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Next-Generation Mobile Technologies

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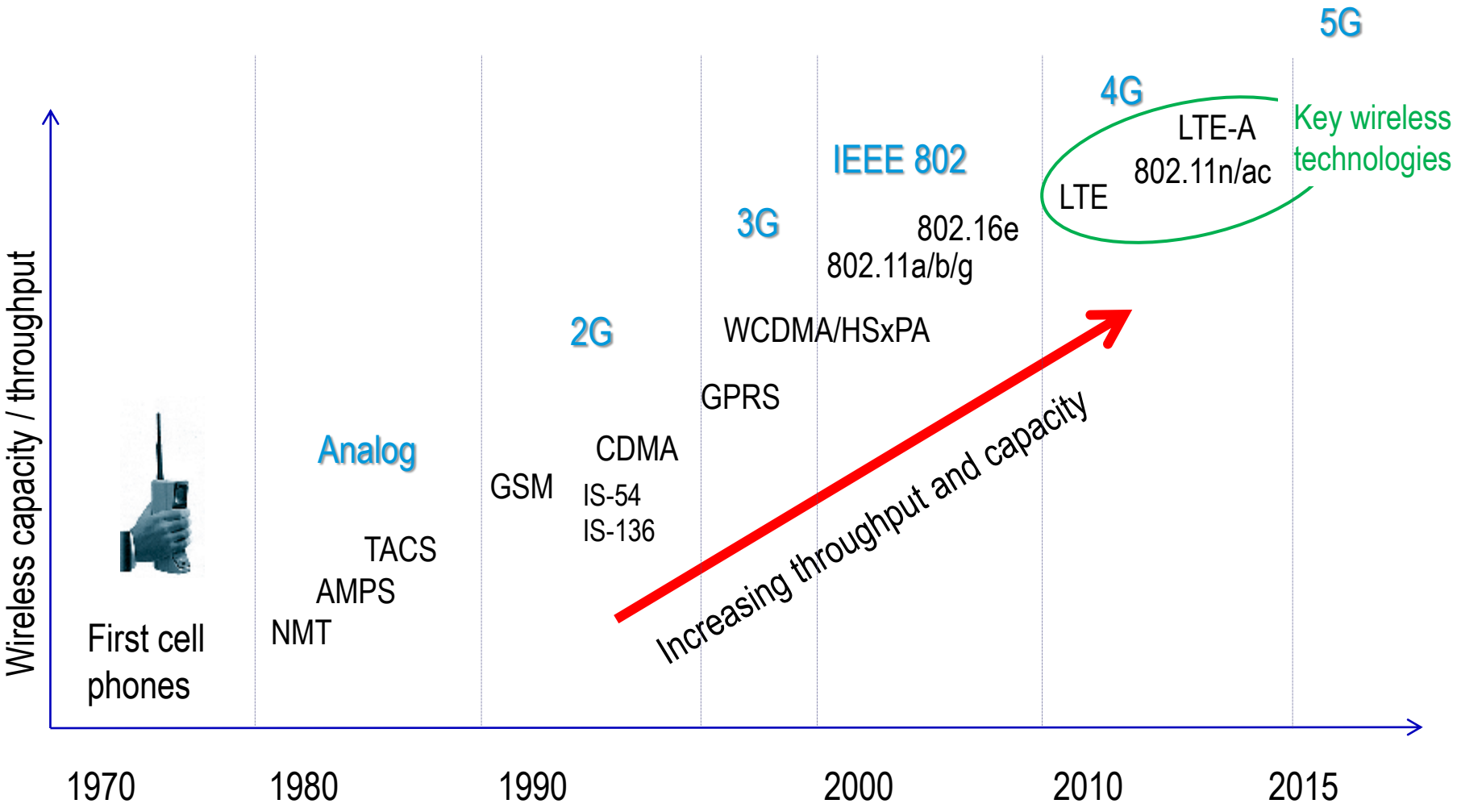
Brief History of Wireless

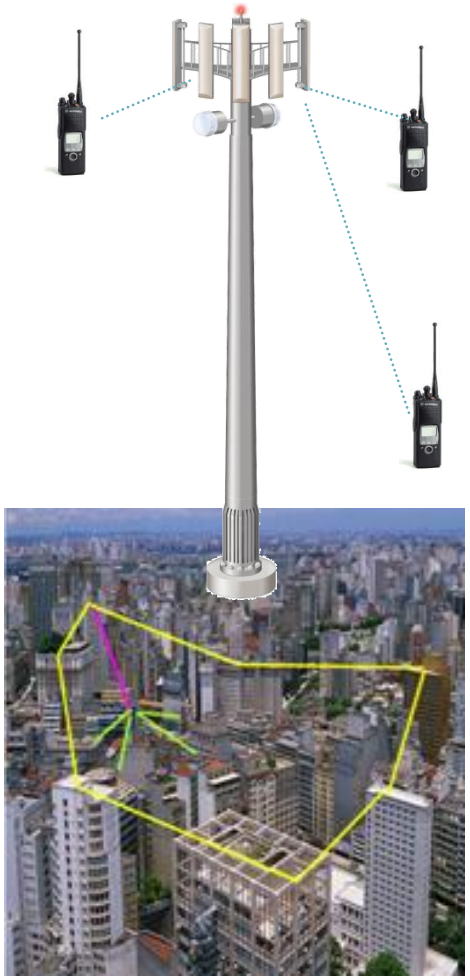


G = generation

Wireless Topologies

- 2G/3G/LTE and most Wi-Fi networks are infrastructure based
- Mesh networks (e.g. 802.11s) are sometimes used to interconnect APs or base stations to the central carrier or corporate network or to the internet
- With the spread of LTE, the trend is towards smaller base stations and smaller cells interconnected via microwave (sometimes Wi-Fi) mesh networks
- Wireless backhaul is starting to displace traditional expensive fiber or copper cabling

Infrastructure network

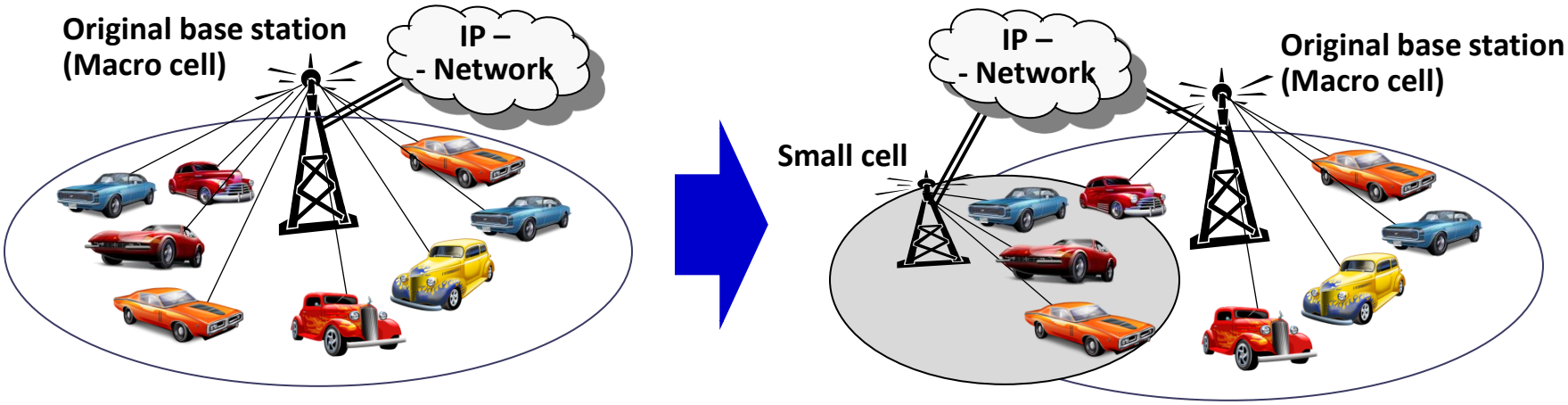


Mesh network

Small 2G/3G/LTE base stations are interconnected via microwave links.

