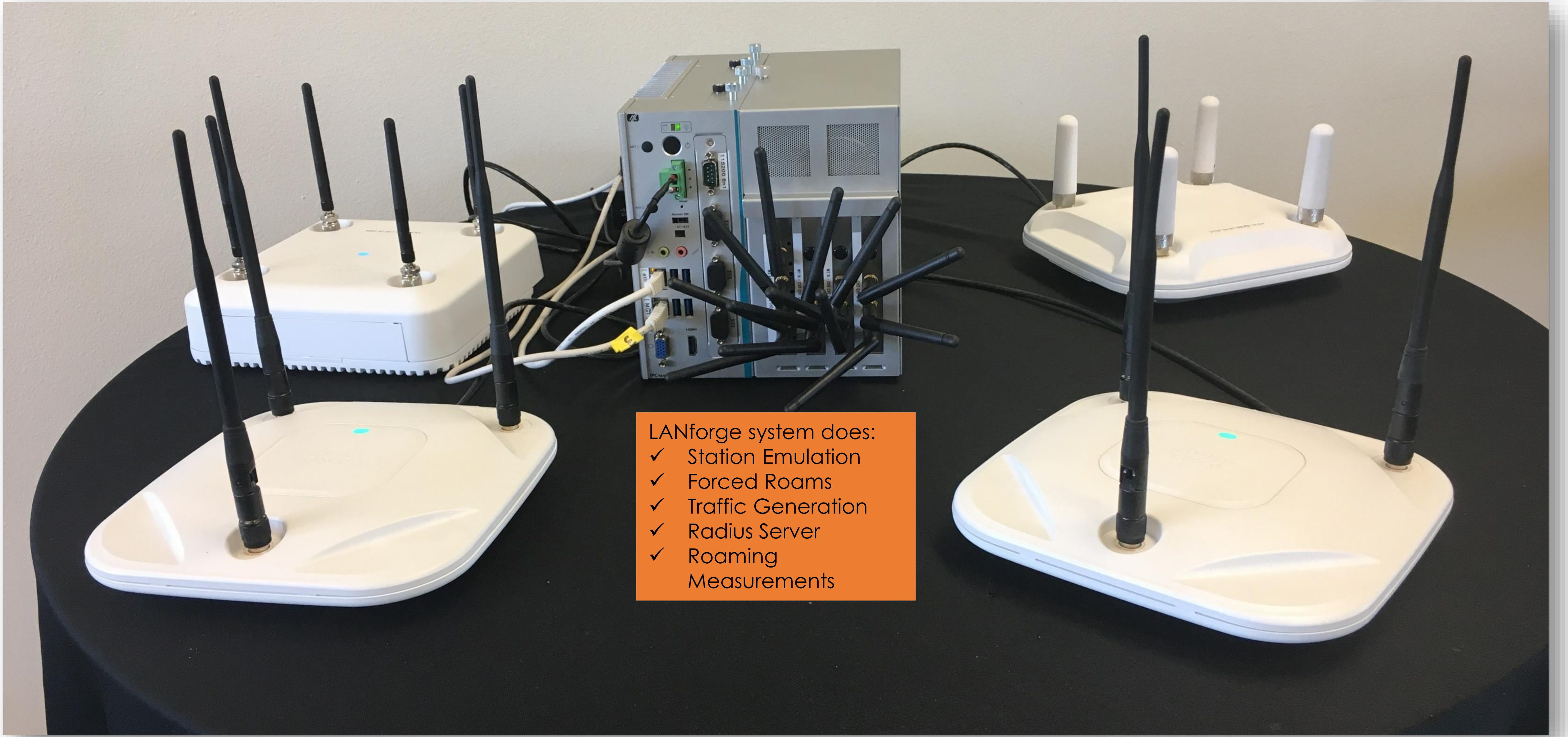


Fast Roaming (over-the-Air)



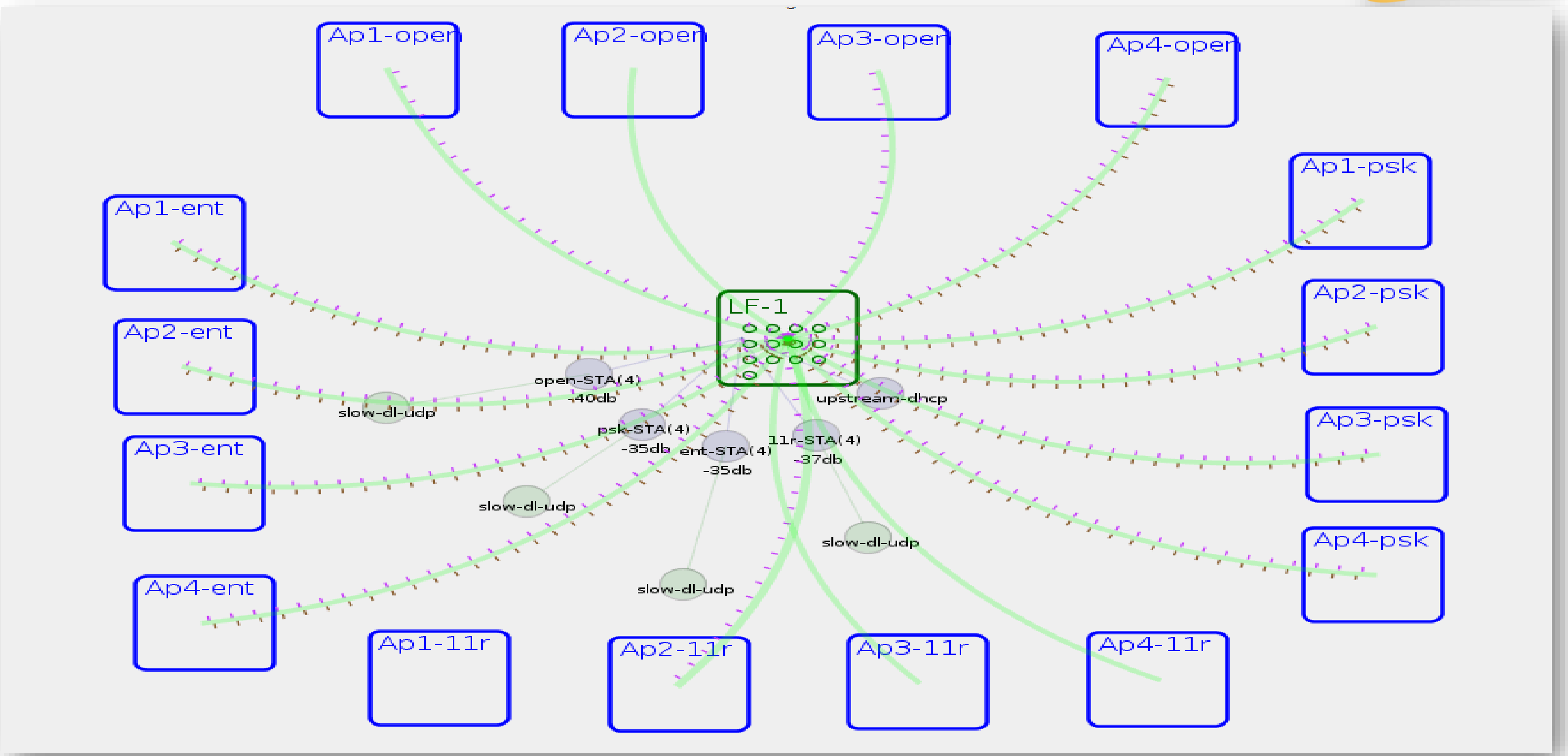
Fast Roaming (over-the-DS)

FORCED ROAM TEST SETUP PICTURE

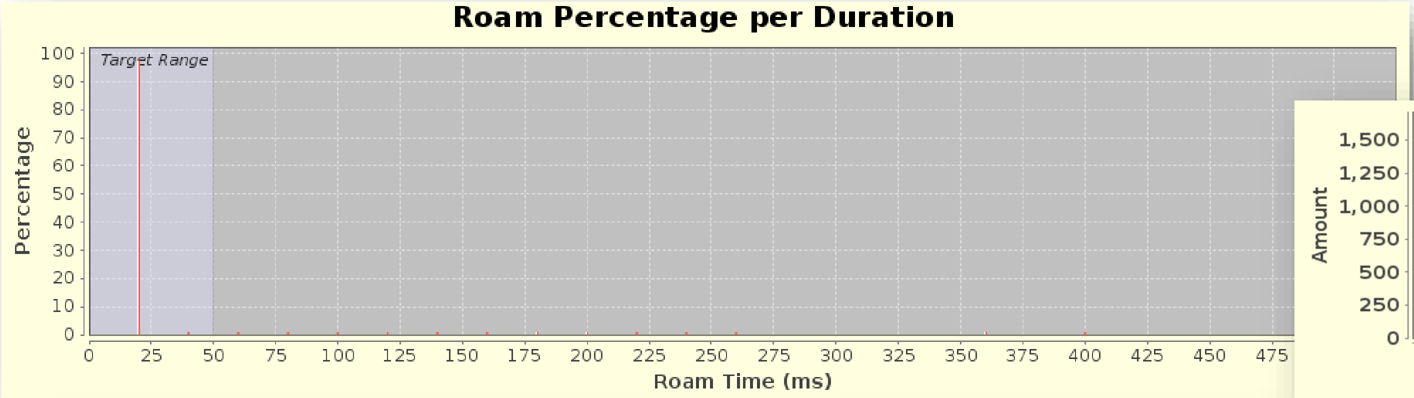


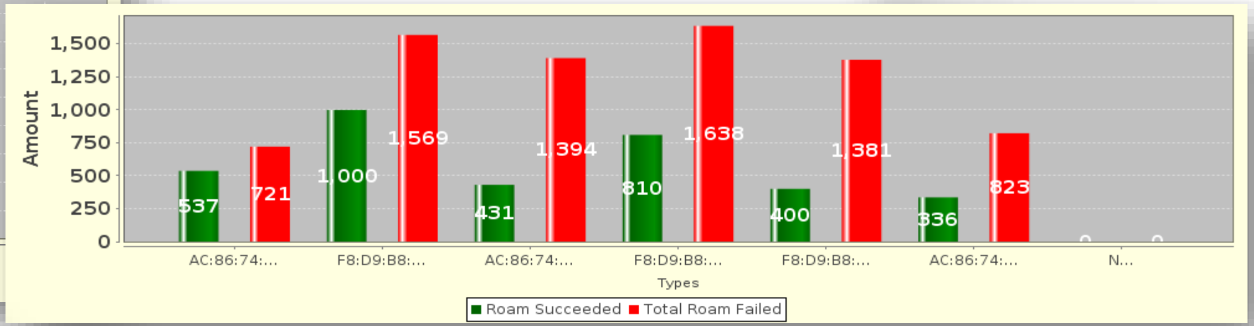
LANforge system does:
- ✓ Station Emulation
- ✓ Forced Roams
- ✓ Traffic Generation
- ✓ Radius Server
- ✓ Roaming Measurements

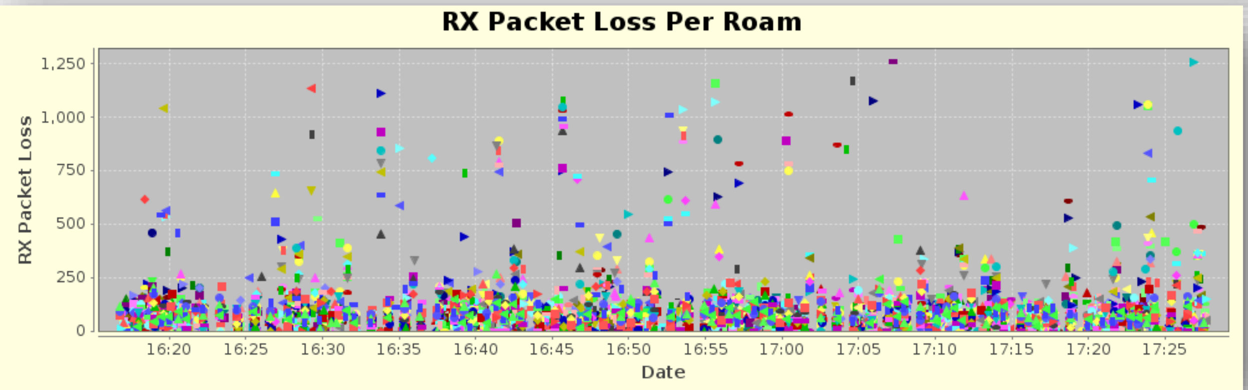
LANforge GUI View

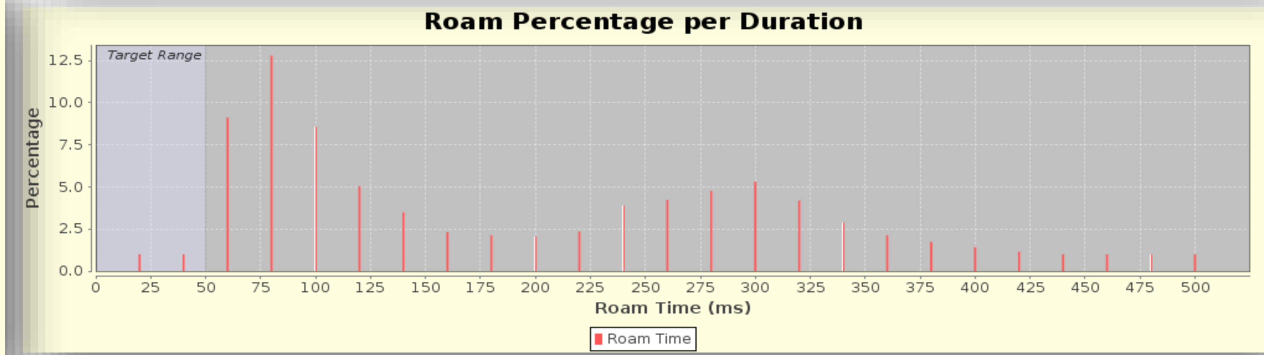


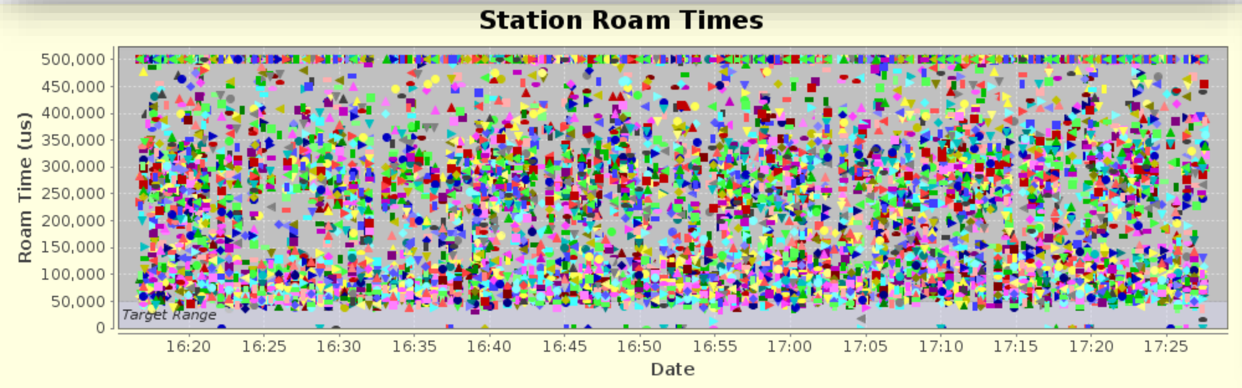
Sample Test Results

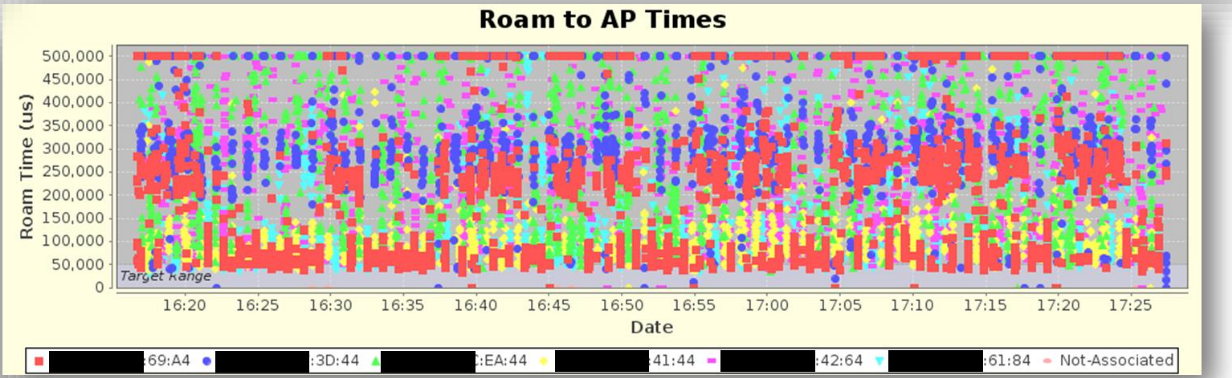




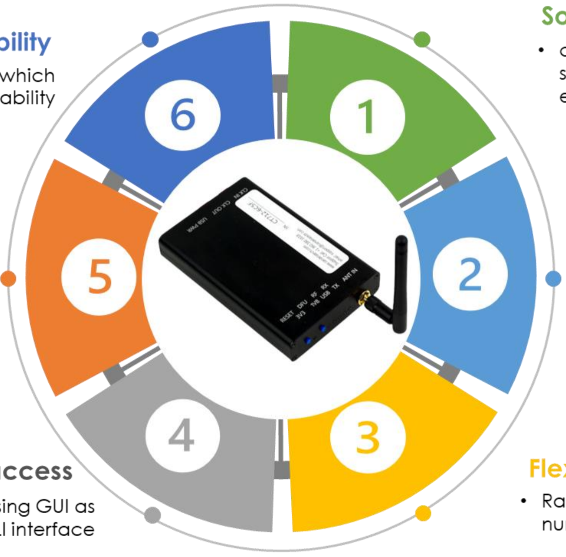








DFS Testing



Software Define radio(SDR)

- capable of transmission or reception of radio signals from 1 MHz to 6 GHz which is used to emulate radar for DFS testing

Signal generation capabilities

- Capable of generating multiple pulse with single PRI in a burst as per standards
- Capable of generating staggered (multiple PRFs within a single burst), chirp and hop test signals

Flexibility

- Radar test parameters like PRI, Pulse width and number of pulses can be configured by the user

Mode of access

- User can access the device using GUI as well as CLI interface

Noise Generator

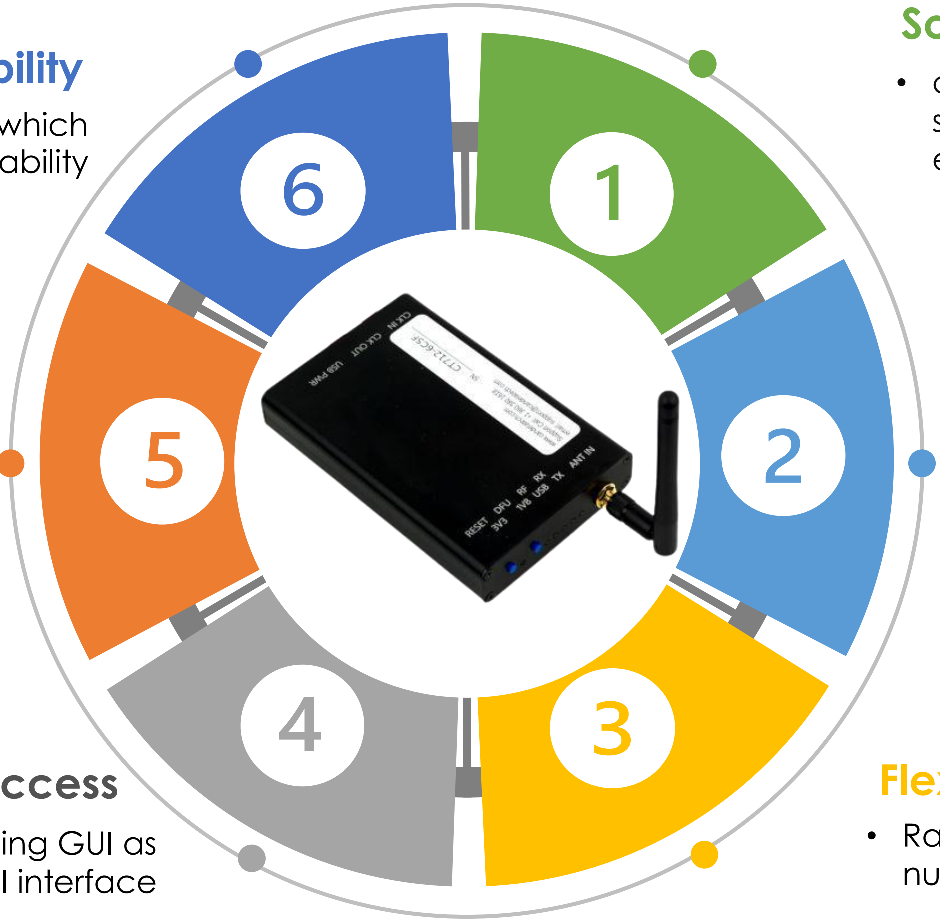
- Can be used to creating the interference to validate the AP behavior

Portability

- This comes in small form factor which makes it a great choice for portability

What is DFS?

- Dynamic Frequency Selection allows APs to detect radar and avoid interference with radar pulses.



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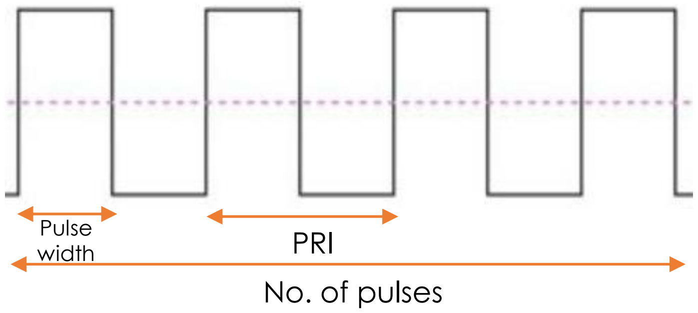
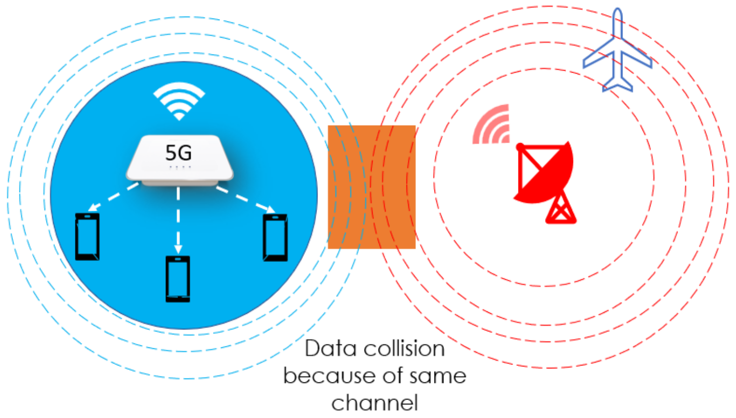
DFS Testbed Images



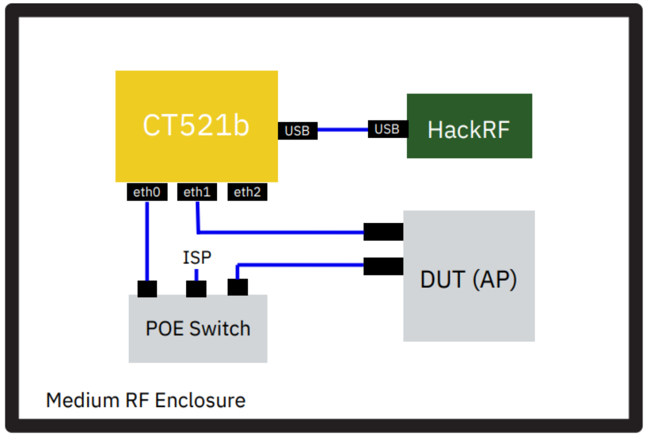
- We can generate various radar signals using an RF generator by adjusting the radar parameters.
- We can perform below test cases using candela LANforge
  1. The detection probability test
  2. The detection Bandwidth test

The DFS solution:

- This setup has the Candela Radar Signal Generator to generate all the Radar pulses.
- The Candela chassis to control the signal generator, run all the automation, and create background traffic and generate test reports.
- Medium RF chamber is used to provide RF isolation for this test setup, all in a super compact form factor.

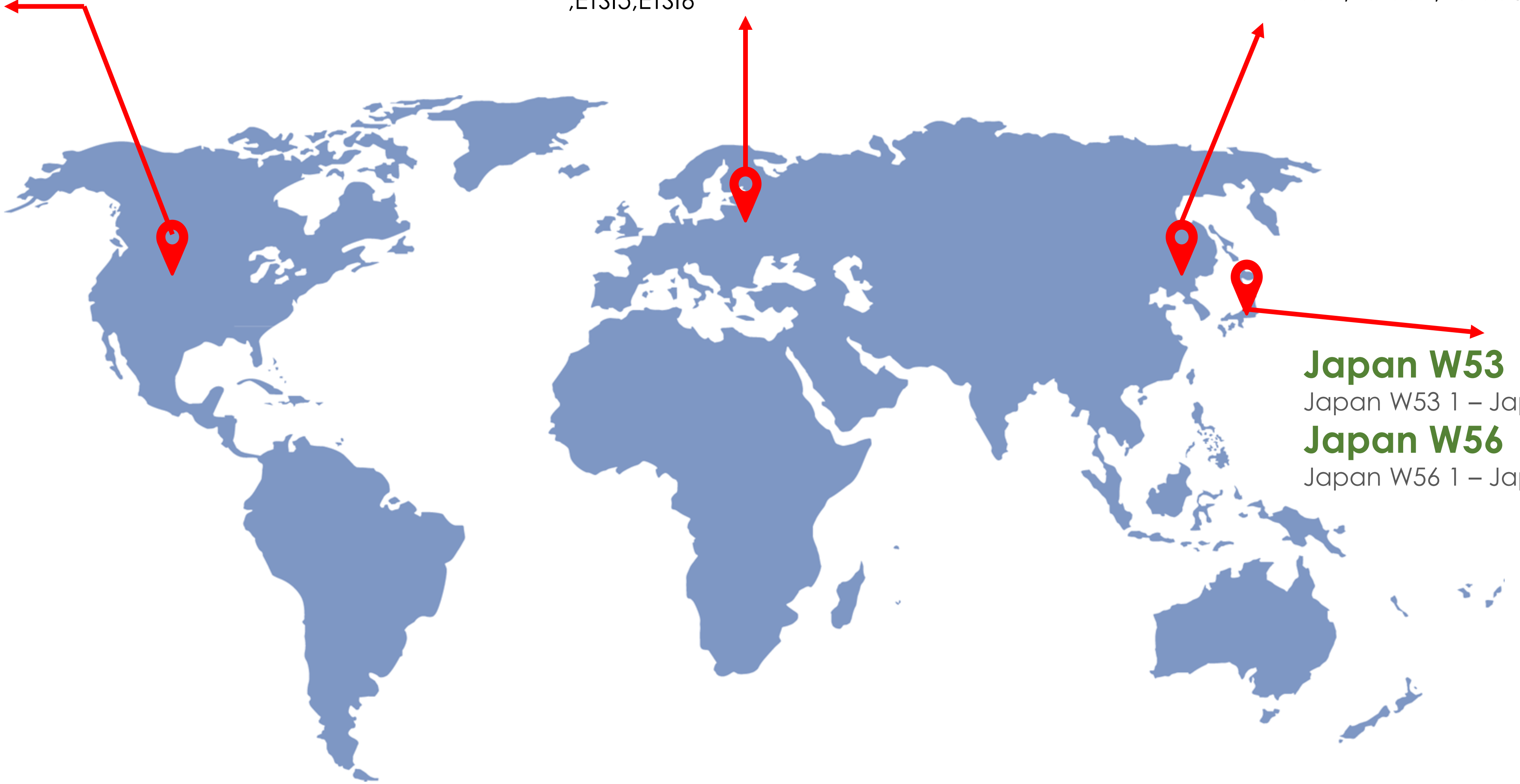


Real world scenario



Candela's Lab setup

regulation's support by candela



Test Signals

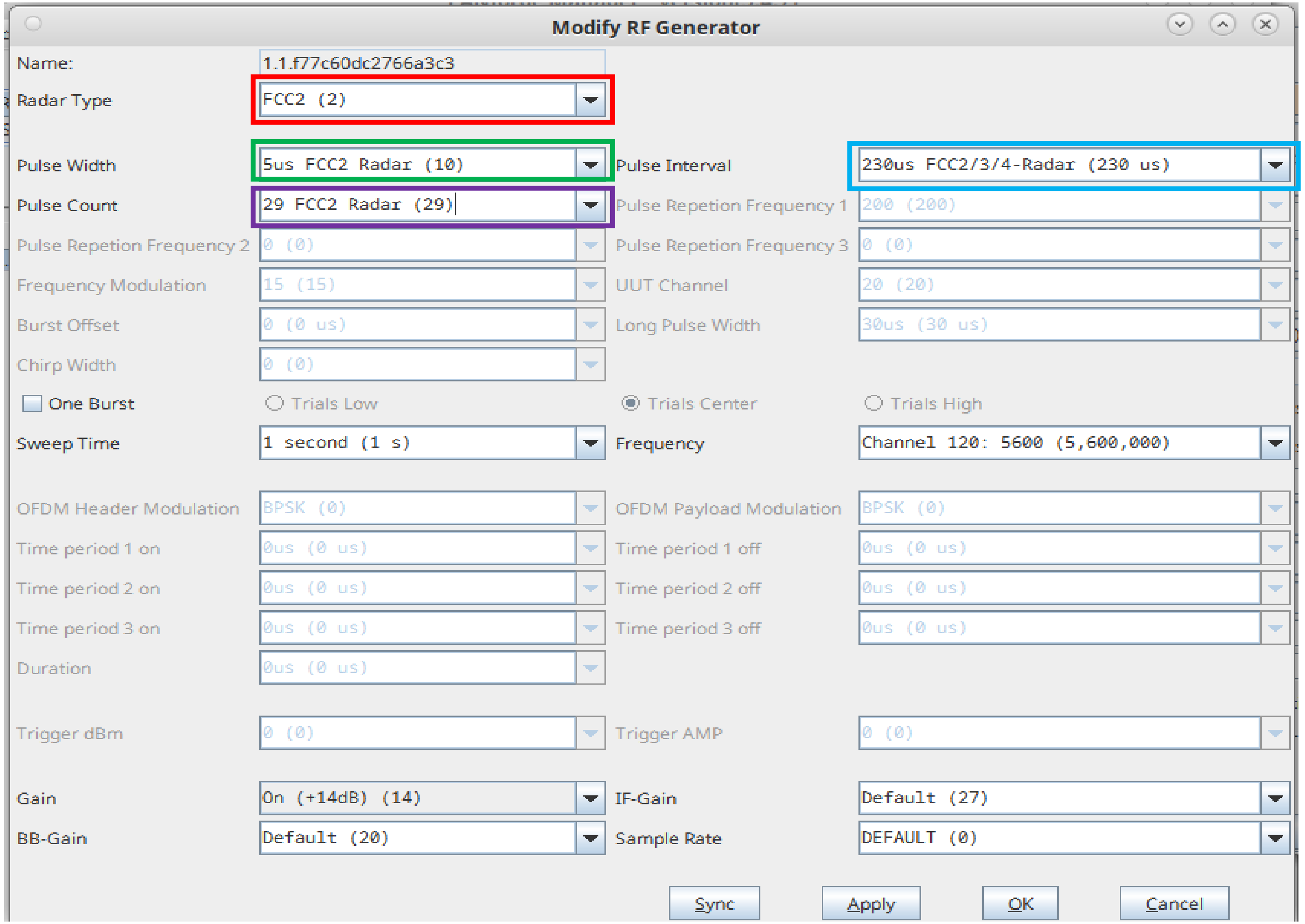
Radar Type	Pulse Width (μsec)	PRI (μsec)	Number of Pulses	Minimum Percentage of Successful Detection	Minimum Number of Trials
0	1	1428	18	See Note 1	See Note 1
1	1	Test A: 15 unique PRI values randomly selected from the list of 23 PRI values in Table 5a	$\text{Roundup}\left\{\left(\frac{1}{360}\right)\cdot\left(\frac{19\cdot10^6}{\text{PRI}_{\mu sec}}\right)\right\}$	60%	30
		Test B: 15 unique PRI values randomly selected within the range of 518-3066 μsec, with a minimum increment of 1 μsec, excluding PRI values selected in Test A			
2	1-5	150-230	23-29	60%	30
3	6-10	200-500	16-18	60%	30
4	11-20	200-500	12-16	60%	30
Aggregate (Radar Types 1-4)				80%	120

Note 1: Short Pulse Radar Type 0 should be used for the detection bandwidth test, channel move time, and channel closing time tests.

Radar test signal # (see note 1 to note 3)	Pulse width W (μs)		Pulse repetition frequency PRF (PPS)		Number of different PRFs	Pulses per burst for each PRF (PPB) (see note 5)
	Min	Max	Min	Max		
1	0,5	5	200	1 000	1	10 (see note 6)
2	0,5	15	200	1 600	1	15 (see note 6)
3	0,5	15	2 300	4 000	1	25
4	20	30	2 000	4 000	1	20
5	0,5	2	300	400	2/3	10 (see note 6)
6	0,5	2	400	1 200	2/3	15 (see note 6)

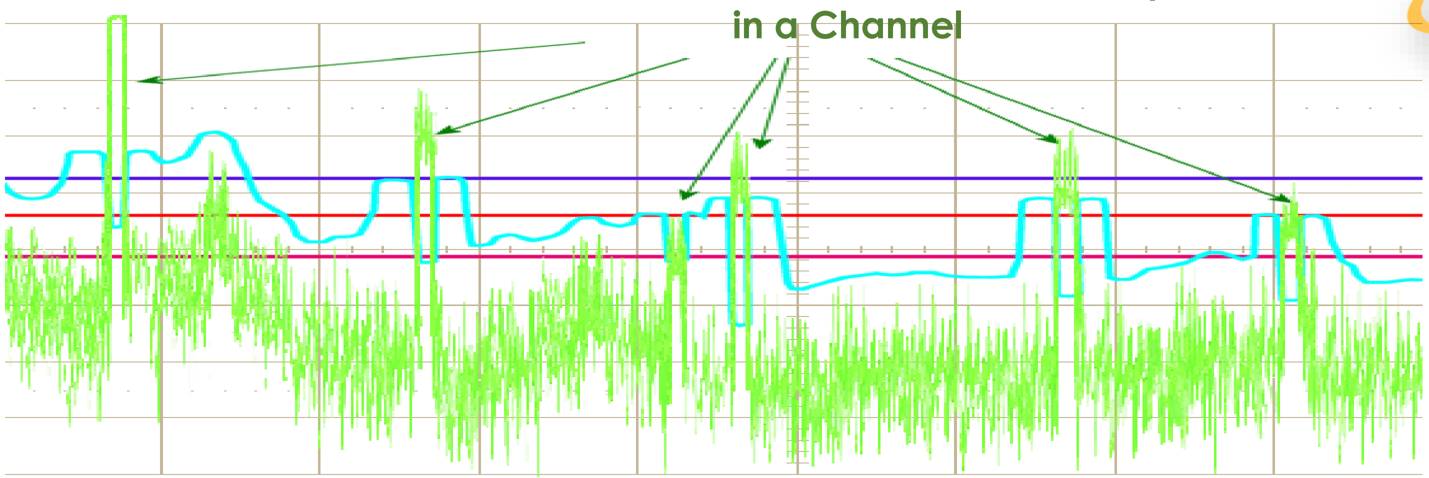
Radar Type	Pulse Repetition Frequency (pps)	Pulse Width (μs)	Number of Pulses (per Burst)	Number of Trials	Burst Period (sec)
1	700	1	18	1	10
2	1800	1	10	1	2
3	330	2	70	1	60
4	3000	1	3 (per Hop)	100 (Number of Hop)	10

LANforge RF Generator GUI:



- The radar signal being tested. The drop down contains list of radar pulses of various standards
- Width of the pulse
- Pulse Repeating Interval of the pulse in a burst
- Number of pulses within a burst

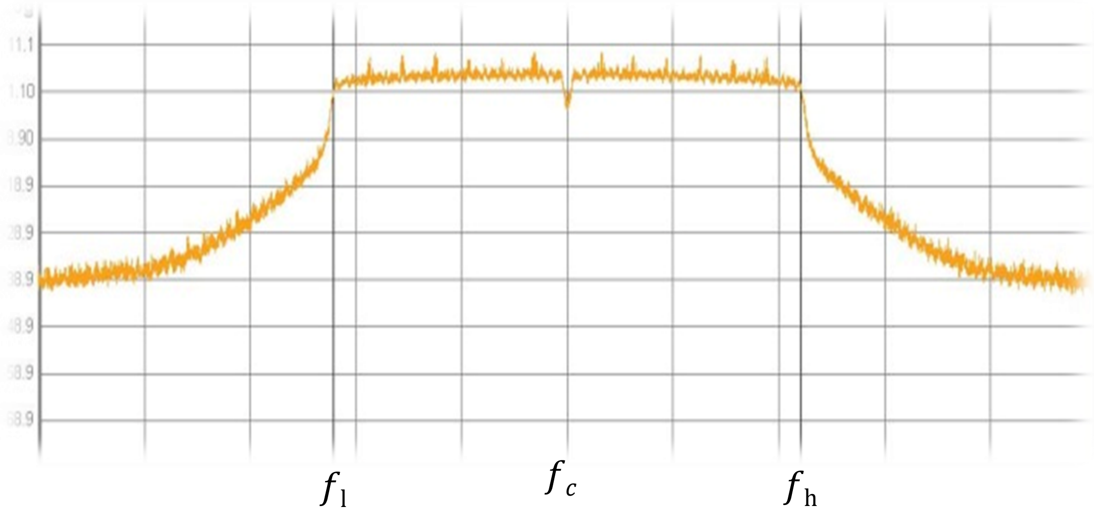
The Detection Probability test:

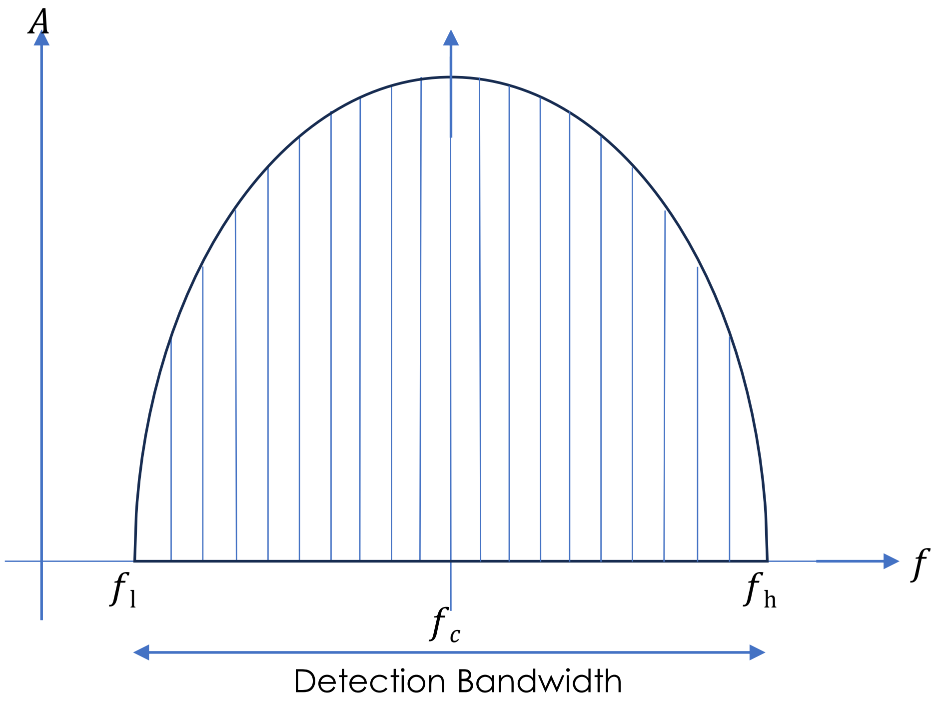


- The detection probability test aims to check if an AP can detect the RADAR pulses which are generated on the active channel of the AP.
- RADAR pulses will be generated based on different parameters like pulse width, number of pulses and Pulse Repeating Interval.
- For a given test case, certain number of trials must be conducted to see if AP detects RADAR.
- The parameters of pulses might vary for every trial based on the type of RADAR pulse being tested. **After triggering the pulses for the specified trials, we need to check how many times the AP can detect the RADAR**.
- The detection percentage of RADAR must be greater than or equal to the specified value by the respective governing bodies.

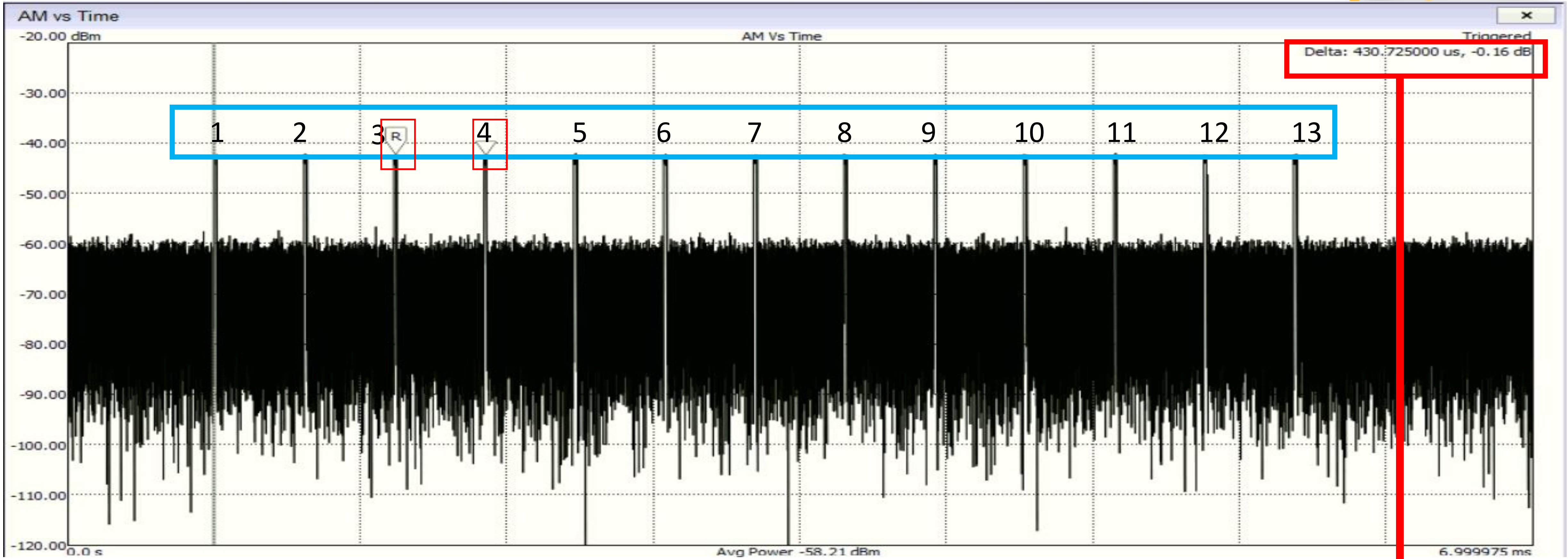
The Detection Bandwidth test:

- Test Objective is to verify radar pulse detection across the entire bandwidth of the AP.
- Radar pulses are sent at every 1MHz frequency step within the AP bandwidth for 10 trails.
- Detection percentage is calculated at every frequency step.
- The range of frequencies with successful detection is calculated and will be checked as per standard's requirements.



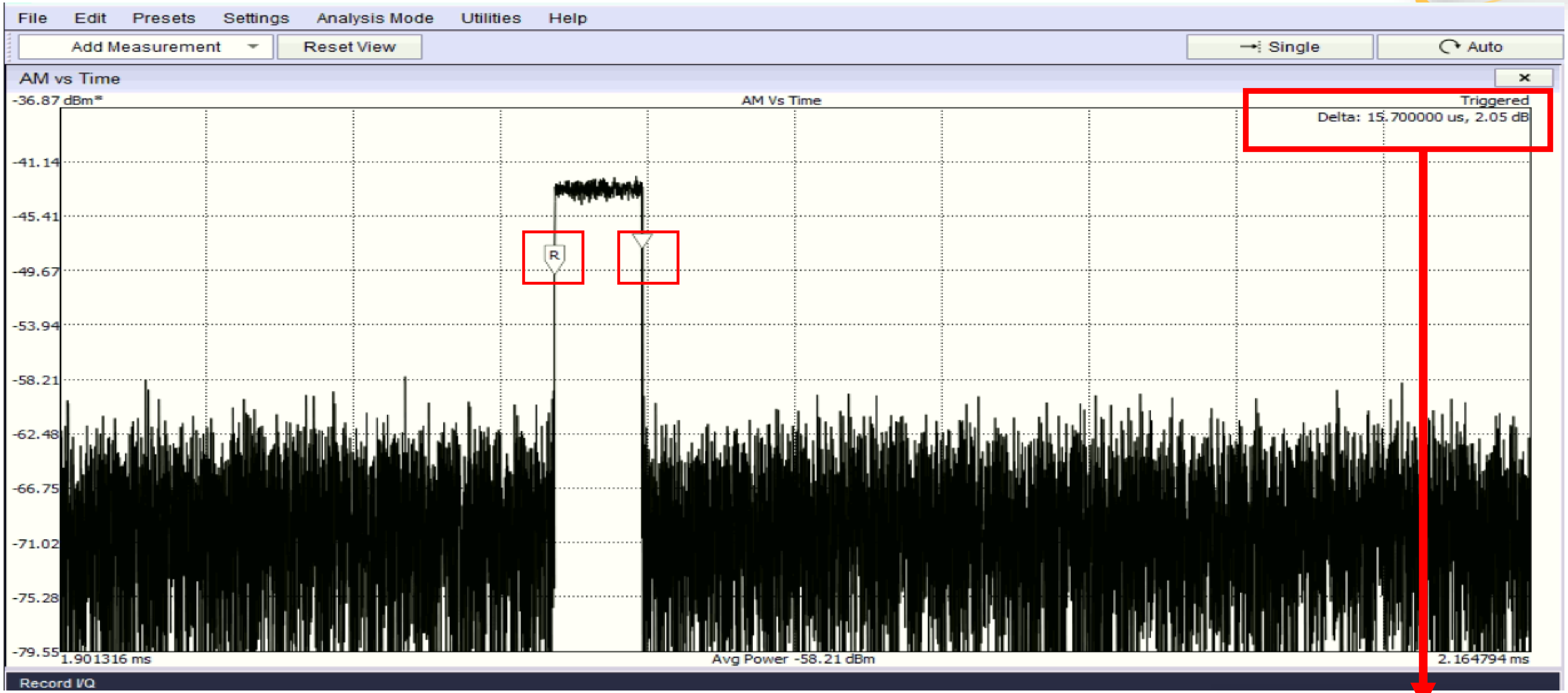


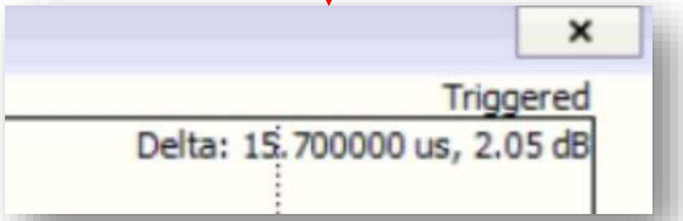
Pulse Captures from Spectrum Analyser



- Emulated 13 Pulses of FCC4
- PRI: 430us

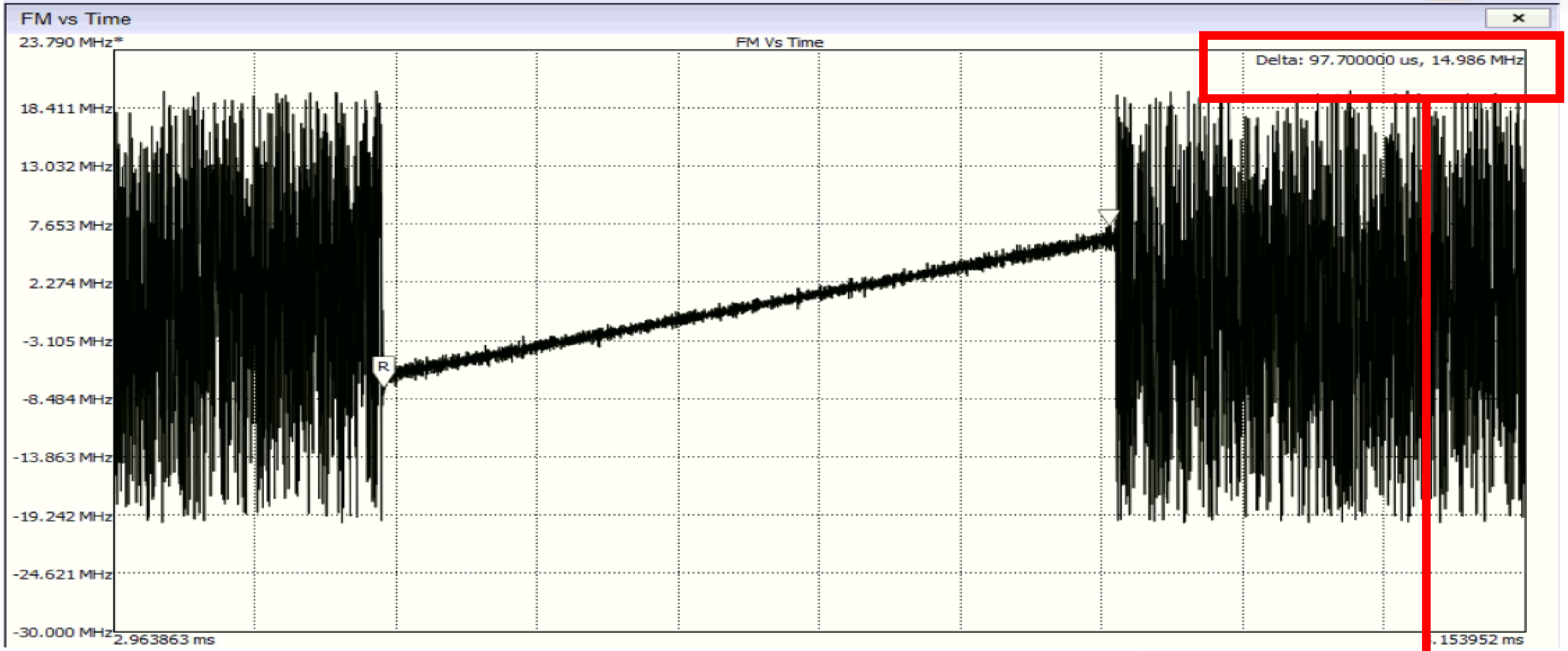
Pulse width Captures from Spectrum Analyser

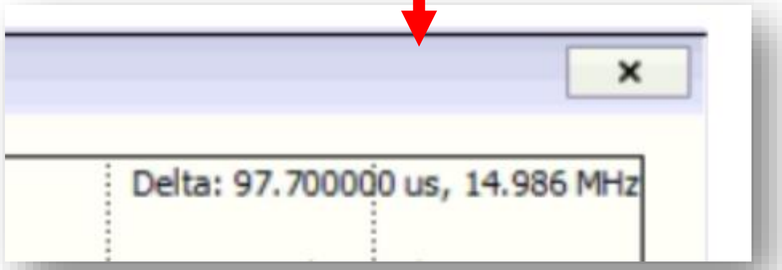




- Configured pulse width 15.7us

Chirp Modulation





- Configured chirp width 15MHz

Sample Test Reports:

Detection Probability Test Report

2023-09-16-20:06:54

est Setup Information

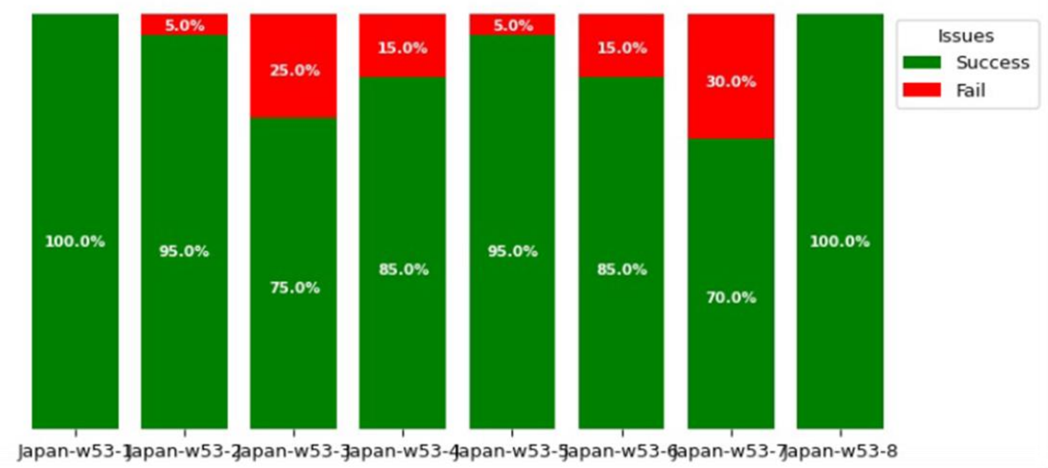
Device under test	DUT Name	Test_AP
	SSID	candelatest
	Test Duration	0:55:26

Objective

etection Probability Test is compilance to the Dynamic Frequency Selection (DFS) Regulation, it creates regulatory specified radar pulses to the DUT epeatedly to measure the probability of detection.

esult Summary

he below graph provides information regarding detection probability percentage for various RADAR Types.



Detection Bandwidth Test Report

2023-09-16-02:17:16

est Setup Information

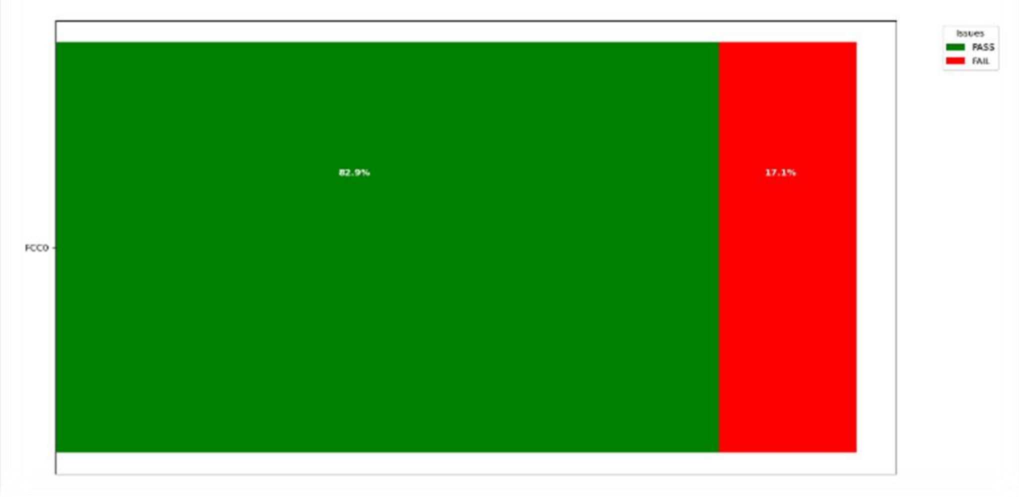
Device under test	DUT Name	NXP_AP
	SSID	None
	Test Duration	1:11:07

Objective

etection Probability Test is compilance to the Dynamic Frequency Selection (DFS) Regulation. The purpose of this test is to subject the DUT to a Type 0 CC radar pulsewhile moving the frequency of the radar signal through the channel to characterized range of frequencies over whichthe DUT can etect the radar pulse.

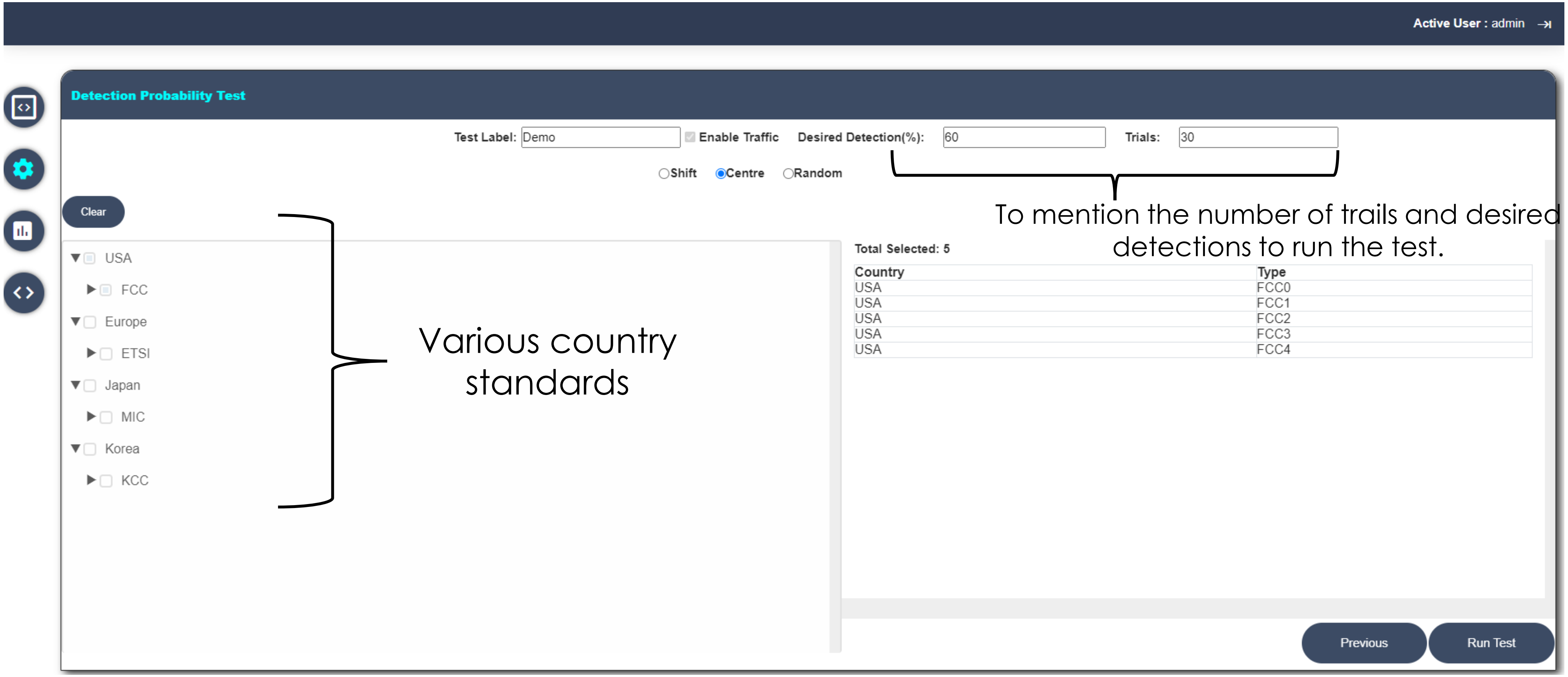
esult Summary

he below graph provides information regarding detection probability percentage for various RADAR Types.

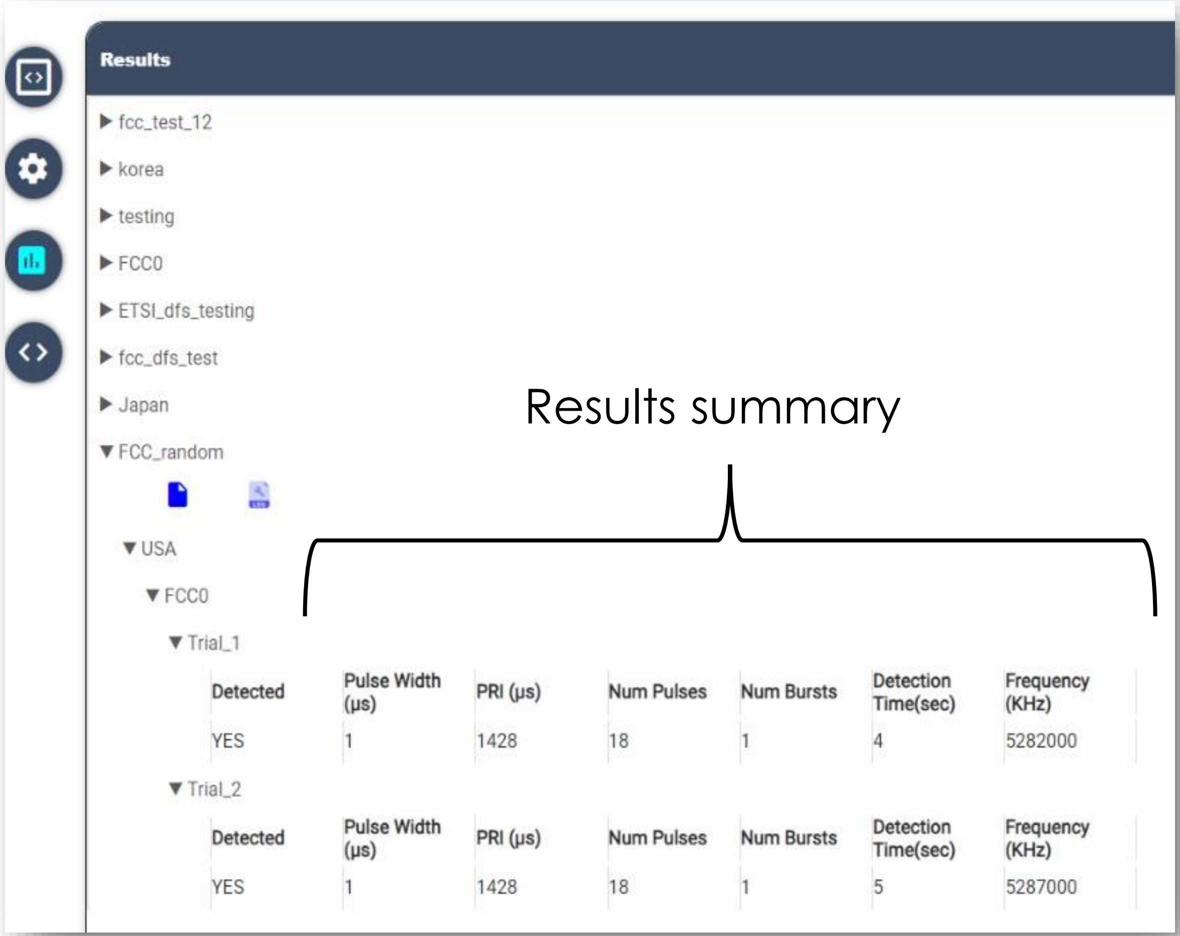


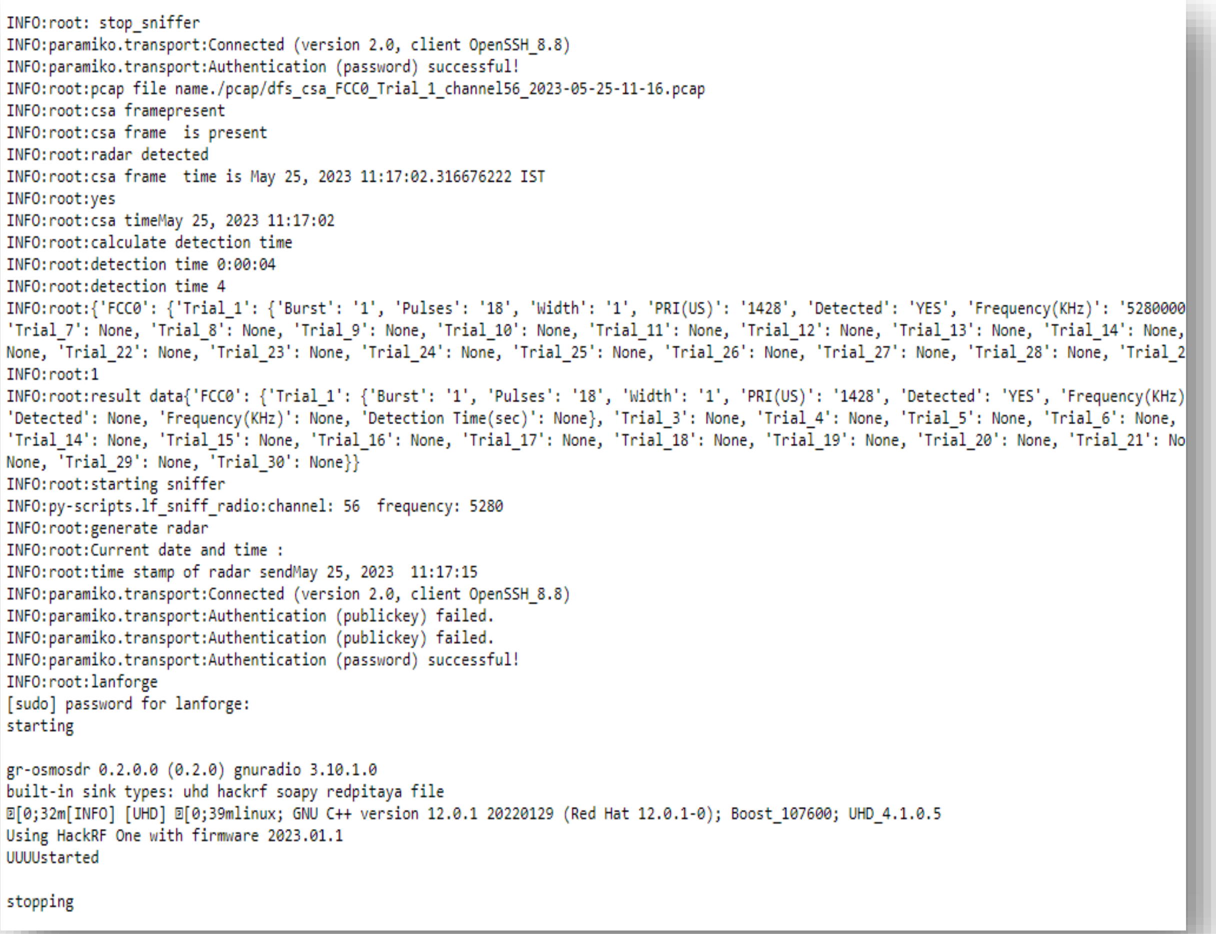
DFS Web-UI:

DFS Web-UI has been designed to execute a wide range of test cases based on various country standards with just a single click, ensuring a user-friendly experience.

