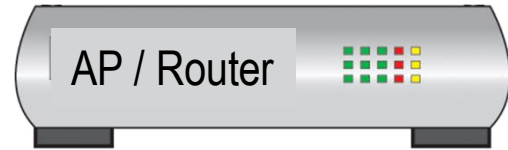




Lecture 1: Introduction to Wireless Test Metrics

A lecture series by octoScope
24-May-2016

Types of Wireless Tests



Performance

- Receiver performance
- Forwarding rate
- Association capacity
- Throughput
- Packet Error Rate (PER)
- Jitter

Behavior

- Roaming
- Data rate / MCS Adaptation
- Automatic Channel Selection
- Channel Width Adaptation
- Dynamic Frequency Selection (DFS)

System

- Interoperability
- Coexistence
- Mesh Self-forming / Self-healing

Wireless Test Standards



2G/3G/LTE	Wi-Fi	Data transport	Applications
3GPP RAN5 →ETSI →PTCRB/GCF (conformance, interoperability)	Wi-Fi Alliance (WMM, WPA, etc.)	IETF RFC 2285, 2544, 2889 (packet loss, latency, jitter)	ITU-T Voice Quality P.800 (MOS); P.862 (PESQ); G.107 (R- Factor)
CTIA (TIS/TRP MIMO-OTA SAR)	IEEE 802.11.2 (range, throughput, latency)		IETF video quality RFC 4445 (MDI MLR, DF)

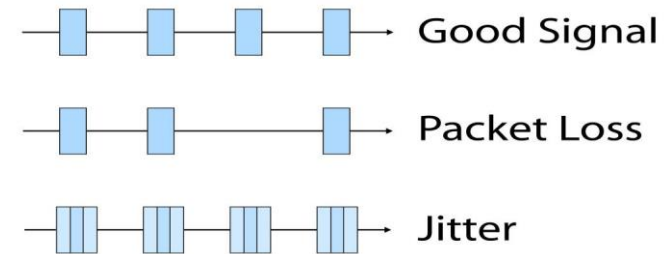
3GPP = 3rd generation partnership project
 RAN = radio access network
 IETF = internet engineering task force
 RFC = request for comments
 GCF = global certification forum
 ITU = international telecommunication union
 ETSI = European Telecommunications Standards Institute
 CTIA = cellular telecommunications internet association

TIS = total isotropic sensitivity
 TRP = total radiated power
 MIMO = multiple input multiple output
 OTA = over the air
 SAR = specific absorption ratio
 WMM = wireless multimedia
 WPA = wireless protected access

NIST = national institute of standard and technology
 SEP = smart energy profile
 MOS = mean opinion score
 PESQ = perceptual speech quality measure
 R-Factor = rating factor
 MDI = Media Delivery Index
 MLR = media loss rate
 DF = delay factor

Voice over Wi-Fi Considerations

- Important to maintain isochronous nature of voice packet streams by controlling delay, jitter and packet loss
- Bursty packet loss due to
 - Roaming
 - Interference from LTE-U or LTE-LAA
- Power consumption – sleep modes
 - APSD (automatic power save delivery)
 - PSMP (power save multi-poll) protocol
- WFA WMM (wireless multi-media) prioritization protocol



IEEE 802.11.2 Performance Test Specification

Defines test methods and metrics for evaluating performance of 802.11 devices and systems

IEEE P802.11.2/D1.01, February 2008

IEEE P802.11.2TM /D1.01


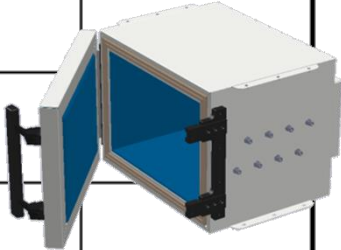
***Draft Recommended Practice for the
Evaluation of 802.11 Wireless
Performance***

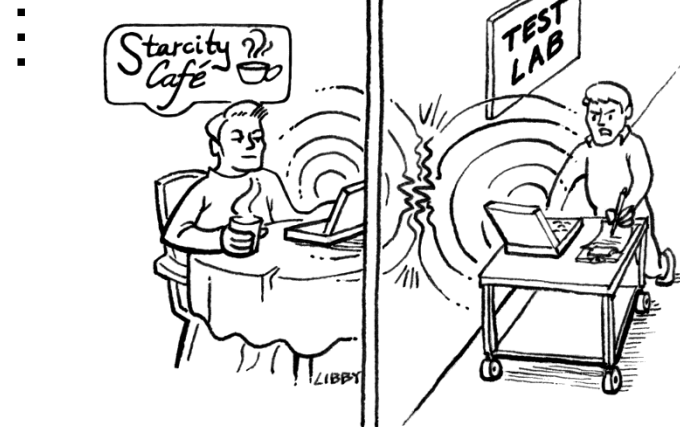
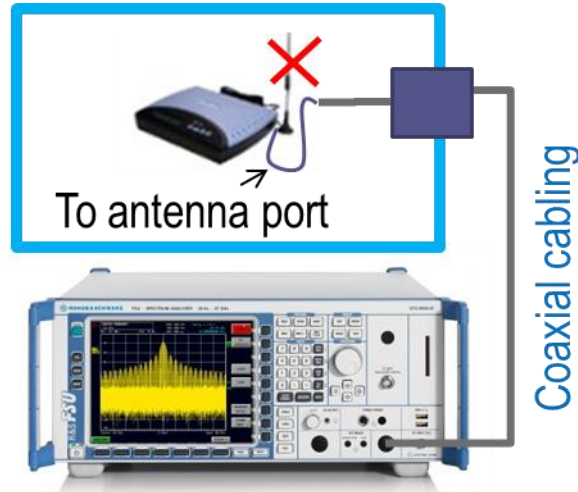
Example 802.11.2 Metrics

- Throughput: overall
- Throughput vs. range
- Throughput vs. attenuation (conducted and OTA)
- Throughput vs. receive power
- Transmit rate adaptation
- Antenna diversity
- Adjacent channel interference
- BSS transition time
- Fast BSS transition time
- Receiver sensitivity in a conducted environment
- Unicast intra-BSS throughput
- Unicast ESS throughput
- Multicast forwarding rate
- Endstation association rate
- Endstation database capacity
- Power consumption
- Coexistence of overlapping BSSs in an OTA environment
- Packet loss
- Latency
- Jitter
- Video performance

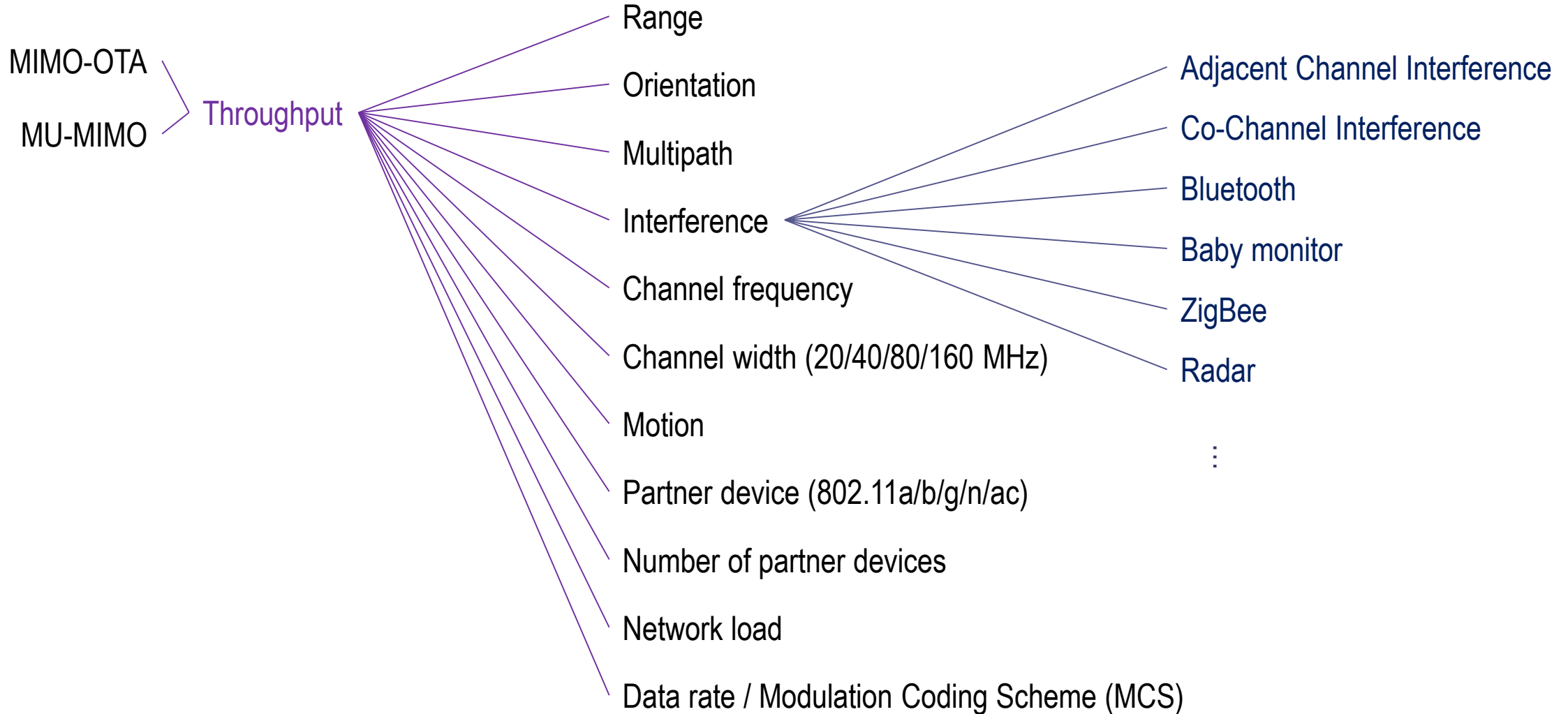
802.11.2 Metrics vs. Test Environments

Table 1—Cross-reference of metrics and environments (continued)

Metric	Conducted test environment	Calibrated over the air test (COAT)	Over the air outdoor LOS	Over the air indoor NLOS	Over the air indoor LOS	Over the air shielded enclosure
Transmit rate adaptation	Y					
Antenna diversity	Y					
Adjacent channel interference	Y					



Throughput



MIMO = multiple input multiple output
MU-MIMO = multi-user MIMO

Forwarding Rate

Forwarding rate

Range

Orientation

Multipath

Interference

Channel frequency

Channel width (20/40/80/160 MHz)

Motion

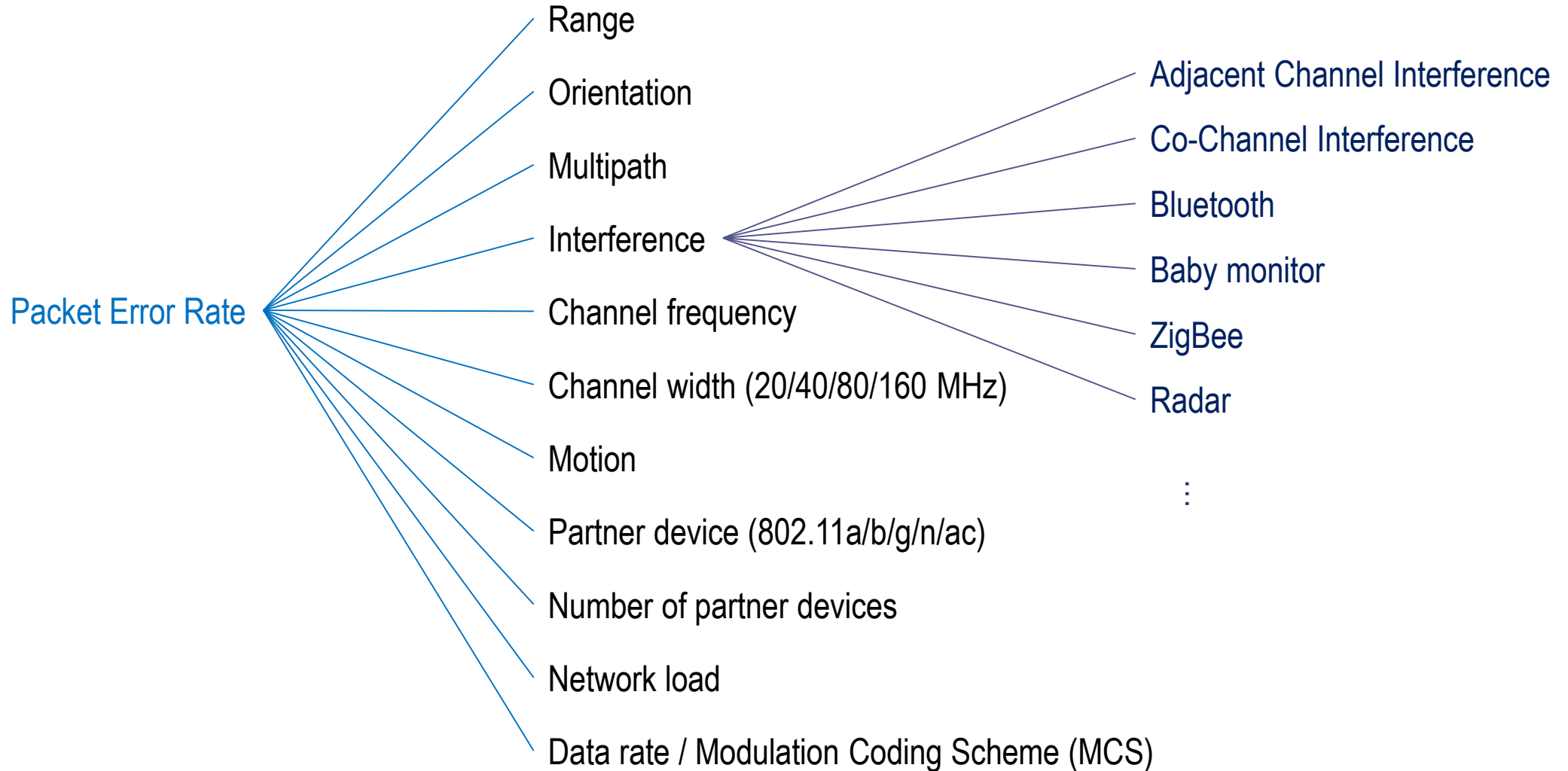
Partner device (802.11a/b/g/n/ac)

Number of partner devices

Network load

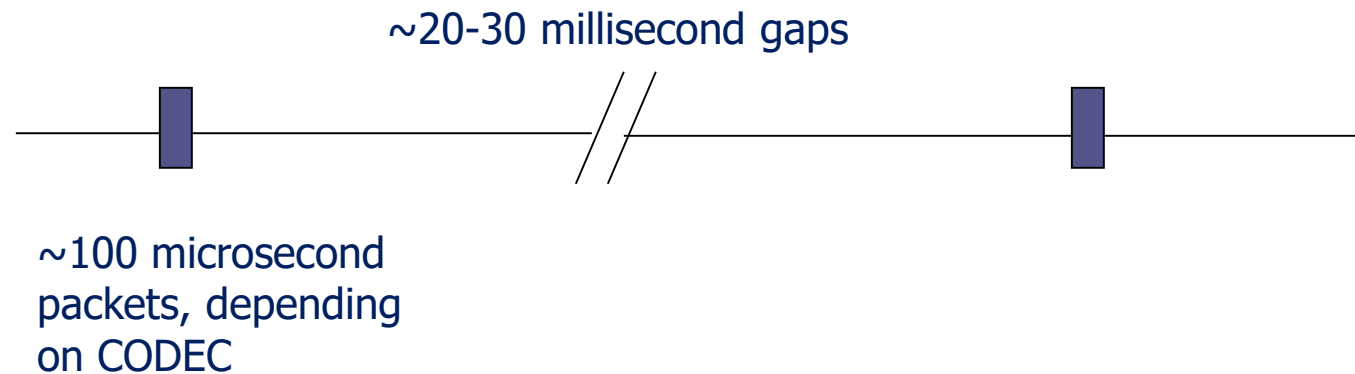
Data rate / Modulation Coding Scheme (MCS)

Packet Error Rate

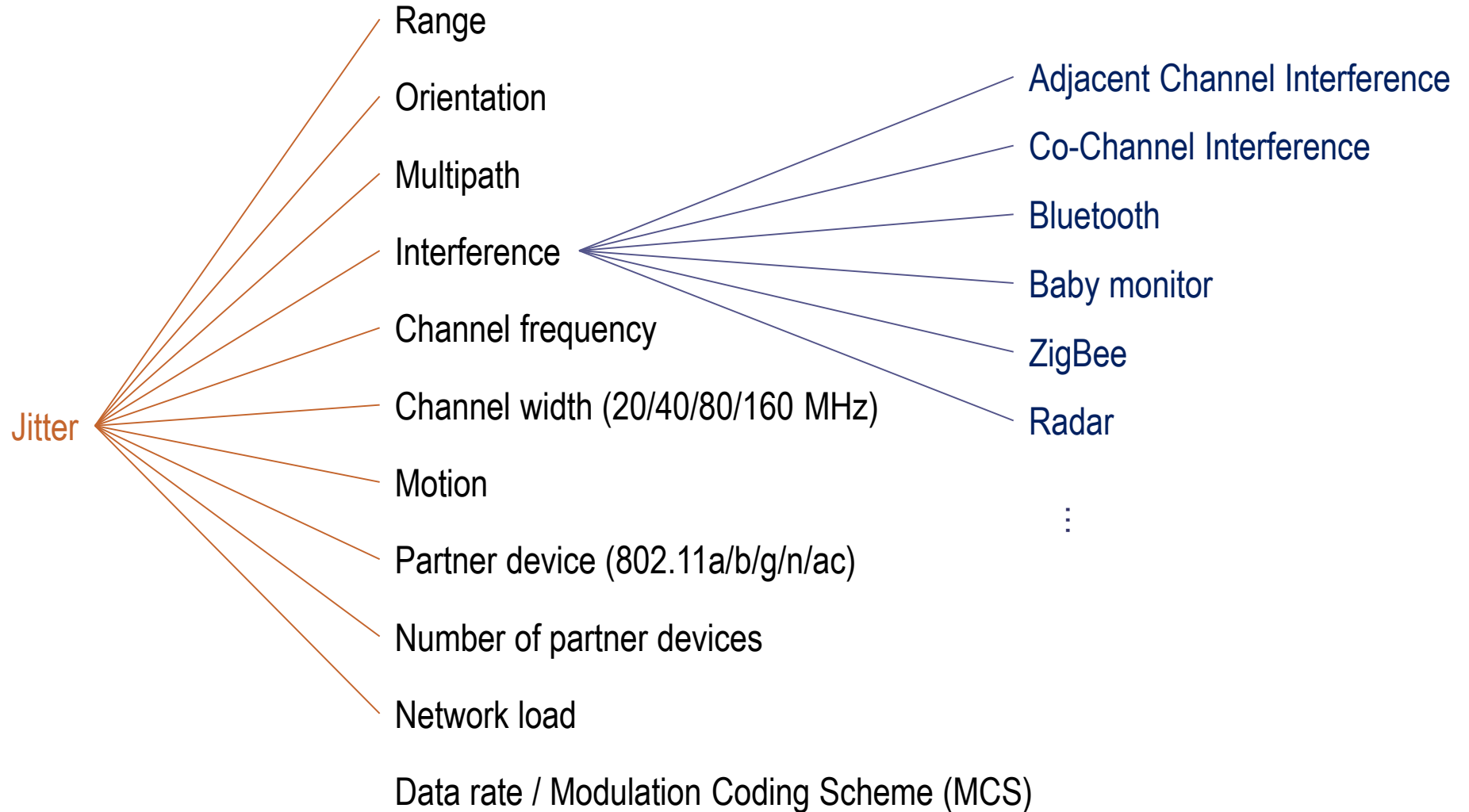


Packet Error Rate / Packet Loss Rate

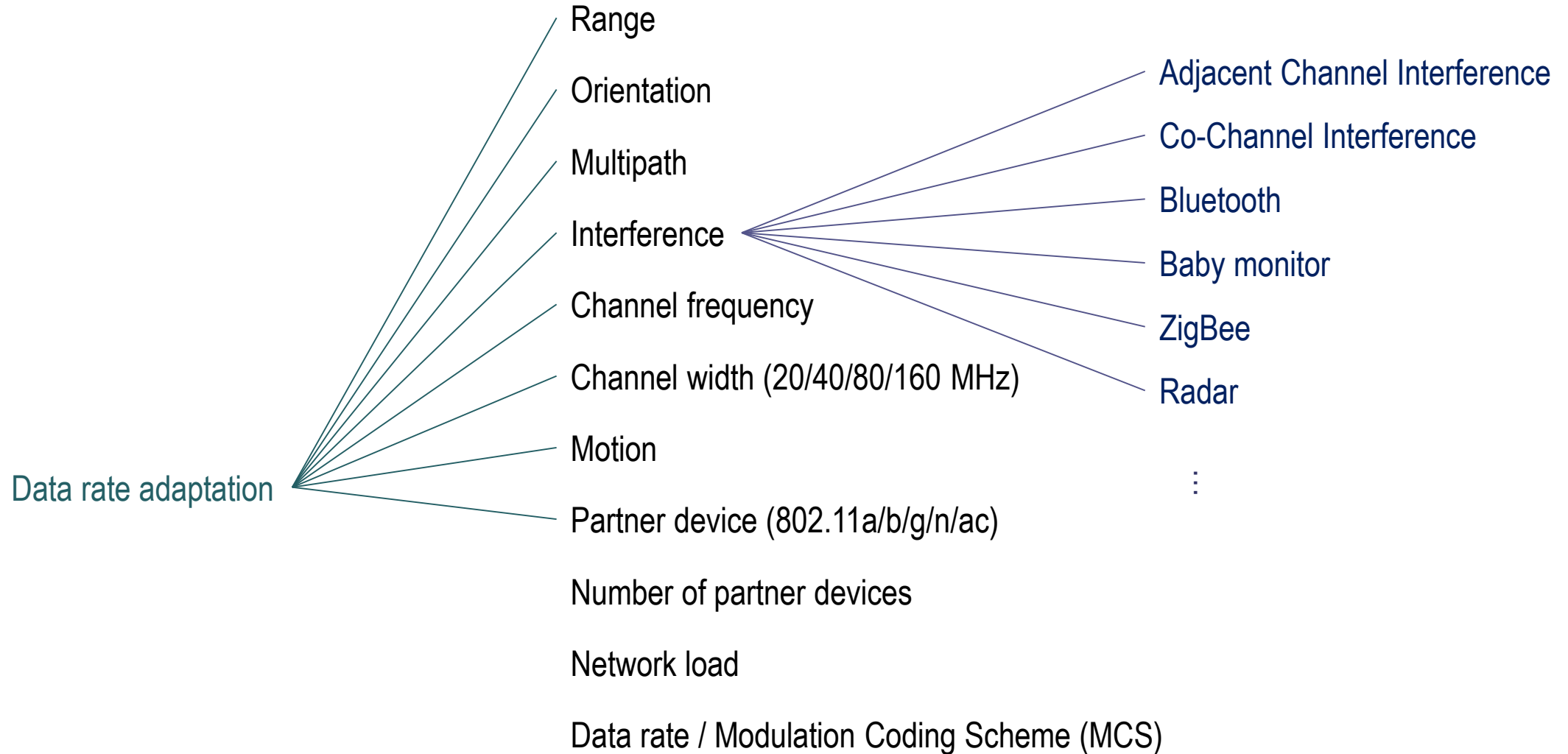
- Packet loss, especially bursty packet loss, causes poor signal quality
- Delay and jitter (variation in delay) can also cause loss of quality
- 200 ms events (signal loss or delay) are audible to the ear
- In 802.11 networks, bursty packet loss can be due to
 - Congestion in the infrastructure
 - Client roaming from one AP to another
 - Interference from LTE-U or LTE-LAA