AP = access point
LTE = long term evolution

Implications of the Small Cell Architecture



- Issues with small cell architecture include
  - Increased instances of cell edge interference
  - Frequent handovers that may cause interruptions in transmission and dropped connections
- Need provisions for simpler automated installation

LTE-Advanced Emerging Specifications

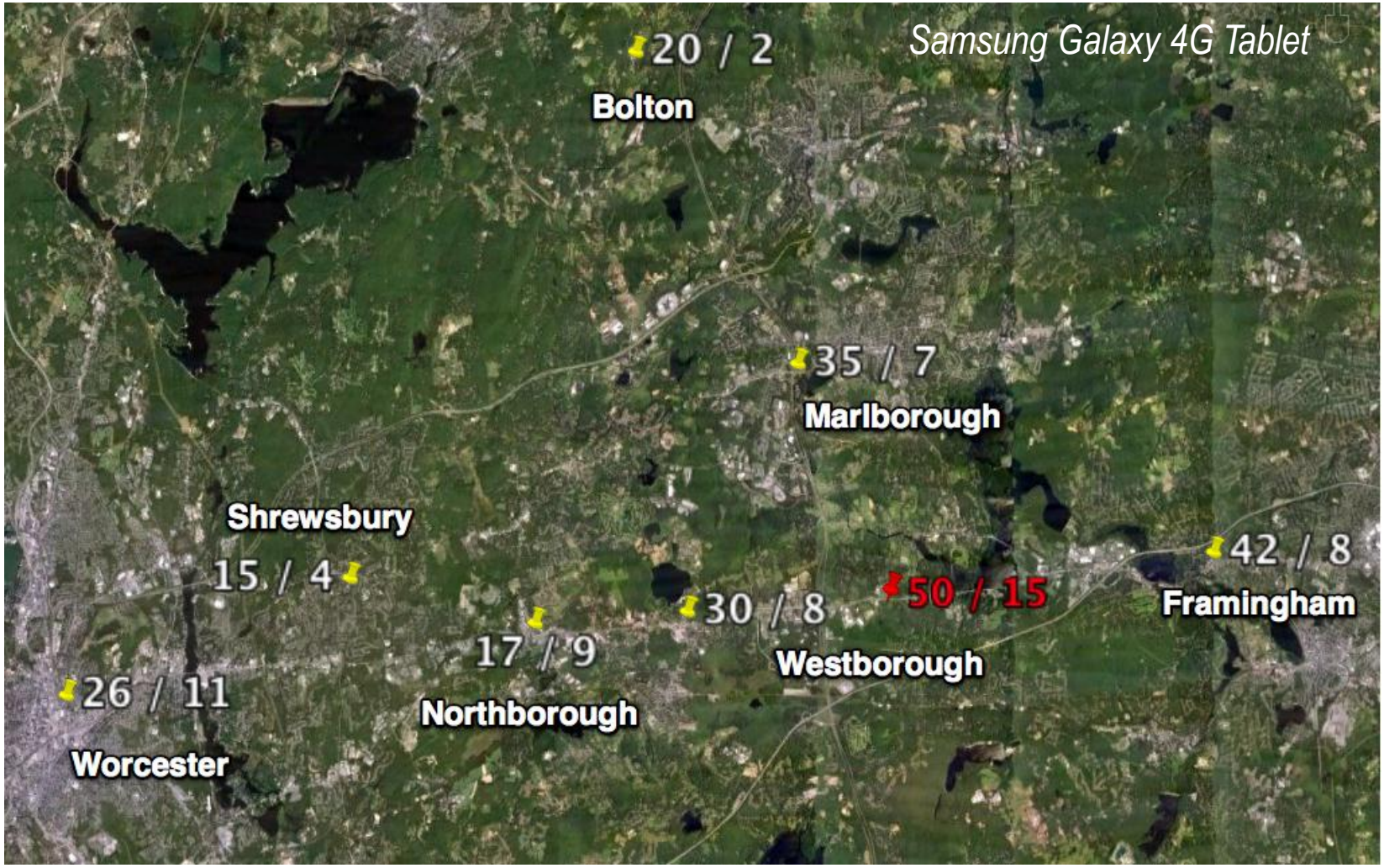
Technologies /Solutions		Objectives
I	**HetNet** Heterogeneous network with Macro/Pico/Femto cells	Eliminate issues with Femto/Micro/Macro-cell converged network
II	**SON** Self Organizing Network	Self configuration of smaller eNBs
III	**Carrier Aggregation**	Implement wider LTE-advanced spectrum with limited spectrum resources. {Asymmetric (DL/UL) band for FDD is available.}
IV	**3G / 4G Handover**	Enable 3G-4G hand-over (currently not available for LTE)
V	**MIMO for Downlink (Up to 8 X 8)**	Higher data transmission for Downlink; beamforming for longer range or for multi-user MIMO
VI	**MIMO for Uplink (Up to 8 X 8)**	Higher data transmission for Uplink or for multi-user MIMO
VII	**Relay**	Higher data rate, Expand coverage, Improve cell-edge reception
VIII	**CoMP** Coordinated multi-point transmission and reception	Helps manage band-edge eNB interference: inter-cell interference coordination (ICIC)

eNB = e Node B
DL = downlink
UL = uplink
FDD = frequency division duplex
MIMO = multiple input multiple output

G	The G's	Peak Data Rate (Mbps)	
		Downlink	Uplink
1	Analog	19.2 kbps	
2	Digital – TDMA, CDMA	14.4 kbps	
3	Improved CDMA variants (WCDMA, CDMA2000)	144 kbps (1xRTT); 384 kbps (UMTS); 2.4 Mbps (EVDO)	
3.5	HSPA (today)	14 Mbps	2 Mbps
3.75	HSPA (Release 7) DL 64QAM or 2x2 MIMO; UL 16QAM	28 Mbps	11.5 Mbps
	HSPA (Release 8) DL 64QAM and 2x2 MIMO	42 Mbps	11.5 Mbps
3.9	WiMAX Release 1.0 TDD (2:1 UL/DL ratio), 10 MHz channel	40 Mbps	10 Mbps
	LTE, FDD 5 MHz UL/DL, 2 Layers DL	43.2 Mbps	21.6 Mbps
	LTE CAT-3	100 Mbps	50 Mbps
4	LTE-Advanced	1000 Mbps	500 Mbps

