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THROUGHPUT TEST METHODS FOR MIMO RADIOS

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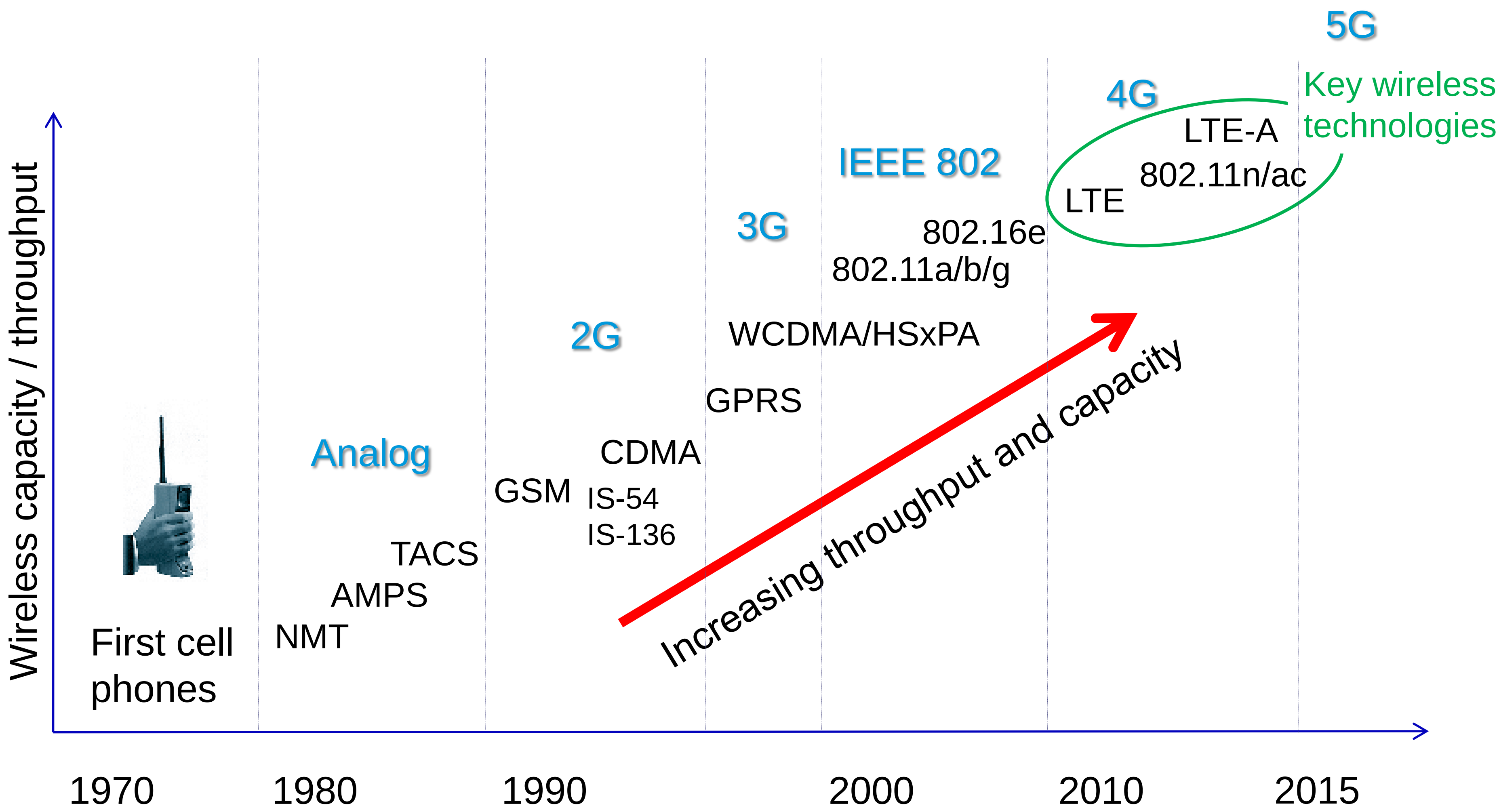
Brief History of Wireless



G = generation

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History of IEEE 802.11

- **1989**: FCC authorizes ISM bands
  - 900 MHz, 2.4 GHz, 5 GHz
- **1990**: IEEE begins work on 802.11
- **1994**: 2.4 GHz products begin shipping
- **1997**: 802.11 standard approved
- **1998**: FCC authorizes UNII Band, 5 GHz
- **1999**: 802.11a, b ratified
- **2003:** 802.11g ratified
- **2006:** 802.11n draft 2 certification by the Wi-Fi Alliance begins
- **2009:** 802.11n certification
- **2013:** 802.11ad (up to 6.8 Gbps)

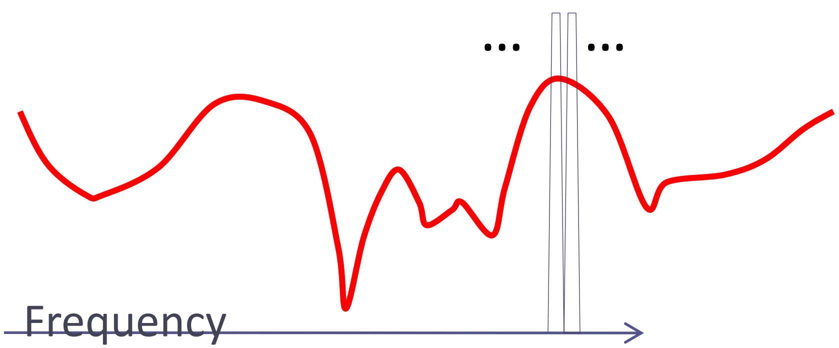
→ **2014:** 802.11ac (up to 6.9 Gbps)

802.11 has pioneered commercial deployment of OFDM and MIMO – key wireless signaling technologies

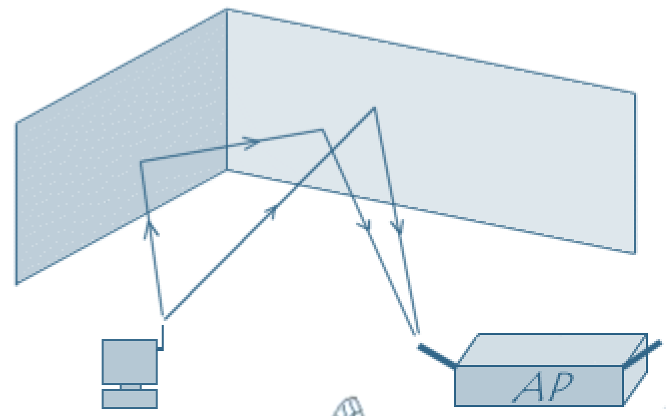
ISM = industrial, scientific and medical
UNII = Unlicensed National Information Infrastructure

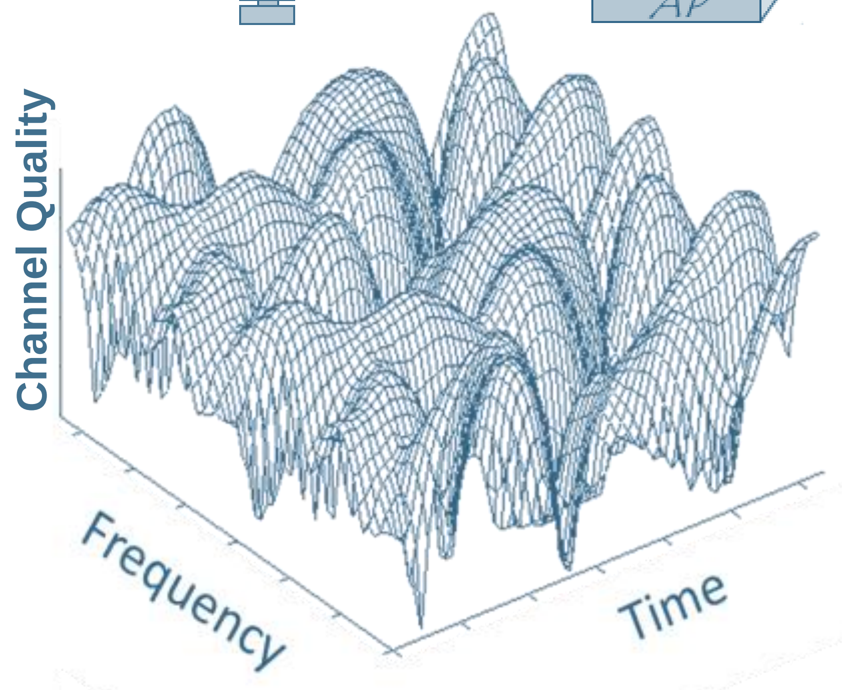
Wireless Channel

- Time and frequency variable
- OFDM transforms a frequency- and time-variable fading channel into parallel correlated flat-fading channels, enabling wide bandwidth operation



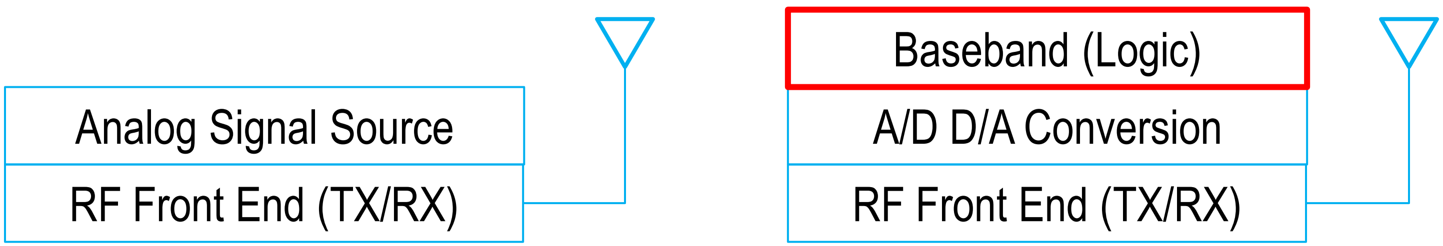
Frequency-variable channel appears flat over the narrow band of an OFDM subcarrier.