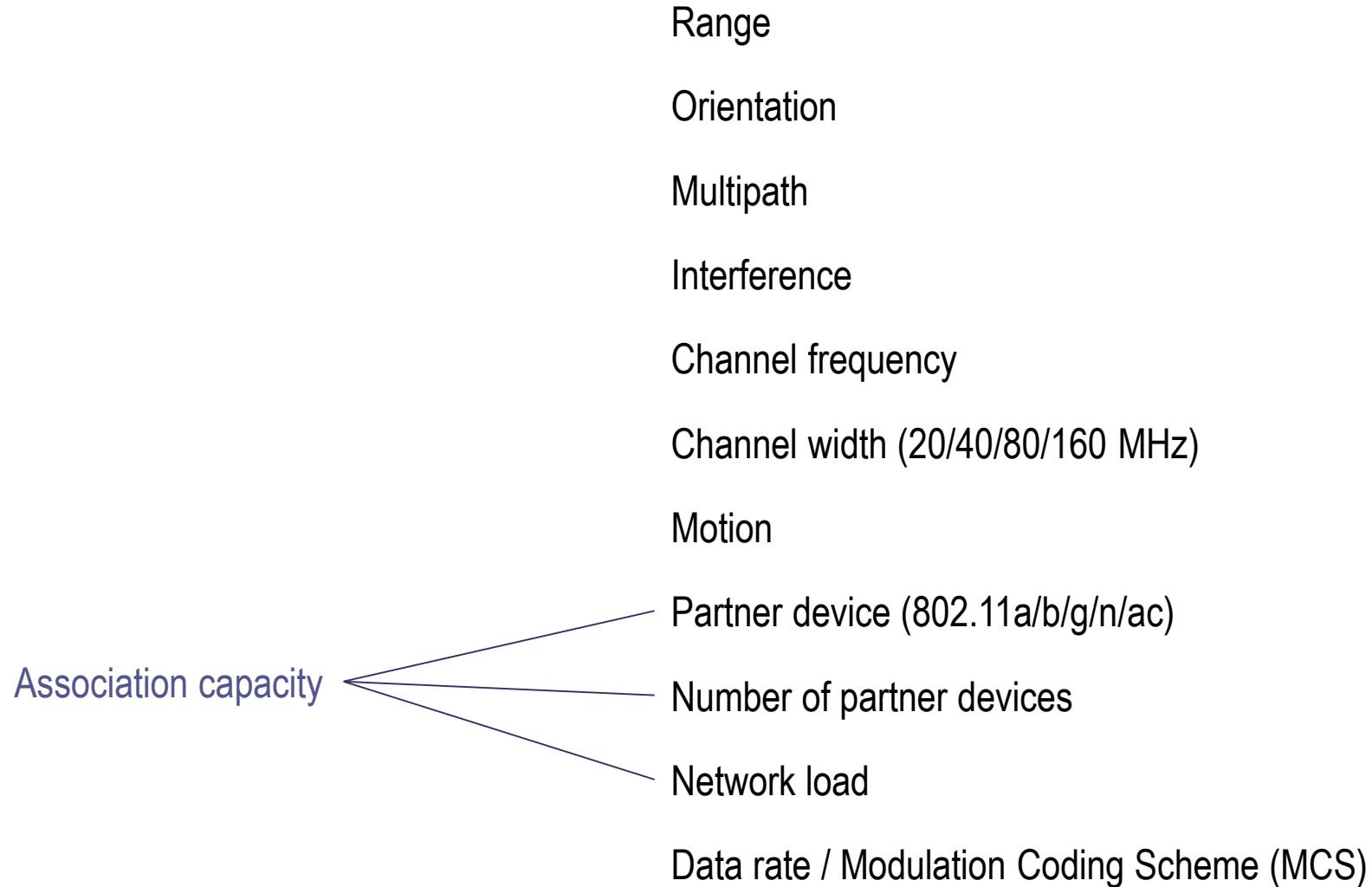
Jitter



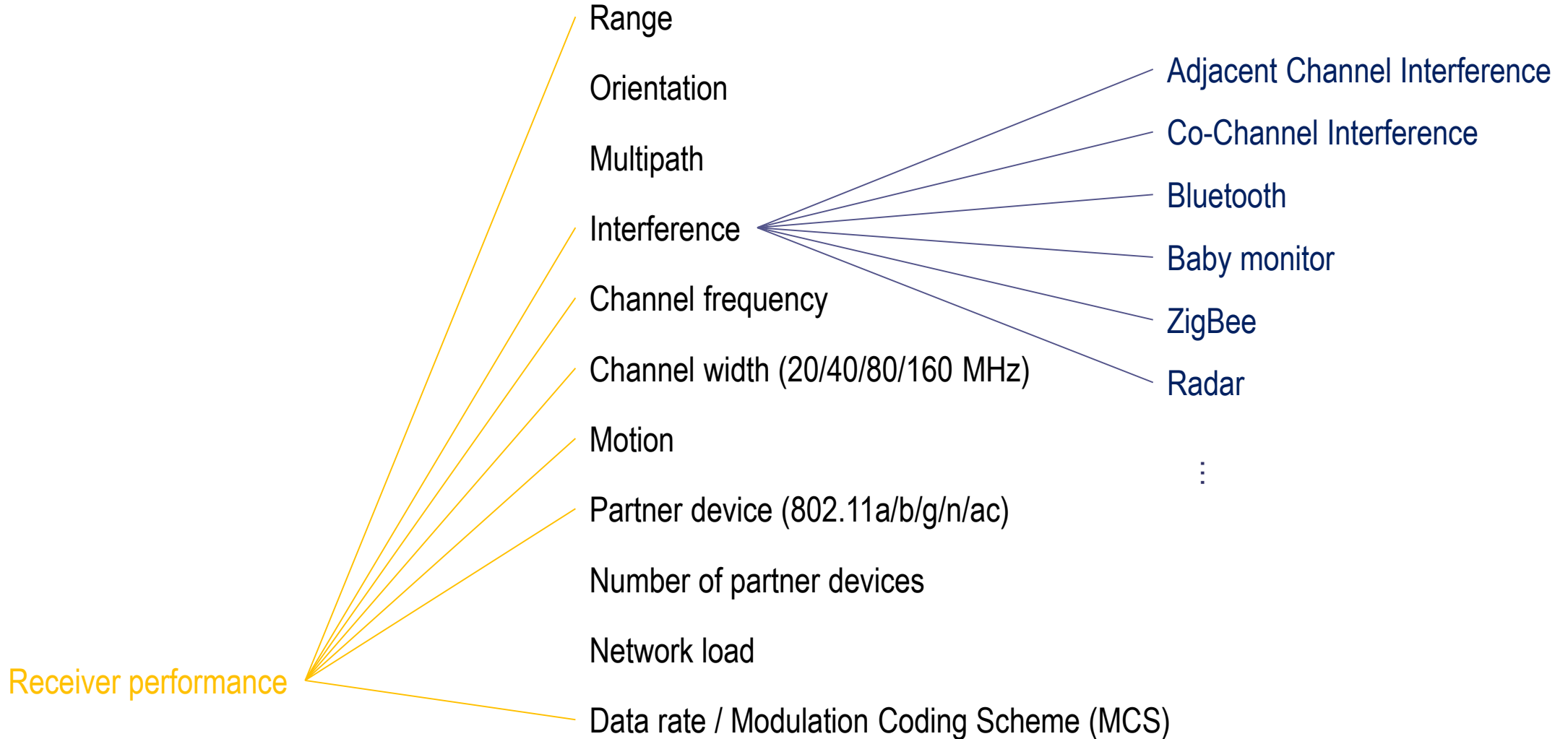
Data Rate Adaptation



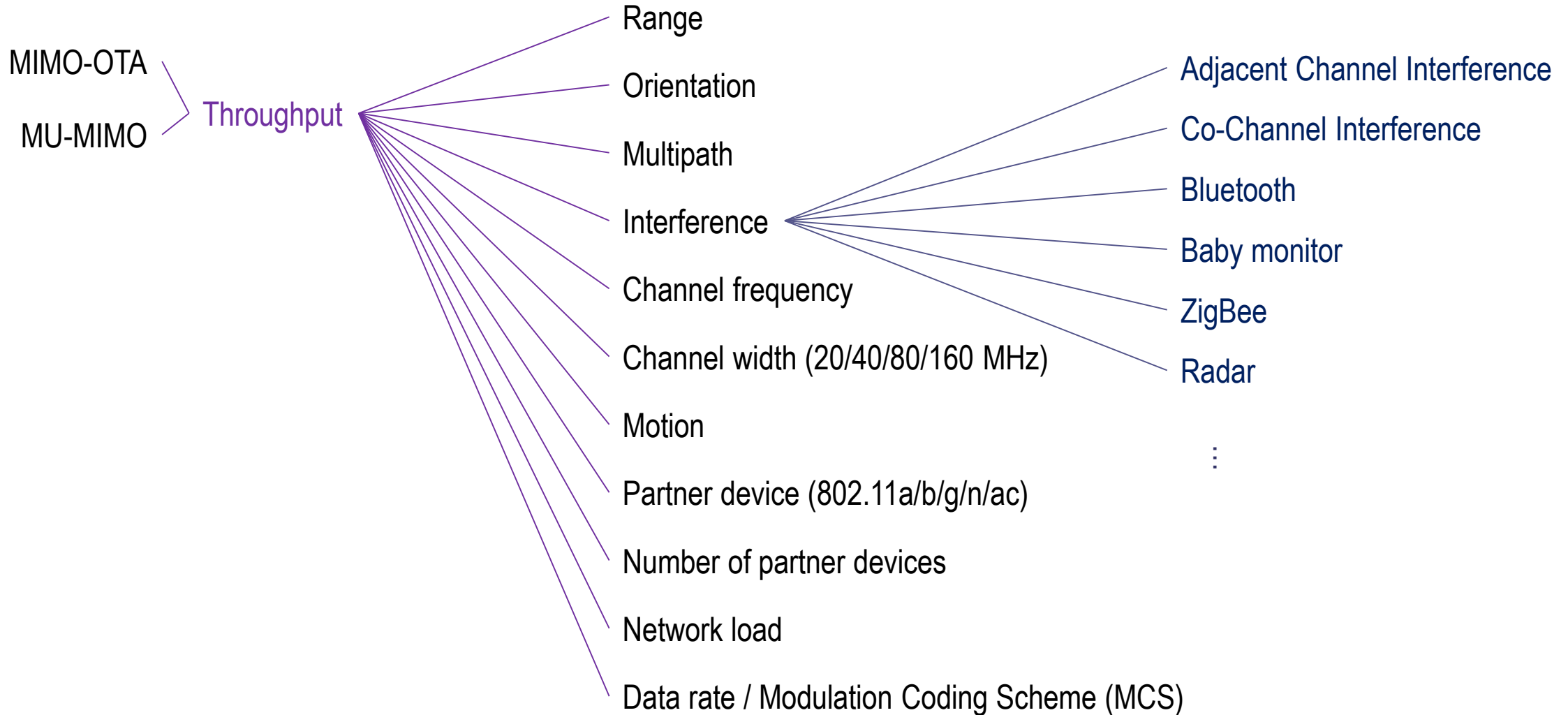
Association Capacity



Receiver Performance

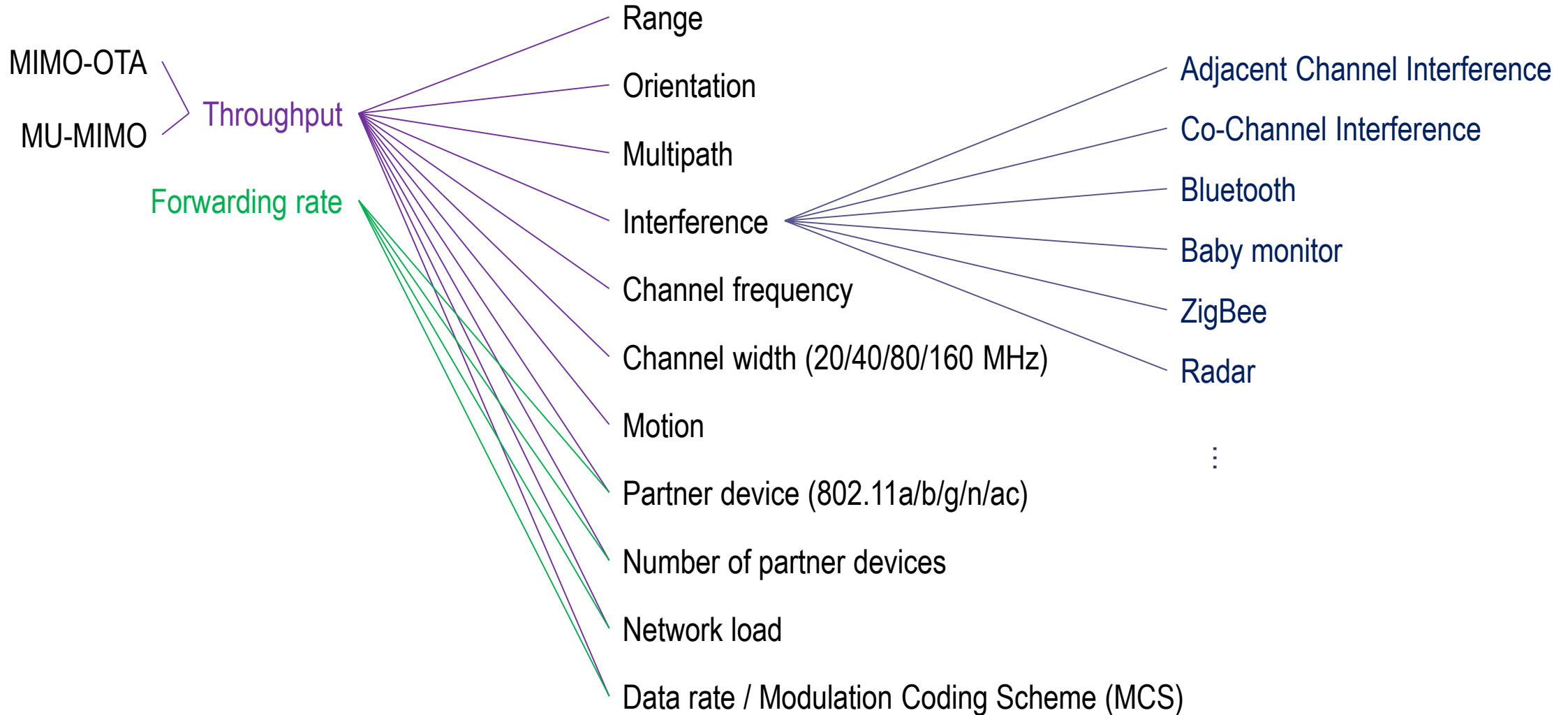


Comprehensive Test Suite



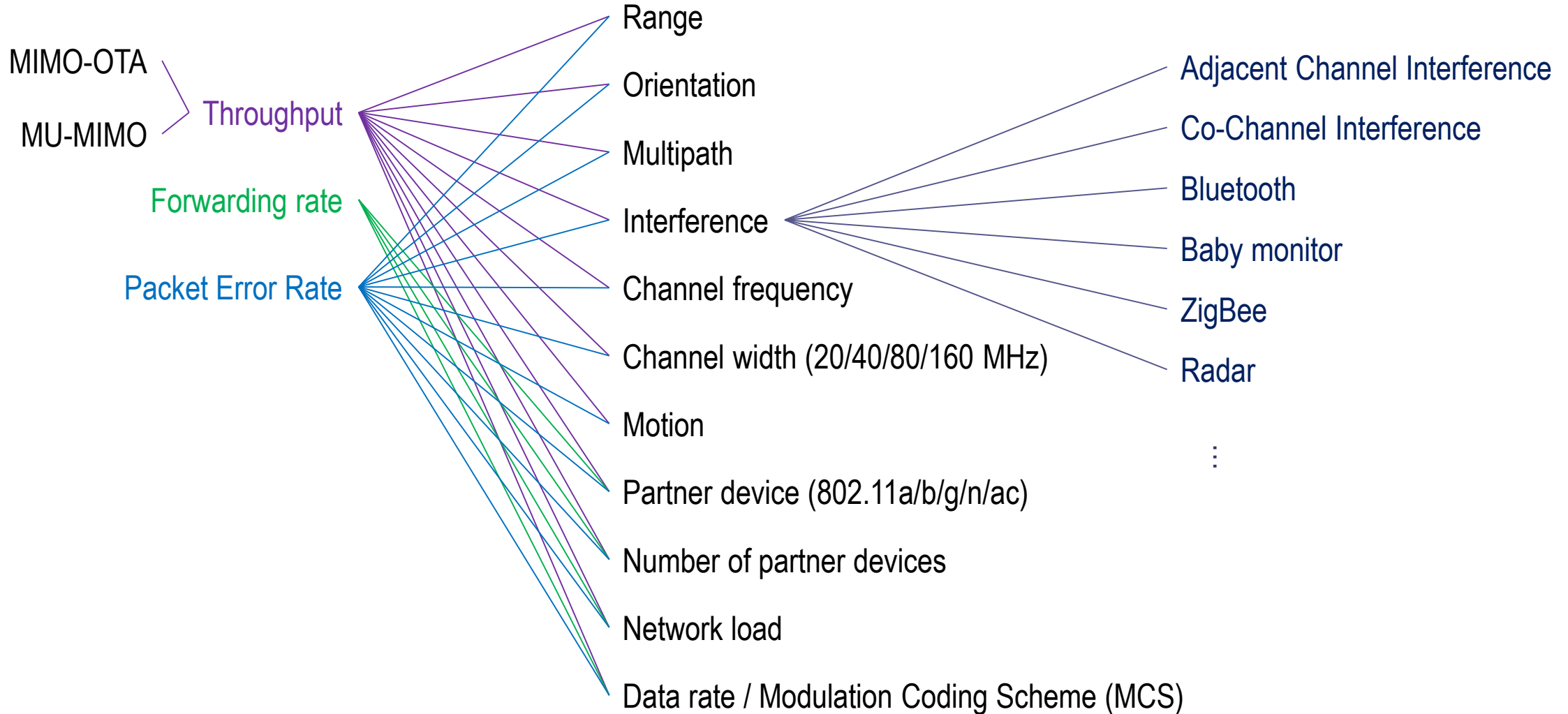
MIMO = multiple input multiple output
MU-MIMO = multi-user MIMO

Comprehensive Test Suite



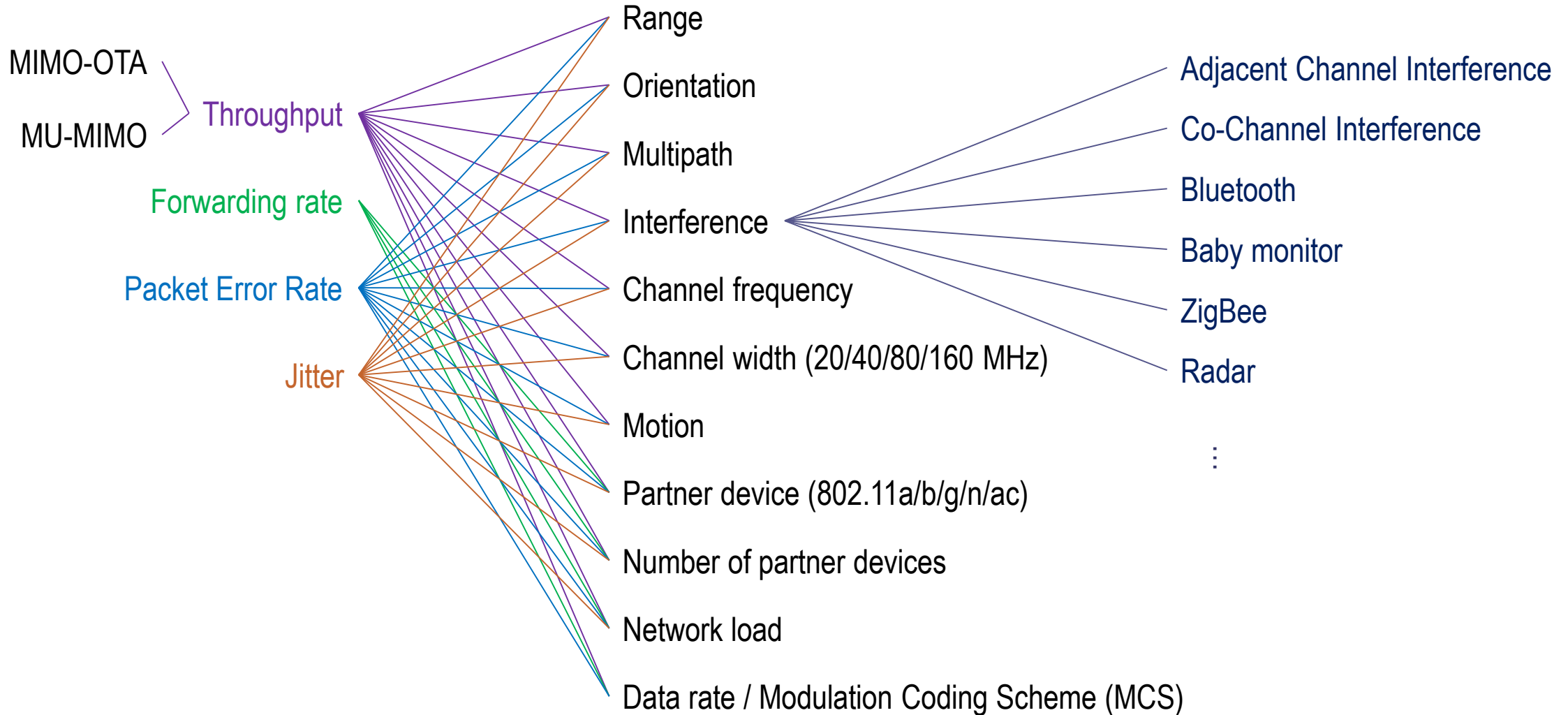
MIMO = multiple input multiple output
MU-MIMO = multi-user MIMO