octoScope's LTE Throughput Measurements

DL/UL, Mbps



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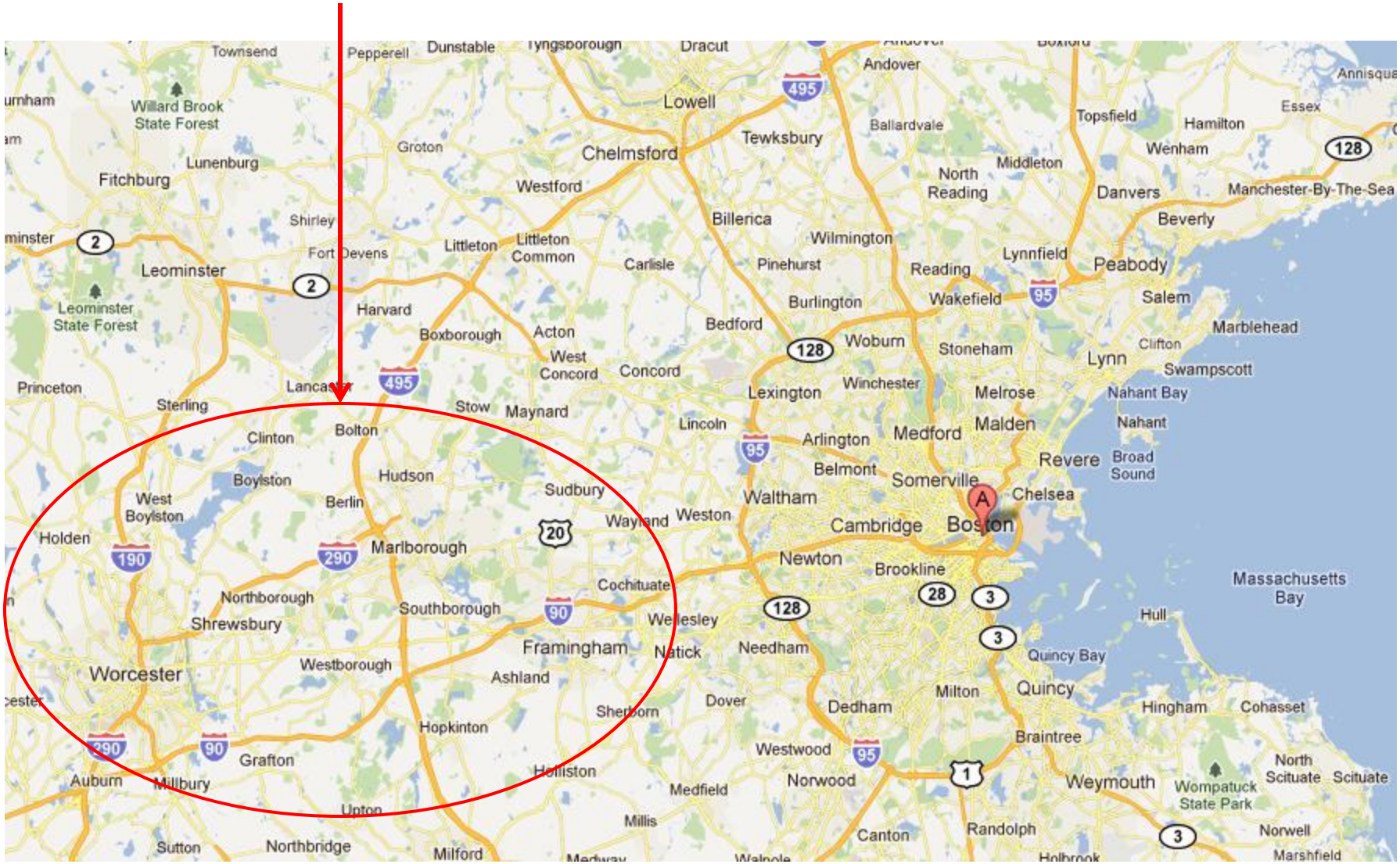
Measurements Performed Here

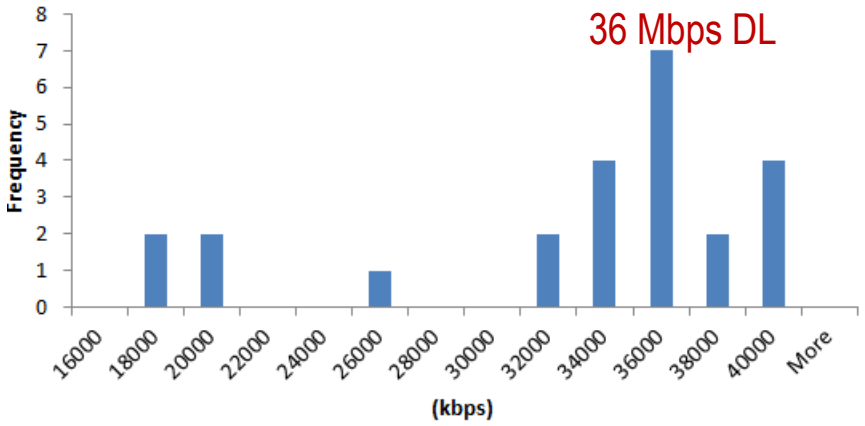


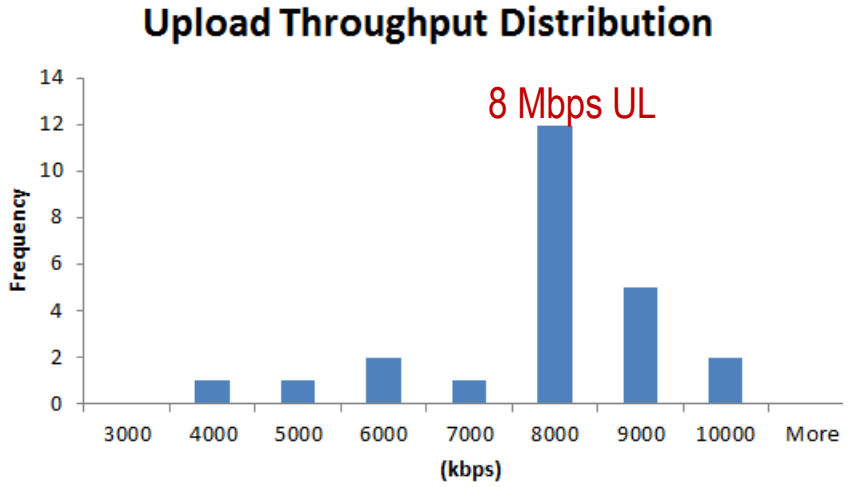
LTE Measurements in the Boston Area

Average Throughput vs. Location in the Car

Location in the car	DL (kbps)	UL (kbps)	Latency (ms)
Inside center of the car	14800	5499	112
Inside driver front window	14527	8824	107
Inside passenger front window	13687	8001	111
Outside the car	19703	8587	112

Impact of Speed (60 mph)