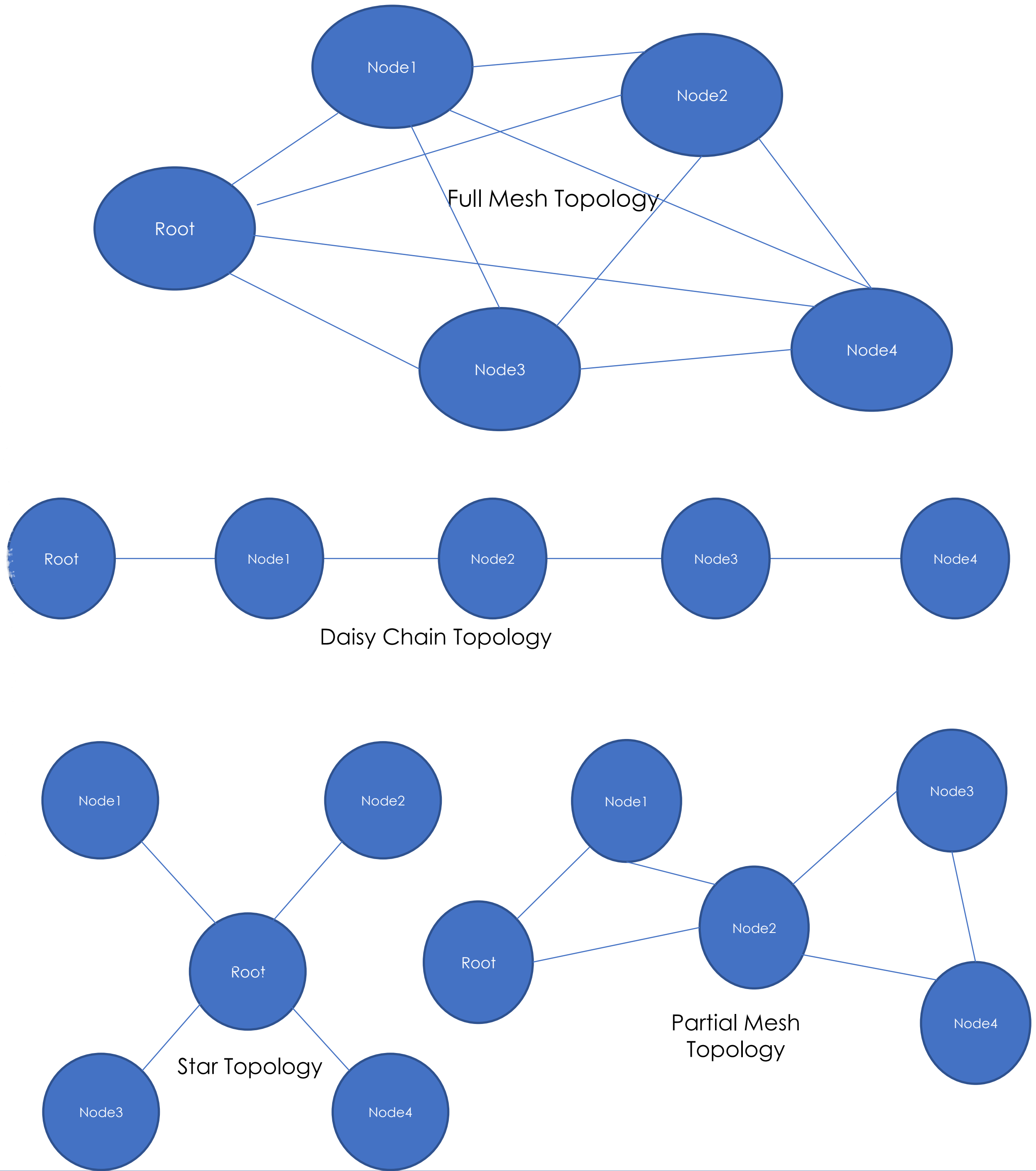


Sample WebGUI results:

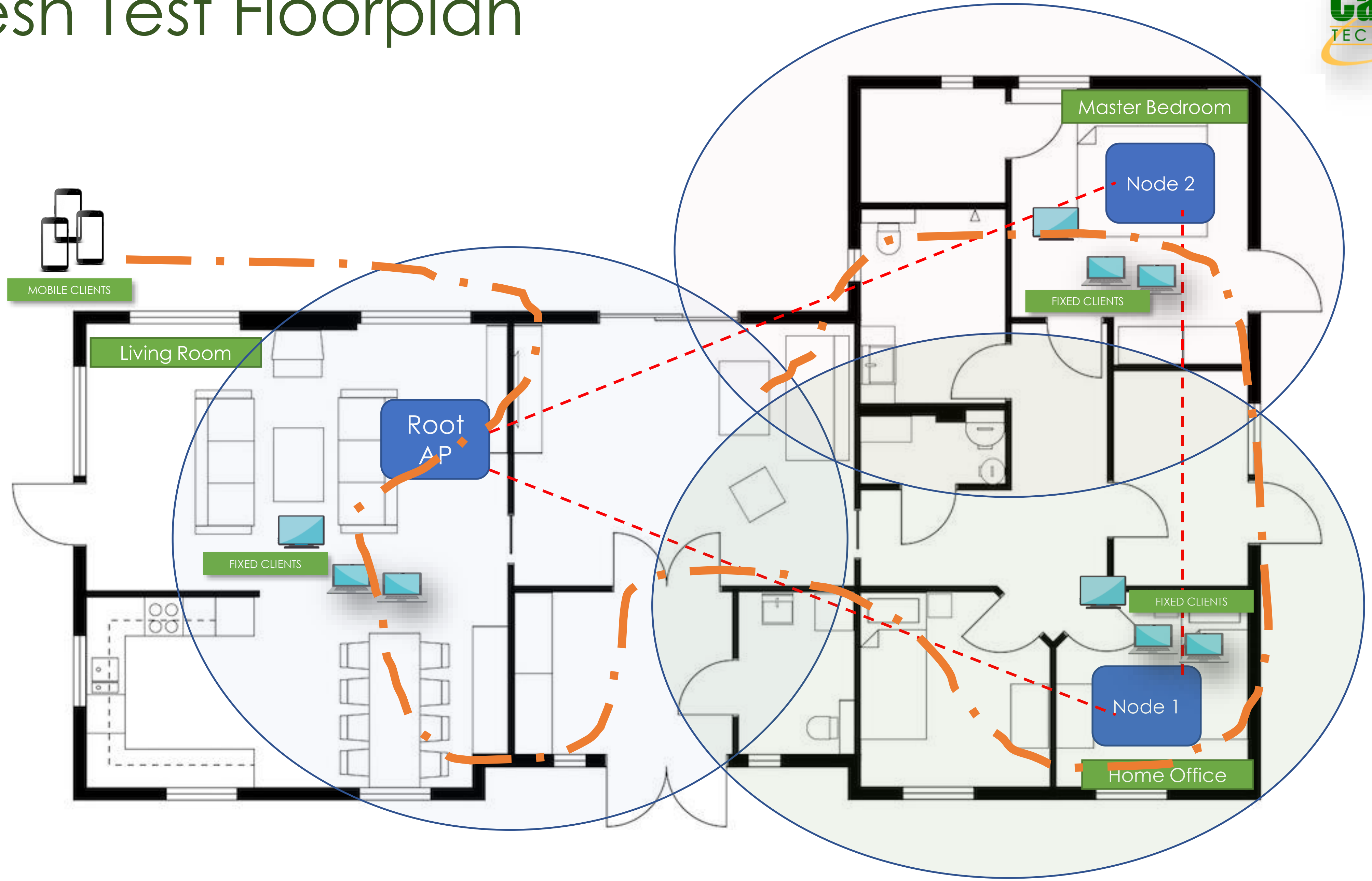




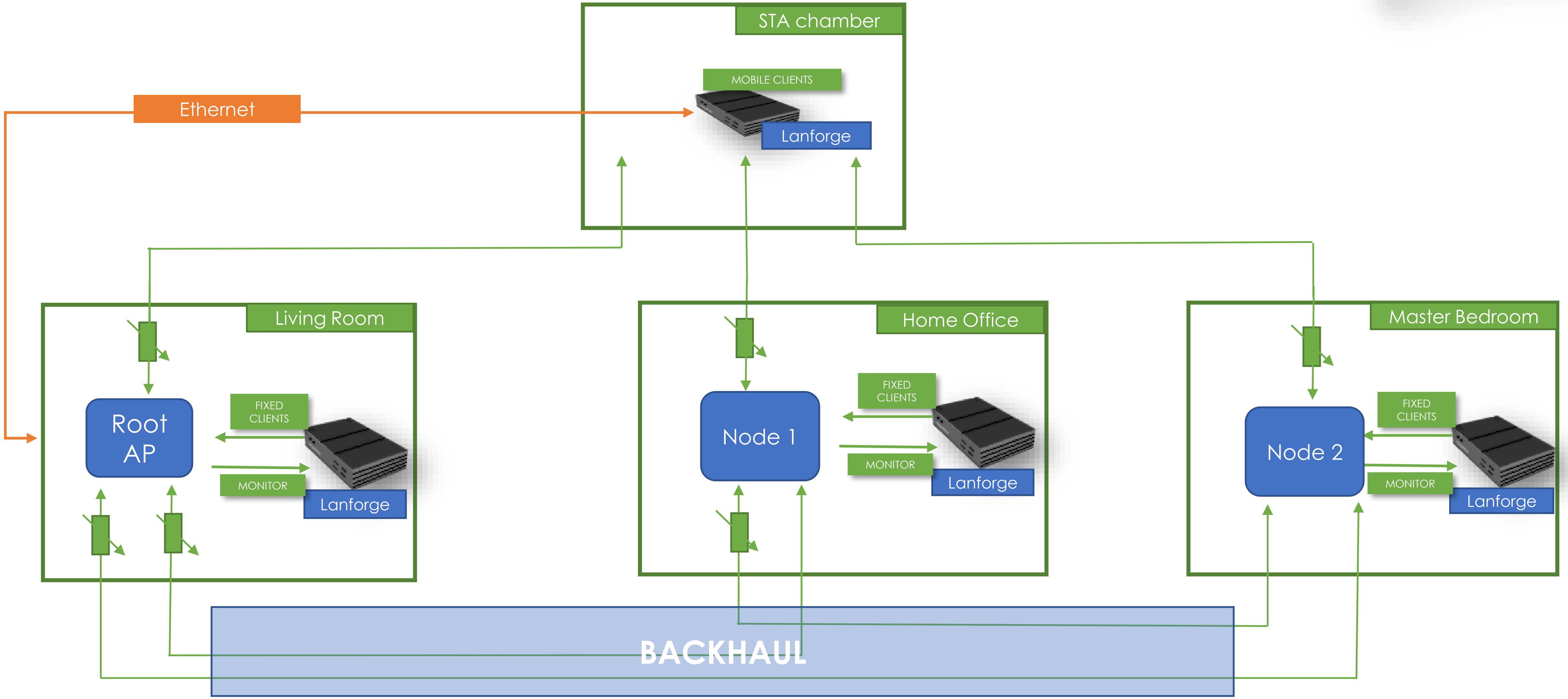
Mesh Test Solution



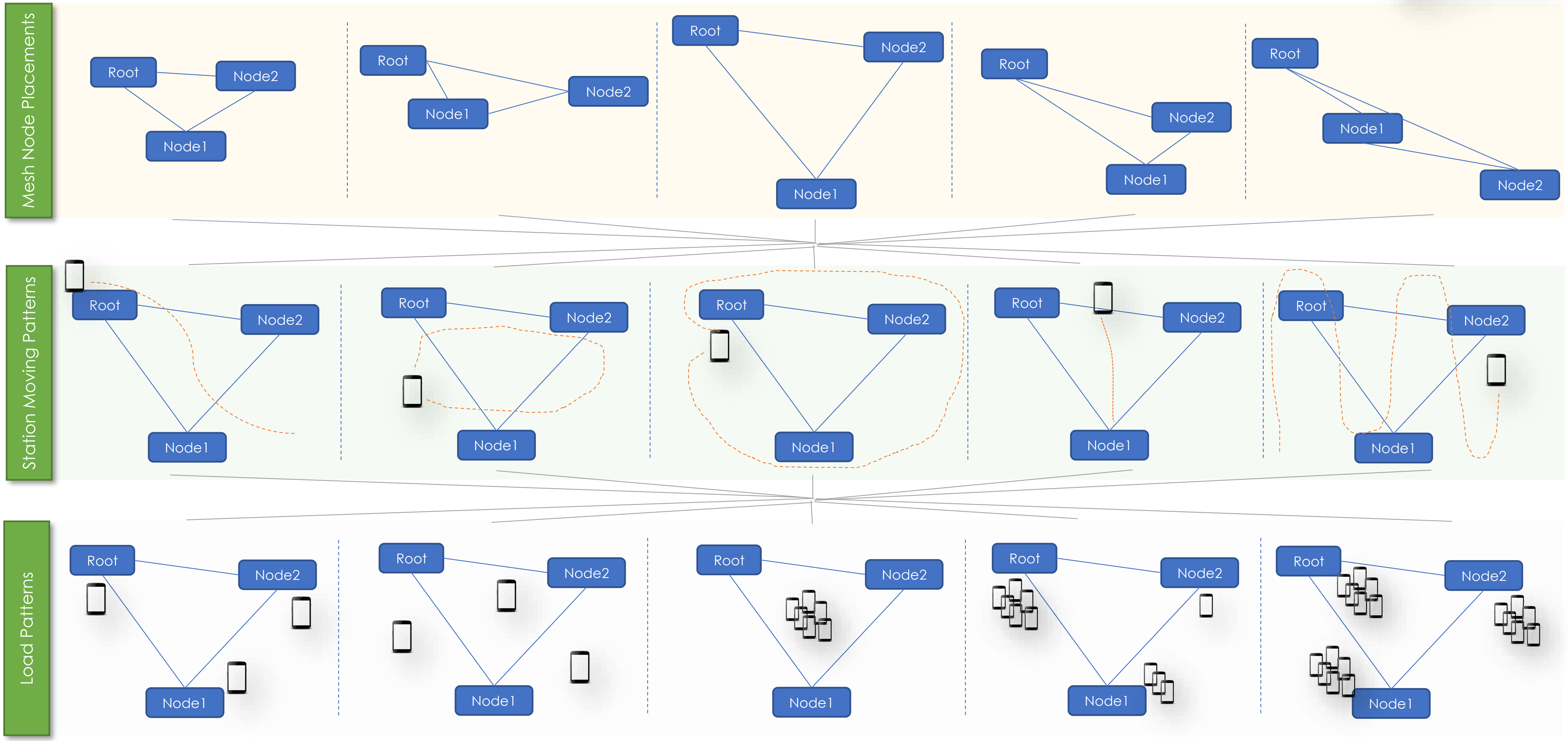
Mesh Test Floorplan



3 Node Testbed Example



Test Automation Variables



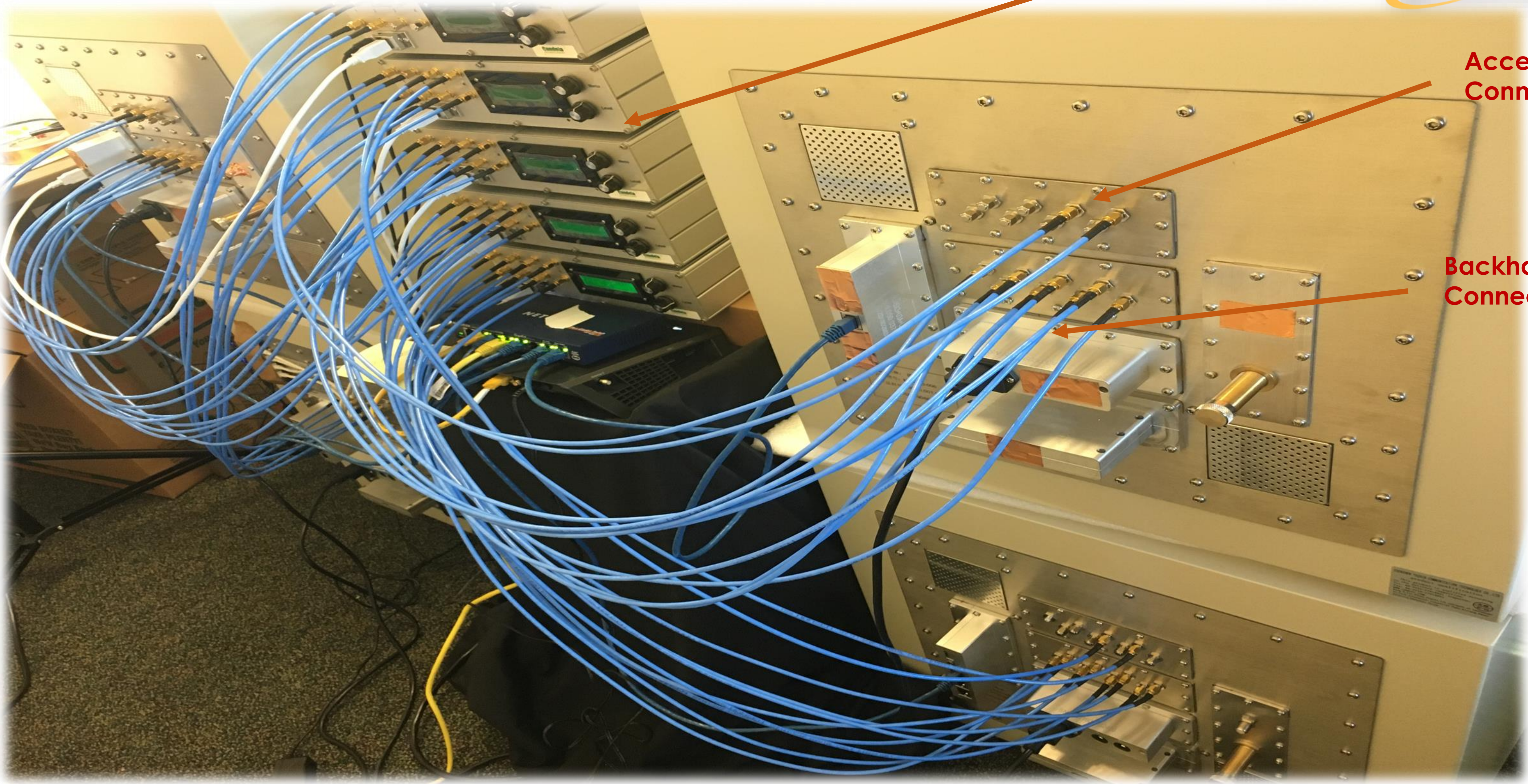
Testbed Picture - Front

Testbed Picture - Back

Programmable Attenuators

Access Connections

Backhaul Connections

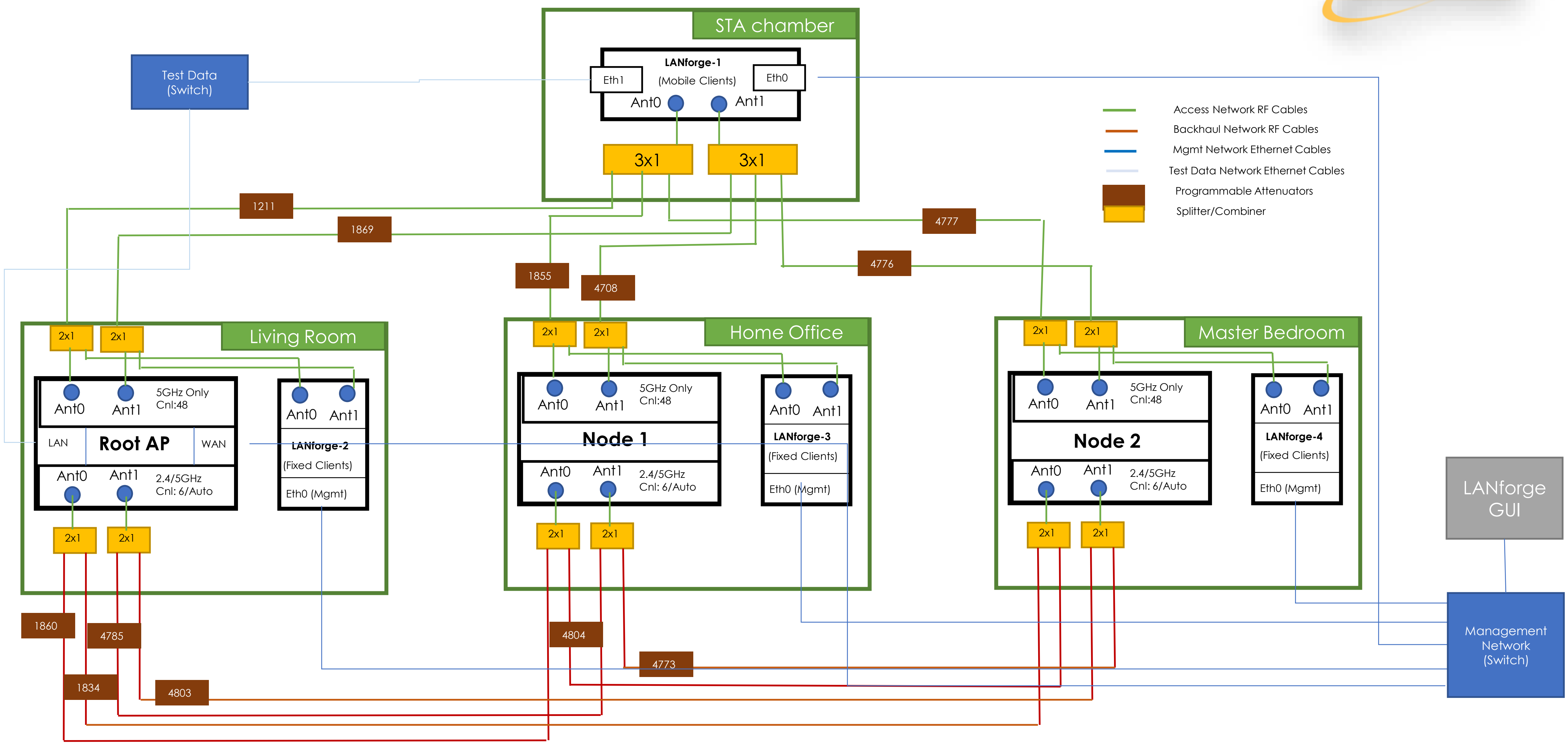


Testbed - Inside

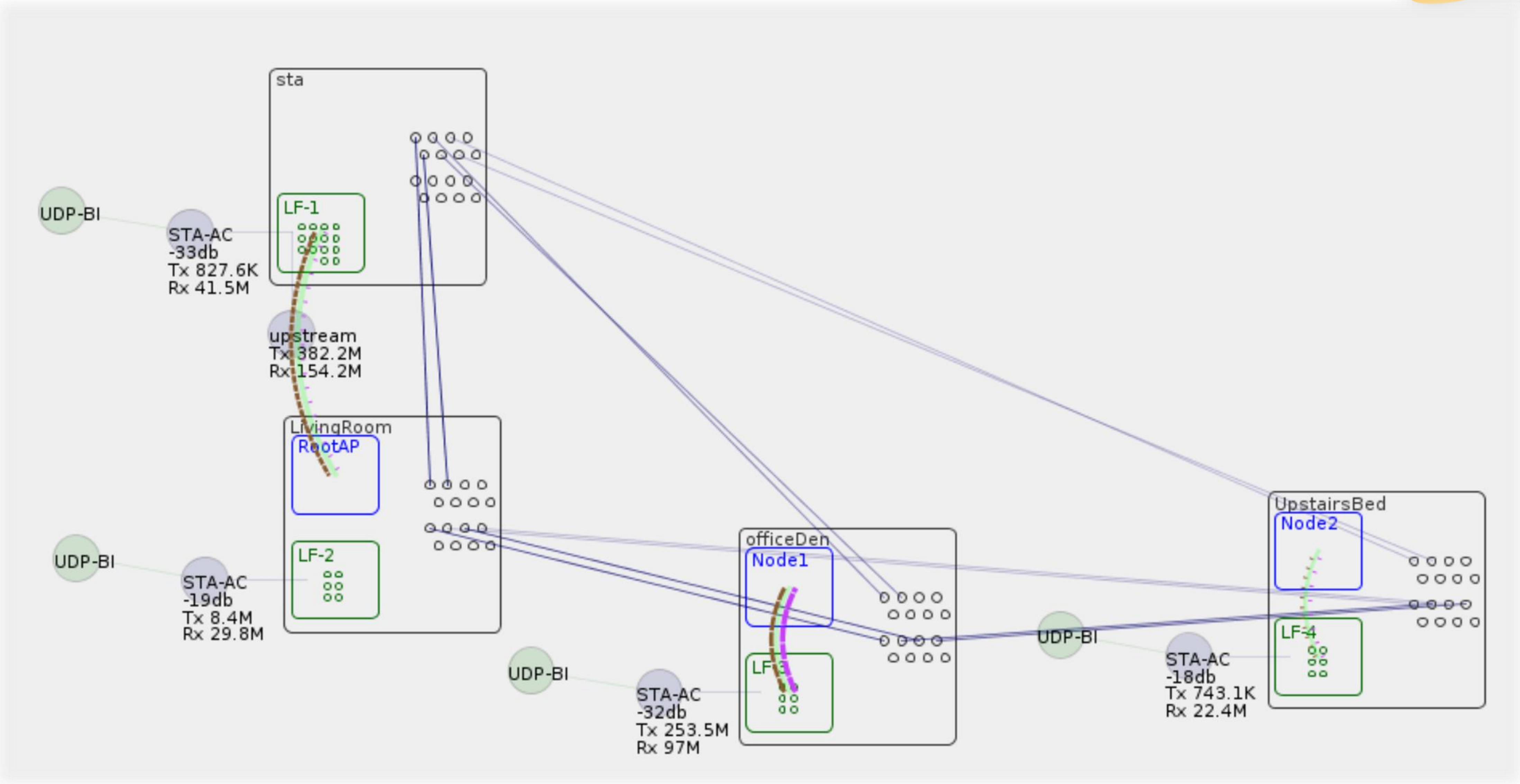
LANforge systems doing Fixed clients, Mobile clients, Background traffic, interference, monitoring, roaming etc…

Mesh AP Nodes under Test

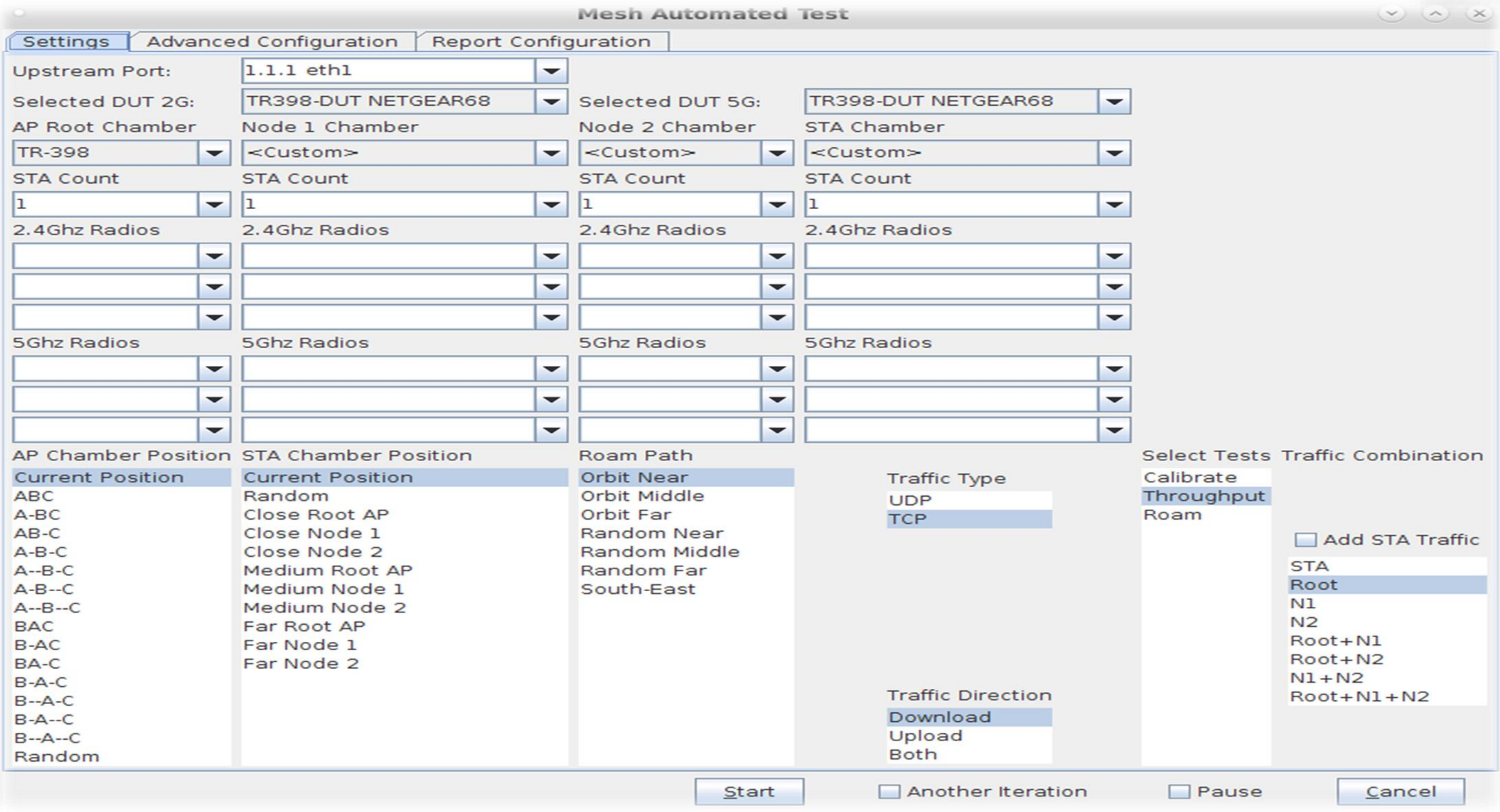
MORE DETAILED TESTBED DIAGRAM



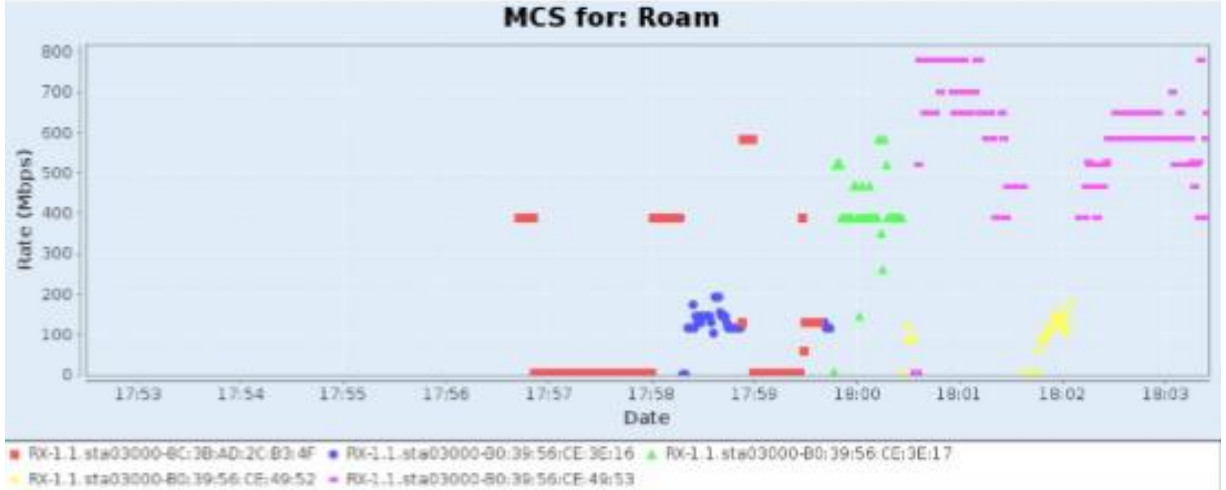
LANforge Chamber View

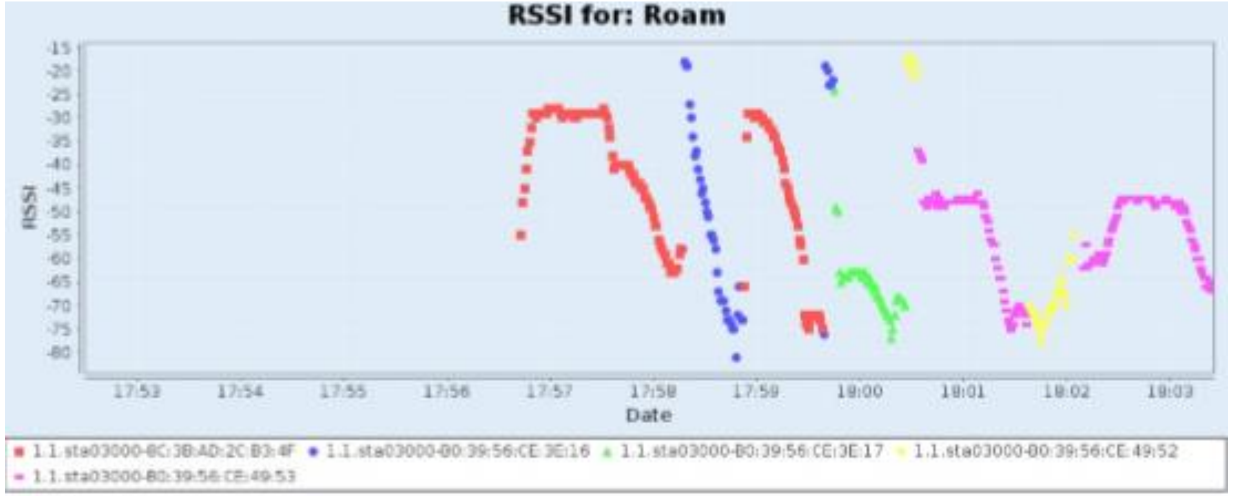


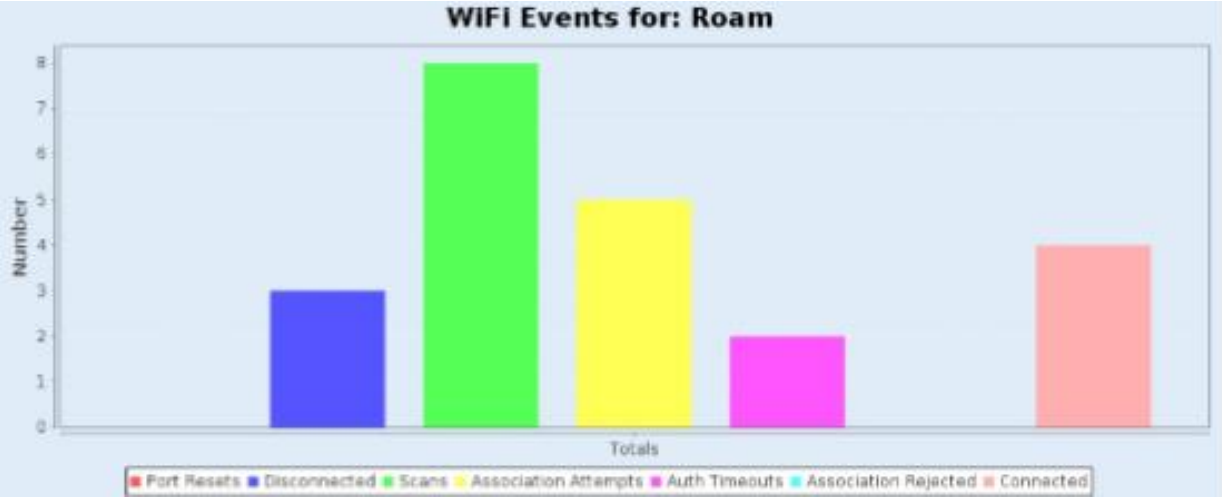
Mesh Automated Test GUI Settings



Mesh Roam Test Results







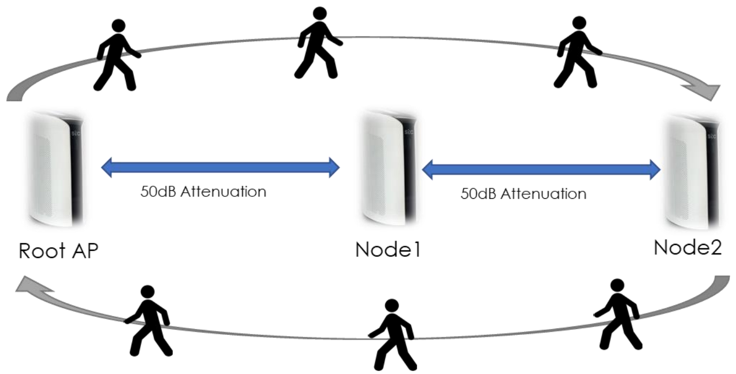
Testbed Building Blocks

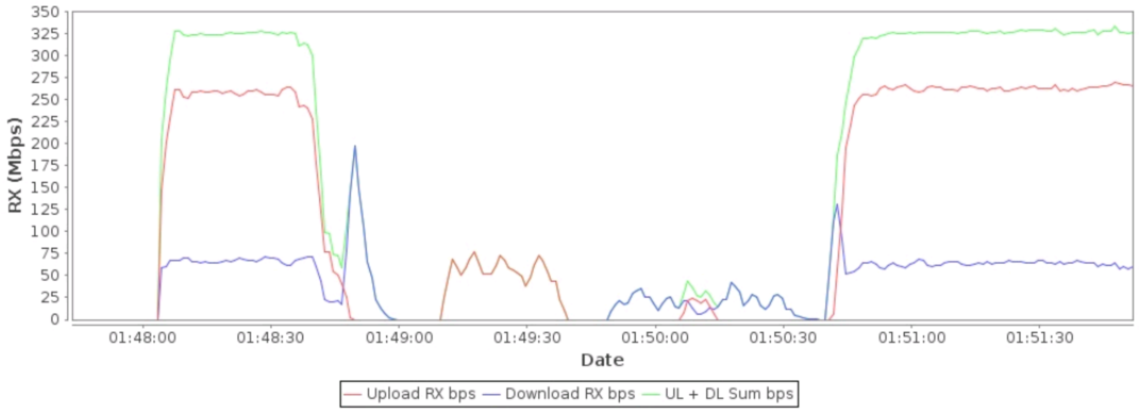
- ✓RF enclosures
- ✓Programmable Attenuators
- ✓RF & Ethernet Cables
- ✓Splitters/Combiners
- ✓LANforge Hardware for Station Emulation
- ✓LANforge-MESH Test Application Software

Key Tests

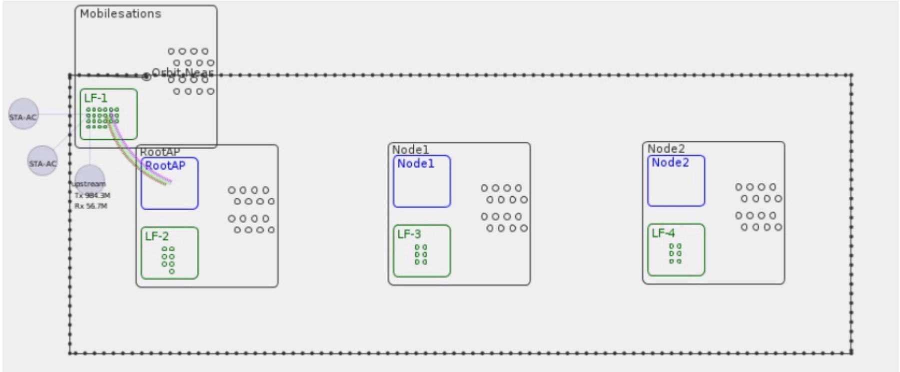
- ✓ Measure maximum upstream and downstream throughput that can be achieved per each hop in the mesh.
- ✓ Repeat test 1 on different channels, Channel Bandwidths, MIMO types.
- ✓ Measure the maximum number of stations each node in the mesh can handle.
- ✓ Measure the connection times and number of connection drops for the stations for each node in the mesh over time.
- ✓ Repeat 1,2,3 and 4 with different distance settings between the nodes in the mesh.
- ✓ Measure the maximum possible distance between the nodes in the mesh where they can all still maintain connectivity.
- ✓ Test how the mesh backhaul can rate adapt and find the best possible channel in a noisy environment.
- ✓ Force a disconnect on a specific link on the mesh and measure time taken to find the next best path in the mesh.
- ✓ Create different levels of co-channel and adjacent channel interference and measure overall performance.
- ✓ Run performance test with different mixes of voice, video and data traffic and measure quality of experience.
- ✓ Repeat tests 1 through 10 with different security types (Open, WPA-PSK, WPA-Enterprise)
- ✓ Test load balancing and band steering capabilities of the nodes in the mesh by creating different amounts of stations and traffic loads on different nodes in the mesh.
- ✓ Test handoff delays for stations handing off been various nodes in the mesh.
- ✓ Measure roaming performance with different security methods and fast roaming methods and 802.11k/v/r
- ✓ Measure performance over distance for stations connecting to each mesh node.

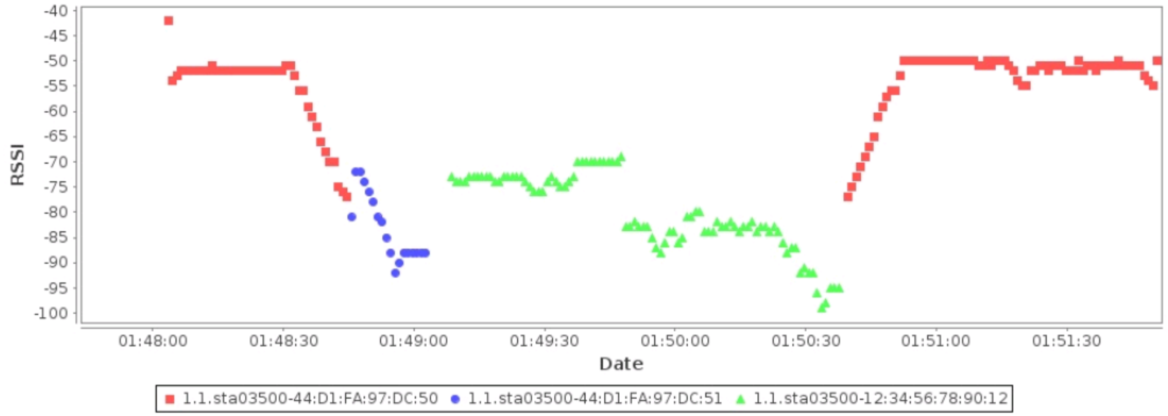
Single Client Mesh Roam Test – 5GHz



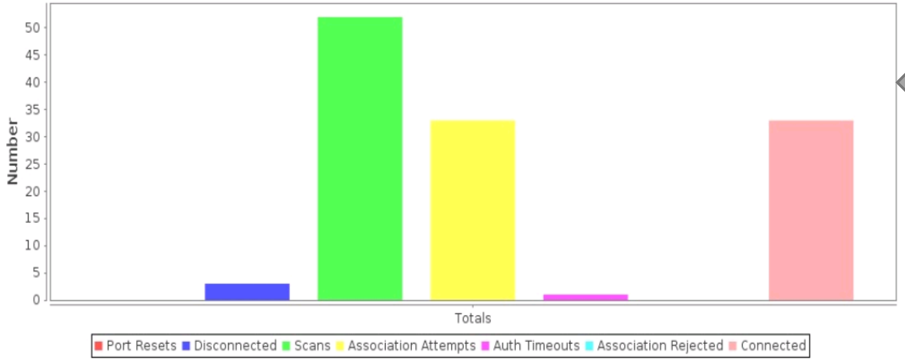


Throughput over the roam cycle



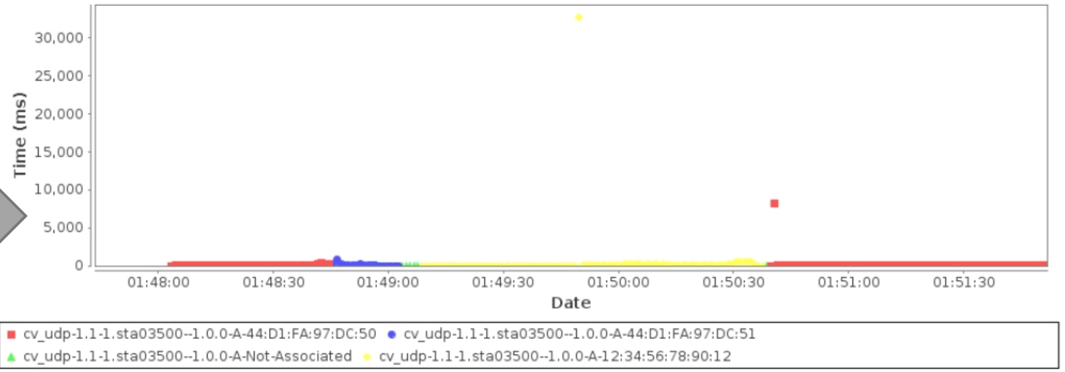


Client RSSI over the roam cycle

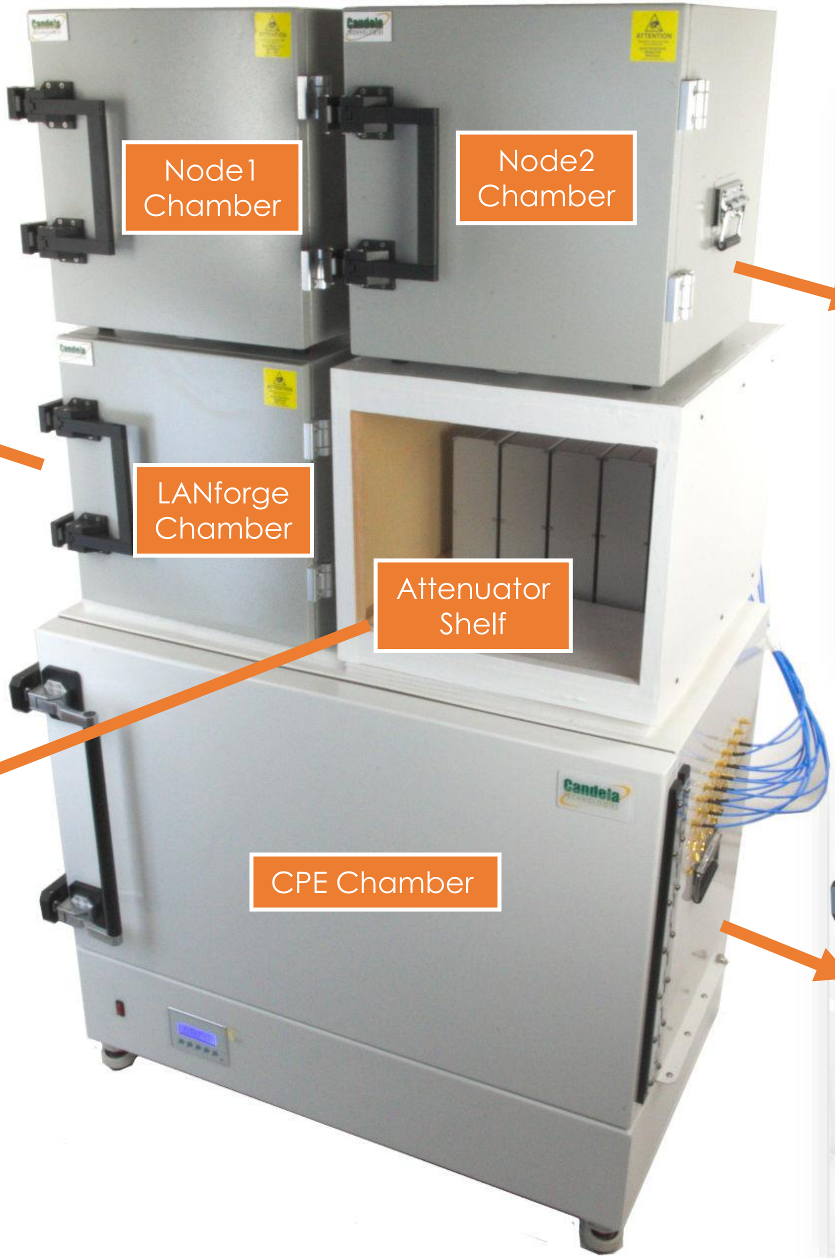


Client Events

Interpacket Gap during the roam cycle



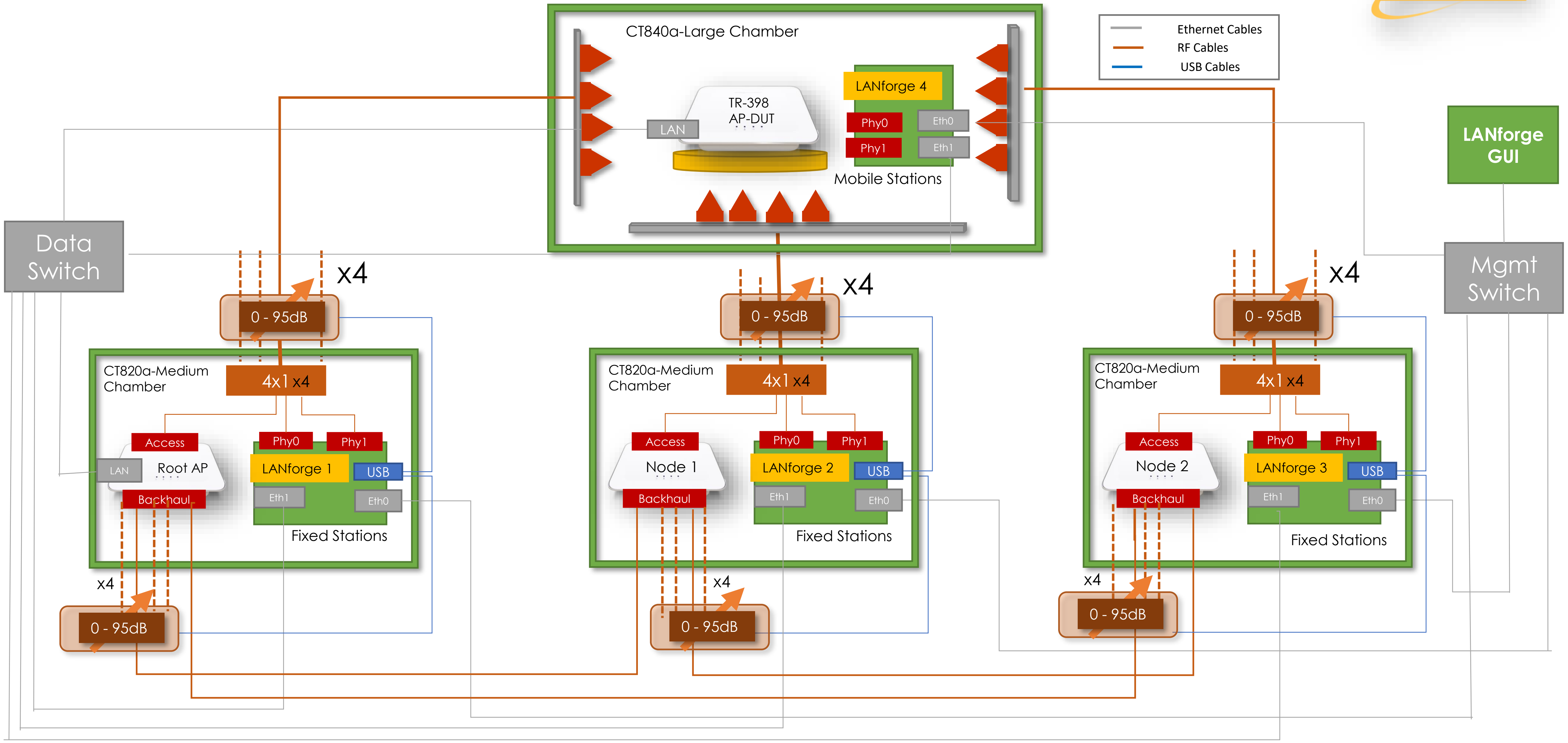
Stacked Chamber Configuration Example (Mesh + TR-398)



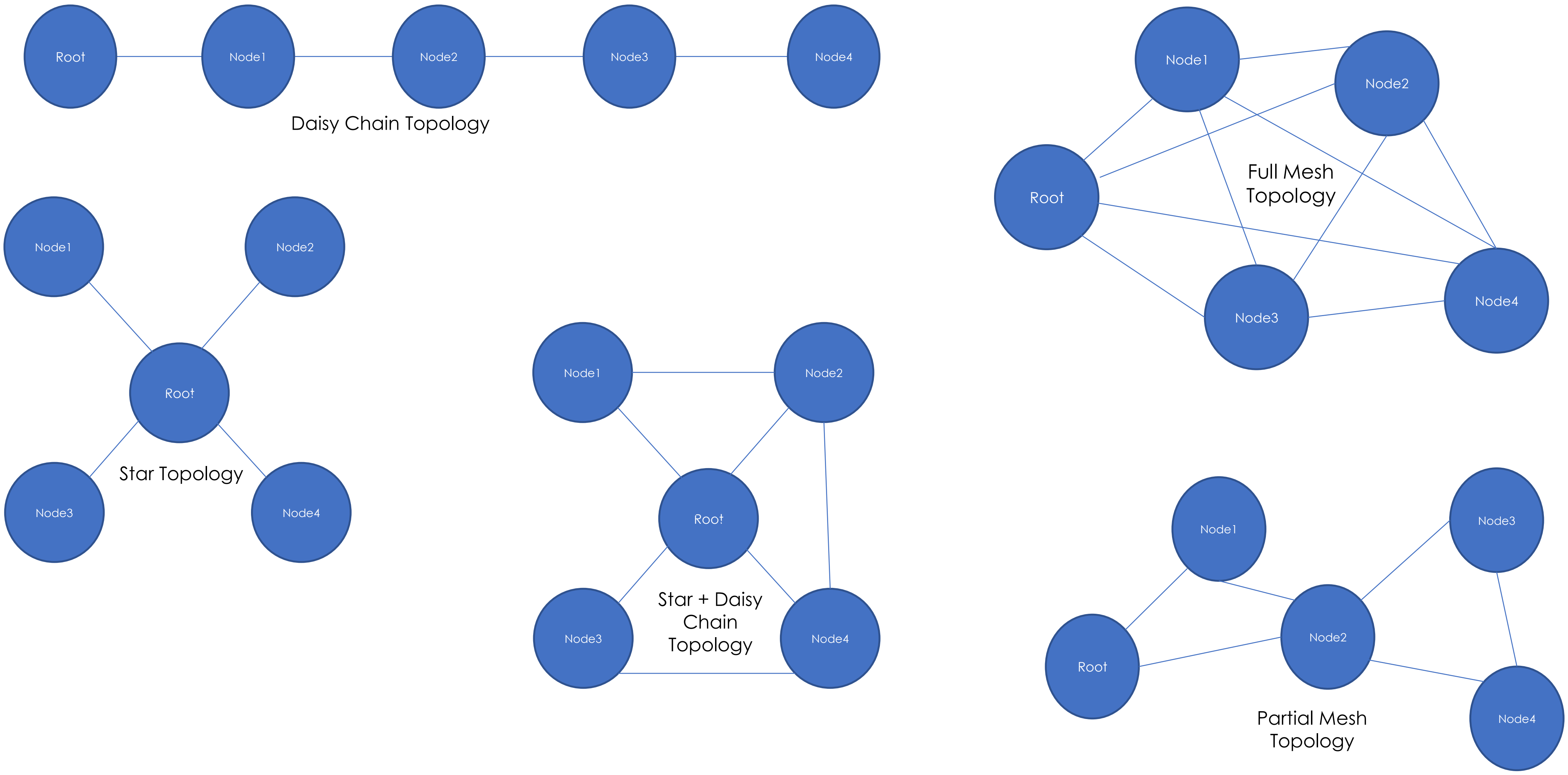
TR-398 + 3-Node Mesh Tested (Cabled)

Every Mesh system is different. In this example the APs are dual-band with 4 antennas on Root AP and 6 Antennas on Extenders

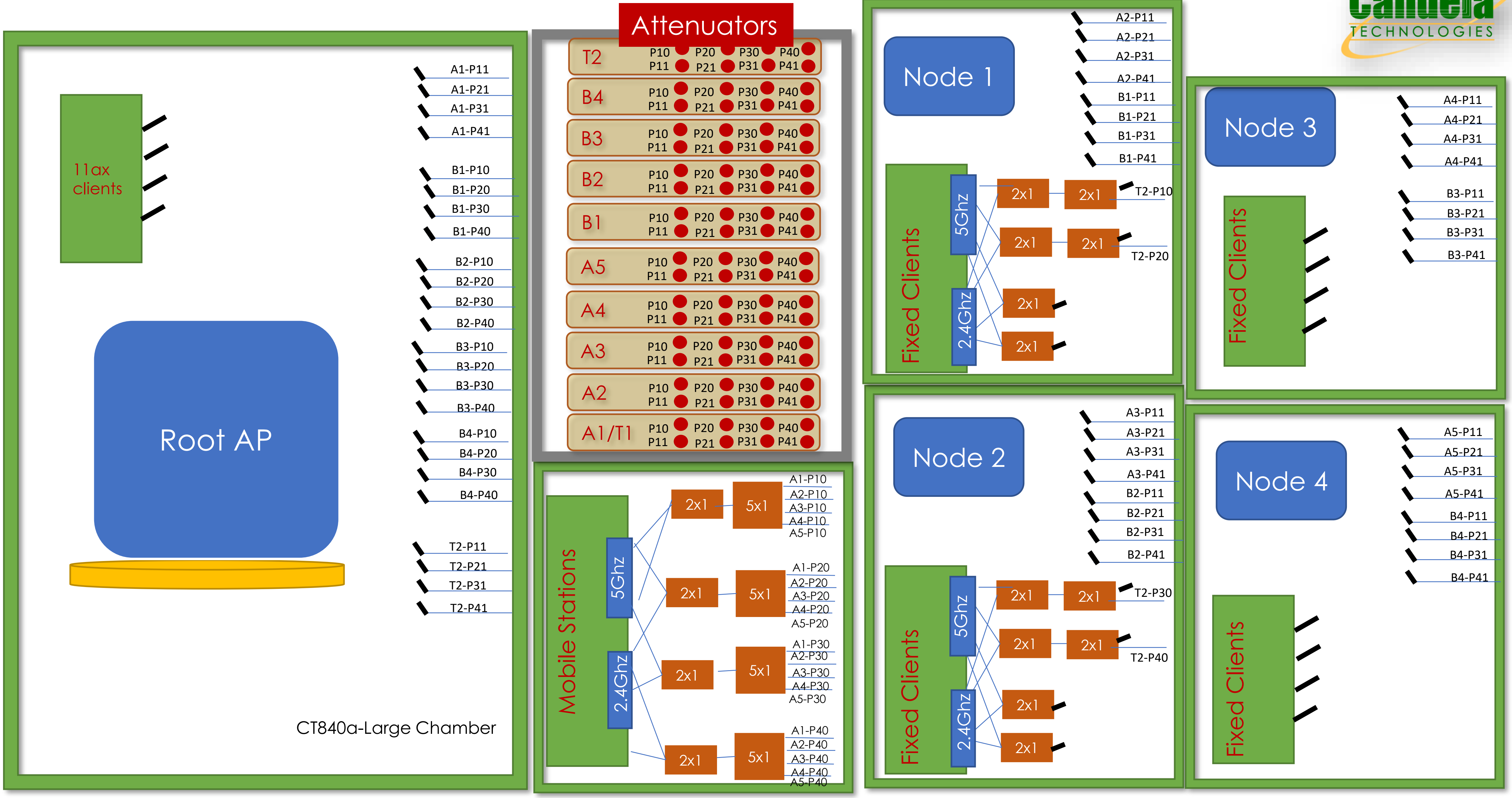
TR-398 + 3-Node Mesh Tested



Root + 4 Satellites Topology Examples



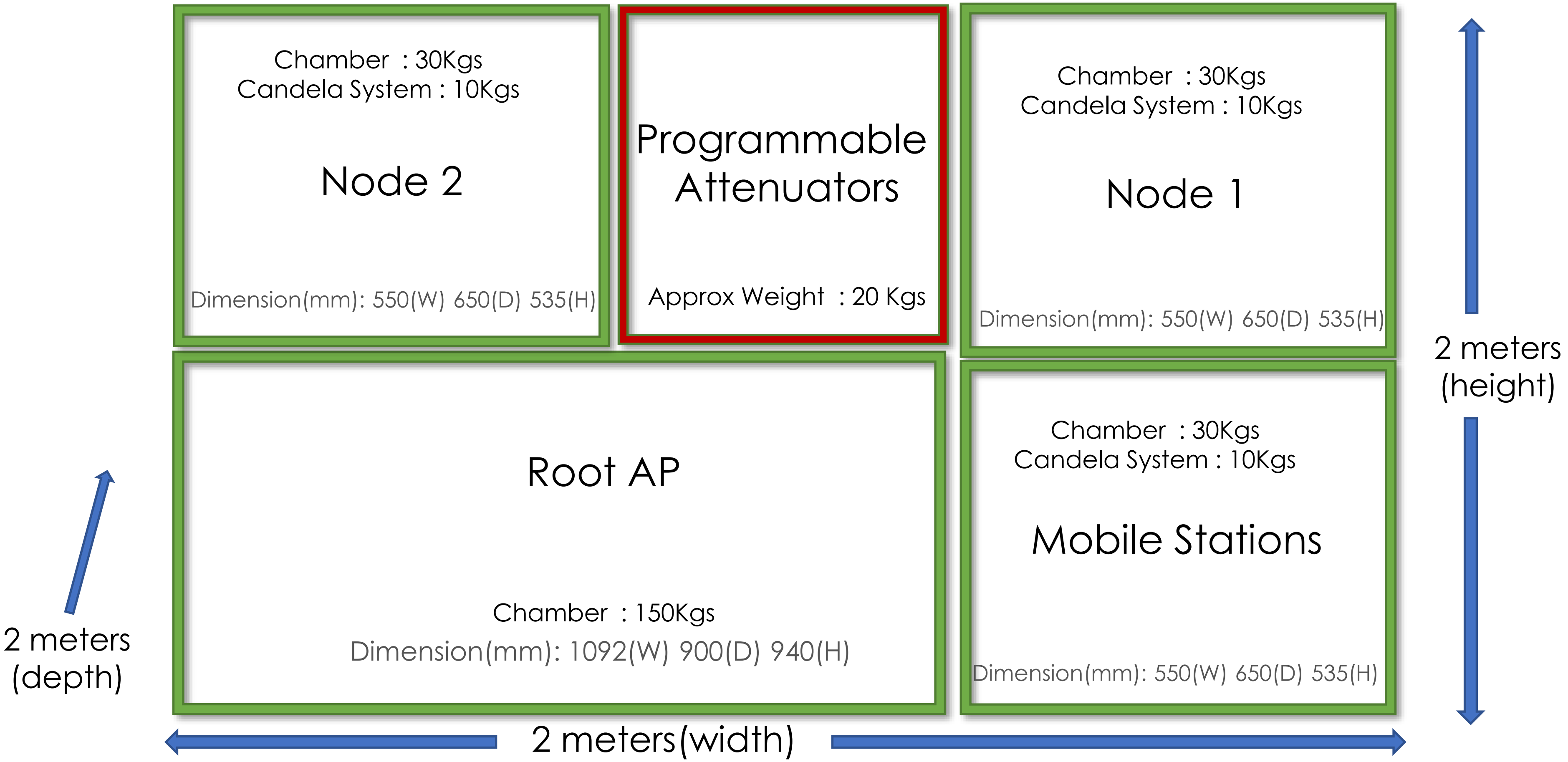
TR-398 + Star Topology Tested Example (Root AP + 4-Nodes)



TR-398 + 3-Node Mesh + 11ax Testbed

TR-398 + 3-Node Mesh + 11ax Testbed

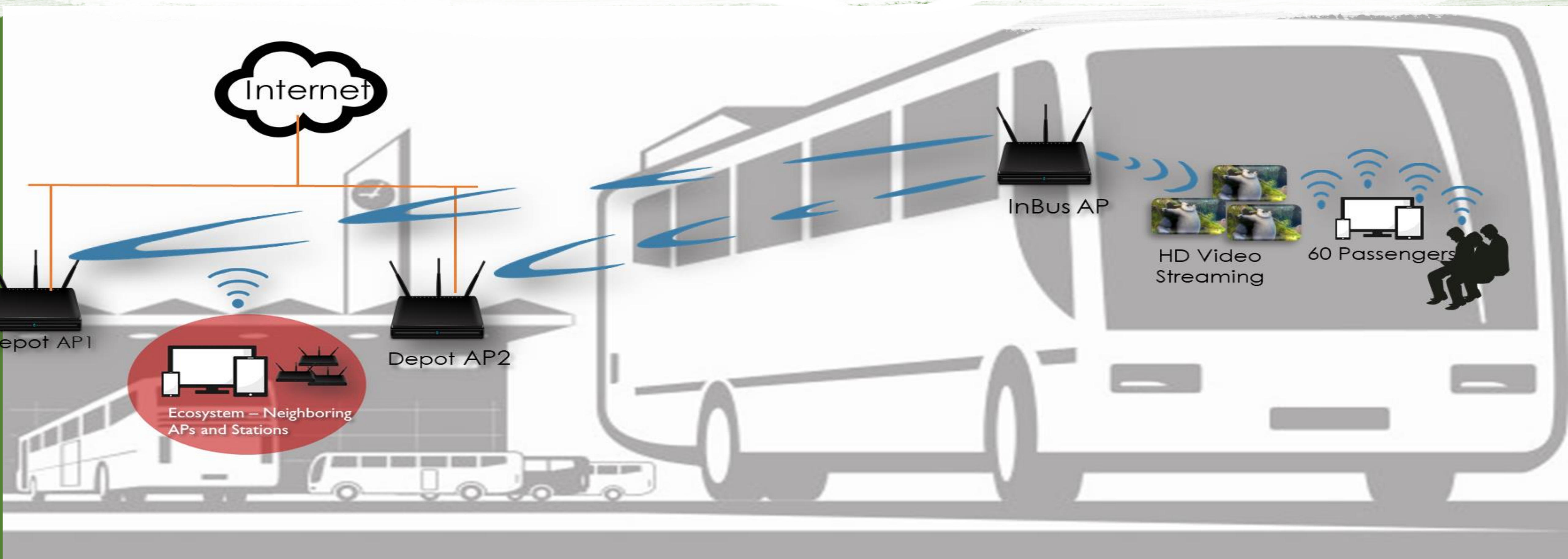
Total Testbed Approximate Weight : ~350 Kgs
Approx space required : 2 meters (width) x 2 meters (depth) x 2 meters (height)
No special power requirements.