OFDM = orthogonal frequency division multiplexing

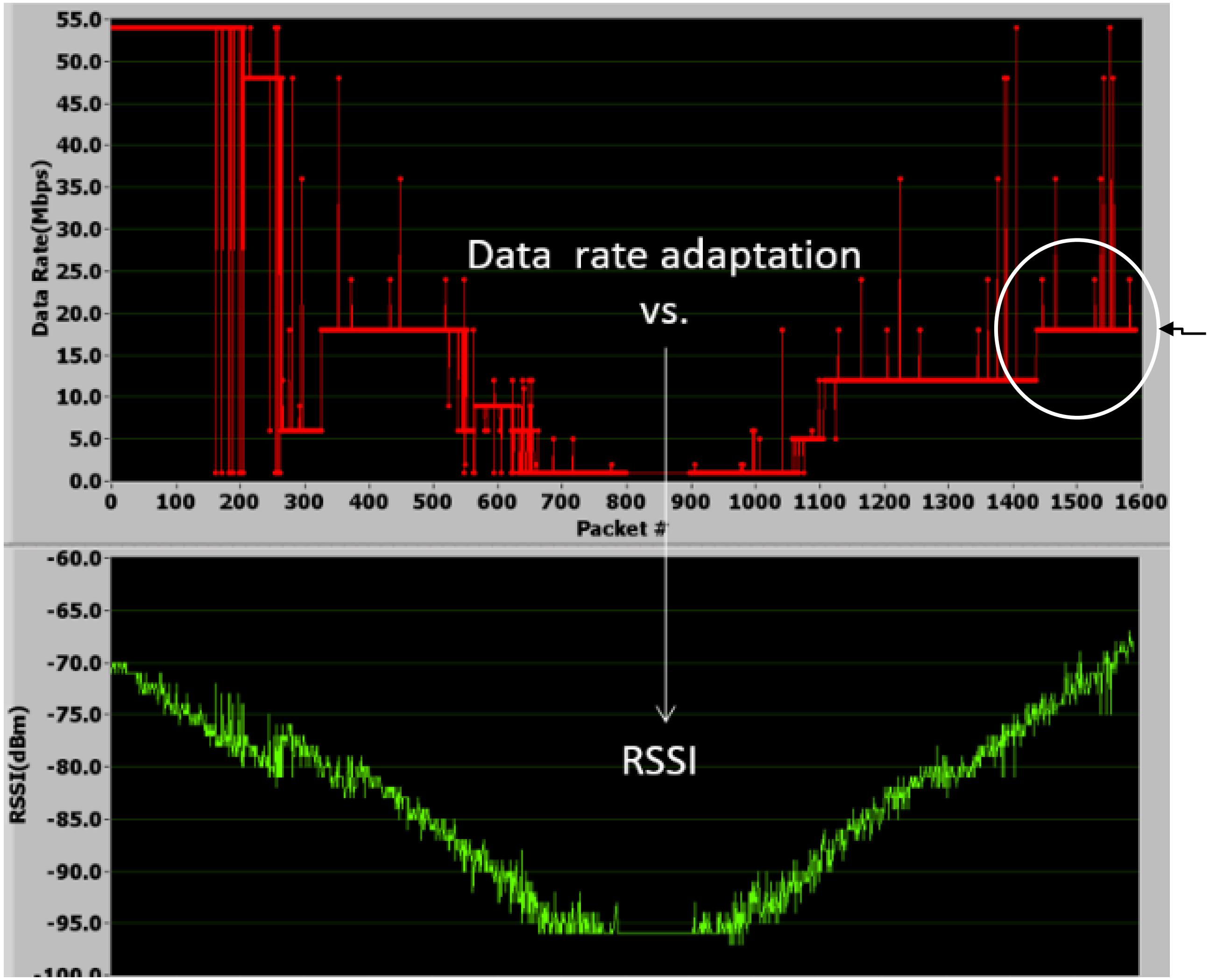
Analog to Logic Transition in Radio Architecture



Old radio architecture

Modern radio architecture

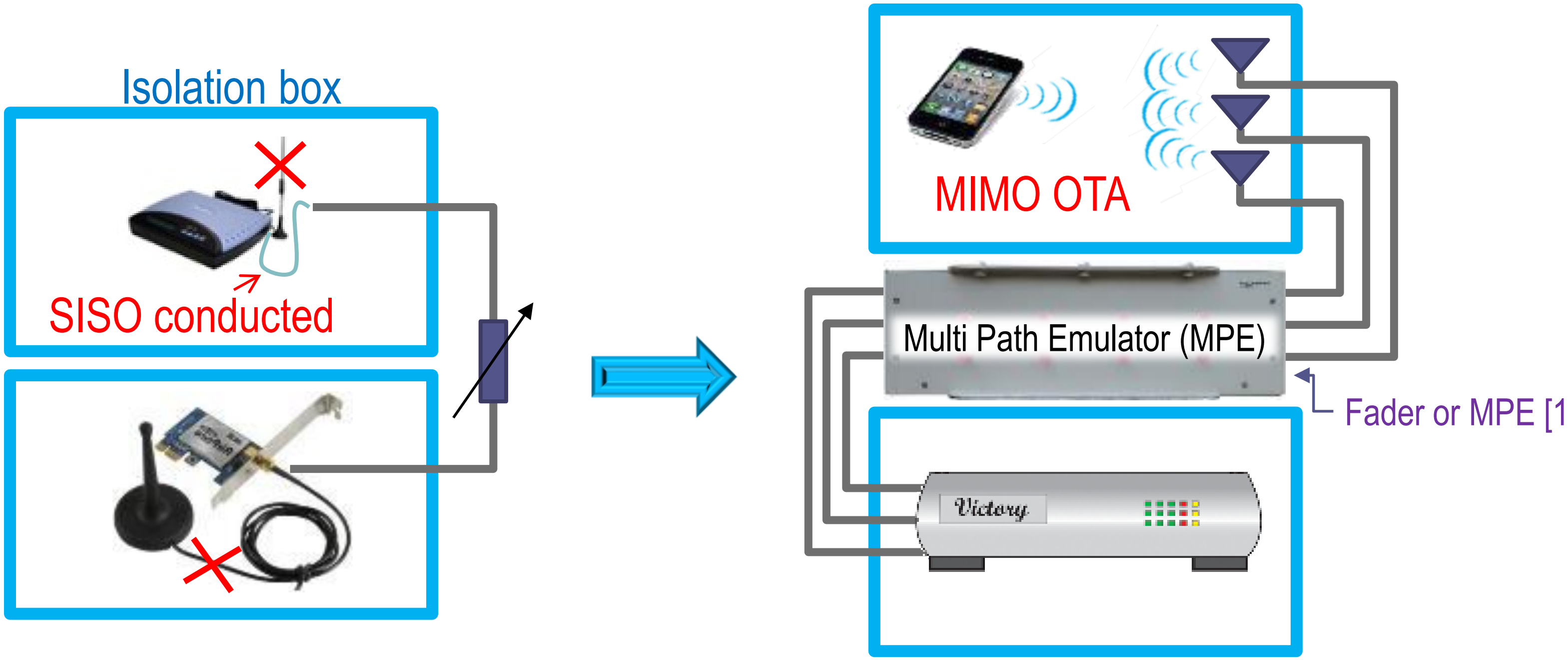
Data Rate Adaptation Example - 802.11g



Adaptation algorithms are stateful.

In this example data rate never recovers to its peak value of 54 Mbps even though favorable channel conditions are restored.

Controlled Environment Testbed



New generation wireless testbeds must support MIMO OTA testing to accommodate MIMO and multi-radio devices with internal antennas.

Adaptation Parameters 802.11a/b/g/n/ac

Adaptation	Variables
Modulation	BPSK, QPSK, 16-QAM, 65-QAM, 256-QAM
Signaling	CCK, DSSS, OFDM
Coding rate	1/2, 3/4, 5/6
# spatial streams	1 to 8
Channel width	Wi-Fi: 20/40/80/160 MHz LTE: up to 20 MHz
Guard Interval (GI)	Wi-Fi: 400/800 ns; LTE: 5.2 usec
MIMO mode	Spatial Multiplexing (SM) TX diversity RX diversity Beamforming

Refer to 802.11 documents [2-3] for details of the latest 802.11 technology

CCK = complementary code keying
DSSS = direct sequence spread spectrum
OFDM = orthogonal frequency division multiplexing
BPSK = binary phase shift keying
QPSK = quadrature phase shift keying
QAM = quadrature amplitude modulation

Example of 802.11ac Device Throughput

Example of throughput measurement of an 802.11ac link using IxChariot™. In this example the test conditions are static, but it appears that the adaptation algorithm of the TX DUT keeps making adjustments resulting in throughput fluctuations vs. time.

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Data Rate Calculation Spreadsheet

Created by octoScope: http://www.octoscope.com/cgi-bin/start.cgi/Array_Pages/Entrance_RequestArticles.html?SourceCode=Whitepapers

802.11n

20 MHz, 1 stream, 1 FEC encoder				*Mandatory*	
MCS Index	R	Nbpscs	Nsd	*Data Rate (Mbps)* 800 ns GI	400 ns GI
0	0.5	BPSK 1	52	6.5	7.2
1	0.5	QPSK 2	52	13.0	14.4
2	0.8	2	52	19.5	21.7
3	0.5	16QAM 4	52	26.0	28.9
4	0.8	4	52	39.0	43.3
5	0.7	64QAM 6	52	52.0	57.8
6	0.8	6	52	58.5	65.0
7	0.8	6	52	65.0	72.2

…

40 MHz, 4 streams, 1 FEC encoder					4
MCS Index	R	Nbpscs	Nsd	*Data Rate (Mbps)* 800 ns GI	400 ns GI
24	0.5	1	108	54.0	60.0
25	0.5	2	108	108.0	120.0
26	0.8	2	108	162.0	180.0
27	0.5	4	108	216.0	240.0
28	0.8	4	108	324.0	360.0
29	0.7	6	108	432.0	480.0
30	0.8	6	108	486.0	540.0
31	0.8	6	108	540.0	600.0

802.11ac

20 MHz, 1 stream					
MCS Index	R	Nbpscs	Nsd	*Data Rate (Mbps)* 800 ns GI	400 ns GI
0	0.50	1	52	6.5	7.2
1	0.50	2	52	13.0	14.4
2	0.75	2	52	19.5	21.7
3	0.50	4	52	26.0	28.9
4	0.75	4	52	39.0	43.3
5	0.67	6	52	52.0	57.8
6	0.75	6	52	58.5	65.0
7	0.83	6	52	65.0	72.2
8	0.75	128QAM 8	52	78.0	86.7

…

80+80 MHz, 8 streams					
MCS Index	R	Nbpscs	Nsd	*Data Rate (Mbps)* 800 ns GI	400 ns GI
0	0.50	1	234	468.0	520.0
1	0.50	2	234	936.0	1040.0
2	0.75	2	234	1404.0	1560.0
3	0.50	4	234	1872.0	2080.0
4	0.75	4	234	2808.0	3120.0
5	0.67	6	234	3744.0	4160.0
6	0.75	6	234	4212.0	4680.0
7	0.83	6	234	4680.0	5200.0
8	0.75	8	234	5616.0	6240.0
9	0.83	8	234	6240.0	6933.3