Comprehensive Test Suite



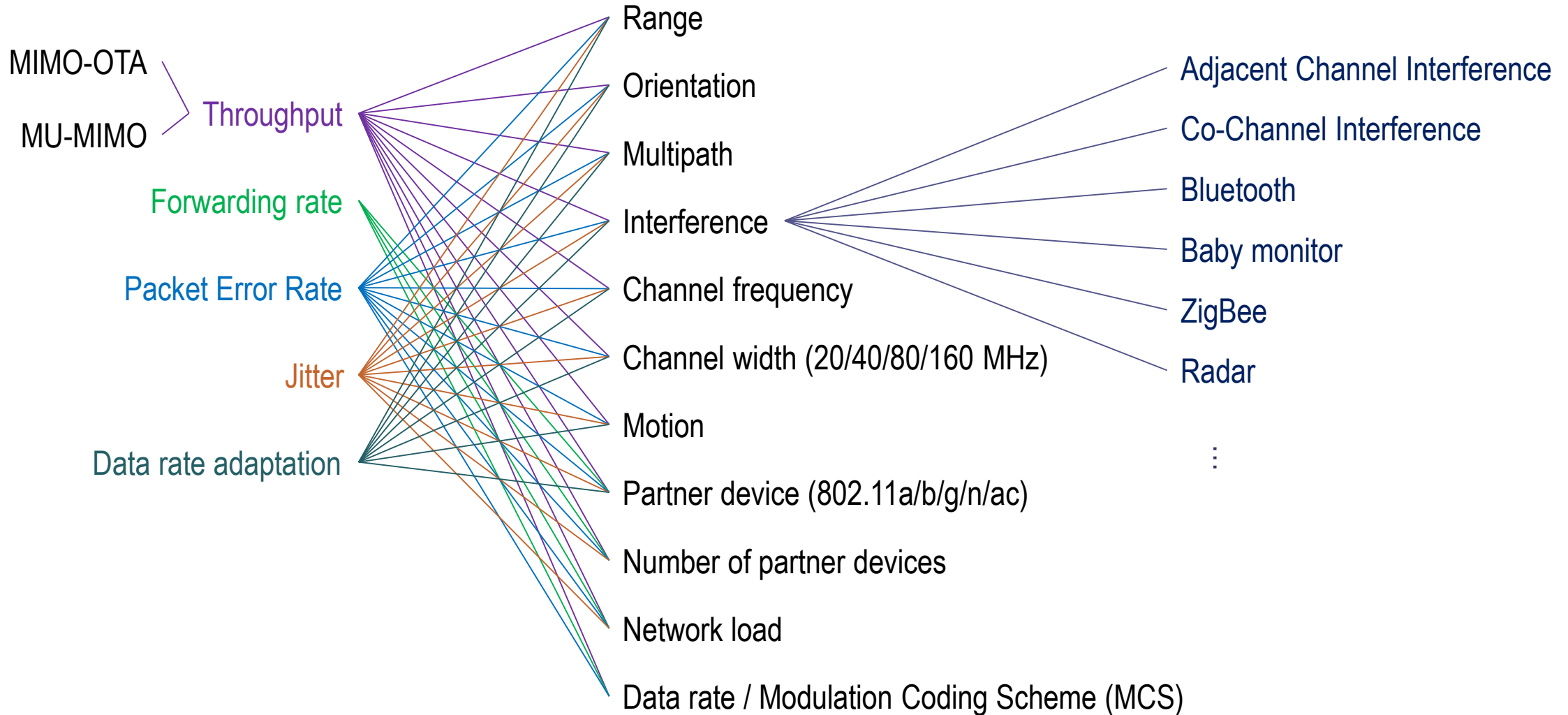
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Comprehensive Test Suite



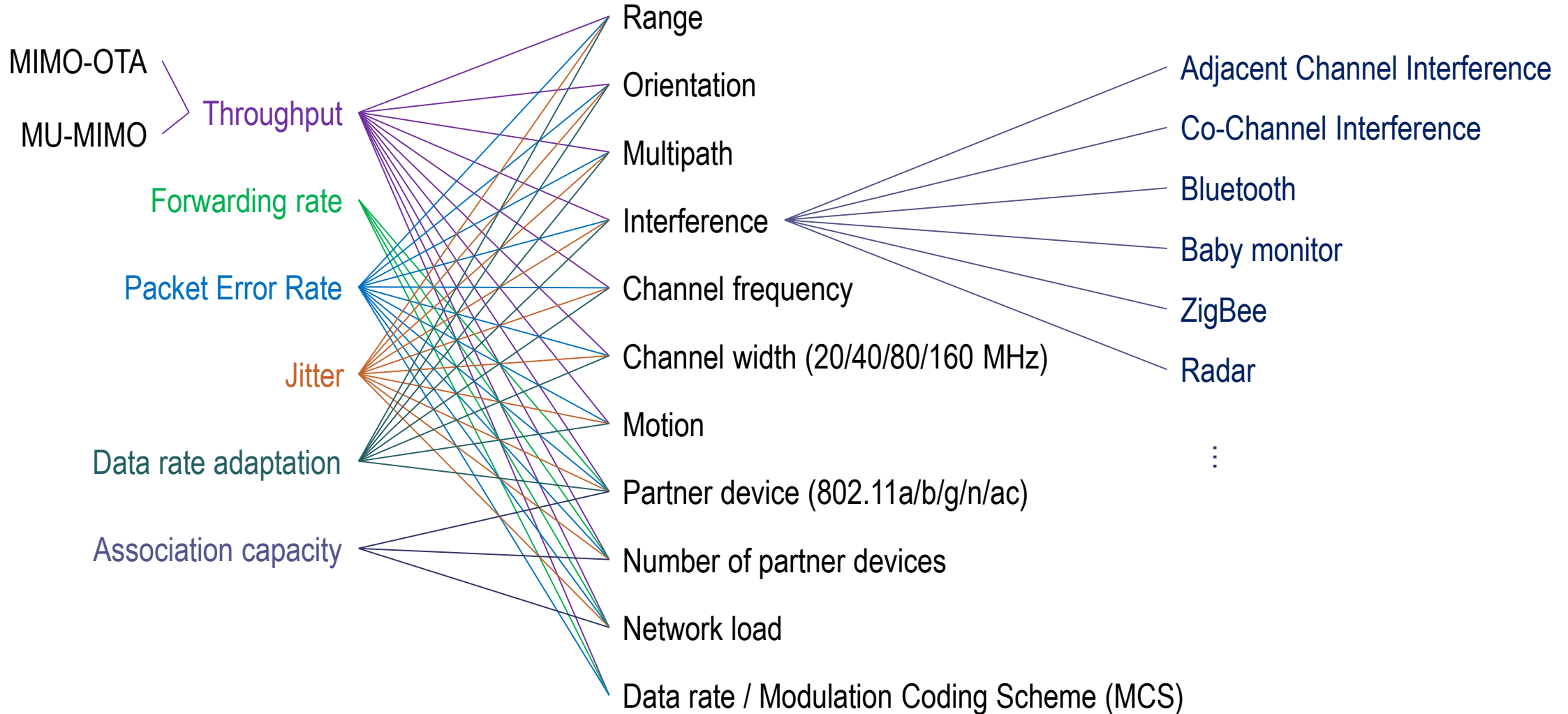
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Comprehensive Test Suite



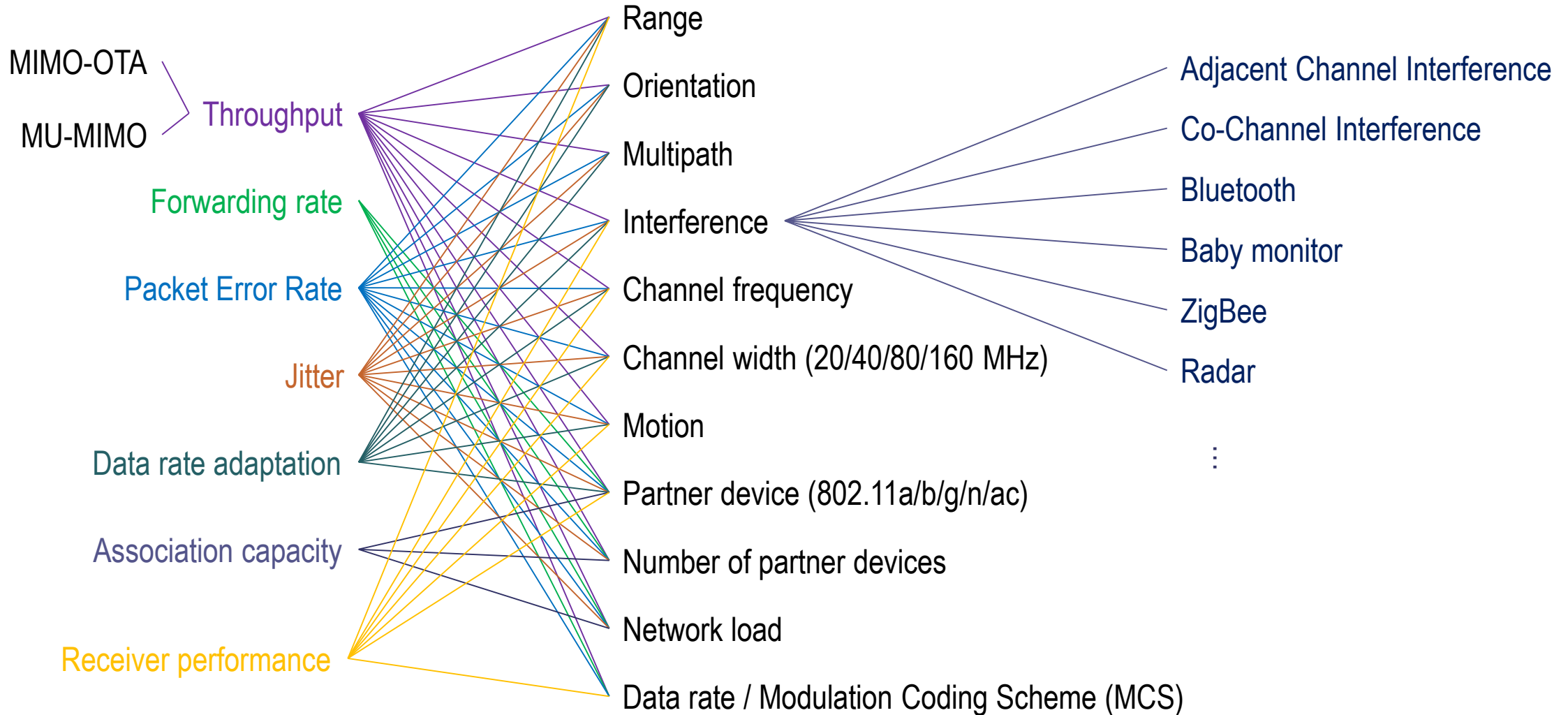
MIMO = multiple input multiple output
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Comprehensive Test Suite



MIMO = multiple input multiple output
 MU-MIMO = multi-user MIMO

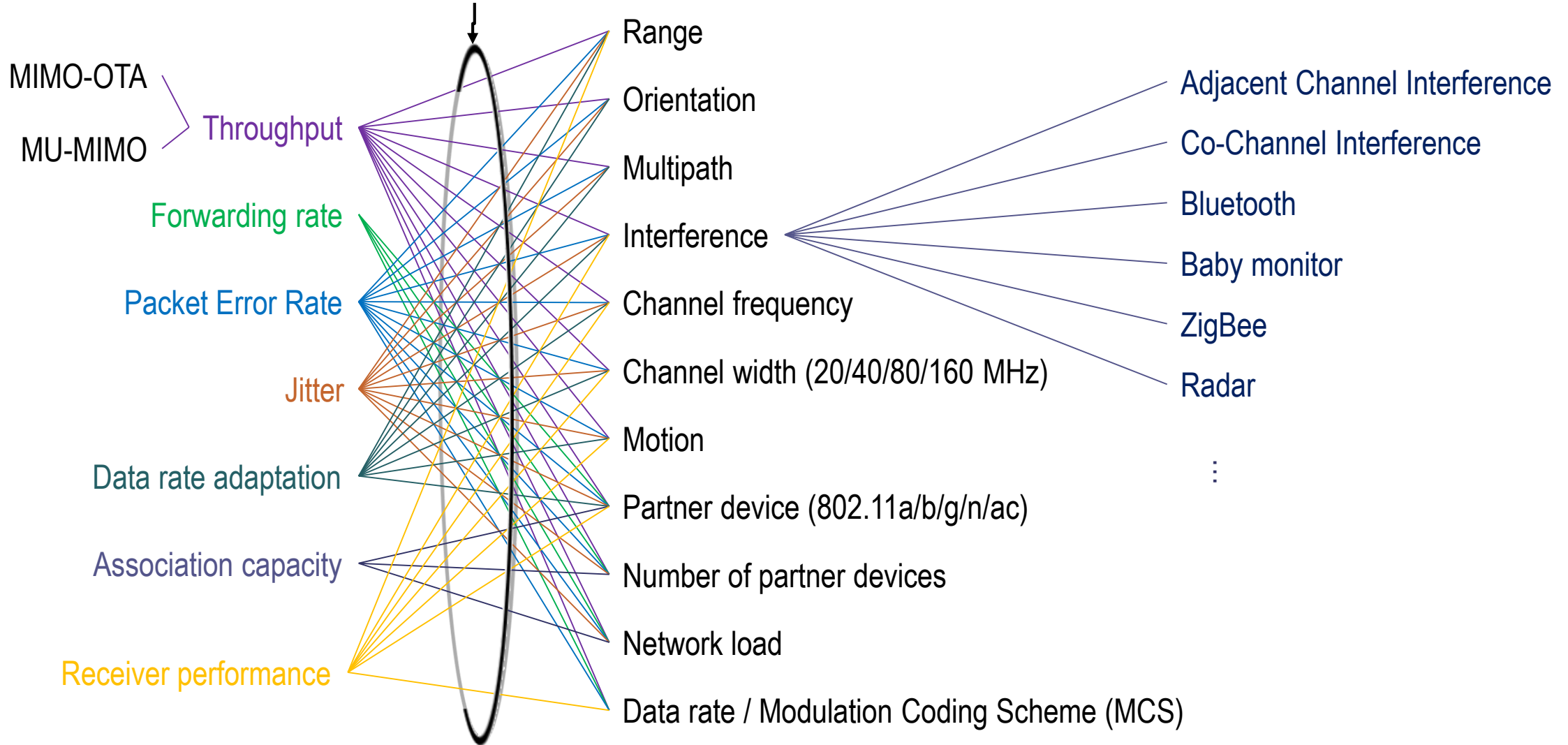
Comprehensive Test Suite



MIMO = multiple input multiple output
MU-MIMO = multi-user MIMO

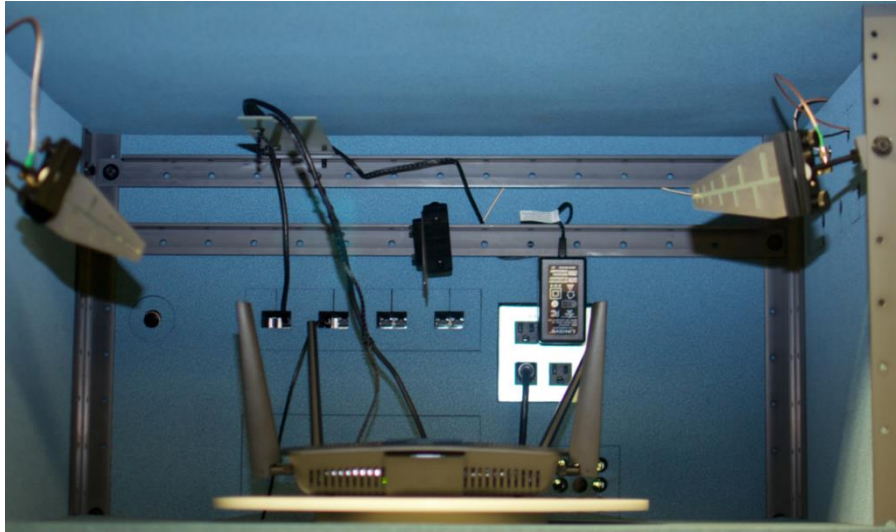
Need for Automation of Controlled RF Environment

Exponential number of tests vs. variables




MIMO = multiple input multiple output
 MU-MIMO = multi-user MIMO

Need for Controlled RF Environment



Windows
Linux
OS/X
Android



Traffic Endpoint



Range

Orientation

Multipath

Interference

Motion

Channel width (20/40/80/160 MHz)

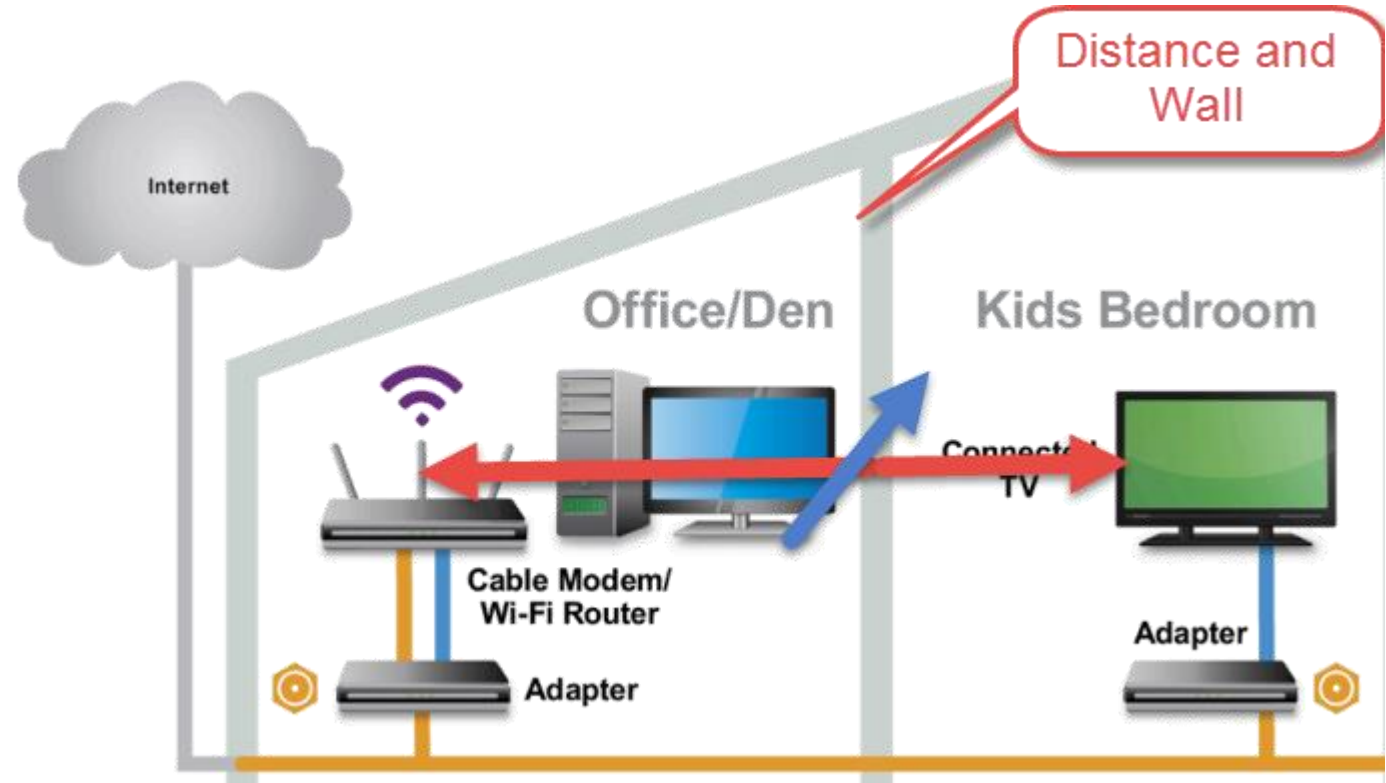
Channel frequency

Partner device (802.11a/b/g/n/ac)

Number of partner devices

Network load

Data rate / Modulation Coding Scheme (MCS)



Environment

Range

Orientation

Multipath

Interference

Motion

Channel width (20/40/80/160 MHz)