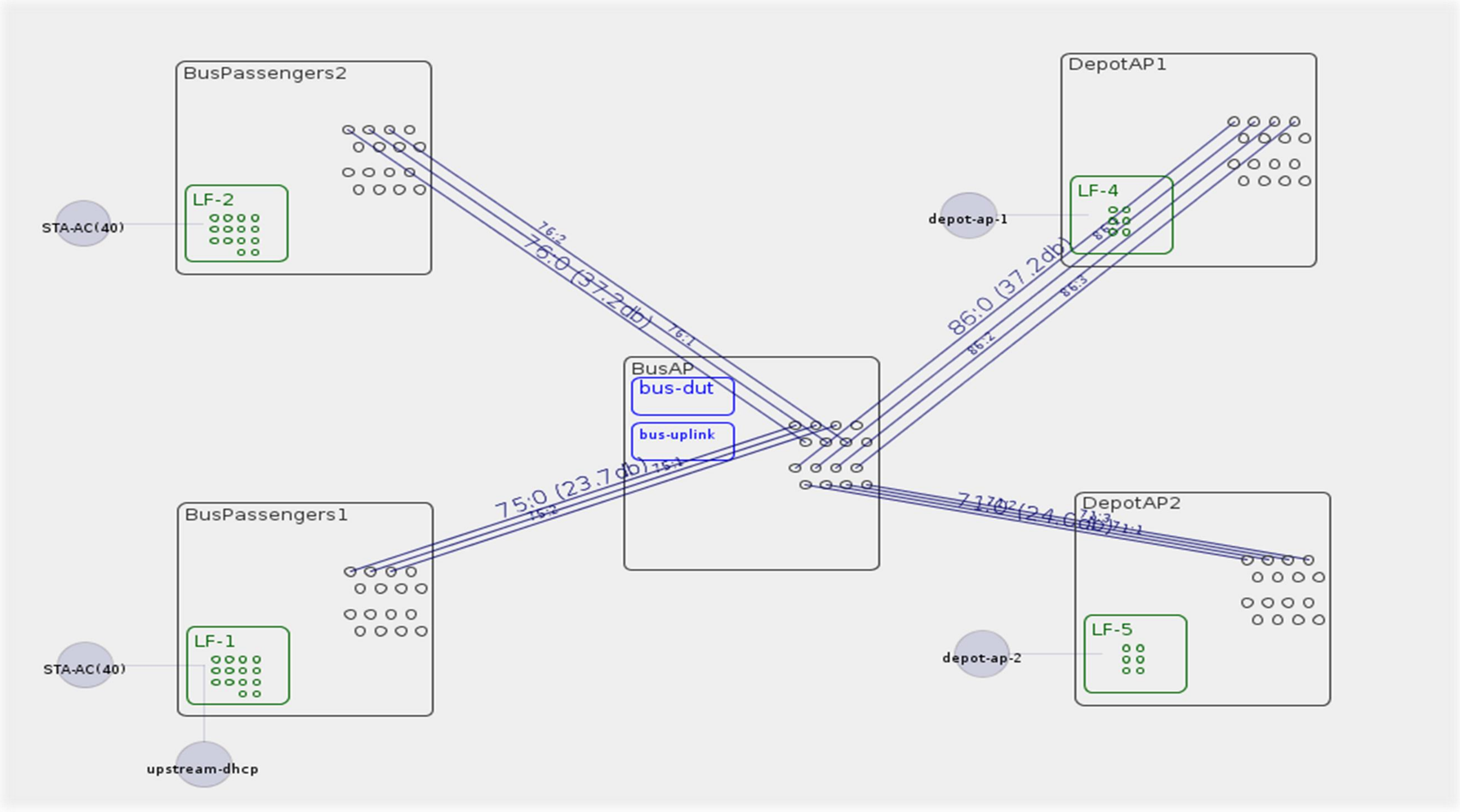
Tests that can be Covered

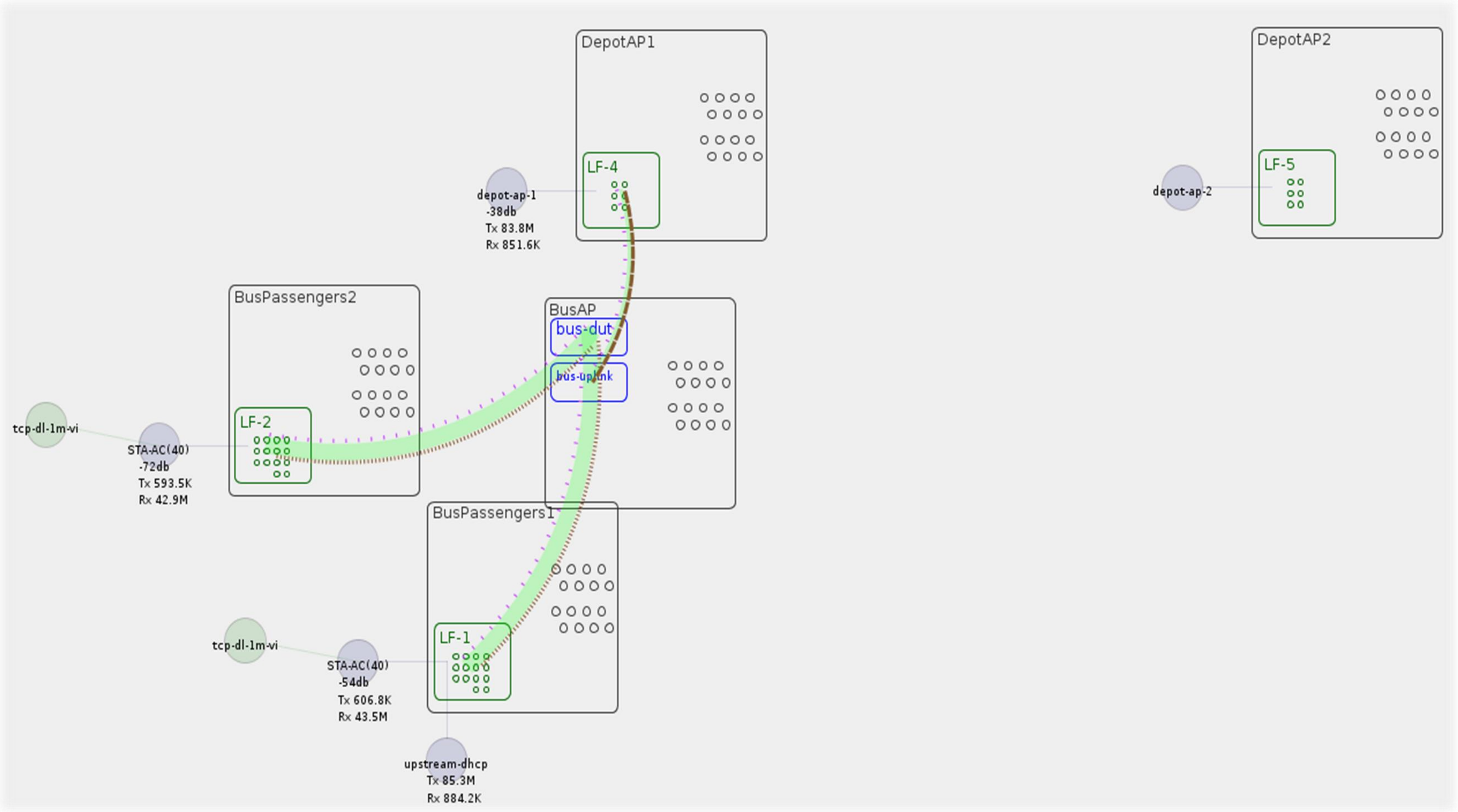
- ✓ **Full Automated TR-398 – 30 hours**
  - ✓ 6.1.1 Receiver Sensitivity Test
  - ✓ 6.2.1 Maximum Connection Test
  - ✓ 6.2.2 Maximum Throughput Test
  - ✓ 6.2.3 Airtime Fairness Test
  - ✓ 6.3.1 Range Versus Rate Test
  - ✓ 6.3.2 Spatial consistency test
  - ✓ 6.4.1 Multiple STAs Performance Test
  - ✓ 6.4.2 Multiple Association/Disassociation Stability Test
  - ✓ 6.4.3 Downlink MU-MIMO Performance Test
  - ✓ 6.5.1 Long Term Stability Test
  - ✓ 6.5.2 AP Coexistence Test
- ✓ **Fully Automated Mesh Tests – 100s of hours**
  - ✓ Mesh Throughput per hop
  - ✓ Mesh Roaming
  - ✓ Performance with various combinations of AP node placements, load pattern etc..
  - ✓ Failover test scenarios
- ✓ **802.11ax Testing**
  - ✓ Functional + Performance
  - ✓ Throughput, latency, mixed mode client performance
  - ✓ OFDMA, Mu-MIMO testing
- ✓ **User Scenario Test Automation – 100s of hours**
  - ✓ Connection Stability test
  - ✓ Multiple traffic stress test
  - ✓ Stress test with active call sessions
  - ✓ Connection stability with MBSSID mode
  - ✓ Client Initiated roaming
  - ✓ Random connect/disconnect test
  - ✓ Video, voice and data traffic stress test
  - ✓ Random connect/disconnect of clients of a radio
- ✓ **Fully Automated Candela Tests – 100s of hours**
  - ✓ WiFi Client Capacity Test
  - ✓ Dataplane Performance Test
  - ✓ Rate vs Range vs Antenna Orientation Test
  - ✓ Client Reset Test
  - ✓ Roaming Test
  - ✓ Band Steering Test
  - ✓ QoS Performance Test
- ✓ **Feature Testing**
  - ✓ Hotspot 2.0 / EAP-SIM/EAP-AKA
  - ✓ Captive Portal Login
  - ✓ EIRP (AP Tx power, Reg Domain Testing)
  - ✓ Speedtest.Net testing
- ✓ **Other Test Scenarios**
  - ✓ Gaming Test Scenarios
  - ✓ Testing WiFi client devices
  - ✓ Video performance Testing – Video streaming
  - ✓ Application Performance with WAN emulation

Transportation Test Scenario

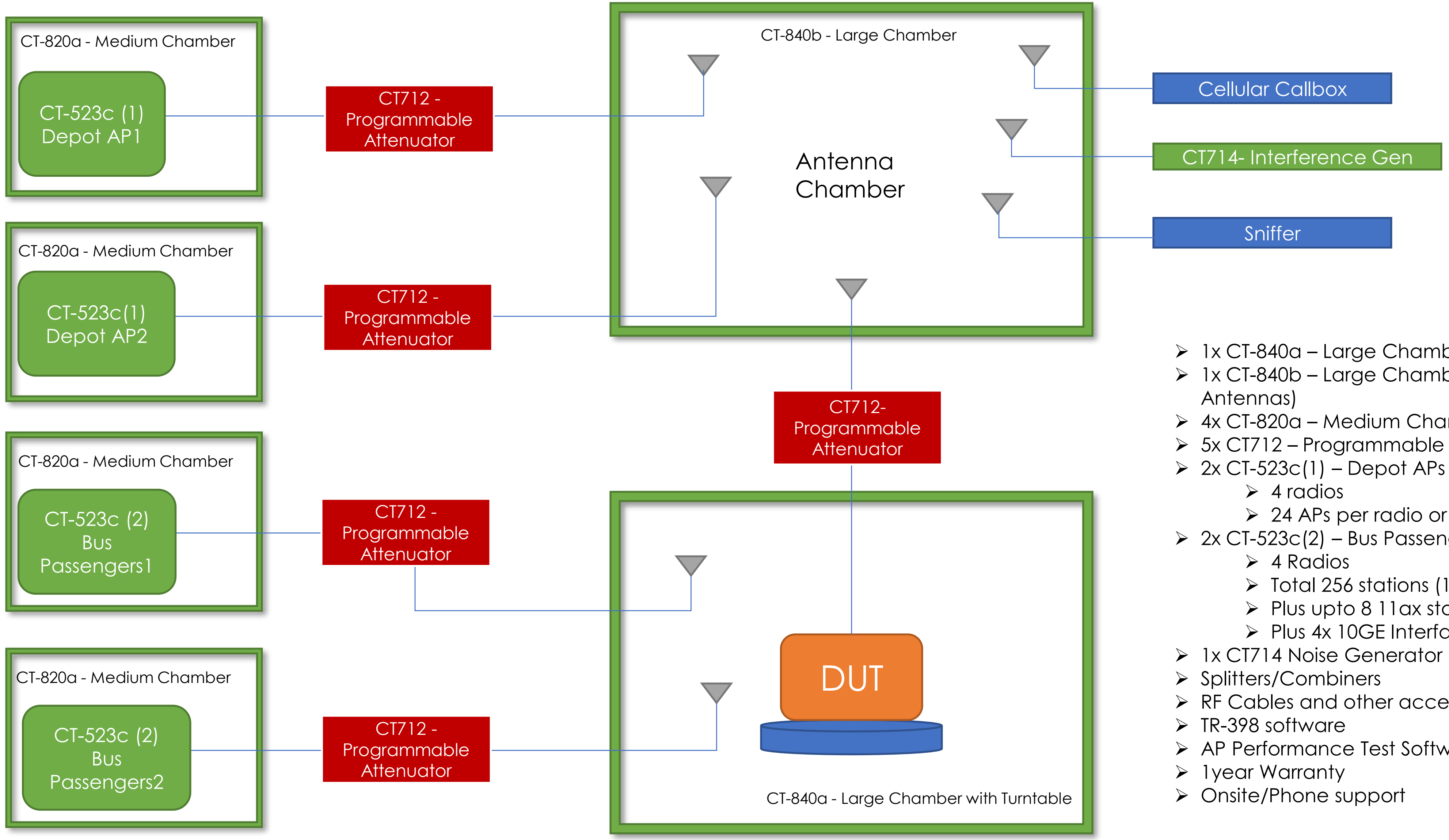



Candela TECHNOLOGIES
BUS PASSENGERS2
BUS PASSENGERS1
BUS AP (DUT)
DEPOT AP1
DEPOT AP2


BusPassengers2
LF-2
STA-AC(40)
76:2
76:0 (37.2db)
76:1
DepotAP1
LF-4
depot-ap-1
86:0 (37.2db)
86:2
86:3
BusAP
bus-dut
bus-uplink
75:0 (23.7db)
75:1
75:2
71:0 (24.0db)
71:2
71:3
71:1
BusPassengers1
LF-1
STA-AC(40)
upstream-dhcp
DepotAP2
LF-5
depot-ap-2


DepotAP1
LF-4
depot-ap-1
-38db
Tx 83.8M
Rx 851.6K
DepotAP2
LF-5
depot-ap-2
BusPassengers2
LF-2
BusAP
bus-dut
bus-uplink
tcp-dl-1m-vi
STA-AC(40)
-72db
Tx 593.5K
Rx 42.9M
BusPassengers1
LF-1
tcp-dl-1m-vi
STA-AC(40)
-54db
Tx 606.8K
Rx 43.5M
upstream-dhcp
Tx 85.3M
Rx 884.2K

WiFi Transportation Testbed



- 1x CT-840a – Large Chamber with Turntable (for DUT)
- 1x CT-840b – Large Chamber without Turntable (for Antennas)
- 4x CT-820a – Medium Chambers
- 5x CT712 – Programmable Attenuators
- 2x CT-523c(1) – Depot APs
  - 4 radios
  - 24 APs per radio or 64 stations per radio
- 2x CT-523c(2) – Bus Passengers
  - 4 Radios
  - Total 256 stations (128 in 5GHz and 128 in 2.4GHz)
  - Plus upto 8 11ax stations
  - Plus 4x 10GE Interfaces
- 1x CT714 Noise Generator
- Splitters/Combiners
- RF Cables and other accessories
- TR-398 software
- AP Performance Test Software
- 1year Warranty
- Onsite/Phone support

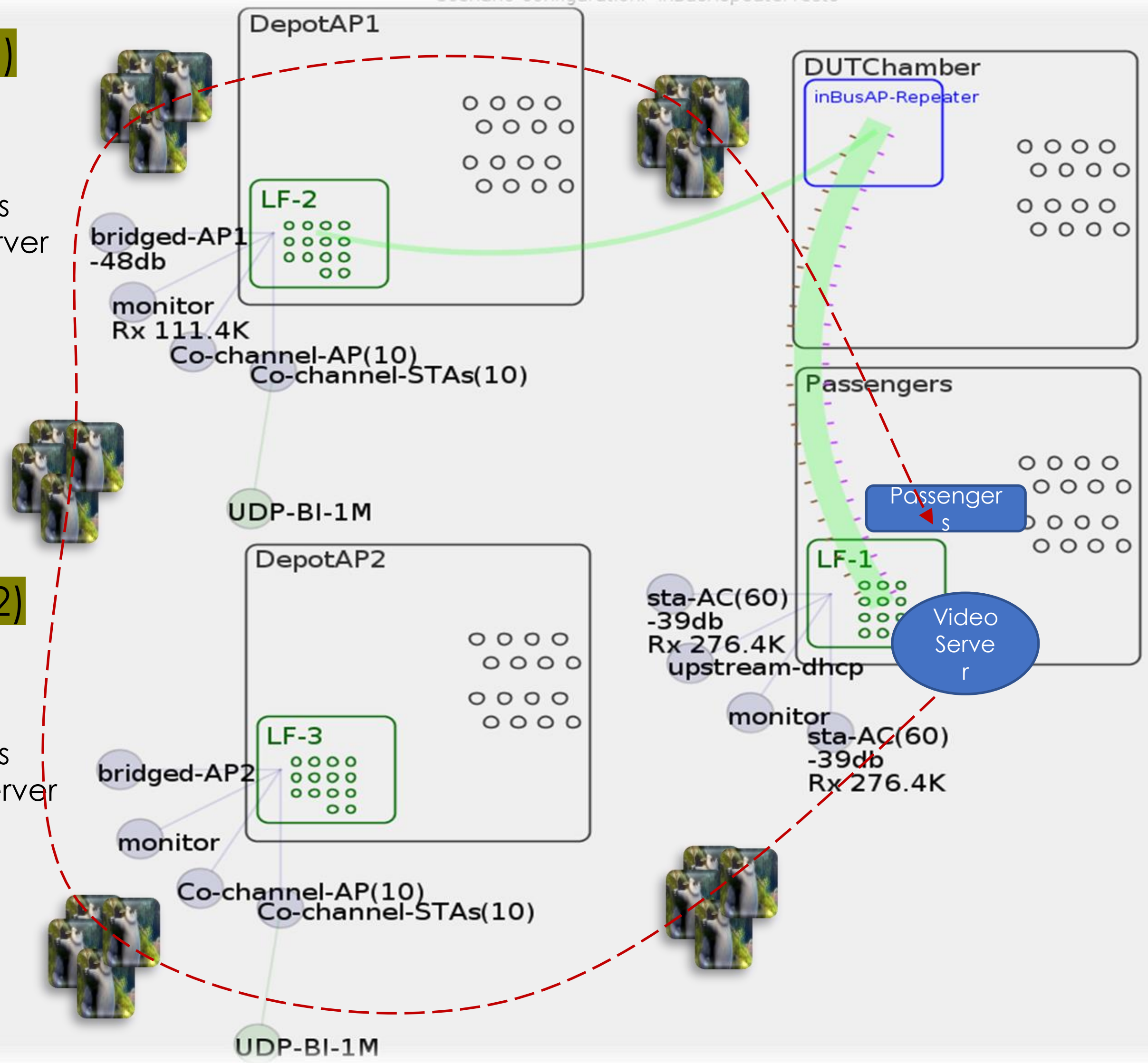
TEST CONFIG IN THE LANforge GUI

LANForge-2 (Depot AP1)

- Radio1: Depot AP1
- Radio2: Sniffer
- Radio3: Co-channel APs
- Radio4: Co-channel STAs
- Eth1: Bridge to Video Server
- Eth0: Management

LANForge-3 (Depot AP2)

- Radio1: Depot AP2
- Radio2: Sniffer
- Radio3: Co-channel APs
- Radio4: Co-channel STAs
- Eth1: Bridge to Video Server
- Eth0: Management

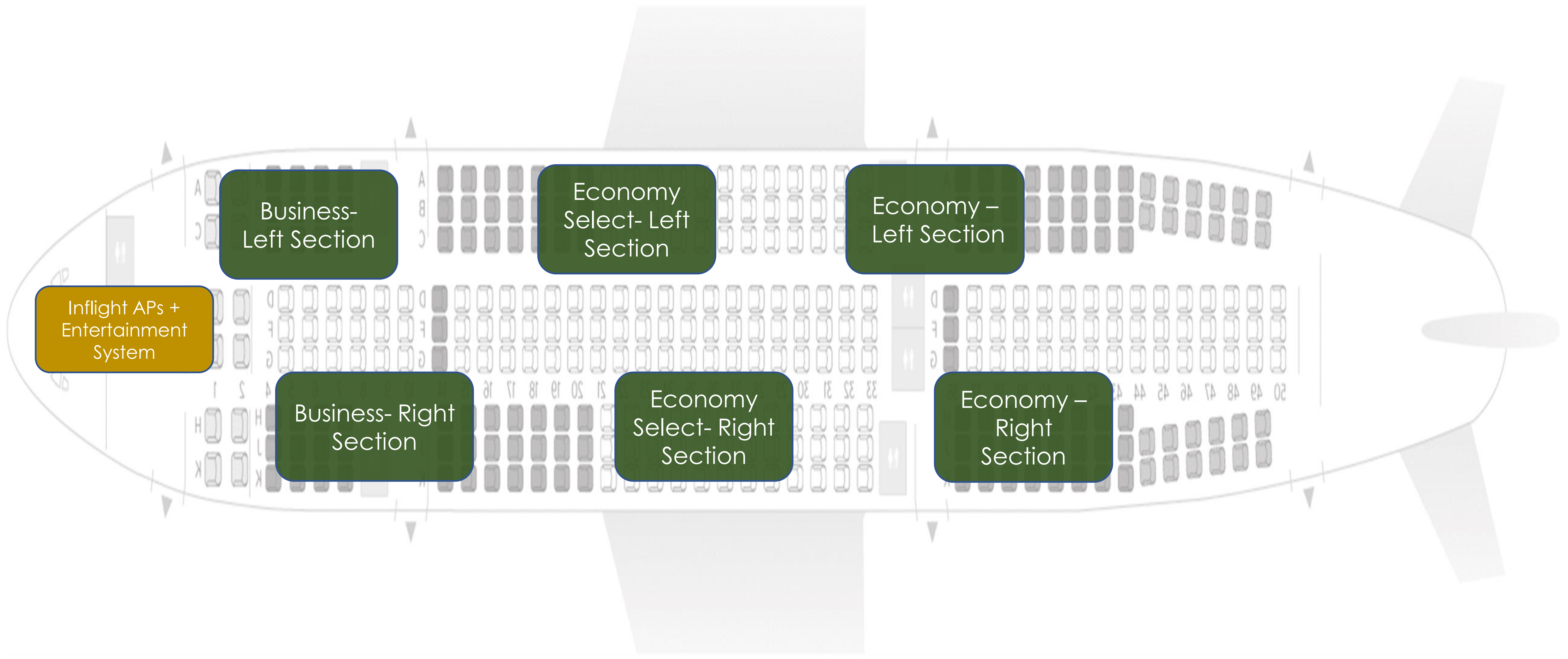


LF-1 (Bus Passengers)

- Radio1: 60 Passengers
- Radio2: More Passengers
- Radio3: Sniffer
- Eth1: Video Server
- Eth0: Management

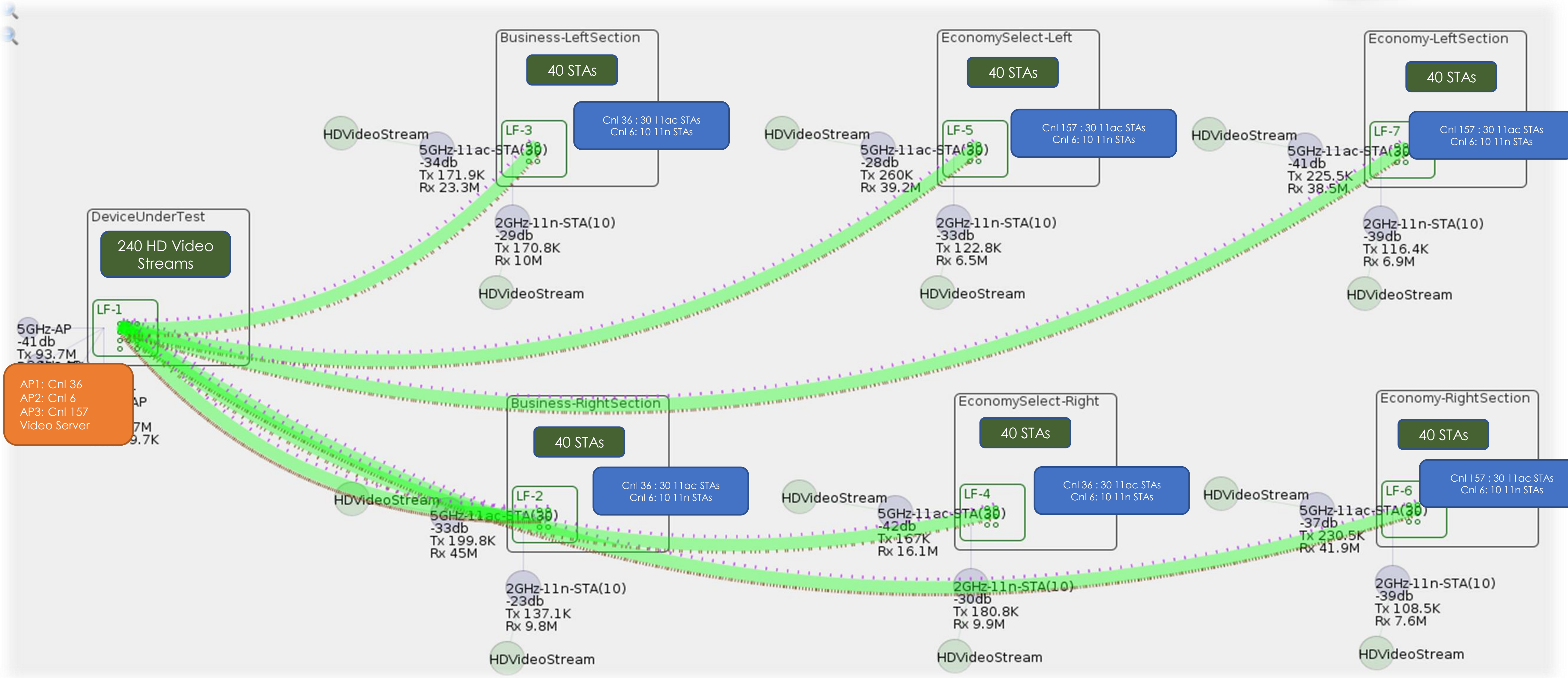
Large Public Venue Test Scenario

Example: Inflight Connectivity Scenario




ECONOMY
DEF
ECONOMY
ABC
ECONOMY
SELECT
ABC
ECONOMY
SELECT
DEF
BUSINESS
DEF
BUSINESS
ABC

TEST CONFIG IN THE LANFORGE GUI



Campus Network Testing

Campus Scenario

In most of the Campuses the Lecture Hall, Library and Cafeteria are the areas where large number of people uses WiFi network

Lecture Hall

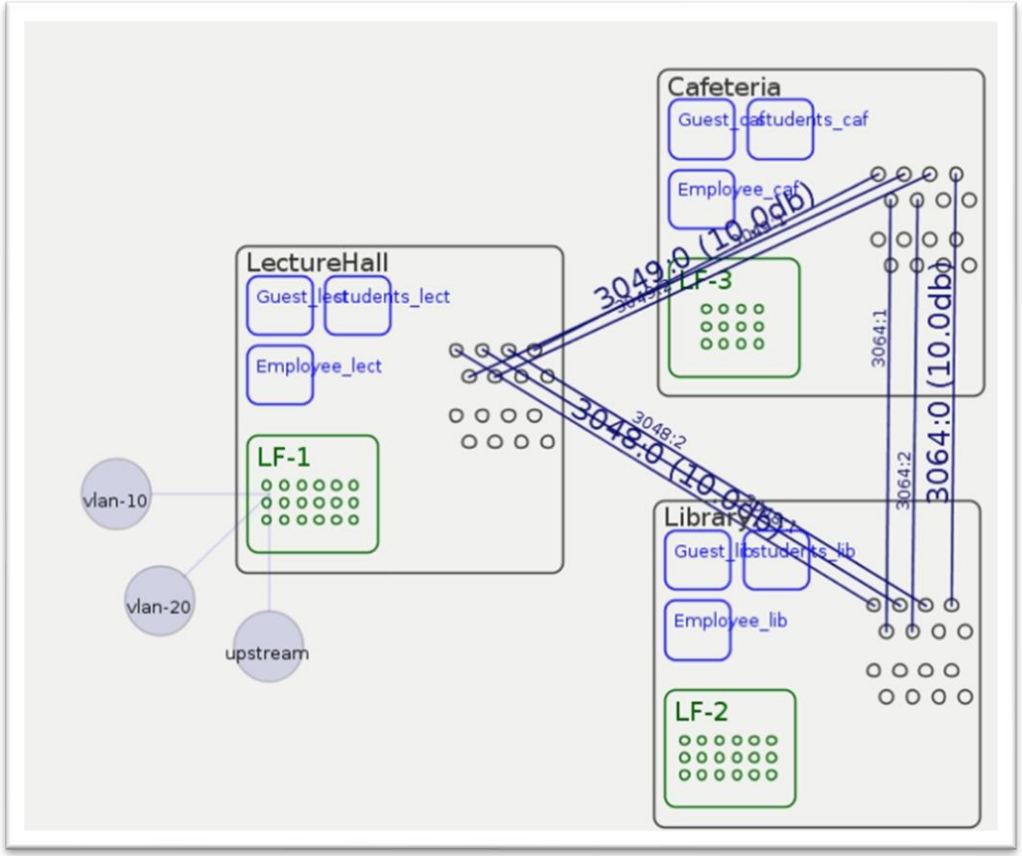
Cafeteria

Library

Campus Scale Scenario in LAB!!

3 Chambers 3 LANforge Units

15 Access Point 1024 Virtual Clients

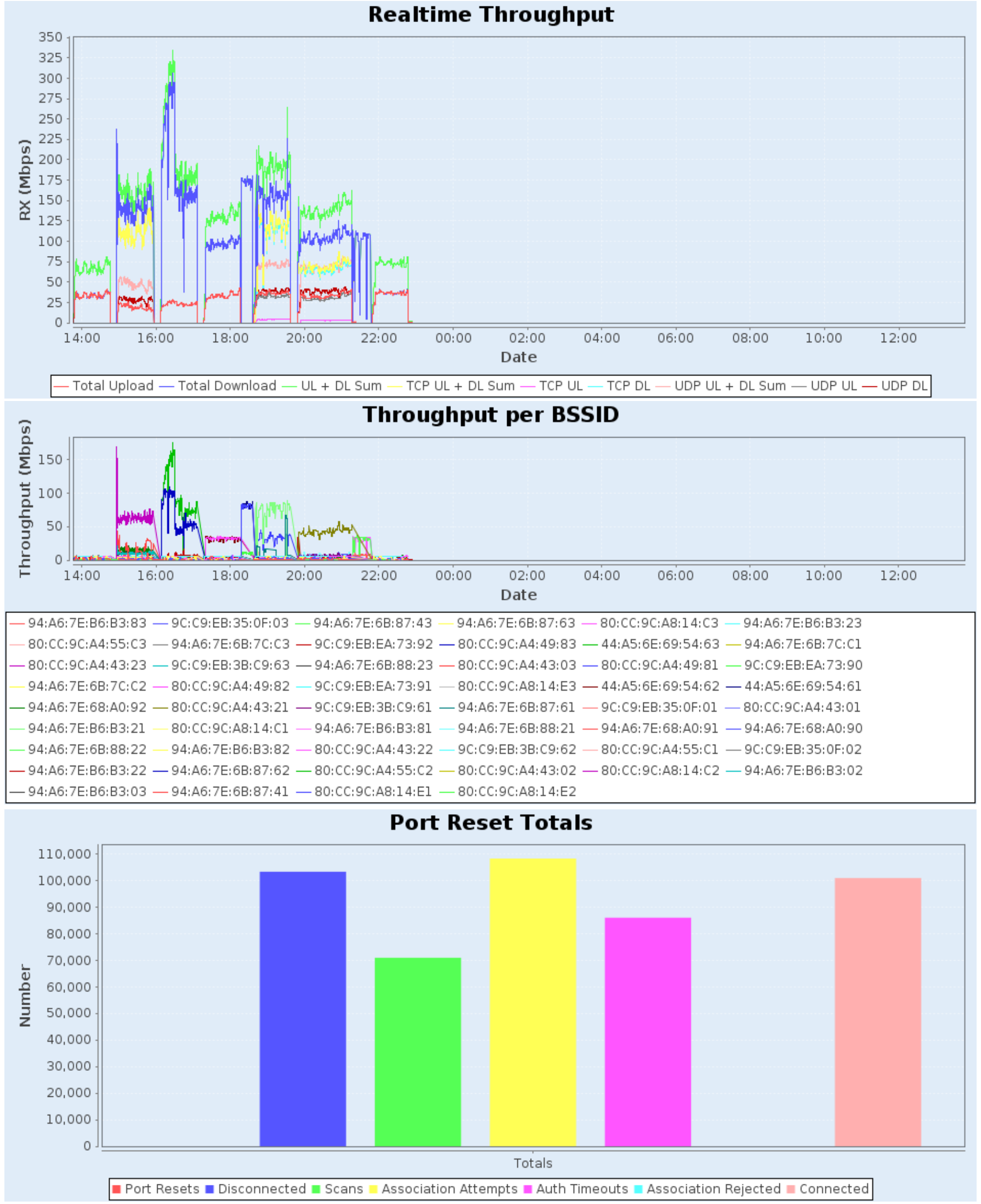


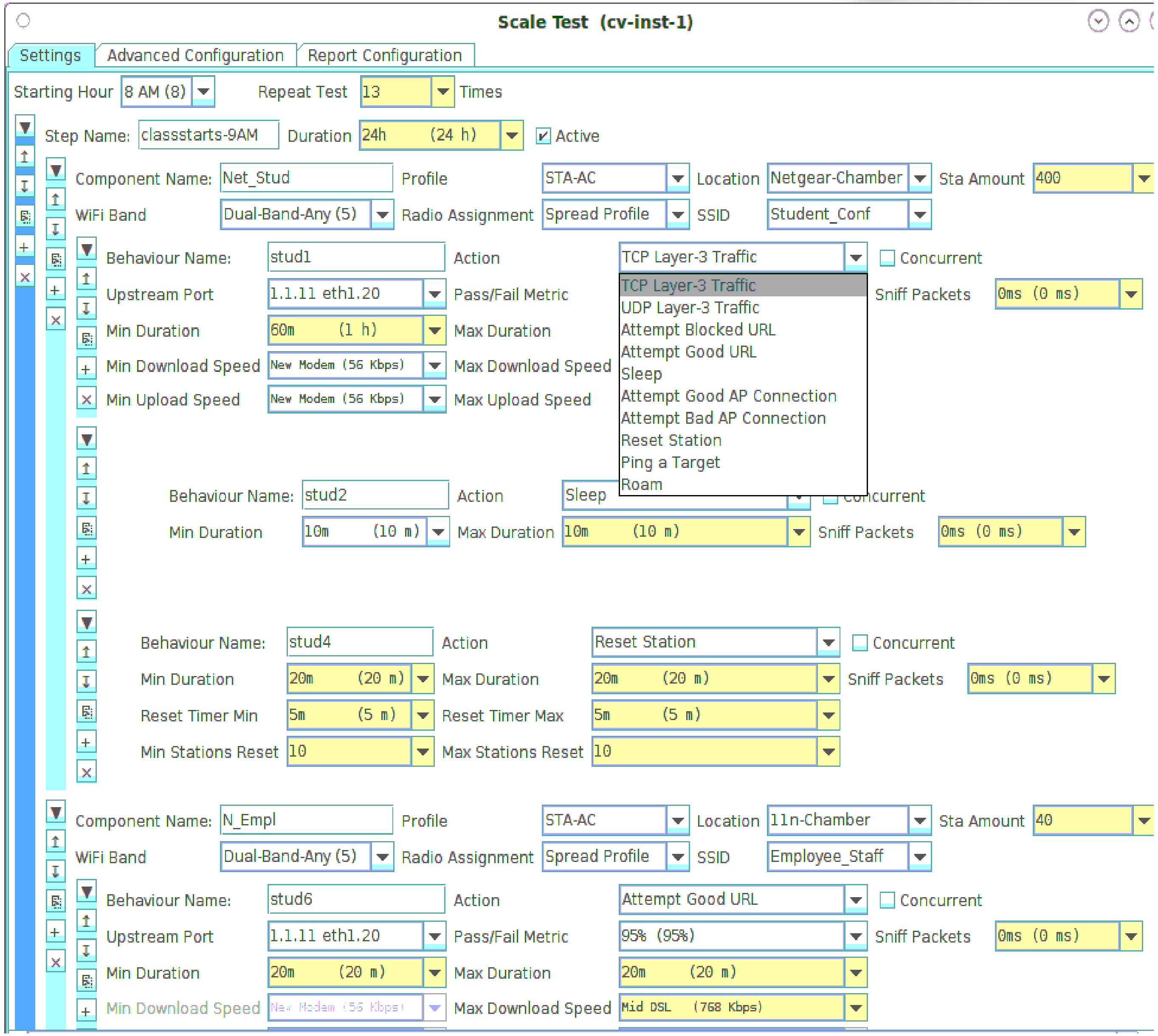
The 24 hour timeline

24 hr

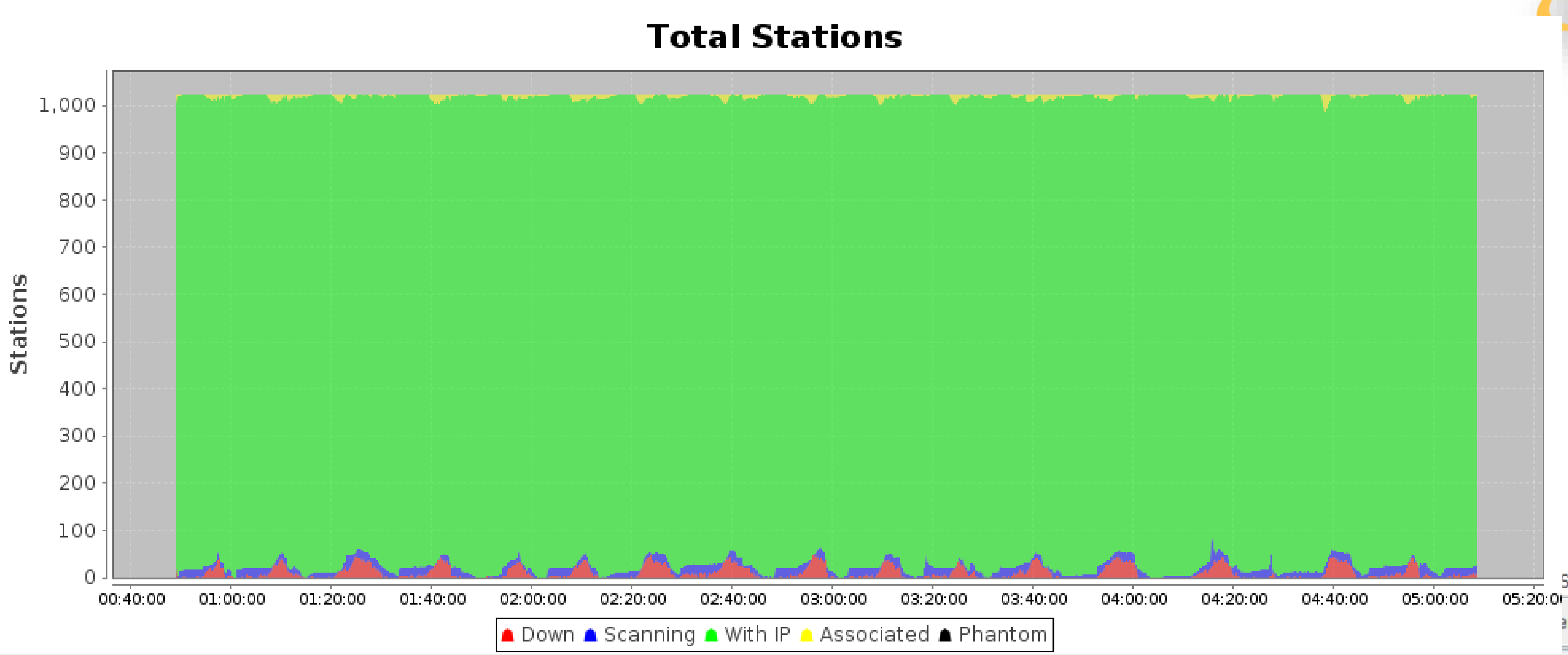
- 8:00 AM — Class Start: Run TCP traffic
- 9:00 AM — It is time to do some FTP download and accessing the URL
- 10:00 AM — Break: Roaming and Minimal traffic
- 10:30 AM — Accessing the URLs, https and blocked URLs
- 11:00 AM — Reset Station
- 12:00 PM — Ping the sessions and Run UDP Traffic
- 12:40PM — Lunch Break: Run the Minimal Background traiic
- 02:00PM — Continue the Maximum TCP Traffic
- 3:00 PM — Sleep
- 3:30PM — Run the FTP download, and webpage streaming
- 4:30PM — Combined traffic TCP/UDP with Roaming
- 5:00 PM — Sleep for next 15 hours with minimal traffic
- 8:00 AM — Class Start

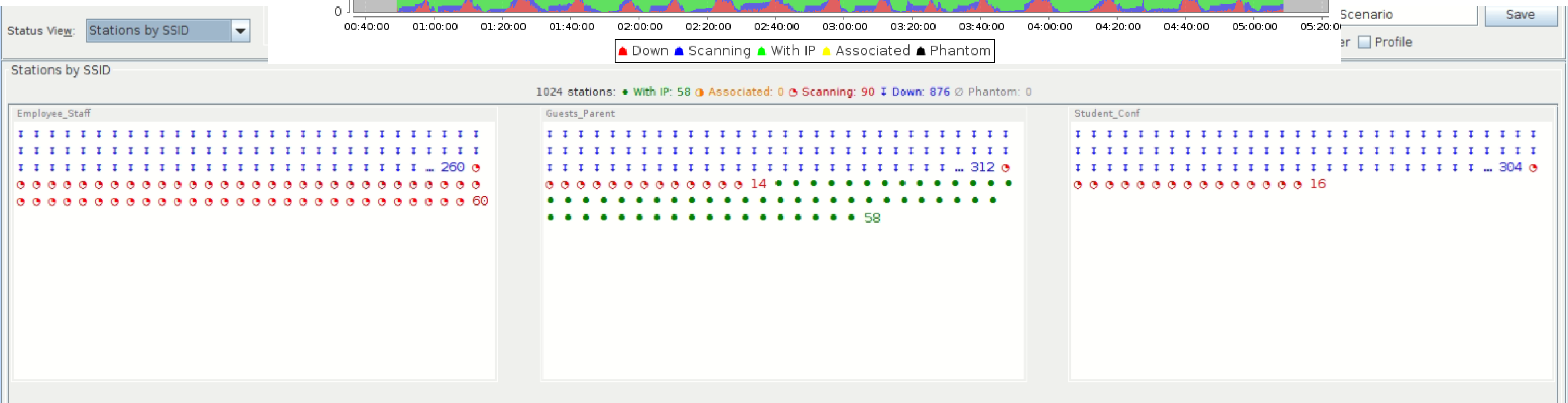
The Scale reports and configurations





The 1024 Clients Visualization





MDU/LPV Client Testbed Requirements

- ✓ Emulate lots of WiFi Stations
  - ✓ Mix of 11ax, 11ac and 11n stations
- ✓ Test lots of APs representing an entire campus.
  - ✓ APs across different channels, SSIDs, security types etc..
- ✓ Test with 1000s of real work traffic streams.
- ✓ Recreate various real work load scenarios in the lab.
  - ✓ Small/Medium size apt building
  - ✓ University Campus
  - ✓ Small and Medium Enterprise
  - ✓ Shopping Mall
  - ✓ Small/medium/Large Hotel
- ✓ Create various types of roaming/mobility patterns.
- ✓ Create groups of APs to test for load balancing
- ✓ Create application layer traffic to test DPI, device profiling, traffic shaping/policing functions on the AP.
- ✓ Test the controller dashboard
- ✓ Test location based analytics
- ✓ Automate 1000s of test cases and DUT configurations.

Example: University Campus Test Profile

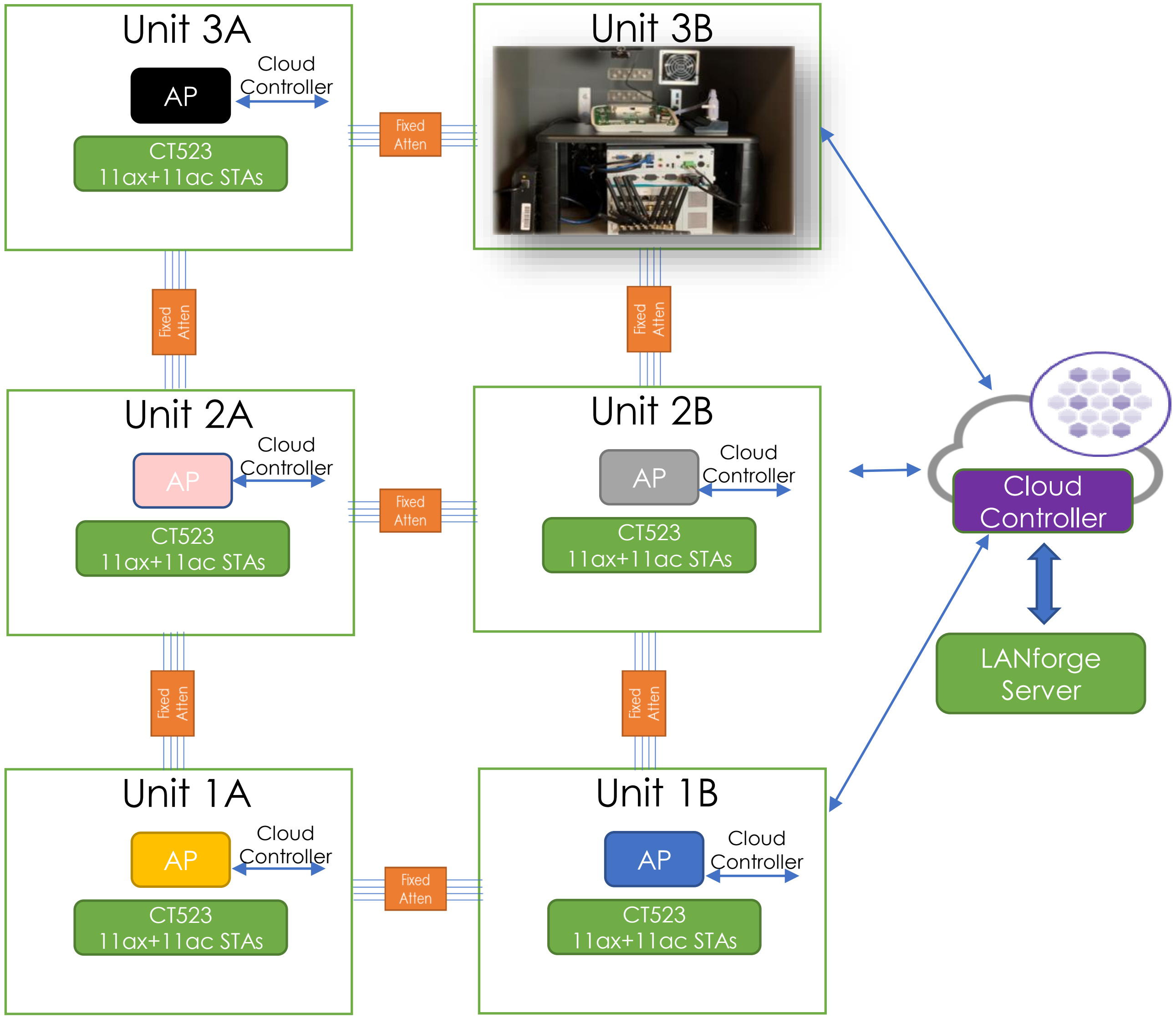
Day-in-the-Life of an University WiFi Network

- 08:00am – 12:00pm
  - ✓ 2000 devices connect to 50 APs across 25 classrooms.
  - ✓ 1000 students start browsing the internet for class research
  - ✓ 500 students watch online lectures
  - ✓ 500 university staff browse internet , place VOIP calls
- 12:00pm – 03:00pm
  - ✓ 1000 students move from classrooms to cafeterias and dorms causing lots of roams.
  - ✓ Students use their personal devices like smartphones and tablets of various kinds.
  - ✓ 200 devices of various kinds (POS terminals, scanners etc..) operate in the cafeterias.
- 03:00pm – 06:00pm
  - ✓ 500 students congregate in the indoor basket ball courts, watch real-time game scores and replays.
  - ✓ 200 students meet in the library and do online research for class projects.
- 06:00pm – 09:00pm
  - ✓ 1000 members are in the school theater participating in the school play and actively sharing details on social media.
  - ✓ 500 students participating in live voting and surveys for student body elections.
  - ✓ 500 students and staff watching soccer game and tweeting.

Key Performance Indicators

- ✓ Client Connection Times
- ✓ Connection Reliability / Uptime
- ✓ Performance over Distance
- ✓ Upload/Download Speeds
- ✓ Roaming Delays
- ✓ Network Latency
- ✓ File Download Times
- ✓ Voice Quality
- ✓ Video buffering and stalls
- ✓ Video streaming Quality
- ✓ Consistent quality over time.
- ✓ Policy Conformance.

Small MDU Testbed

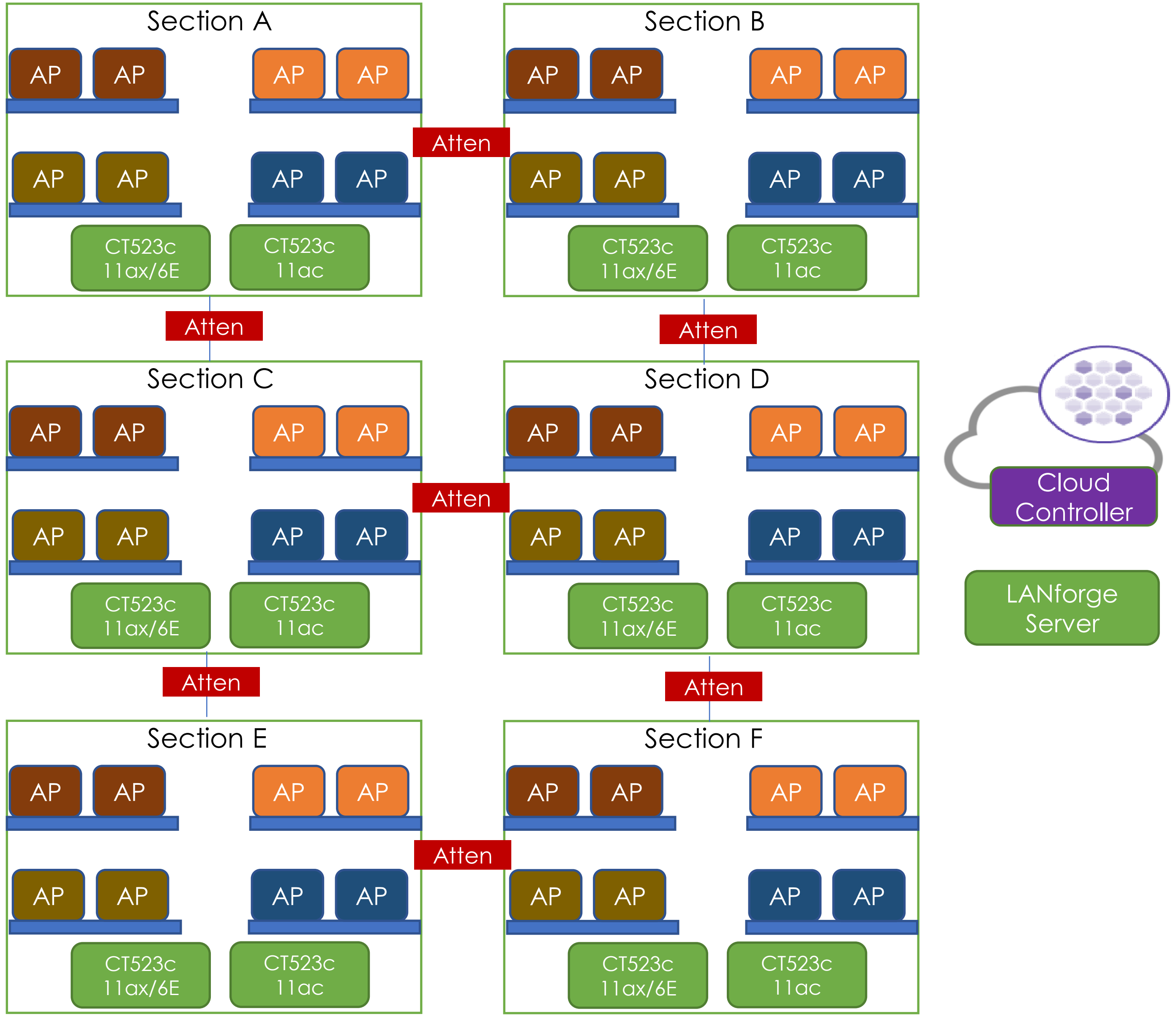


- ✓ 6 unit MDU scenario.
- ✓ All units have TIP APs connected to cloud controller.
- ✓ Create several 11ac, 11ax stations per AP.
- ✓ Test with voice, video, data traffic
- ✓ Day in the life test scenarios
- ✓ Test Interference scenarios
- ✓ Community WiFi test scenarios

Testbed BOM

- ✓ Hardware
  - ✓ CT-523c-8ax-ac2-dual-10GE – 6 units
  - ✓ CT820a Medium Chambers – 6 units
  - ✓ RF Cables and Antennas
- ✓ Software
  - ✓ SW1001m Traffic Stream Licenses
  - ✓ SW1001sta virtual station licenses
- ✓ Support/Warranty
  - ✓ 1-year hardware and software support

Large Public Venue Testbed

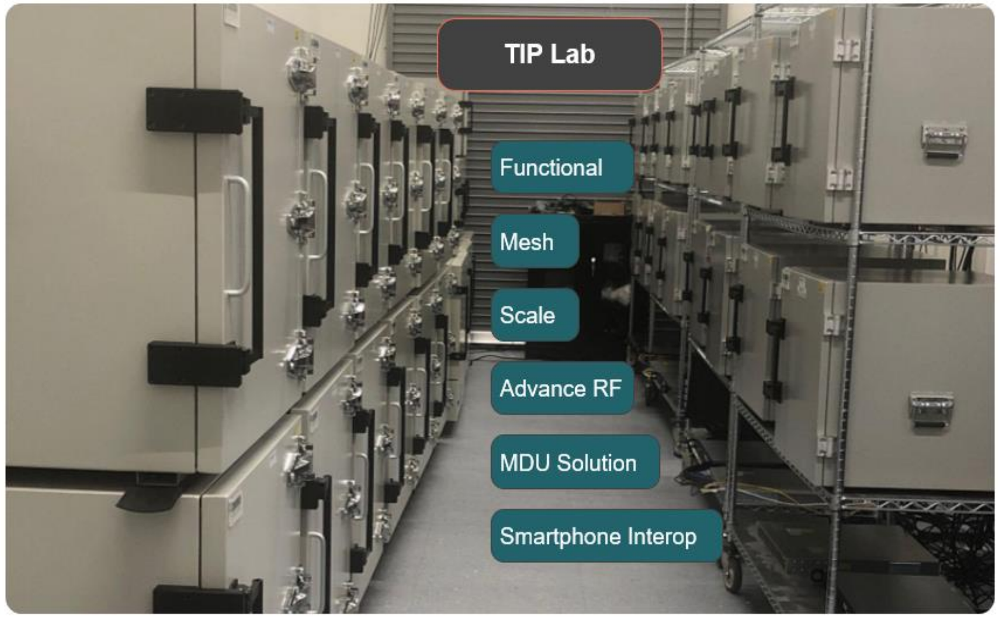


- ✓ Large Public Venue Testing Scenario with several APs.
- ✓ Testbed divided into 6 sections, represents the various physical sections in a large public venue.
- ✓ All units have TIP APs connected to cloud controller.
- ✓ Create 1000s of 802.11ac, 802.11n and 802.11ax clients.
- ✓ Test with voice, video, data traffic
- ✓ Roaming /Load Balancing / Band Steering
- ✓ Day in the life test scenarios
- ✓ Location Analytics Testing
- ✓ Device Profiling, User/Role based policy Management Testing
- ✓ Mis-behaving Client Behavior/ Rouge AP Testing

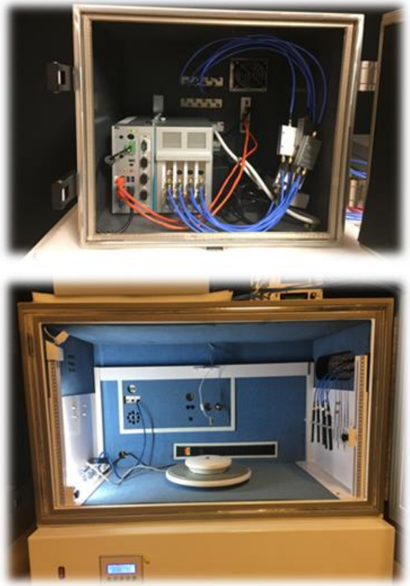
Testbed BOM

- ✓ Hardware
  - ✓ CT-523c-8ax – 6 units
  - ✓ CT523c-3ac-db-2n – 6 units
  - ✓ CT830a Large Chamber – 6 units
  - ✓ RF Cables and Antennas
- ✓ Software
  - ✓ SW1001m Traffic Stream Licenses
  - ✓ SW1001sta virtual station licenses
- ✓ Support/Warranty
  - ✓ 1-year hardware and software support

Community Labs using Candela Test Systems

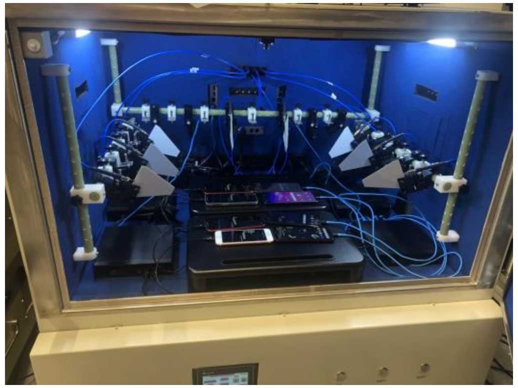


Basic Lab



Advanced Lab

WiFi 6E Lab



Inter-Op Lab

Mesh Lab

MDU Lab

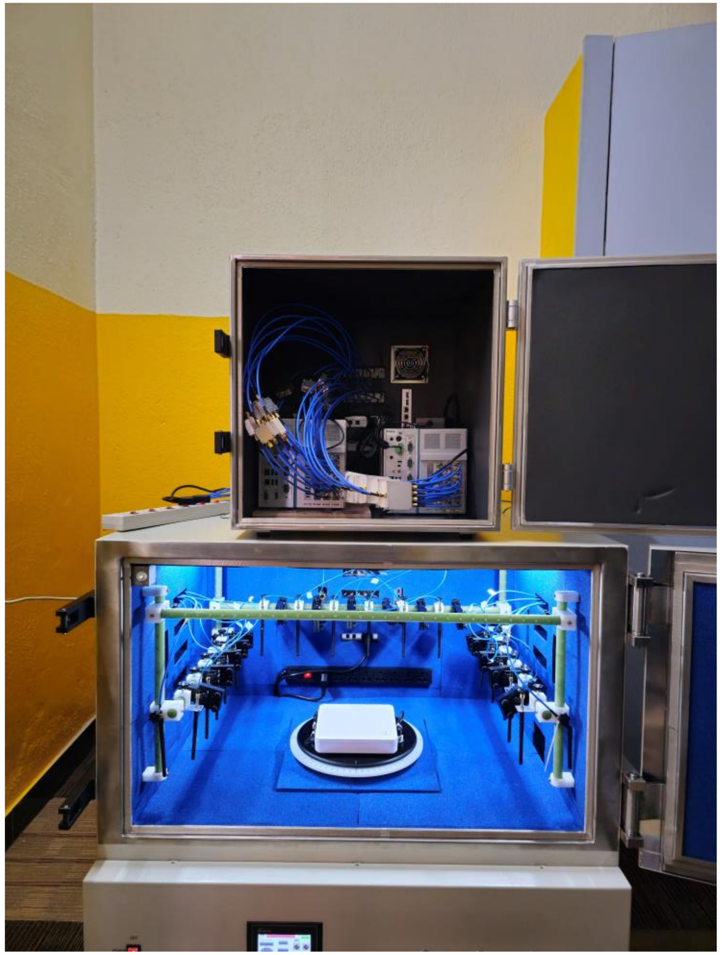
COMMUNITY LAB SETUP IN CALIFORNIA

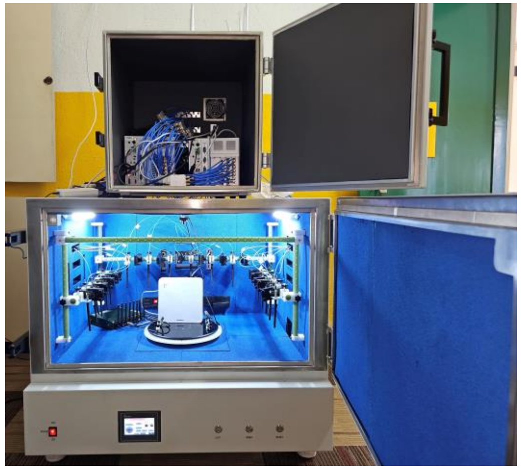
Lots of Lab Testbeds

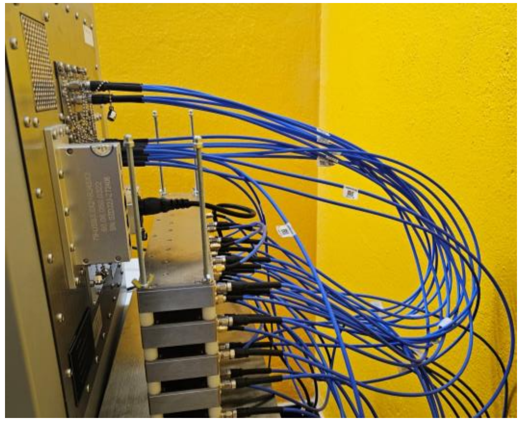
New OpenWiFi Community Lab

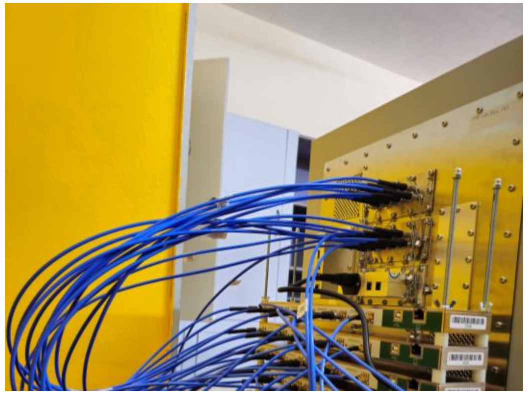
- Located in Bangalore, India
- Address: New polytechnic building, Acharya Institute Dr Sarvepalli Radhakrishnan Rd, Soladevanahalli, Karnataka 560107.
- Hosted by Candela Technologies India Pvt Ltd
- Full OpenWiFi lab testing services offered from this location.

Setting Up The TIP Testbeds in Candela India







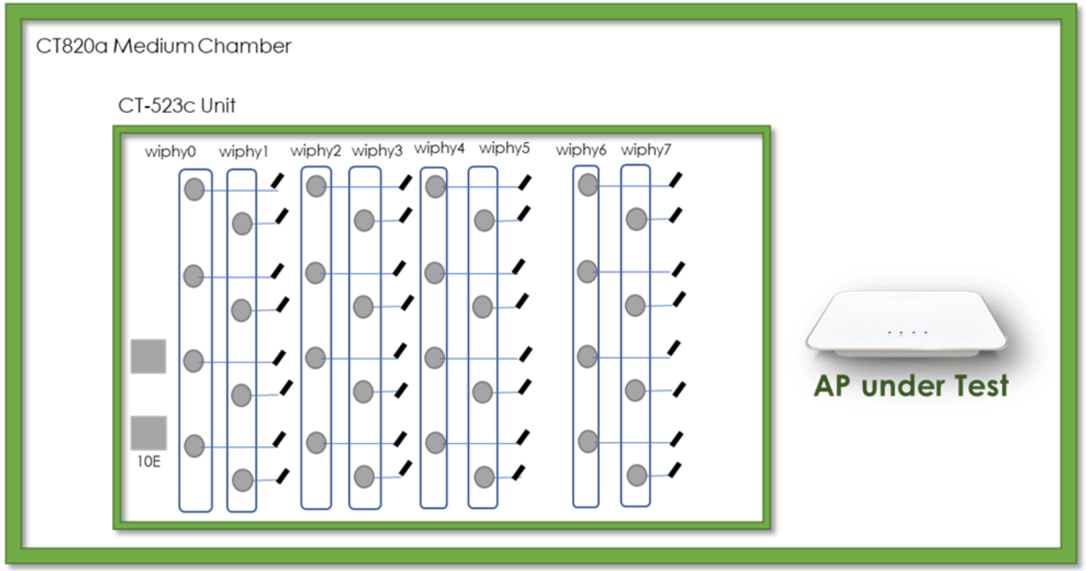


Testcases Summary

Testbed Type	Objective	Test Cases
Basic Testbeds	Run single AP functional/Performance Testing	• Client capacity/connection • Data plane throughput • Dual band performance • Airtime fairness
Advanced Testbeds	Full set of RF level and protocol level test cases on a single AP.	• Receiver sensitivity • Maximum connection / throughput • Airtime fairness, rate vs range • Spatial consistency • Multi STA performance • Downlink Mu-MIMO performance • AP co-existence
Mesh Testbeds	Full set of RF level and protocol level test cases on Mesh APs (Root + 2 Node configuration).	• Throughput per hop, client scale • Roaming, fail over scenarios • Performance over distance • Spatial consistency • Mesh Node Patterns
MDU Testbeds	Full set of RF level and protocol level test cases on a cluster of standalone APs in a high density/crowded environment deployments.	• Client scale • Large scale roaming • Large venue load patters • Traffic shaping/policy • Device profiling/analytics • Load balancing/band steering
WiFi 6E Testbeds	6GHz channels testing on WiFi 6E APs.	• 6 GHz RF performance • 6 GHz functional test cases • Triband Performance • 2.4/5GHz performance and functional tests on 6E APs

Basic Testbeds

Wiring Diagrams



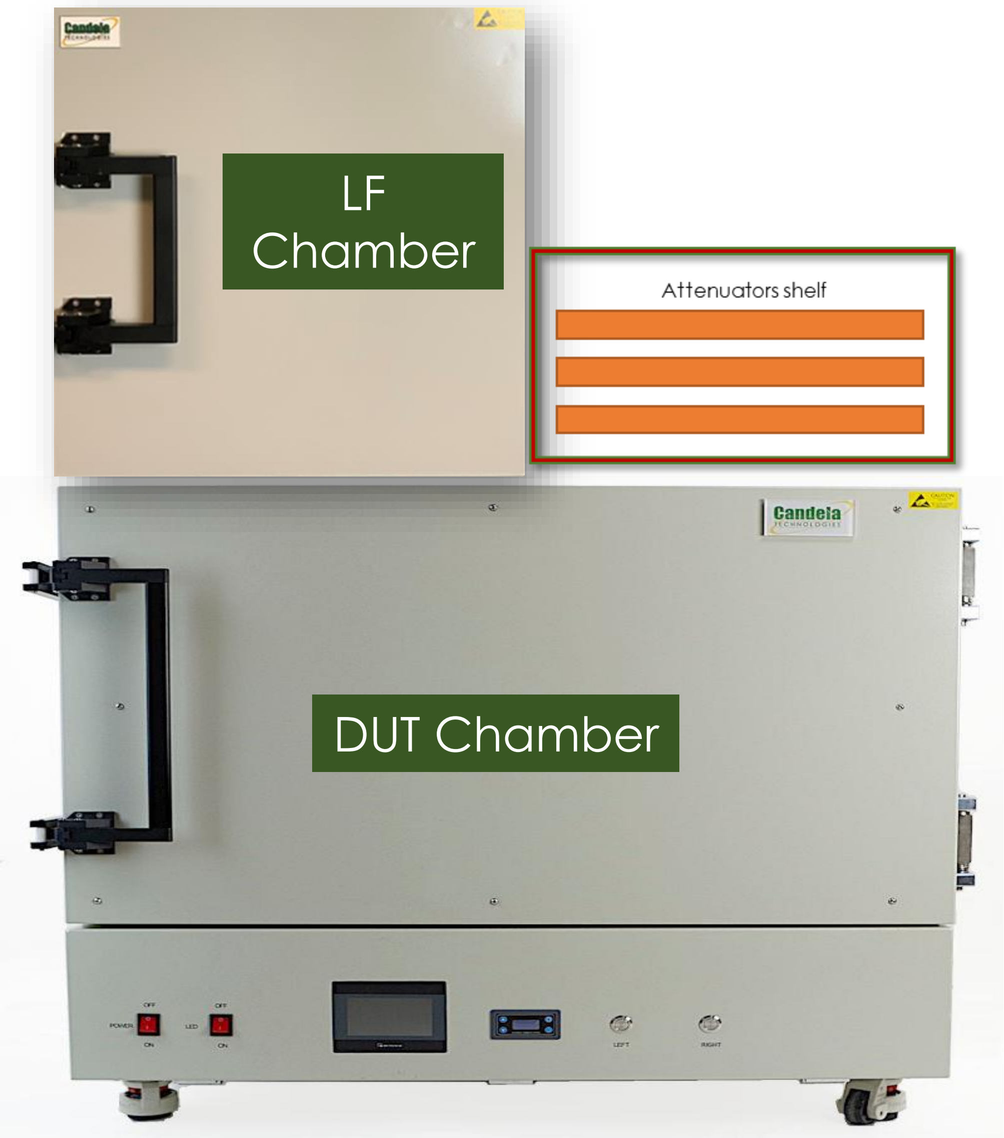
Bill of Materials

- ✓ Hardware
  - ✓ 4x4 MIMO 11ac Wave2 Single Band 5GHz radio – 2 units (64 clients per radio)
  - ✓ 4x4 MIMO 11ac Wave2 Single Band 2.4GHz radio – 2 units (64 clients per radio)
  - ✓ 2x2 MIMO 11ax dual band radio – 4 units (1 client per radio)
  - ✓ RF Enclosures
    - ✓ CT820a Medium Chamber – 1 unit
  - ✓ RF Cables
  - ✓ RF Antennas
- ✓ Software
  - ✓ SW1001m 1GE 1000 Traffic Stream Licenses
  - ✓ SW1100 10GE port
- ✓ Support/Warranty
  - ✓ 1-year hardware and software support

Basic Testbeds - Tests Covered

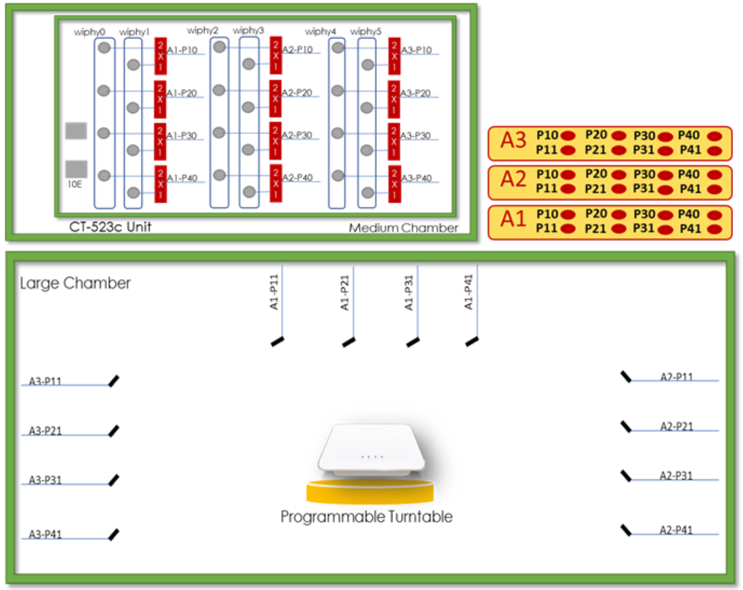
Test Types	Category	Testcase Summary
Dataplane Throughput Test	Performance	Verify the Performance of the AP by sending and receiving packets with different packet sizes.
Dual Band Test	Performance	Verify the performance of the AP by spreading the clients across multiple radios
Multi Station Throughput vs Pkt Sizes	Performance	Verify the Performance of the AP by sending and receiving packets with different packet sizes across different number of clients connected
Wifi Capacity	Performance	Verify the capacity of AP in maintaining concurrent number of clients which can take specific intended load.
Rate Limiting	Functional	Verify that the Client connected on an SSID is rate limited according to the configuration specified
Rate Limiting with Radius	Functional	Verify that the Client connected on an SSID is rate limited according to the configuration specified in radius for the specific user.
Multiple VLAN's	Functional	Verify the connectivity and Datapath for the clients connected across different Vlans
Multi Association Disassociation Test	Performance	Verify the impact on throughput for certain clients when another set of clients joins and leaves the BSS.
Basic Client Connectivity	Functional	Verify that the client can associate and establish Datapath under different configurations and types.
FTP Test	Scale	Verify how many concurrent clients can simultaneously do an Upload and Download test in given time

Advanced Testbeds (11ac)



Bill of Materials

- ✓ Hardware
  - ✓ 4x4 MIMO 11ac Wave2 Single Band 5GHz radio – 3 units (64 clients per radio)
  - ✓ 4x4 MIMO 11ac Wave2 Single Band 2.4GHz radio – 3 units (64 clients per radio)
  - ✓ RF Enclosures
    - ✓ CT820a Medium Chamber – 1 unit
    - ✓ CT840a Large Chamber with Turntable – 1 unit
  - ✓ CT714 Programmable Attenuators – 3 units
  - ✓ 2x1 Splitters – 12 units
  - ✓ RF Cables – (not included in quote, provided at no cost)
  - ✓ RF Antennas –(not included in quote, provided at no cost)
- ✓ Software
  - ✓ SW1001m 1GE 1000 Traffic Stream Licenses
  - ✓ SW1100 10GE port
  - ✓ SW1001sta virtual station
- ✓ Support/Warranty
  - ✓ 1-year hardware and software support

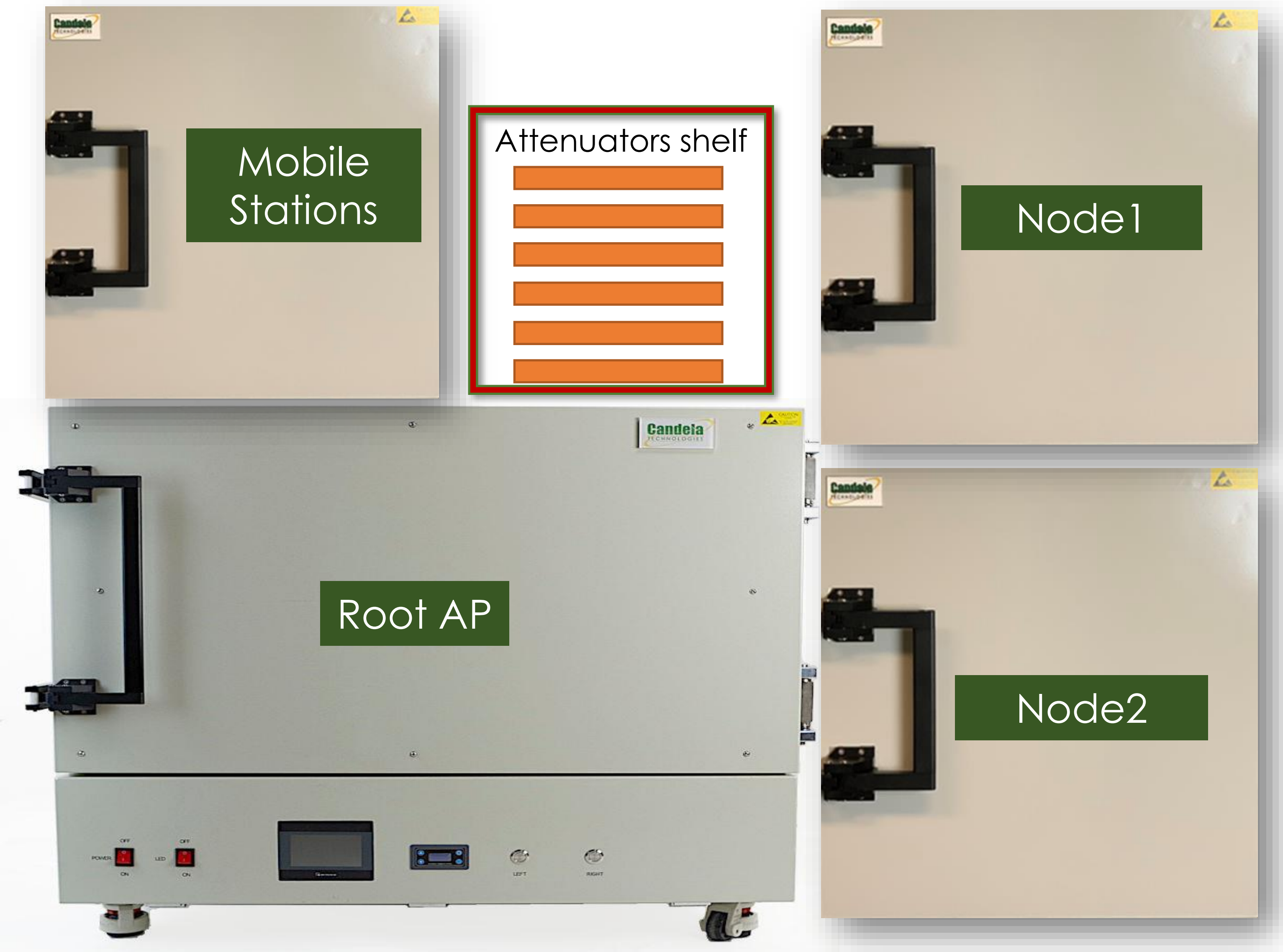


Tests Covered

All Test case from Basic Testbed plus

Test Types	Category	Testcase Summary
Rate vs Range	Performance	Verify the Performance by varying the Distance between AP and client
Spatial Consistency	Performance	Verify the Performance of the AP by changing Orientation and Distance between AP and Station.
Multi Station Performance - Different Distance	Performance	Verify the performance of the AP by spreading the clients at different distances
Rate vs Orientation	Performance	Verify the performance by changing the orientation of AP
Airtime Fairness	Performance	Verify the airtime distribution based on performance in multi station environment with different wifi capability clients.
RX - Sensitivity	Performance	Verify Radio receiver performance to check with different MCS configurations