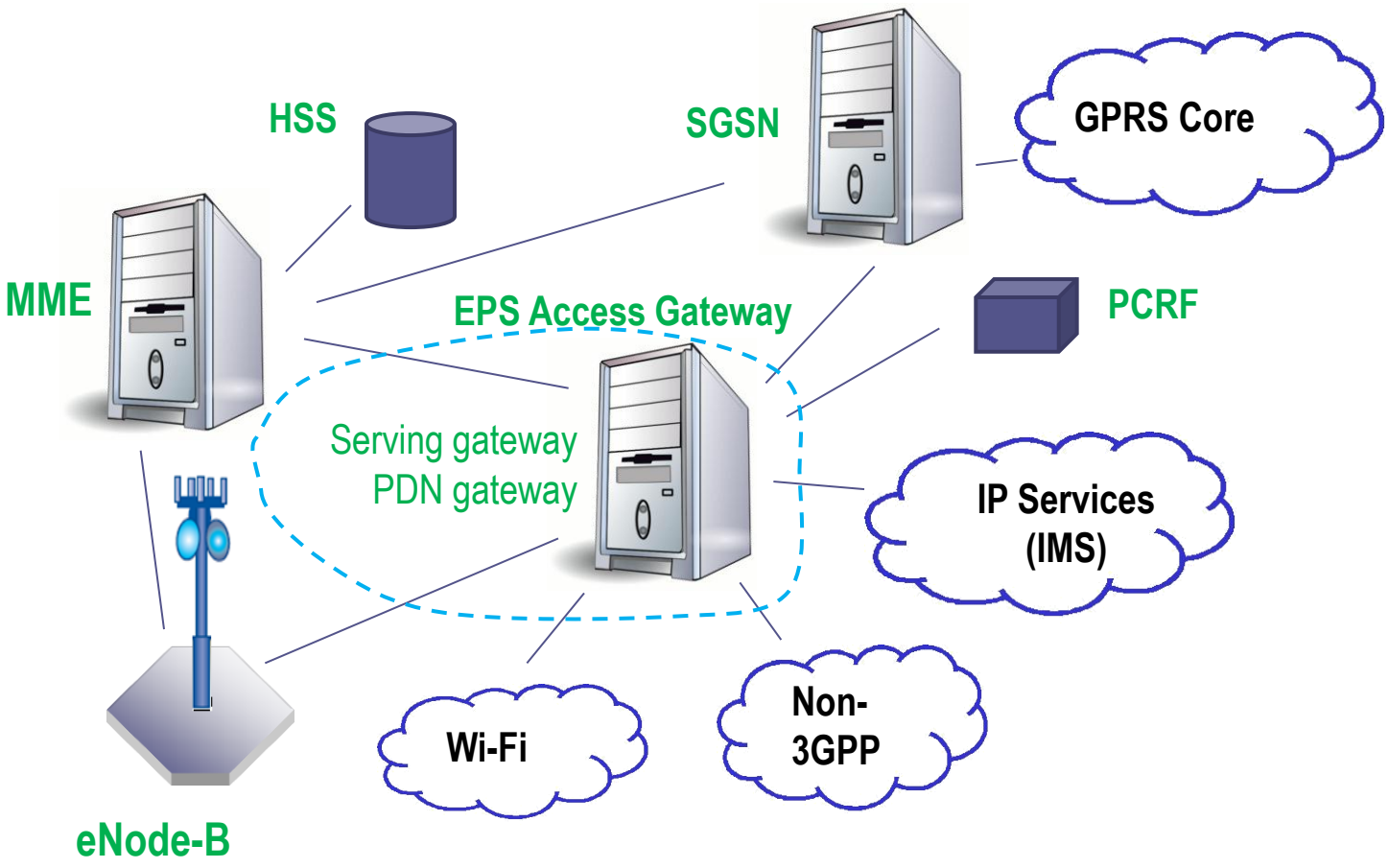


DL = downlink
UL = uplink

Measurements performed by octoScope using speedtest.net in October 2011 on a Verizon LTE network

LTE EPC (Evolved Packet Core)

Flat, low-latency architecture



SGSN = Serving GPRS Support Node
PCRF = policy and charging rules function
HSS = Home Subscriber Server
MME = Mobility Management Entity
PDN = Public Data Network
IMS = IP multimedia subsystem
eNode-B = enhanced Node B (LTE base station)

History of IEEE 802.11

- **1989: FCC authorizes ISM bands (Industrial, Scientific and Medical)**
  - 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: 802.11ac (up to 6.9 Gbps) and 802.11ad (up to 6.8 Gbps)**

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

UNII = Unlicensed National Information Infrastructure

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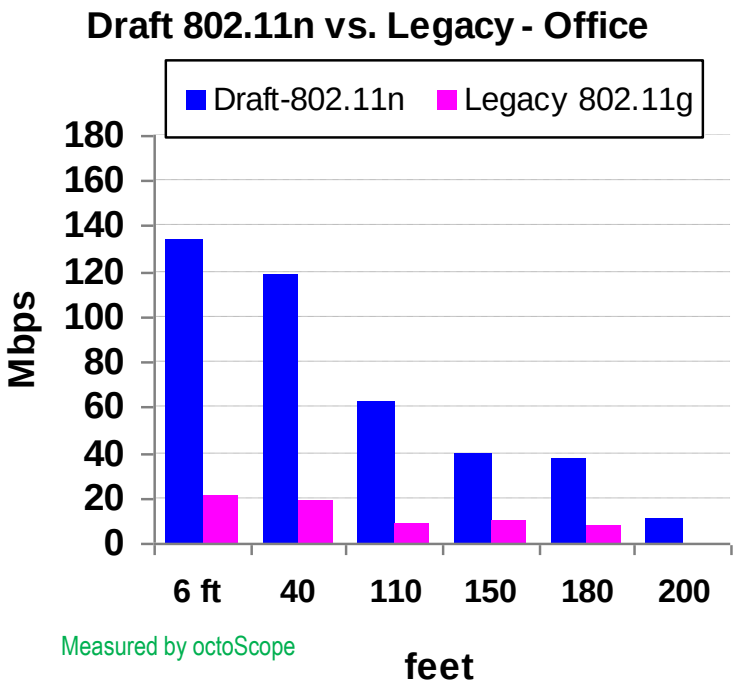
IEEE 802.11a,b,g,n Data Rates

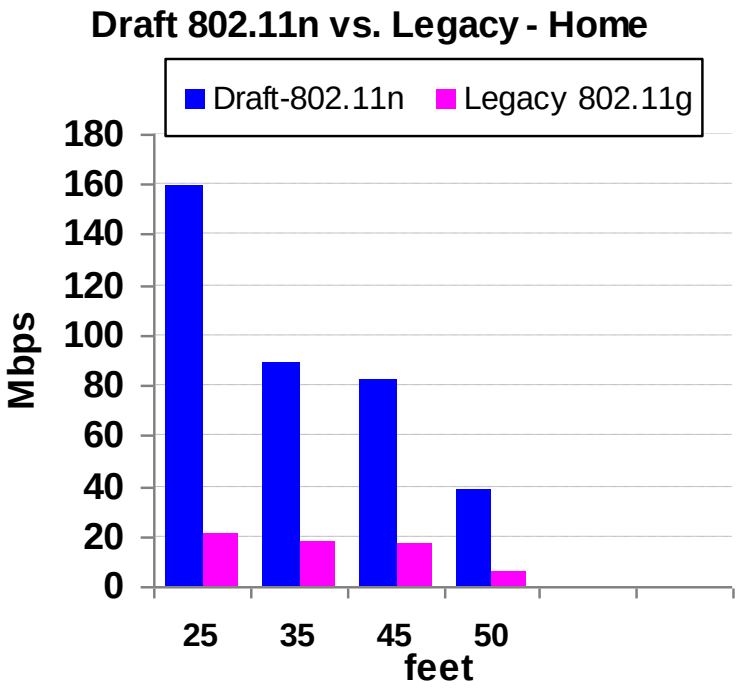
	20 MHz Channel				40 MHz Channel			
	1 stream	2 streams	3 streams	4 streams	1 stream	2 streams	3 streams	4 streams
	Data Rate, in Mbps							
802.11b 2.4 GHz	1, 2, 5.5, 11							
802.11a 5 GHz	6, 9, 12, 18, 24, 36, 48, 54							
802.11g 2.4 GHz	1, 2, 6, 9, 12, 18, 24, 36, 48, 54							
802.11n 2.4 and 5 GHz	6.5, 13, 19.5, 26, 39, 52, 58.5, 65	13, 26, 39, 52, 78, 104, 117, 130	19.5, 39, 58.5, 78, 117, 156, 175.5, 195	26, 52, 78, 104, 156, 208, 234, 260	13.5, 27, 40.5, 54, 81, 108, 121.5, 135	27, 54, 81, 108, 162, 216, 243, 270	40.5, 81, 121.5, 162, 243, 324, 364.5, 405	54, 108, 162, 216, 324, 432, 486, 540
802.11n, SGI enabled 2.4 and 5 GHz	7.2, 14.4, 21.7, 28.9, 43.3, 57.8, 65, 72.2	14.4, 28.9, 43.3, 57.8, 86.7, 115.6, 130, 144.4	21.7, 43.3, 65, 86.7, 130, 173.3, 195, 216.7	28.9, 57.8, 86.7, 115.6, 173.3, 231.1, 260, 288.9	15, 30, 45, 60, 90, 120, 135, 150	30, 60, 90, 120, 180, 240, 270, 300	45, 90, 135, 180, 270, 360, 405, **450**	60, 120, 180, 240, 360, 480, 540, **600**