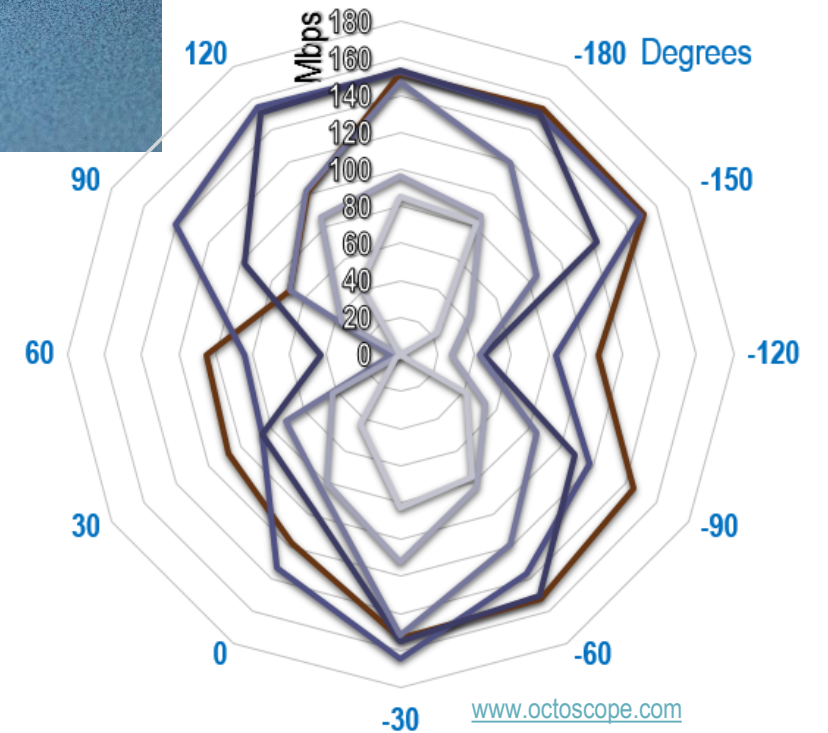
Channel frequency

Partner device

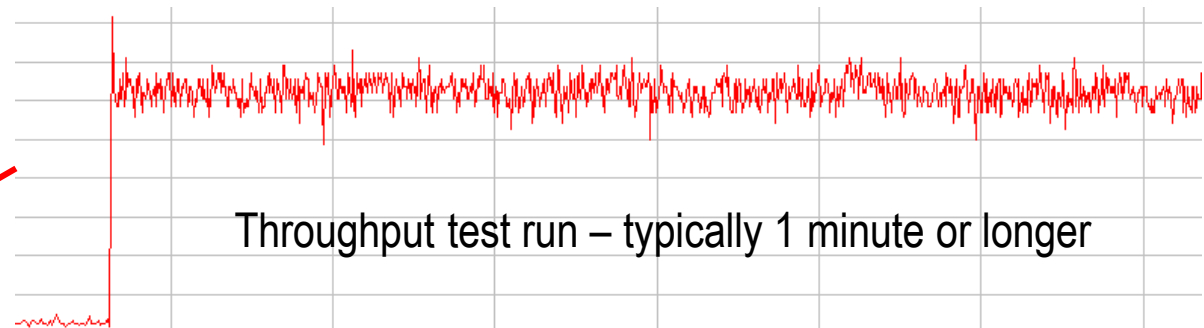
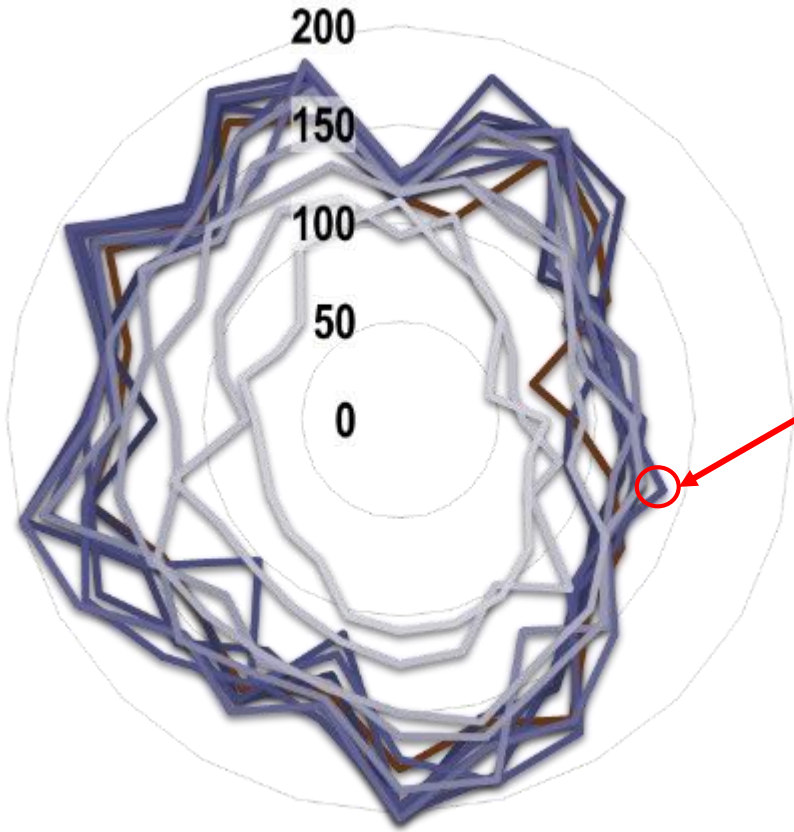
Number of partner devices

Network load

Data rate / Modulation Coding Scheme (MCS)

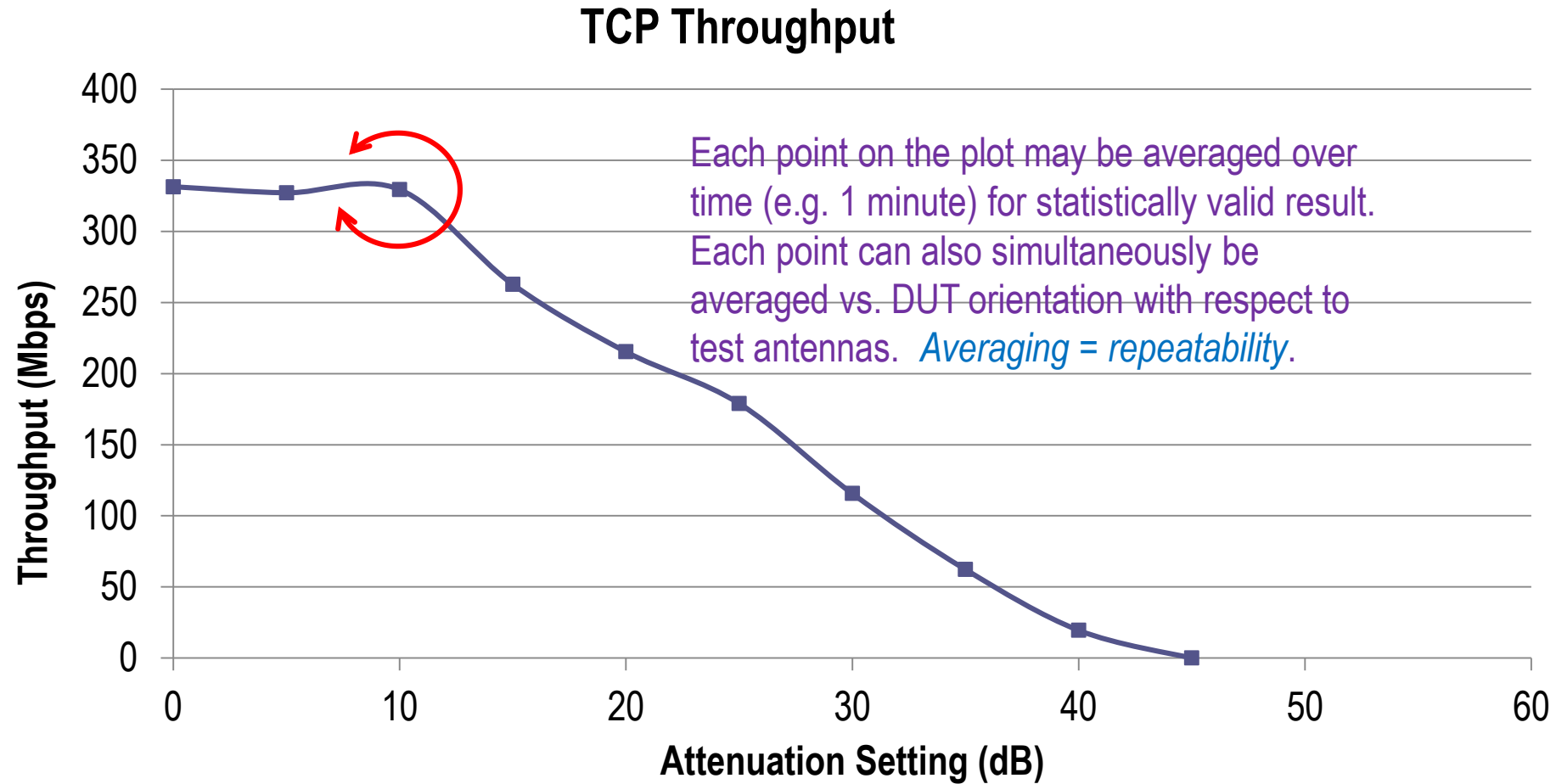


Each Throughput Test Run = 1 Point on The Excel Plot

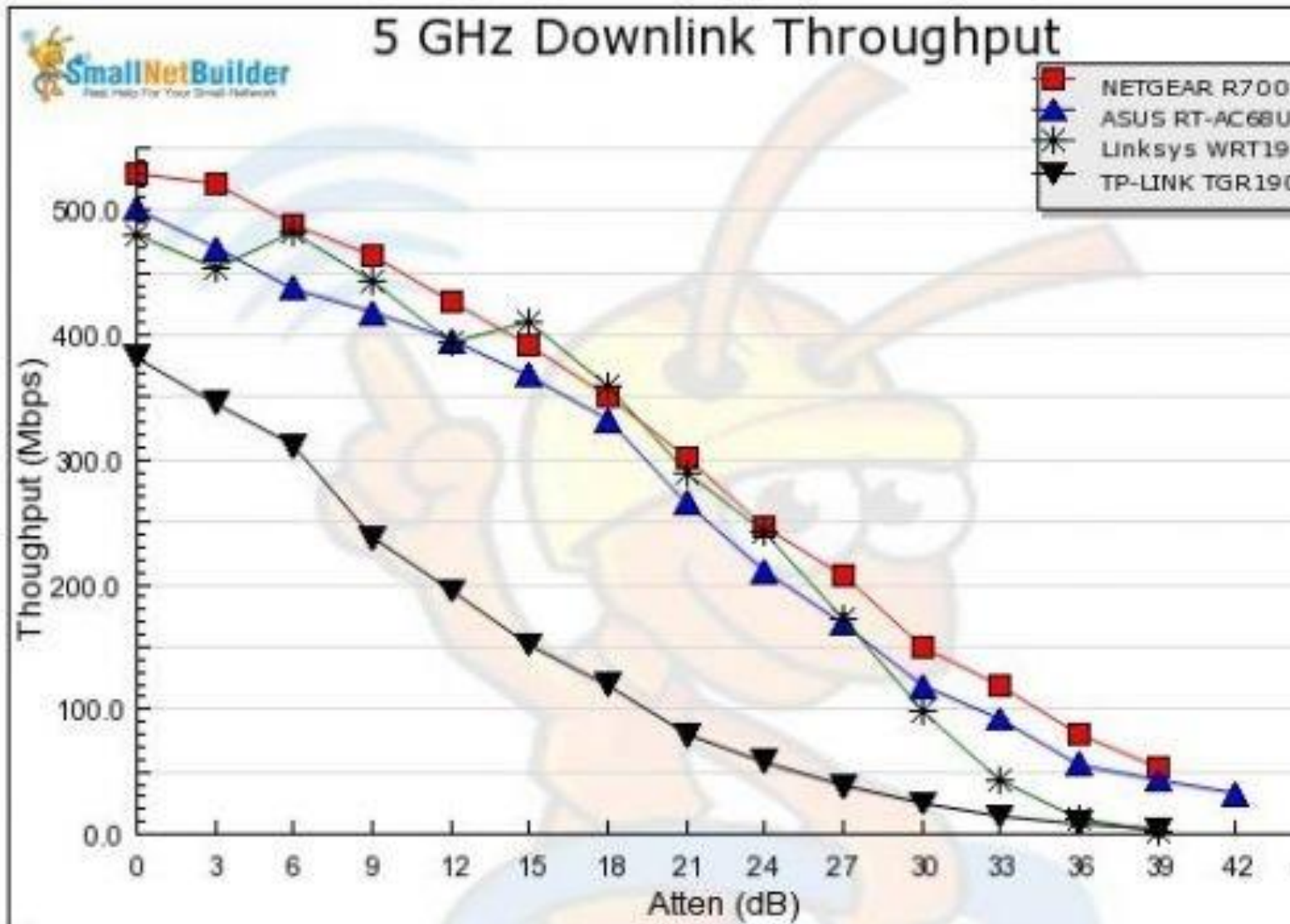


Typical run can have thousands of points. For example,
5 degree rotation * 1 dB attenuation = 4,320 points

Throughput vs. Range Plot



octoBox Industry Benchmark Test Platform



OnHub in test chamber

The Benchmark Summary below shows the average of throughput calculations.

Benchmark Summary
TP-LINK TGR1900
Google OnHub Router

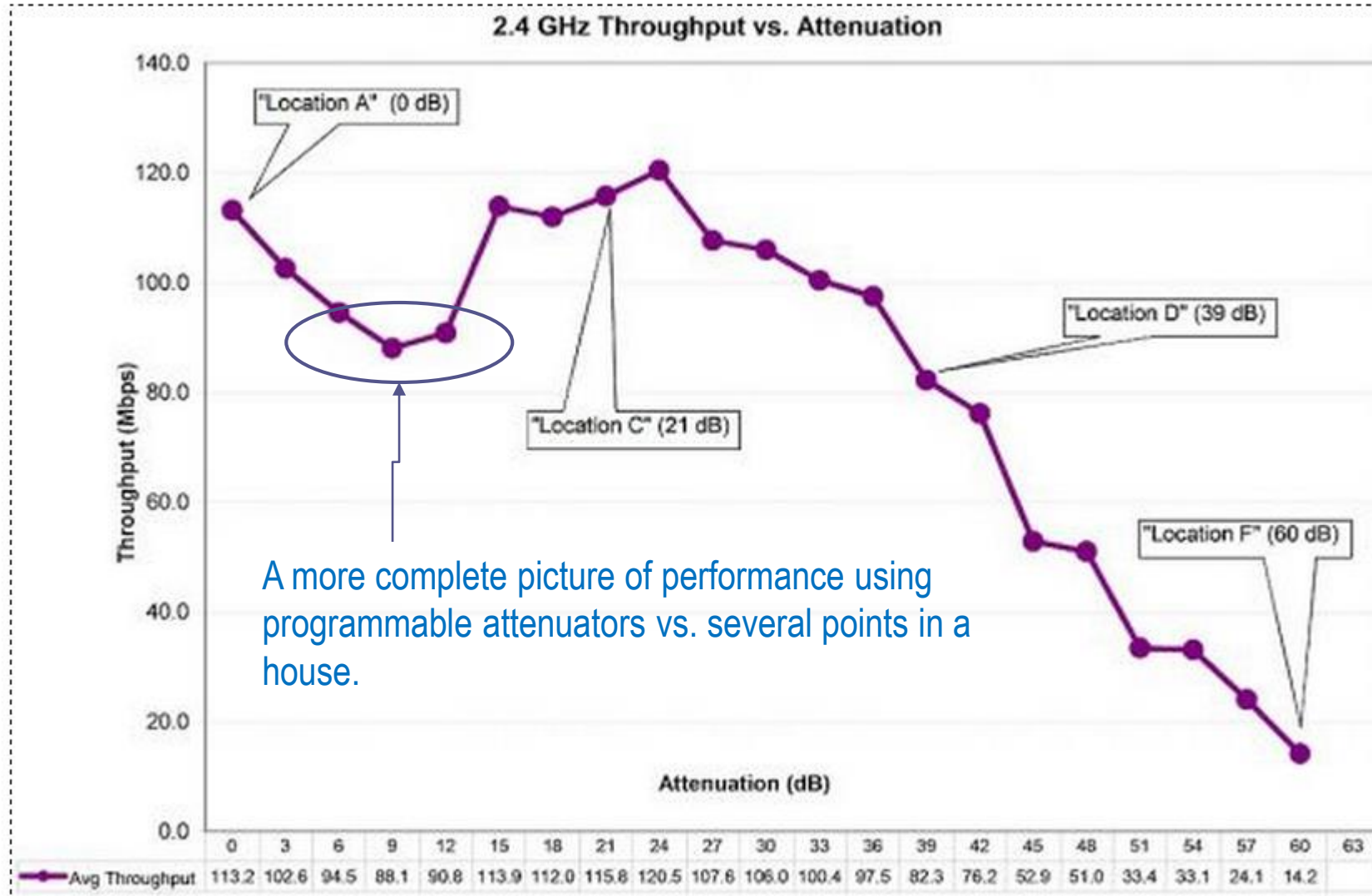
Test Notes:
 Firmware tested: 7077.122.4
 Test client: NETGEAR R7000 in client bridge mode (1.0.3.60 firmware)

LAN to WAN Throughput	817.2	<div style="width: 100%;"></div>
2.4 GHz Downlink	61.3	<div style="width: 10%;"></div>
2.4 GHz Uplink	67.9	<div style="width: 10%;"></div>
5 GHz Downlink	120.0	<div style="width: 15%;"></div>
5 GHz Uplink	141.1	<div style="width: 18%;"></div>

Throughput (Mbps)

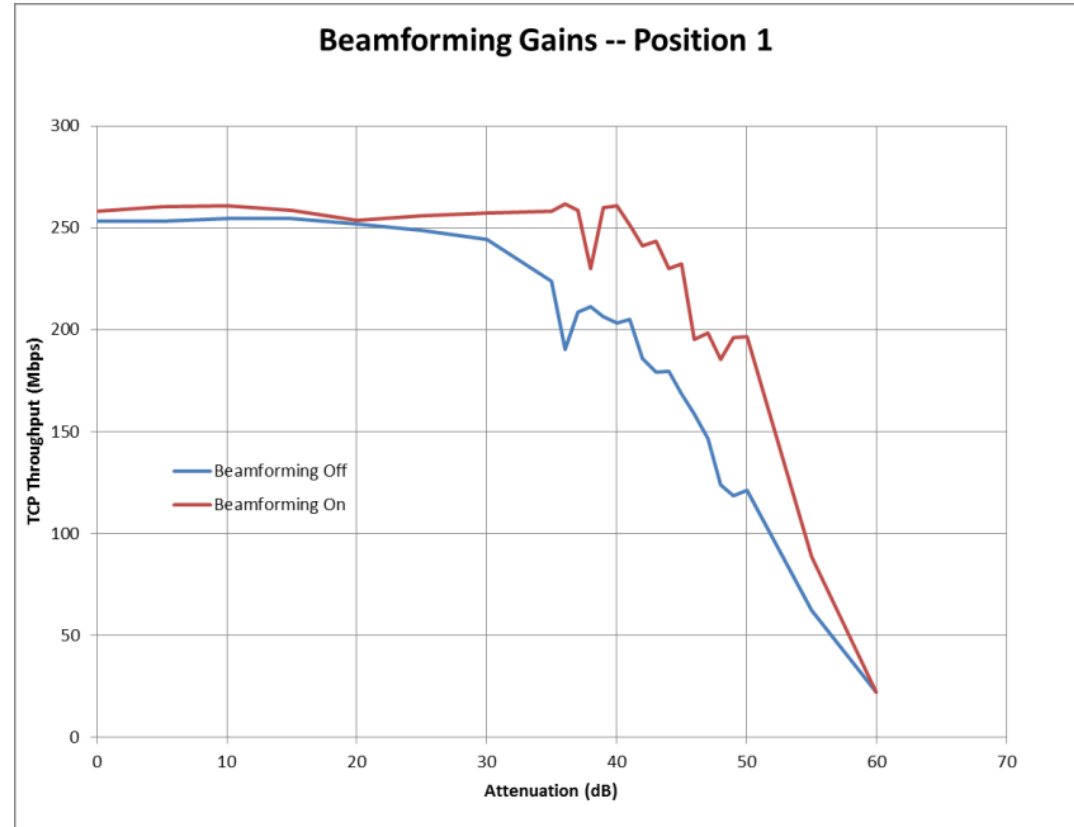
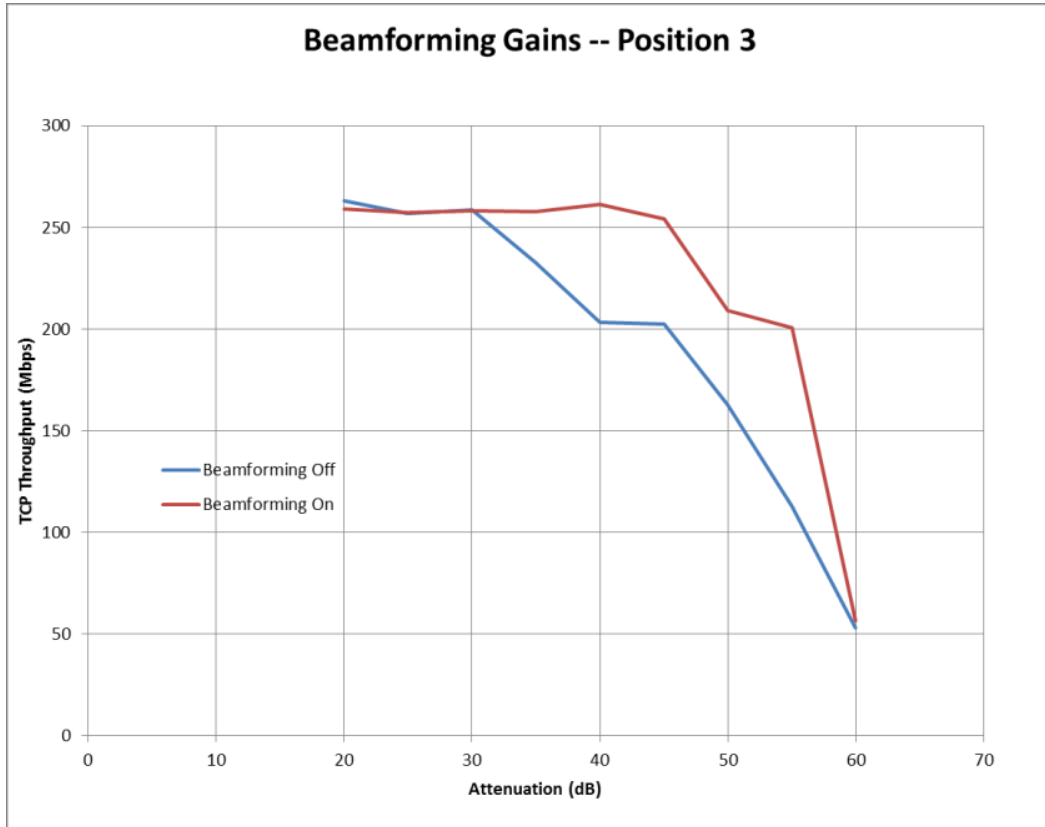
SmallNetBuilder.com Benchmark Testing

Source: http://www.smallnetbuilder.com/images/stories/wireless/how_to_test_wireless/2-4ghz_mpe_test_points.jpg



octoBox MPE Test Location Attenuations - 2.4 GHz

Beamforming Gains



Both positions showing at least a 5dB gain with beamforming

Environment

Range

Orientation

Multipath

Interference

Motion

Channel width (20/40/80/160 MHz)