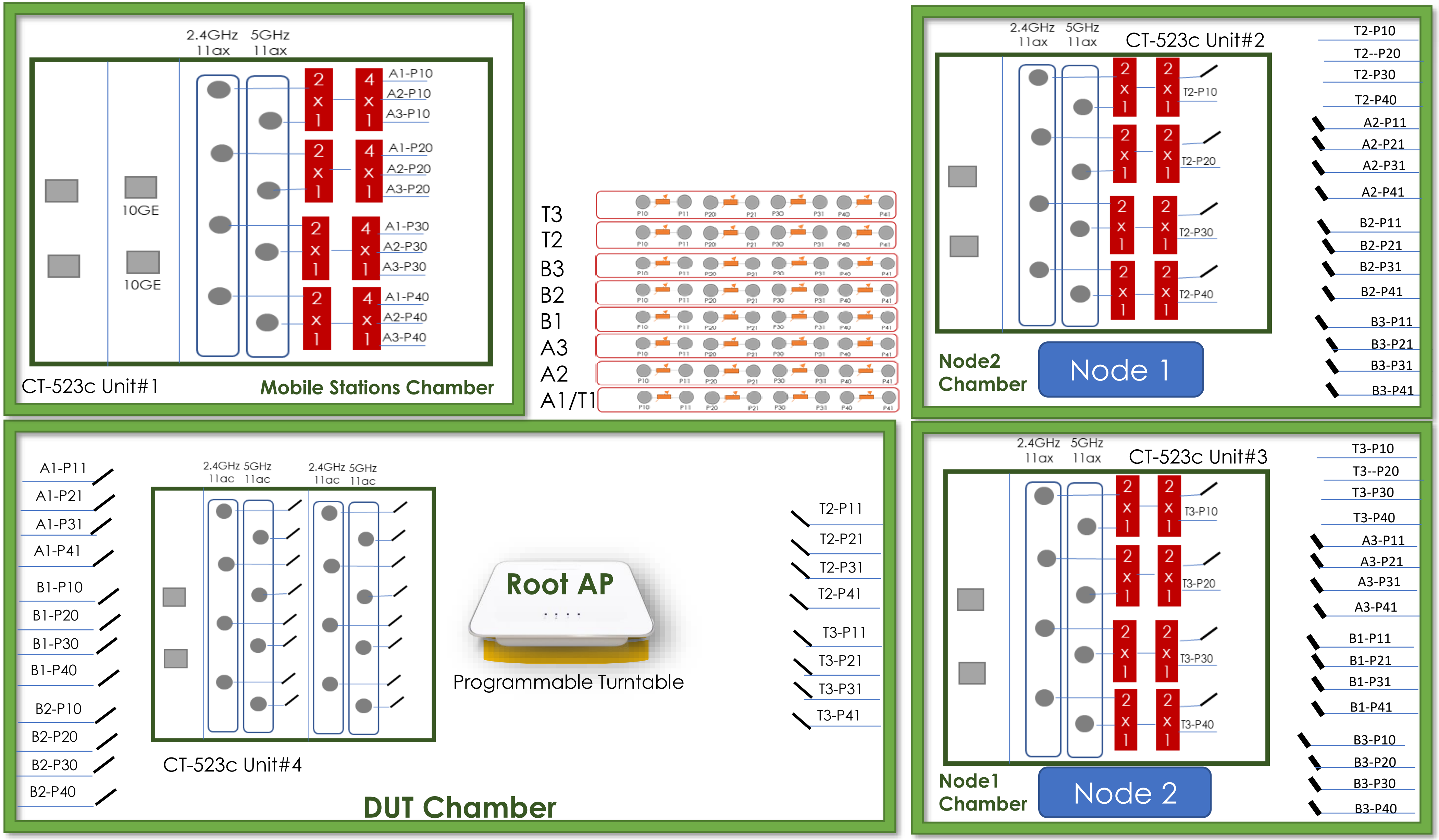
Advanced Testbed + 11ax + 2-Node Mesh Testbed Diagram



Bill of Materials

- ✓ Hardware
  - ✓ Chassis CT-523c-2ax4-db-10GE – 1 units
  - ✓ Chassis CT-523c-2ax4-db – 2 units
  - ✓ Chassis CT-523c-4ac2-db – 1 unit
  - ✓ RF Enclosures
    - ✓ CT820a Medium Chambers – 3 units
    - ✓ CT840a Large Chamber with Turntable – 1 unit
  - ✓ CT714 Programmable Attenuators – 8 units
  - ✓ 4x1 Splitters – 8 units
  - ✓ 2x1 Splitters – 20 units
  - ✓ RF Cables – (not included in quote, provided at no cost)
  - ✓ RF Antennas –(not included in quote, provided at no cost)
- ✓ Software
  - ✓ SW1001m 1GE 1000 Traffic Stream Licenses
  - ✓ SW1100 10GE port
  - ✓ SW1001sta virtual station
- ✓ Support/Warranty
  - ✓ 1-year hardware and software support

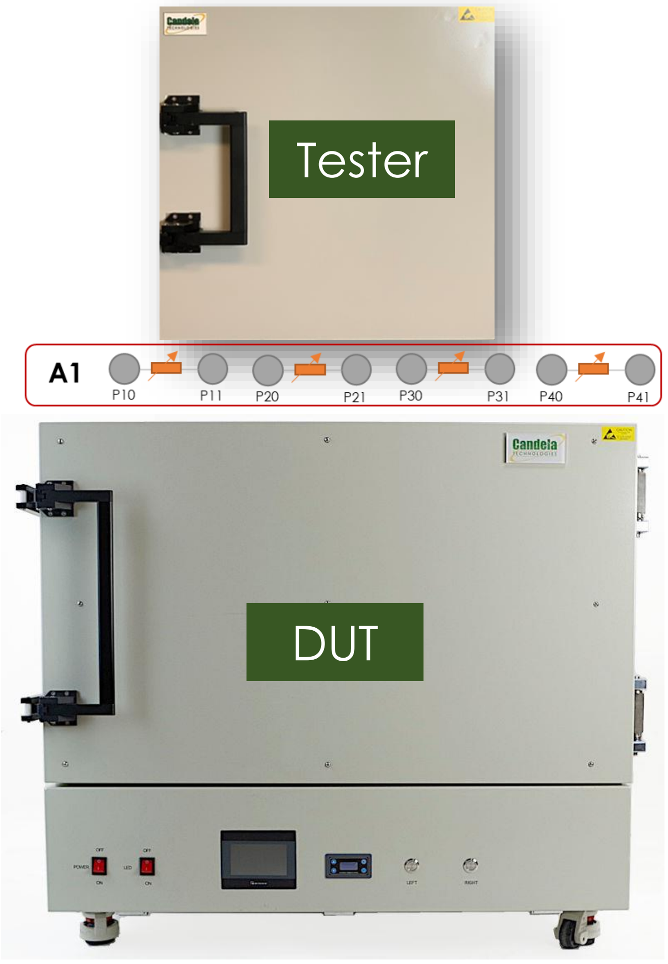
Advanced Testbed + 11ax + 2 Node Mesh Wiring Diagram

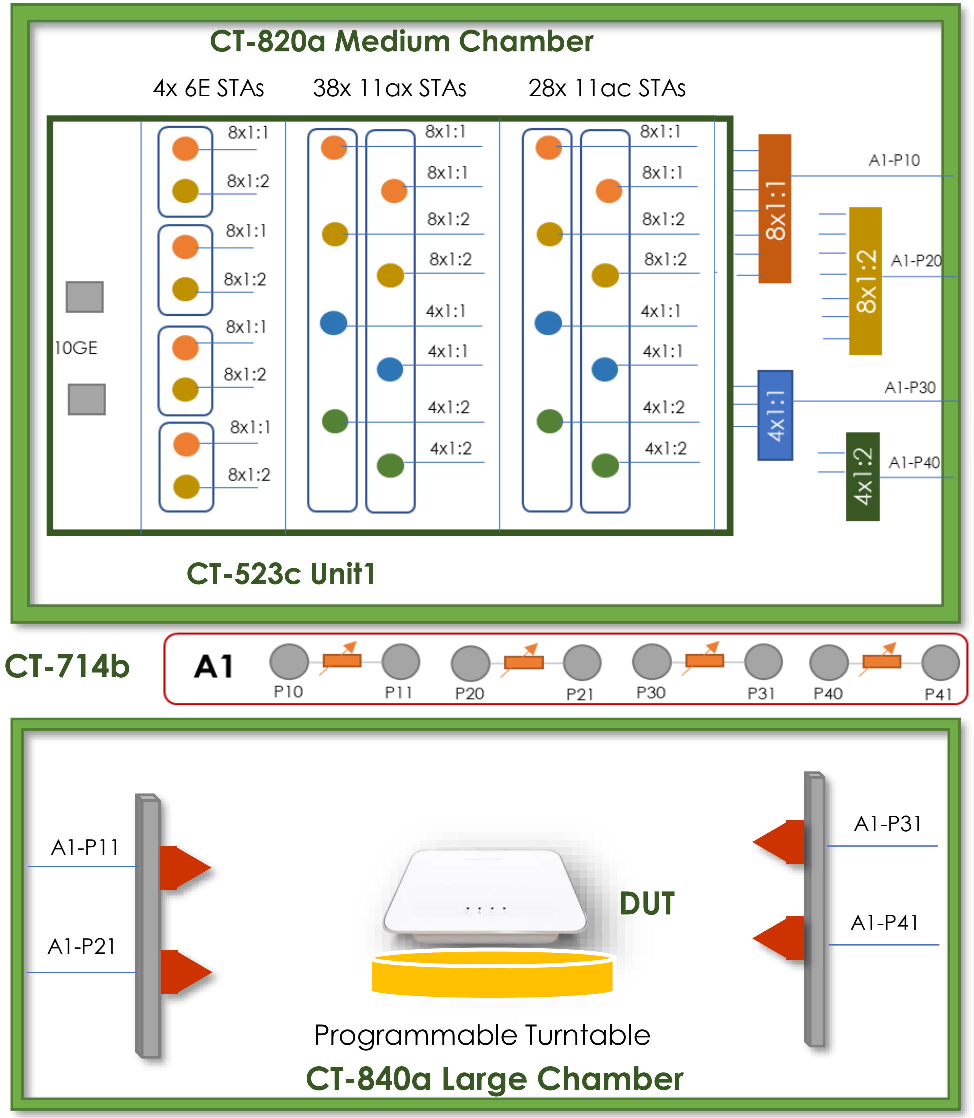


Tests Covered

- ✓ **Automated TR-398 Issue2**
  - ✓ 6.1.1 Receiver Sensitivity Test
  - ✓ 6.2.1 Maximum Connection Test
  - ✓ 6.2.2 Maximum Throughput Test
  - ✓ 6.2.3 Airtime Fairness Test
  - ✓ 6.2.4 Dual-band Throughput Test
  - ✓ 6.2.5 Bidirectional Throughput Test
  - ✓ 6.3.1 Range Versus Rate Test
  - ✓ 6.3.2 Spatial consistency test
  - ✓ 6.3.3 802.11ax Peak Performance Test
  - ✓ 6.4.1 Multiple STAs Performance Test
  - ✓ 6.4.2 Multiple Association/Disassociation Stability Test
  - ✓ 6.4.3 Downlink MU-MIMO Performance Test
  - ✓ 6.5.1 Long Term Stability Test
  - ✓ 6.5.2 AP Coexistence Test
  - ✓ 6.5.3 Automatic Channel Selection Test
- ✓ **Fully Automated Mesh Tests**
  - ✓ Mesh Throughput per hop
  - ✓ Mesh Roaming
  - ✓ Performance with various combinations of AP node placements, load pattern etc..
  - ✓ Failover test scenarios
- ✓ **802.11ax Testing**
  - ✓ Functional + Performance
  - ✓ Throughput, latency, mixed mode client performance
  - ✓ OFDMA, Mu-MIMO testing
- ✓ **User Scenario Test Automation**
  - ✓ Connection Stability test
  - ✓ Multiple traffic stress test
  - ✓ Stress test with active call sessions
  - ✓ Connection stability with MBSSID mode
  - ✓ Client Initiated roaming
  - ✓ Random connect/disconnect test
  - ✓ Video, voice and data traffic stress test
  - ✓ Random connect/disconnect of clients of a radio
- ✓ **Fully Automated Candela Tests**
  - ✓ WiFi Client Capacity Test
  - ✓ Dataplane Performance Test
  - ✓ Rate vs Range vs Antenna Orientation Test
  - ✓ Client Reset Test
  - ✓ Roaming Test
  - ✓ Band Steering Test
  - ✓ QoS Performance Test
- ✓ **Feature Testing (need additional scripting)**
  - ✓ Hotspot 2.0 / EAP-SIM/EAP-AKA
  - ✓ Captive Portal Login
  - ✓ EIRP (AP Tx power, Reg Domain Testing)
  - ✓ Speedtest.Net testing
- ✓ **Other Test Scenarios(need additional scripting)**
  - ✓ Gaming Test Scenarios
  - ✓ Testing WiFi client devices
  - ✓ Video performance Testing – Video streaming

WiFi 6E Testbed Setup Diagram





Hardware BOM

- ✓ Chassis : CT-523c-4axe-2ac4-db-2ac2-db-10GE
  - ✓ Intel AX210 6GHz Clients - 4 nos
  - ✓ MTK dual-band 11ax clients – 38 nos
  - ✓ QCA 11ac Wave2 clients – 128 nos
  - ✓ 10GE Traffic generator
- ✓ CT-820a (Medium Chamber) – 1 unit
- ✓ CT-840a(large Chamber with turntable) – 1 unit
- ✓ CT714b (Programmable Attenuator) – 1 unit
- ✓ 8x1 Splitter – 2 units
- ✓ 4x1 Splitter – 2 units
- ✓ RF cables and Antennas

Tests

- ✓ Throughput benchmark for all 6GHz channels
- ✓ Throughput over Distance
- ✓ Throughput over Antenna Orientation
- ✓ Tx Power Measurement/Compliance in 6GHz
- ✓ Receiver sensitivity test on all 6GHz channels
- ✓ Tri-band Performance (2.4/5/6GHz loaded at same time)

Home in a Box Testing

The 3-approaches of Testing:

In a Real Home

Repeatability:

Scalability :

Automation :

Realism :

In a Screen Room

Repeatability:

Scalability :

Automation :

Realism :

Home-in-a-Box

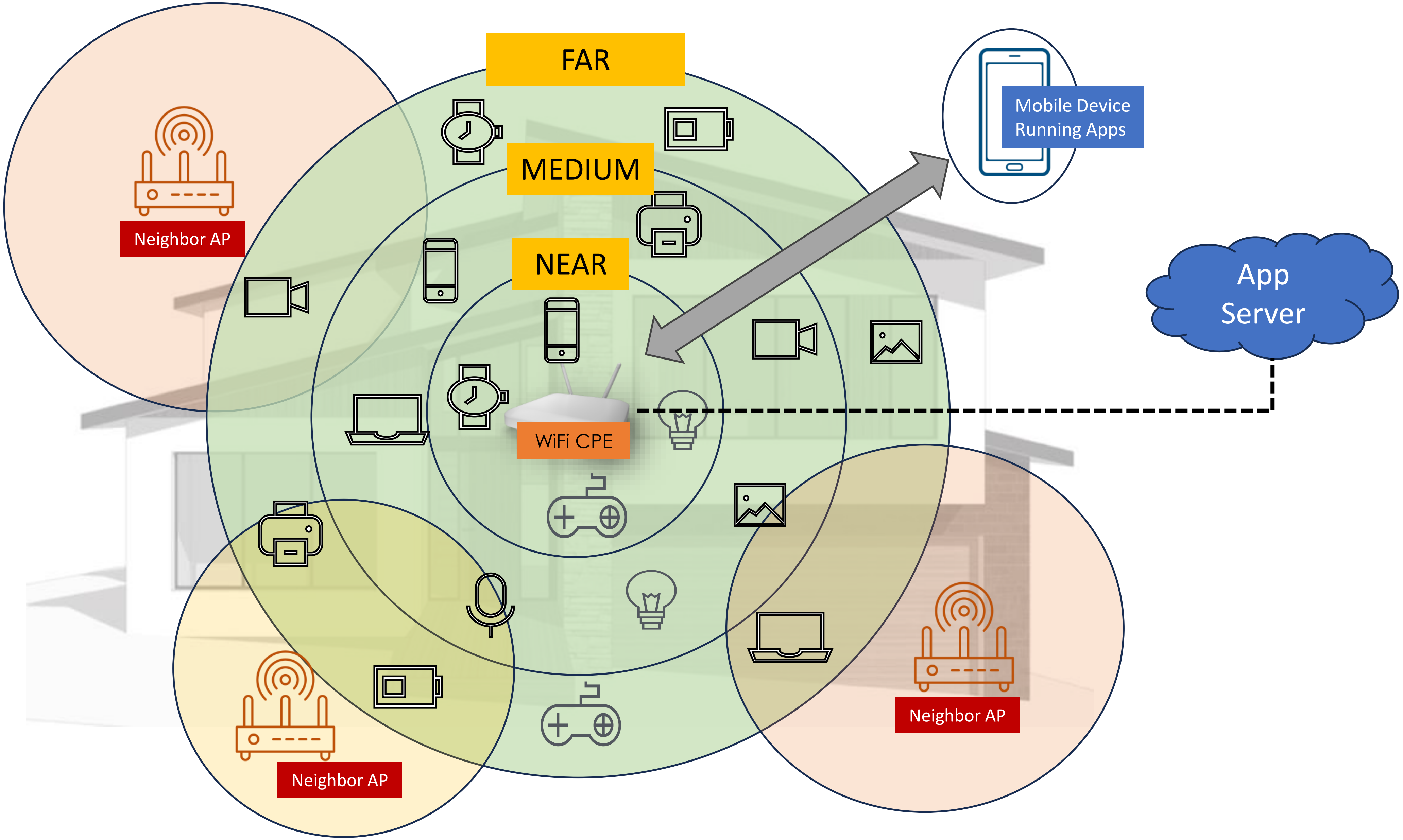
Repeatability:

Scalability :

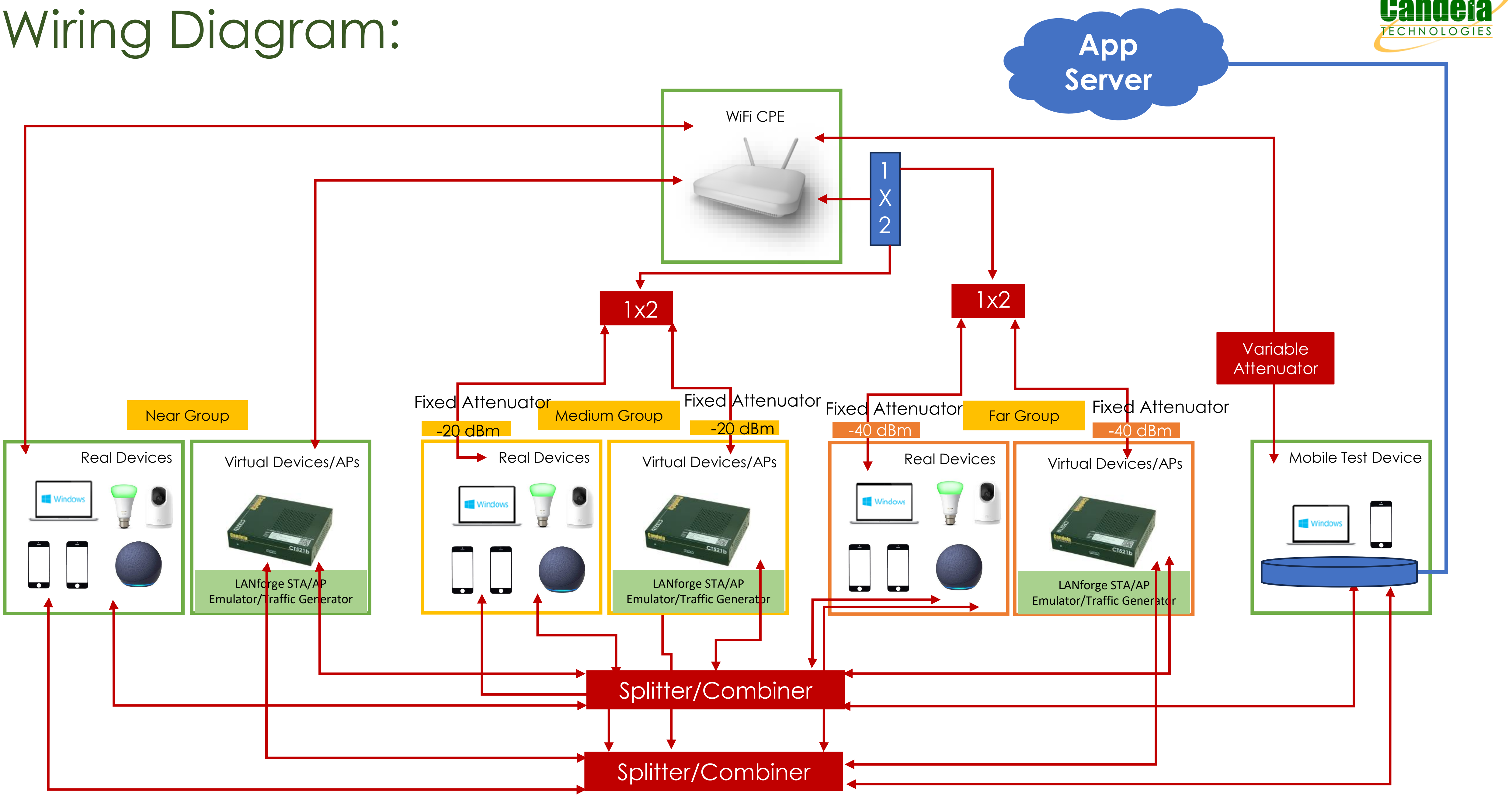
Automation :

Realism :

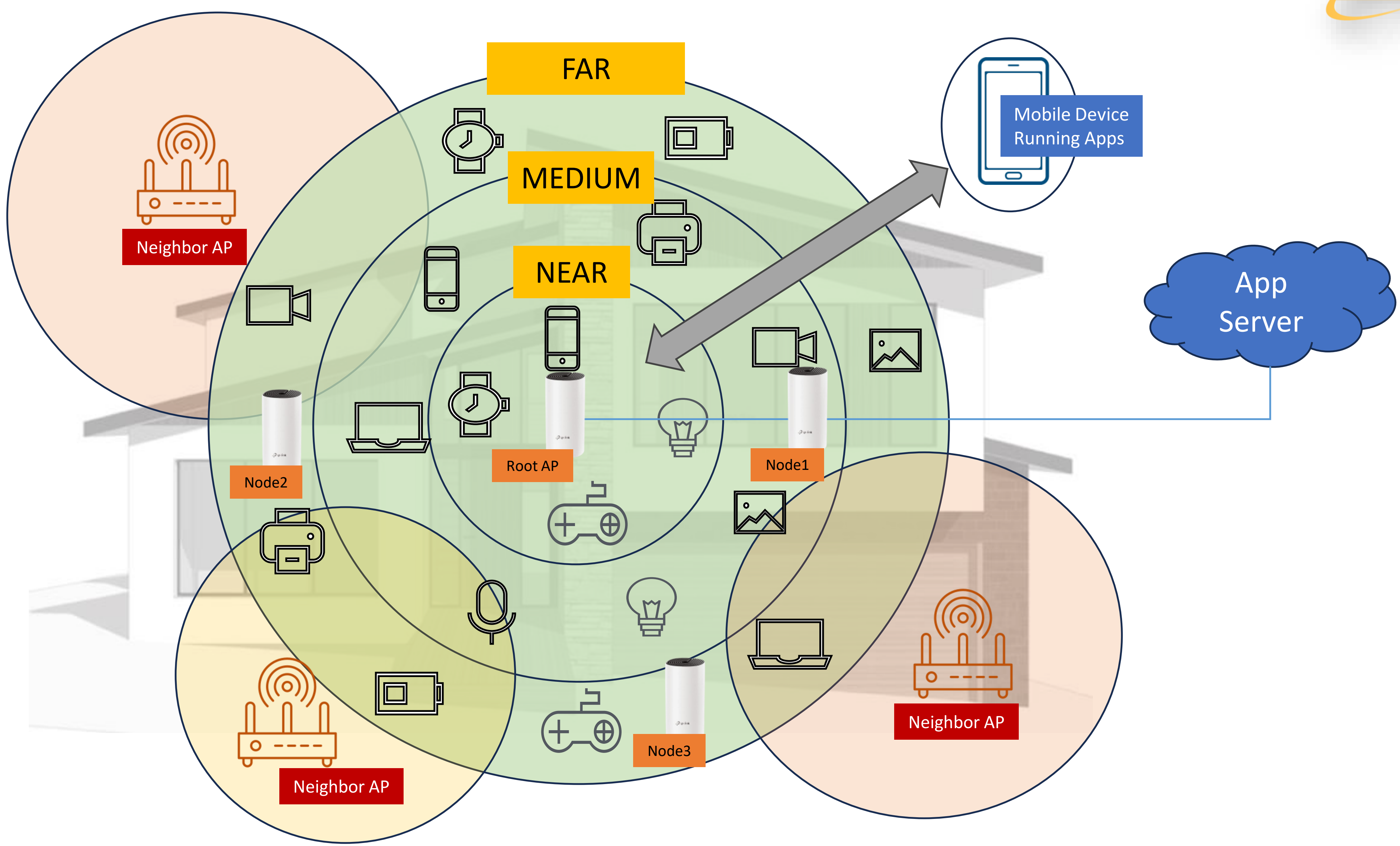
Home in a Box Testbed Topology – Single CPE:



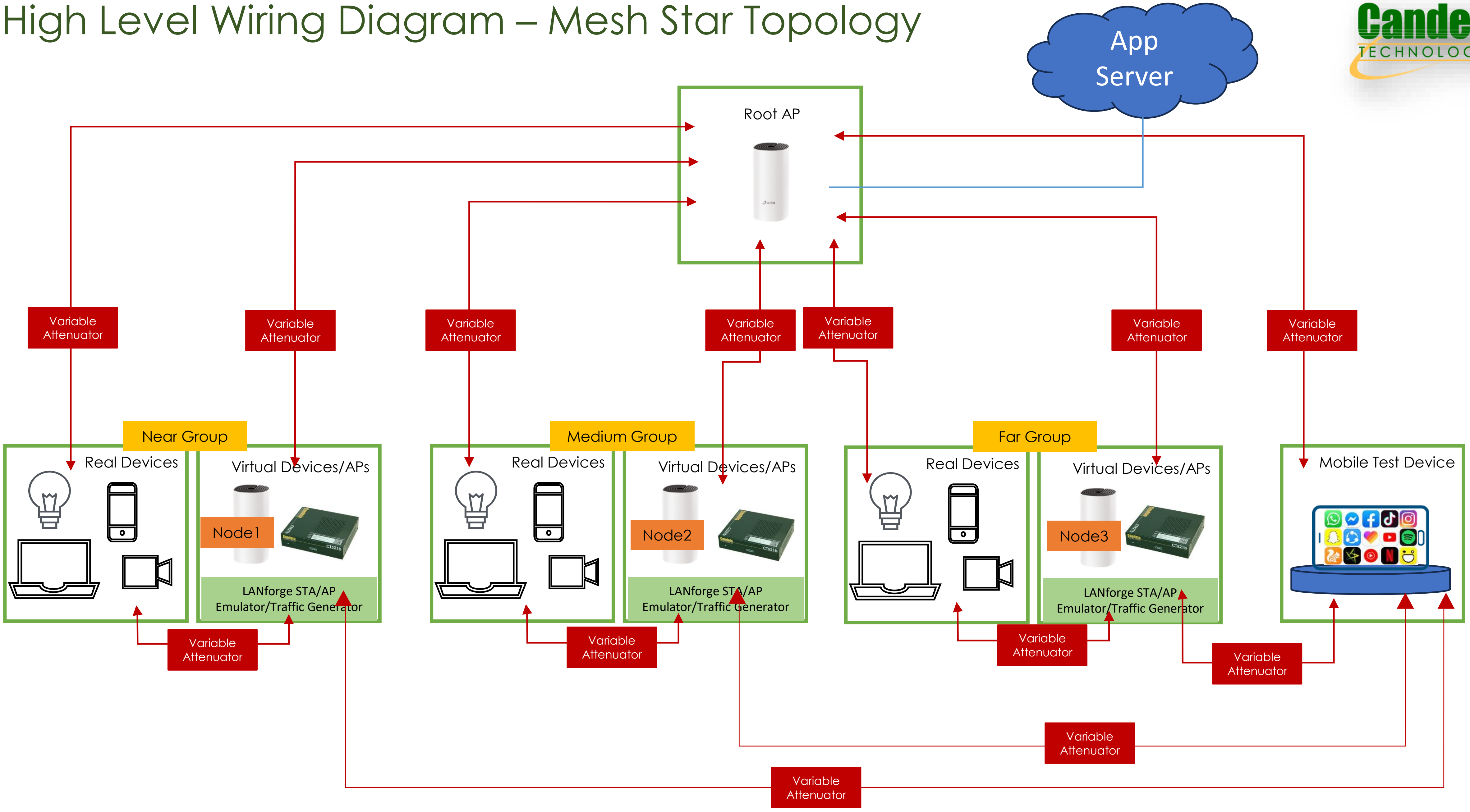
Wiring Diagram:



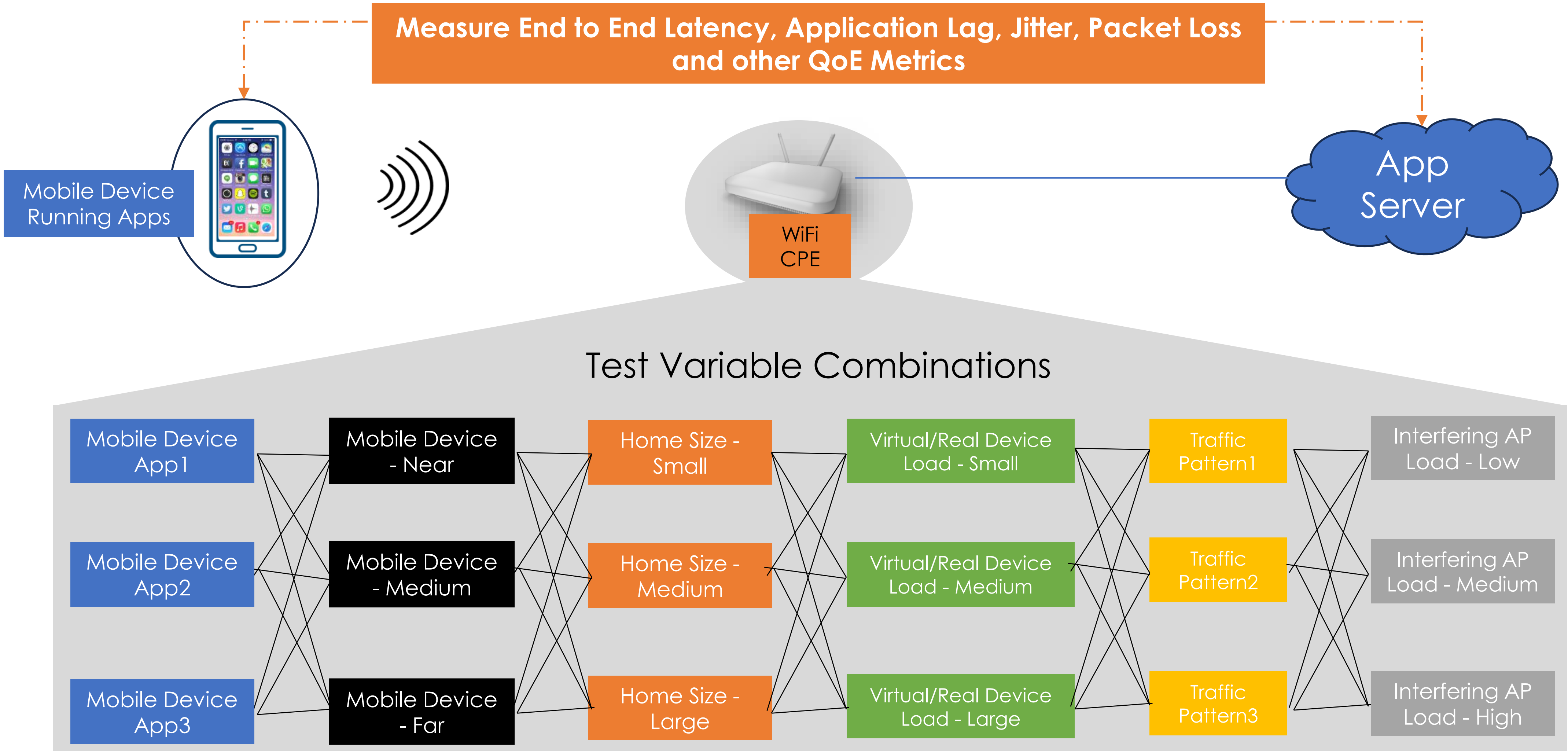
Home-in-a-Box Testbed Topology – Mesh



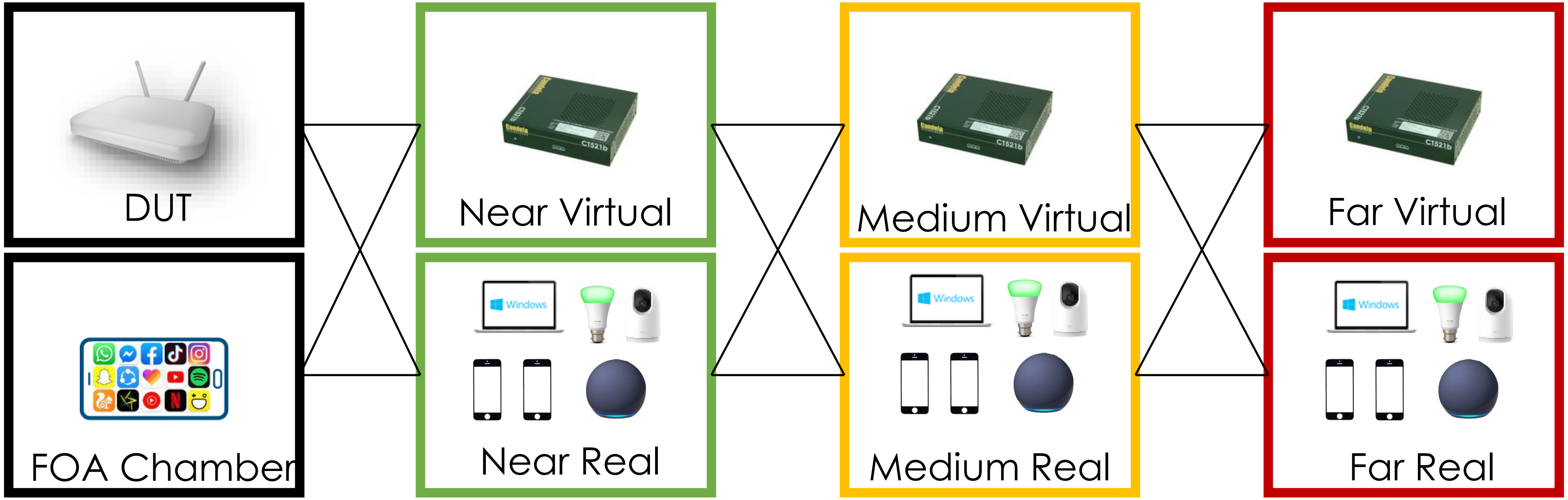
High Level Wiring Diagram – Mesh Star Topology



Possible Test patterns in Home in box Lab:



Test Implementation:



- We will run various kinds of Real world traffics like Video streaming and File download and create interference in the channel, at various distances like Near, Medium and Far and record the channel utilization.
- Now when the channel is occupied, we will run real time applications like YouTube, Facebook etc., and record the parameters like Network Latency, packet loss, Buffers and so on.
- Based on our requirement we can move the Client which is running the application and check the performance at different distances.
- Along with that we can also run various patterns of traffics in the interfering clients such that their activity in the network will be increased.

Traffic Patterns of Interfering Clients:

	STA Type	Radio Type	Application	Upload (Mbps)	Download (Mbps)	Total
Traffic Pattern1	Laptop	abgn-AX 2x2	Zoom call [1080p]	2.5	3	5.5
	Smart Phone	abgn-AC 1x1	YouTube Streaming[4k]	0.76	20	20.76
	Smart Phone	abgn-AC 1x1	Online Gaming	5	25	30
	Alexa echo	abgn-AC 2x2	Internet Music	0.76	1.5	2.26
	Smart Bulb	abgn-AC 1x1	Turn on/off	0.0096	0.384	0.3936
Total Load				9.0296	49.884	58.9136
	STA Type	Radio Type	Application	Upload (Mbps)	Download (Mbps)	Total
Traffic Pattern2	Smart Phone	abgn-AC 1x1	Amazon prime	2	5	7
	Laptop	abgn-AX 2x2	File Download	1	10	11
	Smart Camera	abgn-AC 1x1	Live Recording	0.76	2	2.76
	Alexa	abgn-AC 2x2	Internet Music	0.76	1.5	2.26
	Smart Phone	abgn-AC 1x1	Skype Call	0.128	4	4.128
Total Load				4.648	22.5	27.148
	STA Type	Radio Type	Application	Upload (Mbps)	Download (Mbps)	Total
Traffic Pattern3	Smart TV	abgn-AX 2x2	Netflix	1	15	16
	Oculus	abgn-AX 2x2	VR Streaming	5	15	20
	Smart Phone	abgn-AC 1x1	WhatsApp Video call	1	2.5	3.5
	Alexa	abgn-AC 2x2	Internet Music	0.76	1.5	2.26
	Smart plug	abgn-AC 1x1	Turn on/off	0.0096	0.384	0.3936
Total Load				7.7696	34.384	42.1536

Test Results and observations:

AP QoS Settings	Background Load			FOA Client Settings			Test Results					
	Near	Medium	Far	Distance	Mode	App	Latency	Frames Dropped	Connection Speed	Buffer Health	Video Resolution	FPS
QOS-ON	None	None	None	Near	2x2 11ac	FB Messenger						
QOS-OFF	None	None	None	Near	2x2 11ac	FB Messenger						
QOS-ON	None	None	None	Medium	2x2 11ac	FB Messenger						
QOS-OFF	None	None	None	Medium	2x2 11ac	FB Messenger						
QOS-ON	None	None	None	Far	2x2 11ac	FB Messenger						
QOS-OFF	None	None	None	Far	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1	None	None	Near	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1	None	None	Near	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1	None	None	Medium	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1	None	None	Medium	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1	None	None	Far	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1	None	None	Far	2x2 11ac	FB Messenger						
QOS-ON	None	Traffic Pattern1	None	Near	2x2 11ac	FB Messenger						
QOS-OFF	None	Traffic Pattern1	None	Near	2x2 11ac	FB Messenger						
QOS-ON	None	Traffic Pattern1	None	Medium	2x2 11ac	FB Messenger						
QOS-OFF	None	Traffic Pattern1	None	Medium	2x2 11ac	FB Messenger						
QOS-ON	None	Traffic Pattern1	None	Far	2x2 11ac	FB Messenger						
QOS-OFF	None	Traffic Pattern1	None	Far	2x2 11ac	FB Messenger						
QOS-ON	None	None	Traffic Pattern1	Near	2x2 11ac	FB Messenger						
QOS-OFF	None	None	Traffic Pattern1	Near	2x2 11ac	FB Messenger						
QOS-ON	None	None	Traffic Pattern1	Medium	2x2 11ac	FB Messenger						
QOS-OFF	None	None	Traffic Pattern1	Medium	2x2 11ac	FB Messenger						
QOS-ON	None	None	Traffic Pattern1	Far	2x2 11ac	FB Messenger						
QOS-OFF	None	None	Traffic Pattern1	Far	2x2 11ac	FB Messenger						

Test Results and observations:

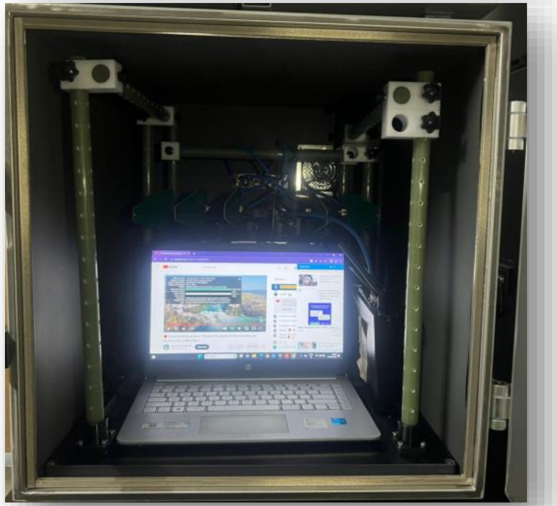
AP QoS Settings	Background Load			FOA Client Settings			Test Results					
	Near	Medium	Far	Distance	Mode	App	Latency	Frames Dropped	Connection Speed	Buffer Health	Video Resolution	FPS
QOS-ON	Traffic Pattern1	Traffic Pattern1	None	Near	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1	Traffic Pattern1	None	Near	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1	Traffic Pattern1	None	Medium	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1	Traffic Pattern1	None	Medium	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1	Traffic Pattern1	None	Far	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1	Traffic Pattern1	None	Far	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1		Traffic Pattern1	Near	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1		Traffic Pattern1	Near	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1		Traffic Pattern1	Medium	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1		Traffic Pattern1	Medium	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1		Traffic Pattern1	Far	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1		Traffic Pattern1	Far	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1	Traffic Pattern1	Traffic Pattern1	Near	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1	Traffic Pattern1	Traffic Pattern1	Near	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1	Traffic Pattern1	Traffic Pattern1	Medium	2x2 11ac	FB Messenger						
QOS-OFF	Traffic Pattern1	Traffic Pattern1	Traffic Pattern1	Medium	2x2 11ac	FB Messenger						
QOS-ON	Traffic Pattern1	Traffic Pattern1	Traffic Pattern1	Far	2x2 11ac	FB Messenger						

Test Results for YouTube Live streaming :

Test Cases	AP QoS Settings	Traffic Patterns			FOA Client Settings				Test Results						
		Near	Medium	Far	Distance	Mode	App	Connected Band	Packet Drop	Latency [s]	Connection Speed [kbps]	Buffer Health [s]	Network Activity [kb]	Video Resolution	FPS
Baseline	QOS-ON	None	None	None	Near	2x2 11ac	YouTube	5 GHz	0 out of 1876	26.95	28645	9.55	565	2160 [4K]	30
	QOS-ON	None	None	None	Medium	2x2 11ac	YouTube	5 GHz	0 out of 1812	28.59	22313	9.79	394	1440 [HD]	30
	QOS-ON	None	None	None	Far	2x2 11ac	YouTube	2.4 GHz	0 out of 2150	29.96	4418	13.61	85	1080p	30
Load Pattern1	QOS-ON	Pattern1	None	None	Near	2x2 11ac	YouTube	5 GHz	0 out of 1880	16.43	23054	7.54	48	1440 [HD]	30
	QOS-ON	Pattern1	None	None	Medium	2x2 11ac	YouTube	5 GHz	0 out of 1864	27.76	26251	17.8	80	2160 [4K]	30
	QOS-ON	Pattern1	None	None	Far	2x2 11ac	YouTube	2.4 GHz	0 out of 1857	29.43	5959	18.22	0	1080p	30
Load Pattern2	QOS-ON	None	Pattern1	None	Near	2x2 11ac	YouTube	5 GHz	0 out of 1896	24.48	39597	16.95	35	2160 [4K]	30
	QOS-ON	None	Pattern1	None	Medium	2x2 11ac	YouTube	5 GHz	81 out of 1857	42.09	6574	0.06	0	1080p	30
	QOS-ON	None	Pattern1	None	Far	2x2 11ac	YouTube	2.4 GHz	0 out of 1846	25.28	17748	18.72	0	1440 [HD]	30
Load Pattern3	QOS-ON	None	None	Pattern1	Near	2x2 11ac	YouTube	5 GHz	0 out of 2203	28.14	24899	16.66	455	2160 [4K]	30
	QOS-ON	None	None	Pattern1	Medium	2x2 11ac	YouTube	5 GHz	0 out of 1867	23.84	14993	3.08	0	1440 [HD]	30
	QOS-ON	None	None	Pattern1	Far	2x2 11ac	YouTube	2.4 GHz	0 out of 2164	34	170	0	4	240p	30
Load Pattern4	QOS-ON	Pattern1	Pattern1	None	Near	2x2 11ac	YouTube	5GHz	0 out of 2238	25.29	9445	15.64	184	1440 [HD]	30
	QOS-ON	Pattern1	Pattern1	None	Medium	2x2 11ac	YouTube	5 GHz	0 out of 1856	28.25	689	18.41	39	360p	30
	QOS-ON	Pattern1	Pattern1	None	Far	2x2 11ac	YouTube	2.4 GHz	0 out of 1962	22.03	319	14.78	0	240p	30
Load Pattern5	QOS-ON	Pattern1	Pattern1	Pattern1	Near	2x2 11ac	YouTube	5 GHz	0 out of 2471	23.44	6586	12.69	0	1080p	30
	QOS-ON	Pattern1	Pattern1	Pattern1	Medium	2x2 11ac	YouTube	5 GHz	0 out of 2465	30.24	689	18.62	0	360p	30
	QOS-ON	Pattern1	Pattern1	Pattern1	Far	2x2 11ac	YouTube	2.4 GHz	0 out of 2086	28.16	319	12.21	0	240p	30

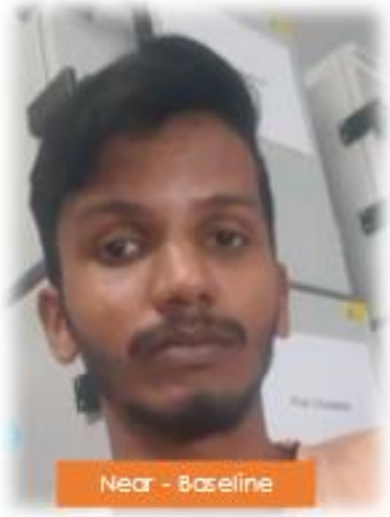
Testbed Images

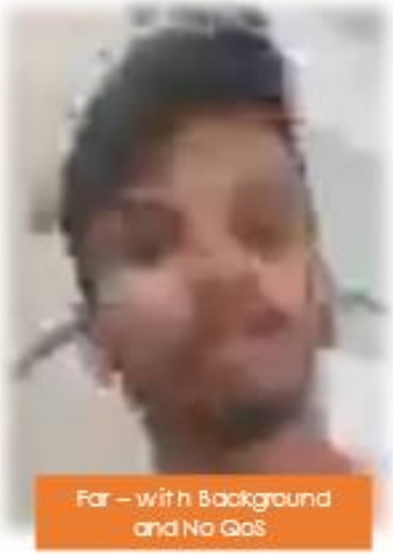
DUT CHAMBER

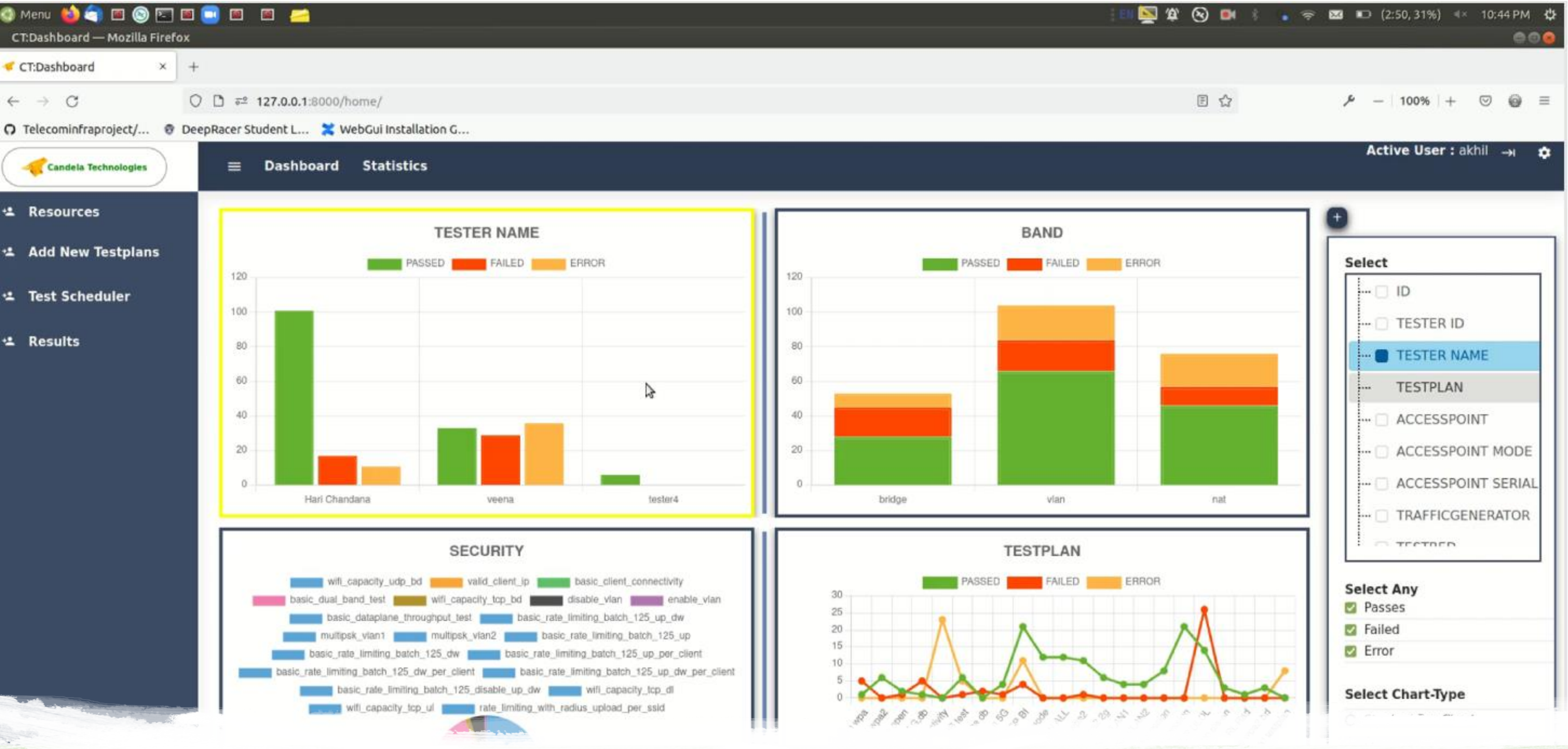


FOA CHAMBER

Subjective Measurements of QoE of Real Video calling and OTT apps in various test conditions

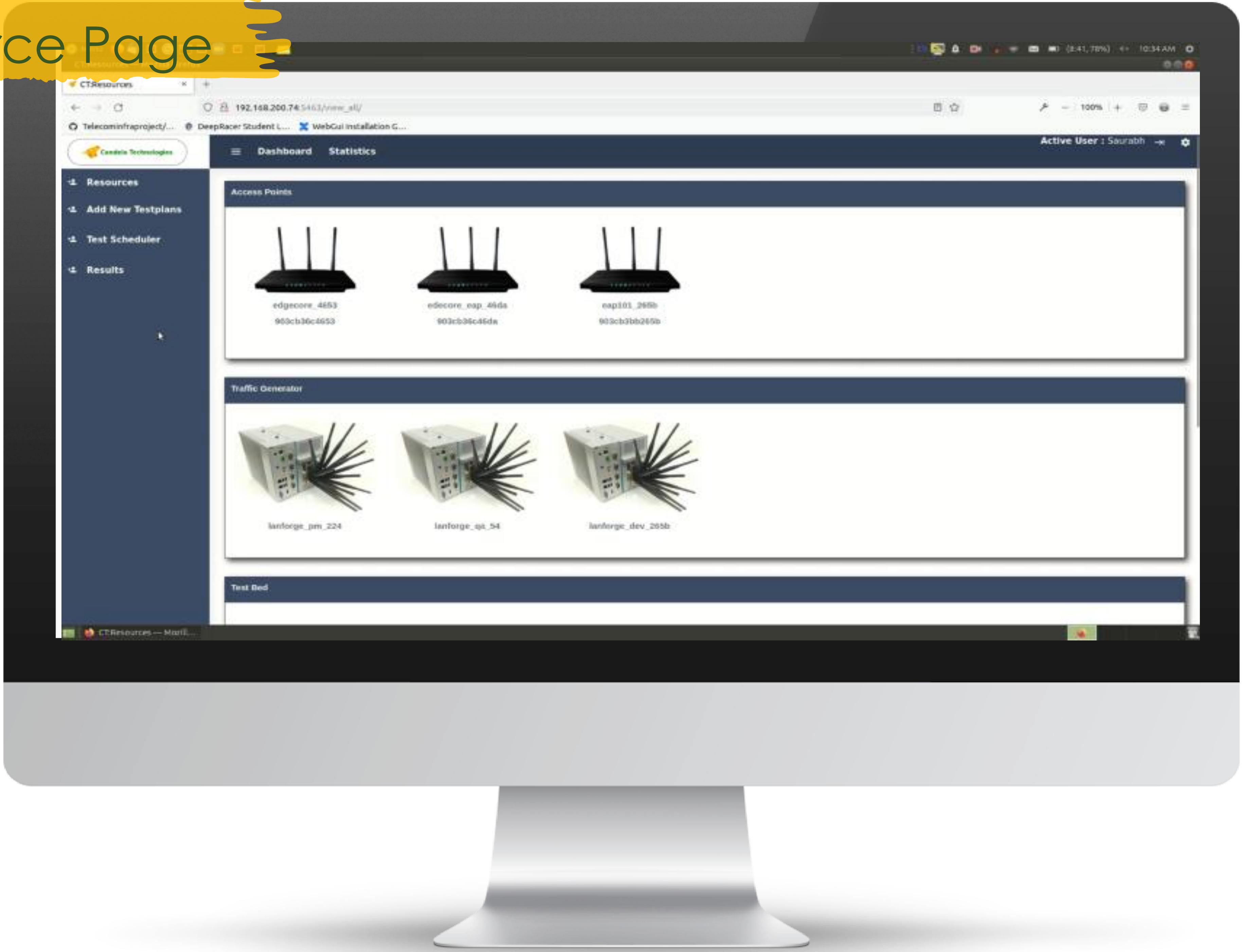


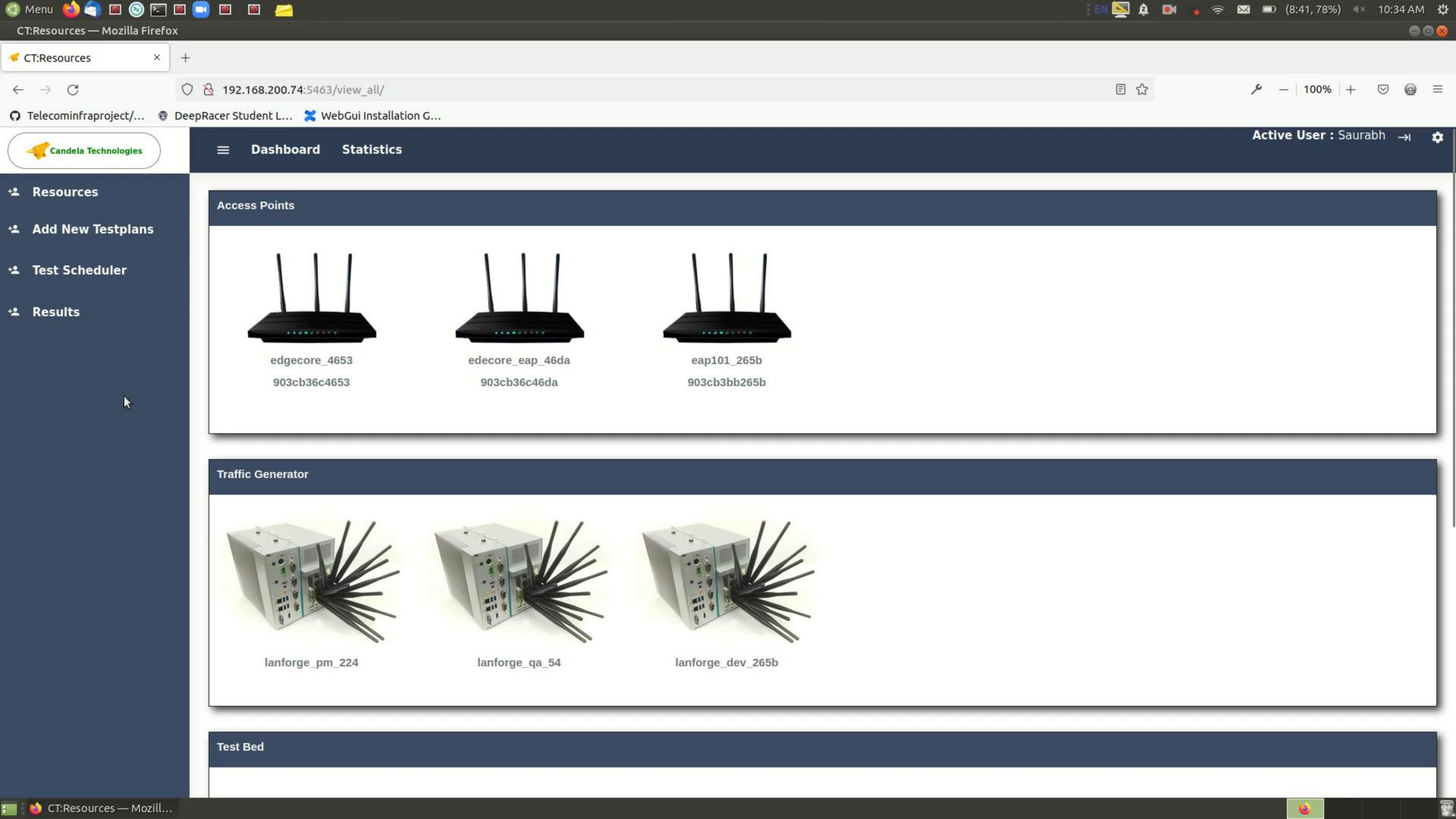




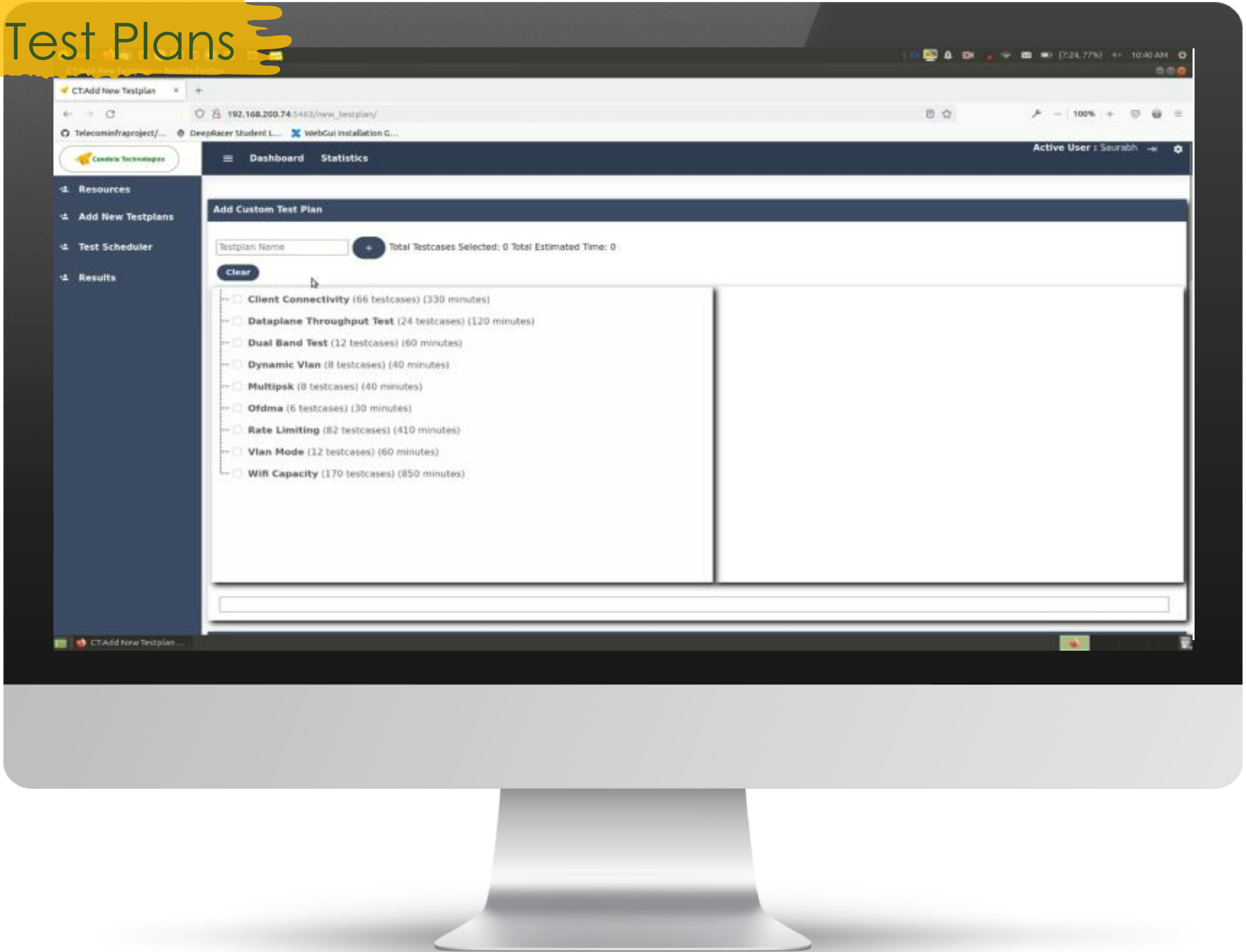
LANforge WebGUI

Resource Page




CT:Resources — Mozilla Firefox
CT:Resources
192.168.200.74:5463/view_all/
Telecominfraproject/...
DeepRacer Student L...
WebGui Installation G...
Candela Technologies
Dashboard
Statistics
Active User : Saurabh
Resources
Add New Testplans
Test Scheduler
Results
Access Points
edgecore_4653
903cb36c4653
edecore_eap_46da
903cb36c46da
eap101_265b
903cb3bb265b
Traffic Generator
lanforge_pm_224
lanforge_qa_54
lanforge_dev_265b
Test Bed
CT:Resources — Mozill...

Create Test Plans



Menu EN (7:24, 77%) 10:40 AM

CT:Add New Testplan — Mozilla Firefox

CT:Add New Testplan

192.168.200.74:5463/new_testplan/ 100%

Telecominfraproject/... DeepRacer Student L... WebGui Installation G...

Candela Technologies

Dashboard Statistics

Active User : Saurabh

- Resources
- Add New Testplans
- Test Scheduler
- Results

Add Custom Test Plan

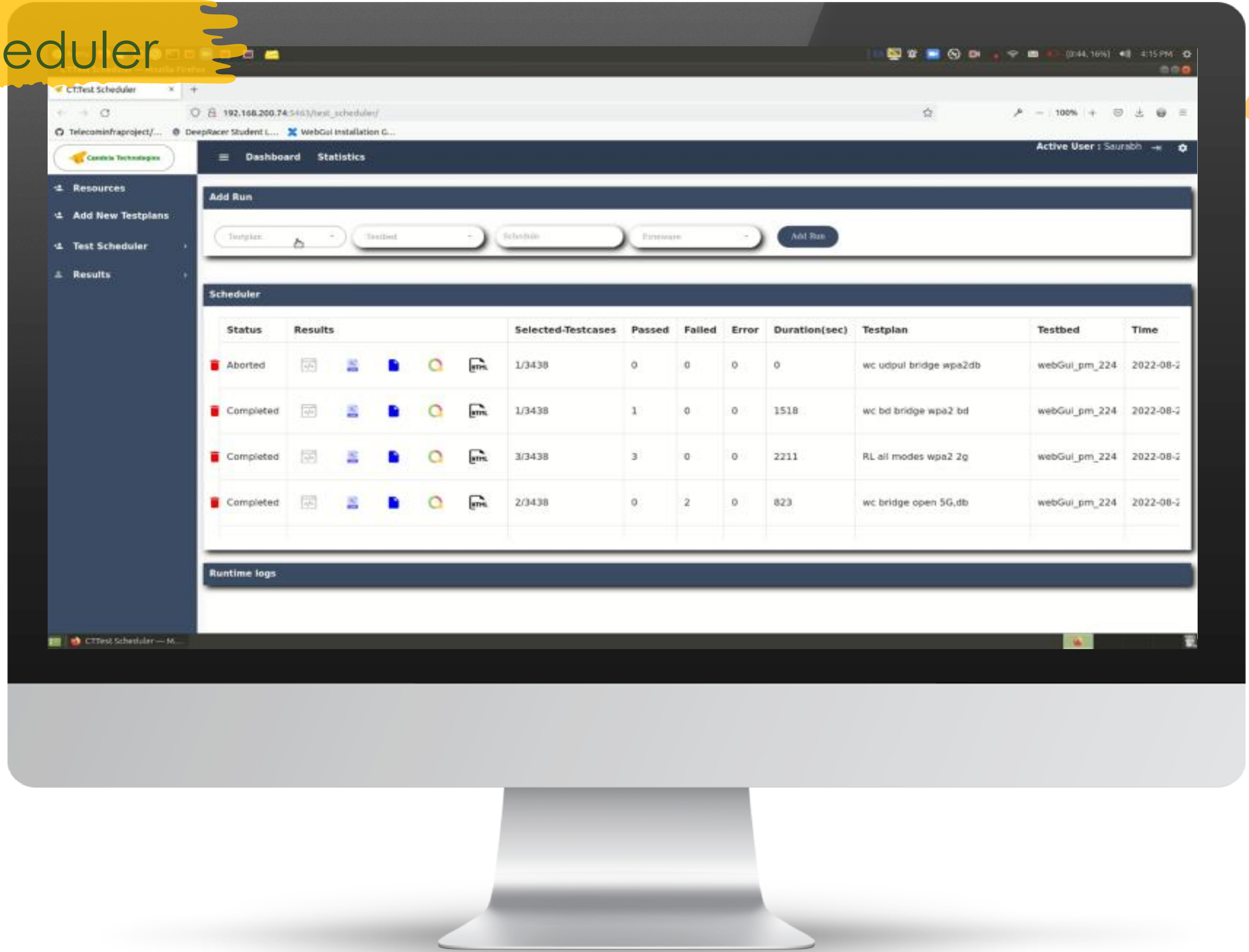
Testplan Name + Total Testcases Selected: 0 Total Estimated Time: 0

Clear

- **Client Connectivity** (66 testcases) (330 minutes)
- **Dataplane Throughput Test** (24 testcases) (120 minutes)
- **Dual Band Test** (12 testcases) (60 minutes)
- **Dynamic Vlan** (8 testcases) (40 minutes)
- **Multipsk** (8 testcases) (40 minutes)
- **Ofdma** (6 testcases) (30 minutes)
- **Rate Limiting** (82 testcases) (410 minutes)
- **Vlan Mode** (12 testcases) (60 minutes)
- **Wifi Capacity** (170 testcases) (850 minutes)

CT:Add New Testplan ...

Test Scheduler



Menu

CT:Test Scheduler — Mozilla Firefox

CT:Test Scheduler

192.168.200.74:5463/test_scheduler/

Telecominfraproject/... DeepRacer Student L... WebGui Installation G...

Candela Technologies

Dashboard Statistics

Active User : Saurabh

- Resources
- Add New Testplans
- Test Scheduler
- Results

Add Run

Testplan | Testbed | Schedule | Firmware | Add Run

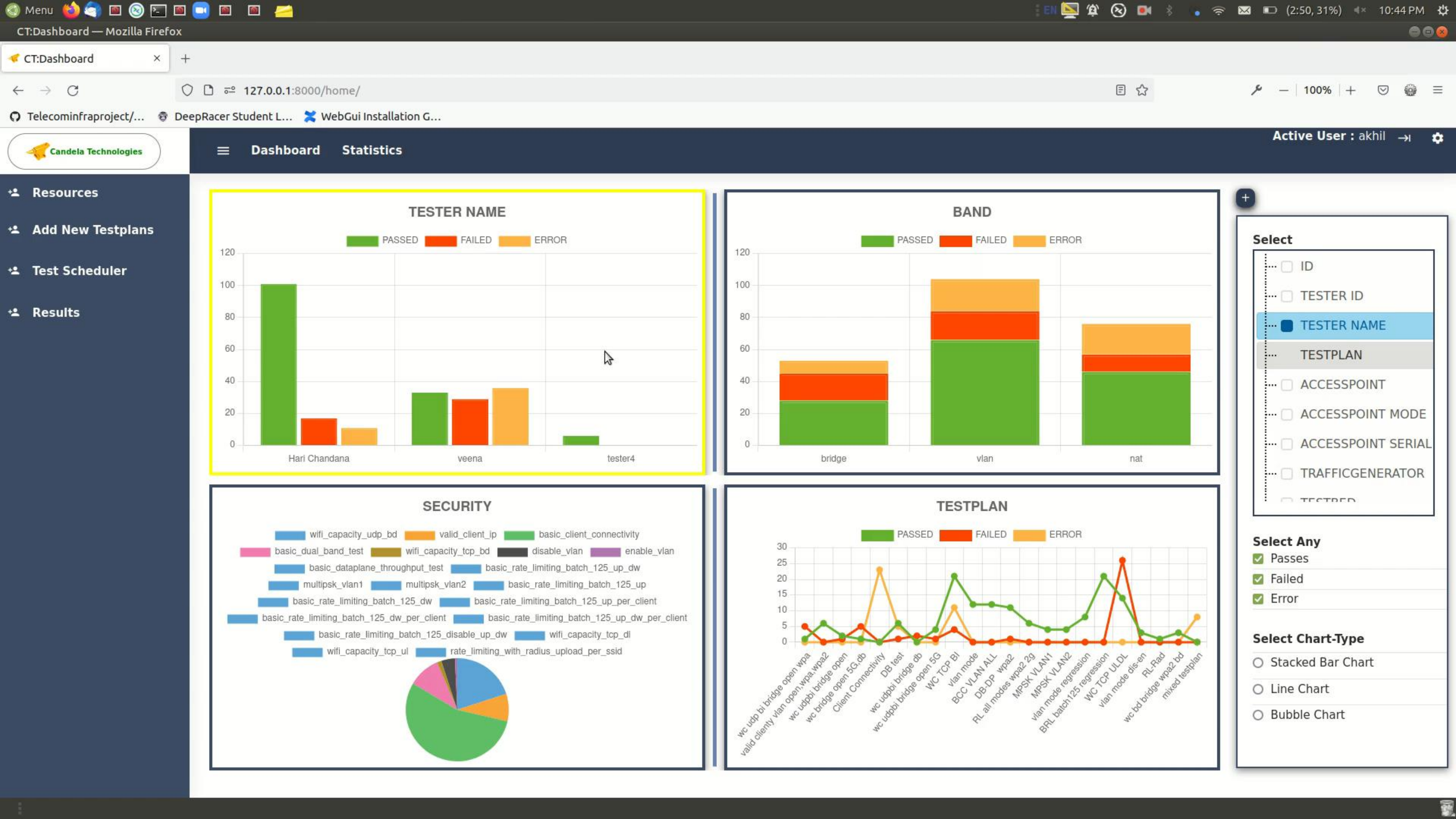
Scheduler

Status	Results	Selected-Testcases	Passed	Failed	Error	Duration(sec)	Testplan	Testbed	Time
Aborted	HTML	1/3438	0	0	0	0	wc udpul bridge wpa2db	webGui_pm_224	2022-08-2
Completed	HTML	1/3438	1	0	0	1518	wc bd bridge wpa2 bd	webGui_pm_224	2022-08-2
Completed	HTML	3/3438	3	0	0	2211	RL all modes wpa2 2g	webGui_pm_224	2022-08-2
Completed	HTML	2/3438	0	2	0	823	wc bridge open 5G,db	webGui_pm_224	2022-08-2

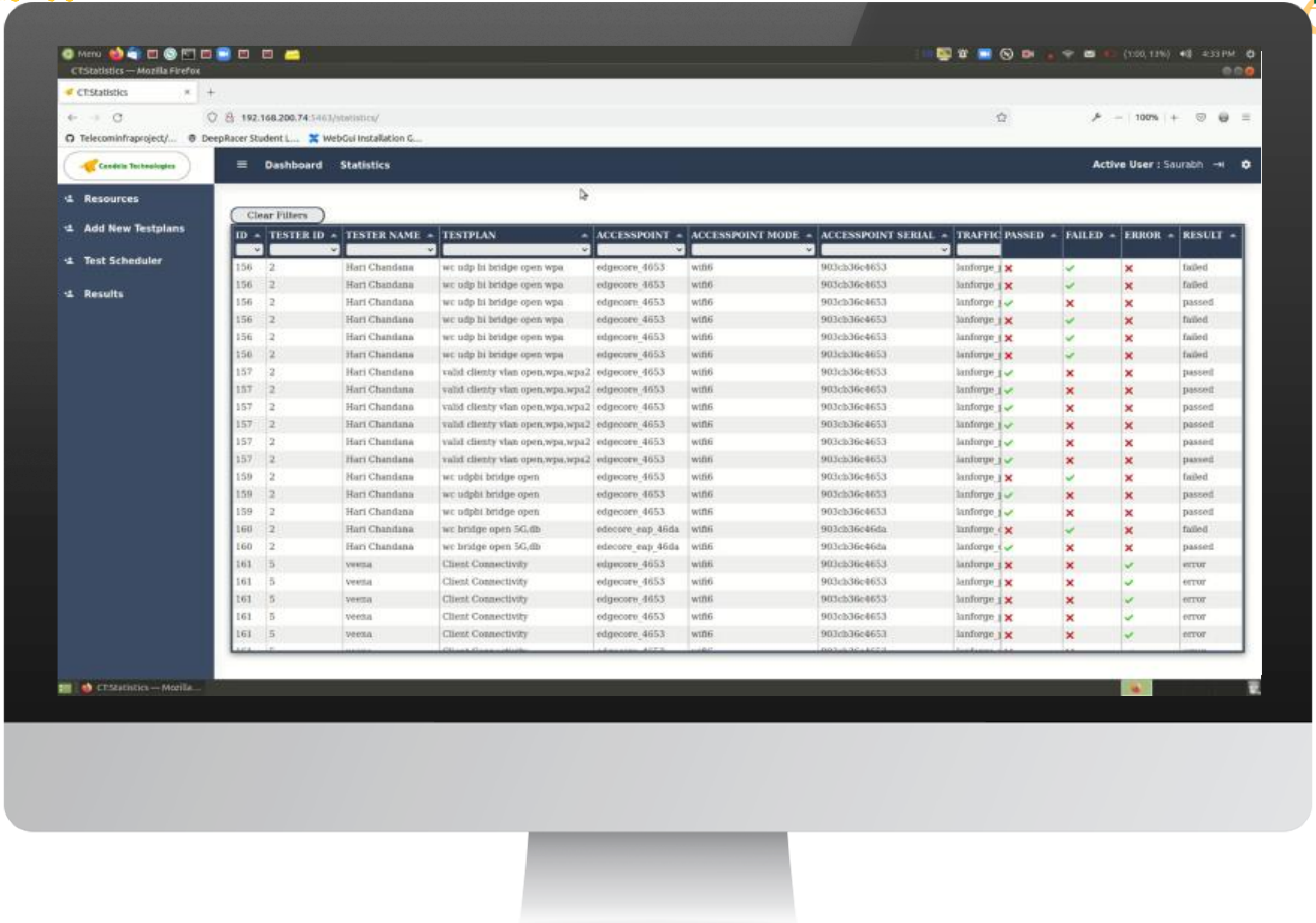
Runtime logs

CT:Test Scheduler — M...