R = coding rate
Nbpscs = Number of coded bits per subcarrier
Nsd = Number of data subcarriers
GI = guard interval

800ns GI data rate in MHz per stream = R*Nbpscs*Nsd/4
400ns GI data rate in MHz per stream = R*Nbpscs*Nsd/3.6

Currently Shipping Maximum Data Rate

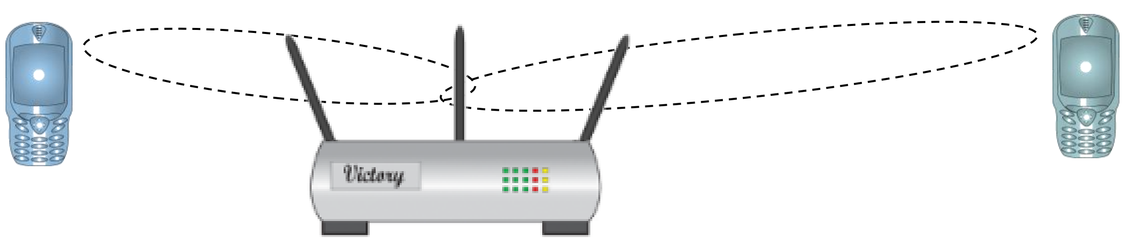
802.11ac

80 MHz, 3 streams					
MCS Index	**R**	**Nbpscs**	**Nsd**	***Data Rate (Mbps)***	
				800 ns GI	**400 ns GI**
0	0.50	1	234	87.8	97.5
1	0.50	2	234	175.5	195.0
2	0.75	2	234	263.3	292.5
3	0.50	4	234	351.0	390.0
4	0.75	4	234	526.5	585.0
5	0.67	6	234	702.0	780.0
6					
7	0.83	6	234	877.5	975.0
8	0.75	8	234	1053.0	1170.0
9	0.83	8	234	1170.0	1300.0

1.3 Gbps

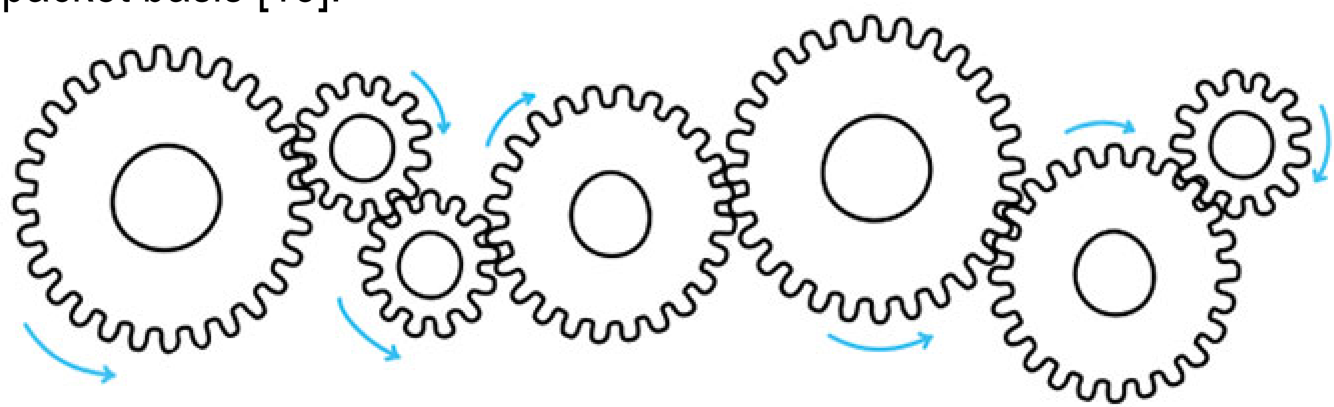
MIMO Modes of Transmission

MIMO Mode	Explanation
Spatial Multiplexing	Use of multiple MIMO radios to transmit two or more data streams in the same channel.
TX diversity	Use of multiple MIMO radios to transmit slightly different versions of the same signal in order to optimize reception of at least one of these versions. TX diversity schemes include space time block coding (STBC), space frequency block coding (SFBC) and cyclic delay diversity (CDD).
RX diversity	Use of multiple MIMO radios to combine multiple received versions of the same signal in order to minimize PER. A common RX diversity technique is maximal ratio combining (MRC).
Combination of TX and RX diversity	Use of TX diversity at the transmitting device in combination with RX diversity at the receiving device.
Beamforming	Use of multiple MIMO transmitters to create a focused beam, thereby extending the range of the link or enabling SM.
Multi-user MIMO (MU-MIMO)	Forming multiple focused beams or using TX diversity techniques to enable simultaneous communications with multiple device. Typically beamforming is done by a base station or an access point (AP) to communicate simultaneously with multiple client devices.



MIMO Test Challenges

- Getting repeatable and consistent measurements is next to impossible in open air conditions. The reasons?
  1. Modern wireless devices are designed to automatically adapt to the changing channel conditions.
  2. Adaptation algorithms programmed into the baseband layer of these radios are complex and sometimes get into unintended states.
  3. Wireless environment is time-, frequency- and position- variable in terms of path loss, multipath, Doppler effects and interference, often stumping the decision logic of the adaptation algorithms.
- MIMO radios can change their data rate from 1 Mbps to over 1 Gbps on a packet-by-packet basis [13].



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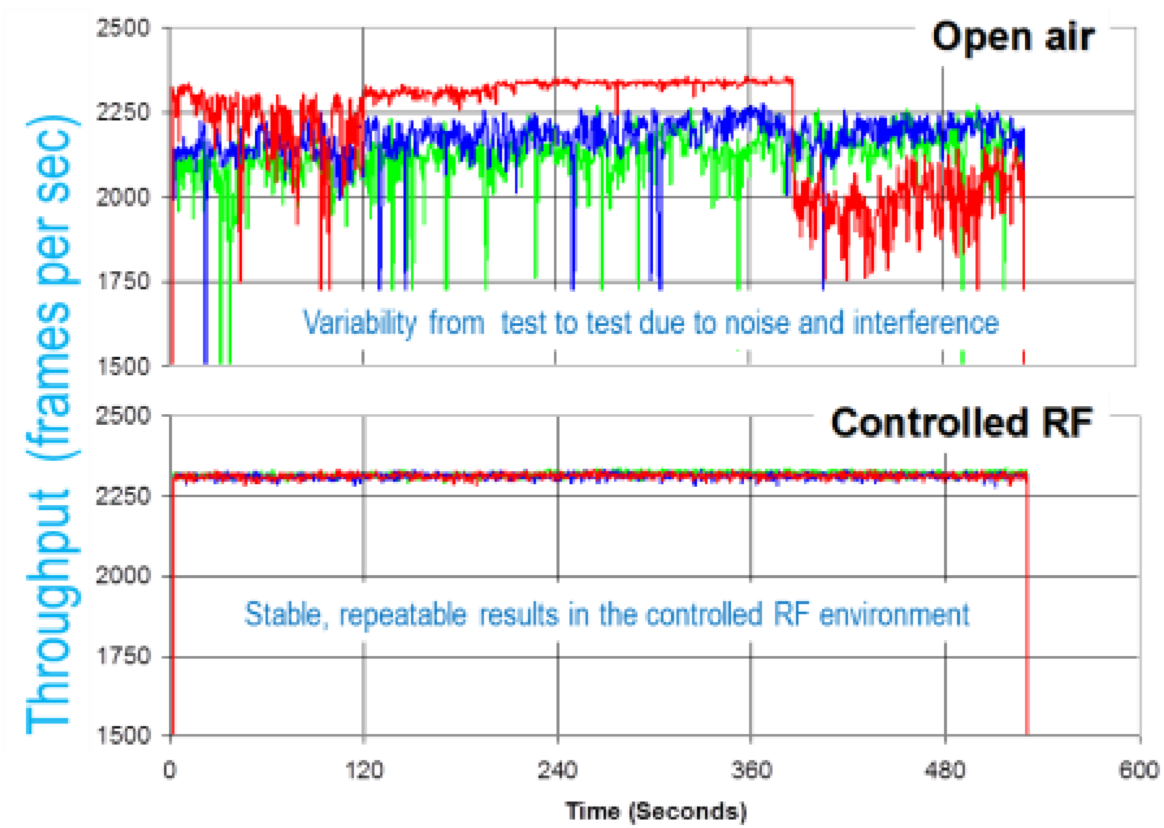
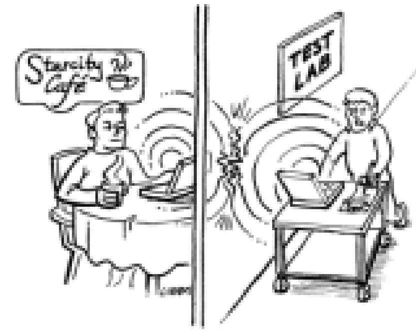
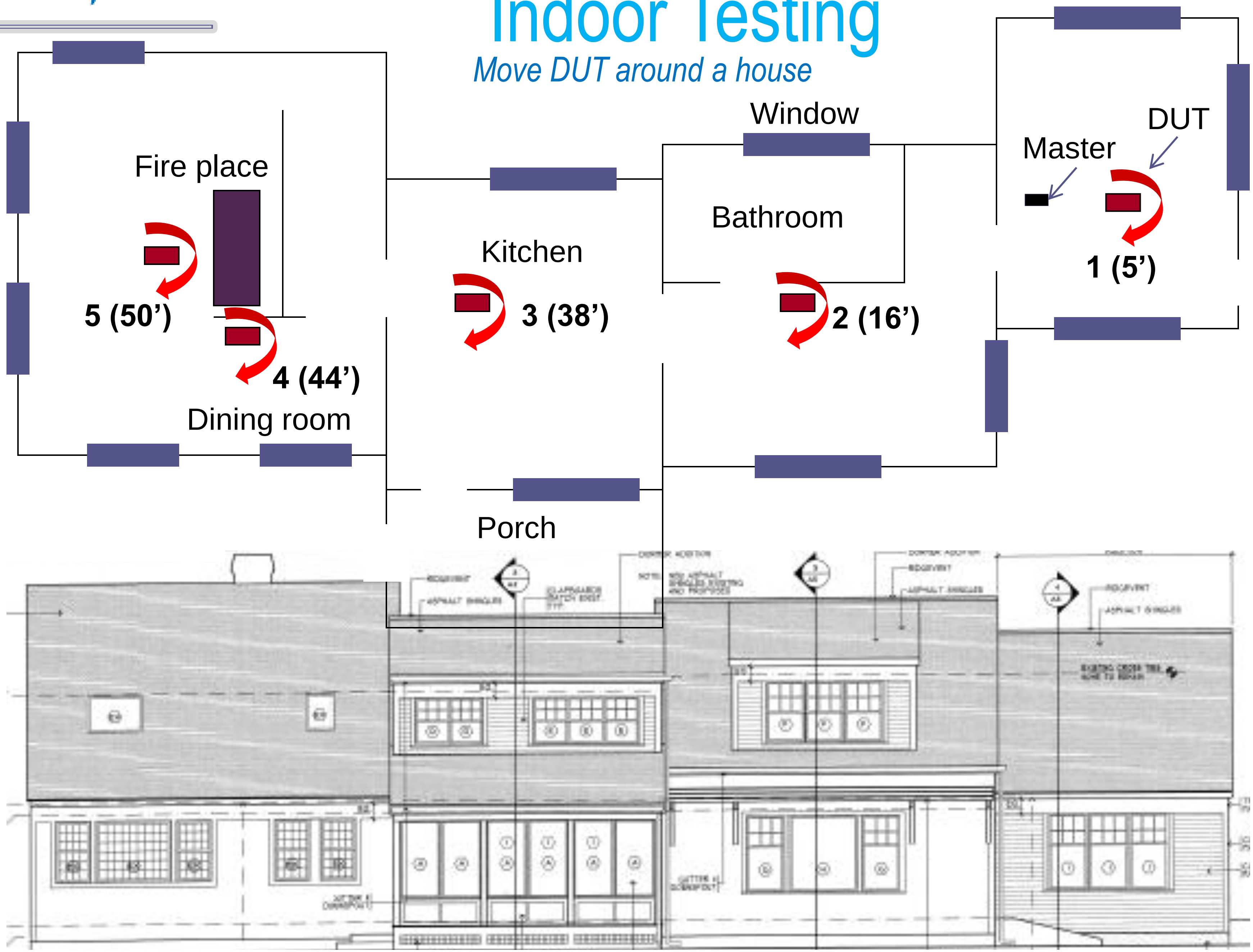
Impact of RF Environment