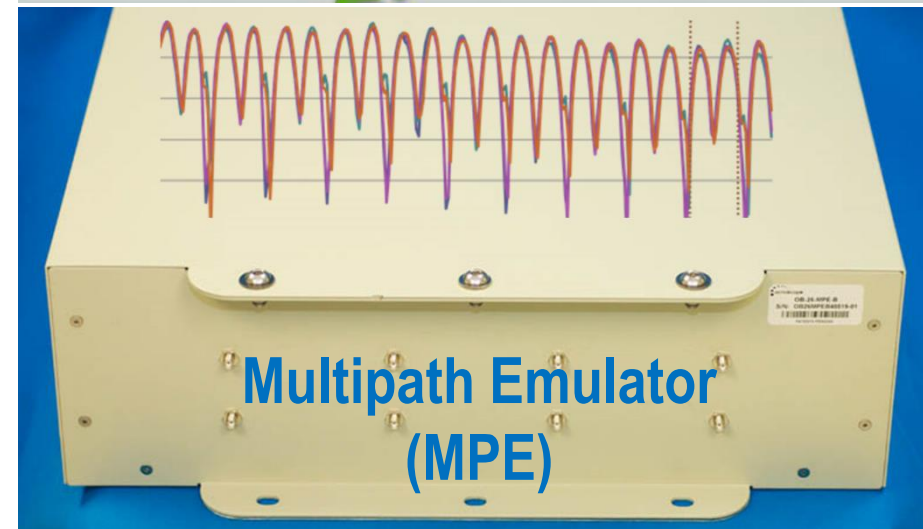
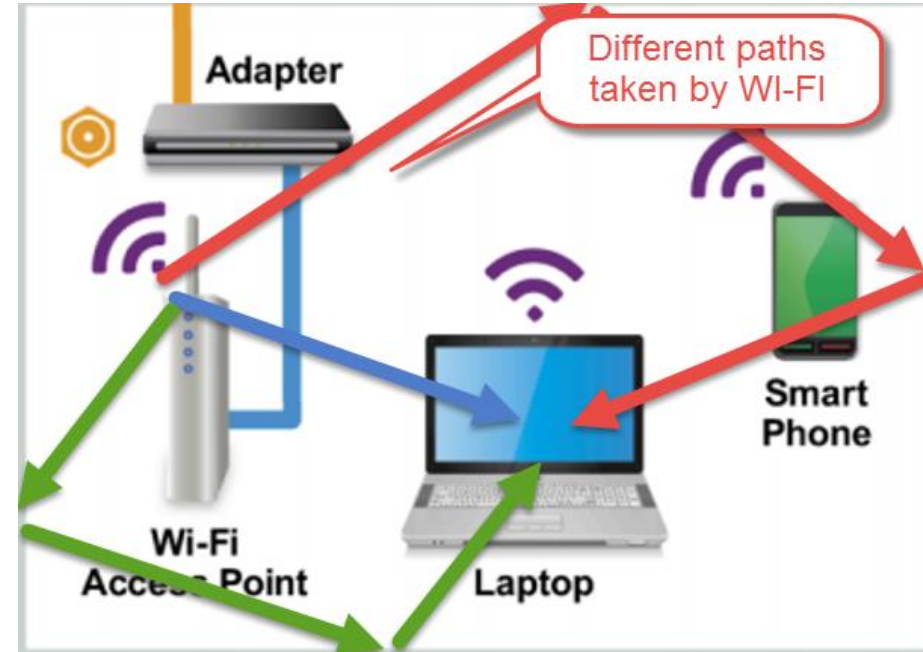
Channel frequency

Partner device

Number of partner devices

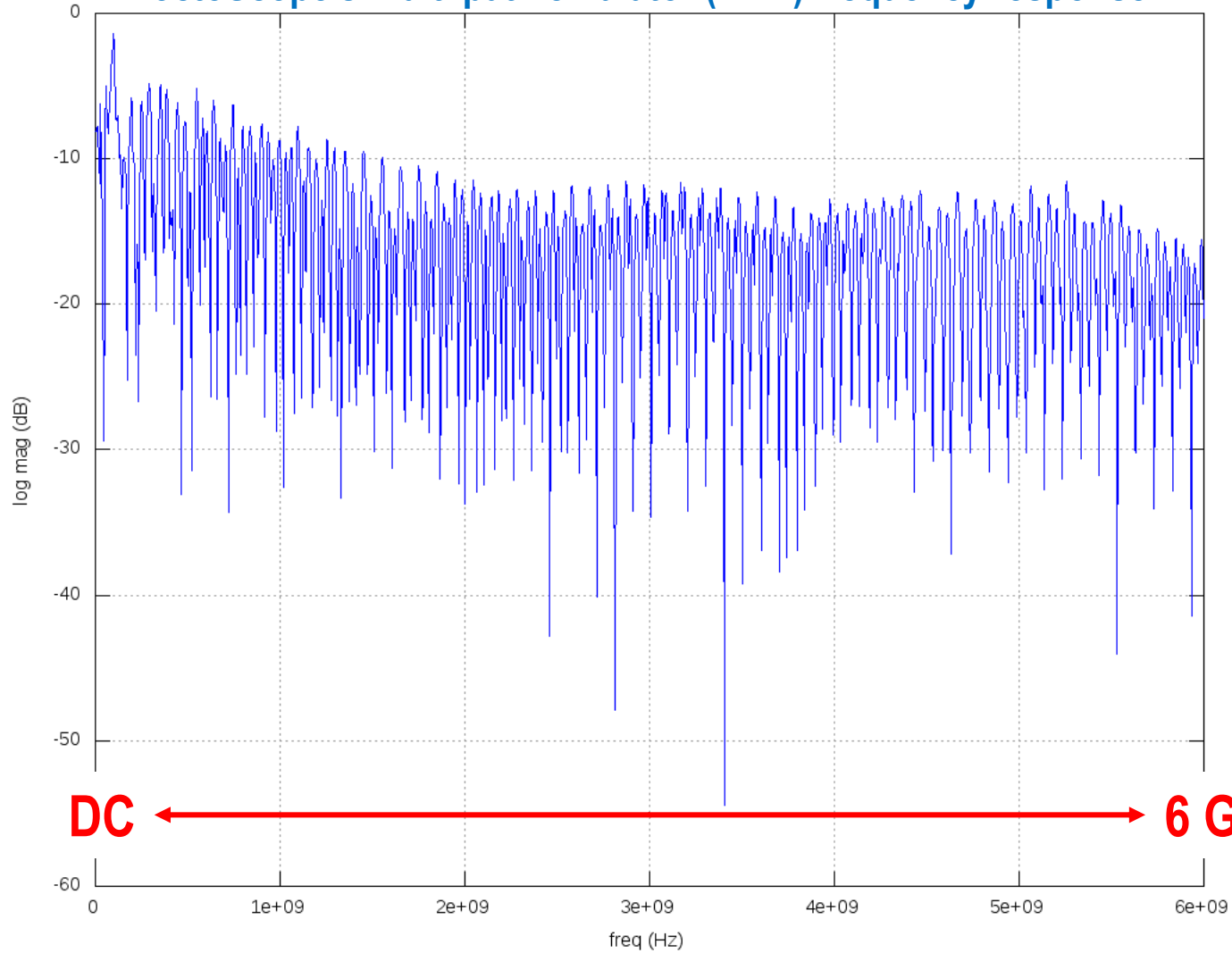
Network load

Data rate / Modulation Coding Scheme (MCS)



MPE Broadband Frequency Response

octoScope's multi path emulator (MPE) frequency response

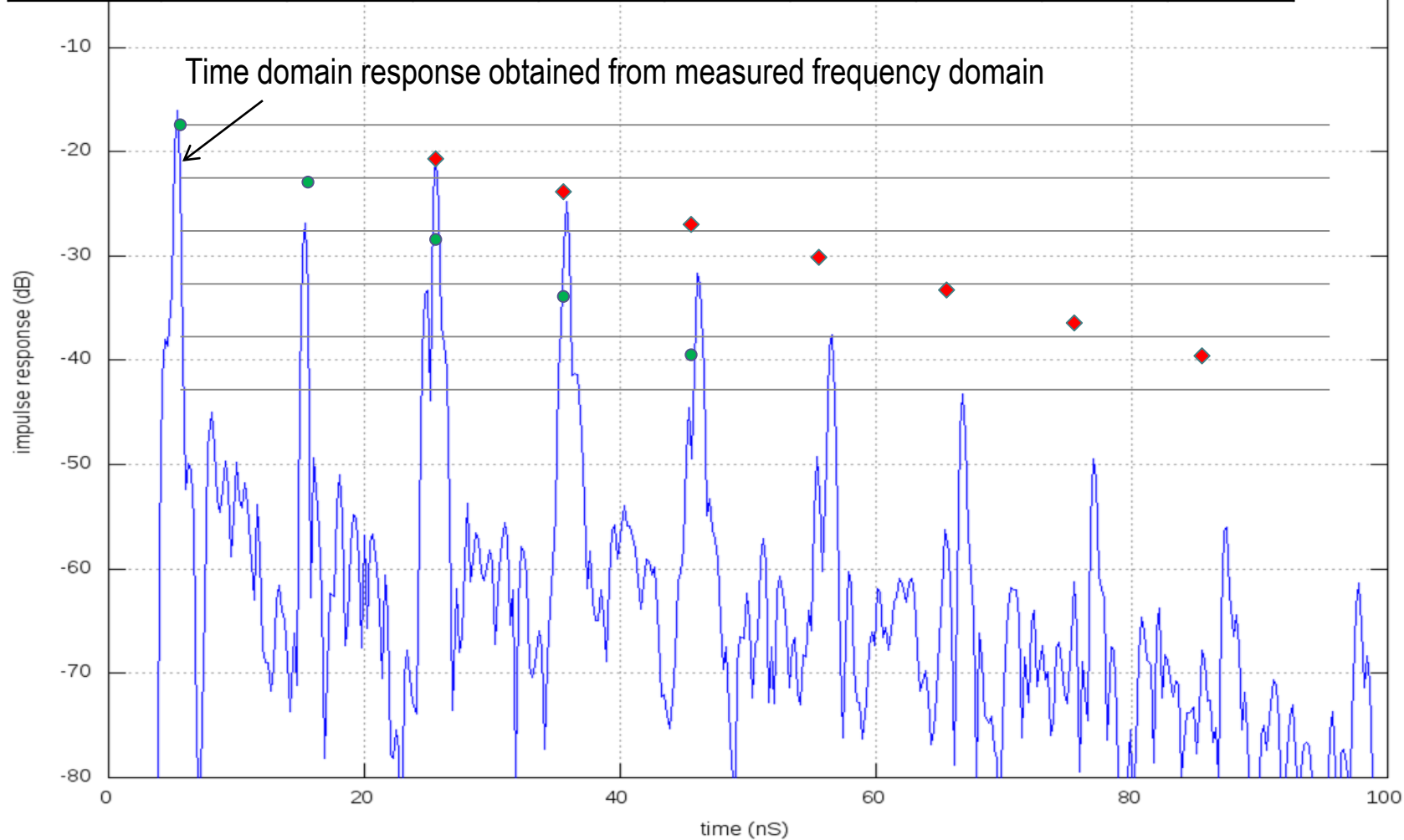


Wide-open frequency response

No limit to operating channel width
20/40/80/160 MHz channel support

octoBox-MPE vs. IEEE Model B

Model B	0ns	10 ns	20ns	30ns	40ns	50ns	60ns	70ns	80ns
Cluster 1	0	-5.4	-10.8	-16.2	-21.7				
Cluster 2			-3.2	-6.3	-9.4	-12.5	-15.6	-18.7	-21.8



Range

Orientation

Multipath

Interference

Motion

Channel width (20/40/80/160 MHz)

Channel frequency

Partner device

Number of partner devices

Network load

Data rate / Modulation Coding Scheme (MCS)



Adjacent Channel Interference

Co-Channel Interference

Bluetooth

Baby monitor

ZigBee

Radar

⋮



iGen Browser Based GUI – Traffic Interference

System **Traffic** Monitor Waveform File Manager

802.11 Interface: 802.11ac

Channel width: 40 MHz

Guard Interval: Short

MCS (Mbps): 0 (15 Mbps)

Primary Channel: 124 (5620 MHz)

Secondary Channel: 128

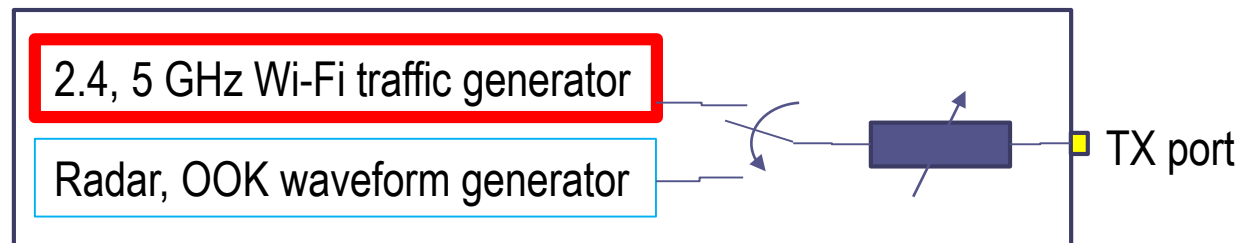
Input file: single_TCIPacket_3128B.pcap

Play Mode: Loop until <stop>

Priority (WMM): Best Effort

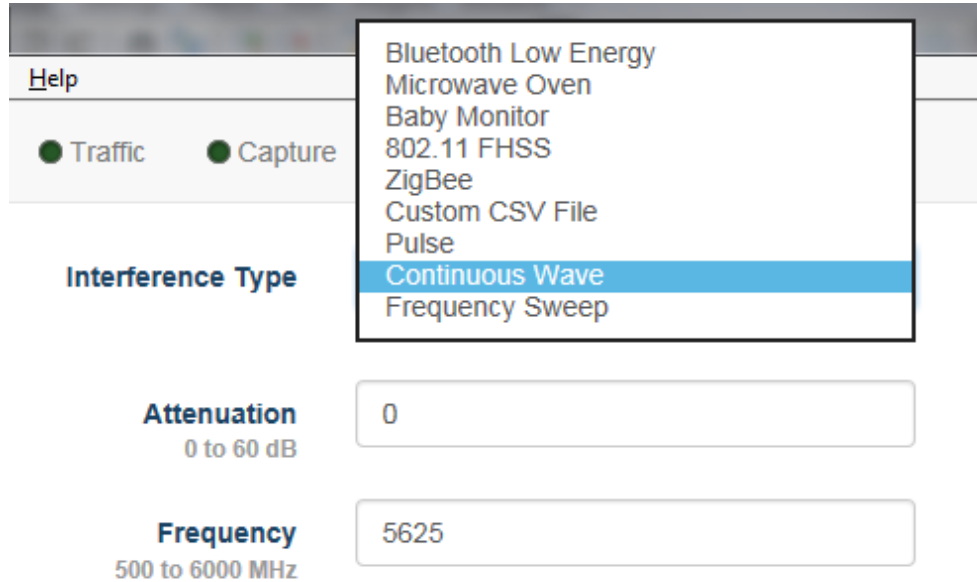
Inter-Packet Gap: 300 μ sec
300 μ sec minimum

Attenuation: 0
0dB to 60dB

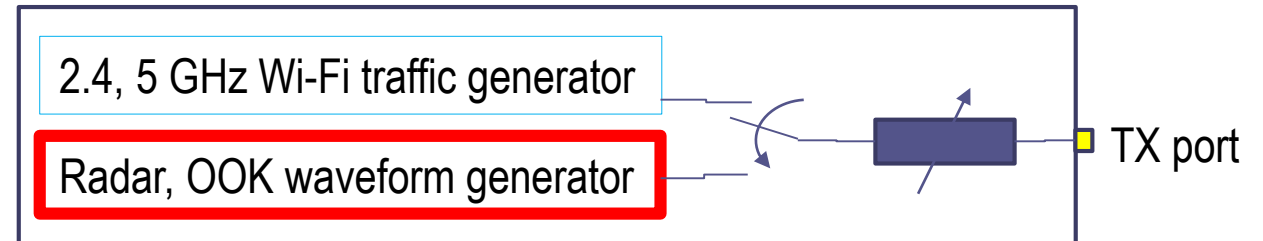


WMM = wireless multi media
MCS = modulation coding scheme

iGen Browser Based GUI – Waveform Interference



OOK waveforms between 500 MHz and 6 GHz
 User definable waveforms downloadable as CSV files



CSV = comma separated variable
 FHSS = frequency hopping spread spectrum
 OOK = on off keying

Environment

Range

Orientation

Multipath

Interference

Motion

Channel width (20/40/80/160 MHz)

Channel Frequency

Partner device

Number of partner devices

Network load

Data rate / Modulation Coding Scheme (MCS)



Channel

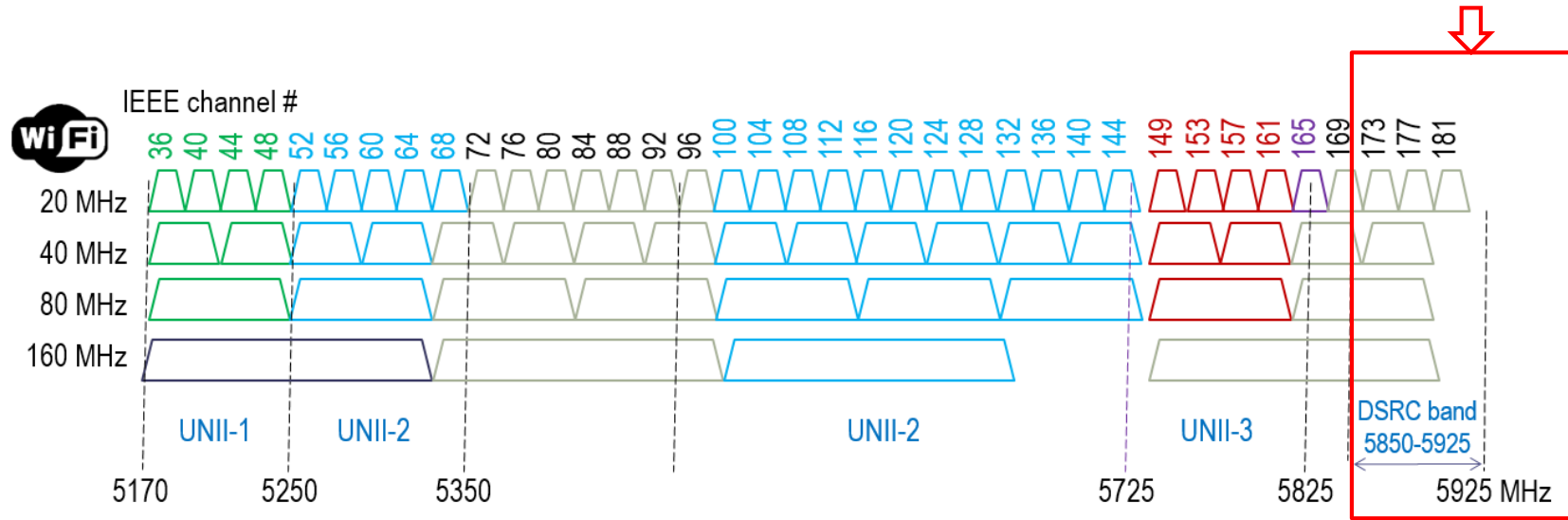
Range

Orientation

Multipath

Interference

Motion



Channel width (20/40/80/160 MHz)

Channel frequency

octoBox testbed frequency range
700 MHz to 6 GHz

Partner device

Number of partner devices

Network load

Data rate / Modulation Coding Scheme (MCS)

Client Testing

Range

Orientation

Multipath

Interference

Motion

Channel width (20/40/80/160 MHz)

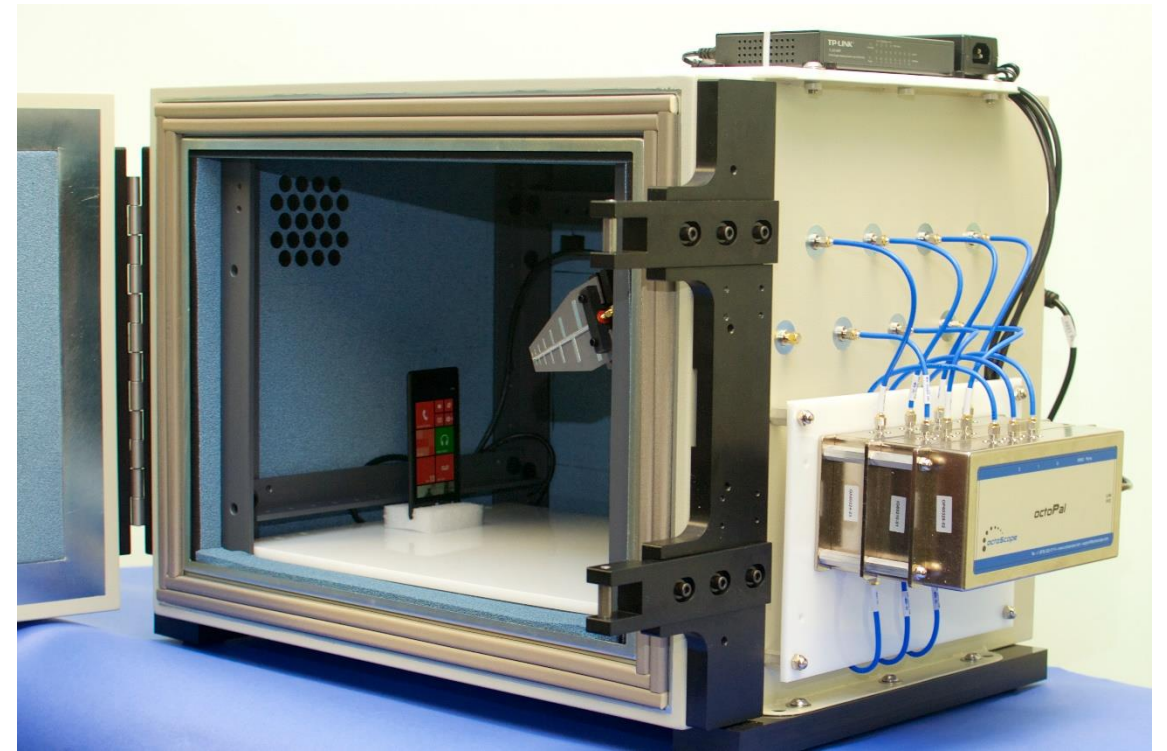
Channel frequency

AP type (802.11a/b/g/n/ac)

Number of APs

Network load

Data rate / Modulation Coding Scheme (MCS)



AP Testing

Range

Orientation

Multipath

Interference

Motion

Channel width (20/40/80/160 MHz)