SGI = short guard interval

MIMO vs. SISO Throughput



Vendor 1

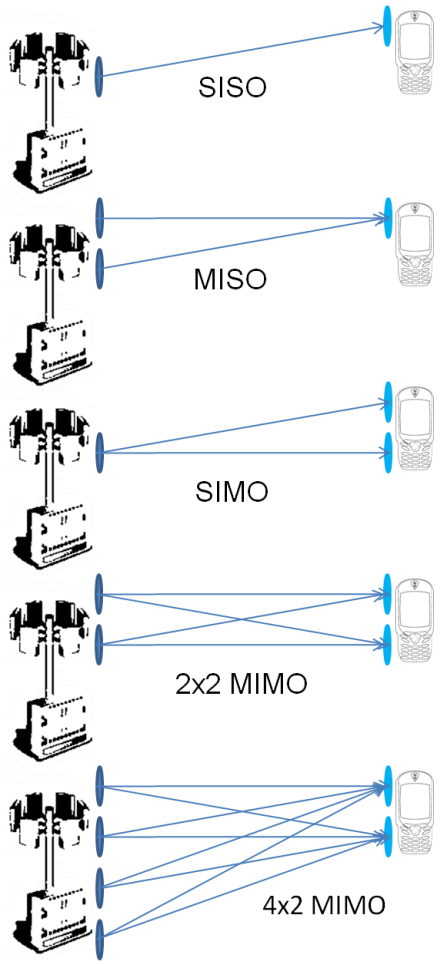


Vendor 2

MIMO = multiple input multiple output
SISO = single input single output

Multiple Antenna Techniques

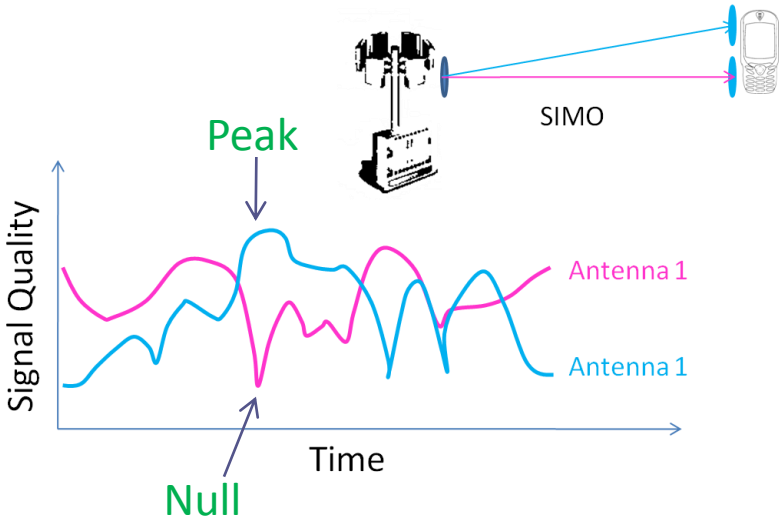
- **SISO (Single Input Single Output)**
  - Traditional radio
- **MISO (Multiple Input Single Output)**
  - Transmit diversity (STBC, SFBC, CDD)
- **SIMO (Single Input Multiple Output)**
  - Receive diversity, MRC
- **MIMO (Multiple Input Multiple Output)**
  - SM to transmit multiple streams simultaneously; can be used in conjunction with CDD; works best in high SNR environments and channels de-correlated by multipath
  - TX and RX diversity, used independently or together; used to enhance throughput in the presence of adverse channel conditions
- **Beamforming**

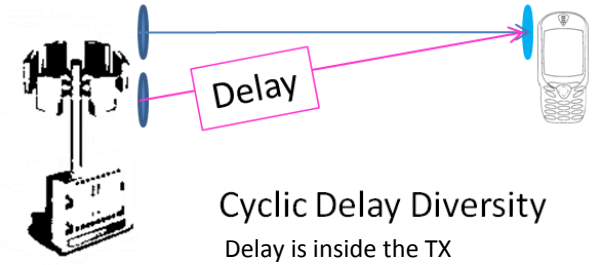


SM = spatial multiplexing
SFBC = space frequency block coding
STBC = space time block coding
CDD = cyclic delay diversity
MRC = maximal ratio combining
SM = Spatial Multiplexing
SNR = signal to noise ratio

MIMO Based RX and TX Diversity

- When 2 receivers are available in a MIMO radio MRC can be used to combine signals from two or more antennas, improving SNR
- MIMO also enables transmit diversity techniques, including CDD, STBC, SFBC
- TX diversity spreads the signal creating artificial multipath to decorrelate signals from different transmitters so as to optimize signal reception





Cyclic Delay Diversity

Delay is inside the TX

MIMO = multiple input multiple output
SIMO = single input multiple outputs
SM = spatial multiplexing
SFBC = space frequency block coding
STBC = space time block coding
CDD = cyclic delay diversity
MRC = maximal ratio combining
SM = Spatial Multiplexing
SNR = signal to noise ratio

IEEE 802.11 Very High Throughput

- The goal of the 802.11 VHT effort is to achieve >1 Gbps throughput at nomadic (walking) speeds to support HD video transmission and high speed data applications TGac and TGad

TGac

- Under 6 GHz (2.4 and 5 GHz bands)
- Up to 6.9 Gbps
- Higher order MIMO (> 4x4)
- 8 spatial streams
- Multi-user (MU) MIMO

TGad

- 60 GHz band
- Up to 6.8 Gbps
- Capitalize on work already done by 802.15.3c in the 60 GHz band
- Beamforming