Indoor Testing

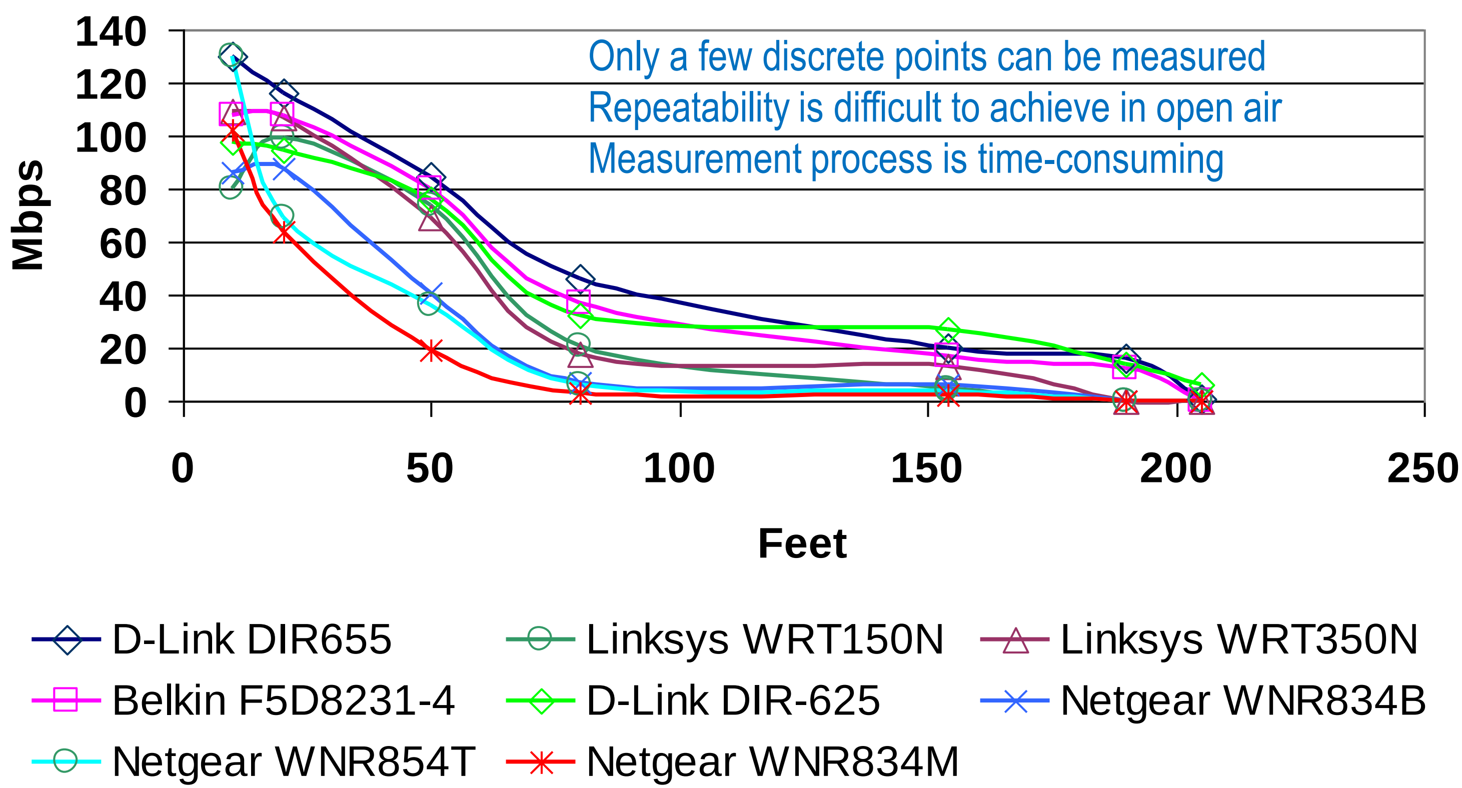
Move DUT around a house

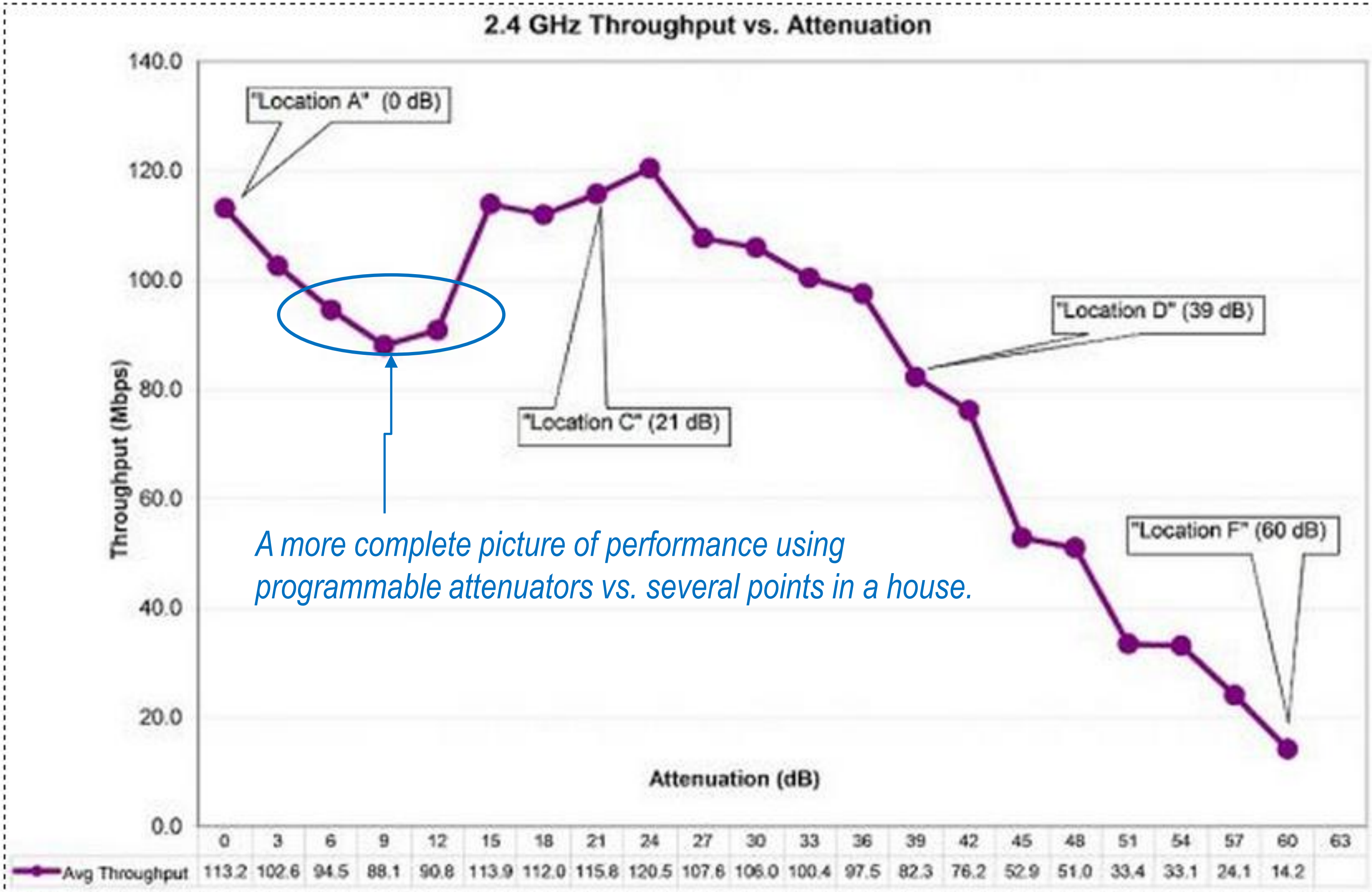


Example Test Results – Real Home

octoScope test of 802.11n pre-standard products, 2007

http://www.octoscope.com/English/Collaterals/Articles/octoScope_CompetitiveTest802.11nProducts_20070619.pdf