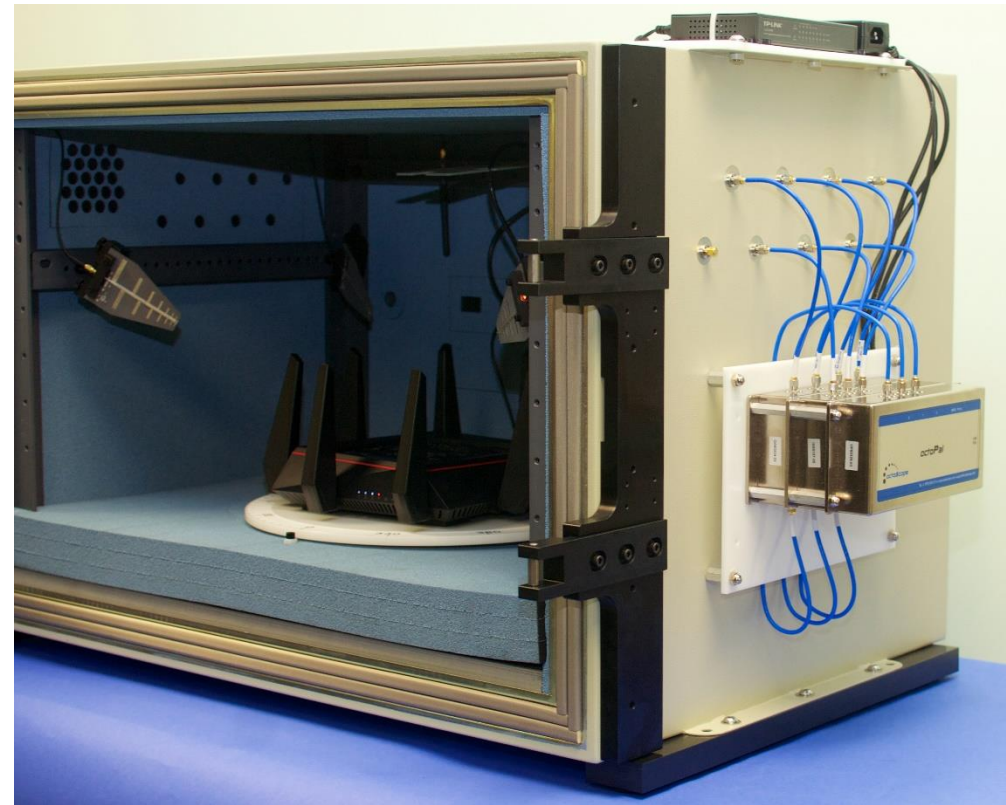
Channel frequency

Client type (802.11a/b/g/n/ac)

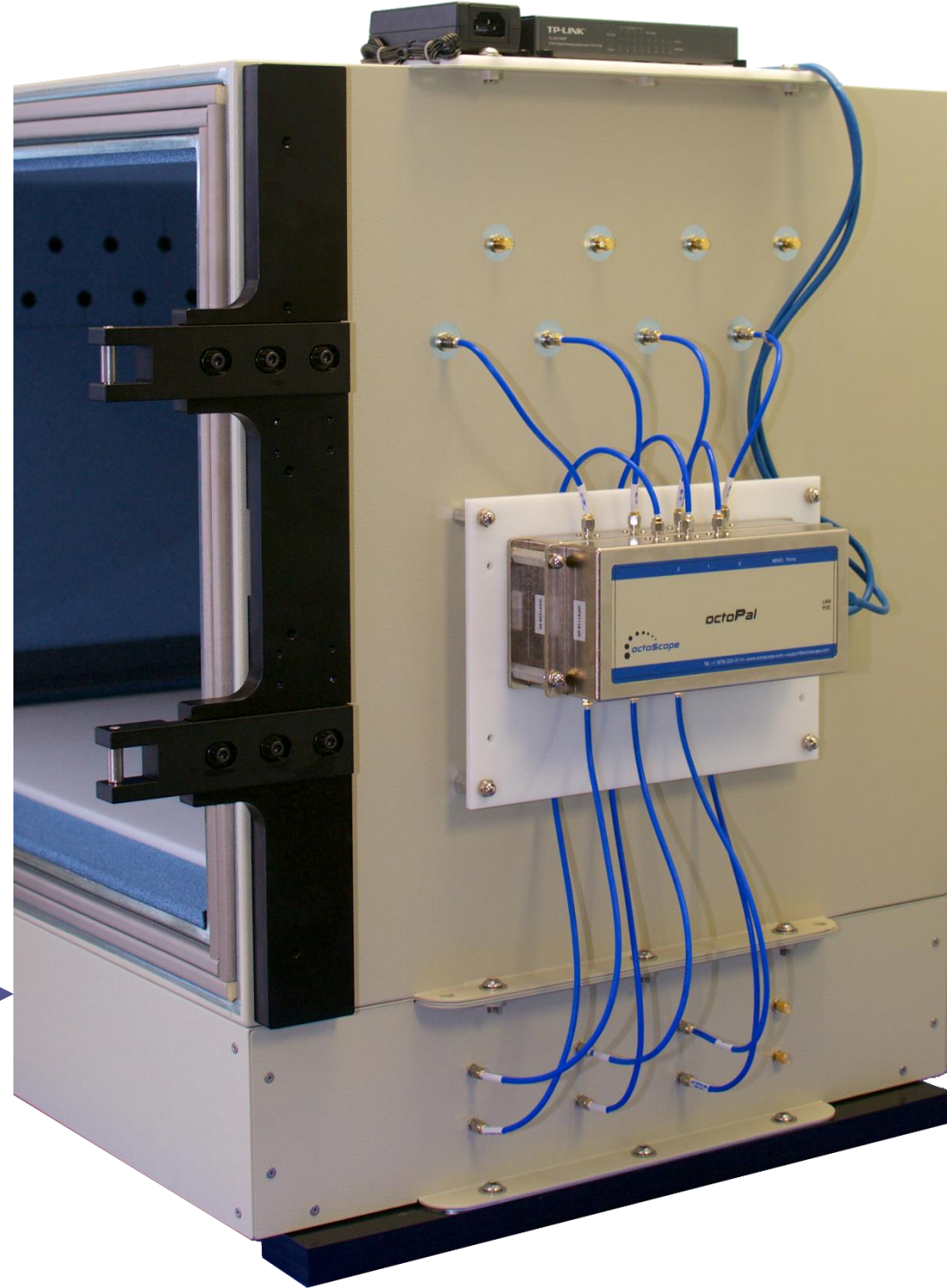
Number of clients

Network load

Data rate / Modulation Coding Scheme (MCS)



Multipath Emulator (MPE)



Adaptation

Range

Orientation

Multipath

Interference

Motion

Channel width (20/40/80/160 MHz)

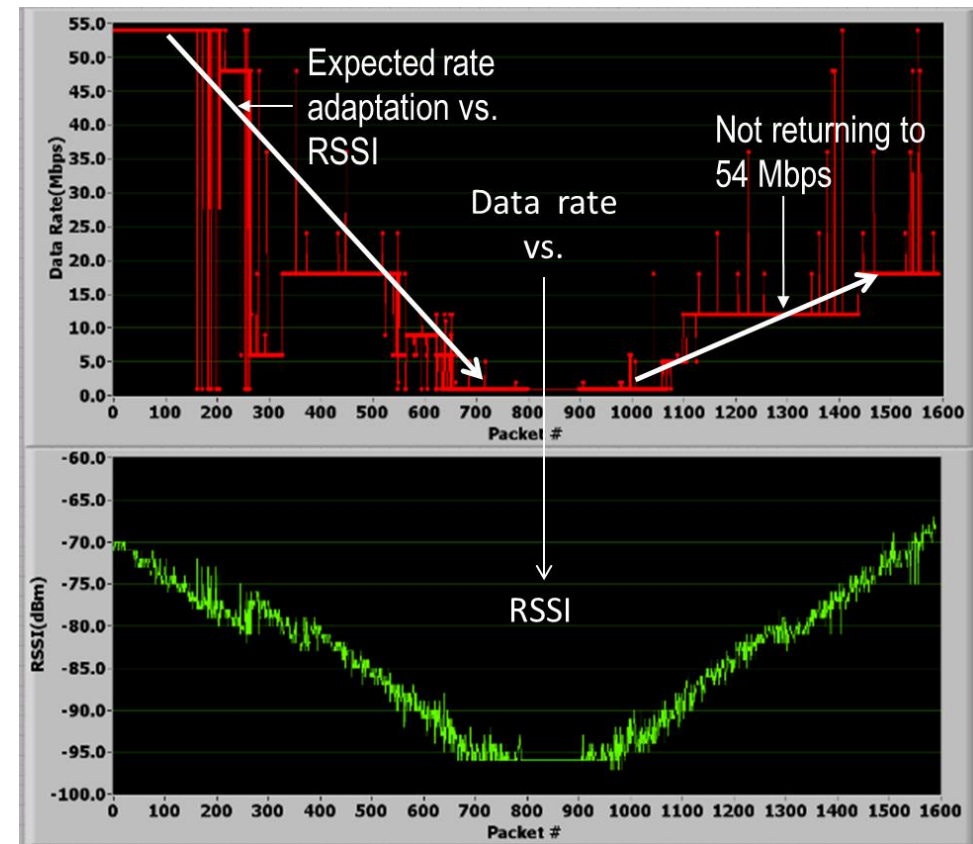
Channel frequency

Client type (802.11a/b/g/n/ac)

Number of clients

Network load

Data rate / Modulation Coding Scheme (MCS)



Examples of Wireless Adaptation Techniques

MIMO mode

Data rate or MCS

Roaming

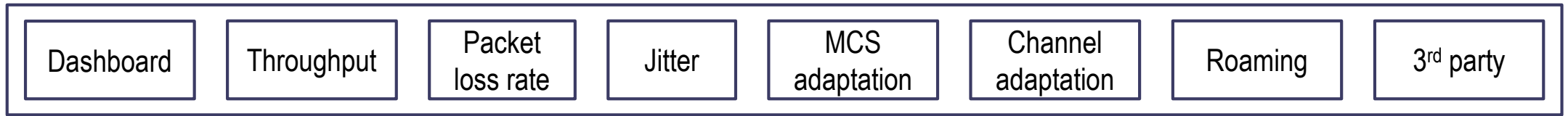
Channel frequency

Channel width

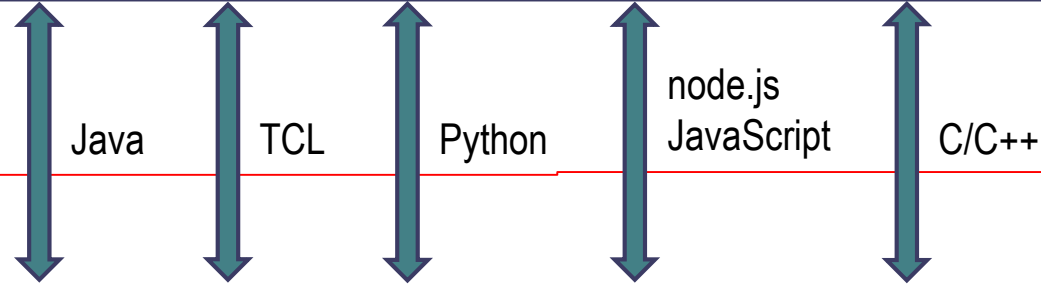
Band steering

octoScope Test Automation Applications and API

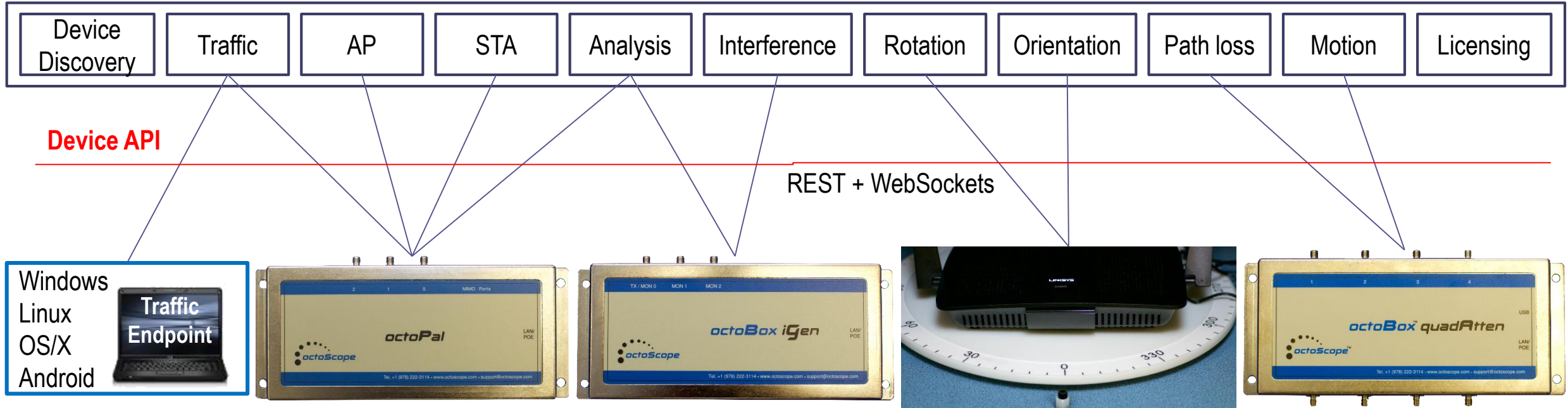
Applications



Testbed API



Device API



API = application programming interface

Throughput Script

Configuration

Test Result

General

Throughput measurement duration (sec)

30

Stop on error

Yes

Traffic

Remote Endpoint

octoPal at 192.168.15.6

Protocol

TCP

Direction

Console to remote endpoint

Discard initial measurements (s)

0

Number of streams

1

Offered load (MBit/s)

1000

Range

Change DUT range

Yes

quadAtten

quadAtten at COM2

Start attenuation (dB)

0

End attenuation (dB)

60

Step (dB)

10

Orientation

Change DUT orientation

Yes

Turn Table

Turn Table at COM4

Rotation speed (RPM)

2

Start position (deg)

-180

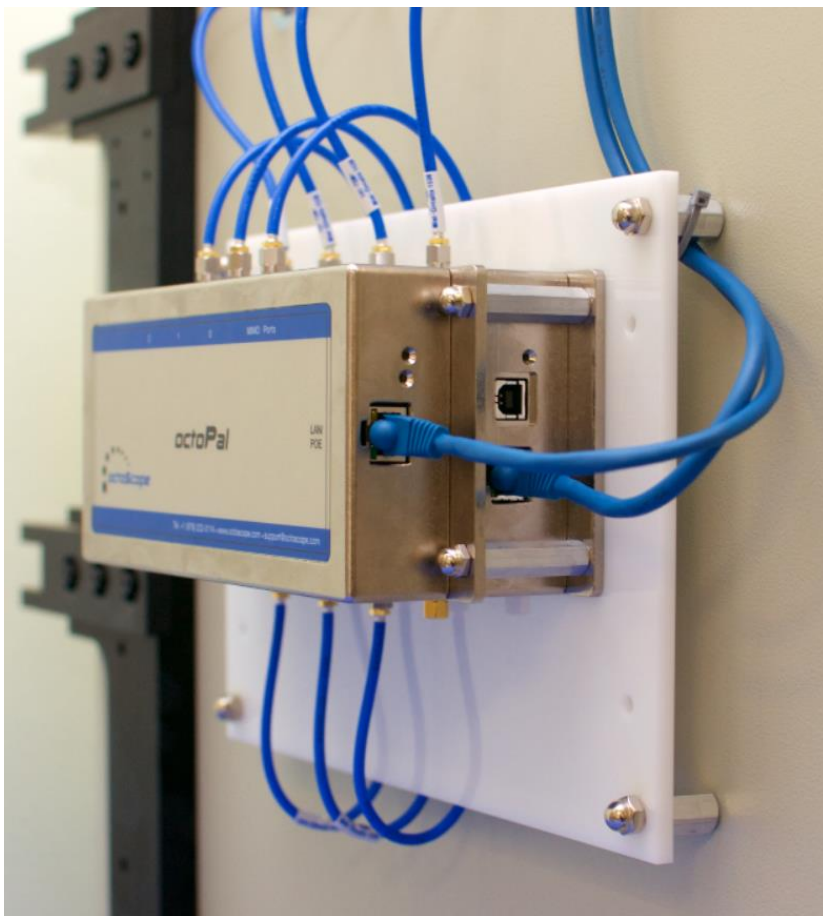
End position (deg)

180

Rotation step (degrees)

15

octoPal Partner Device



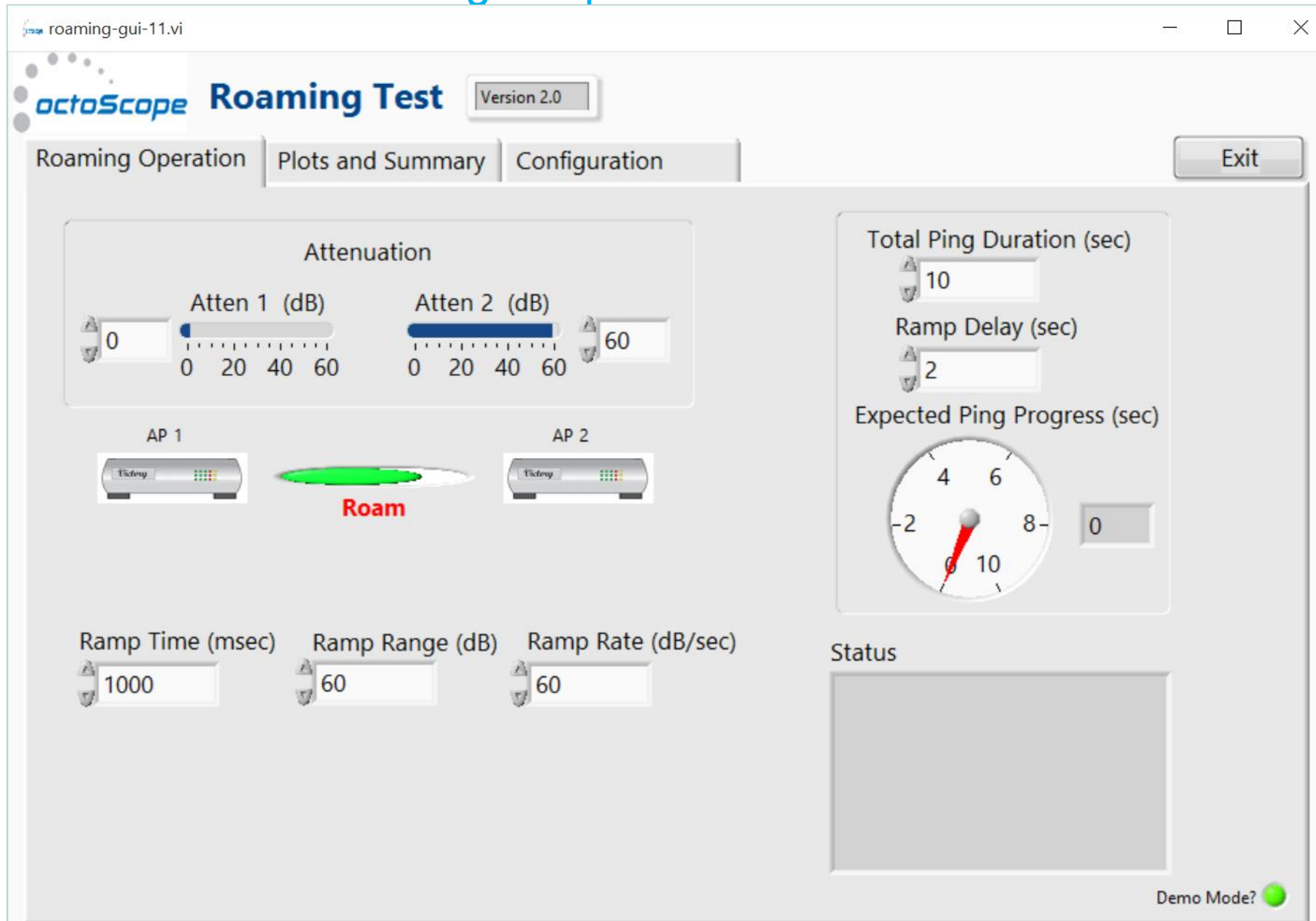
Mode	Station <input type="button" value="v"/>
SSID	octoscope
Security	WPA2 <input type="button" value="v"/>
Security Password	<input type="text"/>
IP Address	10.100.100.89
IP Subnet Mask	255.255.255.0
802.11 Interface	802.11ac <input type="button" value="v"/>
Channel Width	80 MHz <input type="button" value="v"/>
Guard Interval	Short <input type="button" value="v"/>
MCS (Mbps)	Adapt <input type="button" value="v"/>
Primary Channel	Scan <input type="button" value="v"/>
Secondary Channel	<input type="text"/>
Priority (WMM)	Best Effort <input type="button" value="v"/>
Maximum Number of Streams	3 <input type="button" value="v"/>

Association Status: Associated
Channel: 149 (5745 MHz)
Beacon RSSI: -20 dBm
Data RSSI: -20 dBm
TX Rate: 1.3 Gb/s
RX Rate: 65 Mb/s



The commands were submitted successfully.

Roaming Script



The screenshot shows the 'Roaming Test' GUI with the following elements:

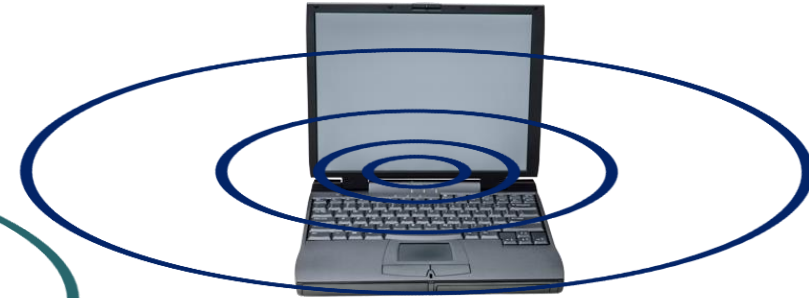
- Navigation:** 'Roaming Operation' (selected), 'Plots and Summary', 'Configuration', and an 'Exit' button.
- Attenuation Section:** Two sliders for 'Atten 1 (dB)' (set to 0) and 'Atten 2 (dB)' (set to 60). Below are icons for 'AP 1' and 'AP 2' with a green oval between them labeled 'Roam'.
- Timing Section:** 'Total Ping Duration (sec)' (10), 'Ramp Delay (sec)' (2), and 'Expected Ping Progress (sec)' (0). The progress is shown on a circular gauge with a red needle pointing to 0.
- Rate Section:** 'Ramp Time (msec)' (1000), 'Ramp Range (dB)' (60), and 'Ramp Rate (dB/sec)' (60).
- Status:** A large empty rectangular area.
- Footer:** 'Demo Mode?' with a green indicator light.