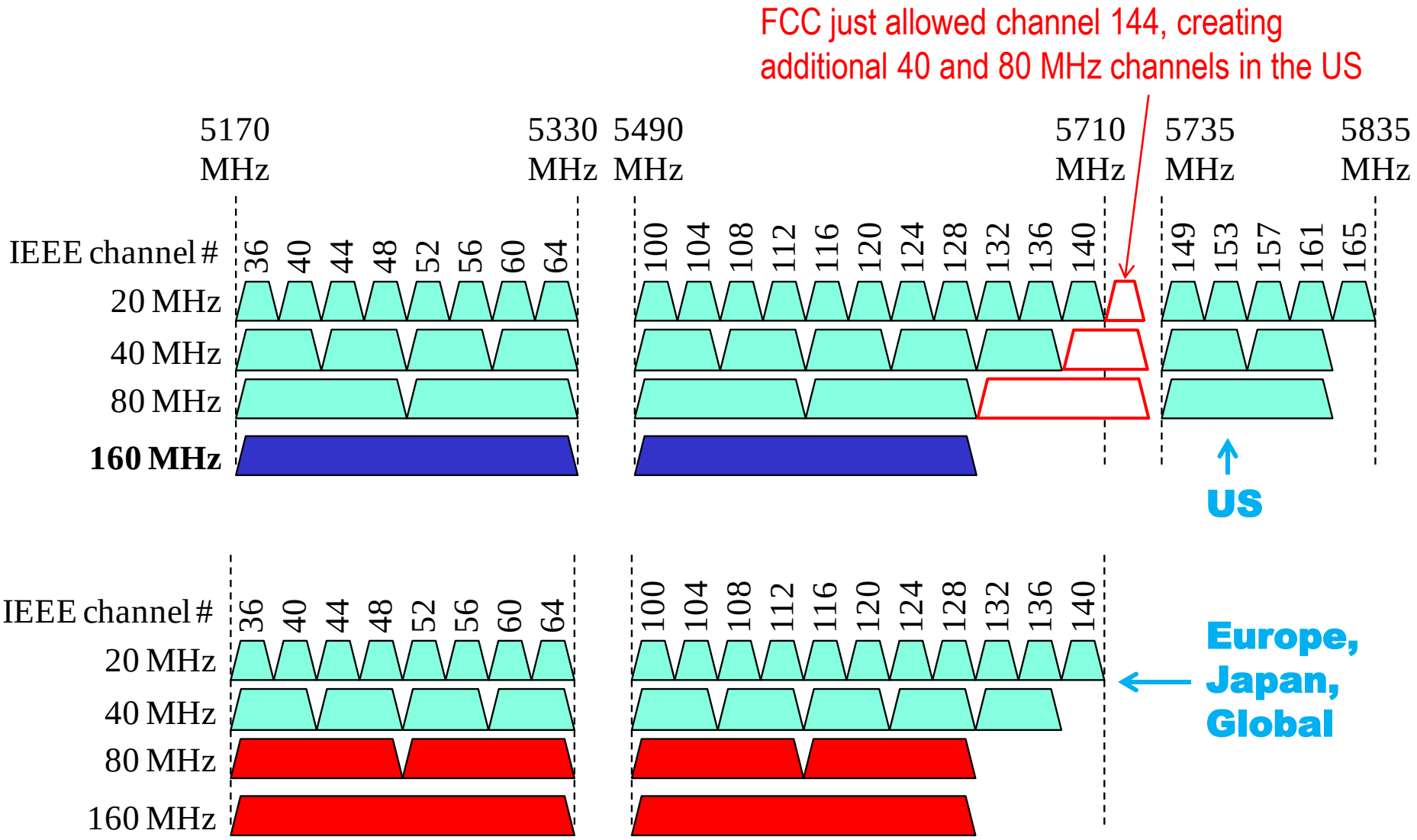
VHT = very high throughput

TGac – Next Generation Wi-Fi

- **Up to 6.9 Gbps of PHY data rate**
- **Higher order MIMO (> 4x4)**
- **8 spatial streams**
- **Multi-user (MU) MIMO**
  - Up to 4 users; up to 4 streams per user
- **Higher bandwidth channels (20, 40, 80, 80+80 and 160 MHz)**

MU-MIMO
Multiple beamformed streams in the same channel

802.11 Channels



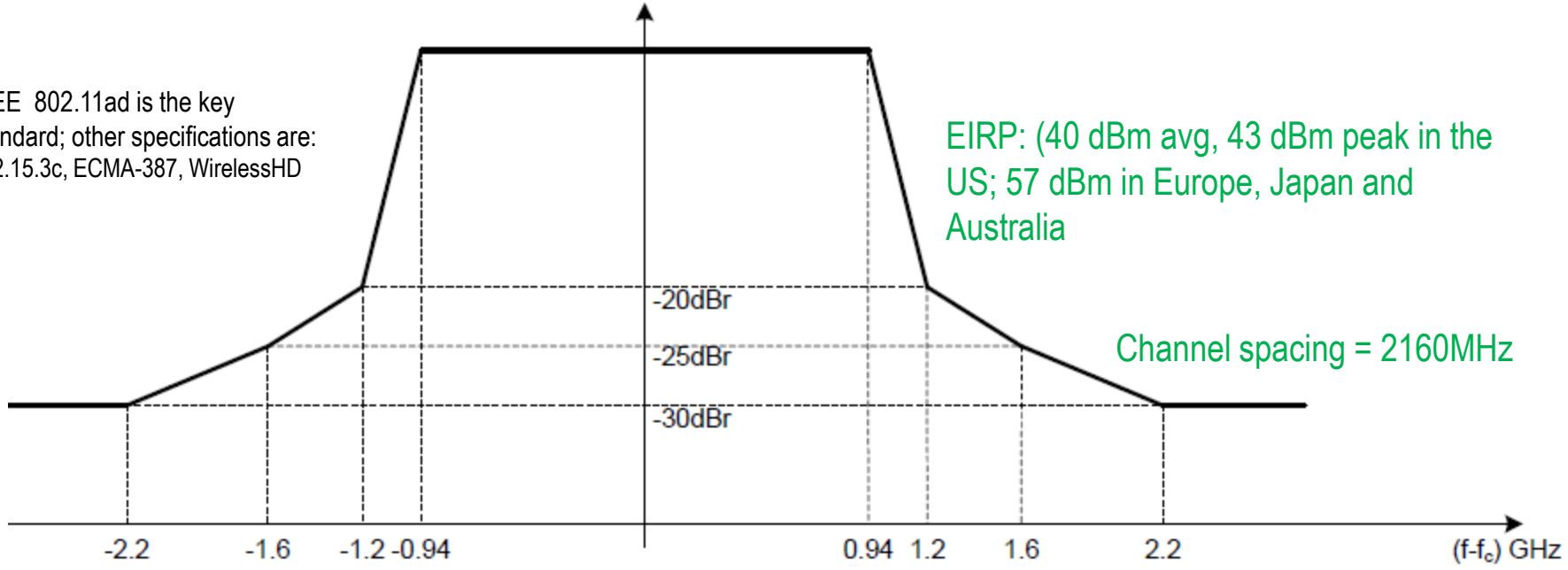
802.11ad 60 GHz Channels

Channel	f_c (GHz)	Country
1	58.32	US
2	60.48	US, Japan, EU, Australia
3	62.64	US, Japan, EU
4	64.80	Japan, EU

Channel 2 must be supported →

IEEE 802.11ad is the key standard; other specifications are: 802.15.3c, ECMA-387, WirelessHD

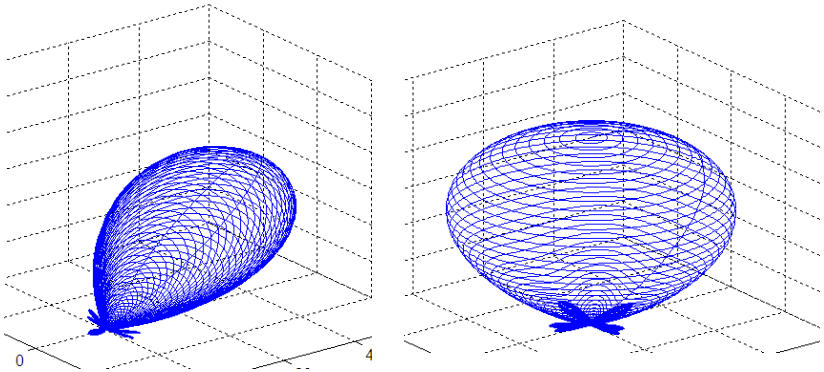
EIRP: (40 dBm avg, 43 dBm peak in the US; 57 dBm in Europe, Japan and Australia