octoBox MPE Test Location Attenuations - 2.4 GHz

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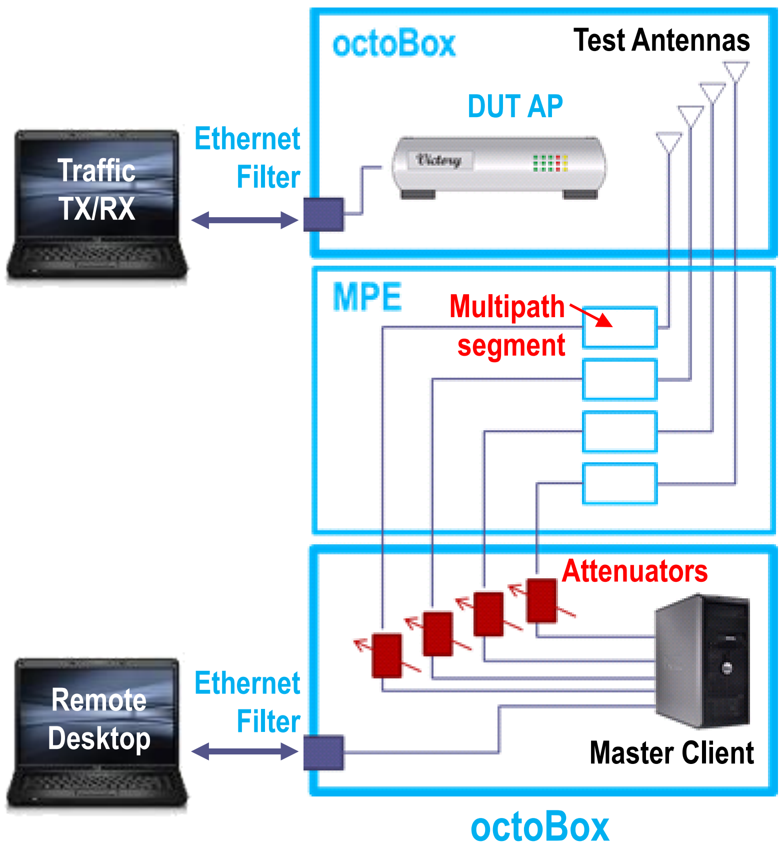
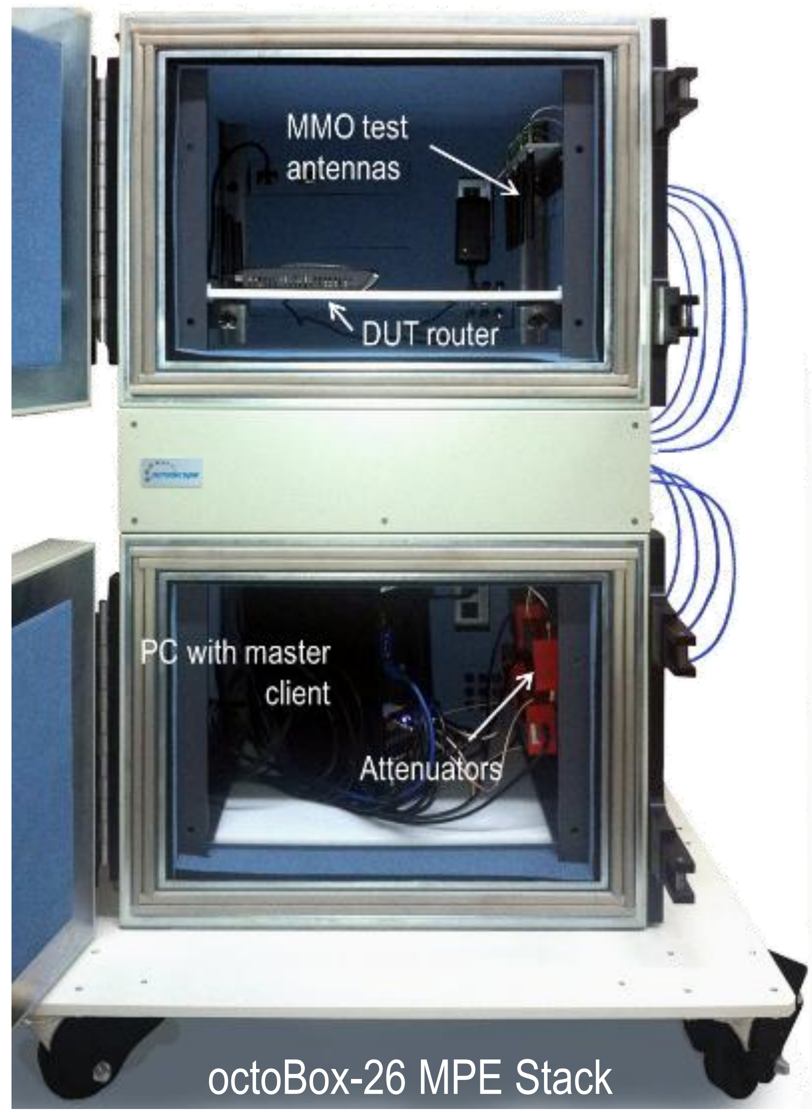
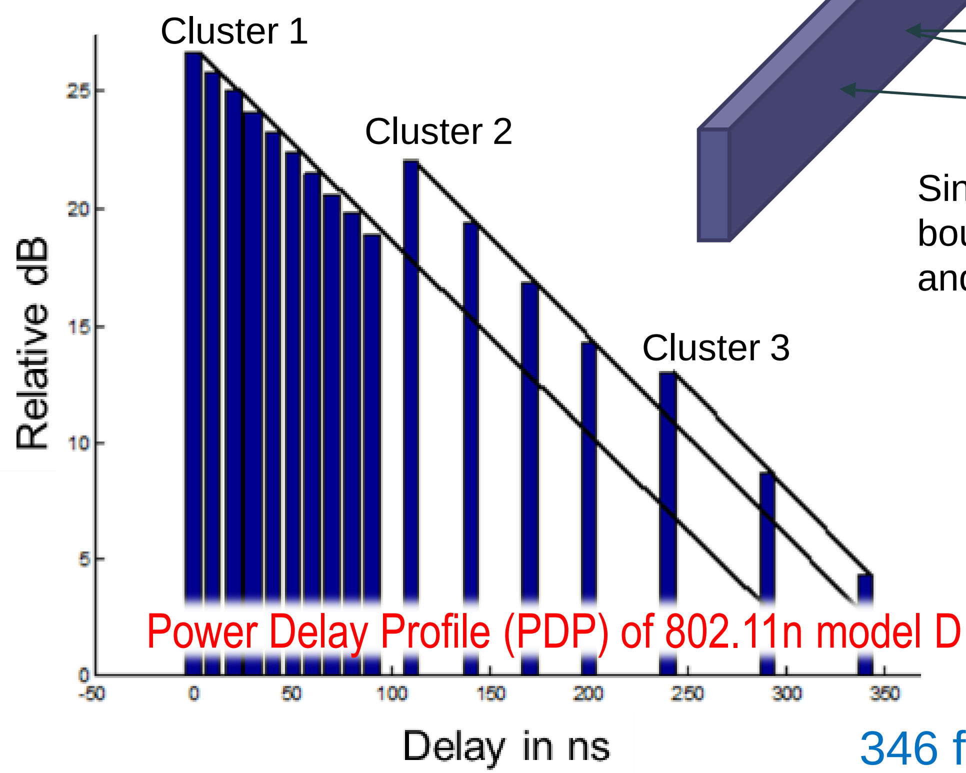
octoBox-MPE MIMO OTA Testbed Diagram





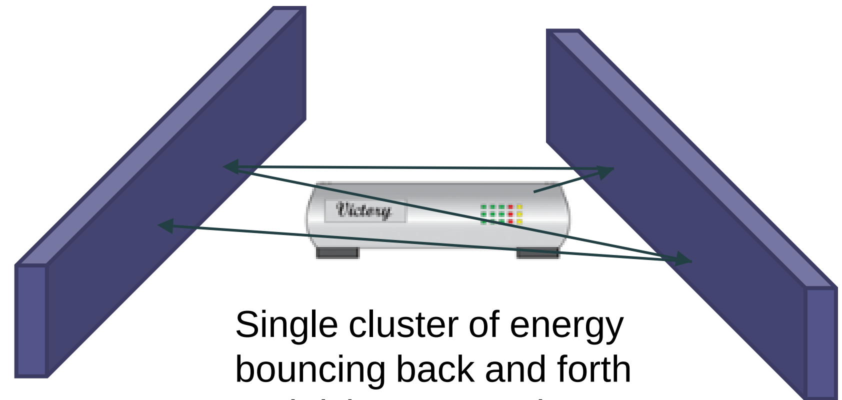
OTA = over the air

Clusters and Power Delay Profile



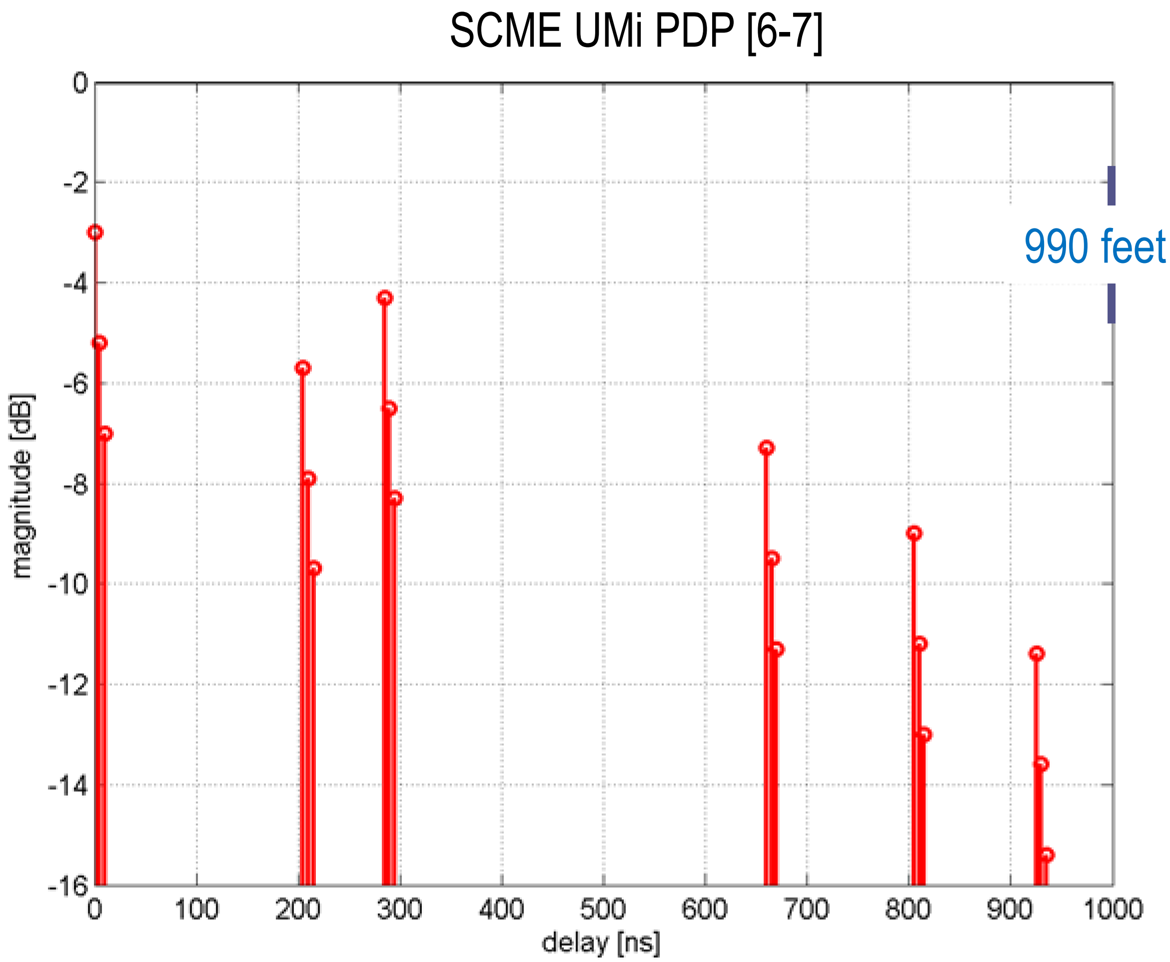
Power Delay Profile (PDP) of 802.11n model D