Results Dashboard


Menu
10:44 PM
CT:Dashboard — Mozilla Firefox
CT:Dashboard
127.0.0.1:8000/home/
100%
Telecominfraproject/...
DeepRacer Student L...
WebGui Installation G...
Candela Technologies
Dashboard
Statistics
Active User : akhil
Resources
Add New Testplans
Test Scheduler
Results
TESTER NAME
PASSED FAILED ERROR
Hari Chandana
veena
tester4
BAND
bridge
vlan
nat
SECURITY
wifi_capacity_udp_bd
valid_client_ip
basic_client_connectivity
basic_dual_band_test
wifi_capacity_tcp_bd
disable_vlan
enable_vlan
basic_dataplane_throughput_test
basic_rate_limiting_batch_125_up_dw
multipsk_vlan1
multipsk_vlan2
basic_rate_limiting_batch_125_up
basic_rate_limiting_batch_125_dw
basic_rate_limiting_batch_125_up_per_client
basic_rate_limiting_batch_125_dw_per_client
basic_rate_limiting_batch_125_up_dw_per_client
basic_rate_limiting_batch_125_disable_up_dw
wifi_capacity_tcp_dl
wifi_capacity_tcp_ul
rate_limiting_with_radius_upload_per_ssid
TESTPLAN
wc udp bi bridge open wpa
valid clienty vlan open,wpa,wpa2
wc udpbi bridge open
wc bridge open 5G,db
Client Connectivity
DB test
wc udpbi bridge db
wc udpbi bridge open 5G
WC TCP BI
vlan mode
BCC VLAN ALL
DB-DP wpa2
RL all modes wpa2 2g
MPSK VLAN1
MPSK VLAN2
vlan mode regression
BRL batch125 regression
WC TCP ULDL
vlan mode dis-en
RL-Rad
wc bd bridge wpa2 bd
mixed testplan
Select
ID
TESTER ID
TESTER NAME
TESTPLAN
ACCESSPOINT
ACCESSPOINT MODE
ACCESSPOINT SERIAL
TRAFFICGENERATOR
Select Any
Passes
Failed
Error
Select Chart-Type
Stacked Bar Chart
Line Chart
Bubble Chart

Test Statistics



ID	TESTER ID	TESTER NAME	TESTPLAN	ACCESSPOINT	ACCESSPOINT MODE	ACCESSPOINT SERIAL	TRAFFIC	PASSED	FAILED	ERROR	RESULT
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
159	2	Hari Chandana	wc udpbi bridge open	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
159	2	Hari Chandana	wc udpbi bridge open	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
159	2	Hari Chandana	wc udpbi bridge open	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
160	2	Hari Chandana	wc bridge open 5G,db	edecore_eap_46da	wifi6	903cb36c46da	lanforge_	✗	✓	✗	failed
160	2	Hari Chandana	wc bridge open 5G,db	edecore_eap_46da	wifi6	903cb36c46da	lanforge_	✓	✗	✗	passed
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error

CT:Statistics — Mozilla Firefox

192.168.200.74:5463/statistics/

Candela Technologies

Dashboard Statistics

Active User : Saurabh

- Resources
- Add New Testplans
- Test Scheduler
- Results

Clear Filters

ID	TESTER ID	TESTER NAME	TESTPLAN	ACCESSPOINT	ACCESSPOINT MODE	ACCESSPOINT SERIAL	TRAFFIC	PASSED	FAILED	ERROR	RESULT
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
156	2	Hari Chandana	wc udp bi bridge open wpa	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
157	2	Hari Chandana	valid clienty vlan open,wpa,wpa2	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
159	2	Hari Chandana	wc udpbi bridge open	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✓	✗	failed
159	2	Hari Chandana	wc udpbi bridge open	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
159	2	Hari Chandana	wc udpbi bridge open	edgecore_4653	wifi6	903cb36c4653	lanforge_	✓	✗	✗	passed
160	2	Hari Chandana	wc bridge open 5G,db	edecore_eap_46da	wifi6	903cb36c46da	lanforge_	✗	✓	✗	failed
160	2	Hari Chandana	wc bridge open 5G,db	edecore_eap_46da	wifi6	903cb36c46da	lanforge_	✓	✗	✗	passed
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error
161	5	veena	Client Connectivity	edgecore_4653	wifi6	903cb36c4653	lanforge_	✗	✗	✓	error

Candela India Test House

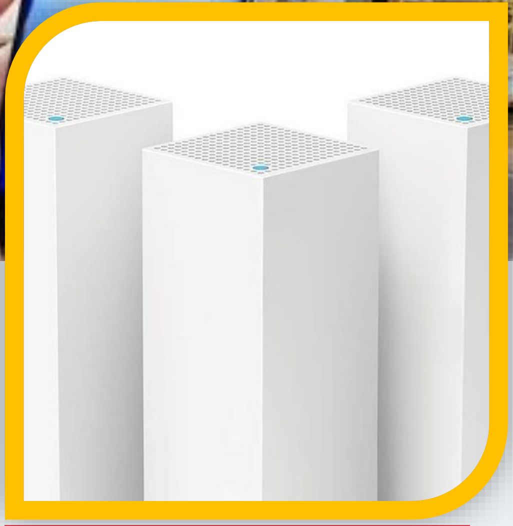
Test House – 3500 Sqft Apartment

- Brick and Mortar construction
- Tile flooring.
- 10 feet ceilings.
- Standard wooden doors, wooden cupboards and cabinets.
- 4- Bed, 4-Bath, Living, Dining, Kitchen and Media Rooms.
- Independent building with very little or no external WiFi or RF interference
- Fully equipped home with all furniture and furnishings
- Lots of WiFi Devices of various types (Laptops, Smartphones, Tablets, TVs, Cameras, IoT Devices etc…)

Devices Under Test

Single AP/Router

Full Performance Analysis of a Single WiFi Access Point in the Test House



Full Mesh Systems

Test Full in home WiFi Mesh System for Coverage, Capacity and Mobility

Computing Devices

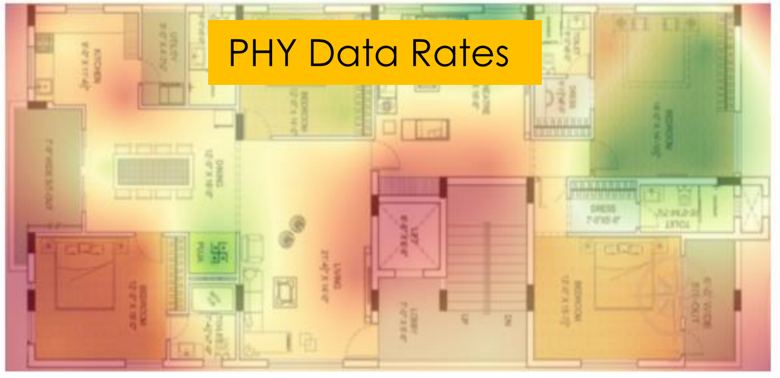
Test the latest WiFi Laptops, Smartphone and Tablets

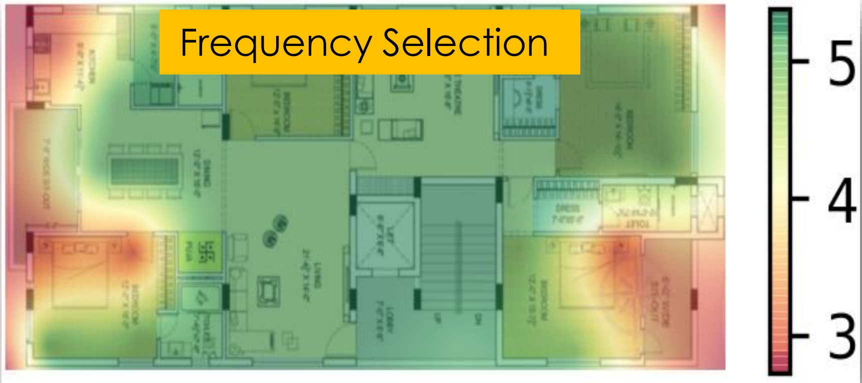
Smart Home Devices

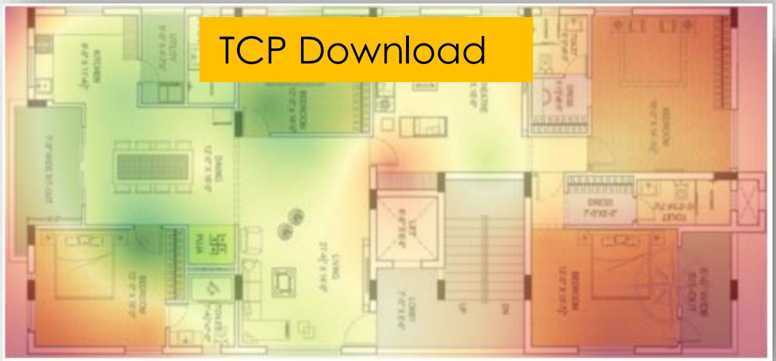
All Smart Home devices including Consumer Electronics and Home Automation/Security Devices

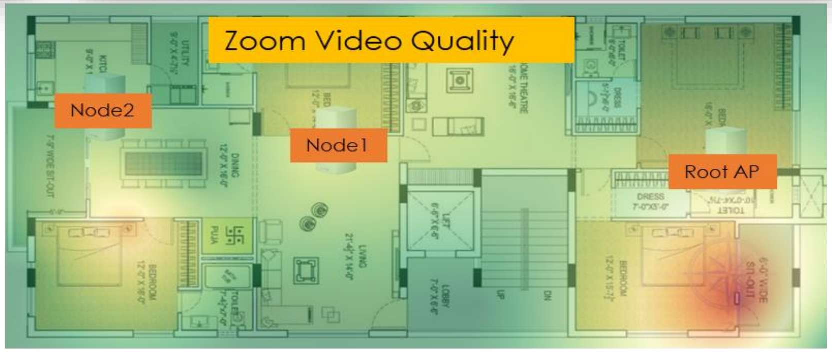
Coverage/User Experience Heatmaps

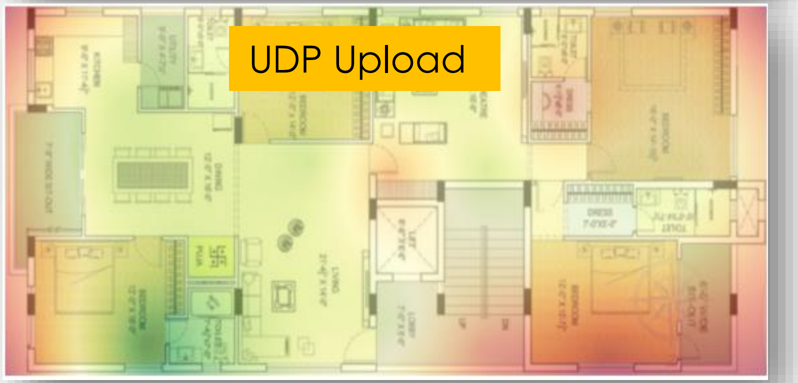
Candela TECHNOLOGIES

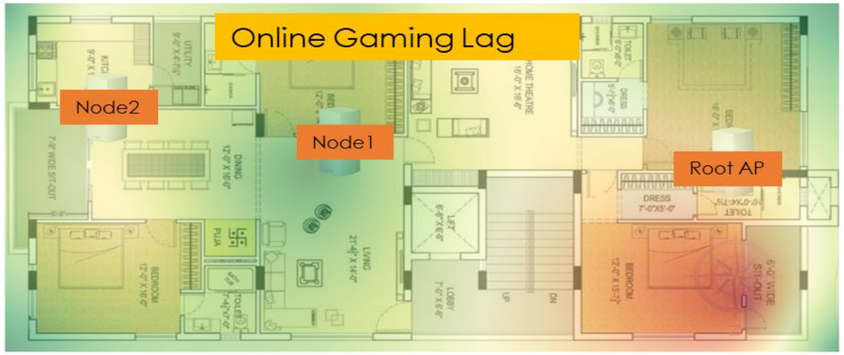




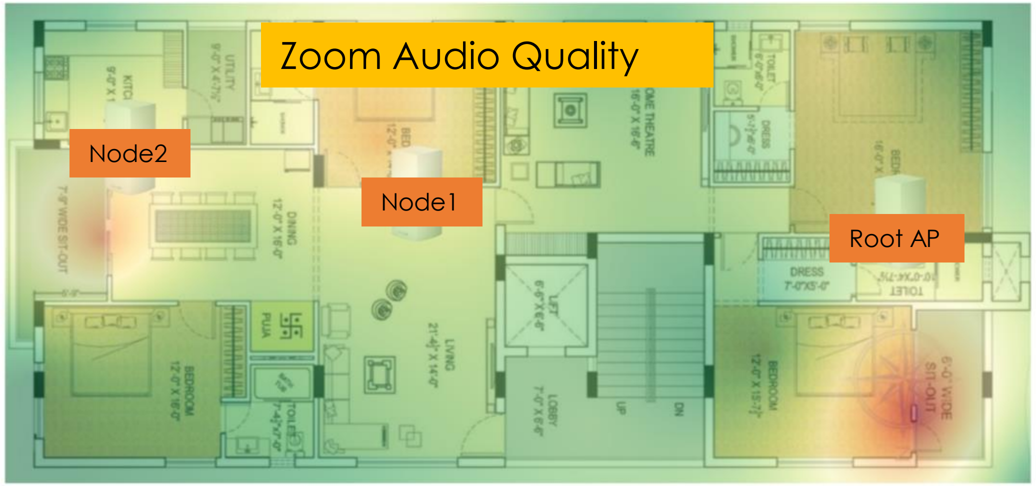


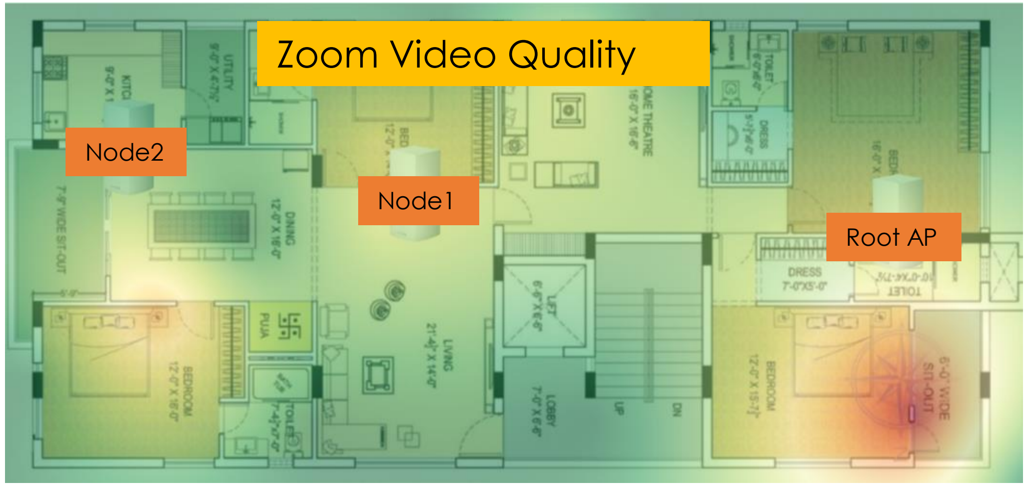


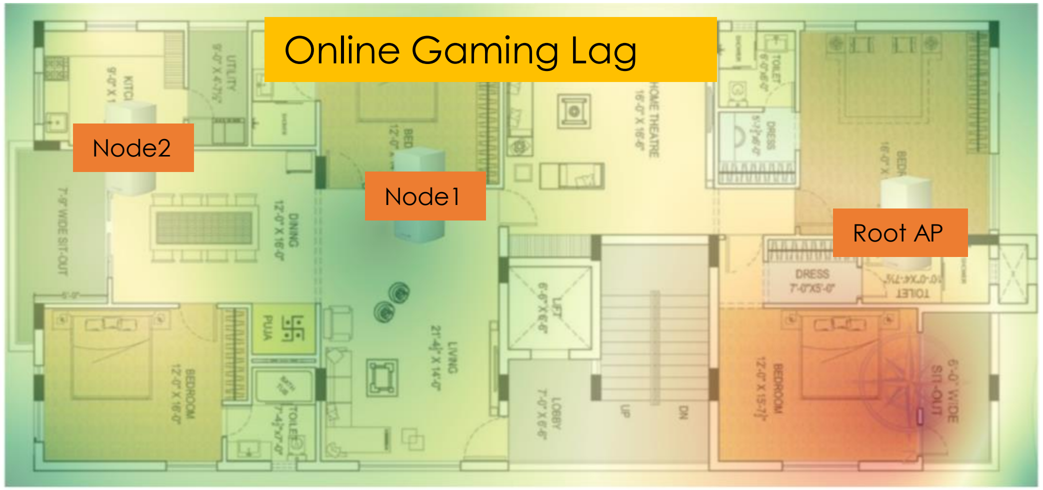


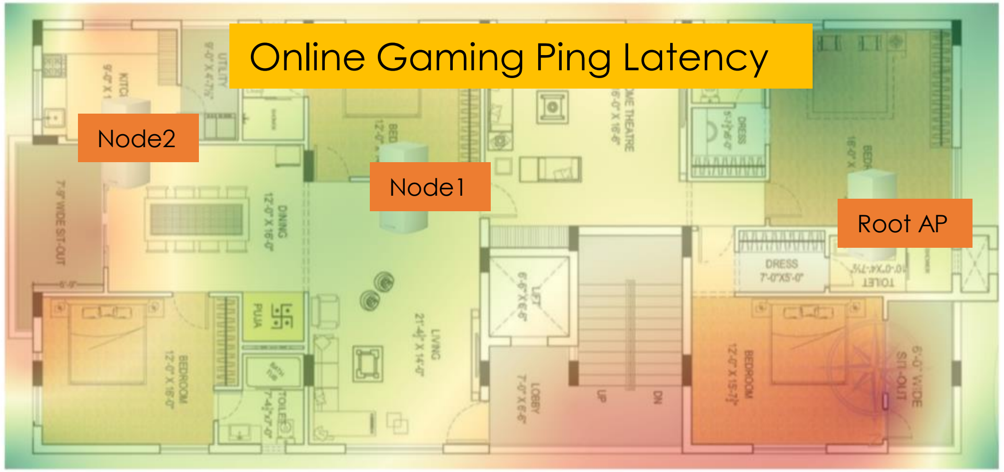


User Experience Heatmaps









Sample Coverage Test Results

	Signal Strength	PHY Rates	Channel Selection	UDP Downstream	UDP Upstream	TCP Downstream	TCP Upstream	Latency
Living Room	PASS	FAIL	FAIL	FAIL	PASS	FAIL	FAIL	FAIL
Dining Room	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Kitchen	FAIL	FAIL	PASS	FAIL	PASS	FAIL	PASS	PASS
Guest Bedroom1	PASS	FAIL	FAIL	PASS	FAIL	PASS	PASS	PASS
Guest Bedroom2	PASS	PASS	FAIL	PASS	FAIL	PASS	FAIL	FAIL
Media Room	PASS	FAIL	PASS	PASS	FAIL	PASS	FAIL	FAIL
Kids Bedroom	FAIL	FAIL	PASS	PASS	PASS	FAIL	PASS	PASS
Master Bedroom	PASS	PASS	FAIL	FAIL	FAIL	PASS	FAIL	FAIL

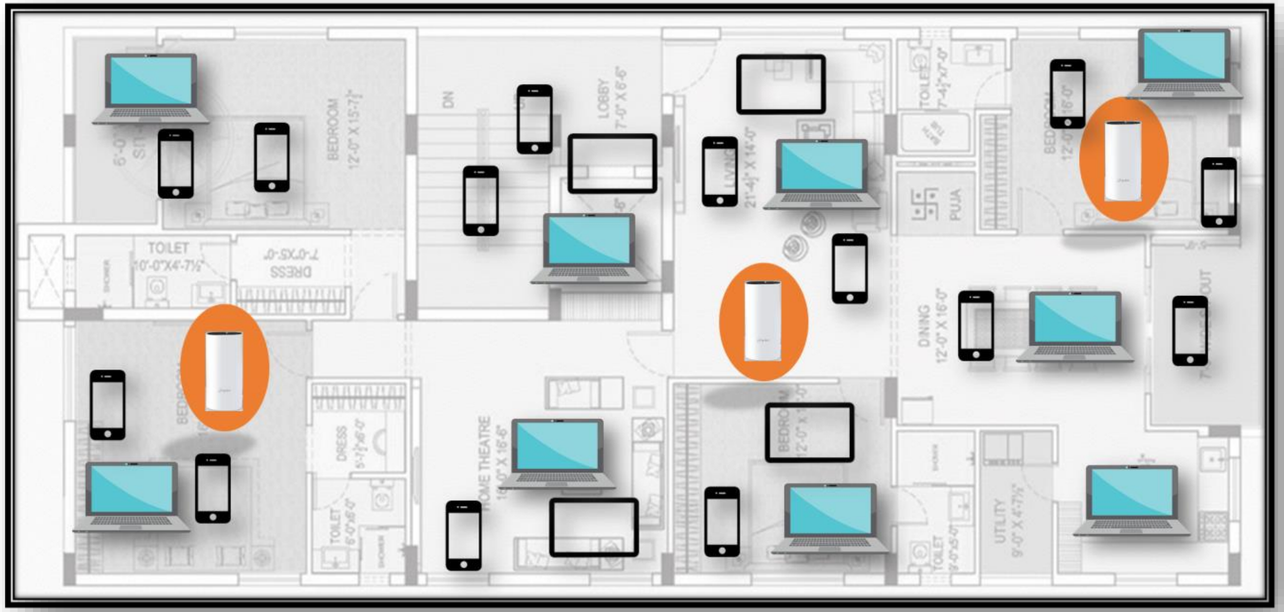
Example Candela WiFi Coverage Score: 82/100

Signal Strength : 95/100
Range : 72/100
Upstream Throughput : 60/100
Downstream Throughput : 75/100
Band Selection : 45/100

	Avg Signal Strength	Avg UDP Downstream	Avg UDP Upstream	Avg TCP Downstream	Avg TCP Upstream	Avg Latency
Living Room	-35 dBm	10 Mbps	66 Mbps	10 Mbps	10 Mbps	450 ms
Dining Room	-62 dBm	56 Mbps	59 Mbps	96 Mbps	56 Mbps	32 ms
Kitchen	-75 dBm	12 Mbps	32 Mbps	12 Mbps	12 Mbps	64 ms
Guest Bedroom1	-43 dBm	93 Mbps	13 Mbps	93 Mbps	93 Mbps	92 ms
Guest Bedroom2	-46 dBm	67 Mbps	17 Mbps	74 Mbps	67 Mbps	364 ms
Media Room	-32 dBm	97 Mbps	7 Mbps	67 Mbps	97 Mbps	523 ms
Kids Bedroom	-74 dBm	85 Mbps	85 Mbps	15 Mbps	85 Mbps	45 ms
Master Bedroom	-49 dBm	5 Mbps	5 Mbps	85 Mbps	5 Mbps	423 ms

Test House – Capacity Testing

Test Tools:
- Laptops, Smartphones, Tablets, Other Virtual Clients.
- iPerf/LANforge software



Test Steps (Objective Scoring):
- AP under test is placed in specific location in the house.
- All the real client devices are placed at specific areas in the house at short, mid and far range distances.
- Candela LANforge units are also placed in specific areas to create more client load.
- Iperf traffic is run on all real clients.
- Performance measurements are made with increasing number of clients and increasing amount of traffic load.

Test Steps (Subjective Scoring):
- Tests are performed with real wireless TVs and real video streaming on the various client devices.
- Real voice calls are placed for voice quality testing.
- Test engineers observe video and audio quality over a period of time and provide subjective scoring based on their user experience.
- Test are run with different amount of background loads and interference

Key Measurements:
- Throughput measurements are made for various high density, low density and high load and low load scenarios.
- Client connection times are measured
- And load balancing efficiency is also measured across all the radios.
- Video and Voice Quality – subjective scoring

Sample Capacity Test Results – Objective Measurements

	Distance	Low Load (1 Mbps/client)			High Load (5Mbps/client)		
		Low Density	Medium Density	High Density	Low Density	Medium Density	High Density
Living Room	Near	1	5	8	1	5	8
Dining Room	Medium		2	4		2	4
Kitchen	Far		2	4		2	4
Guest Bedroom1	Far	1	2	4	1	2	4
Guest Bedroom2	Medium	1	2	4	1	2	4
Media Room	Near		4	8		4	8
Kids Bedroom	Medium	1	1	4	1	1	4
Master Bedroom	Medium	1	2	4	1	2	4
Total Clients		5	20	40	5	20	40
Total Load(Mbps)		5	20	40	25	120	200

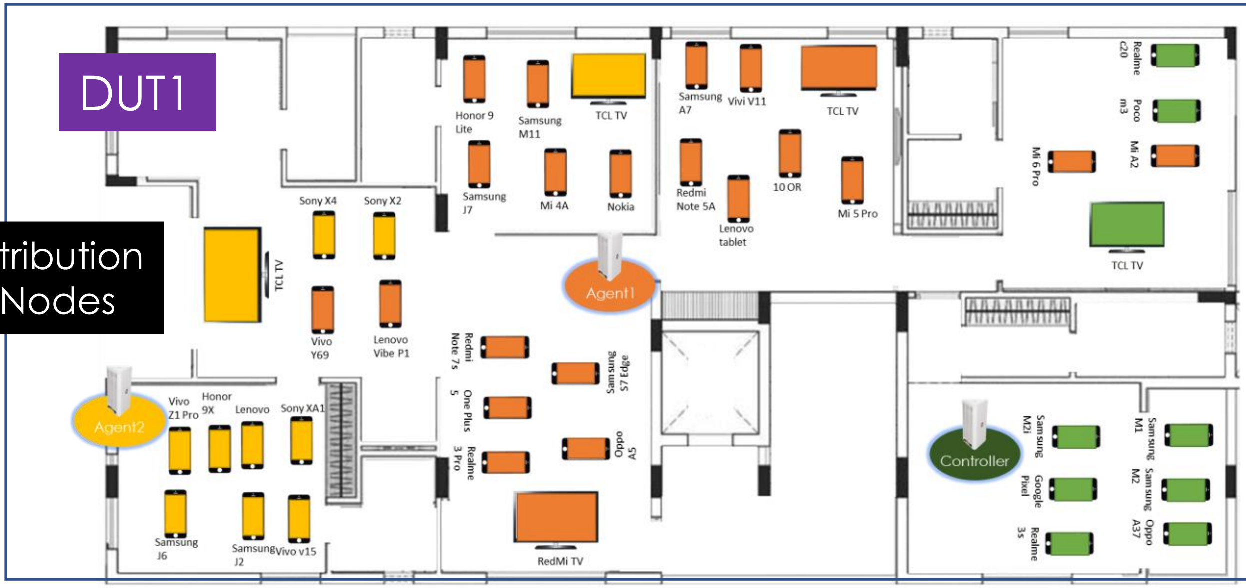
Example Candela WiFi Capacity Score: 82/100

Client Connection Time : 95/100
Range : 72/100
Low Load Performance: 60/100
High Load Performance: 75/100
Load Balancing: 45/100

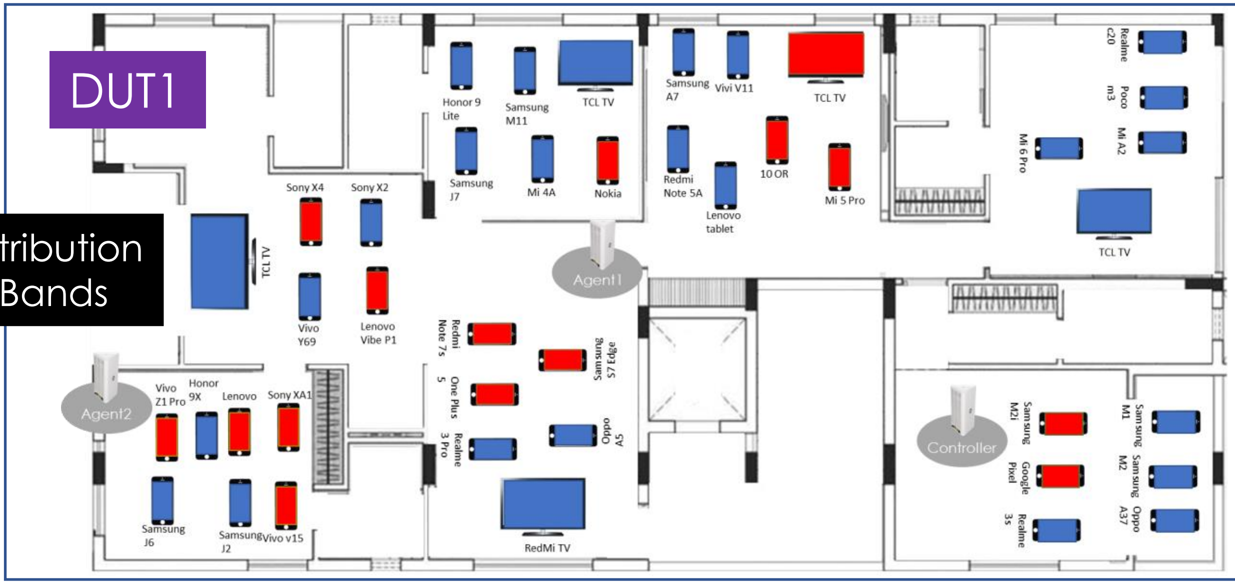
	Distance	Low Load (1 Mbps/client)			High Load (5Mbps/client)		
		Low Density	Medium Density	High Density	Low Density	Medium Density	High Density
Living Room	Near	PASS	FAIL	FAIL	FAIL	PASS	FAIL
Dining Room	Medium	FAIL	PASS	PASS	PASS	PASS	PASS
Kitchen	Far	FAIL	FAIL	PASS	FAIL	PASS	FAIL
Guest Bedroom1	Far	PASS	FAIL	FAIL	PASS	FAIL	PASS
Guest Bedroom2	Medium	PASS	PASS	FAIL	PASS	FAIL	PASS
Media Room	Near	PASS	FAIL	PASS	PASS	FAIL	PASS
Kids Bedroom	Medium	FAIL	FAIL	PASS	PASS	PASS	FAIL
Master Bedroom	Medium	PASS	PASS	FAIL	FAIL	FAIL	PASS

Mesh Testing - Device Distribution by Nodes and Bands

Distribution By Nodes

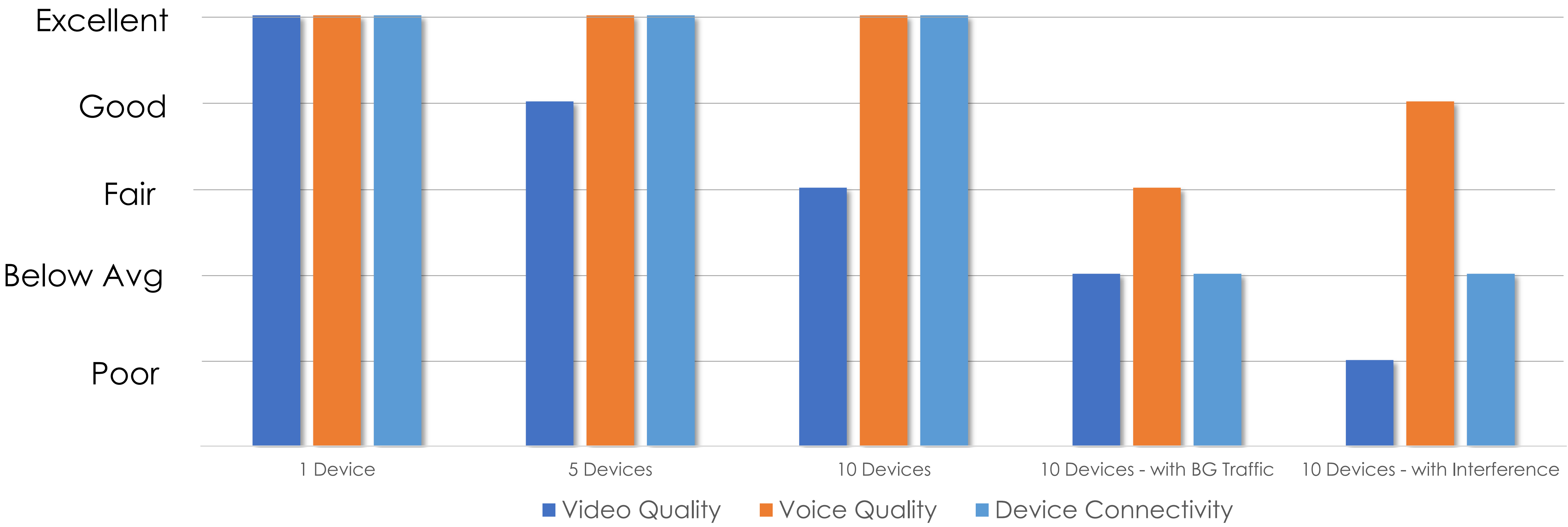


Distribution By Bands



2.4GHz   5GHz

Sample Capacity Test Results – Subjective Scoring



Test House – Mobility Testing

Test Tools:

- Test Laptop/Smartphone.
- iPerf/LANforge software

Test Steps (Objective Scoring):

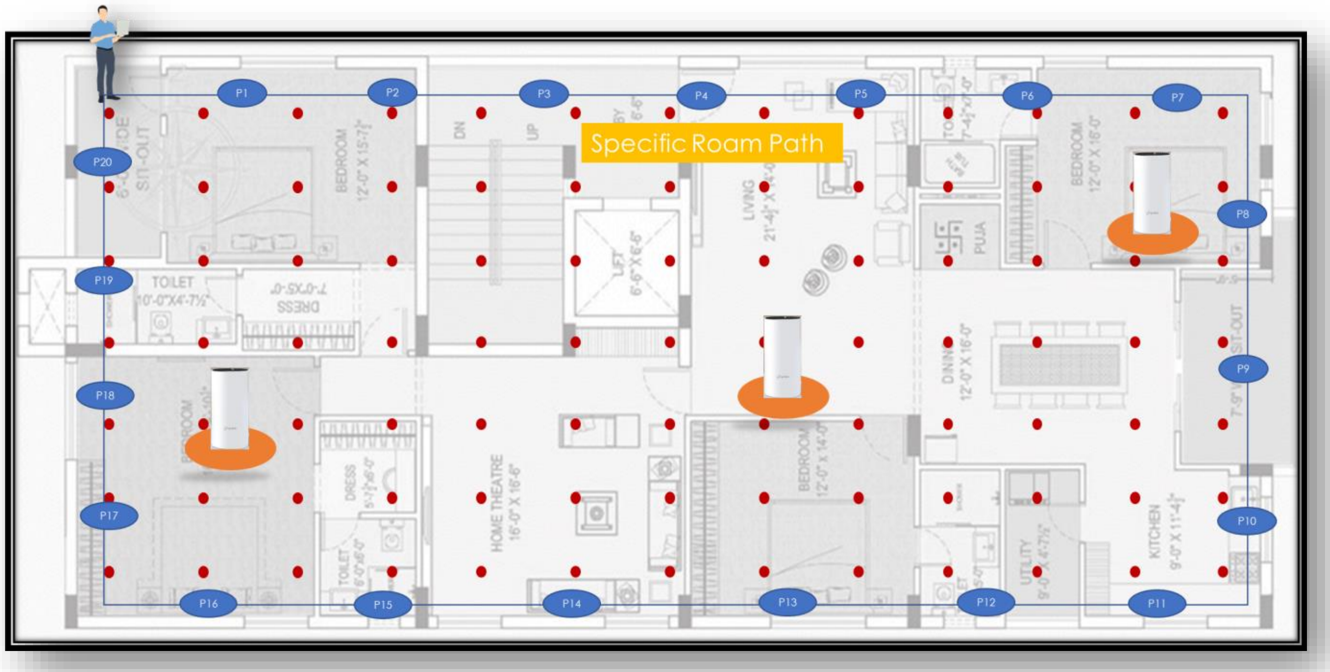
- This tests applies on to Residential Mesh systems
- The test path is clearly marked in the house
- The test moves along the test path and makes measurements at various test points.
- The result are plotted and presented.

Key Measurements:

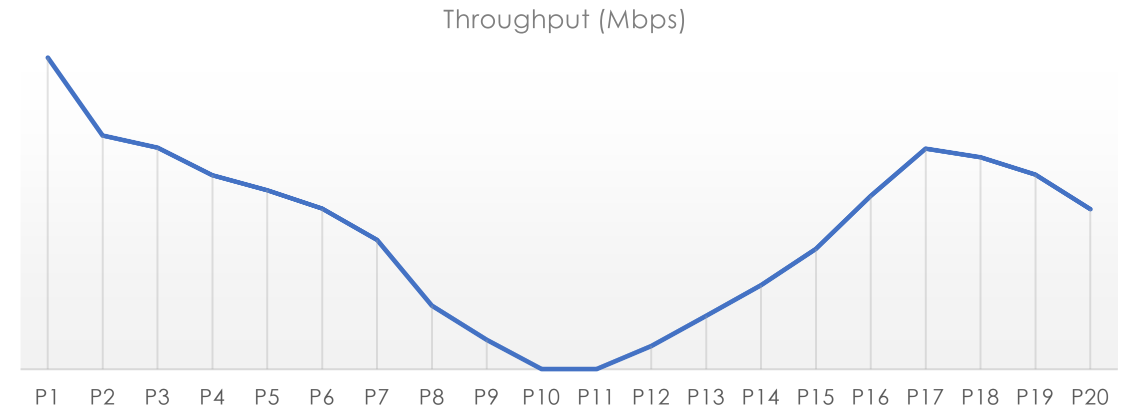
- Throughput/latency/jitter at various points on the mobility path.
- Roam pattern, selected AP and Band at each point on the mobility path.
- Any service interruption noticed due to client disconnection.

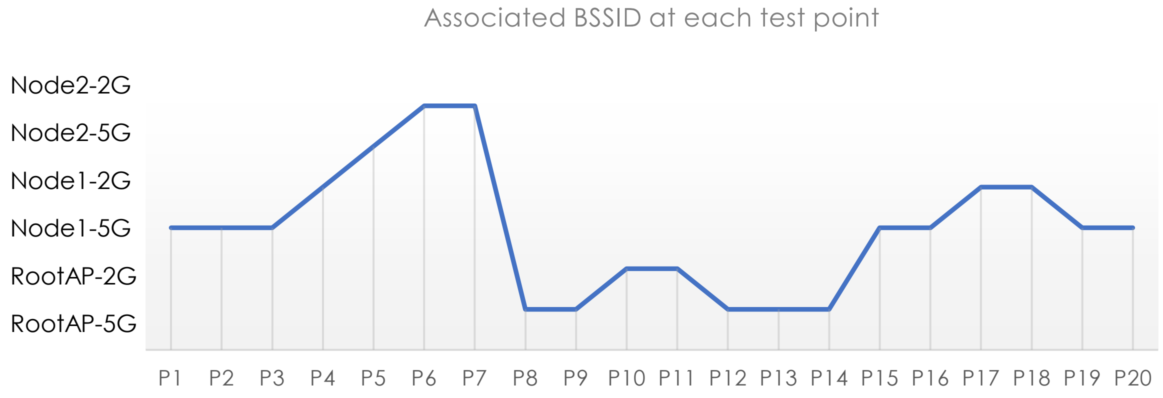
Sample Candela WiFi Mobility Score: 82/100

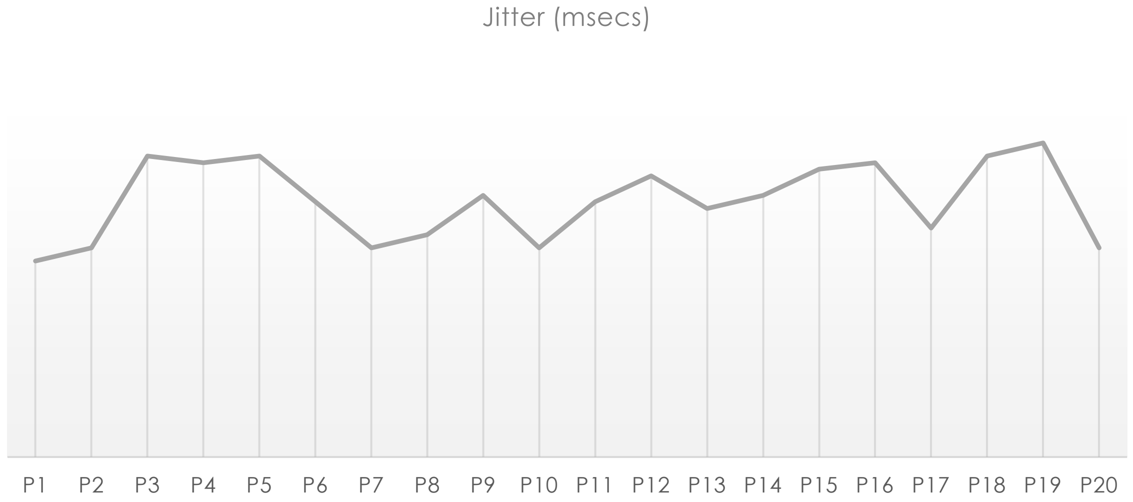
Throughput : 95/100
Client Connection : 72/100
AP Selection: 60/100

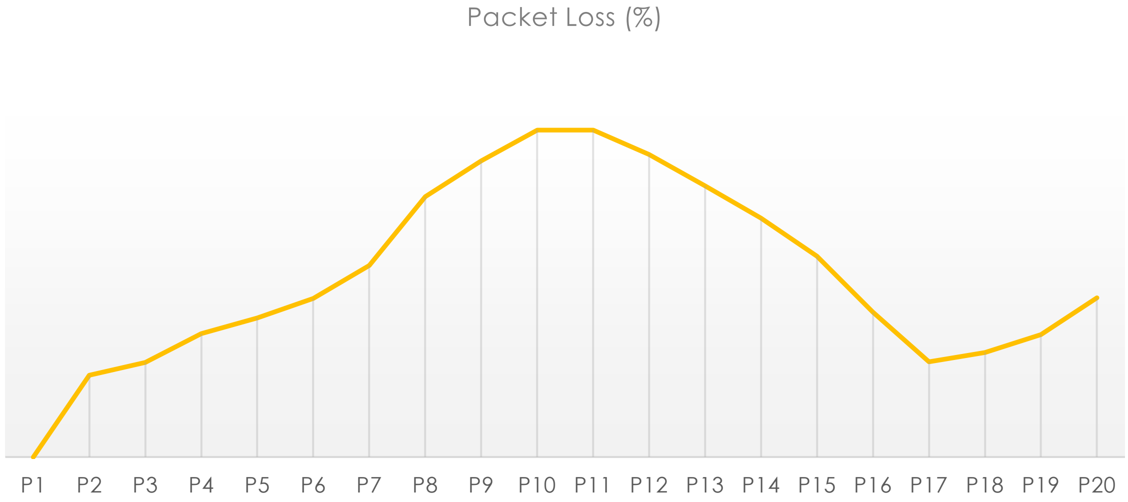


Mobility Test Results









Test House – Interoperability Testing

Test Tools:
- Interoperability test device
- iPerf/LANforge software

Test Steps (Objective Scoring):
- Do basic coverage testing with the single device at 5 different marked points in the house.
- Do throughput testing at one specific location in the house and measure Upstream/Downstream performance.
- Check for basic client connectivity with all security types.

Vs

Nighthawk AX12 WiFi 6 Router

iPhone12

Key Measurements:
- Throughput
- Client connection times
- coverage

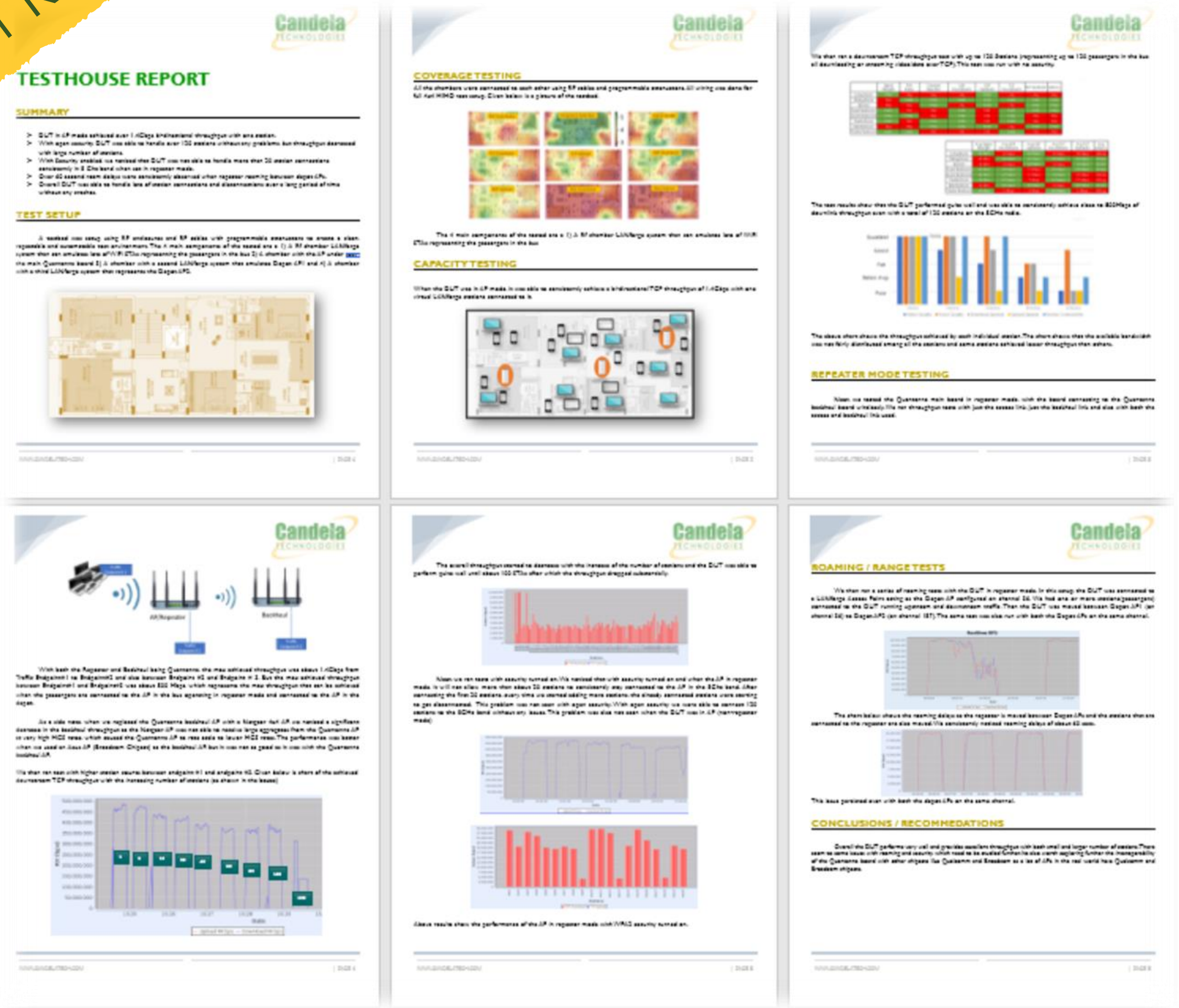
Sample Candela WiFi Interoperability Score: 82/100

Throughput : 95/100
Client Connection : 72/100
Coverage: 60/100

Device	Signal Strength	Throughput	Client Connection
iPhone 12	PASS	FAIL	FAIL
Oppo A37fw	FAIL	PASS	PASS
Vivo Y95	FAIL	FAIL	PASS
Oppo F15	PASS	FAIL	FAIL
Samsung A50	PASS	PASS	FAIL
Redmi K20Pro	PASS	FAIL	PASS
Redmi Note 3	FAIL	FAIL	PASS
Vivo V9 Youth	PASS	PASS	FAIL

Test Reports

- Comprehensive Test Reports which Include:
  - Information about the Device Under Test
  - Overall Weighted Average Test score.
  - Over summary of the observed results
  - Individual test scores for each test category
  - The actual performance tables and charts.
  - All supporting data/results
  - Report conclusion and analysis summary
  - Expert analysis and recommendations.



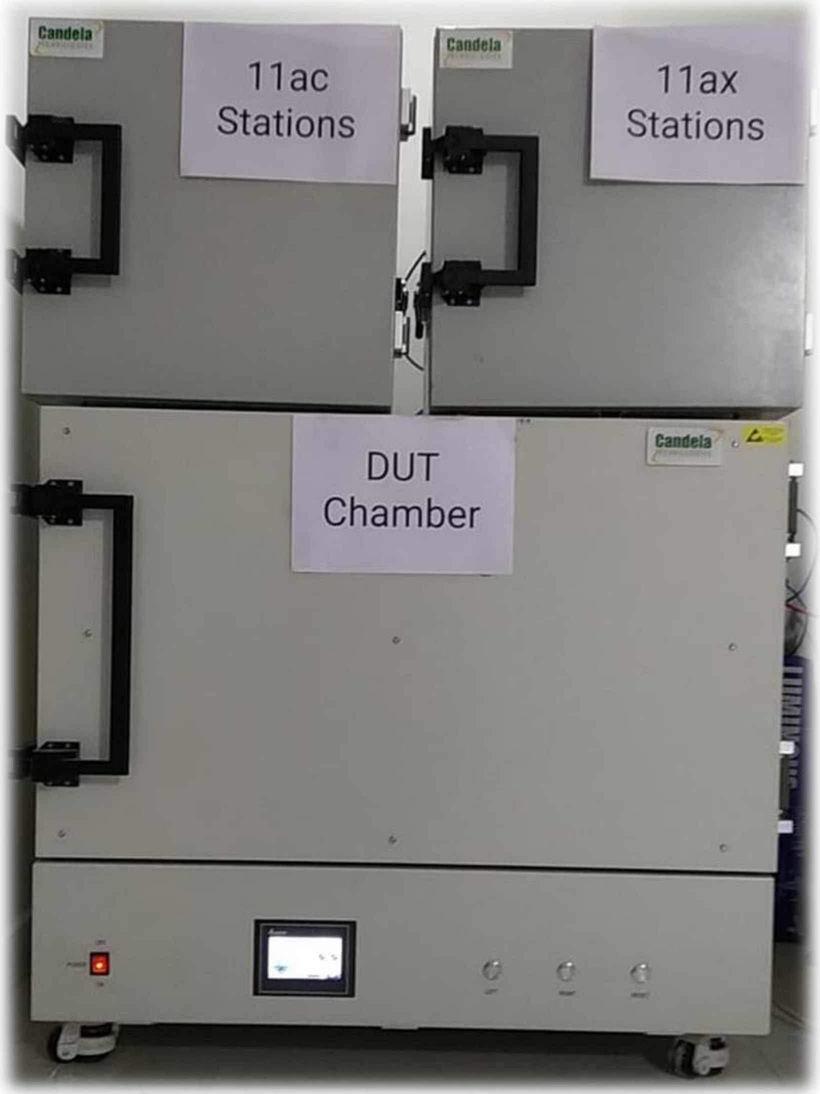
Candela India Office

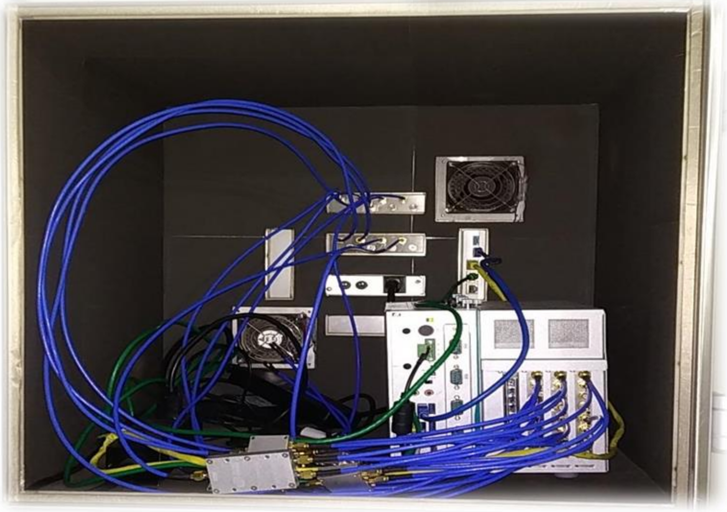

Candela
TECHNOLOGIES
CAWIN
Candela Acharya
Wireless INnovation lab
ACHARYA
Industry Lab in College Campus.
Industry /Academia collaboration.
Student Internships and Job Opportunities.
Wireless Networking Center of Excellence


i ♥ ACHARYA

Candela India Lab Setups

Testbed Images





TELECOM INFRA PROJECT
OpenWiFi
11ac
Stations
11ax
Stations
DUT
Chamber
RUCKUS

Candela India Lab Setups

APs Tested in our India Lab

AP Performance - Test as a Service

Total Wireless Experience

BASIC
Basic AP Performance

3 Days

- ✓ AP General Performance Test
- ✓ Client Capacity
- ✓ Client Connection Rate
- ✓ Multi-band Test
- ✓ Multi-SSID Test
- ✓ Long Duration Stress Test

This engagement helps vendors quickly qualify APs as new firmware without have to setup their own lab

ADVANCED
Performance & Functionality

1 week

- ✓ All test in BASIC
- ✓ Receiver Sensitivity
- ✓ Performance over Distance
- ✓ Roaming
- ✓ QoS
- ✓ Traffic Mix Tests
- ✓ Airtime Fairness/Mixed Mode Clients

This is most advanced set of tests that can be run for higher end Access Points

EXPERT
Full set of Tests

2 weeks

- ✓ All Tests in ADVANCED
- ✓ Power Save Test
- ✓ Band Steering Test
- ✓ Video Performance
- ✓ Interference Test
- ✓ MU-MIMO Performance
- ✓ WAN Impairments Test

Covers even more advanced set of tests for higher end enterprise class APs

COMPREHENSIVE
Vendor Selection/Qualification

4 weeks

- ✓ Run all test in Expert
- ✓ Compare test results for multiple DUTs
- ✓ Provide a recommendation based on comparative score sheet.
- ✓ Provide expert Analysis

Helps with selecting the right vendors by running several tests across vendors and providing comparative results

- ➢ Tests will be run in Candela test lab. All test engagements provide a detailed executive report with result summary and details.
- ➢ Candela will provide all test equipment, an expert test engineer and customer to provide the DUT and DUT config

Sample Comparison Results Summary

Num	Tests	Vendor A Access Point	Vendor B Access Point	Vendor C Access Point
1	Throughput – 5GHz	Excellent	Good	Average
2	Throughput – 2.4GHz	Excellent	Good	Good
3	Client Capacity – 5GHz	Excellent	Good	Average
4	Client Capacity – 2.4GHz	Excellent	Good	Average
5	Rate vs Range – 5GHz	Excellent	Good	Average
6	Rate vs Range – 2.4GHz	Good	Average	Good
7	Dual Band Throughput	Excellent	Poor	Poor
8	Airtime Fairness – 5GHz	Excellent	Not Functional	Not Functional
9	Airtime Fairness – 2.4GHz	Excellent	Not Functional	Not Functional
10	Roaming Performance	Excellent	Poor	Average
11	Spatial Consistency -5GHz	Excellent	Poor	Poor
12	Spatial Consistency -2.4GHz	Excellent	Average	Average
13	Mu-MIMO Performance	Excellent	Not Functional	Not Functional
14	QoS Performance	Excellent	Average	Poor
15	Client Connection Rate	Average	Excellent	Poor
16	Near/Far Clients Performance – 5GHz	Excellent	Average	Average
17	Near/Far Clients Performance – 2.4GHz	Average	Poor	Good
18	Long Term Stability	Average	Poor	Average

Access Point Testcases

Category	Sub-Category	Test Cases developed for
Command and Control	Firmware	Upgrades/Downgrades, AP boots/reboots, System resources
	Configuration & Communication	AP provisioning, ZTP, setting up networks/channels/profiles/APs, cloud connectivity, DHCP/Radius and other services, Alarms
	Operation Modes	Bridge/vlan/router modes,
	Physical & Virtual Interfaces	Basic functions of LAN/WAN/WLAN physical interfaces, indicators/LEDs, virtual interfaces (SSIDs/VLANs etc..)
	GUI/APIs	GUI settings (Read/Write) , API calls (Push/Pull)
Functional Testing	BSS Capabilities	Basic/Extended Capabilities, Security, QoS, RRM, DFS, 802.11a/b/g/n/ac/ax/k/v/r/i/u/w settings, reg domains etc..
	Connectivity & Security	Basic connectivity with all WPA/2/3 Personal/Enterprise, All EAP method, Passpoint. Captive Portal, WPS etc…
	Radio Resource Management	Load Balancing, Band Steering, Auto Channel Selection, DFS
	Smart WiFi	Role/User/Device/Network based policies, Traffic Shaping, Int Detection/Mitigation, DPI, threat detection, Location Services
	QoS & Mobility & Power Save	WMM, Fast Roaming, Open Roaming, Network assisted handoff, Legacy/WMM/MIMO Power Save
Performance Testing	Throughput Benchmark	Throughout for STA Modes/MIMO types/STA counts/BW settings/Traffic Types/Direction/Packet Sizes etc..
	Multiband Performance	Single/Dual/Tri band performance
	Mobility Performance	Rate vs Range, Rate vs Antenna Orientation, Roaming Delay, Roaming performance with different security types
	Radio Performance	Receiver Sensitivity, Transmitter Quality, Reg Domain TX power testing.
	Application Performance	VOIP Performance, Youtube/OTT Video Streaming, HTTP/FTP Performance, Social Media Apps performance
Stress and Endurance Testing	Day in Life Test	Mix of Stations/APs/SSIDs/Security Types/User Policies/Traffic/Device Load Patterns over time in a 10 hour day
	48-hour Stress Test	Full system load across all interfaces with maximum stations/traffic run for 48 hours
	Load Patterns #1,#2, #3	Various real world load patterns run over long durations.
Use Case Testing	Single AP SOHO	TR-398 or similar test plan for comprehensive single SOHO AP testing, Qualification/Badge Program
	SOHO Mesh	Throughput Per Hop, Mesh Failover, Roaming, Load Balancing, Qualification/Badge Program
	Med-Enterprise Network	Medium Size Enterprise Network Use cases, Qualification/Badge Program
	Multi Dweller Unit (MDU)	MDU Test plan with clear PASS/FAIL results , Qualification/Badge Program
	Campus Network/ LPV	Campus Network/Large Public Venue Test Plan/Operator Network, Qualification/Badge Program

802.11ac Access Point Test Plan - Overnight

Basic Client Connectivity

- Connect and Disconnect 20 clients each on 2.4Ghz and 5Ghz radios using Open, WPA-PSK, WPA-Enterprise methods, measure connecting times and connection drops.

Benchmark Throughput

- Run full line rate traffic with single client in 4x4 MIMO 80Mhz mode in 5GHz and 3x3 MIMO 40 Mhz in 2.4GHz. Measure and Benchmark maximum throughput.

Full System Performance

- Load all radios and ethnet interfaces simultaneously with full line rate traffic and measure the maxium achieved system throughput

Roaming Performance

- Create lots of clients and connect them to the AP and then cause lots of roams across various security types and measure romaing performance

Reciever Sensitivity

- Fix the MCS rates on the client and send traffic with same MCS rate but different transmit power values and measure receiver sensitivity at all power level. Run test at all MCS rates

Rate vs Range

- Measure performance over distance for various traffic types both Upstream and Downstream.

Client Capacity

- Run a throughput test with 1,2,5,10,20 and 40 clients. Repeat test on both 2.4GHz and 5GHz bands.

Mu-MIMO

- Create 3 STAs (1x 2x2 MIMO and 2x SISO) and measure the increase in troughput when Mu-MIMO feature is enabled.

Airtime Fairness

- Connect 1x 802.11ac client and 1x 802.11n client and 1x 802.11a client, run equal amount of traffic on all three clients and see if AP distributes airtime fairly.

QoS Performance

- Create different voice, video and data traffic streams with different DSCP settings and WMM settings and check to make sure the AP provides better throughput to high priority traffic.

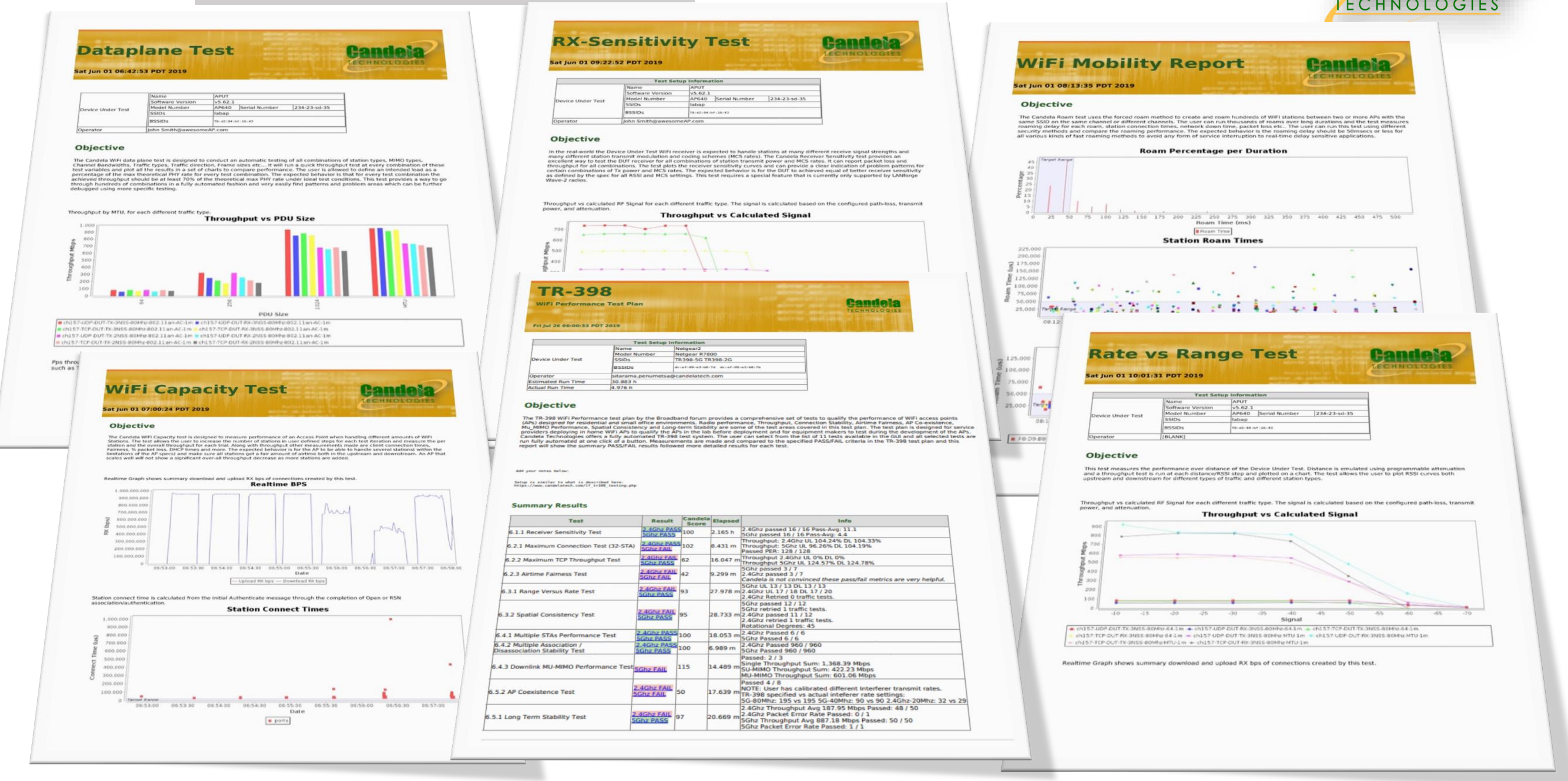
DFS Conformance

- Generate different types of Radar Pulses and make sure the AP can detect Radar and move to a differen channel and stay off channel.