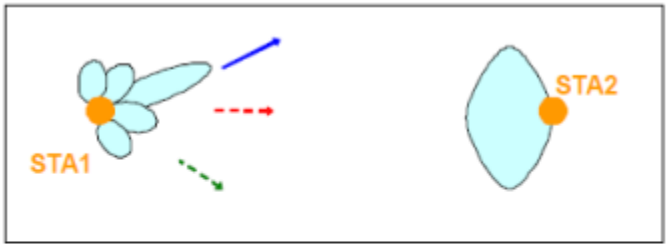


Channel spacing = 2160MHz

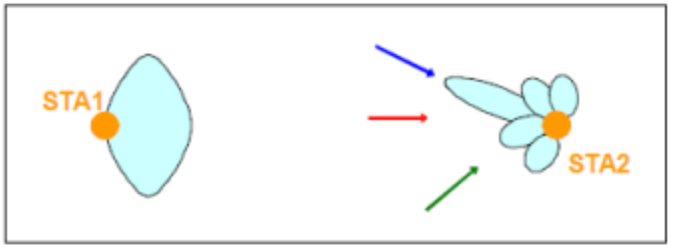
Beamforming and Beam Steering

- **Beamforming is a feature of 802.11ac and central to 802.11ad**
- **Optimizes the range by focusing the energy between transmitting and receiving nodes**

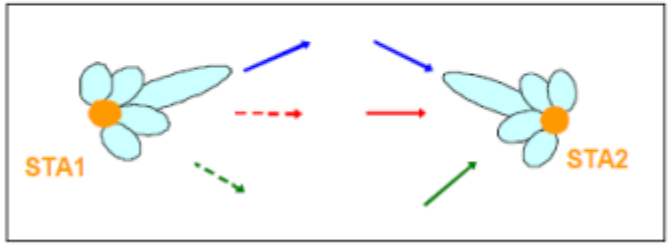




(a) I-TXSS in SLS



(b) I-MID



(c) I-BC (Beam Combining)

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IEEE 802.11 Emerging Specifications

Standard	Overview	Specification			Standard completion (Target)
		Transmission rate	Communication range	User velocity	
11ac	***High Throughput w/ wider channels***	Up to **6.9 Gbps**			**Dec/13**
11ad	***High Throughput in 60 GHz band***	Up to **6.8 Gbps**	**10 m at 1 Gbps**		**Dec/12**
11af	***Wi-Fi on TV White Space***	802.11n/ac rates scaled to channel	Up to **5 km**		**Dec/13**
11ah	***Sub 1 GHz***	**> 100 kbps**	**1 km**		**Mar/15**
11ai	***Wi-Fi for mobile***	***Fast initialization (target 100 ms)***		Target: **+ 200 km/h**	**Mar/14**

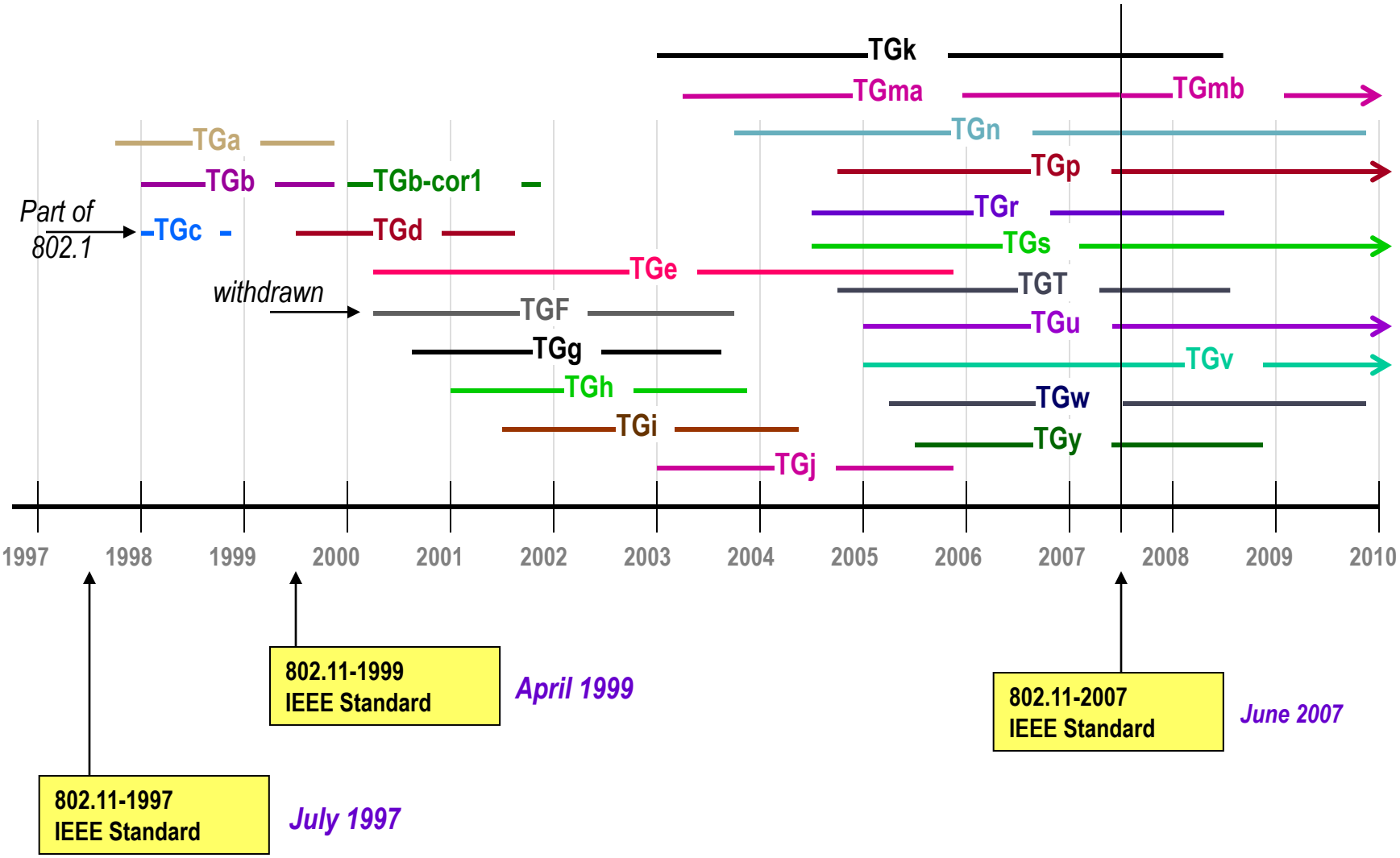
802.11 Past Task Groups – Ratified

- ✓ **TGma – Maintenance**
- ✓ **TGa – 5 GHz OFDM PHY**
- ✓ **TGb – 2.4 GHz 11 Mbps; DSSS PHY**
- ✓ **TGc – Bridging (part of 802.1)**
- ✓ **TGd – Additional regulatory domains**
- ✓ **TGe – Quality of Service**
- ✓ **TGf – Inter-AP protocol**
- ✓ **TGg – 2.4 GHz OFDM PHY**
- ✓ **TGh – Radar avoidance (DFS, TPC)**
- ✓ **TGi – Security**