346 feet



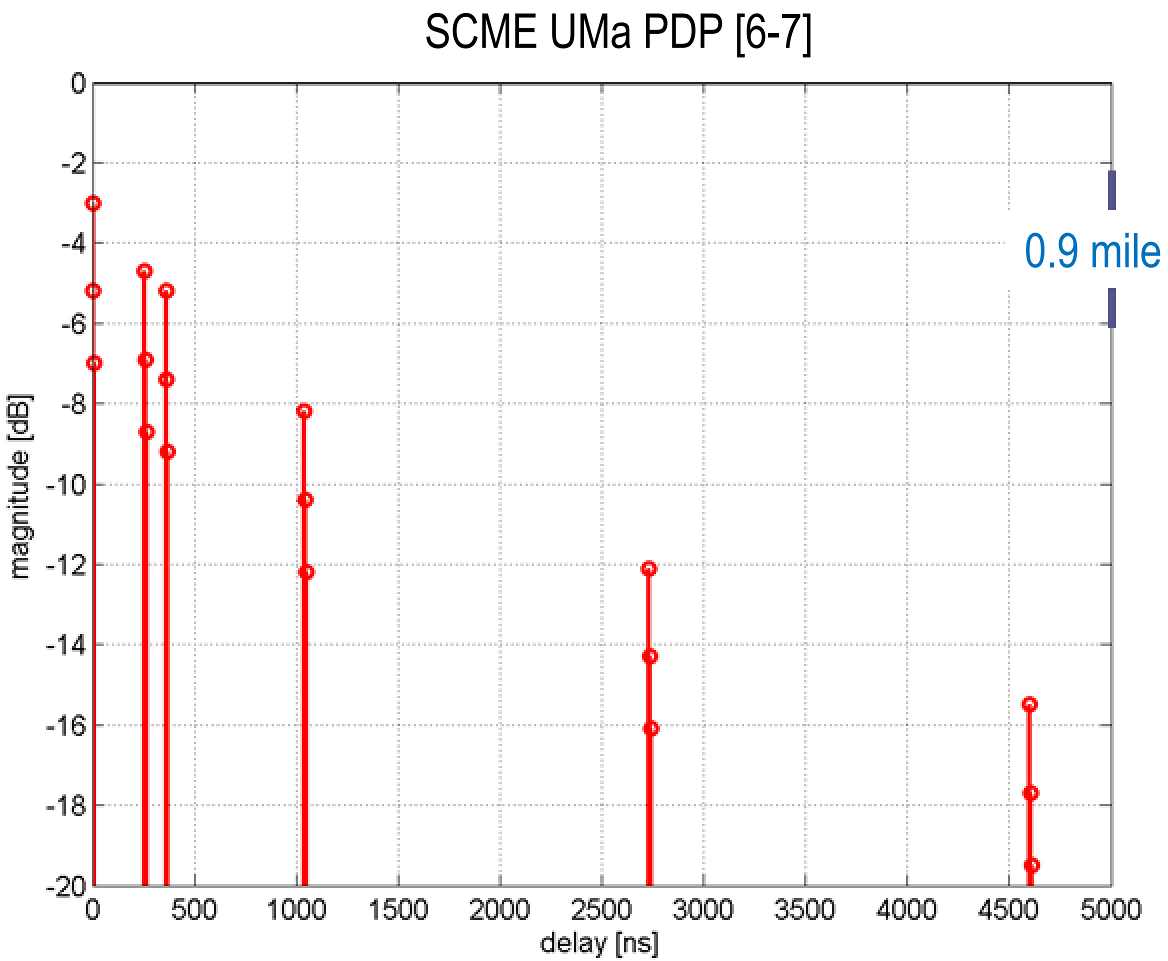
Single cluster of energy bouncing back and forth and dying out vs. time.

SCME Urban Micro-cell Model PDP



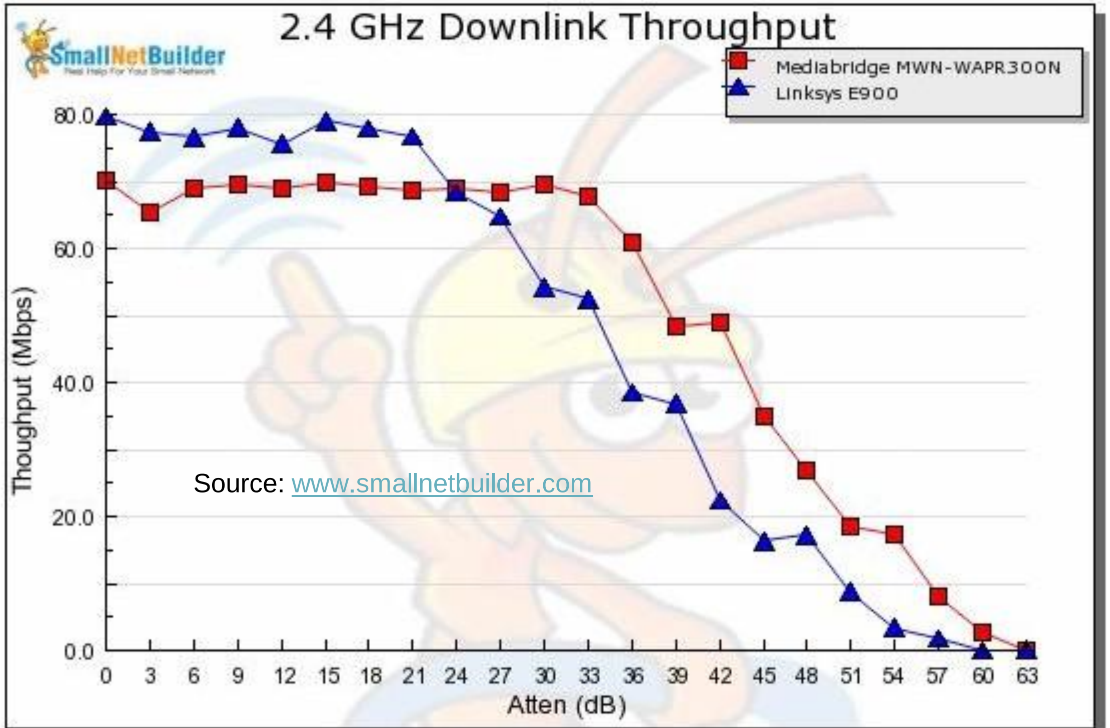
SCME = spatial channel models extended
UMi = Urban Micro
PDP = power delay profile

SCME Urban Macro-cell Model PDP



SCME = spatial channel models extended
UMa = Urban Macro
PDP = power delay profile

Benchmarking of MIMO Throughput

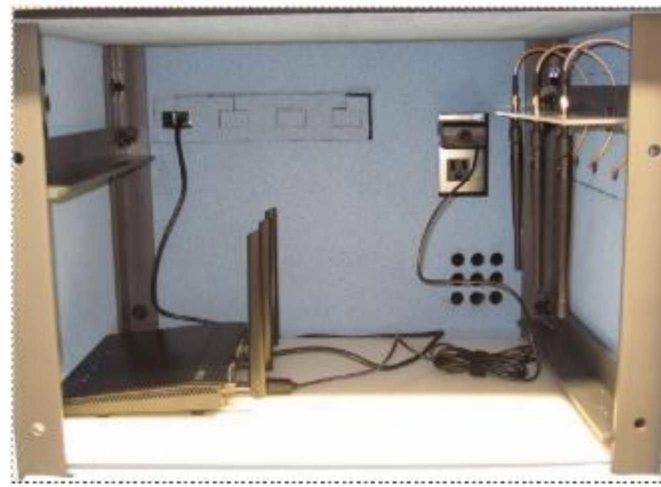


Source: www.smallnetbuilder.com

Product	Atten (dB)																					
	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63
Mediabridge Medialink Wireless N Broadband Router (MWN-WAPR300N)	70	65	69	70	69	70	69	69	69	69	70	68	61	49	49	35	27	18	17	8	3	0
Test Notes for Mediabridge Medialink Wireless N Broadband Router (MWN-WAPR300N): Test client: ASUS PCE-AC66U (Win 7 6.30.95.26 driver) for 2.4 & 5 GHz tests																						
Linksys Wireless-N300 Router (E900)	80	77	77	78	76	79	78	77	68	65	54	52	39	37	22	16	17	9	3	2	0	0
Test Notes for Linksys Wireless-N300 Router (E900): Test client: ASUS PCE-AC66U (Win 7 6.30.95.26 driver) for 2.4 & 5 GHz tests																						