Lond Duration Stability

- Connect lots of clients and run traffic for a 24 hour period and look for any instability in the AP performance

PDF TEST REPORTS



Customized Dashboards

Test Result Summary

Candela TECHNOLOGIES

- Test Cycle 1
- Test Cycle 2
- Test Cycle 3
- Test Cycle 4
- Test Cycle 5

Dashboard - Summary

By Test Category

Category	PASSED	FAILED	%
Sanity (1.5hrs)	25	12	63%
Functional (0.8hrs)	63	21	85%
Performance (8.7hrs)	68	15	90%
Load/Stress (0.5hrs)	19	16	56%
Smart WiFi (2.2hrs)	45	9	92%
Longevity (9.5hrs)	8	2	80%

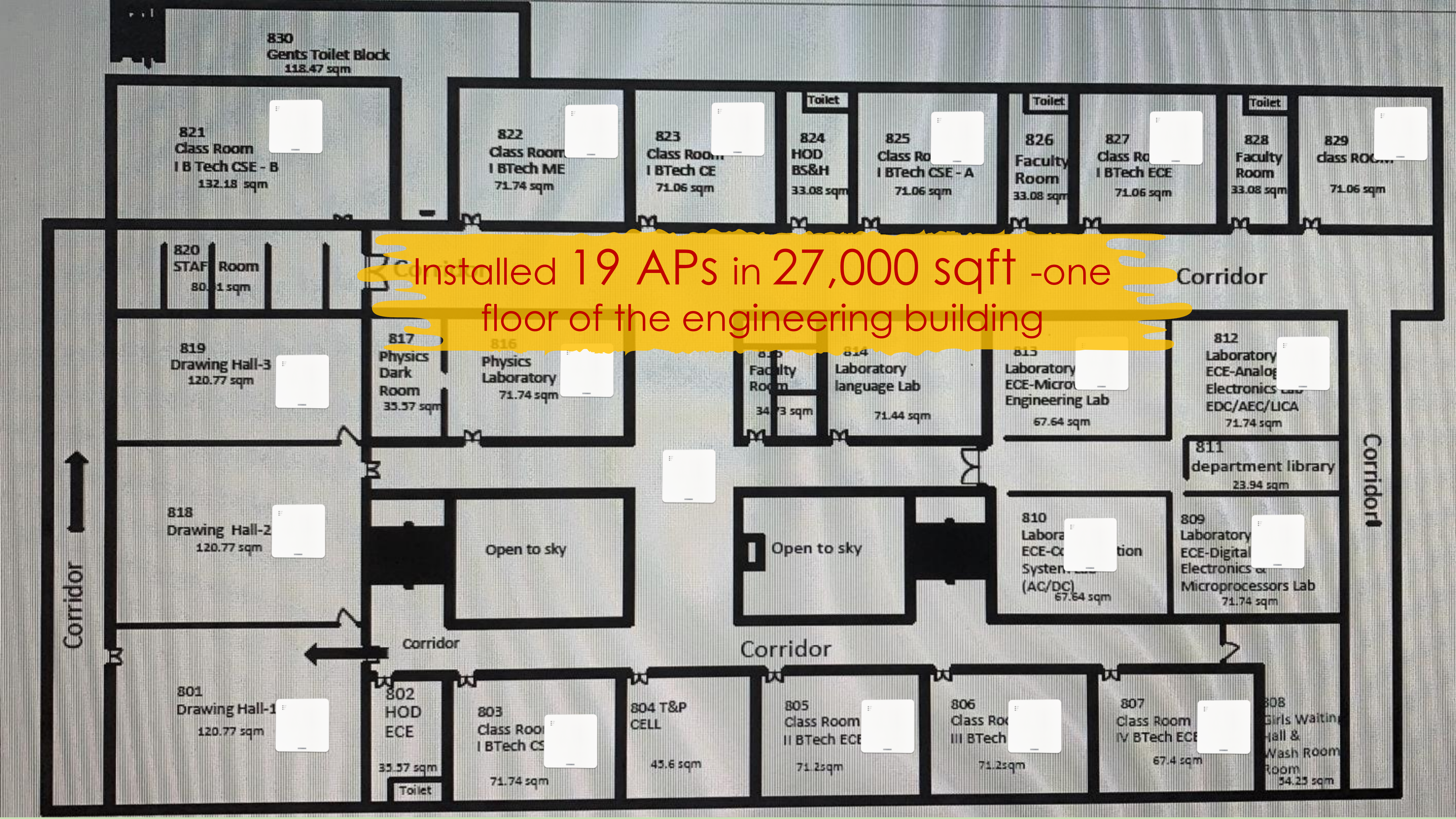
By Firmware Build

Build	PASSED	FAILED	%
R1.0-34-567 (3.5hrs)	25	25	50%
R2.1-45-456 (3.5hrs)	20	30	40%
B1.3-43-545 (3.5hrs)	30	20	60%
B1.7-45-566 (3.5hrs)	5	45	10%
R1.3-54-345 (3.5hrs)	40	10	80%
R1.7-45-565 (3.5hrs)	50	0	100%

By Access Point Model

Model	PASSED	FAILED	%
AP102 (1.5hrs)	8	12	40%
AP304 (1.5hrs)	15	5	75%
RG564 (1.5hrs)	18	2	90%
R123 (1.5hrs)	16	4	80%
BR652 (1.5hrs)	10	10	50%
AP101 (1.5hrs)	20	0	100%

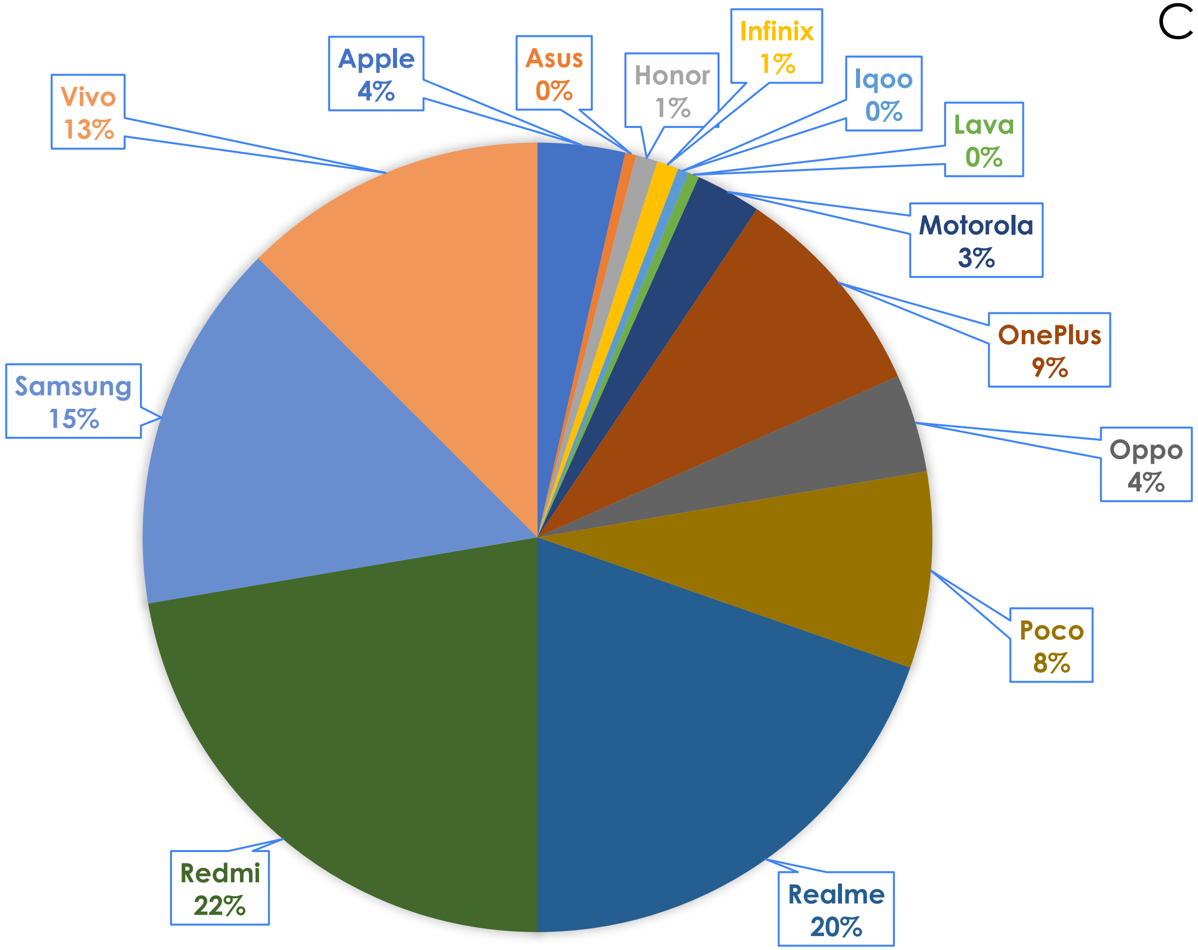
Testing OpenWiFi APs on Real College Campuses



Installed 19 APs in 27,000 sqft -one floor of the engineering building
830
Gents Toilet Block
118.47 sqm
821
Class Room
I B Tech CSE - B
132.18 sqm
822
I BTech ME
71.74 sqm
823
I BTech CE
71.06 sqm
Toilet
824
HOD
BS&H
825
I BTech CSE - A
71.06 sqm
826
Faculty
Room
827
I BTech ECE
71.06 sqm
828
Faculty
Room
829
71.06 sqm
820
Room
Corridor
819
Drawing Hall-3
120.77 sqm
817
Physics
Dark
Room
816
Physics
Laboratory
71.74 sqm
814
Laboratory
language Lab
71.44 sqm
813
Laboratory
Engineering Lab
67.64 sqm
812
Laboratory
EDC/AEC/LICA
71.74 sqm
811
department library
23.94 sqm
818
120.77 sqm
Open to sky
Open to sky
810
(AC/DC)
67.64 sqm
809
Laboratory
ECE-Digital
Microprocessors Lab
71.74 sqm
Corridor
Corridor
Corridor
801
120.77 sqm
802
HOD
ECE
35.57 sqm
Toilet
803
71.74 sqm
804 T&P
CELL
45.6 sqm
805
Class Room
71.2sqm
806
III BTech
71.2sqm
807
Class Room
67.4 sqm
808
54.25 sqm


396 Devices Connected!
All Students connecting to WiFi Network

Over 400 Smartphones used the test



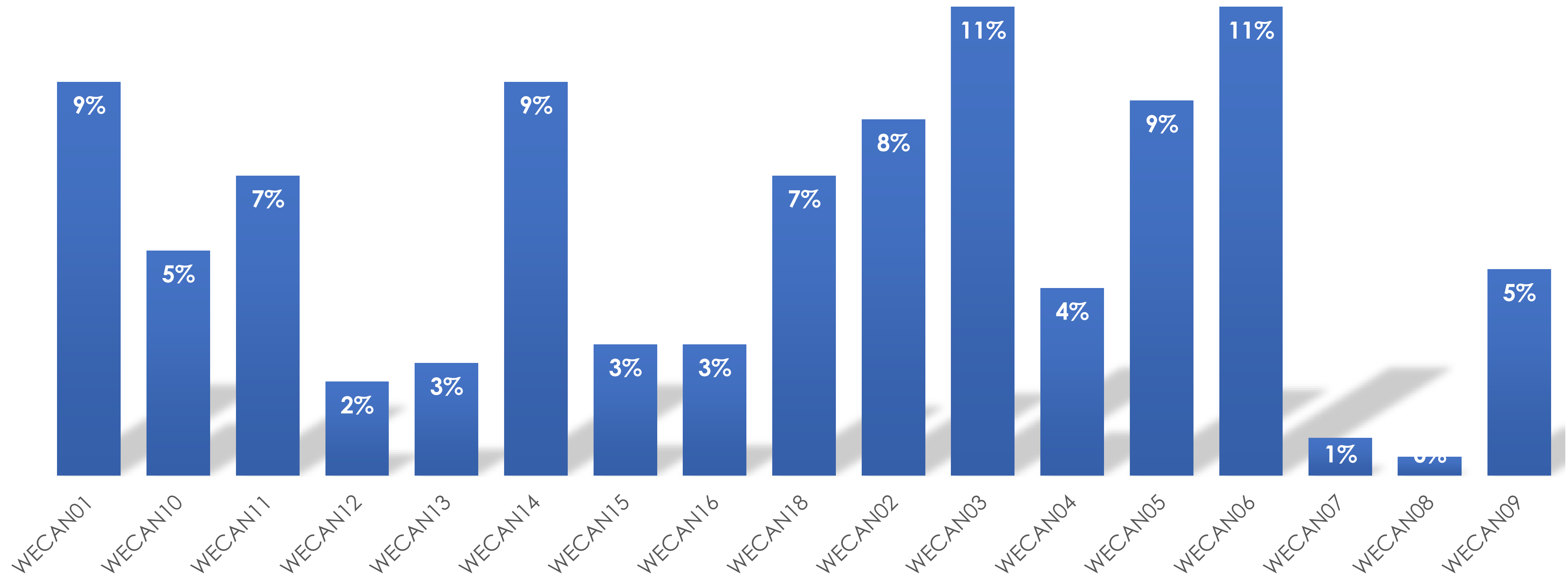
PHONE BRANDS

Close to 100 Different Phone Models

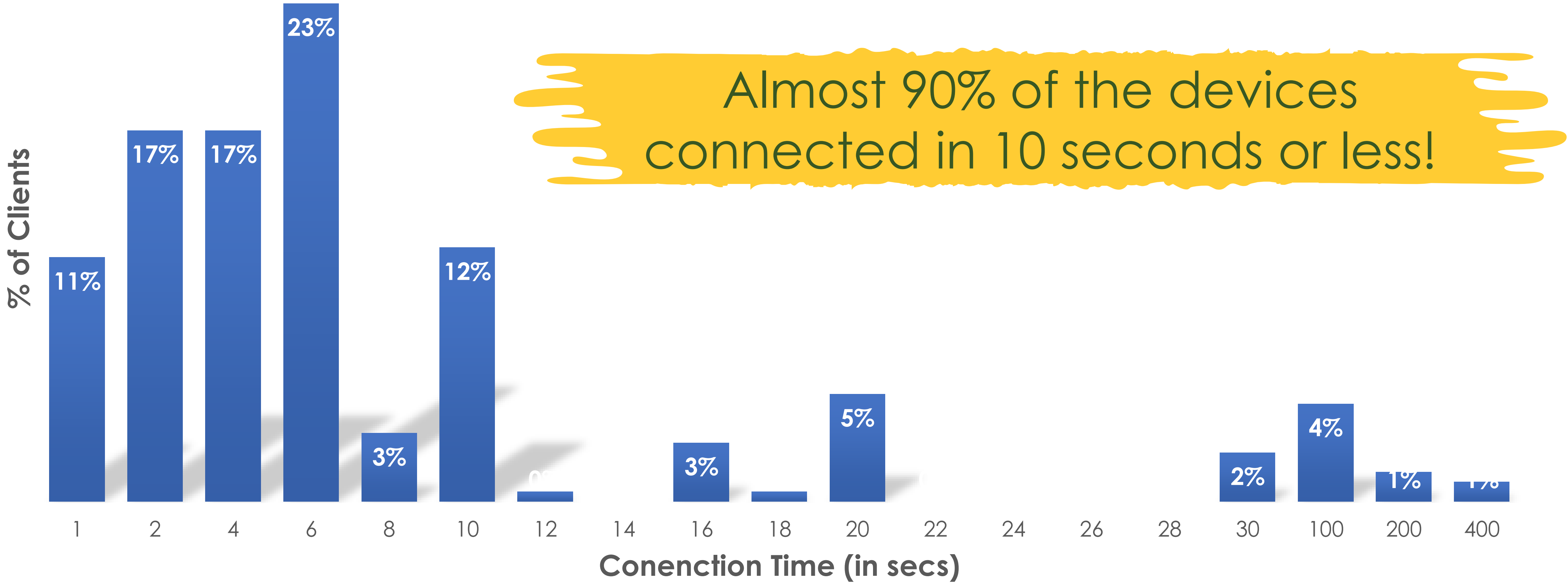
OnePlus 8	Oppo A3s	Samsung A9	Samsung A51
Redmi Note 9 Pro	Samsung J6+	Redmi Nore 8	Vivo 21e
Realme C5	Samsung A30	OPPO A31	Poco X3
Realme 2 Pro	Vivo X60	Apple 6s	Vivo V19
Realme Narzo	Redmi Note 5 Pro	Samsung M32	Redmi 10
Apple XS	Realme 8 Pro	Redmi 7	Vivo Y21
Redmi A3	Redmi 8 Pro	Poco M2pro	Poco F1
Samsung M31	Samsung M30	Motorola Plus	Samsung F19
Motorola E4	OnePlus 9R	Realme 8	Samsung A5
OnePlus 7T	Poco XR	Vivo V11	Vivo Z1 Pro
Redmi K20 pro	Samsung J7	Realme Master	Samsung M31s
Redmi Note 7 Pro	Vivo V20 Pro	Samsung F12	Realme XT
Redmi Note 7S	Samsung M21	Realme RMX1911	Redmi 10i
Vivo V7	Redmi Note 10	Samsung A70	Iqoo 7
Realme 7	Infinix Hot 8	Realme C3	Apple 11
Redmi 6 Pro	OnePlus Nord	Poco C3	Samsung M20
Redmi Note 7	Poco M2	Vivo S1	Samsung M10
Redmi Note 8	Realme 3	Realme 3i	Realme 5 Pro
Realme 5	Redmi Note 9	Vivo V9	Realme X2
Redmi Note 4	Samsung A21	Samsung F41	Redmi K20
Vivo V15 Pro	Redmi Prime	Redmi Note 5	Oppo A37
Samsung J7 Max	Realme X7	Samsung S6	Oppo F19 Pro
Poco M2 Pro	Infinix X625D	Honor 8x	OnePlus 7
Redmi Note 6	Samsung M12	Vivo Y20	Redmi 5A
Realme 6 Pro	Realme C12	Apple SE	

Over 400 devices connected across 17 APs with tests running for about 2 hours. All APs were up 100% of the time with no reboots or crashes

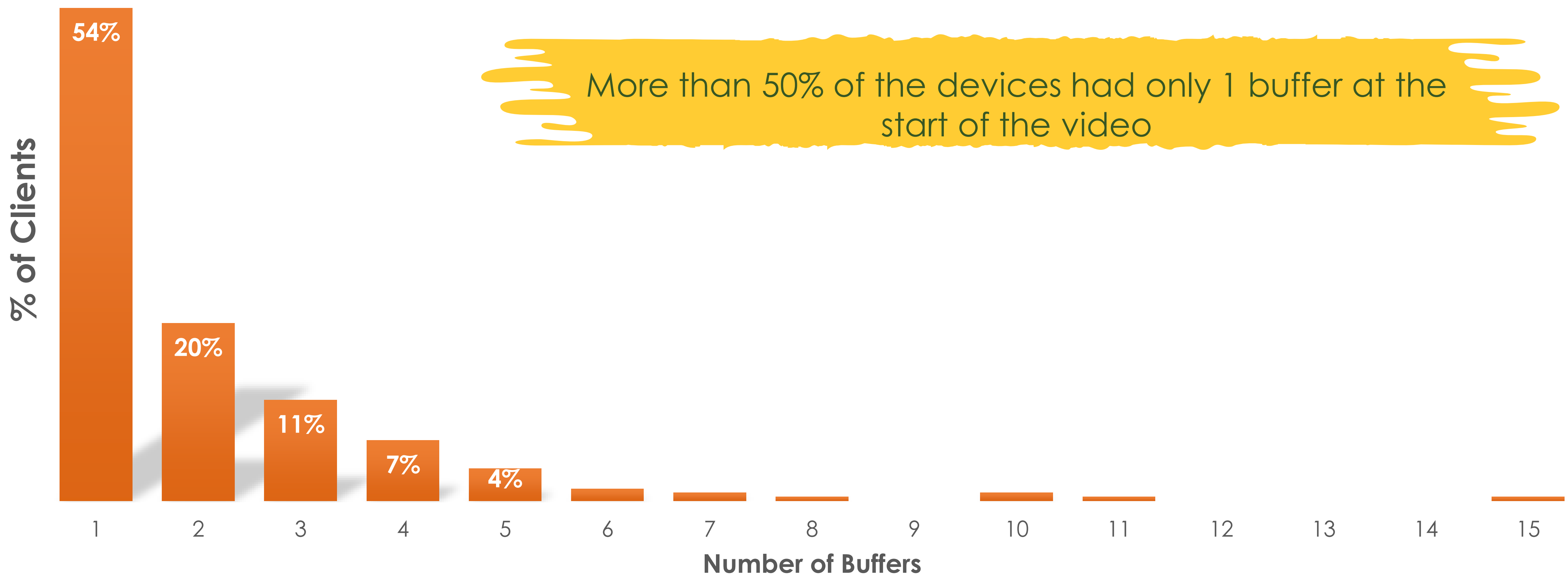
Percentage of Clients on each AP



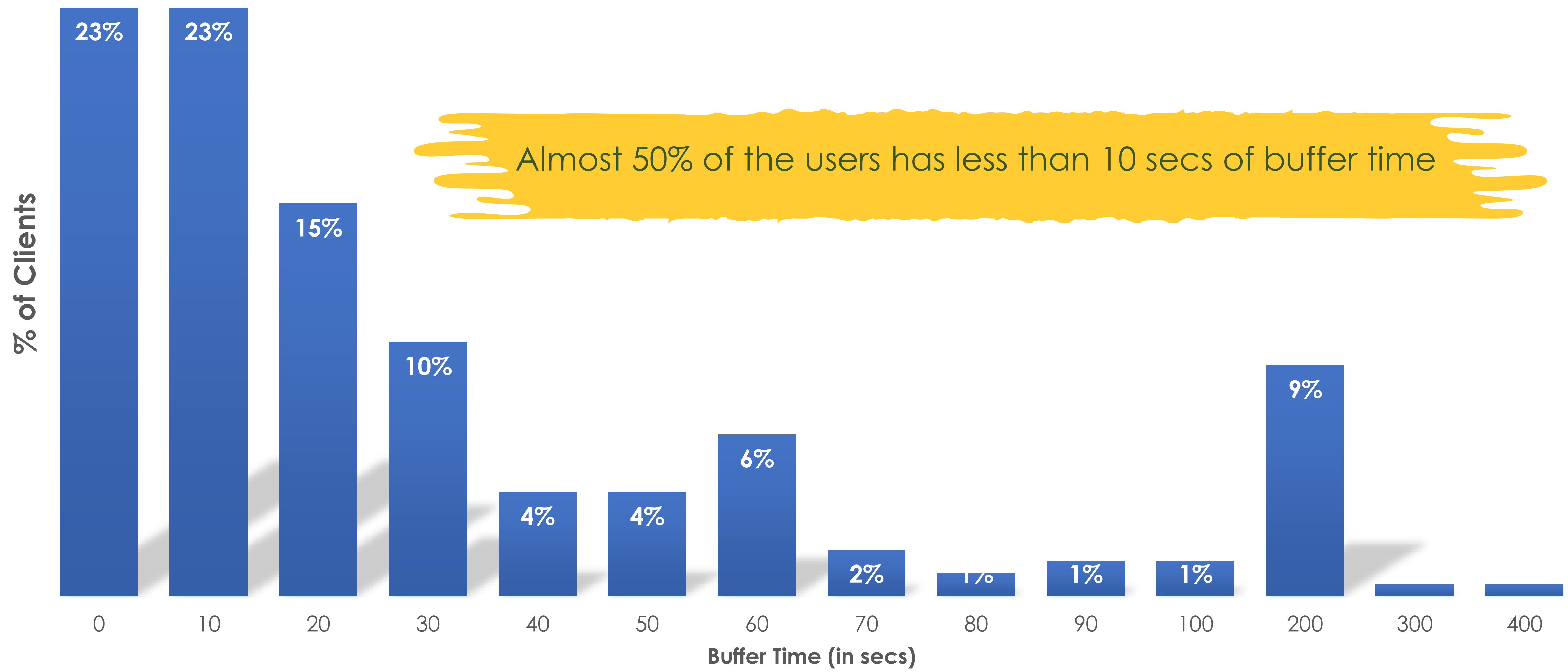
Client Connection Time (in Secs) Distribution



Number of YouTube Buffers Distribution

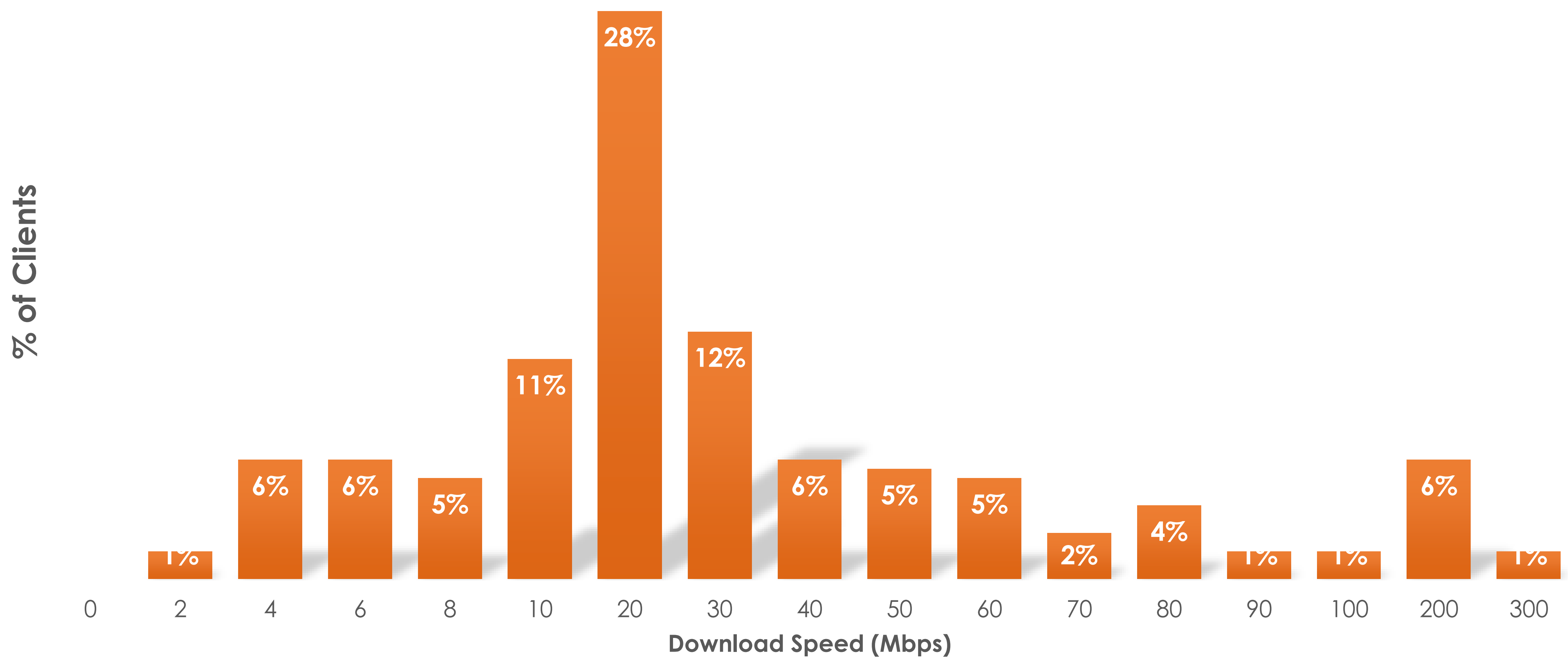


Buffer Time (in secs) Distribution - 8 min Video

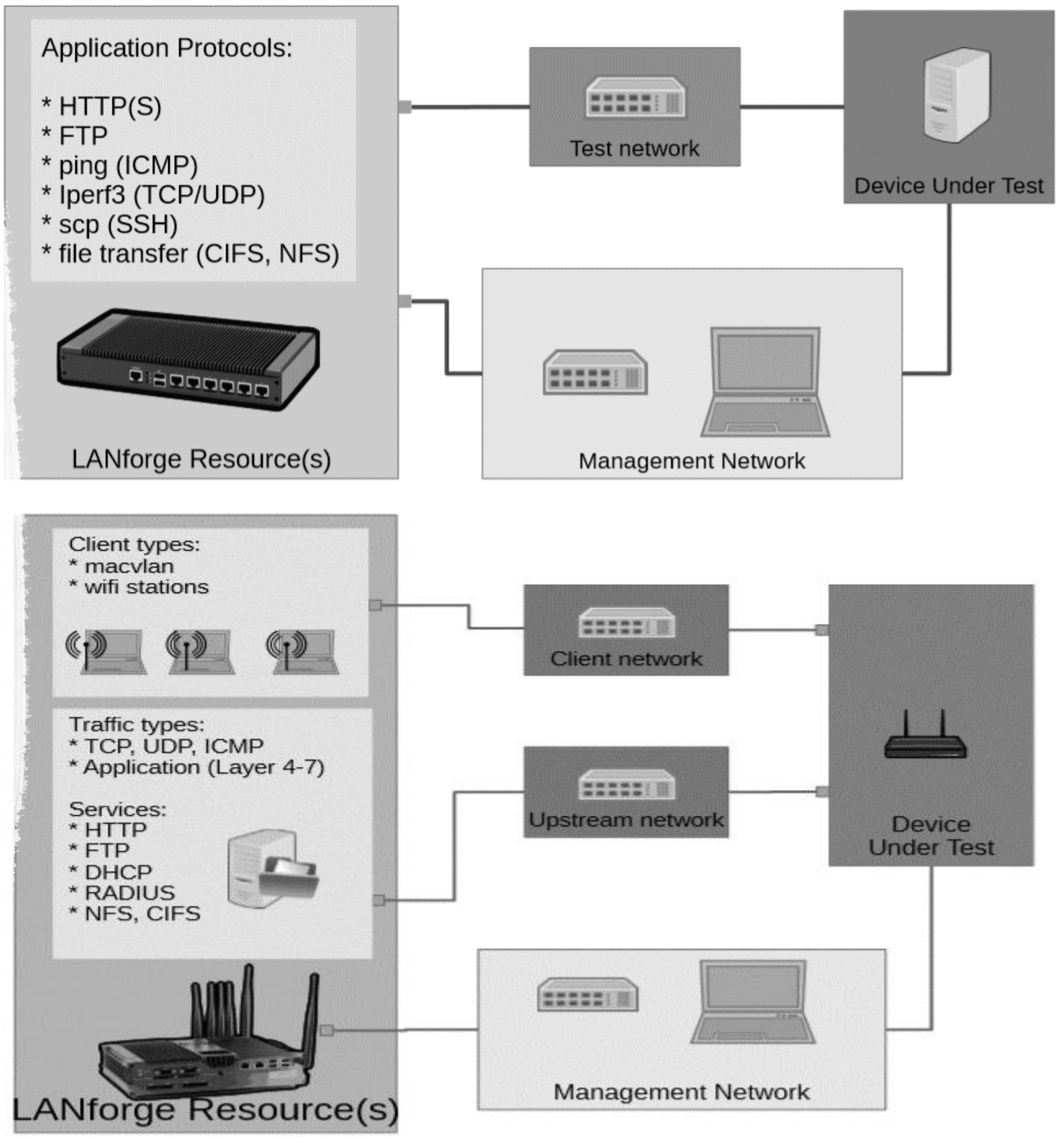


99% of the devices had 4Mbps or better download speed

SpeedTest.net Download (Mbps)

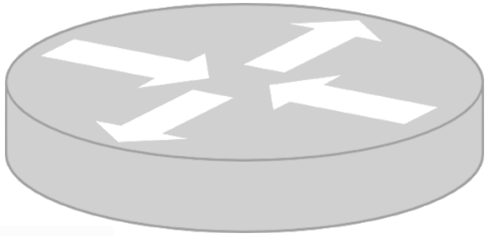


LANforge-FIRE

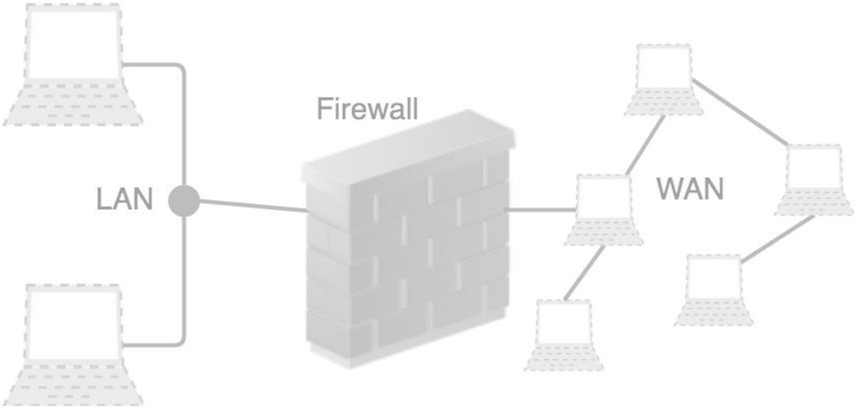


LANforge – FIRE : What Can You Test?

Test Switches



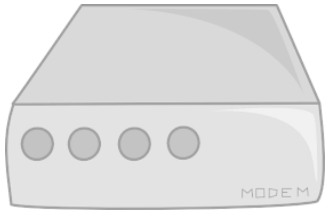
Test Routers



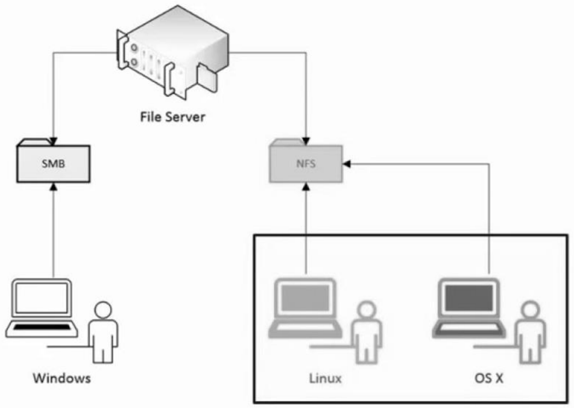
Test Firewalls

Test Applications

Test Network Servers



Test Cable Modems



Test Network File Systems

Test Media Gateways

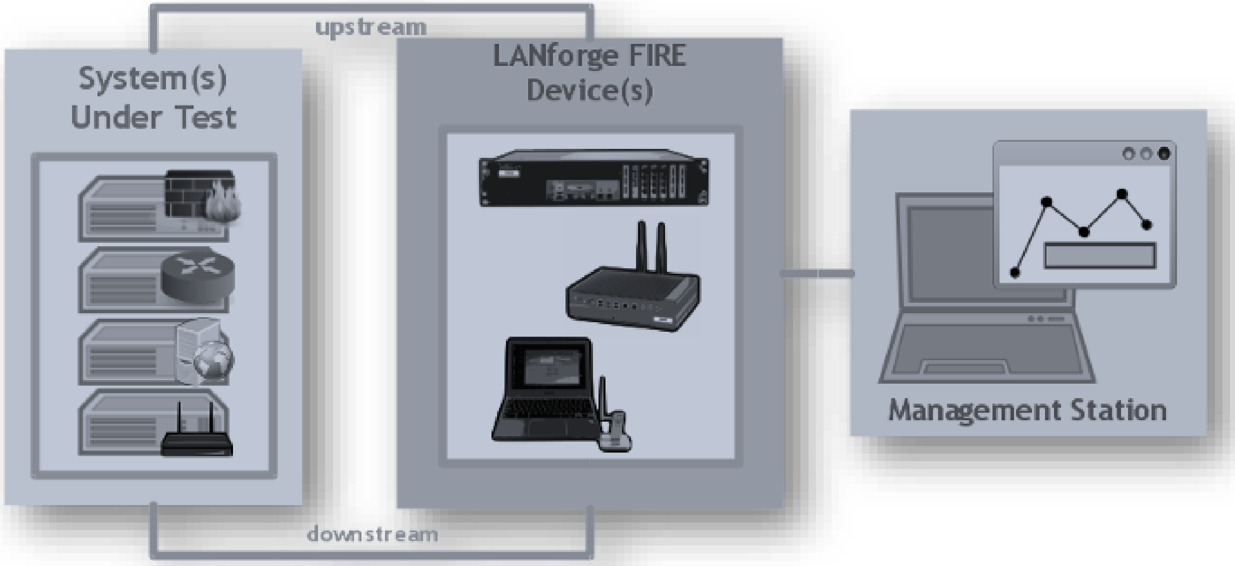
Test WiFi APs + Controllers

LANforge – FIRE : Network Traffic Generation

LANforge FIRE generates and receives various network protocols. It is used to create load on a network under test. It reports statistics such as packets sent and received, latency, packet-loss and many other network characteristics. LANforge supports real protocols and stateful TCP connections, so it can generate load against web servers, VOIP gateways, firewalls, load-balancers and many other network components. LANforge can virtualize network adapters and wifi station interfaces. It can also act as a router or group of routers supporting OSPF, RIP, BGP and Multicast (PIM, IGMP). LANforge supports IPv4 and IPv6.

The LANforge system consists of a single manager process, and one or more traffic generator machines (resources). The resources are connected to the manager over a management network. Devices under test are connected to the non-management ports of LANforge systems. If needed, LANforge can also generate traffic on the management network.

The LANforge GUI may run on the LANforge machines or on the customer's PCs. The GUI should connect to the manager machine. Multiple GUIs can be used concurrently.



LANforge – FIRE : Use Cases

- Validate network equipment for throughput, stability and performance, at up to 10Gbps speeds. All supported protocols can be used concurrently for a very realistic traffic mix.
- 24 and 48-port modules especially cost-effective for testing many slower systems, such as DSL, Cable-Modem, and Satellite modems.
- WiFIRE models can emulate up to 1200 WiFi stations per chassis for testing access points and other wireless infrastructure.
- VOIP Call generation can be used to load SIP gateways and other VOIP infrastructure. It can report various statistics, including PESQ quality scores.
- HTTP, HTTPS, FTP and similar load generation can be used to test web servers, load balancers, and related equipment.
- LANforge can support 50,000+ concurrent stateful TCP connections, so it can be used to test firewalls, routers, and other equipment that pays close attention to higher level protocols.

Protocols Supported

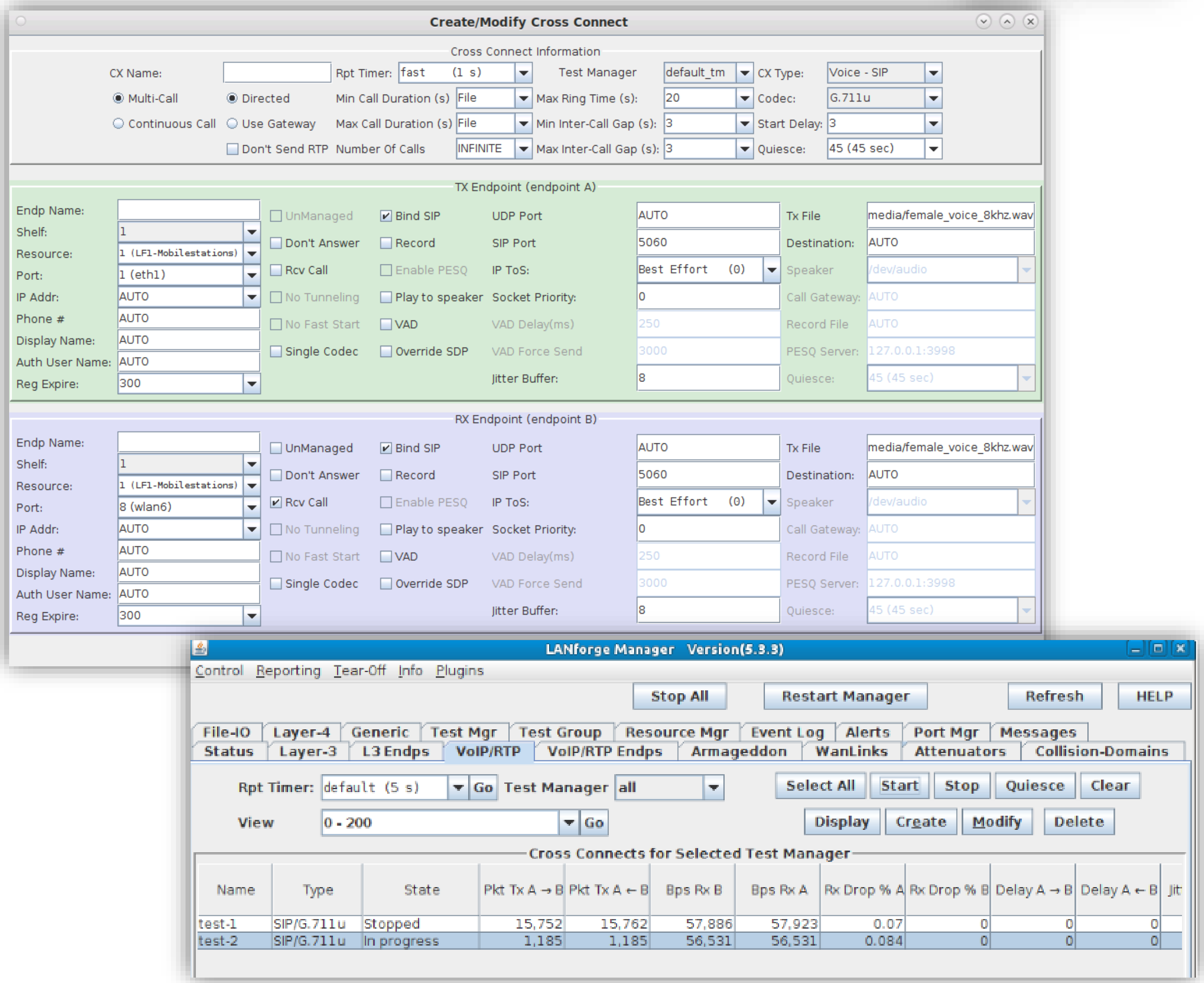
- Layer 2:
  - Raw-Ethernet
- Layer 3:
  - UDP/IP (6 Gbps+ bi-directional, 3 streams, 24k byte PDUs, 1500 MTU, 10G, to self, some drops)
  - UDP/IPv6 (6 Gbps+ bi-directional, 3 streams, 24k byte PDUs, 1500 MTU, 10G, to self, some drops)
  - IGMP Multicast UDP (500+ receivers)
  - IGMP Multicast UDP over IPv6 (500+ receivers)
  - Stateful TCP/IP (9.8Gbps+ on wire, 9.3Gbps goodput, bi-directional with 24K byte writes, 30 streams, 1500 MTU, 10G, to self)
  - Stateful TCP/IPv6 (9.8Gbps+ on wire, 9.1Gbps goodput, bi-directional with 24K byte writes, 30 streams, 1500 MTU, 10G, to self)
  - Stateful SCTP/IP (850Mbps, bi-directional, 3 streams. No hardware offload exists, CPU bound.)
  - Stateful SCTP/IPv6 (850Mbps, bi-directional, 3 streams. No hardware offload exists, CPU bound. Requires global-scope IPv6 addresses
- Layer 4-7:
  - FTP
  - SFTP
  - HTTP (9 Gbps+ download, 65,000+/13,000+ Requests per Second, 6,000+ concurrent connections
  - HTTPS (1 Gbps+ download),SCP, TFTP (1400+ concurrent connections, ~1Gbps throughput)
  - TELNET
  - DNS (Used and Reported by most Layer 4-7 traffic types)
  - VoIP Call Generator (SIP, RTP, RTCP, PESQ/MOS), 1000+ calls per machine.
  - Browser based video streaming.
- File-IO:
  - NFS 17+Gbps (dual 10G NICs, mostly reading), 1000+ virtual clients.
- Generic:
  - Ping
  - Speedtest.NET
  - iPerf

More Supported Features.

- Supports over 50,000 concurrent TCP connections on a single high-end machine
- Supports real-world compliance with ARP protocol.
- Supports ToS (QoS) settings for TCP/IP and UDP/IP connections.
- Utilizes libcurl for FTP, SFTP, TFTP, SCP, TELNET, HTTP and HTTPS (SSL) protocols.
- Supports file system test endpoints (can be used for NFS, NFSv4, SMB, and iSCSI file systems too!). Can emulate 1000+ CIFS and/or NFS clients with unique mount points, IPs, MACs, etc
- Supports custom and command-line programs, like nmap and ping.
- Custom packet builder interface allows hand crafting of headers and payloads. Headers supported at Layer 2 include ARP, SNAP/LLC, 802.1Q, 802.1QinQ and MPLS. Some Layer 3 protocol headers supported include IP, IPX, UDP, TCP, ICMP, IGMP, IP-ENCAP, RDP, IPinIP and IPv6 protocols.
- Uses publicly available Linux or Windows networking stack for increased standards compliance.
- Supports 20 or more physical data-generating Ethernet ports per 2U LANforge chassis.
- Emulates over 2000 unique machines with one physical interface with the MAC-VLAN feature.
- Supports over 2000 802.1Q VLANs
- Supports PPPoE, including automated creation and deletion of the PPP interfaces
- Supports 802.11a/b/g/n/AC with WiFIRE feature set.

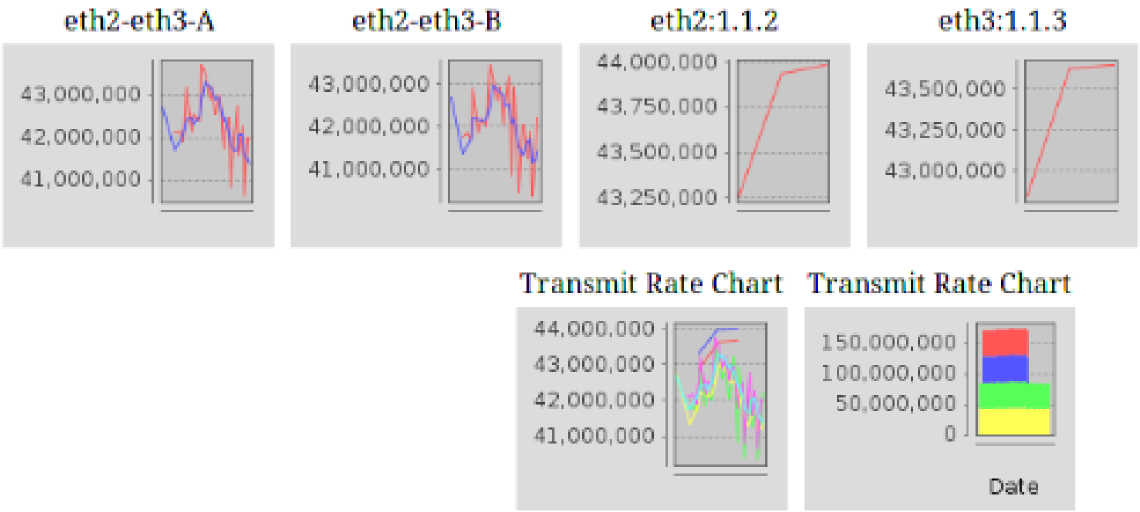
LANforge VoIP/RTP Call Generator Features.

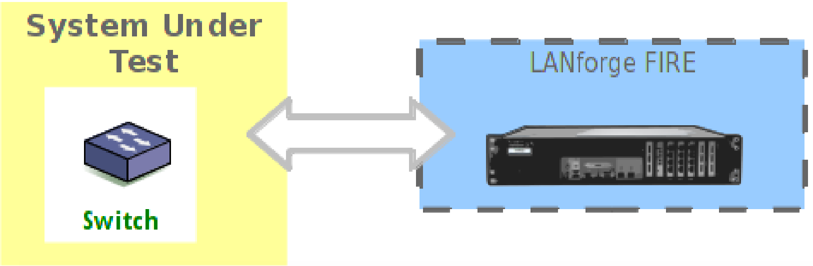
- SIP protocol used for call management.
  - SIP/UDP supported.
  - Can use directed mode, where VoIP phones call directly to themselves.
  - Can also use Gateway mode where the VoIP phones register with a SIP gateway.
  - SIP authentication is supported.
- RTP protocol used for streaming media transport, and supports many CODECS.
- Supports PESQ automated voice quality testing.
- RTCP protocol used for streaming media statistics
- Each LANforge VoIP/RTP endpoint can play from a wav file and record to a separate wav file. Almost any sound file can be converted to the correct wav file format with tools bundled with LANforge. Sample voice files are included.
- Support for 1000 or more emulated VoIP phones per machine (hardware dependent).
- LANforge VoIP/RTP endpoints can call other LANforge endpoints or third party SIP phones like Cisco and Grandstream. Third party phones can also call LANforge endpoints and hear the WAV file being played.
- Can expose wandering latency scenarios caused by lack of network time sync.

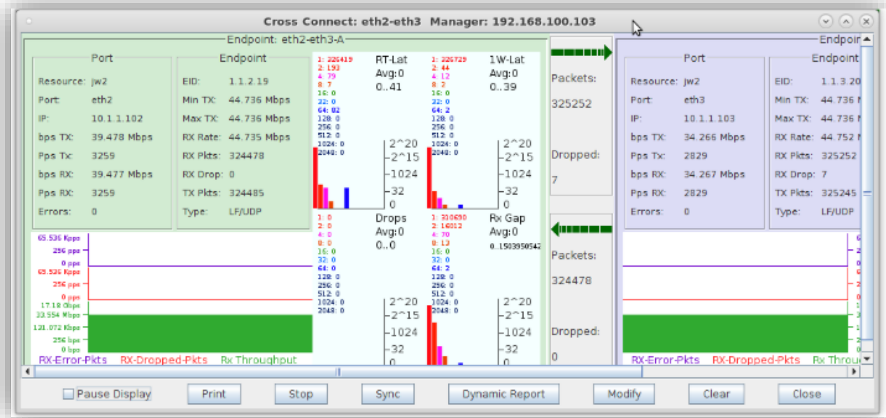


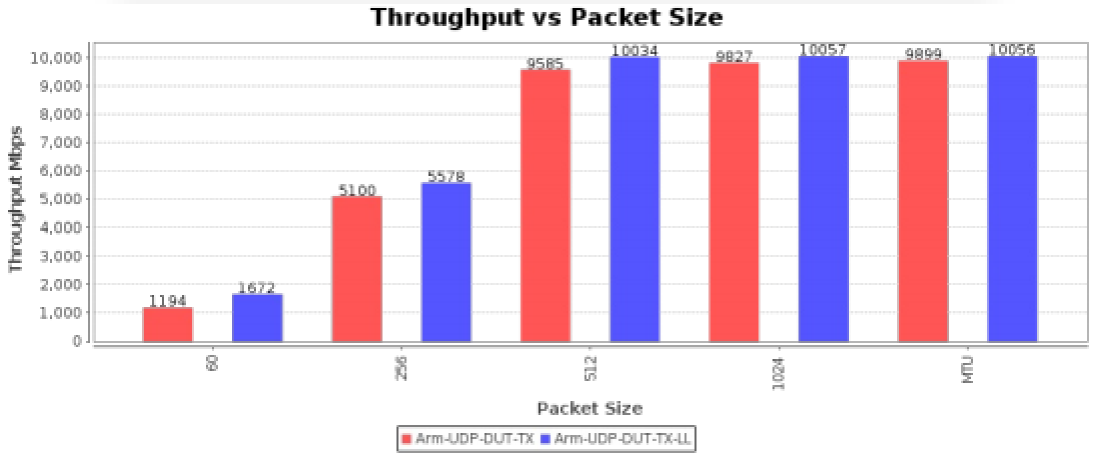
Testing L2-3 Switches

- Total aggregate throughput testing
- Per port throughout testing
- CAM table limit testing
- Routing/VLAN testing
- QoS Testing
- Multicast Testing



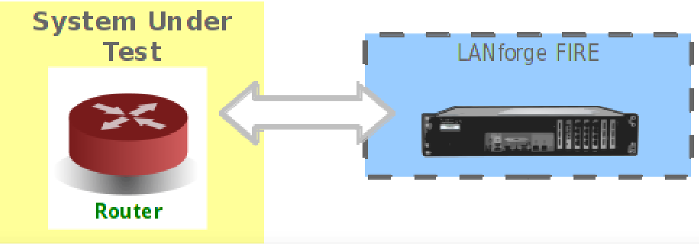


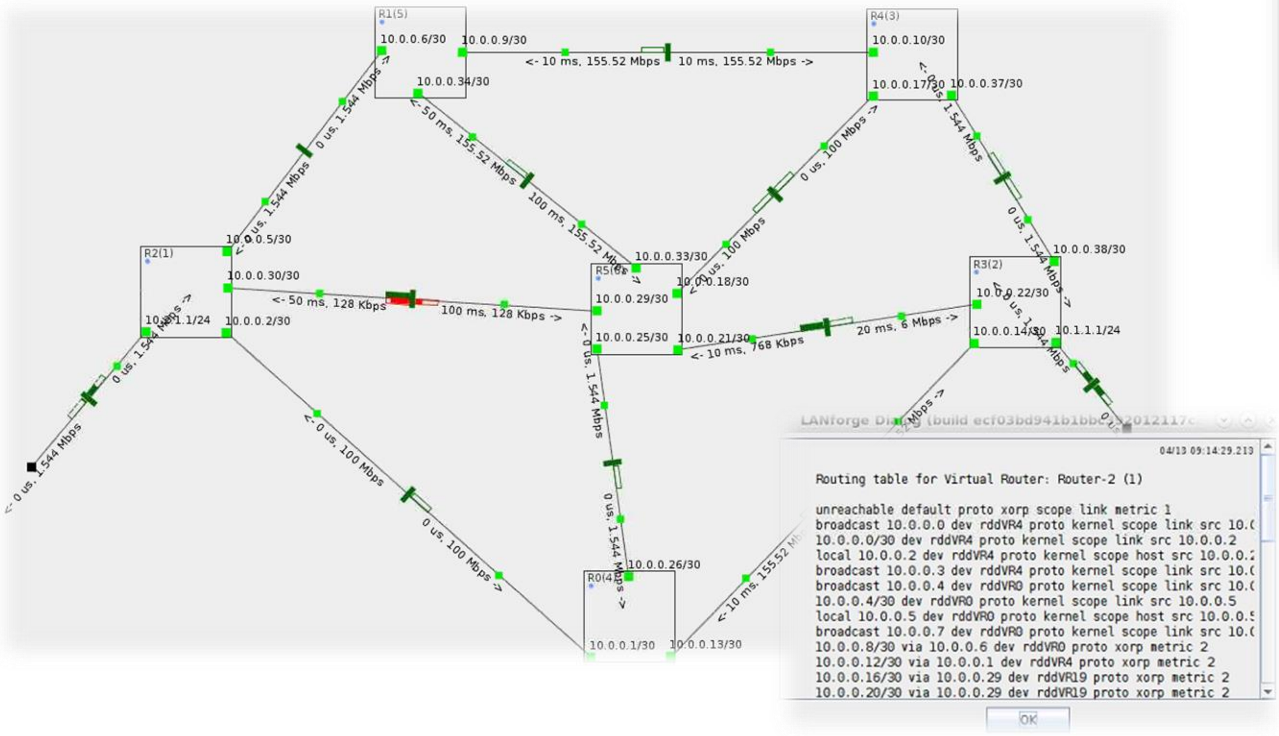


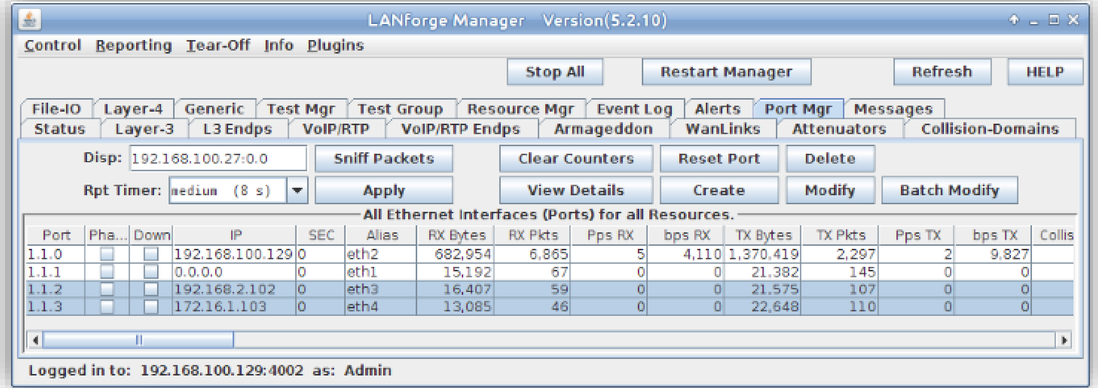


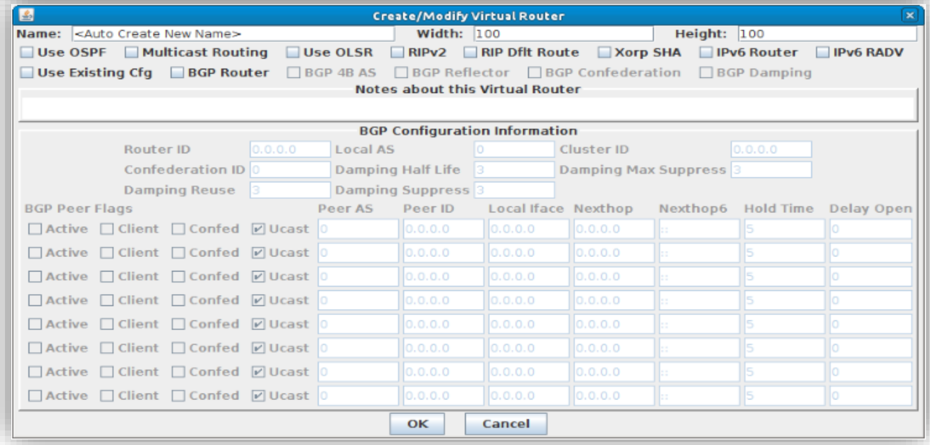
Testing Routers

- Testing various routing protocols (RIP, OSPF)
- Multicast/Broadcast Testing
- Routing Table lookup/route propagation Testing
- Link Failover Scenarios testing





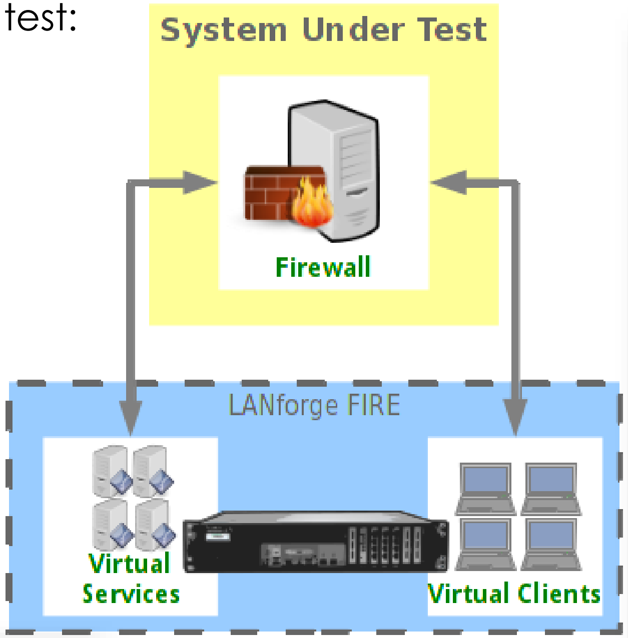


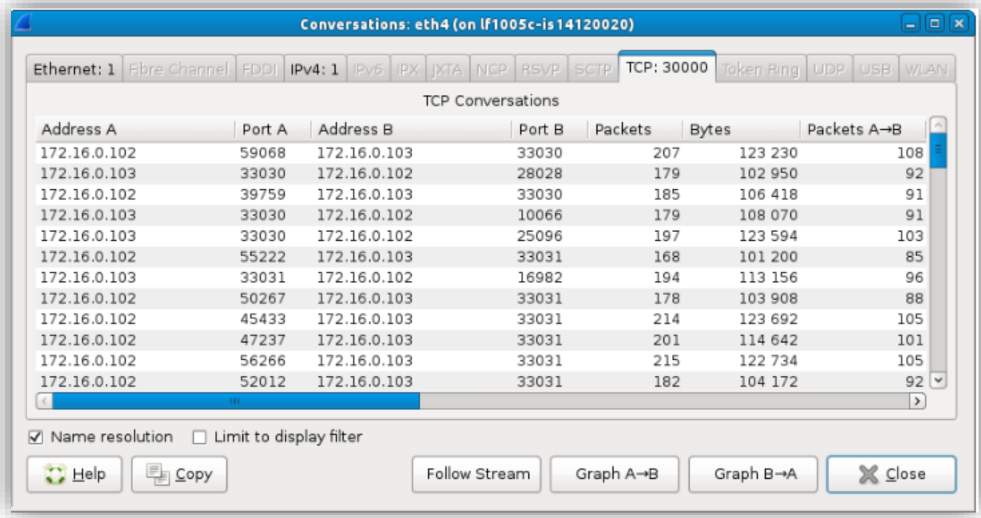


Testing Firewalls

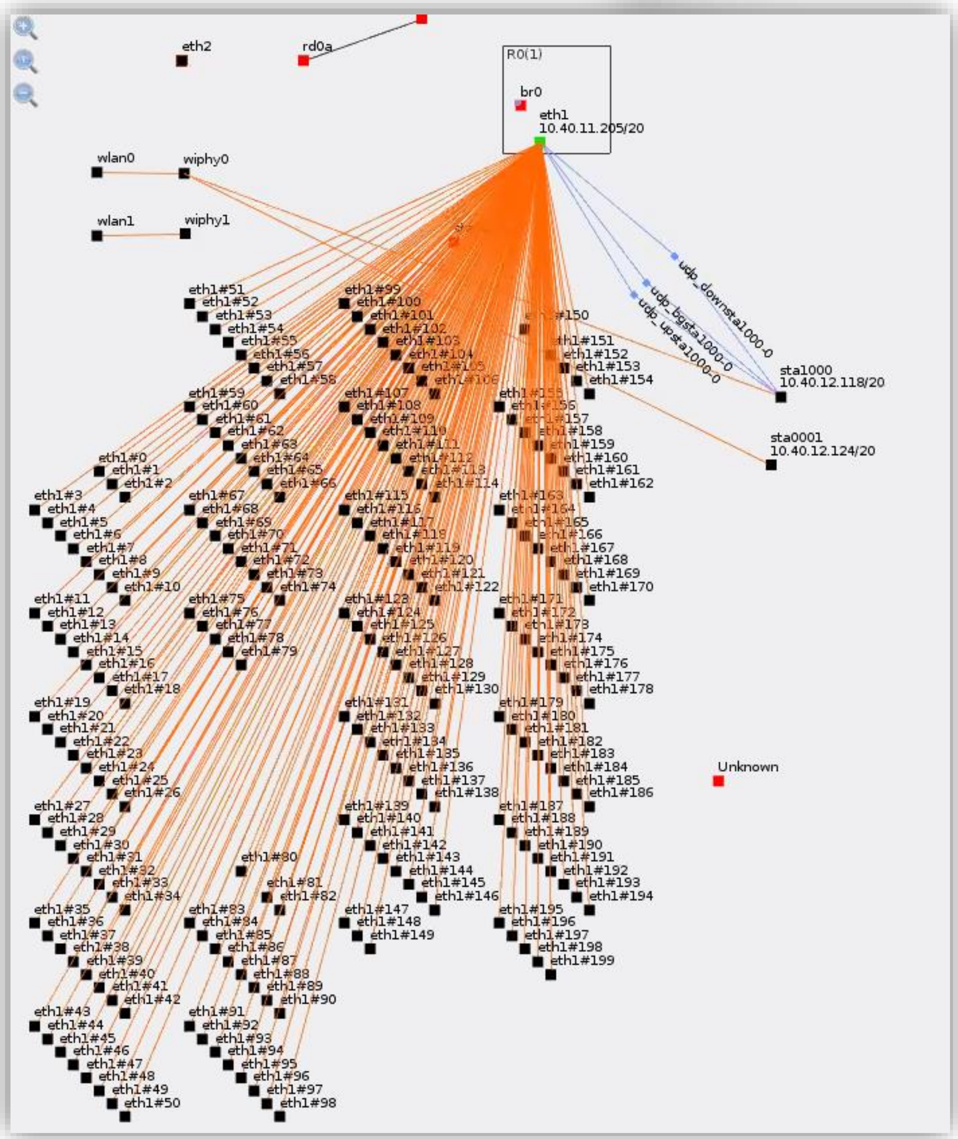
Generate application layer traffic at scale to test:

- Access/Content/Service Policies
- Burst Rates
- Fragmentation
- VLANs
- Proxy re-direction
- Traffic shaping
- Inspection Policies
- DoS Attacks





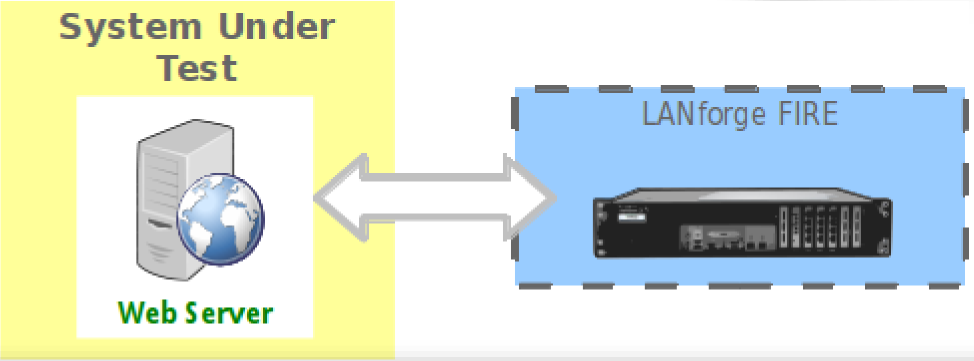
Address A	Port A	Address B	Port B	Packets	Bytes	Packets A→B
172.16.0.102	59068	172.16.0.103	33030	207	123 230	108
172.16.0.103	33030	172.16.0.102	28028	179	102 950	92
172.16.0.102	39759	172.16.0.103	33030	185	106 418	91
172.16.0.103	33030	172.16.0.102	10066	179	108 070	91
172.16.0.103	33030	172.16.0.102	25096	197	123 594	103
172.16.0.102	55222	172.16.0.103	33031	168	101 200	85
172.16.0.103	33031	172.16.0.102	16982	194	113 156	96
172.16.0.102	50267	172.16.0.103	33031	178	103 908	88
172.16.0.102	45433	172.16.0.103	33031	214	123 692	105
172.16.0.102	47237	172.16.0.103	33031	201	114 642	101
172.16.0.102	56266	172.16.0.103	33031	215	122 734	105
172.16.0.102	52012	172.16.0.103	33031	182	104 172	92

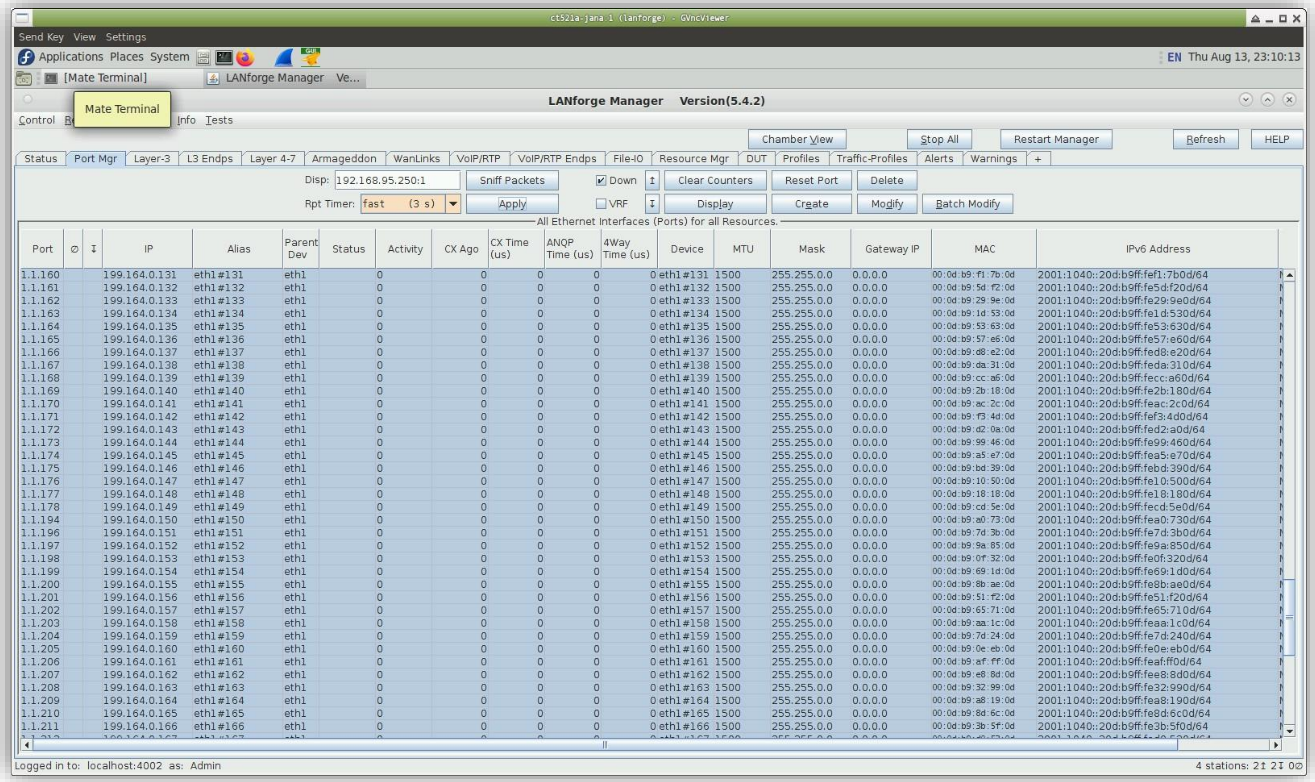


Testing Webservers

Generate application layer traffic at scale to test:

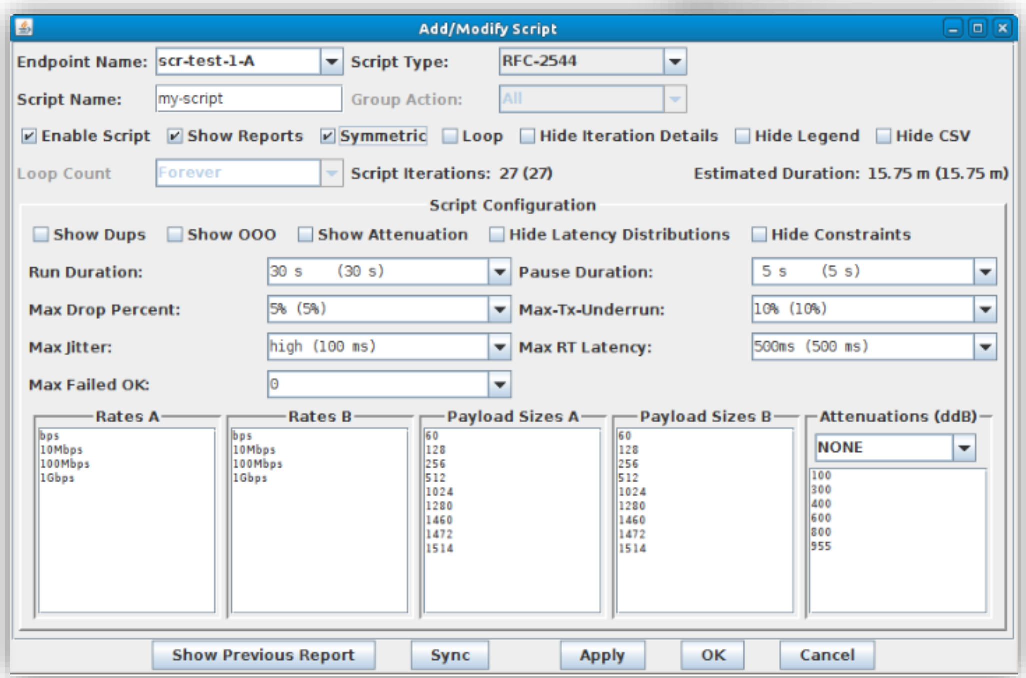
- Effective URLs/second
- Throughput per request size
- Response Times / Time to first byte
- Client Scale
- Connections per Client
- Performance over Time
- Failover/redundancy Scenarios

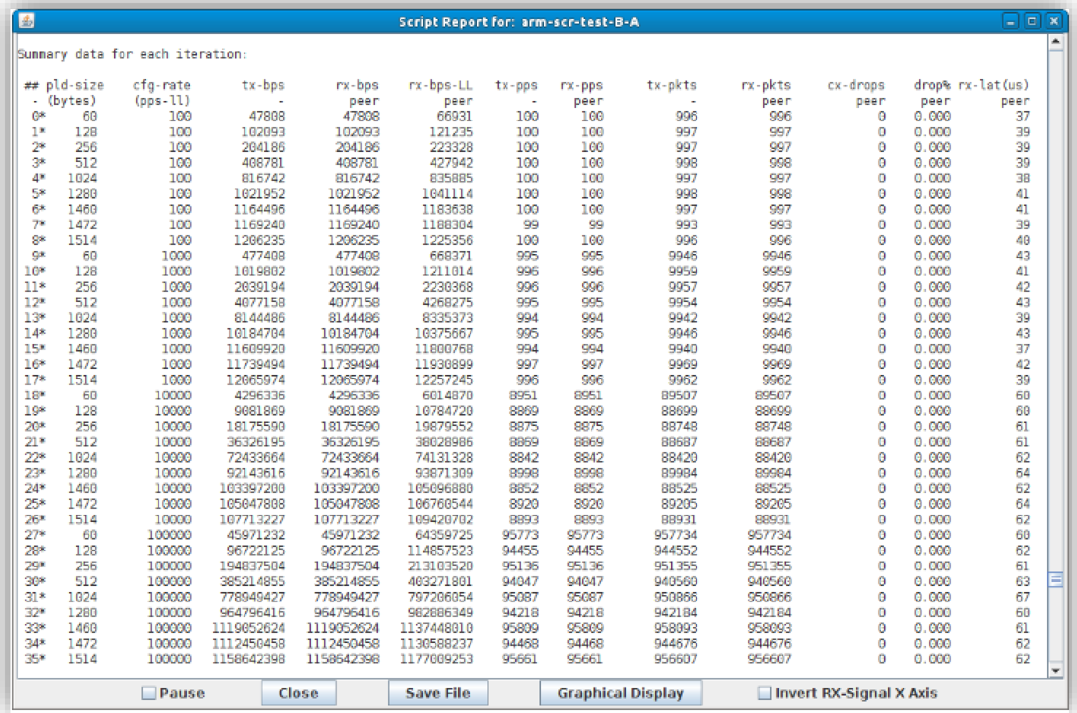




RFC2544 Test Example

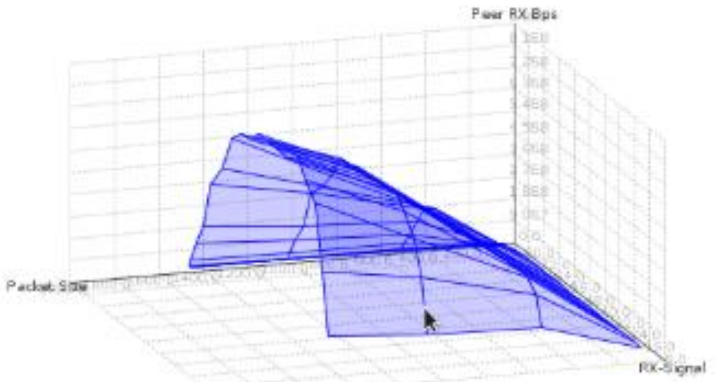
- Testing performance with 1xN, Nx1, NxM endpoint mappings.
- TCP/UDP line rate performance at different Payload sizes and Traffic rates.
- Set PASS Criteria for Max % Packet drops. Max Jitter, Max Latency, Tx-underruns
- Measure WiFi performance over distance.
- Generate reports in text, CSV, HTML and PDF formats.