Controls motion,
velocity, pinging,
graphical reporting

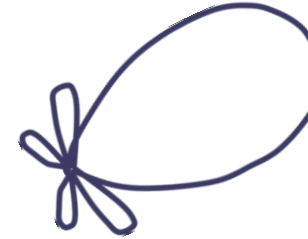
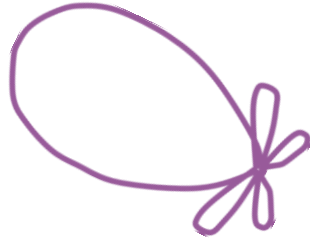
Stackable
Configurable
Controlled
RF Testbed



Conventional RF Propagation – One Device at a Time



Support for MU-MIMO and Beamforming

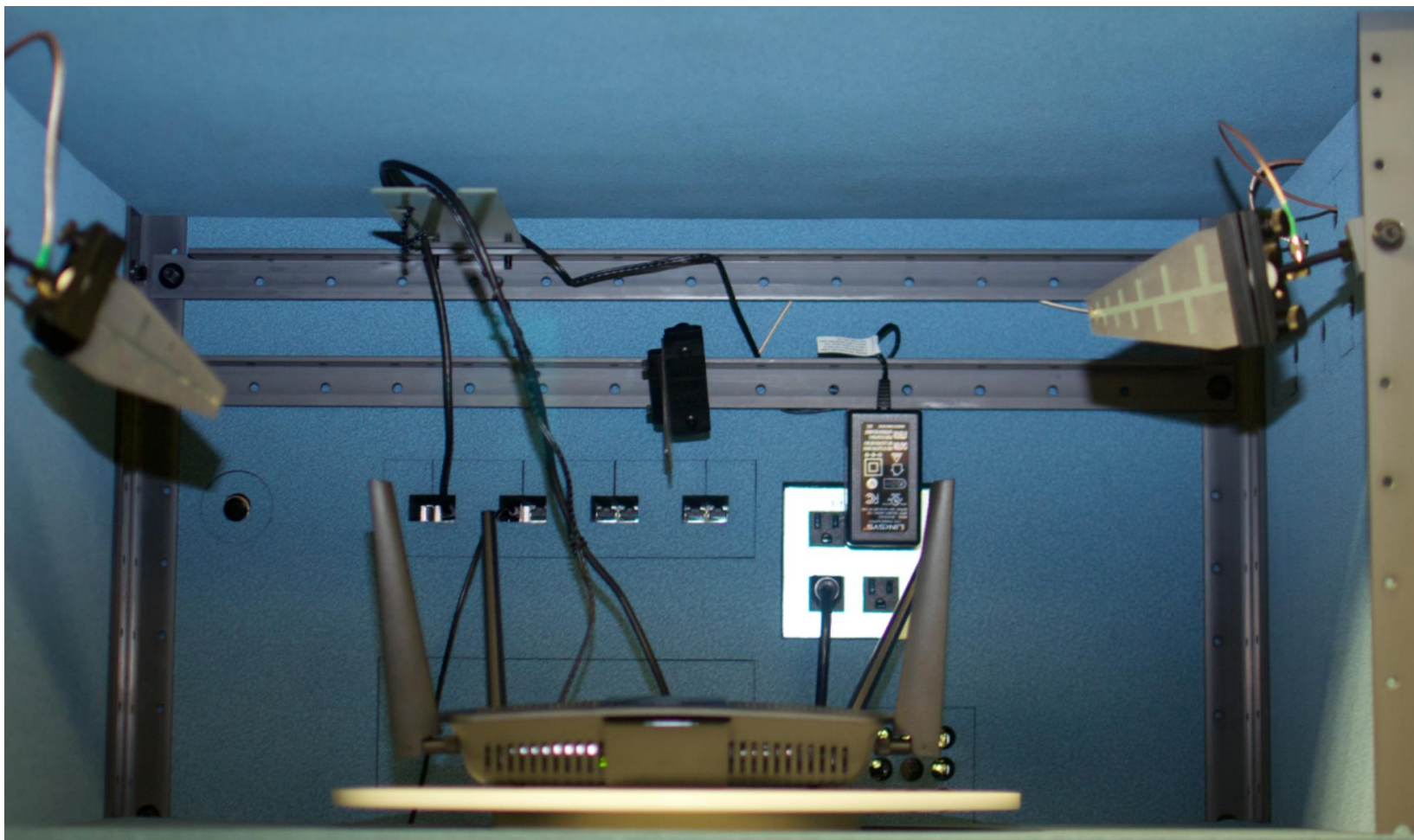


802.11 MU-MIMO beamforming techniques enable stations to transmit simultaneously in the same airlink and on the same channel frequency.



MU-MIMO = multi user multiple input multiple output

MU-MIMO Gains



PATENT PENDING

Run #	MU-MIMO OFF (Mbps)	MU-MIMO ON (Mbps)
1	360	935
2	355	935
3	358	934
4	361	938
5	357	946
6	357	946

Over 2.6x gain

```
Command Prompt - iperf -s
Microsoft Windows [Version 6.1.7601]
Copyright (c) 2009 Microsoft Corporation. All rights reserved.

C:\Users\N...> iperf -s
Server listening on TCP port 5201
TCP window size: 64.0 KByte (default)

Command Prompt - iperf -s
Microsoft Windows [Version 6.1.7601]
Copyright (c) 2009 Microsoft Corporation. All rights reserved.

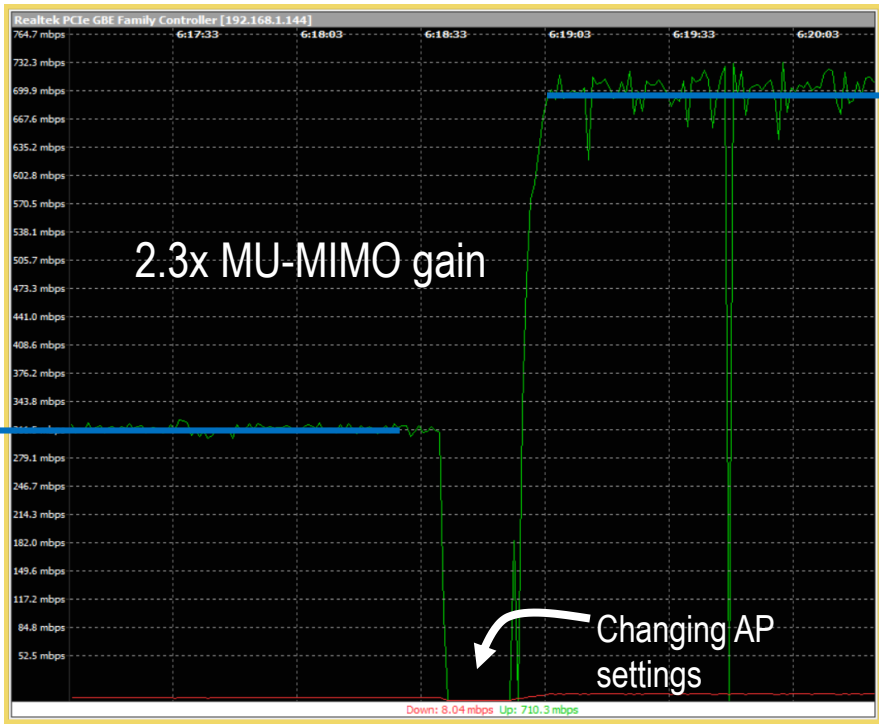
C:\Users\N...> iperf -s
Server listening on TCP port 5201
TCP window size: 64.0 KByte (default)

Command Prompt - iperf -s
Microsoft Windows [Version 6.1.7601]
Copyright (c) 2009 Microsoft Corporation. All rights reserved.

C:\Users\N...> iperf -s
Server listening on TCP port 5201
TCP window size: 64.0 KByte (default)
```

1G Ethernet

MU-MIMO Beamforming in the octoBox Testbed



MU-MIMO OFF
311 Mbps

MU-MIMO ON
700 Mbps

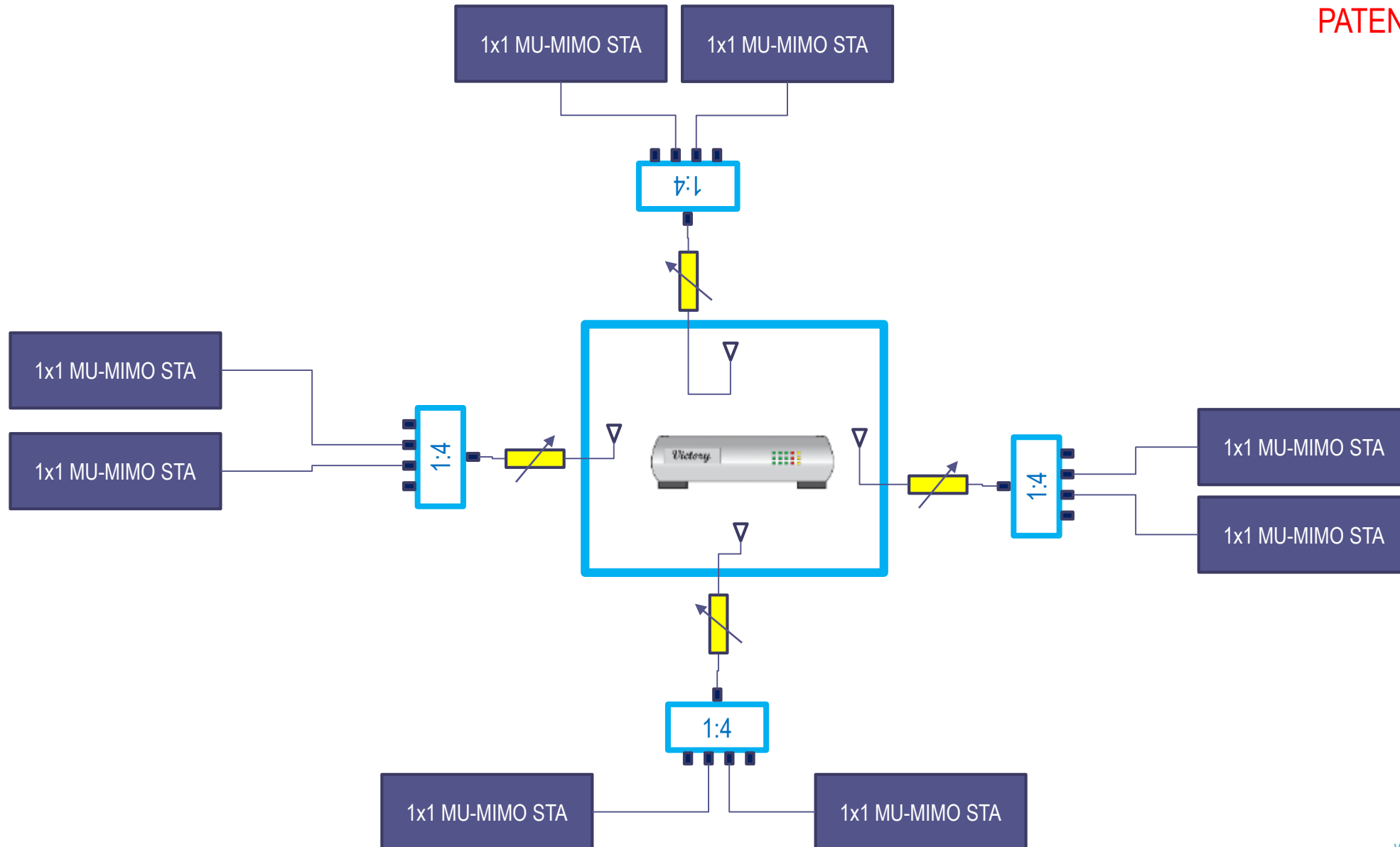
2.3x MU-MIMO gain

Changing AP
settings



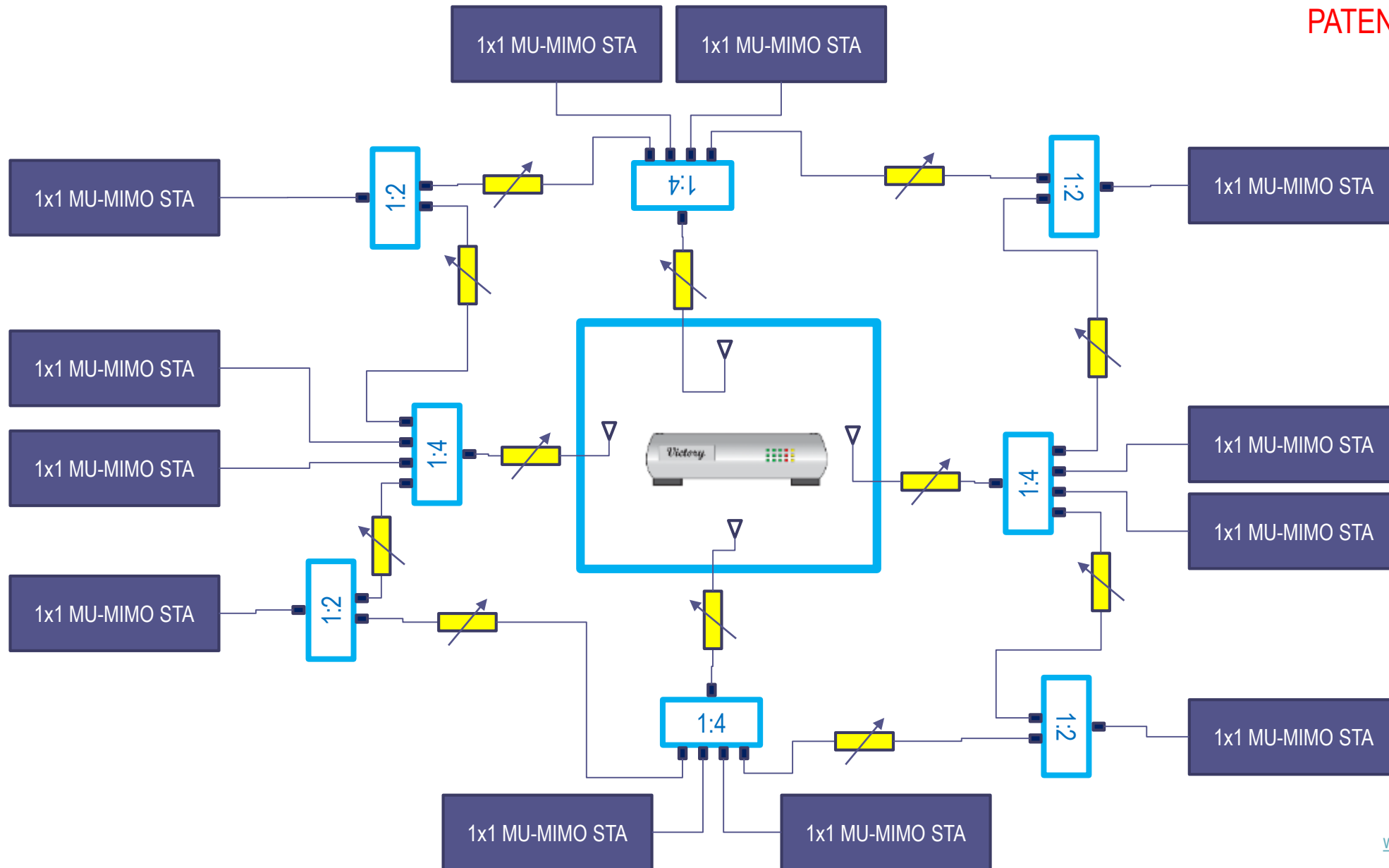
MU-MIMO with Controllable Correlation

PATENT PENDING

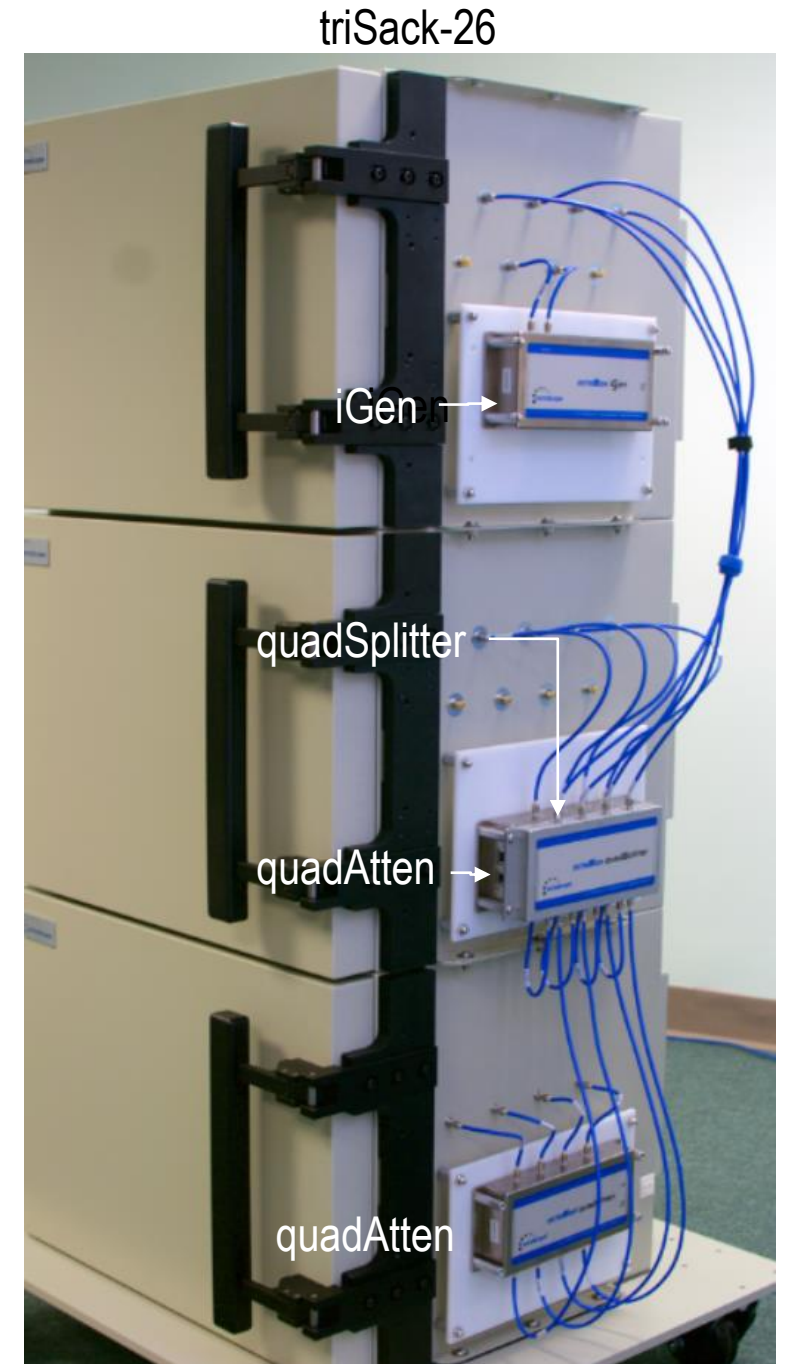
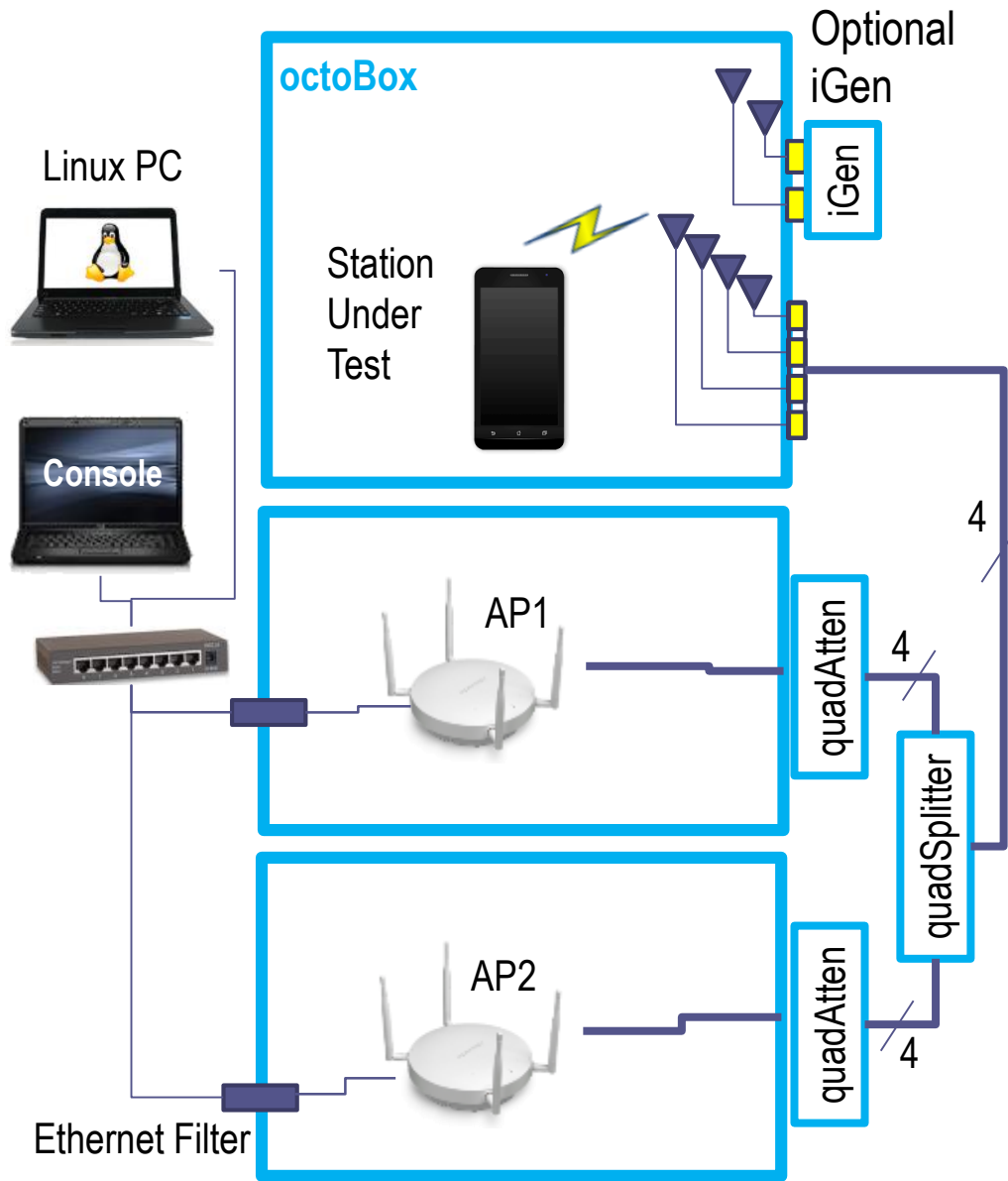