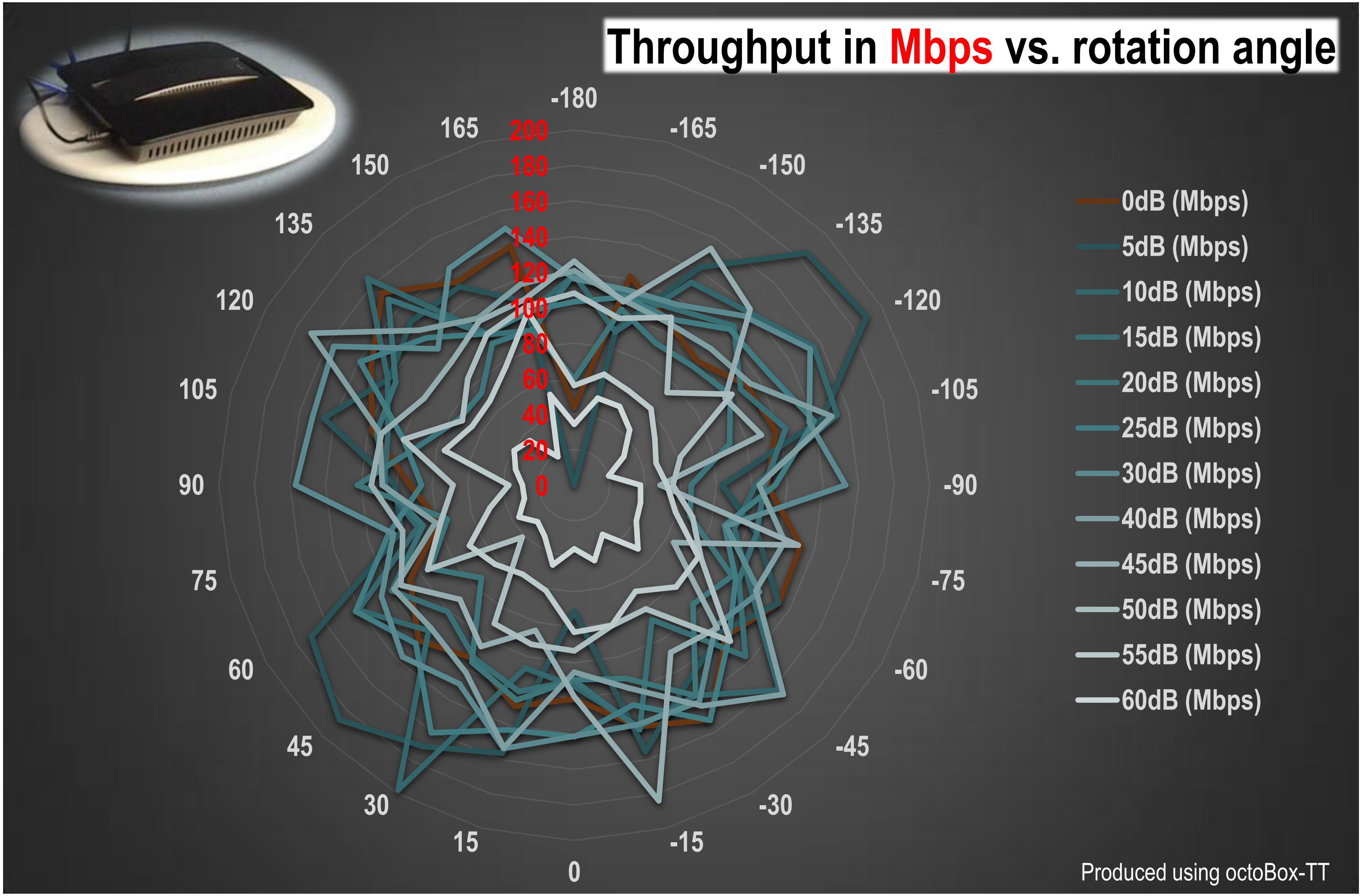
Linksys EA6500 in Upper Test Chamber - "0 degree" Position

And here is an ASUS RT-AC66U in the same starting test position.



http://www.smallnetbuilder.com/wireless/wireless-howto/32082-how-we-test-wireless-products-revison-7

Turntable Throughput Test Data




Watch video at this link:
http://www.youtube.com/watch?v=04JOt-3aivg
OB-38-TT

Concluding Thoughts

- Test engineers face difficult challenges when measuring MIMO performance because
  - Wireless channel environment is constantly changing
  - Radio operating mode changes to adapt to the changing environment
  - Makes it difficult to obtain repeatable test results
- To guarantee repeatable and meaningful results the testbed must be
  - Capable of creating a range of realistic wireless channel conditions in a consistent manner
  - Well isolated to keep interference from impacting the performance of highly sensitive radios
  - Easy to maintain isolation vs. use
- A testbed used for benchmarking must be able to support multiple spatial streams showing maximum throughput of the DUT

For More Information

- To download white papers, presentations, test reports and articles on wireless topics, please visit http://www.octoscope.com/English/Resources/Articles.html

Thank you

www.octoscope.com

References

1. Azimuth ACE, Spirent VR5, Anite Propsim faders are the most popular faders on the market today. octoScope's multipath emulator, MPE, is a simpler non-programmable fader that comes built into a controlled environment test bed with 2 octoBox anechoic chambers.
2. IEEE P802.11-REVmc/D2.3, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications", December 2013
3. IEEE P802.11ac/D6.0, "Draft STANDARD for Information Technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz", July 2013
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12. IEEE P802.11.2/D1.0, "Draft Recommended Practice for the Evaluation of 802.11 Wireless Performance", April 2007
13. "802.11 Data Rate Computation" spreadsheet, 12/2013, http://www.octoscope.com/cgi-bin/start.cgi/Array_Pages/Entrance_RequestArticles.html?SourceCode=Whitepapers

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Recent Online 5-Lecture Webinar

- **On-line course: Testing MIMO Radios**

Part I: Wireless Technology Update
This opening session will provide an overview of wireless technology and an update on the IEEE and LTE standards. We will focus on today's key wireless technologies: WiFi and LTE. Our material will also include an overview of industry standards for wireless test.

Part II: All You Ever Want to Know About Channel Emulation
Today's lecture will get into the details of wireless channel modeling and channel emulation equipment. A complex but important topic, channel emulation is at the heart of MIMO testing. At the end of the lecture you will know the basic theory of channel modeling, understand the available solutions, and have an overview of relevant standards activities.

Part III: MIMO Over the Air (OTA) Test Methods
Today we will discuss MIMO OTA test methods and the emerging standards. At the end of this lecture you will have an understanding of MIMO OTA test challenges and the many factors that impact MIMO throughput.

Part IV: Open Air vs. Controlled Test Environment
This lecture will examine real-life and controlled environment test methods and metrics. We will look at the tradeoffs of testing in open air vs. testing in an RF environment where real-life wireless channel conditions are emulated.

Part V: Benchmark Testing of MIMO Performance
In this lecture you will learn about benchmark test methods and challenges in achieving maximum performance of MIMO devices in a repeatable and reproducible manner. In addition, we will wrap up any loose ends from the previous days' lectures and answer any remaining questions.

DesignNews
Jan 27–31, 2014

Links to the 5 lectures

http://www.designnews.com/lecture.asp?doc_id=271003
http://www.designnews.com/lecture.asp?doc_id=271004
http://www.designnews.com/lecture.asp?doc_id=271006
http://www.designnews.com/lecture.asp?doc_id=271007
http://www.designnews.com/lecture.asp?doc_id=271008

Supplemental Material

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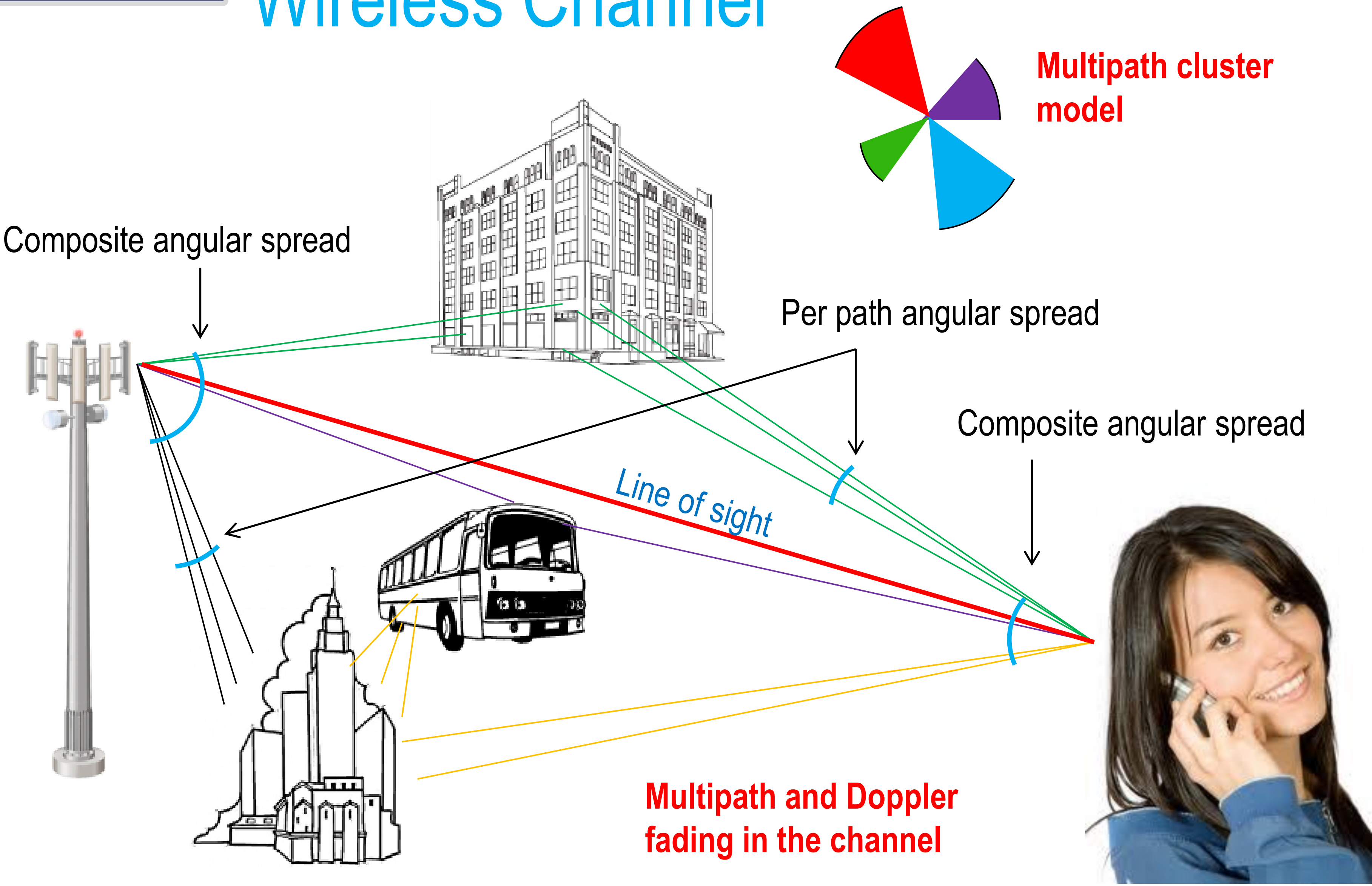
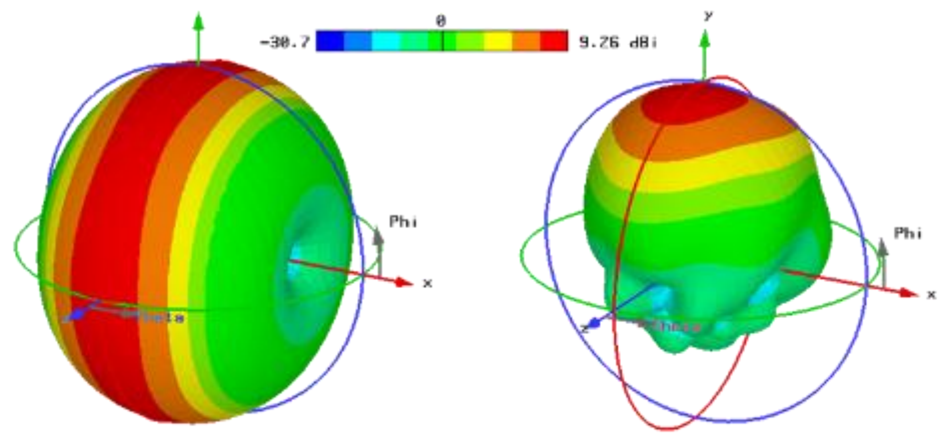
Wireless Channel