Script Report for: arm-scr-test-B-A

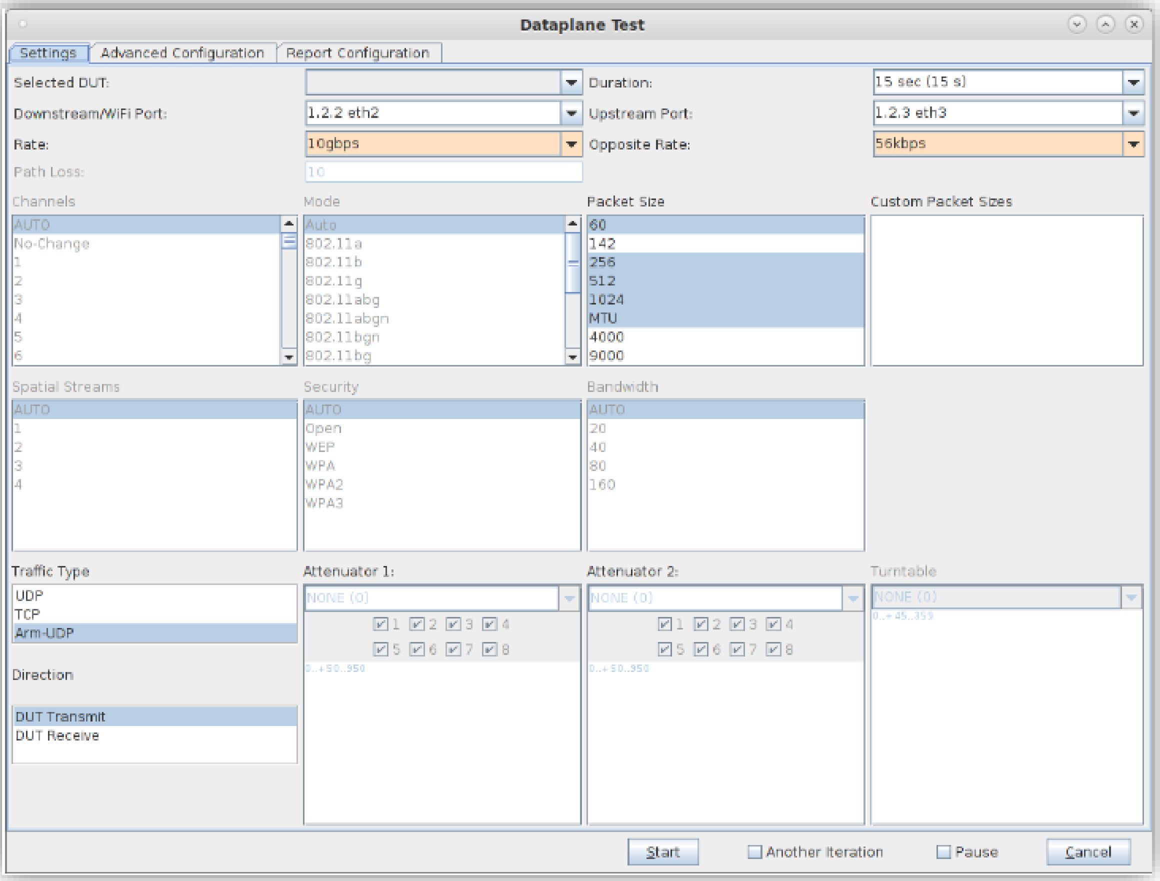
Summary data for each iteration:

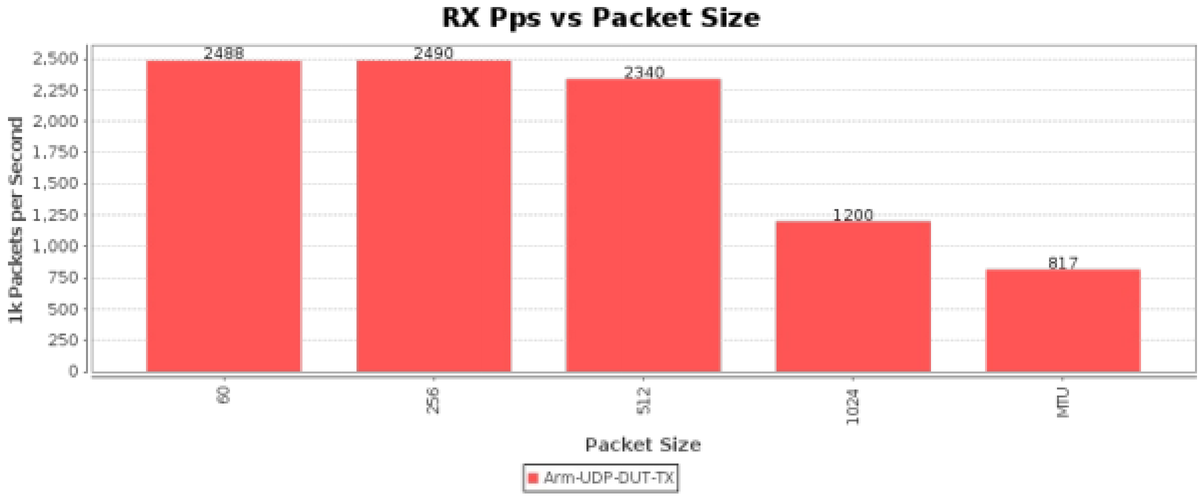
## -	pld-size (bytes)	cfg-rate (pps-ll)	tx-bps -	rx-bps peer	rx-bps-LL peer	tx-pps -	rx-pps peer	tx-pkts -	rx-pkts peer	cx-drops peer	drop% peer	rx-lat(us) peer
0*	60	100	47808	47808	66931	100	100	996	996	0	0.000	37
1*	128	100	102093	102093	121235	100	100	997	997	0	0.000	39
2*	256	100	204186	204186	223328	100	100	997	997	0	0.000	39
3*	512	100	408781	408781	427942	100	100	998	998	0	0.000	39
4*	1024	100	816742	816742	835885	100	100	997	997	0	0.000	38
5*	1280	100	1021952	1021952	1041114	100	100	998	998	0	0.000	41
6*	1460	100	1164496	1164496	1183638	100	100	997	997	0	0.000	41
7*	1472	100	1169240	1169240	1188304	99	99	993	993	0	0.000	39
8*	1514	100	1206235	1206235	1225356	100	100	996	996	0	0.000	40
9*	60	1000	477408	477408	668371	995	995	9946	9946	0	0.000	43
10*	128	1000	1019802	1019802	1211014	996	996	9959	9959	0	0.000	41
11*	256	1000	2039194	2039194	2230368	996	996	9957	9957	0	0.000	42
12*	512	1000	4077158	4077158	4268275	995	995	9954	9954	0	0.000	43
13*	1024	1000	8144486	8144486	8335373	994	994	9942	9942	0	0.000	39
14*	1280	1000	10184704	10184704	10375667	995	995	9946	9946	0	0.000	43
15*	1460	1000	11609920	11609920	11800768	994	994	9940	9940	0	0.000	37
16*	1472	1000	11739494	11739494	11930899	997	997	9969	9969	0	0.000	42
17*	1514	1000	12065974	12065974	12257245	996	996	9962	9962	0	0.000	39
18*	60	10000	4296336	4296336	6014870	8951	8951	89507	89507	0	0.000	60
19*	128	10000	9081869	9081869	10784720	8869	8869	88699	88699	0	0.000	60
20*	256	10000	18175590	18175590	19879552	8875	8875	88748	88748	0	0.000	61
21*	512	10000	36326195	36326195	38028986	8869	8869	88687	88687	0	0.000	61
22*	1024	10000	72433664	72433664	74131328	8842	8842	88420	88420	0	0.000	62
23*	1280	10000	92143616	92143616	93871309	8998	8998	89984	89984	0	0.000	64
24*	1460	10000	103397200	103397200	105096880	8852	8852	88525	88525	0	0.000	62
25*	1472	10000	105047808	105047808	106760544	8920	8920	89205	89205	0	0.000	64
26*	1514	10000	107713227	107713227	109420702	8893	8893	88931	88931	0	0.000	62
27*	60	100000	45971232	45971232	64359725	95773	95773	957734	957734	0	0.000	60
28*	128	100000	96722125	96722125	114857523	94455	94455	944552	944552	0	0.000	62
29*	256	100000	194837504	194837504	213103520	95136	95136	951355	951355	0	0.000	61
30*	512	100000	385214855	385214855	403271801	94047	94047	940560	940560	0	0.000	63
31*	1024	100000	778949427	778949427	797206054	95087	95087	950866	950866	0	0.000	67
32*	1280	100000	964796416	964796416	982886349	94218	94218	942184	942184	0	0.000	60
33*	1460	100000	1119052624	1119052624	1137448010	95809	95809	958093	958093	0	0.000	61
34*	1472	100000	1112450458	1112450458	1130588237	94468	94468	944676	944676	0	0.000	62
35*	1514	100000	1158642398	1158642398	1177009253	95661	95661	956607	956607	0	0.000	62

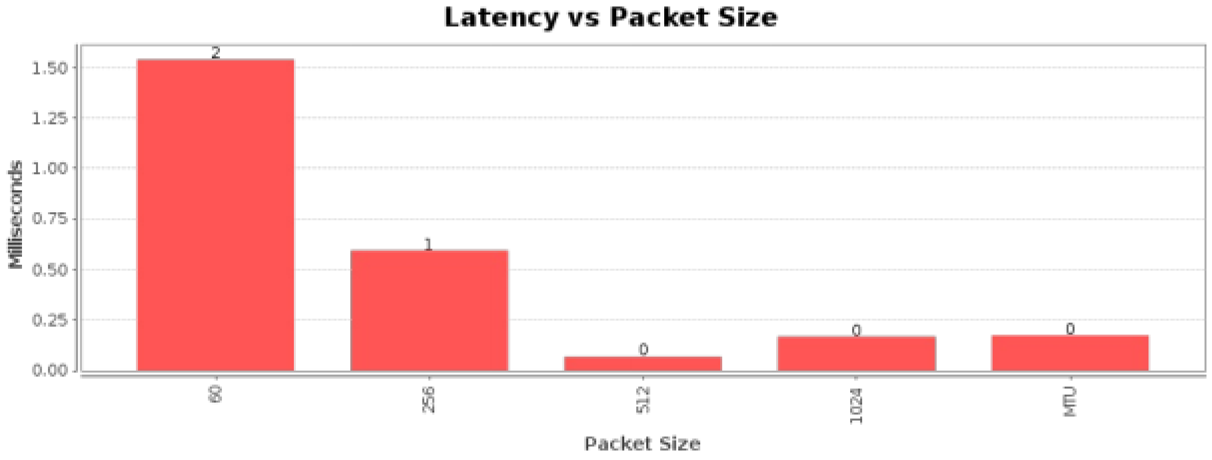


Dataplane Test on 10Gig Switched Network

- Support for 10GE copper and fiber.
- Full line rate testing.
- Measure Throughput, latency, packet loss, Jitter.
- Generate reports in text, CSV, HTML and PDF formats.

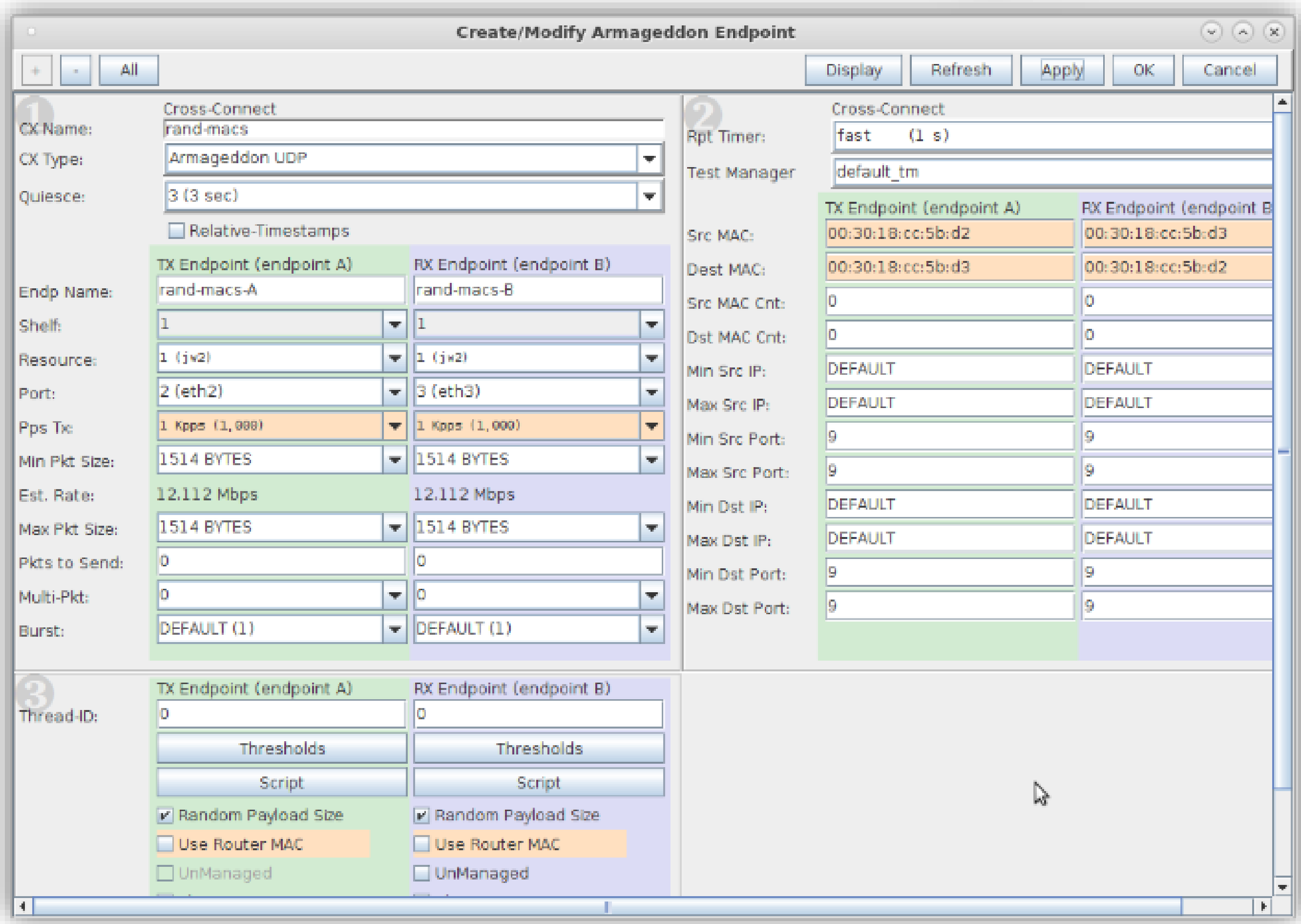






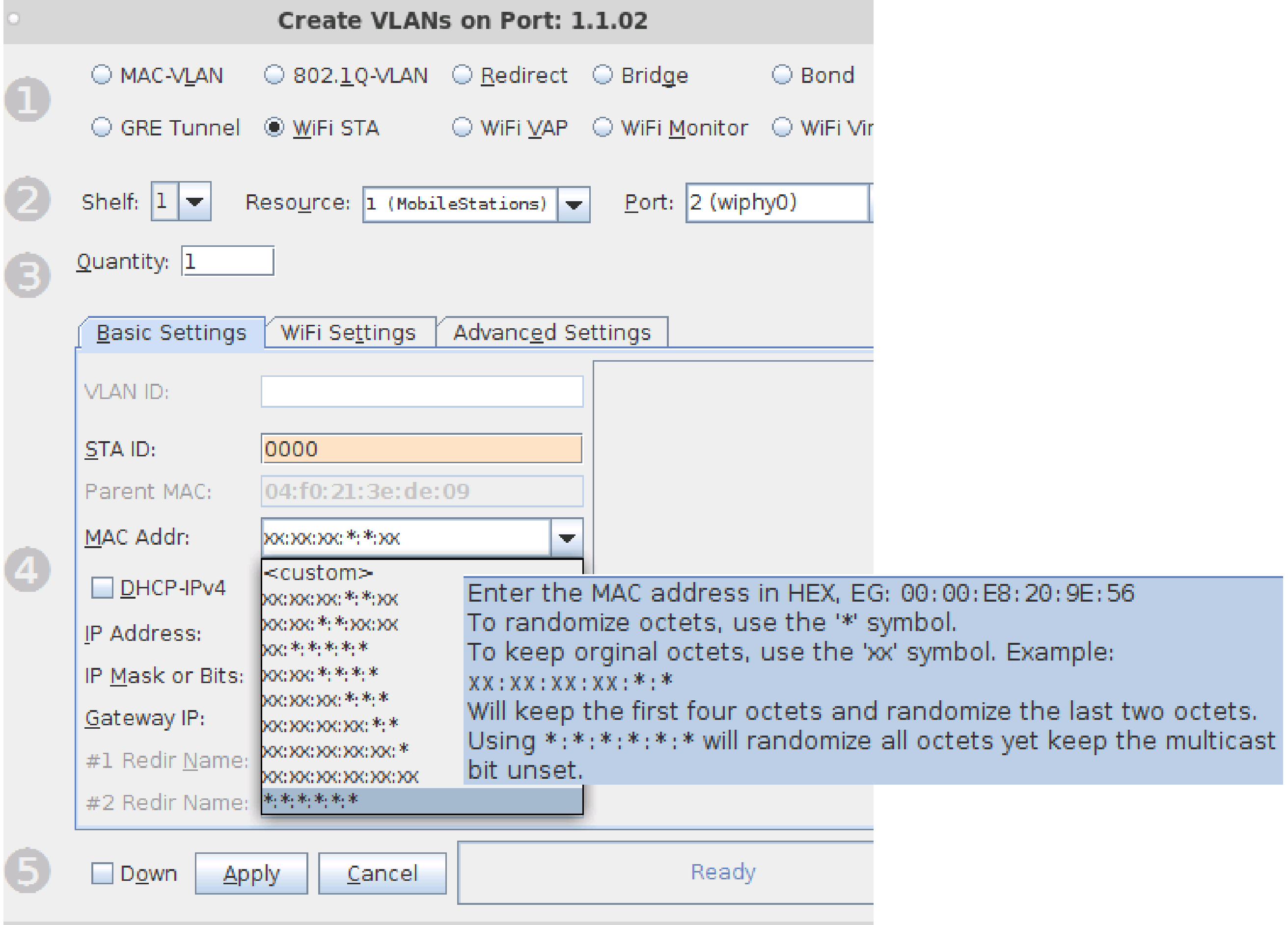
Accelerated UDP Testing

- Uses pktgen Kernel module to generate accelerated UDP /stateless TCP traffic to test full throughput capacity of the device under test.
- Tester can generate multiple duplicates of the same packet to further accelerate traffic generation.



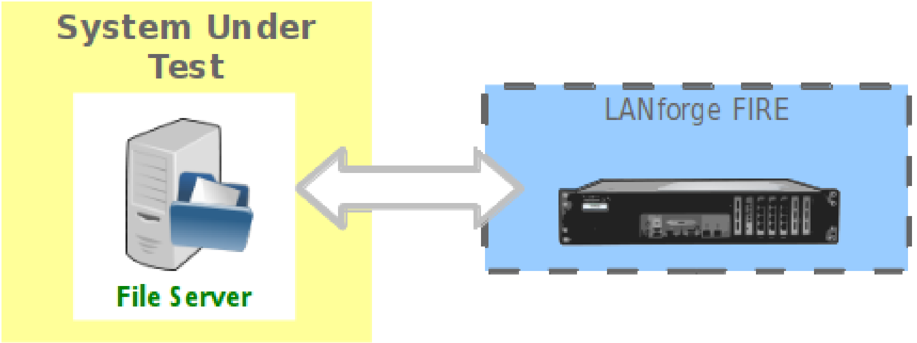
Random MAC address Example

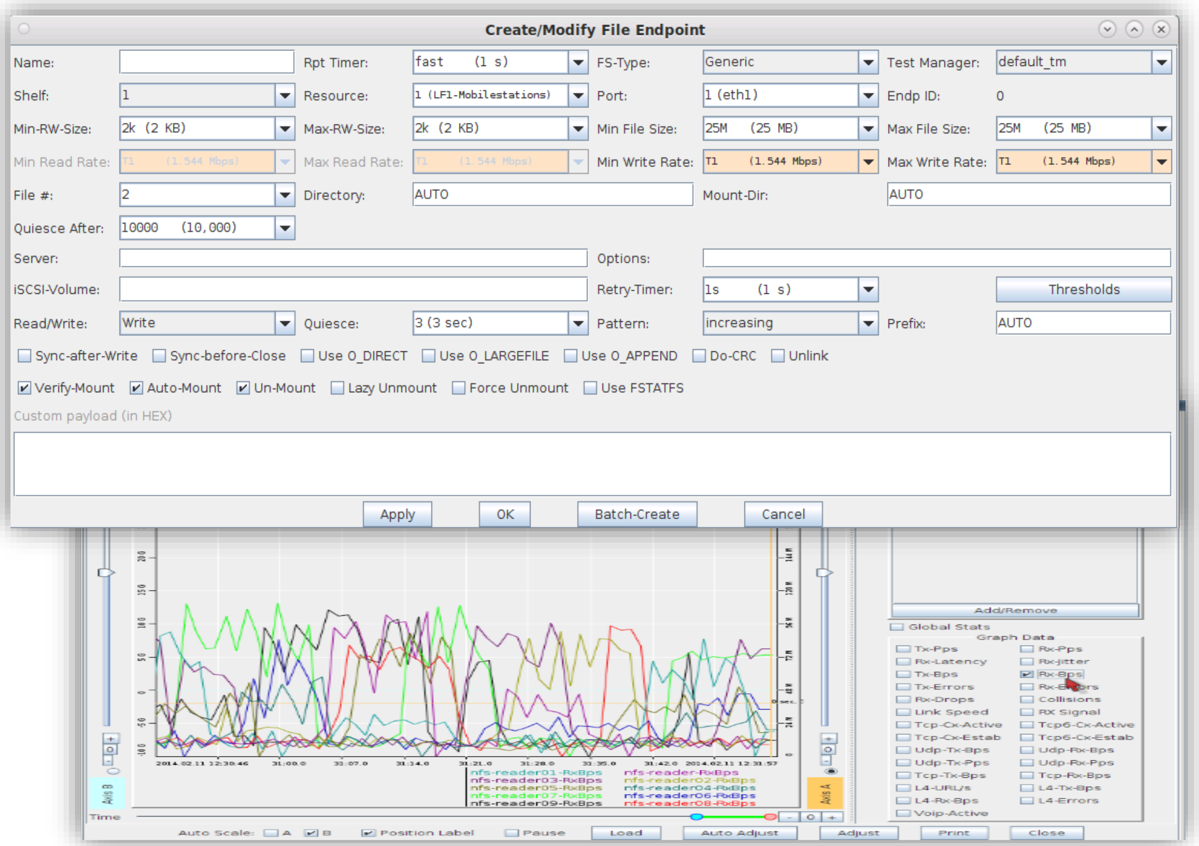
- Create internet scale connections with 1000s of endpoints
- Saturate look up tables on Device under Test
- Saturate DHCP addresses.
- Create effect of lots of different endpoints arriving and leaving in a large public venue scenario.
- Use well known MAC OUI for device profiling and MAC address based policy testing.

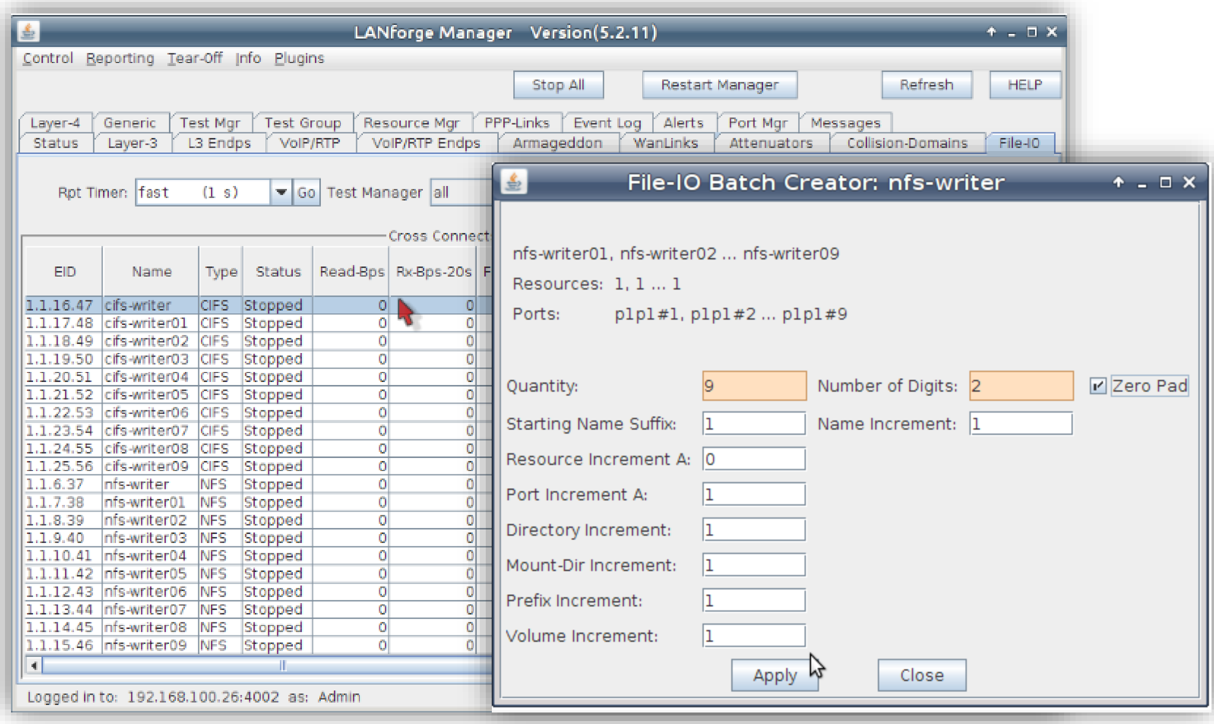


File IO Endpoint Testing

- Measure Throughput with large file Reads/writes over the network.
- Measure scaled File I/O with 100s of thousands of end points.
- Supports NFS 3/NFS 4/TFTP/SCP/Samba/CIFS testing
- Measure File Reads/Writes per second, Throughput (Mbps), IO Failures, CRC Failures

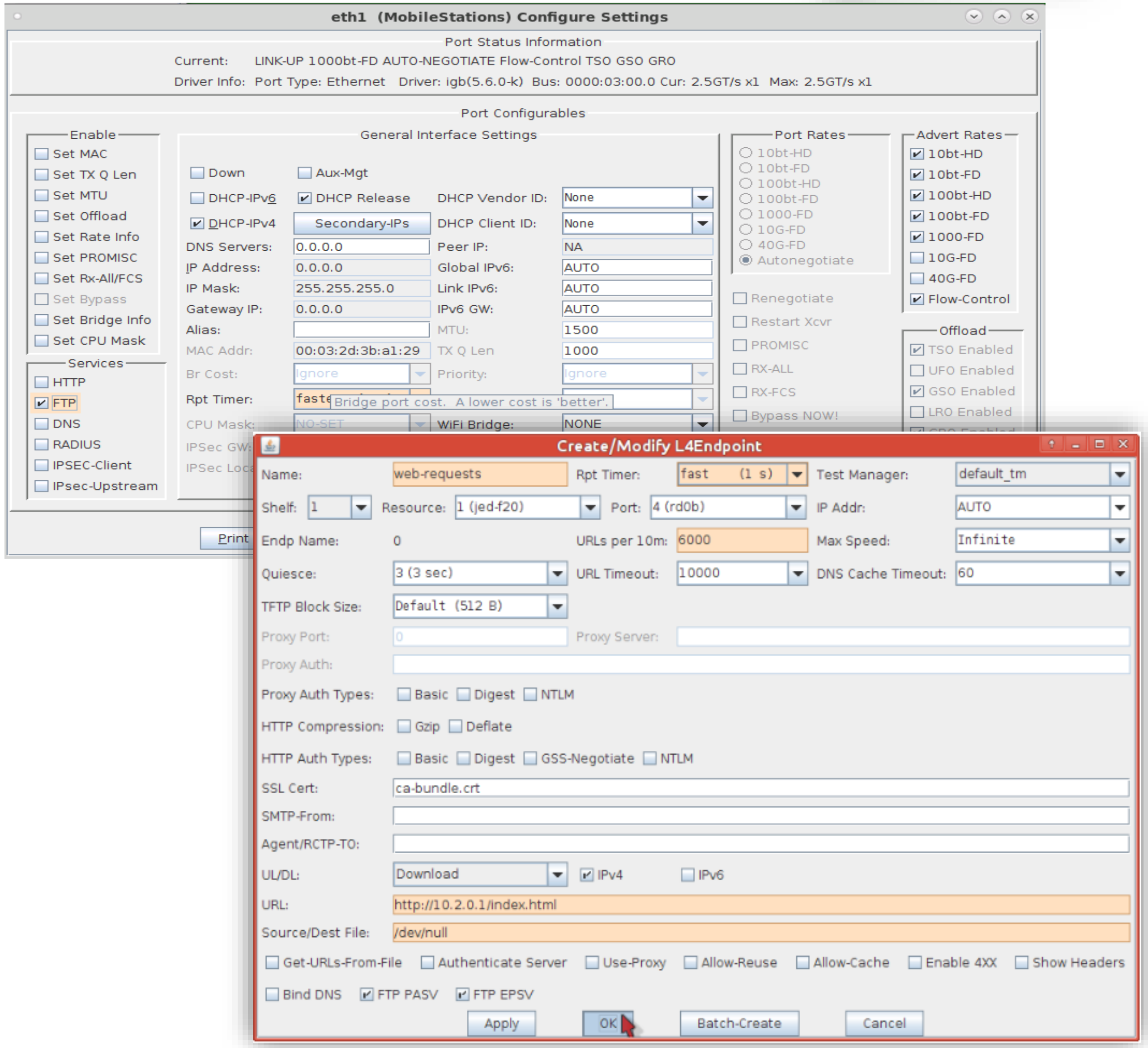






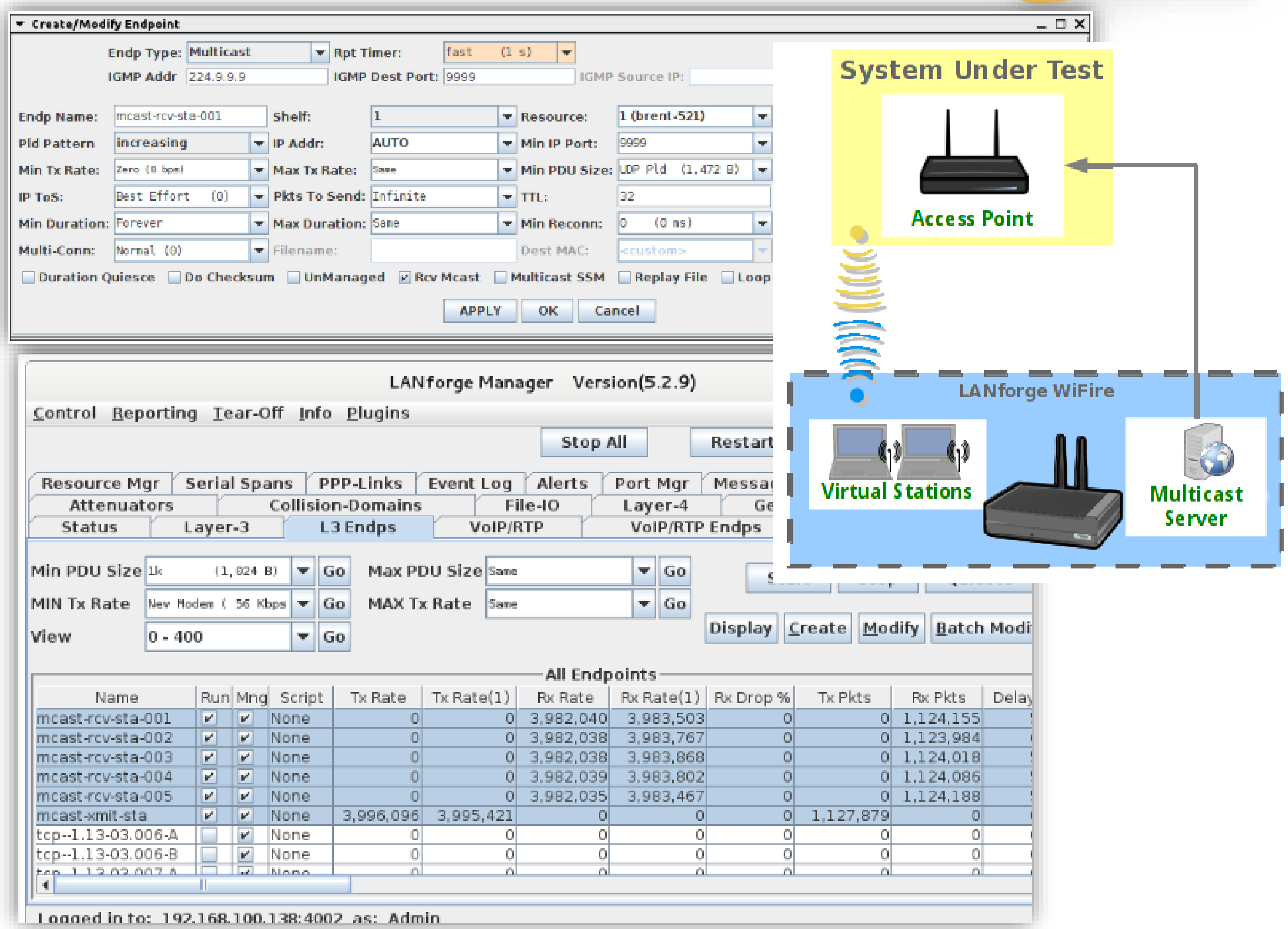
HTTP/FTP/DNS Traffic Generation

- Can run FTP server service to test FTP uploads
- Can run HTTP service to perform transaction testing and create lots of Web calls
- Example: Create 10,000 web requests/per sec of 15Kbyte files and measure URLs/sec and failed requests.
- Can act as upstream DNS server for firewall testing.



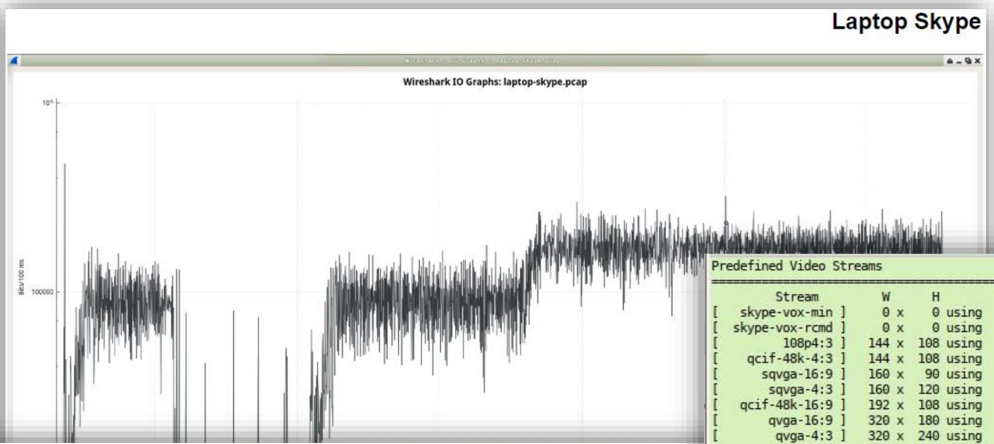
Multicast Testing

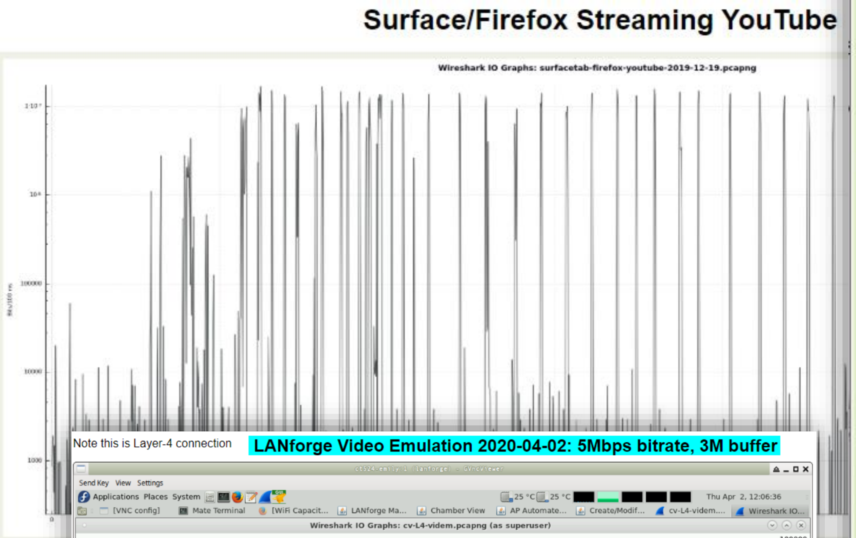
- Can create lots of multicast endpoints to test real networks/routers
- Can create virtual routers to test Multicast endpoints.
- Create lots of IGMP groups and test end points join/leaves and traffic flows.
- Support for IPv4/IPv6
- Test multicast throughput with several multicast groups at scale.
- Generate IGMP join/leave message floods.

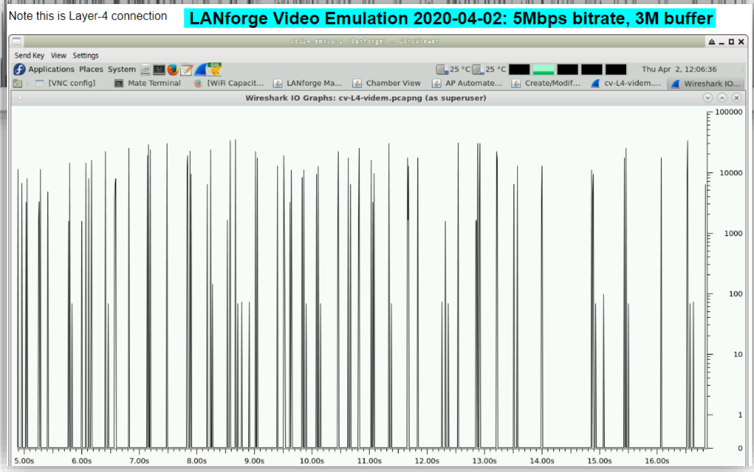


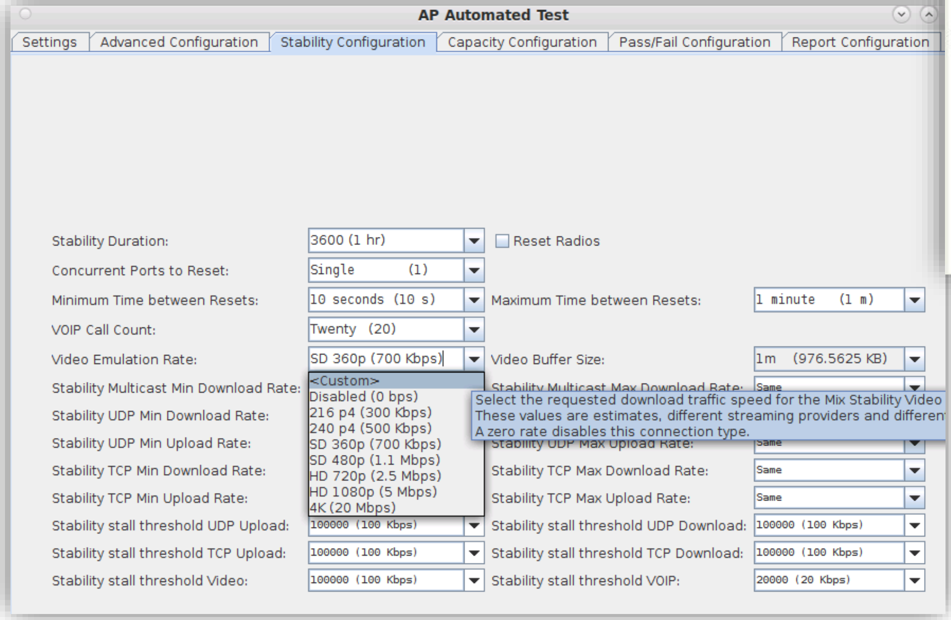
Video Streaming Traffic

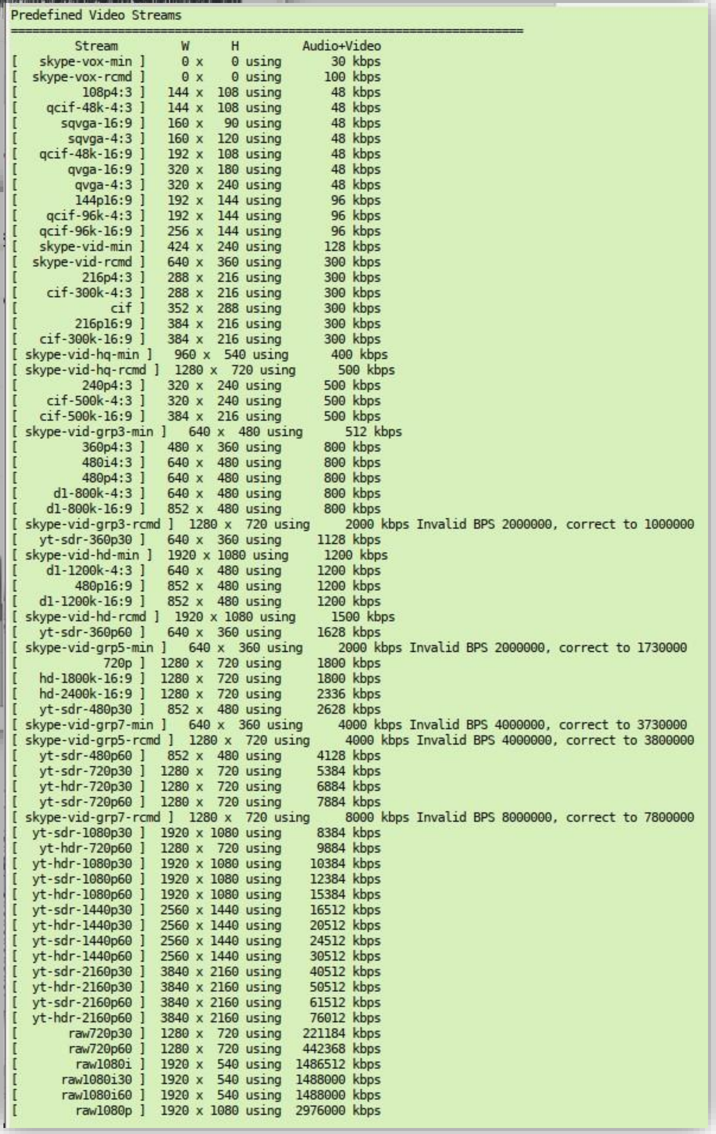
- Emulate live video transmission from different types of devices and different video qualities.
- Examples:
  - Streaming 1080p Youtube video on a surface tables
  - Skype conversation on a smartphone at 480x360, 720p, 1080i and 1080p resolutions
- Measure throughput, latency, packet loss, frequency of video buffering/stalls, connections/streaming gaps.











```
Predefined Video Streams
=========================================================================
         Stream        W      H         Audio+Video
[   skype-vox-min ]     0 x    0 using       30 kbps
[  skype-vox-rcmd ]     0 x    0 using      100 kbps
[         108p4:3 ]   144 x  108 using       48 kbps
[     qcif-48k-4:3 ]  144 x  108 using       48 kbps
[      sqvga-16:9 ]   160 x   90 using       48 kbps
[       sqvga-4:3 ]   160 x  120 using       48 kbps
[   qcif-48k-16:9 ]   192 x  108 using       48 kbps
[       qvga-16:9 ]   320 x  180 using       48 kbps
[        qvga-4:3 ]   320 x  240 using       48 kbps
[        144p16:9 ]   192 x  144 using       96 kbps
[    qcif-96k-4:3 ]   192 x  144 using       96 kbps
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[   skype-vid-min ]   424 x  240 using      128 kbps
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[         216p4:3 ]   288 x  216 using      300 kbps
[    cif-300k-4:3 ]   288 x  216 using      300 kbps
[             cif ]   352 x  288 using      300 kbps
[        216p16:9 ]   384 x  216 using      300 kbps
[   cif-300k-16:9 ]   384 x  216 using      300 kbps
[ skype-vid-hq-min ]   960 x  540 using      400 kbps
[ skype-vid-hq-rcmd ]  1280 x  720 using      500 kbps
[         240p4:3 ]   320 x  240 using      500 kbps
[    cif-500k-4:3 ]   320 x  240 using      500 kbps
[   cif-500k-16:9 ]   384 x  216 using      500 kbps
[ skype-vid-grp3-min ]   640 x  480 using      512 kbps
[         360p4:3 ]   480 x  360 using      800 kbps
[         480i4:3 ]   640 x  480 using      800 kbps
[         480p4:3 ]   640 x  480 using      800 kbps
[     d1-800k-4:3 ]   640 x  480 using      800 kbps
[    d1-800k-16:9 ]   852 x  480 using      800 kbps
[ skype-vid-grp3-rcmd ]  1280 x  720 using     2000 kbps Invalid BPS 2000000, correct to 1000000
[    yt-sdr-360p30 ]   640 x  360 using     1128 kbps
[ skype-vid-hd-min ]  1920 x 1080 using     1200 kbps
[    d1-1200k-4:3 ]   640 x  480 using     1200 kbps
[        480p16:9 ]   852 x  480 using     1200 kbps
[   d1-1200k-16:9 ]   852 x  480 using     1200 kbps
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[    yt-sdr-360p60 ]   640 x  360 using     1628 kbps
[ skype-vid-grp5-min ]   640 x  360 using     2000 kbps Invalid BPS 2000000, correct to 1730000
[            720p ]  1280 x  720 using     1800 kbps
[    hd-1800k-16:9 ]  1280 x  720 using     1800 kbps
[    hd-2400k-16:9 ]  1280 x  720 using     2336 kbps
[    yt-sdr-480p30 ]   852 x  480 using     2628 kbps
[ skype-vid-grp7-min ]   640 x  360 using     4000 kbps Invalid BPS 4000000, correct to 3730000
[ skype-vid-grp5-rcmd ]  1280 x  720 using     4000 kbps Invalid BPS 4000000, correct to 3800000
[    yt-sdr-480p60 ]   852 x  480 using     4128 kbps
[    yt-sdr-720p30 ]  1280 x  720 using     5384 kbps
[    yt-hdr-720p30 ]  1280 x  720 using     6884 kbps
[    yt-sdr-720p60 ]  1280 x  720 using     7884 kbps
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[   yt-sdr-1080p30 ]  1920 x 1080 using     8384 kbps
[    yt-hdr-720p60 ]  1280 x  720 using     9884 kbps
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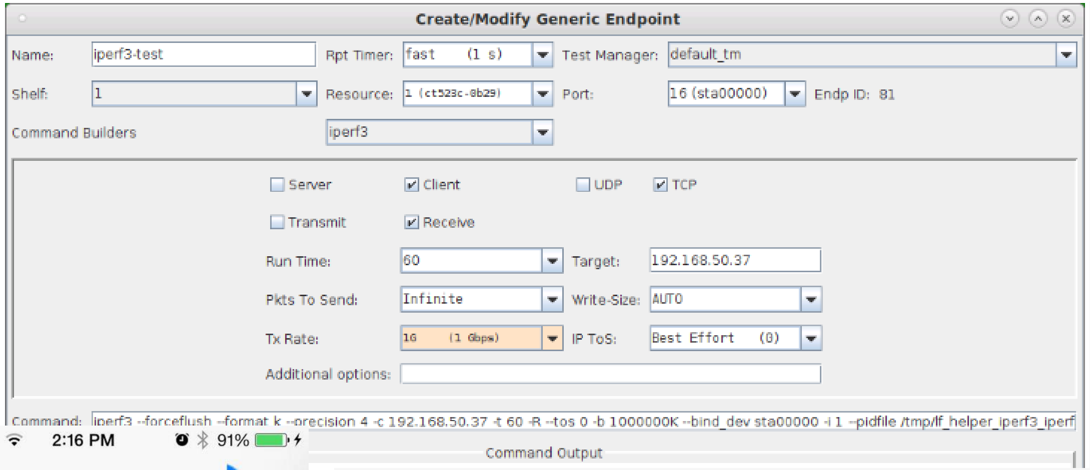
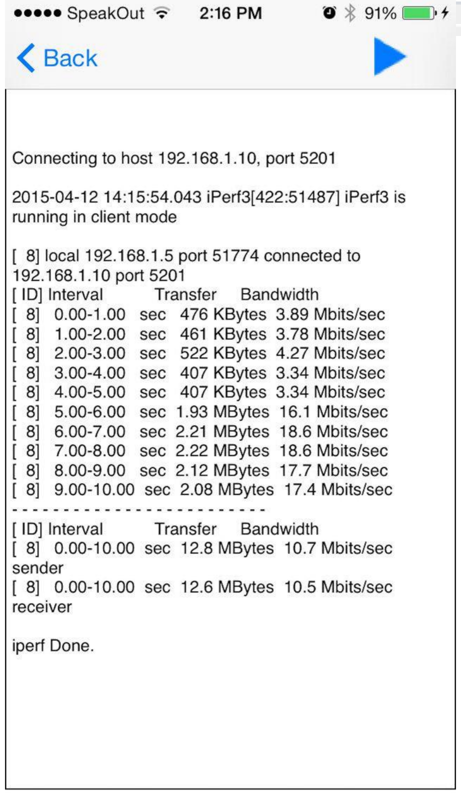
[   yt-hdr-1080p60 ]  1920 x 1080 using    15384 kbps
[   yt-sdr-1440p30 ]  2560 x 1440 using    16512 kbps
[   yt-hdr-1440p30 ]  2560 x 1440 using    20512 kbps
[   yt-sdr-1440p60 ]  2560 x 1440 using    24512 kbps
[   yt-hdr-1440p60 ]  2560 x 1440 using    30512 kbps
[   yt-sdr-2160p30 ]  3840 x 2160 using    40512 kbps
[   yt-hdr-2160p30 ]  3840 x 2160 using    50512 kbps
[   yt-sdr-2160p60 ]  3840 x 2160 using    61512 kbps
[   yt-hdr-2160p60 ]  3840 x 2160 using    76012 kbps
[       raw720p30 ]  1280 x  720 using   221184 kbps
[       raw720p60 ]  1280 x  720 using   442368 kbps
[        raw1080i ]  1920 x  540 using  1486512 kbps
[      raw1080i30 ]  1920 x  540 using  1488000 kbps
[      raw1080i60 ]  1920 x  540 using  1488000 kbps
[        raw1080p ]  1920 x 1080 using  2976000 kbps
```

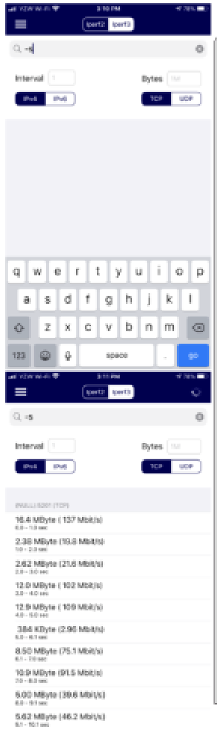
iPerf Traffic Testing

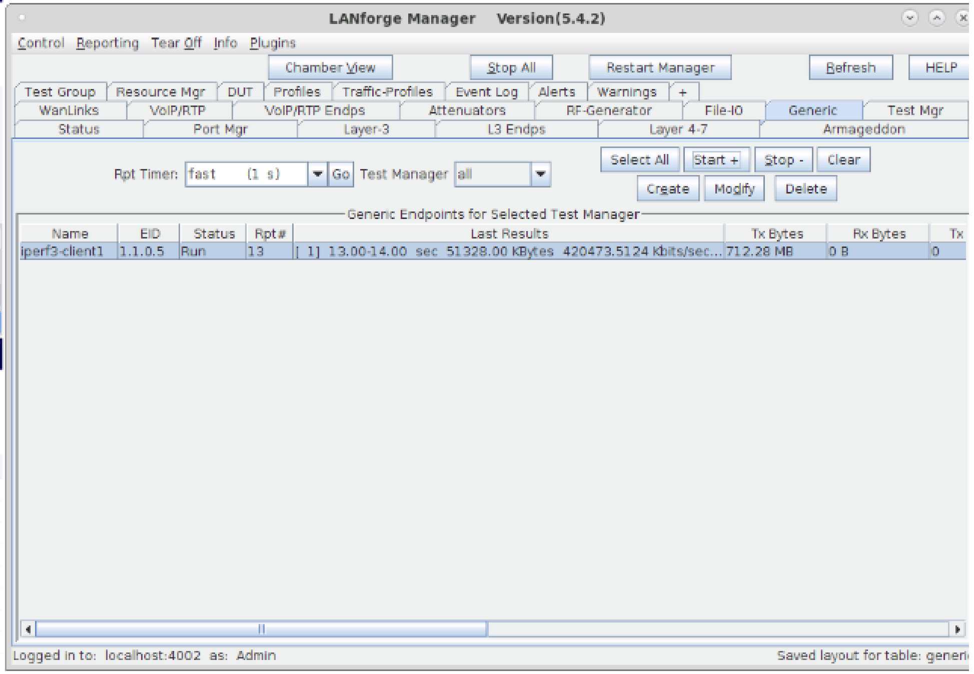
- Supports testing with iPerf clients and servers.
- User can load iPerf on any type of handheld devices and test with Candela.
- Can test phones/tablets/wireless printers/scanners/medical equipment/consumer electronics devices that run Windows, Linux, Mac OS and other variants of compact embedded Operating Systems.
- Users can test real wired/wireless endpoints in the presence of Candela emulated Wired/Wireless endpoints creating lots of background traffic.
- Candela offers an improved iPerf 3 client to create multiple connections.



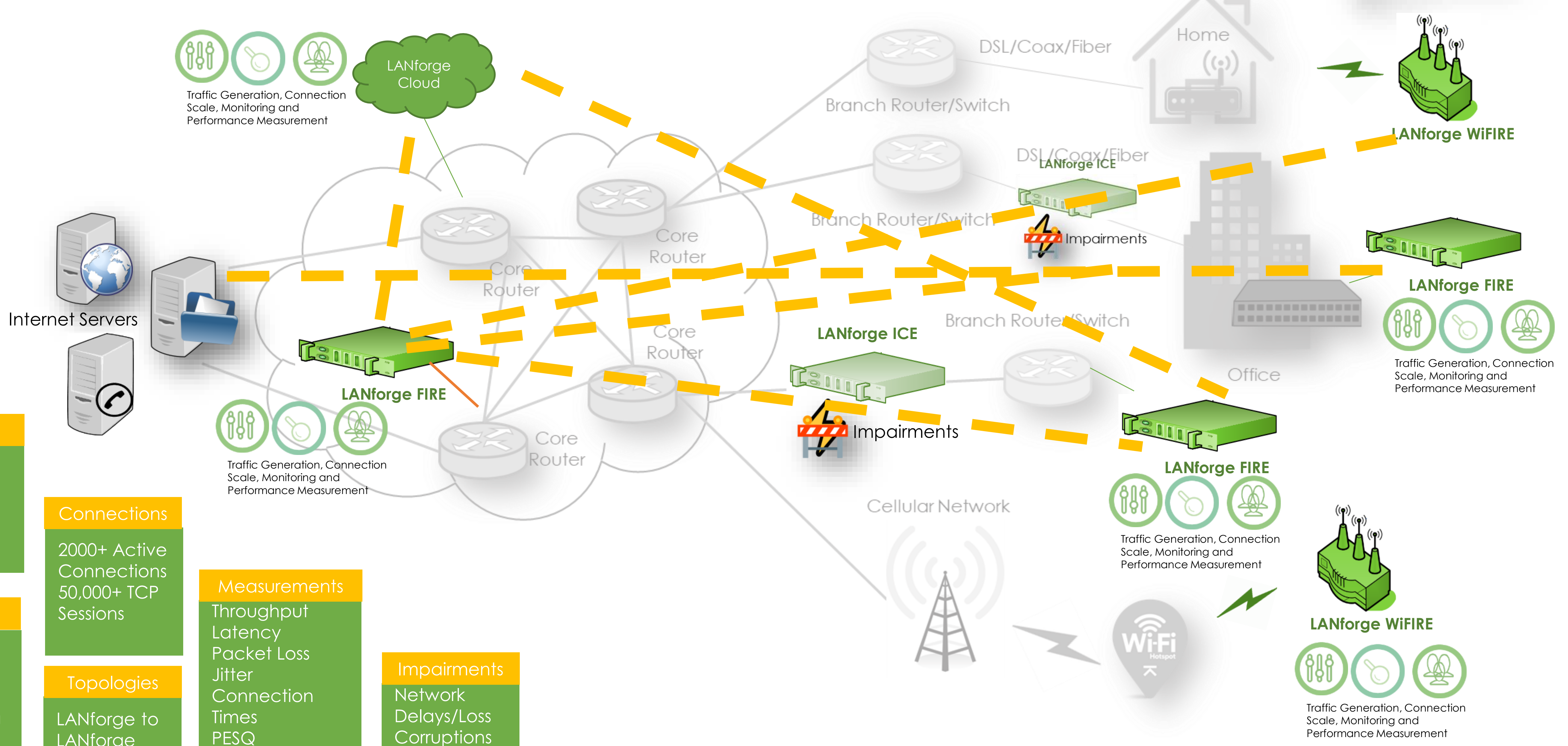


For mobile devices, start the iperf3 server on the mobile devices first, then start the clients.





Network Testing with Candela LANforge



Traffic
TCP/UDP
VOIP
HTTP/HTTPS
FTP

Interfaces
1Gbps
10Gbps
WiFi-802.11a/b/g/n/ac

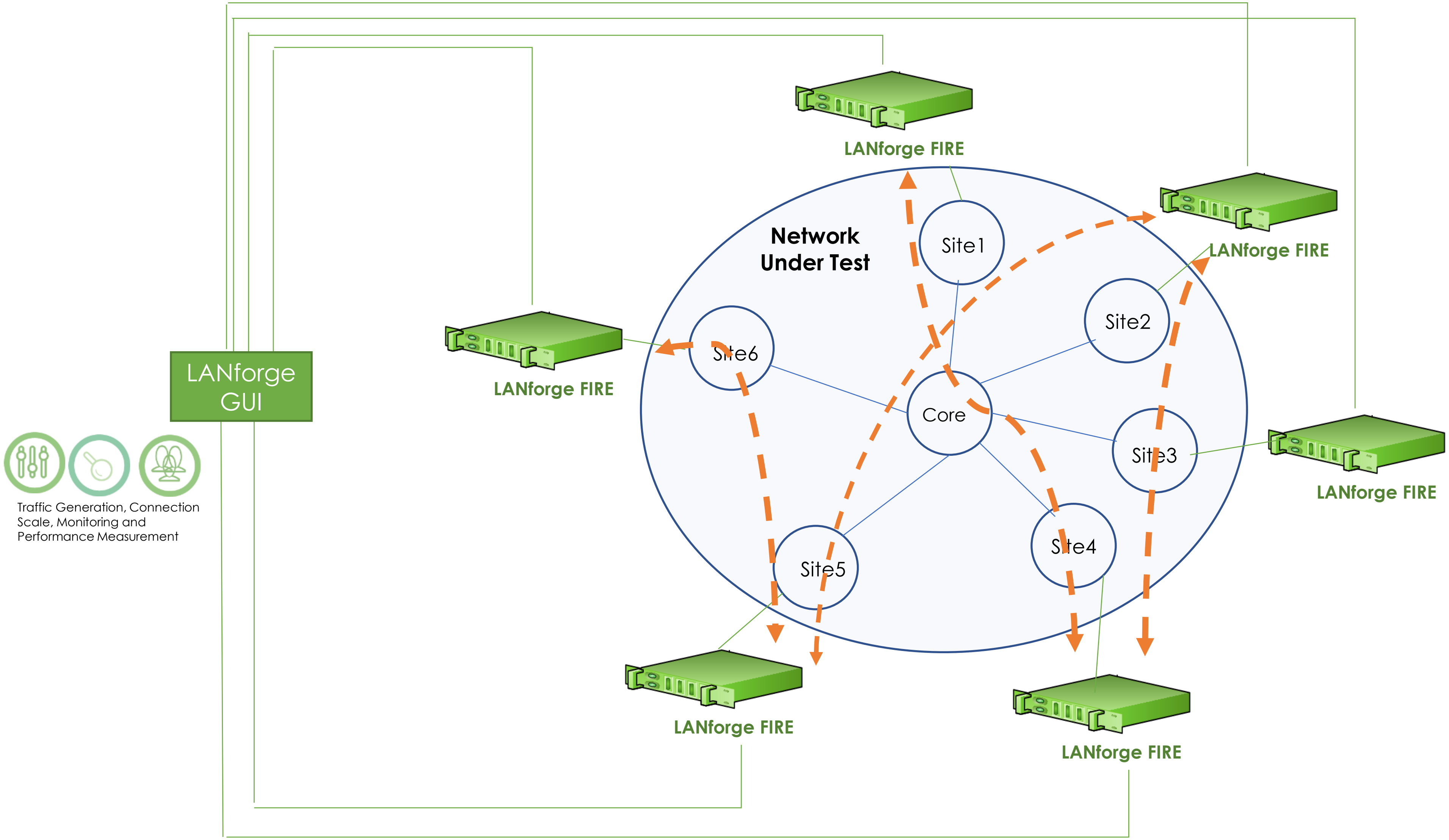
Connections
2000+ Active Connections
50,000+ TCP Sessions

Topologies
LANforge to LANforge
LANforge to Real Servers

Measurements
Throughput
Latency
Packet Loss
Jitter
Connection Times
PESQ

Impairments
Network Delays/Loss
Corruptions
Duplication/
Reordering

Network Test Setup

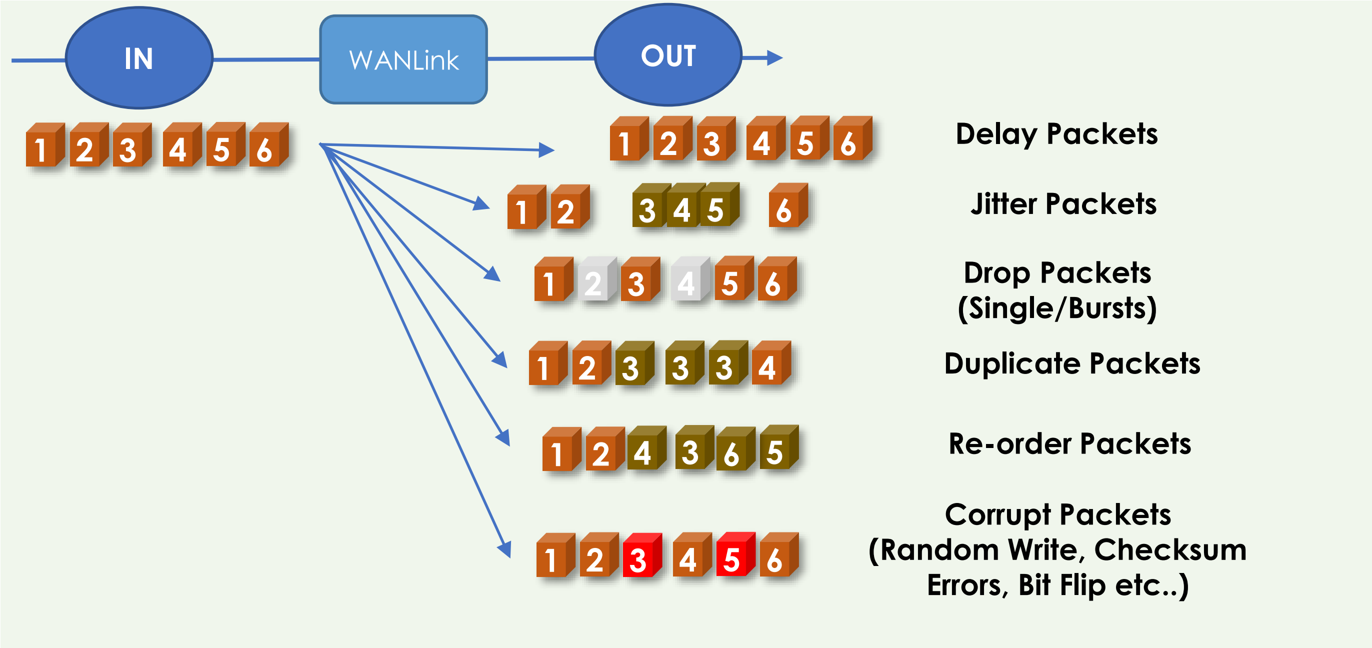


LANforge- FIRE : Systems

Product	Description	Price
Remote Endpoint: **CT314**	Most affordable system, supports single 10/100 Ethernet port. Optional single b/g/n WiFi station interface. Useful for network monitoring.	USD 595
Network in a Box: **CT502-1G**	Simulate up to 250 ethernet devices with unique MAC, IP Address and routing table over 6 physical ports with gigabit traffic generation. Excellent for testing routers and firewalls that monitor traffic flows. For low speed networks, consider the more affordable: CT502.	USD 12,250
Gigabit Generator: **CT503**	Generate and receive up to 8 Gbps of traffic with a single system. The CT503 is configured with 8 10/100/1000 Ethernet interfaces, and other options with more or fewer ports are available. This system is excellent for testing multi-port high-speed networks.	USD 16,295
CT503-10G	Generate and receive 10 Gbps of traffic with a single system. The CT503-10G is configured with two 10 Gigabit Fiber interfaces. Other options including portable systems and more ports are available. This system is excellent for testing multi-port high-speed networks. For even more capacity, consider the CT503-10G-4 system.	USD 15,155
10 Gig Combo Generator: **CT503-MIX**	Generate and receive 12+ Gbps of traffic with a single system. The CT503-MIX is configured with two 10 Gigabit Fiber interfaces and 12 1Gbps SFP interfaces. This system is designed to be a general purpose network traffic generator for high-speed networks.	USD 47,805
48-port Last-Mile Traffic Generator: **CT570**	Generate and receive up to 2 Gbps of traffic across 48 10/100 ethernet interfaces utilizing a single LANforge machine and a 48-port managed ethernet switch. This system is excellent for testing DSL, Cable Modem, and other networks with a large number of lower-speed network devices.	USD 31,900
File-IO Generator: **CT510-10G**	Generate up to 2000 unique NFS, CIFS and other File-IO sessions. Excellent for testing File Servers and network storage devices. for the individual calls.	USD 21,655
VoIP Call Generator: **CT505-30**	Generate up to 30 concurrent SIP calls with RTP. Excellent for testing SIP gateways, routers and QoS configurations. Includes optional PESQ module that provides automated perceptive quality scoring for the individual calls. See also: CT505-100. Systems supporting up to 500 calls are also available.	USD 14,350

LANforge-ICE

IMPAIRMENTS



TEST APPLICATIONS

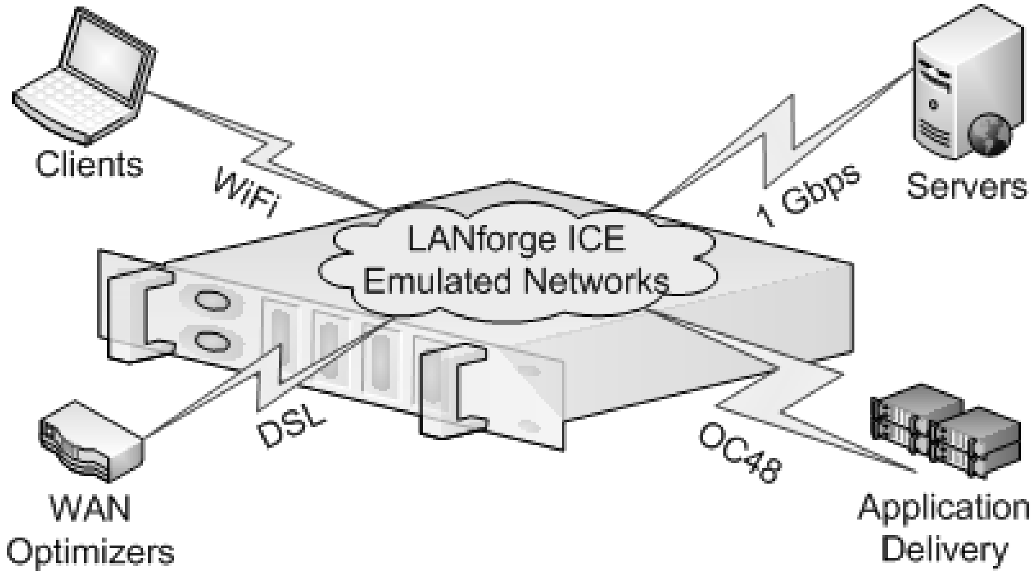
- ✓ Satellite Networks
- ✓ Cellular Backhaul
- ✓ Real-time streaming video
- ✓ VOIP testing
- ✓ Industrial Applications
- ✓ Remote Equipment Control
- ✓ Time Sensitive Networks
- ✓ Distributed Online Gaming
- ✓ Stock Trading Applications
- ✓ IoT Applications
- ✓ Cloud Computing
- ✓ Security/Denial of Service

LANforge – ICE : WAN Emulation/Impairments

LANforge ICE can add impairments in a controlled and reproducible manner to aid in testing applications and network equipment that must operate over a network.