MU-MIMO with Controllable Correlation

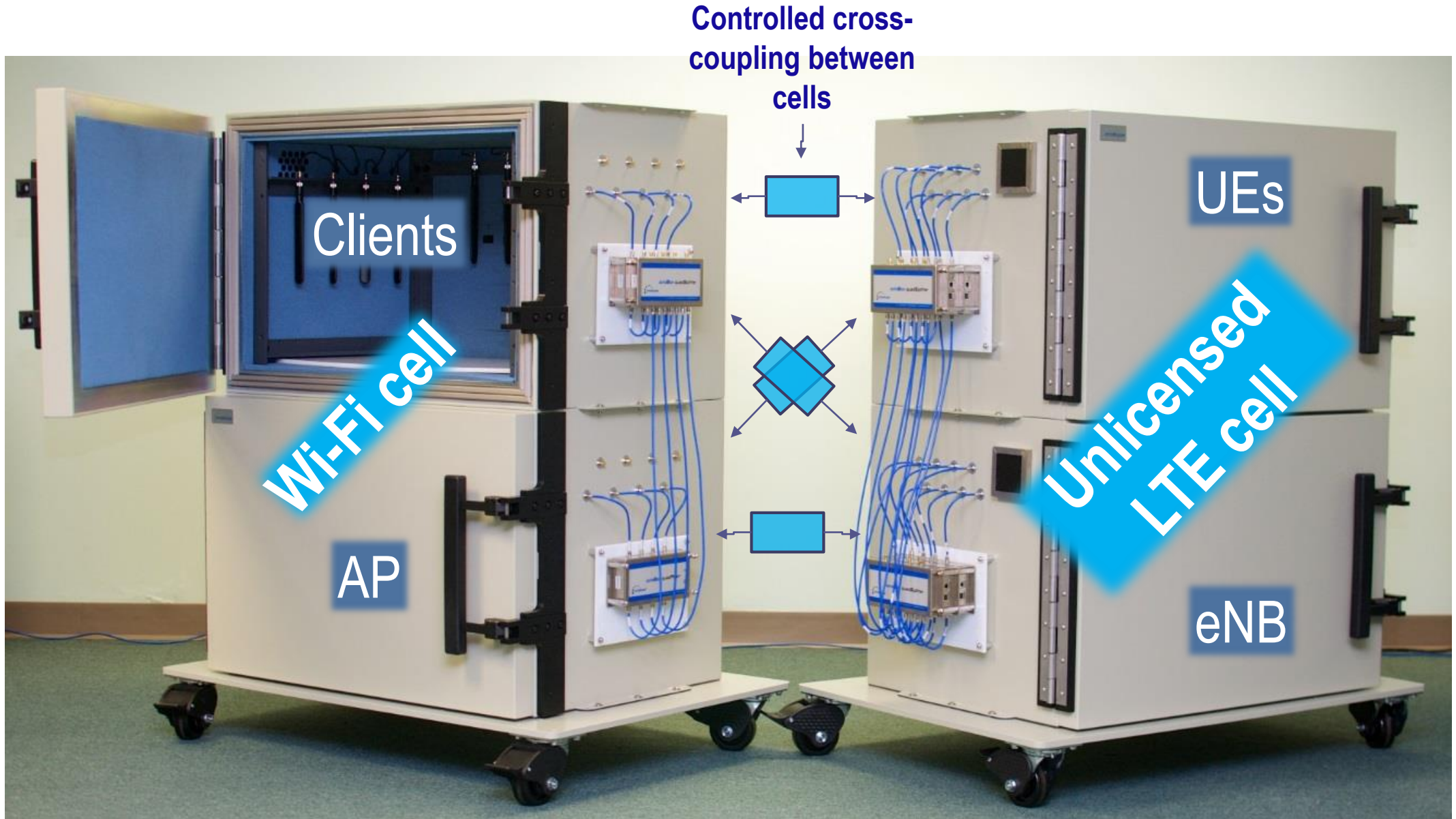
PATENT PENDING



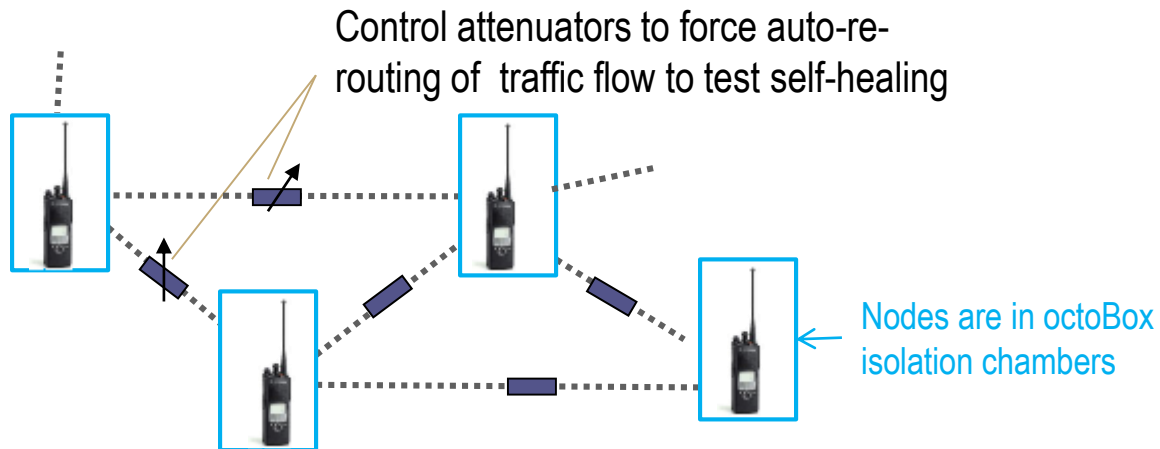
Configurable for a Wide Variety of Tests



Support for Coexistence Testing



Example Mesh Test Configuration



Controlled RF Environment Hardware
(OPTIONAL for Members; required for Authorized Test Labs)

Item	Vendor	Part #	Quantity	Price (est.)
octoBox Shielded RF Chamber	Octoscope	OB-26X-SILVER	3	Contact Octoscope for quote info@octoscope.com +1.978.222.3114
octoBox stack base with casters	Octoscope	OB-26-BASE		
octoBox Quad Attenuator	Octoscope	OB-quad	1	

Specified for Thread certification

Support for All Key Wireless Technologies



Large Scale System Test Configurations

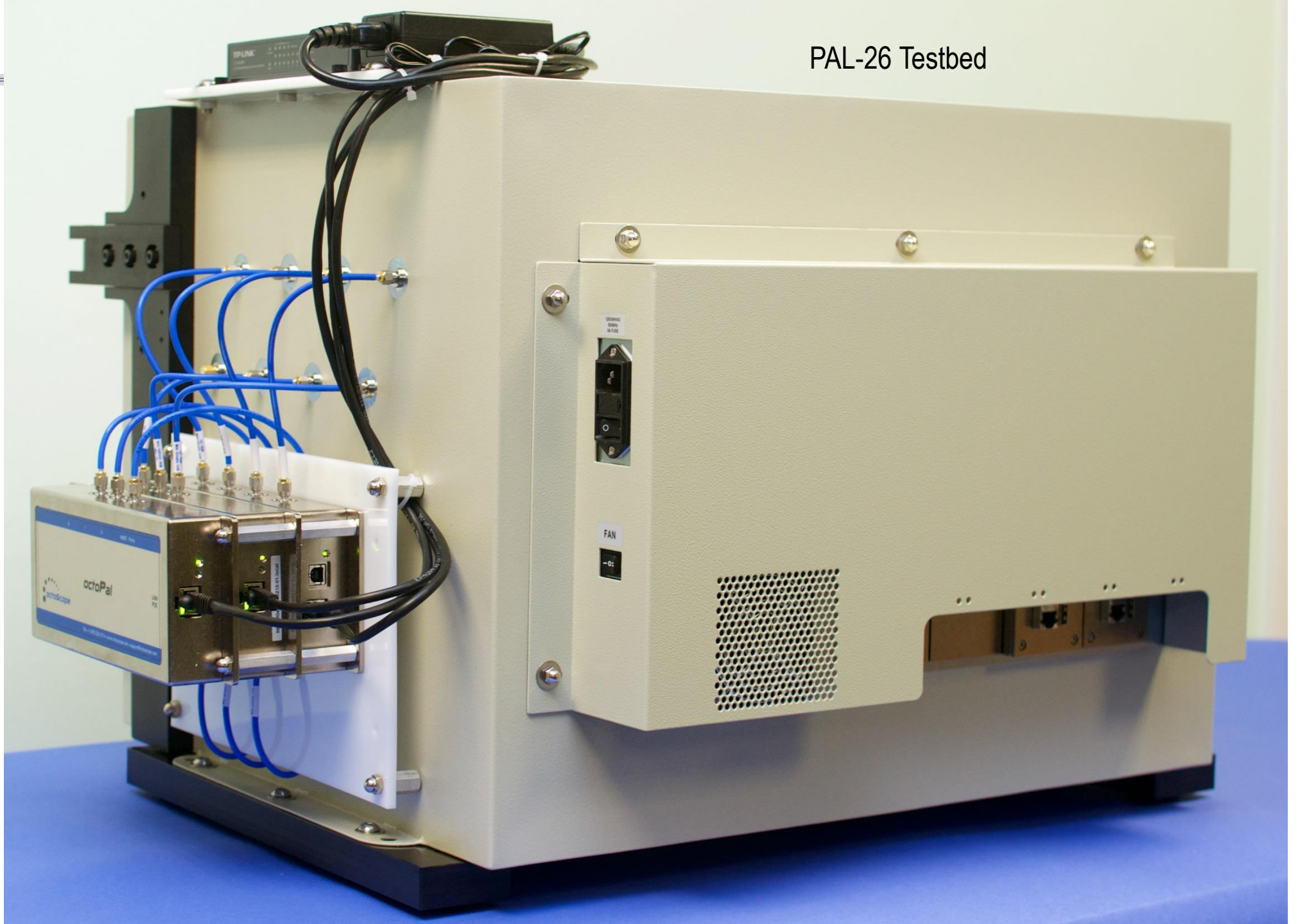


Flexible Stacking Options



Fully
Featured
PAL
Benchtop
Testbed

PAL-26 Testbed



Fully Isolated MIMO RF Building Blocks



Fully Isolated MIMO RF Building Blocks



Fully Isolated MIMO RF Building Blocks



TX / MON 0

MON 1

MON 2

LAN /
POE

octoBox iGen



octoScope

Tel. +1 (978) 222-3114 • www.octoscope.com • support@octoscope.com

Fully Isolated MIMO RF Building Blocks

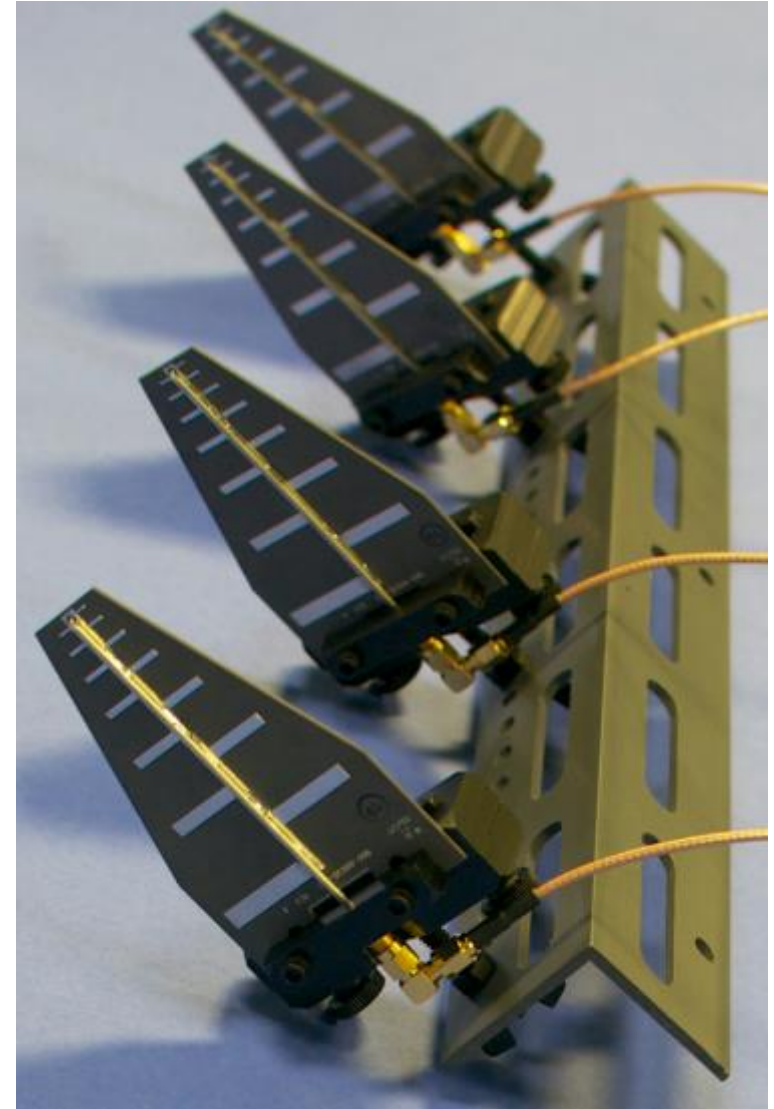
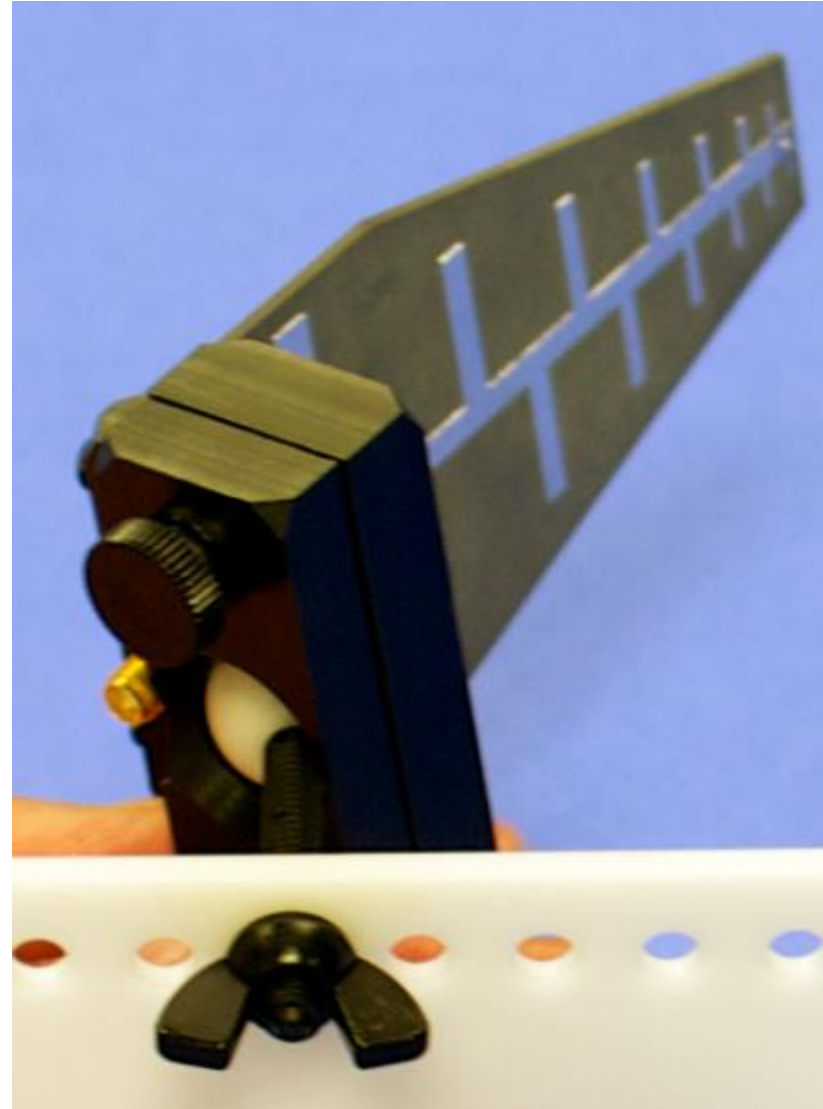
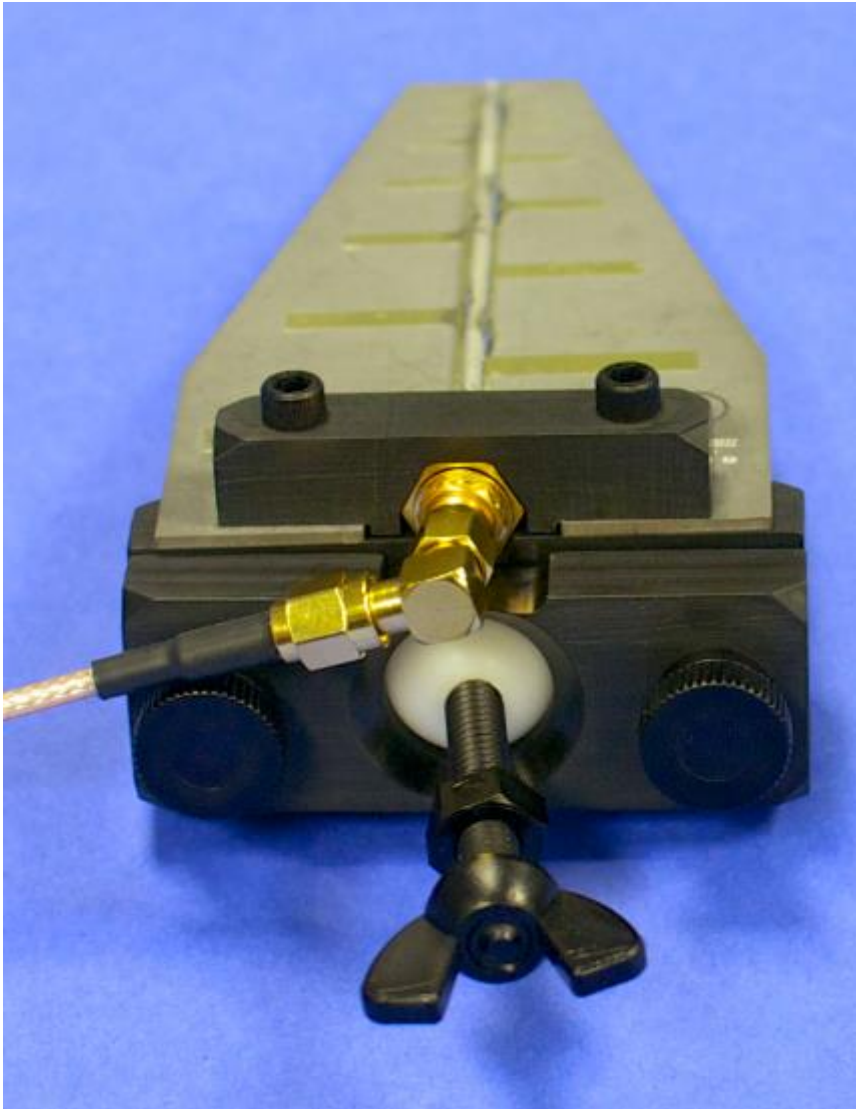




Complete Isolation Through Careful Filtering and Sealing



Built-in High Gain Antennas



Flexible Antenna Arrangement



Easy to Integrate with a Variety of Instruments

Cellular Network Simulators (LTE, LTE-A, LTE-U, 2G, 3G)

NEW



MT8821C 6GHz Cellular UE RF Tester
 LTE – Up to 5CC CA, LTE-U, up to 4x4 MIMO, GSM/WCDMA/TDSCDMA/CDMA/EVDO



MT8820C 3.8GHz Cellular UE RF Tester
 LTE/WCDMA/GSM/TDSCDMA/CDMA/EVDO

NEW



MD8475B 6GHz Cellular UE Signaling Tester
 LTE – Up to 4CC CA, LTE-U, up to 2x2 MIMO (4x4 MIMO in Future), GSM/WCDMA/TDSCDMA/CDMA/EVDO



MD8475A Cellular UE Signaling Tester
 LTE – Up to 2CC CA, up to 2x2 MIMO, GSM/WCDMA/TDSCDMA/CDMA/EVDO

Spectrum Analyzers



MS2830A Spec An
 3.6GHz/6GHz/13.5GHz/26.5GHz/43GHz/90GHz
 VSA Options for WiFi/DSRC/BT/Cellular
 Up to 125MHz Analysis Bandwidth



MS2690A 6GHz Spec An
 MS2691A 13.5GHz
 MS2692A 26.5GHz
 VSA Options for WiFi/DSRC/BT/Cellular
 Up to 160MHz Analysis Bandwidth



MS2720T Handheld Battery Operated Spec An
 9GHz/13GHz/20GHz/32GHz/43GHz

NEW



MS27101A 6GHz Indoor Remote Access Spectrum Analyzer
 Access Via the web From anywhere

NEW



MS27102A 6GHz Outdoor Remote Access Spectrum Analyzer
 Access Via the web From anywhere

Power Meters



ML2437A/38A Power Meter



ML2495A/96A Pulse Power Meter



ML2487A Wideband Peak Power Meter



MA24XXXA USB Power Sensors (9 models)

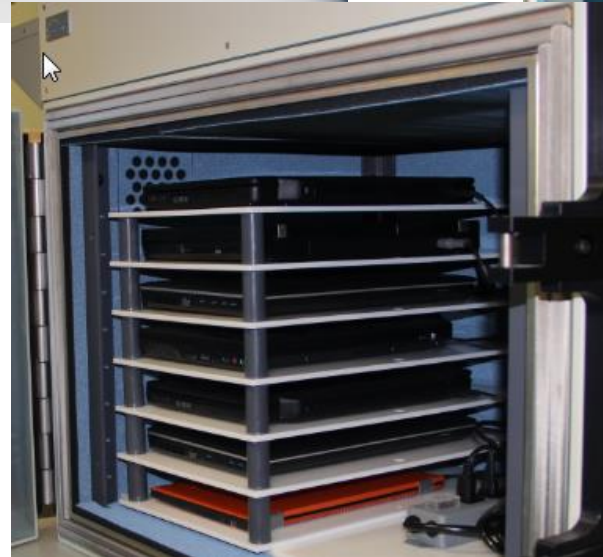
Anritsu has been doing RF for over 100 years

www.anritsu.com

Flexible Device Arrangement



Plastic hardware,
brackets and shelving
maintain controlled
anechoic environment



Anechoic Turntable Construction



Ships Fully Configured
and Ready to Use