Shape of Antenna Field

- Shape of the antenna field varies from product to product
- Field can be blocked by metal surfaces such as batteries, ground planes, etc.

simulation of a dipole antenna field

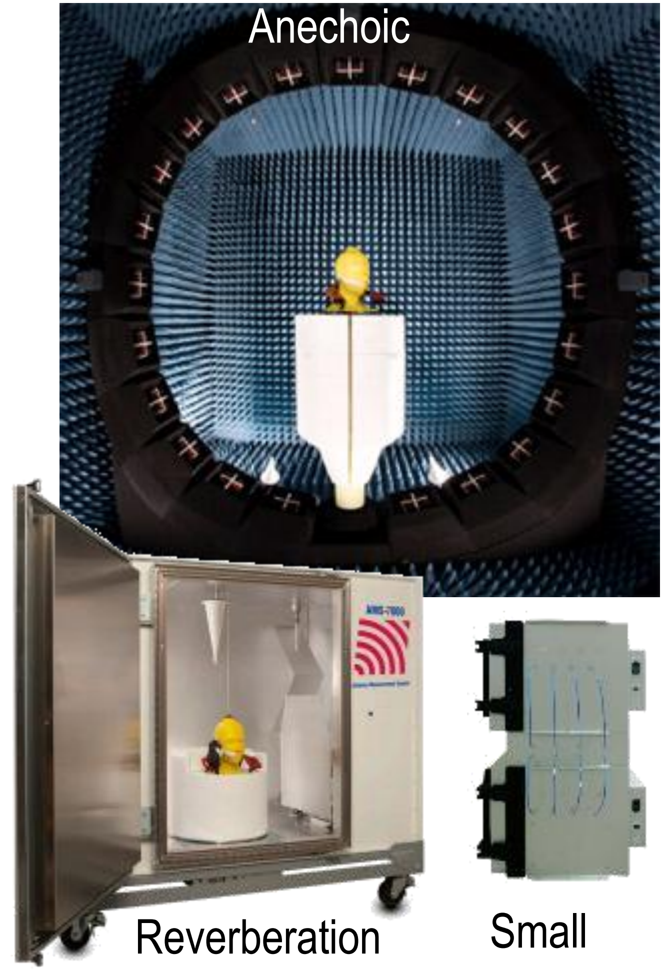


open air

inside a Wi-Fi device

MIMO OTA Test Methods

- Standards for traditional TIS/TRP 3D OTA test methods were developed by CTIA for SISO radios
- Emerging standards for MIMO OTA test methods focus on throughput FOM
- Anechoic, reverberation, 2-Stage and other test methods are being developed by 3GPP and CTIA



TRP = Total Radiated Power
TIS = Total Isotropic Sensitivity
OTA = over the air
FOM = figure of merit
CTIA = Cellular Télécommunications & Internet Association
3GPP = 3rd Generation Partnership Project

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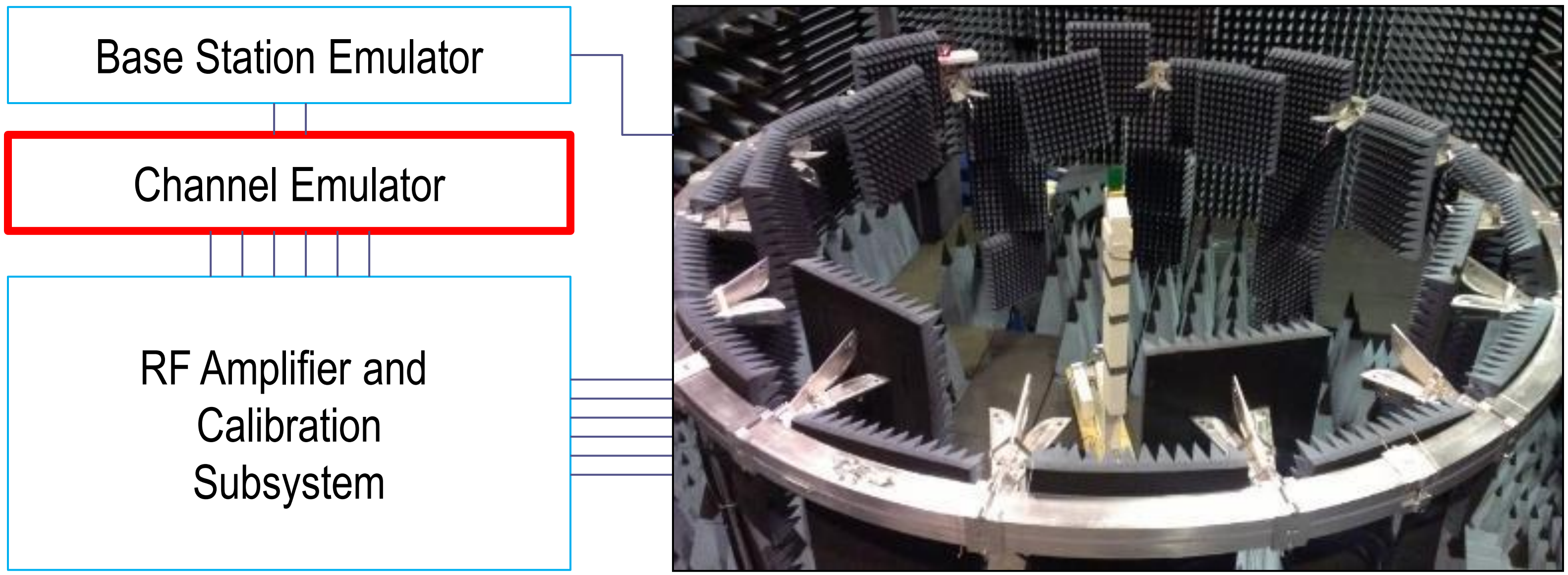
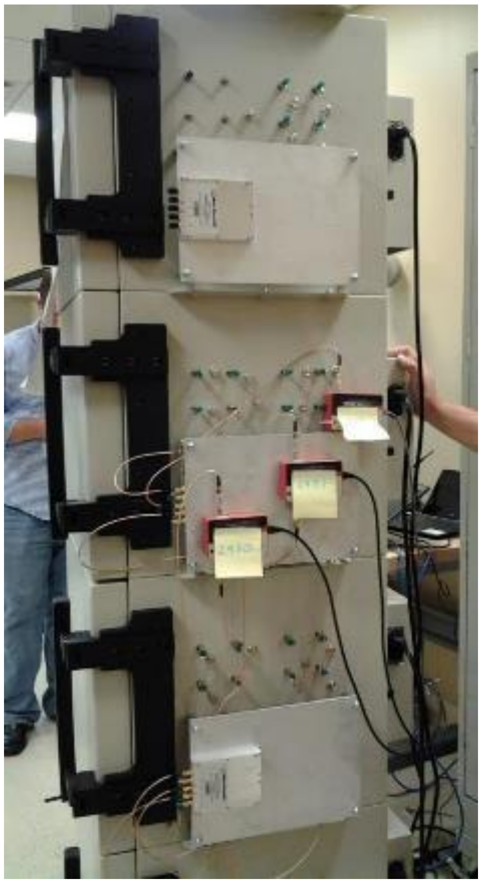
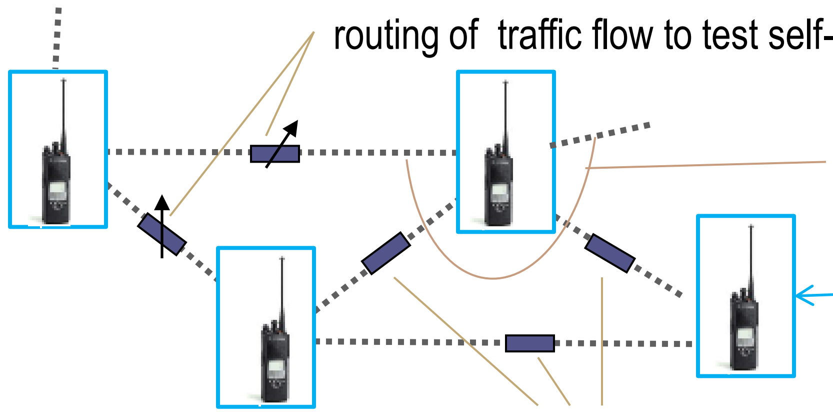
MIMO OTA Anechoic Chamber Testbed



Wireless Mesh Test Configuration





octoBox quadStack isolation enclosures with built-in RF combiners and attenuators

Connected Car (DSRC) Testbed

octoBox quadStack

Emulate groups of connected vehicles traveling over a busy highway interchange