LANforge-ICE supports many impairments: latency, bandwidth, jitter, packet loss, packet reordering and more. It can act as a layer-2 pass-through device for easy insertion into the system under test. It also supports 802.1Q VLANs, router emulation, bridges and other network elements for more advanced emulation needs. Emulation speeds range from 10bps to 9.8Gbps, and some systems support more than 48 concurrent emulations.

Some users may want to simulate an entire LAN or WAN network. LANforge ICE supports Bridges (switches) including spanning tree protocol, as well as OSPF, BGP, RIP and multicast routers. IPv4 and IPv6 routing protocols are supported, and the bridge will handle any Ethernet frame. LANforge is running real router and bridge software, so it can exchange messages with external equipment to populate routes and set up spanning trees.



LANforge – ICE : Use Cases

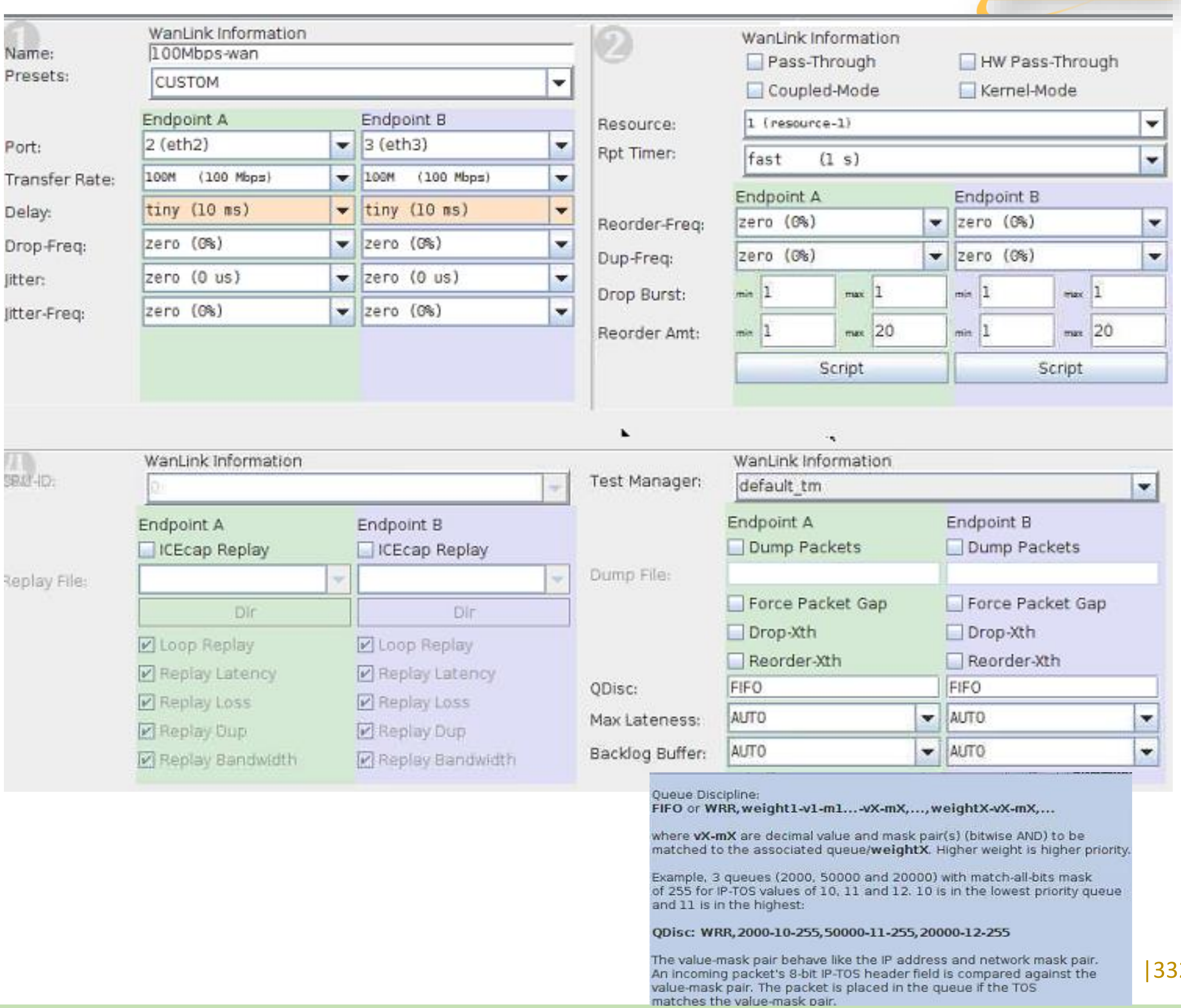
- Verify applications can run over a WAN before migrating applications to remote data center.
- Test multi-player games and other interactive real-time group applications.
- Test streaming media CODECs and network stacks in a controllable manner.
- Test LAN based applications for adverse network conditions.
- Verify data-replication services can function properly over degraded networks.
- Simulate large complicated networks
- Do specific application testing by impairing only a certain subset of packets.

LANforge – ICE : Features Summary

- ✓ General purpose WAN and Network impairment emulator: Validates stability and functionality of devices and programs over a wide variety of network conditions.
- ✓ Able to simulate DS1, DS3, OC-3, OC-12, OC-24, OC-48, GigE, DSL, Cable Modem, Satellite links and other rate-limited networks, from 10bps up to 9.8 Gbps speeds (full duplex).
- ✓ Can modify various network attributes including: network-speed, latency, jitter, packet-loss, packet-reordering, and packet-duplication.
- ✓ Supports Packet corruptions, including bit-flips, bit-transposes and byte-overwrites.
- ✓ Supports WanPath feature to allow configuration of specific behavior between different IP subnets or MAC addresses using a single pair of physical interfaces.
- ✓ WanPaths can also impair packets based on an arbitrary filter that is created using the powerful and well documented tcpdump filter syntax.
- ✓ Supports WAN emulation across virtual 802.1Q VLAN interfaces for more efficient use of valuable physical network interfaces.
- ✓ Supports routed and bridged mode for more flexibility in how your configure your network and LANforge ICE.
- ✓ Supported routing protocols include: static, OSPF, RIP, OLSR, BGP, and Multicast (PIM, IGMP). Most protocols support both IPv4 and IPv6.
- ✓ Supports 'WAN-Playback' allowing one to capture the characteristics of a live WAN and later have LANforge ICE emulate those captured characteristics.
- ✓ Allows packet sniffing and network protocol decoding with the integrated Wireshark sniffer.

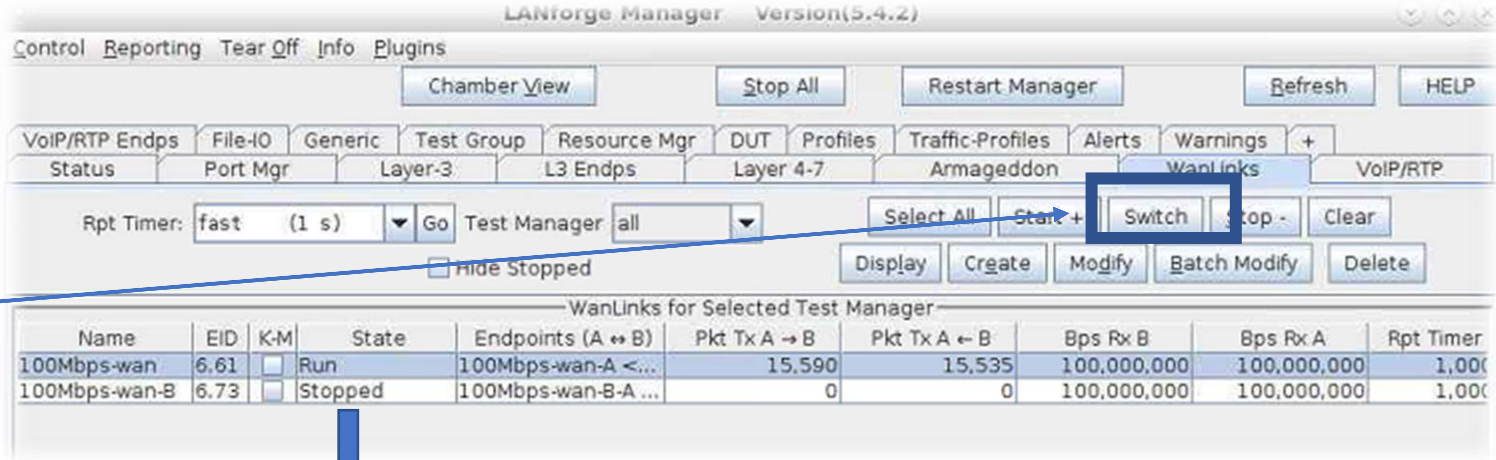
LANforge – ICE : Advanced Settings

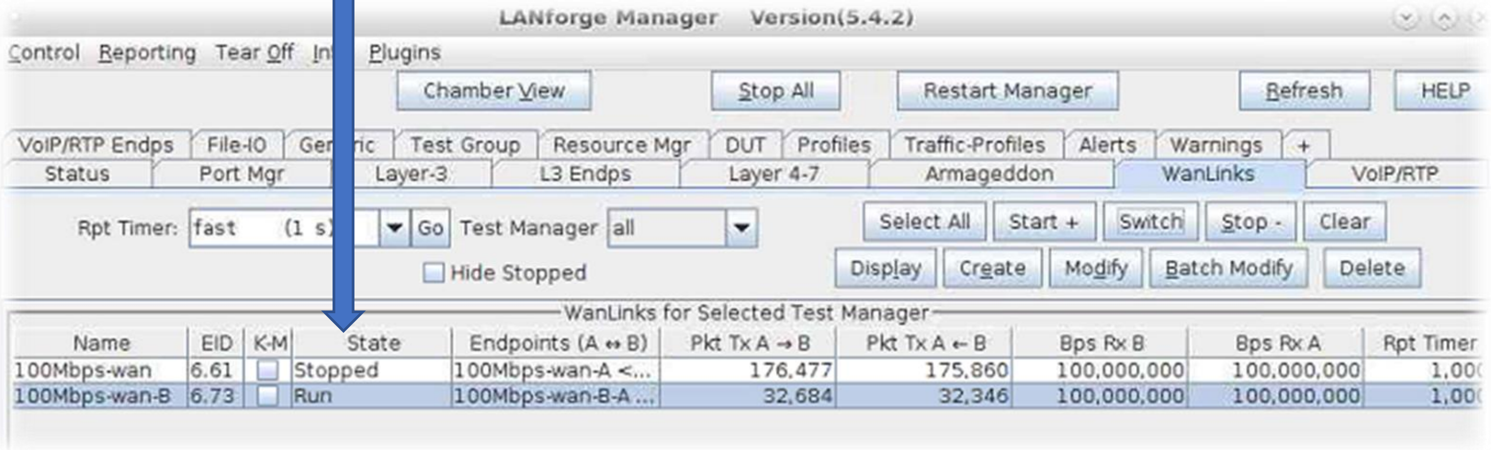
- On a per network link basis the user can apply the following advanced impairment settings:
  - Packet Drop Frequency
  - Packet Re-order Frequency
  - Packet Duplicate Frequency
  - Drop Bursts
  - Reorder Amount
  - Dump Packets of certain type
  - Force Packet Gap
  - Drop Xth packet
  - Reorder Xth packet
  - Changing Queuing Mechanism to:
    - FIFO
    - WRR (Weighted Round robin)



LANforge – ICE : Real-Time Impairments

- Setup a certain impairment profile on a WANLink.
- Create a peer link with the different impairments
- While traffic is running, use the Switch button to change the impairment in run time to the peer WAN Link





Gaming Networks

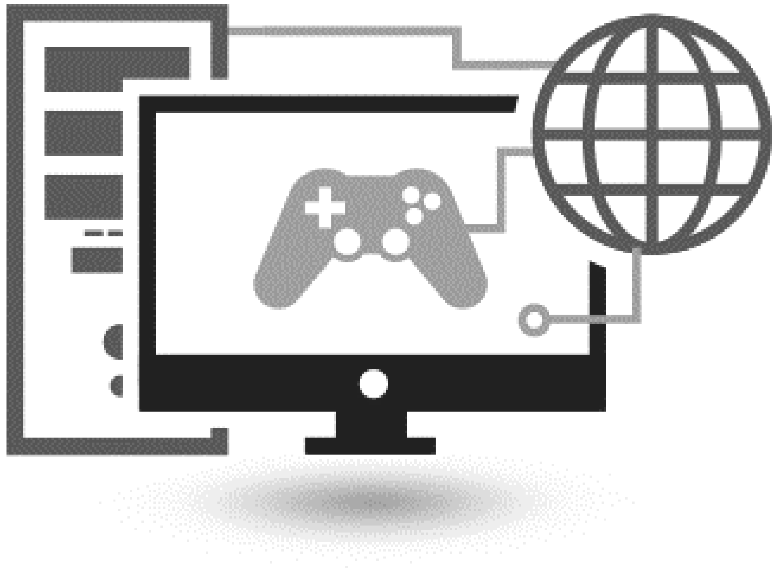
Candela TECHNOLOGIES

Challenges:

- How do we ensure a high quality gaming experience given variable network conditions?
- What are the network limits of a particular game or gaming platform?
- How do we ensure that 3rd party game developers test to the same requirements?

Key Performance Indicators:

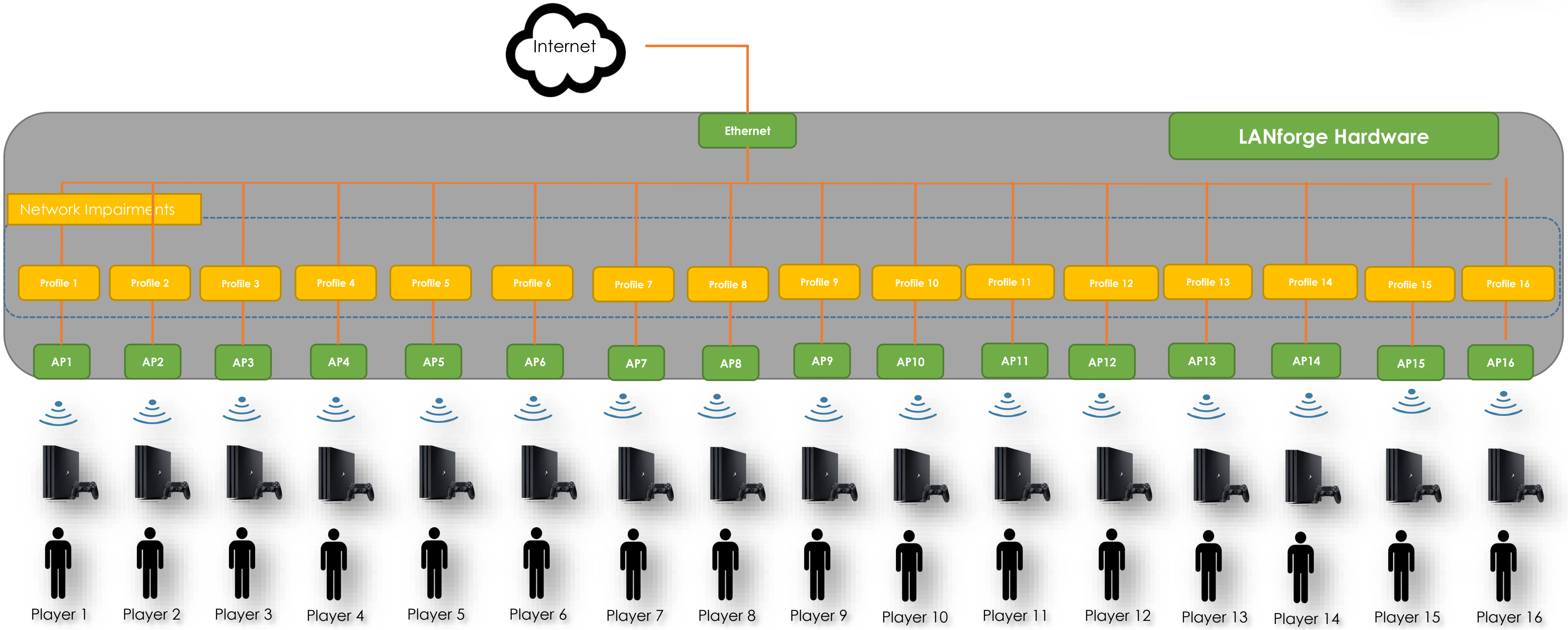
- User Experience
- Latency/Lag
- Jitter, variable latency



Testing Gaming over the Network

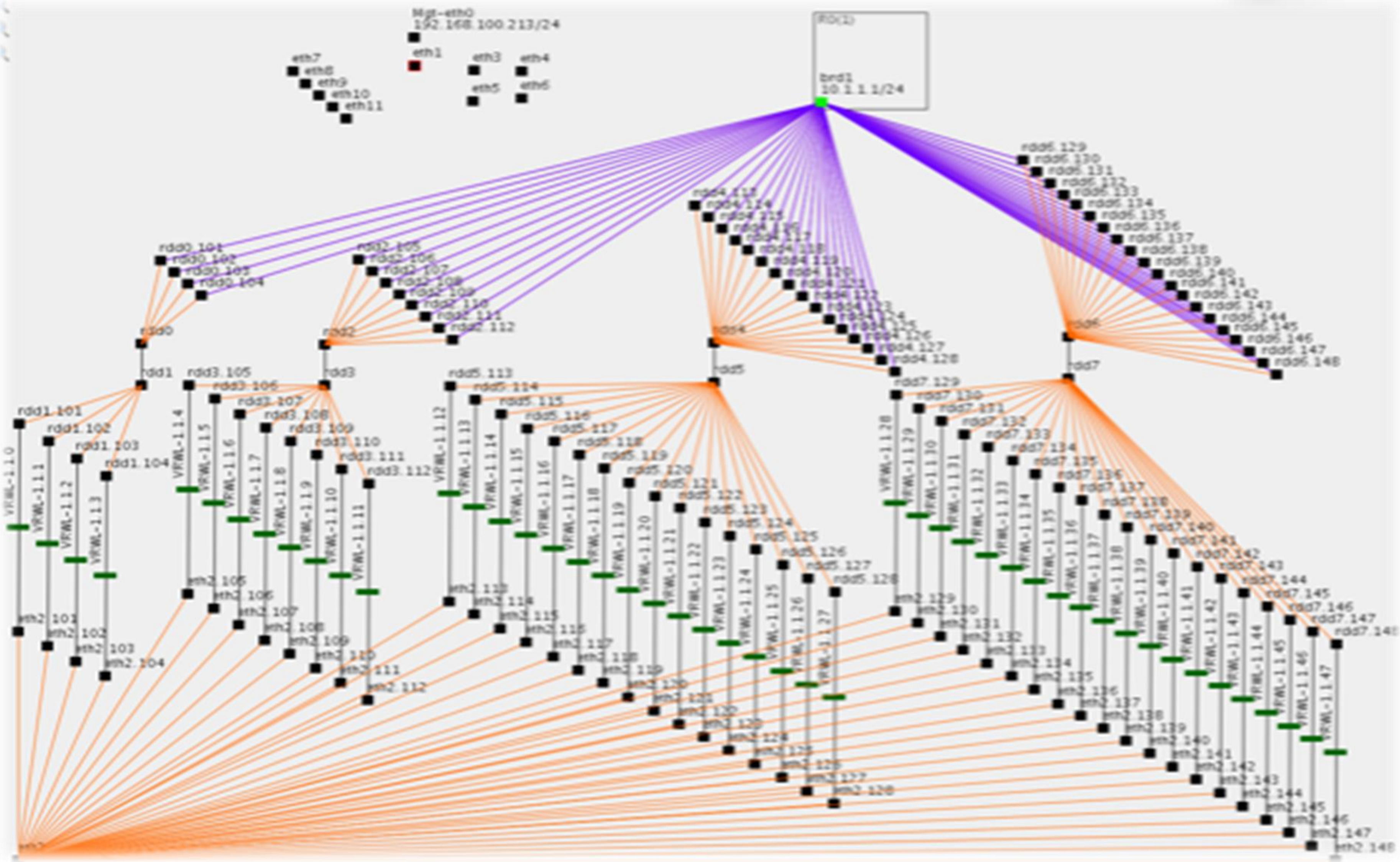
Player 1
Player 2
NETWORK
GAMING
CONSOLE

16 Game Console Example Setup



48 Game Console Test Example

- ➢ Unique emulation profile per gaming console.
- ➢ Can test upto 48 gaming consoles at a time.
- ➢ Can emulate DSL, Cable Modem, Satellite and other type of network links.
- ➢ Can dynamically change impairment profiles during the test.
- ➢ Easy to integrate with real game servers allowing for testing with real gaming applications over the Internet.
- ➢ Can easily create test groups /profiles.
- ➢ Real time sniffing and analysis of any of the network links.



Banking/Finance Networks

Challenges:

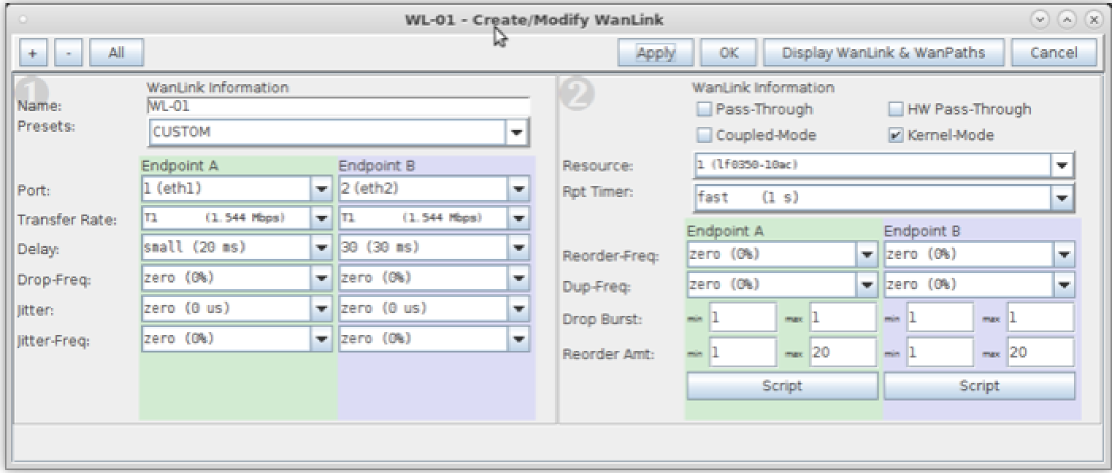
- Prototyping large scale network additions or modifications before going live.
- Speed an Accuracy of applications over very diverse network conditions.
- Create the redundancy and security needed.
- Handling large data transfers.

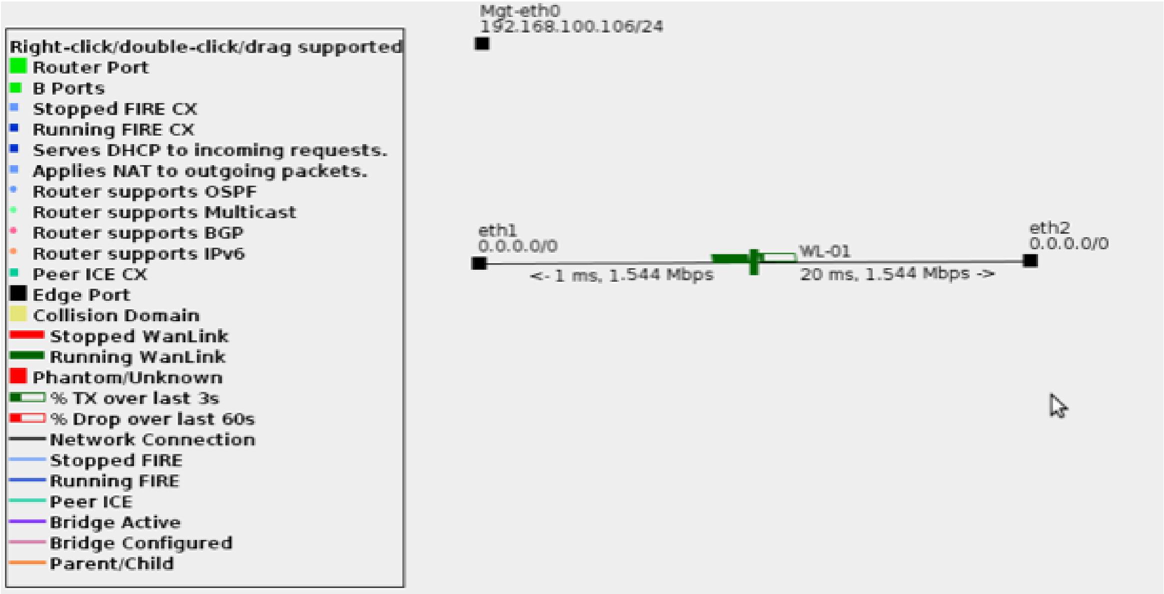
Key Performance Indicators:

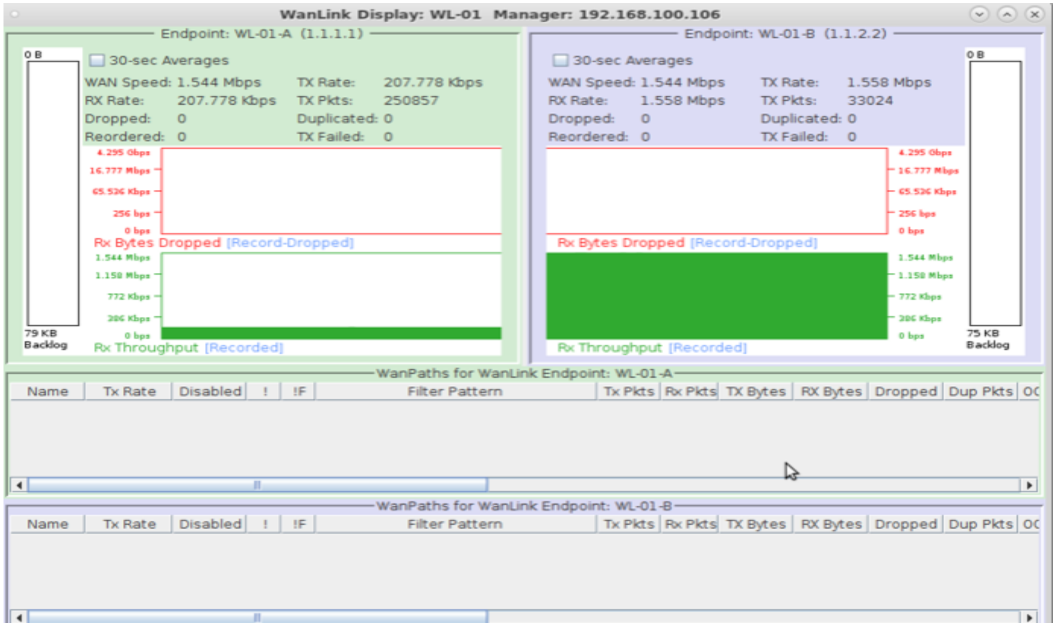
- Application performance
- Failure Downtime/Resiliency
- Network Latency

Simple WAN Emulation Example

- Simple but highly effective way of emulating WAN impairment between two bank branch office sites.
- Below example shows a WANLink that is rate limited to 1.544Mbps on both sides and 1msecs of latency on one side and 20 msecs of latency on the other side.
- Similar configurations can created very easily and can be automated to create 100s of combinations to represent various real world scenarios for testing transactions across various sites.
- Configuration can be scaled to match the complexity of large distributed financial institutions.







Defense Networks

Challenges:

- Verifying multiple devices, systems and applications can perform under adverse network conditions.
- Verifying backup and redundant systems perform as expected.
- Accurately emulating geographically diverse networks.

Key Performance Indicators:

- Communication delay/Jitter
- Application adaptability
- Worst case scenario performance

Network Corruptions Example

- LANforge ICE allows for creation of extensive amount of corruptions on the network to mimic security attacks and corruption of information on the network.
- Users can take various real-world behaviors and recreate them using LANforge ICE features.

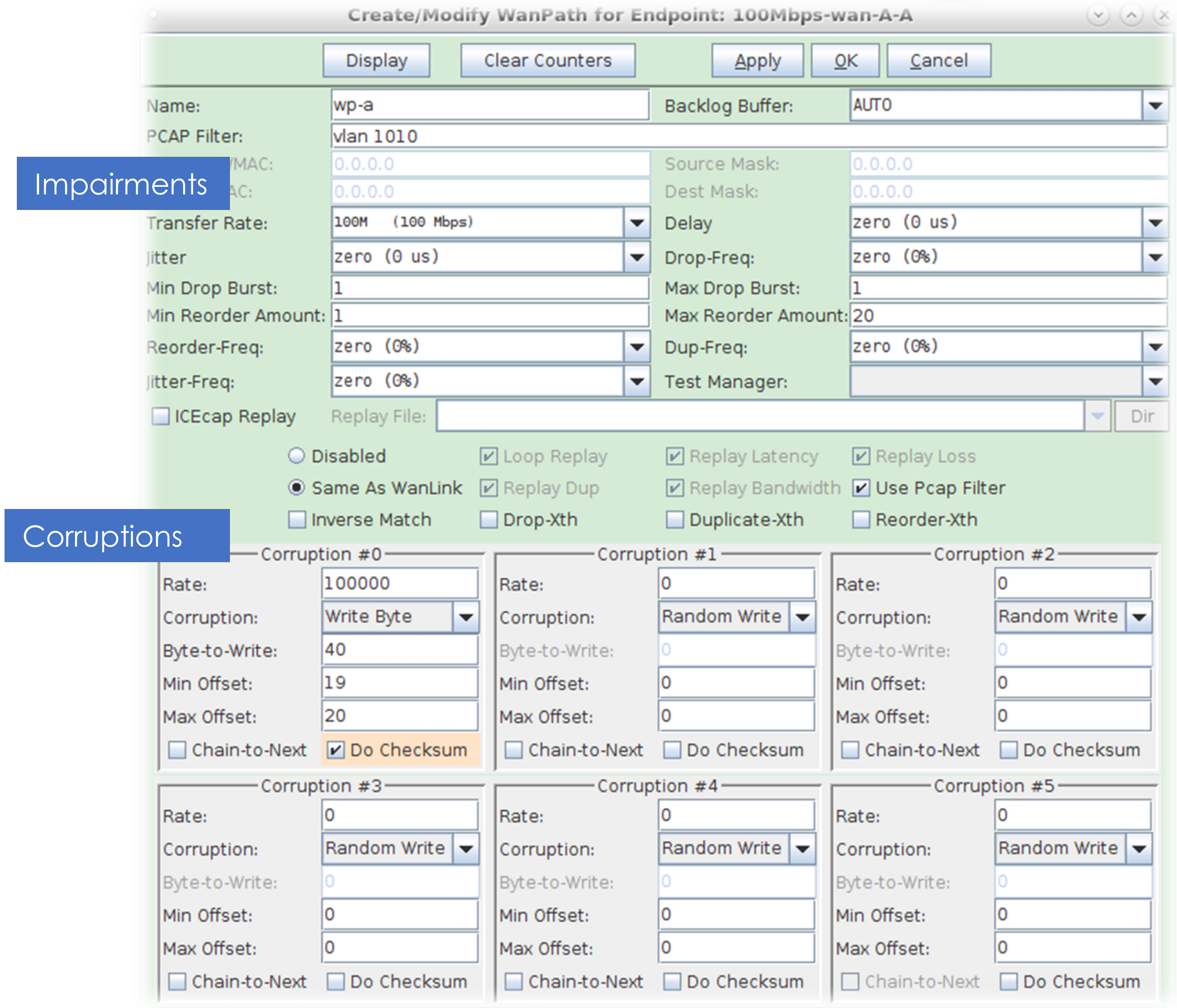
LANforge-ICE supports bit and byte error corruptions in ethernet frames. The **Rate** field determines how often to apply the corruption (out of 1 million packets).

Select the type of corruption you want to apply from the **Corruption** drop-down menu:

•***Random Write***: Will write a random byte to one byte between the min and max offset into the ethernet frame.
•***Write Byte***: Will write the byte specified in the **Byte-to-Write** field to a location between the Min and Max Offset into the ethernet frame.
•***Bit-Flip***: Will flip one bit from 0 to 1 or 1 to zero in a byte between the Min and Max Offset into the ethernet frame.
•***Bit-Transpose***: Will transpose two bits in a byte between the Min and Max Offset into the ethernet frame.

The **Min** and **Max Offset** fields determine the location of the corruption. If Min is less than Max, the corruption will be at a random byte between Min and Max.
If the **Chain-to-Next** checkbox is selected, any time this corruption is applied, the ***next*** corruption will be applied as well. This can allow you to reliably generate multiple corruptions in a single packet.

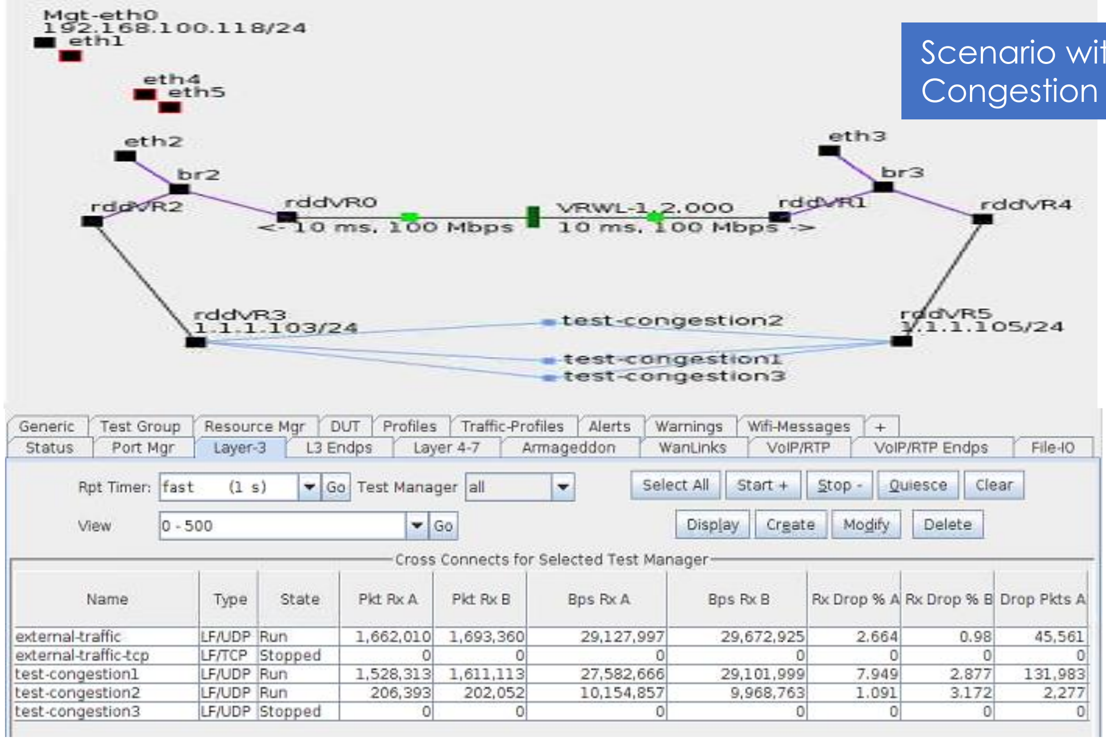
If the **Checksum** checkbox is selected, LANforge will attempt to recalculate the IPv4, UDP, and TCP checksum for the packet after applying the corruption. This will allow the errored packet to be accepted by the stacks on the receiving machine as if the data were actually valid.



Example Operation in Hostile Defense Network conditions

- LANforge can be used to add background congestion to mimic real world hostile network conditions.
- Impairments can be created on the WAN Links and congestion can be added separately to make the testing more real world.
- Congestion can be created in the form of Constant Bit Rate or bursty TCP and/or UDP traffic.

Scenario with WAN Links + Traffic Congestion

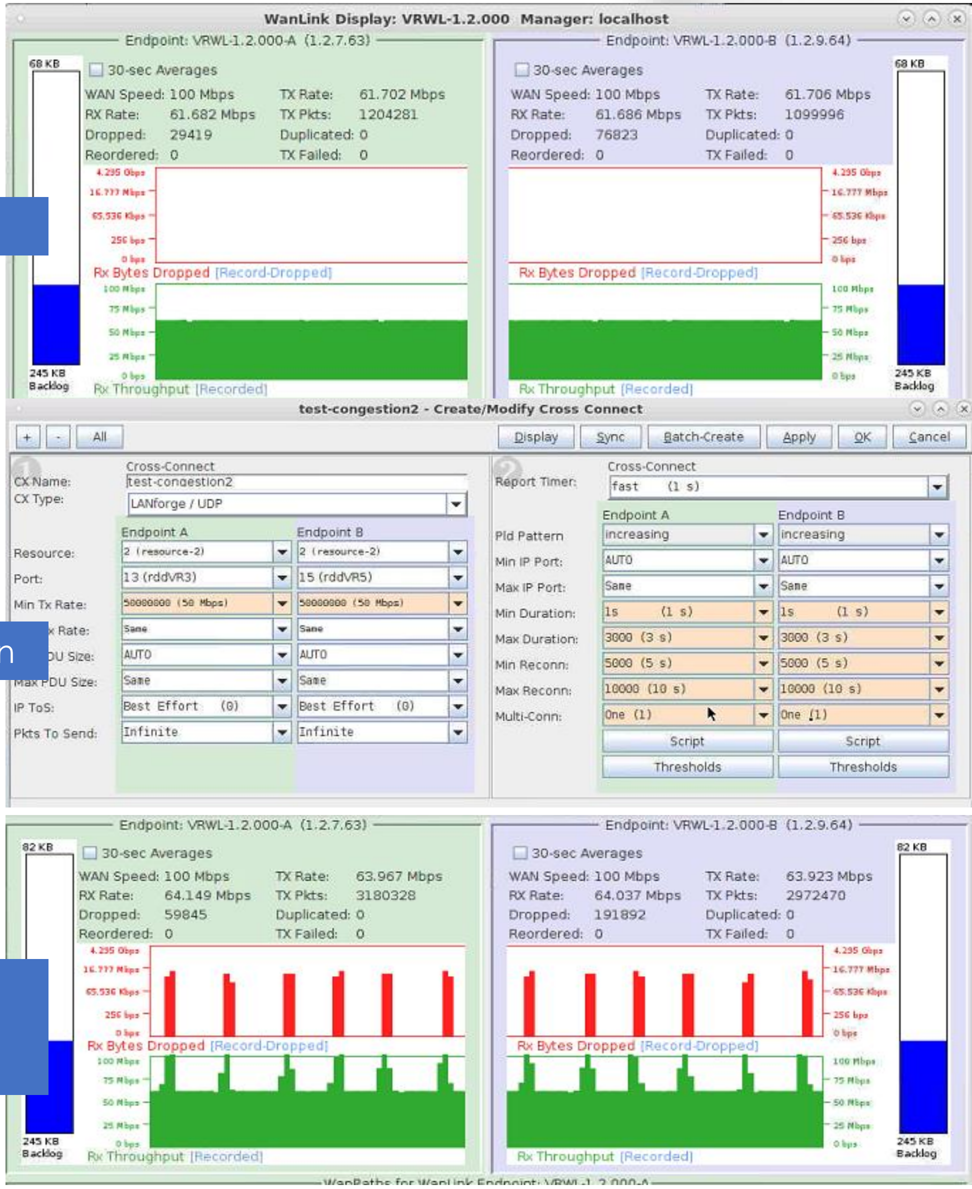


Name	Type	State	Pkt Rx A	Pkt Rx B	Bps Rx A	Bps Rx B	Rx Drop % A	Rx Drop % B	Drop Pkts A
external-traffic	LF/UDP	Run	1,662,010	1,693,360	29,127,997	29,672,925	2.664	0.98	45,561
external-traffic-tcp	LF/TCP	Stopped	0	0	0	0	0	0	0
test-congestion1	LF/UDP	Run	1,528,313	1,611,113	27,582,666	29,101,999	7.949	2.877	131,983
test-congestion2	LF/UDP	Run	206,393	202,052	10,154,857	9,968,763	1.091	3.172	2,277
test-congestion3	LF/UDP	Stopped	0	0	0	0	0	0	0

No Congestion

Add Congestion

Effects on Application Performance



Enterprise IT Networks

Challenges:

- Doing more with less.
- Troubleshoot, Isolate and eliminate network bottlenecks.
- Network upgrades, how do we test an upgrade before installing it?
- How to ensure smoot operation of high bandwidth applications across sites spread all across the world

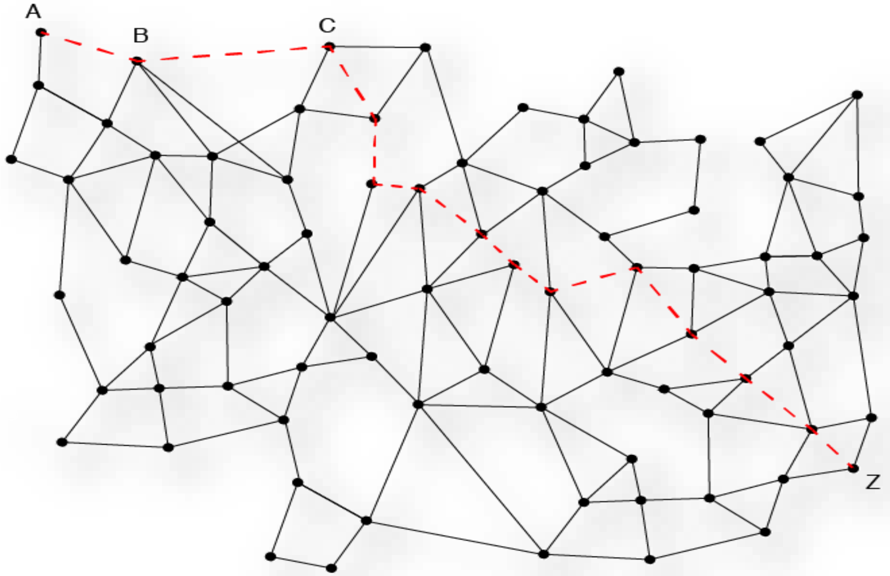
Key Performance Indicators:

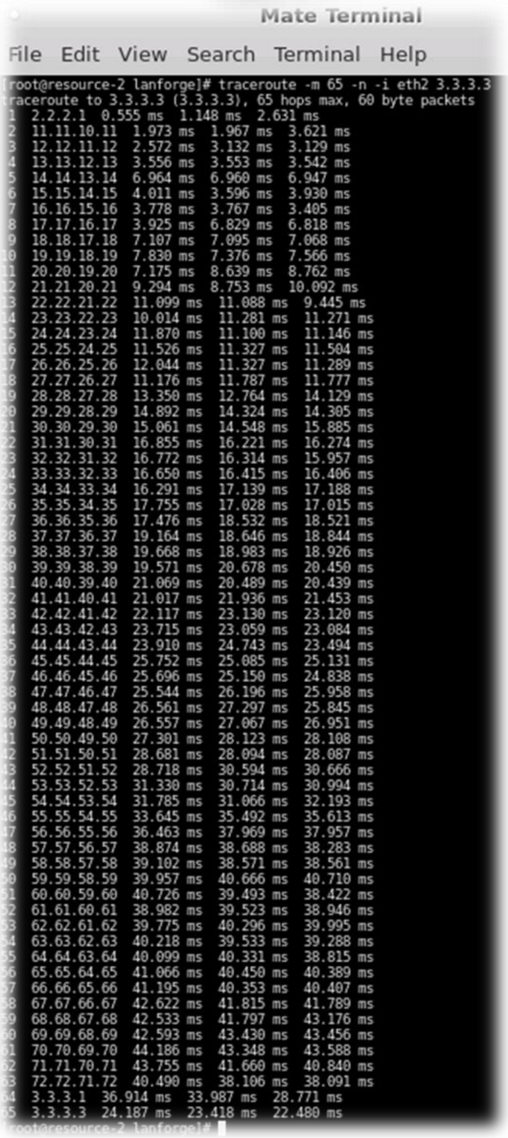
- End user Experience
- Reduced trouble tickets
- Application Performance

64 Hop WAN Emulation Example

- Enterprise IT has to test applications to work well across several network hops on the Internet
- How can you test an application by **emulating the entire internet in a box**?
- Can you create multiple virtual routers/hops to test high BW/low latency enterprise IT application over the Internet?

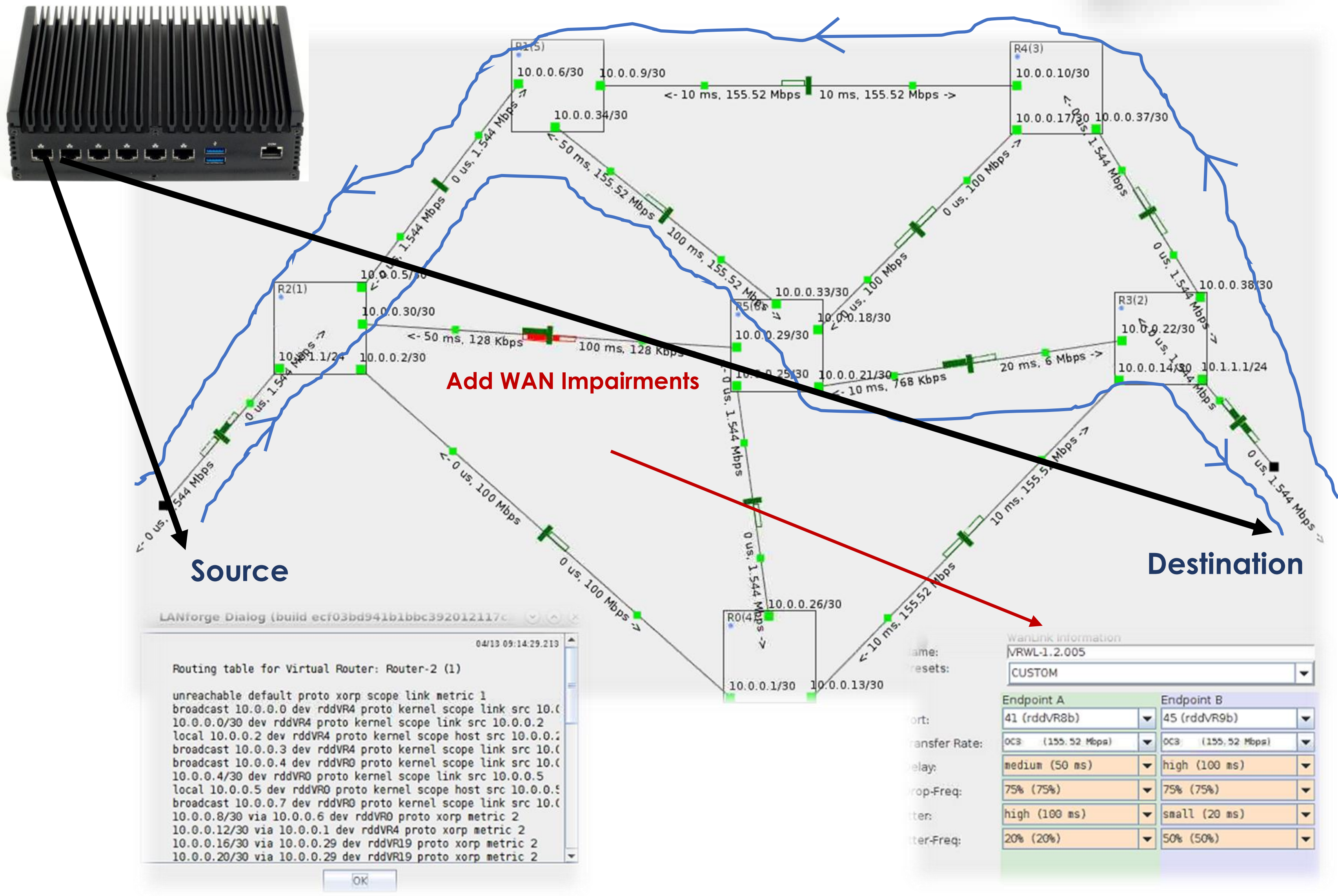
- LANforge ICE can be used to create an entire virtual network between two ethernet ports.
- User can create virtual routers on each hop
- User can apply different impairment profiles for each virtual hop.
- End to End and per hop network latencies , packet loss and jitter can be measured and reported.
- End to End application performance can be measured.





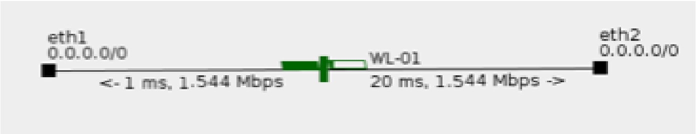
Internet in a Box Example

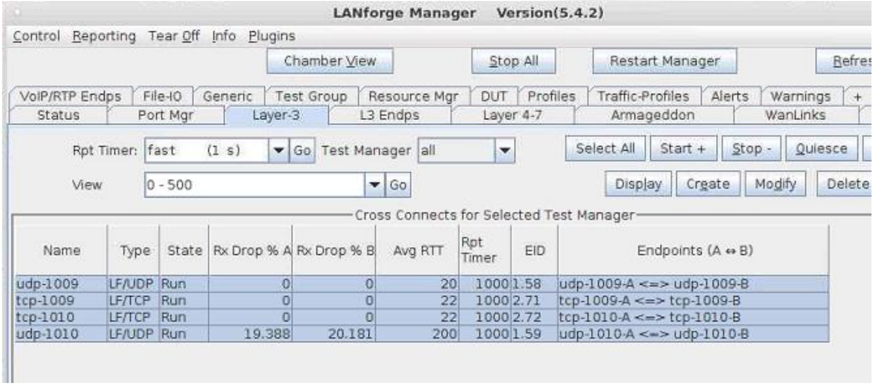
- LANforge ICE allows users to create several virtual routers and paths between two physical ports.
- Various router protocols like OSPF, RIP, BGP and others can programmed.
- Various impairments can be created on the virtual router links and the router protocols can tested.
- End to end performance of applications can tested.
- This allows enterprise IT engineers to model and create various real-world network scenarios and the entire internet in a box and test applications, network policies etc...before implementing them on real networks.

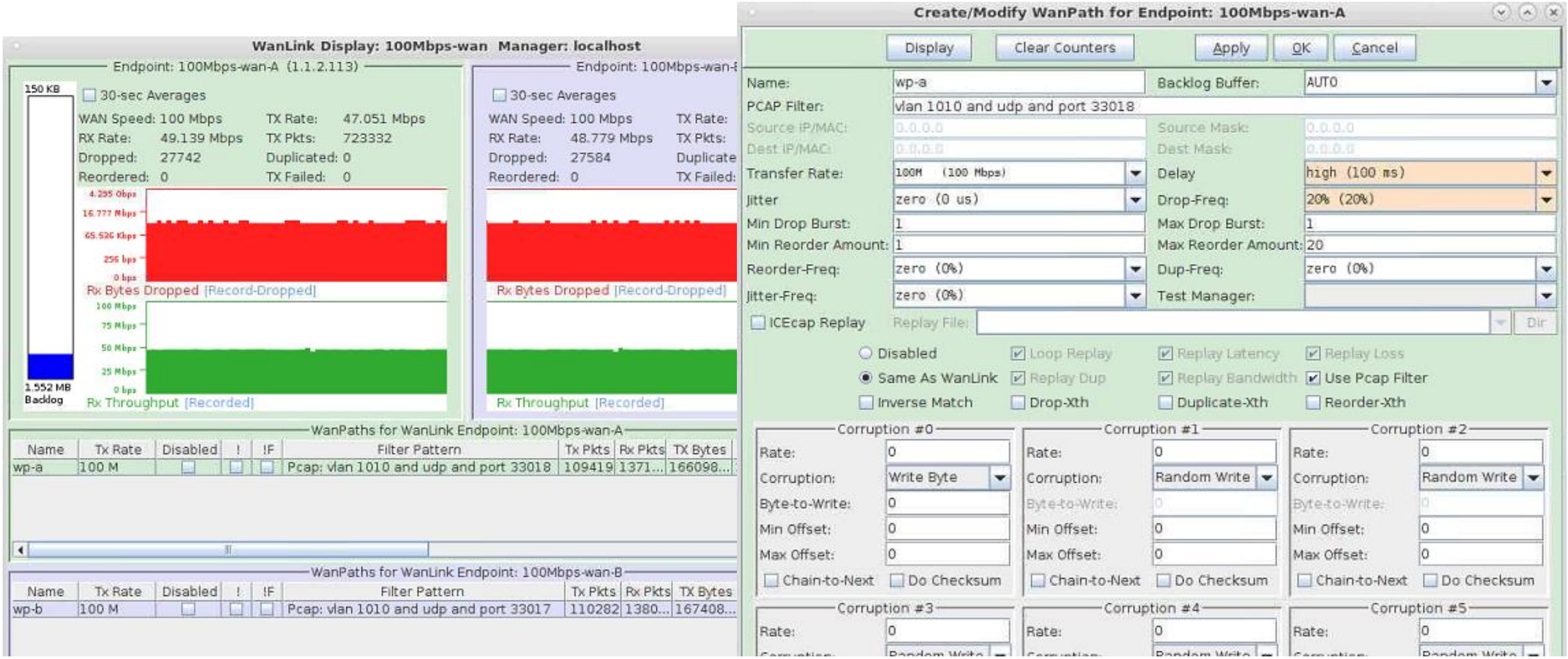


Traffic Shaping/Profiling on Network Links

- User can take any WANlink and use the WANpaths features to apply impairments based on very specific filters.
- For example apply a certain impairment profile for a traffic stream on vlan 1010 doing udp traffic on port 33018…..simply apply the wireshark filter **“vlan 1010 and udp and port 33018”** and select the type of impairments and/or corruptions the user wishes to apply.
- Several such wanpaths can be created and this feature can be used to test how traffic shaping/policing rules are effecting applications.

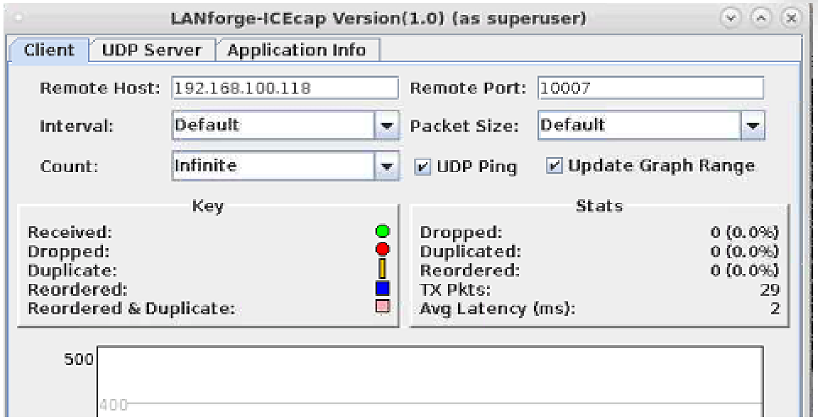






Record and Replay Network Impairments

- Record impairments (latency, loss, packet duplication, Jitter etc…) on real networks using ICEcap
- The impairments are saved in the form of XML file.
- One or more XML files can then be loaded into WAN emulation WANLink to replay the impairments.
- The user is allowed to replay one or more or all the components of the recorded impairments and allowed to loop replay those impairments.




```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE NETWOR_X SYSTEM "NetworX_1_1.dtd">
- <NETWOR_X CREATED_ON_DATE="Wed Mar 07 15:46:20 PST 2018" CREATED_ON_HOST_NAME="192.168.100.197" NETWOR_X_VERSION="1.1" NAME="NETWORX_NAME" ID="NETWORX_ID">
    <NET_OBJECTS/>
    <LINKS/>
  - <RECORDING_DATA>
    - <DATA_BLOCK NAME="ICEcap_Imported_Data">
        <RECORDING_DETAILS DESCRIPTION="" IMPORTED_INTERVAL_LENGTH="0" IMPORTED_INTERVAL_START_TIME="1520466380609" CREATE_DATE="Wed Mar 07 15:46:20 PST 2018" ORIGIN_VERSION="1.0-beta" ORIGIN="ICEcap"
          PAYLOAD_SIZE="56" DESTINATION_IP="www.google.com/172.217.12.228:0" SOURCE_IP="192.168.100.197:0" RECORDING_HOST="" RECORDING_NAME="" SAMPLE_INTERVAL="1000"/>
      - <LATENCY_AND_LOSS_DATA SAMPLE_INTERVAL="1000">
          <LAT>101</LAT>
          <TS>0</TS>
          <LOS>10</LOS>
          <DUP>1</DUP>
          <LAT>103</LAT>
          <TS>1</TS>
          <LOS>5</LOS>
          <DUP>7</DUP>
          <LAT>101</LAT>
          <TS>2</TS>
          <LOS>7</LOS>
          <DUP>8</DUP>
          <LAT>107</LAT>
          <TS>3</TS>
          <LOS>5</LOS>
          <DUP>6</DUP>
          <LAT>101</LAT>
          <TS>4</TS>
          <LOS>8</LOS>
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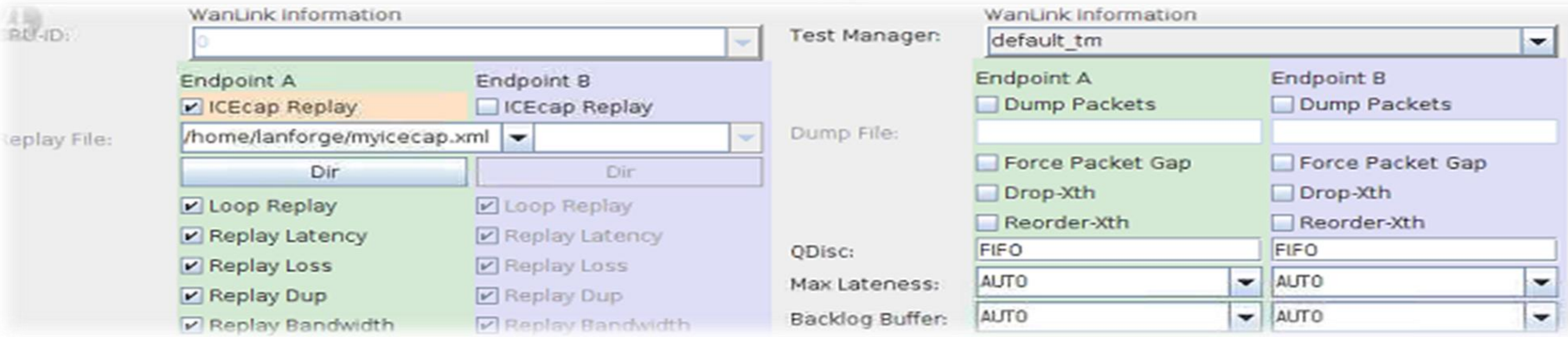


LANforge ICE – Product Models

CT910	45 Mbps WAN emulation with 3 ports	USD 995
CT913	1Gbps WAN Emulator with 3 ports	USD 4,995

CT920	45 Mbps WAN emulation with 3 ports	USD 2,995
CT922	155 Mbps WAN emulation with 3 ports	USD 4,190

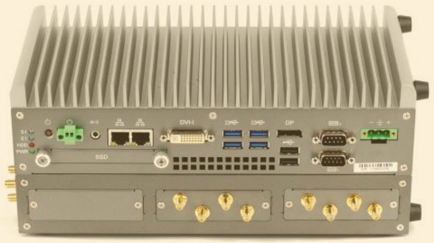
CT934	1 Gbps WAN emulation with 6 ports	USD 7,995

CT962	155 Mbps WAN emulation with 8 ports	USD 5,120
CT963	1Gbps with 8 ports copper or 4 ports fiber	USD 7,995
CT964	1Gbps with(10+ secs latency) 8 ports copper or 4 ports fiber	USD 9,290
CT966	10Gbps WAN Emulator, fiber and copper	USD 12,995

CT970-10	Supports 10 unique WAN Emulators	USD 12,000
CT963-16	Supports 16 unique WAN Emulators	USD 17,000
CT964-24	Supports 24 unique WAN Emulators	USD 24,995
CT966-48	Supports 48 unique WAN Emulators	USD 29,460

LANforge System Capabilities

Candela TECHNOLOGIES



LANforge Hardware

Station Emulation
Emulate 1000s of highly realistic wired and wireless LAN stations

AP Emulation
Emulate 100s of Access Points

Network Elements
DHCP servers, Virtual Bridges, Virtual Routers, SIP Servers, Radius Servers

WAN Emulation
Create network errors, delays, packet duplication, packet re-ordering

Traffic Generation
Native LANforge traffic, VOIP, TCP, UDP, Real Application traffic, iPerf Integration

Monitoring
Real-time packet wired and wireless packet capturing and statistics

Signal Generation
Random noise, WiFi Packet Generation

WiFi TEST HARDWARE

CT-521b

2-radio 802.11a/b/g/n/ac 3x3 MIMO – Low end system (Max throughput 300 Mbps)

CT-522

2-radio 802.11a/b/g/n/ac 3x3 MIMO – 264 stations

CT-523b

3-radios 802/11a/b/g/n/ac 4x4 MIMO – 600 stations, 24 APs, 2 Ethernet

CT-523c

4 radios 802.11ab/g/n/ac 4x4 MIMO, 10G Ethernet ports – Latest Addition

CT-525

6 radios 802.11a/b/g/n/ac 4x4 MIMO– upto1200 stations, 6 Ethernet Ports, 48 APs

WiFi TEST ACCESSORIES

RF Enclosures

80dB+ Isolation, Multiple sizes, A/C power, 16x SMAs, 3x 10GE, 2x USB, Fan, supports all WiFi Channels

Programmable Attenuator

0-95dBm attenuation, 0.5dB steps, 0.7-6 GHz

Radar Signal Generator

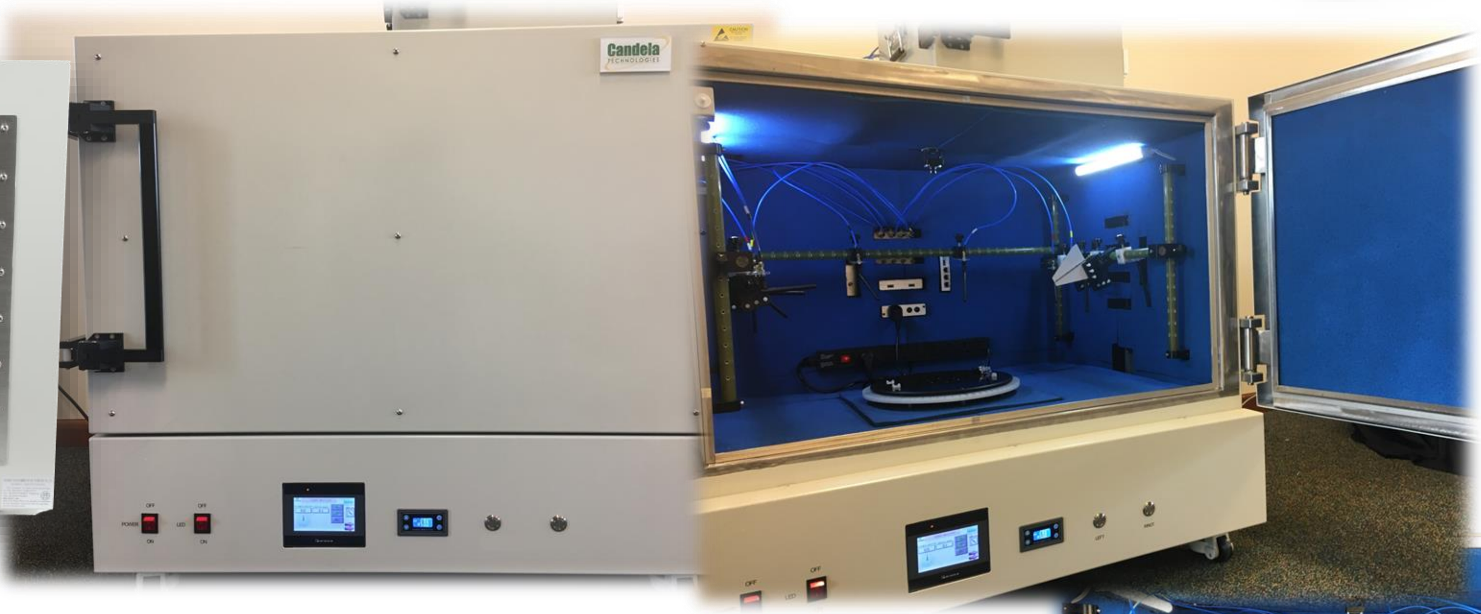
Radar Pulses, Noise and Signal Generation, All WiFi channels supported.

Cables, Splitters, Antennas, Adapters

Semi-flexible RF cables (various sizes), 4x1, 2x1 and 8x2 splitter, all varieties of adapters and antennas

Candela RF Enclosures

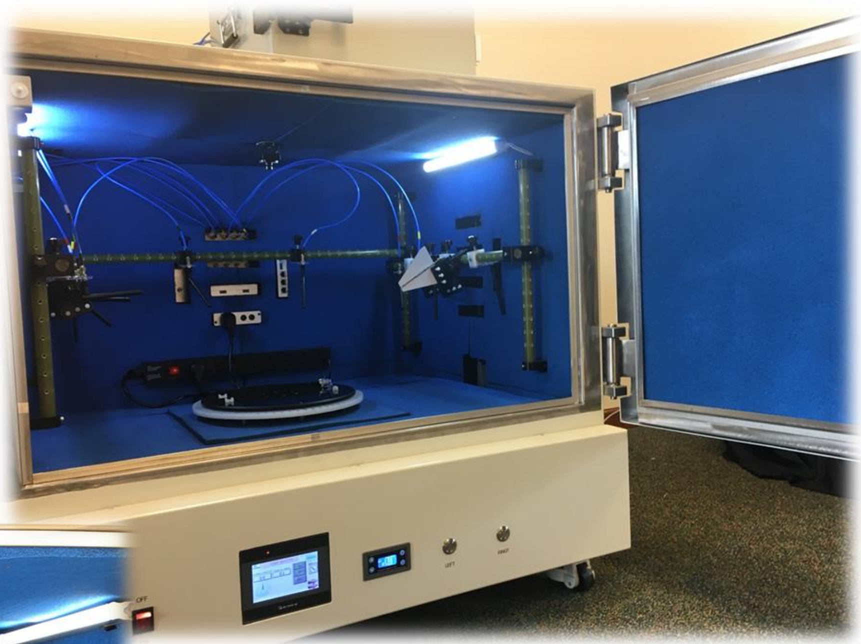
CT820a
Medium RF
Enclosure

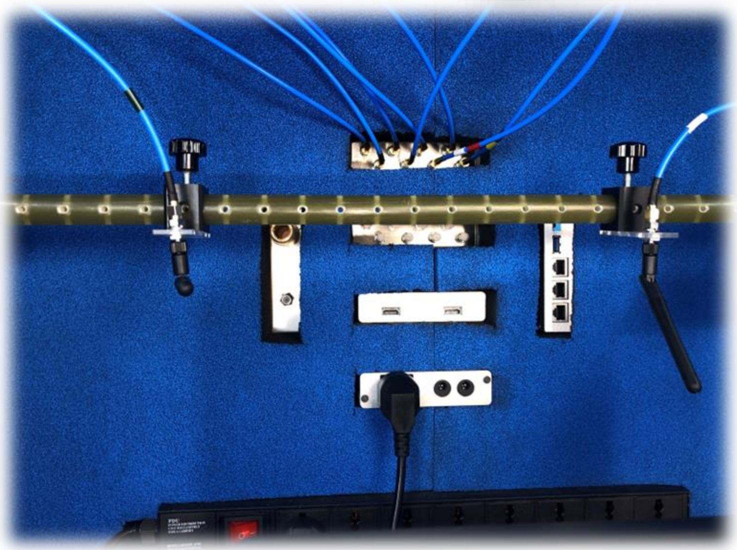


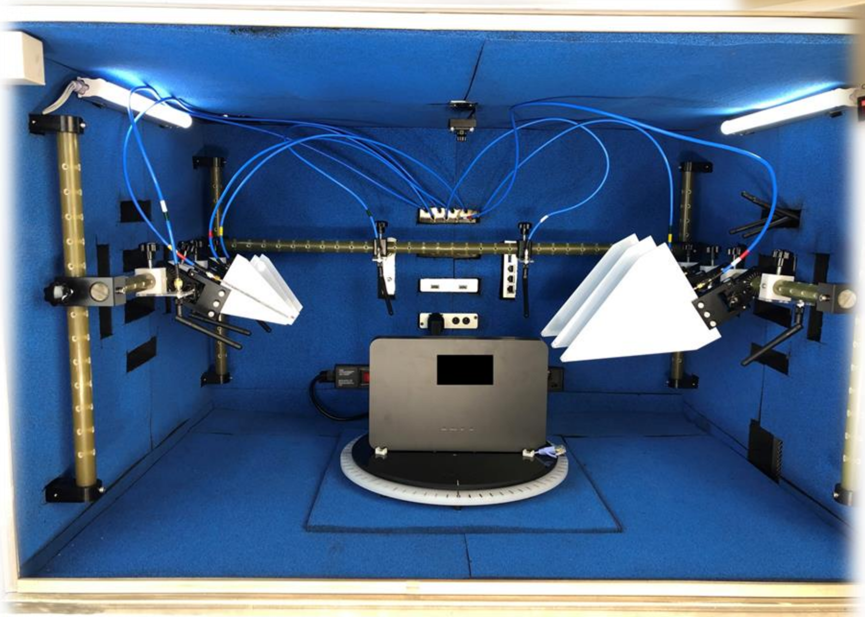
CT840a
Large RF
Enclosure-2D

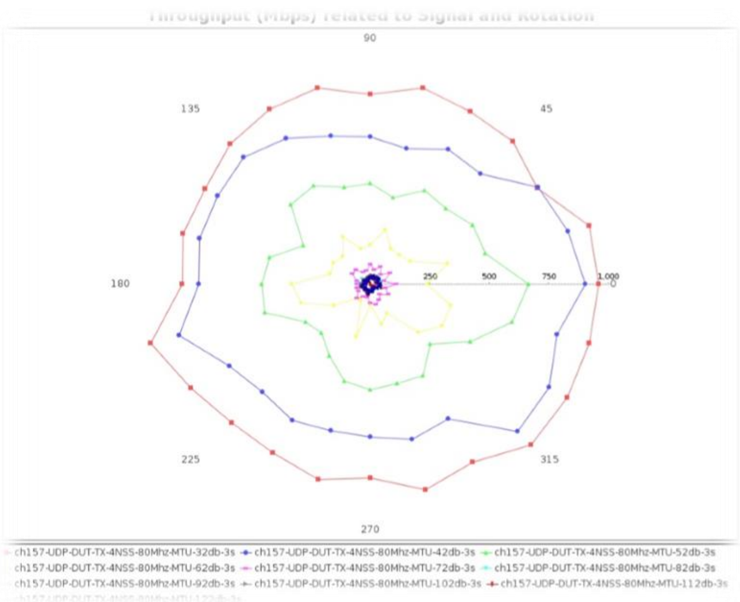
CT810a
Small RF
Enclosure

Chamber with Turntable









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