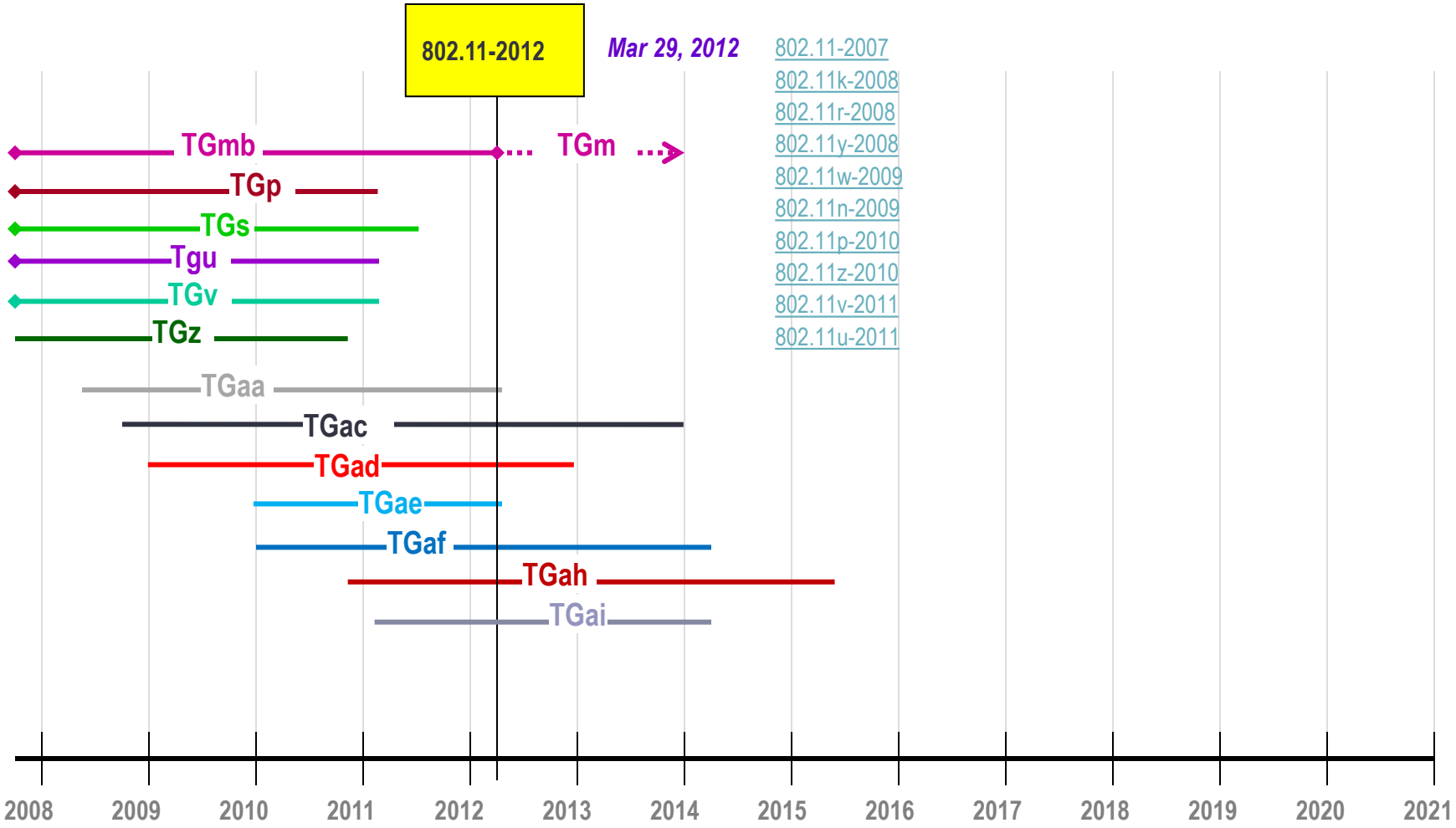
- ✓ **TGk** – Radio Resource Measurements
- ✓ **TGn** – High Throughput; MIMO
- ✓ **TGp** – Vehicular ITS networks (WAVE/DSRC)
- ✓ **TGr** – Fast Roaming
- ✓ **TGs** – Mesh networking
- ✓ **TGT** – IEEE 802 Performance
- ✓ **TGu** – InterWorking with External Networks
- ✓ **TGv** – Wireless network management
- ✓ **TGw** – Protected Management Frames
- ✓ **TGy** – 3650-3700 MHz Operation in US
- ✓ **TGz** – Direct Link Setup
- ✓ **TGaa** – Robust streaming of AV Transport Streams
- ✓ **TGae** – Prioritization of management frames

OFDM = orthogonal frequency division multiplexing
DSSS = direct sequence spread spectrum
DSRC = dedicated short range communications
WAVE = wireless access vehicular environment
ITS = intelligent transportation systems
MIMO = multiple input multiple output
DFS = dynamic frequency selection
TPC = transmit power control
TG = task group

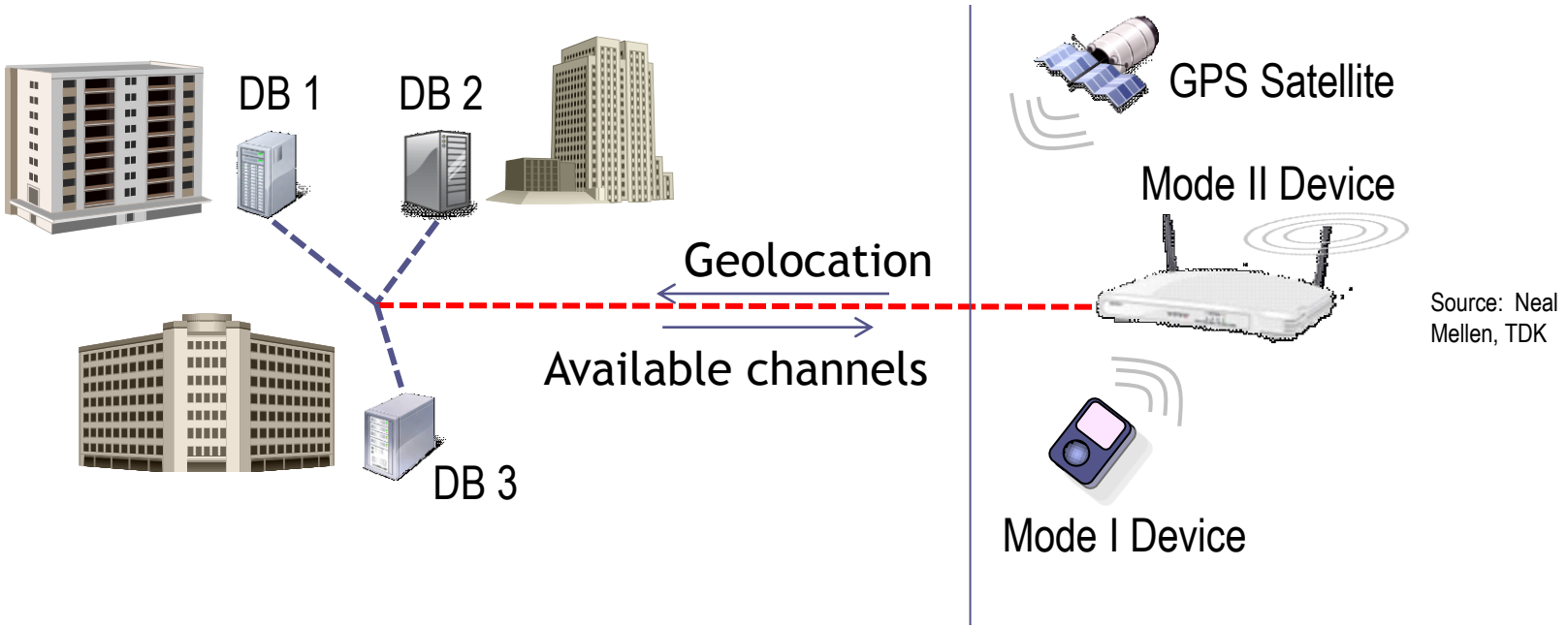
IEEE 802.11 Timeline



IEEE 802.11 Timeline (continued)

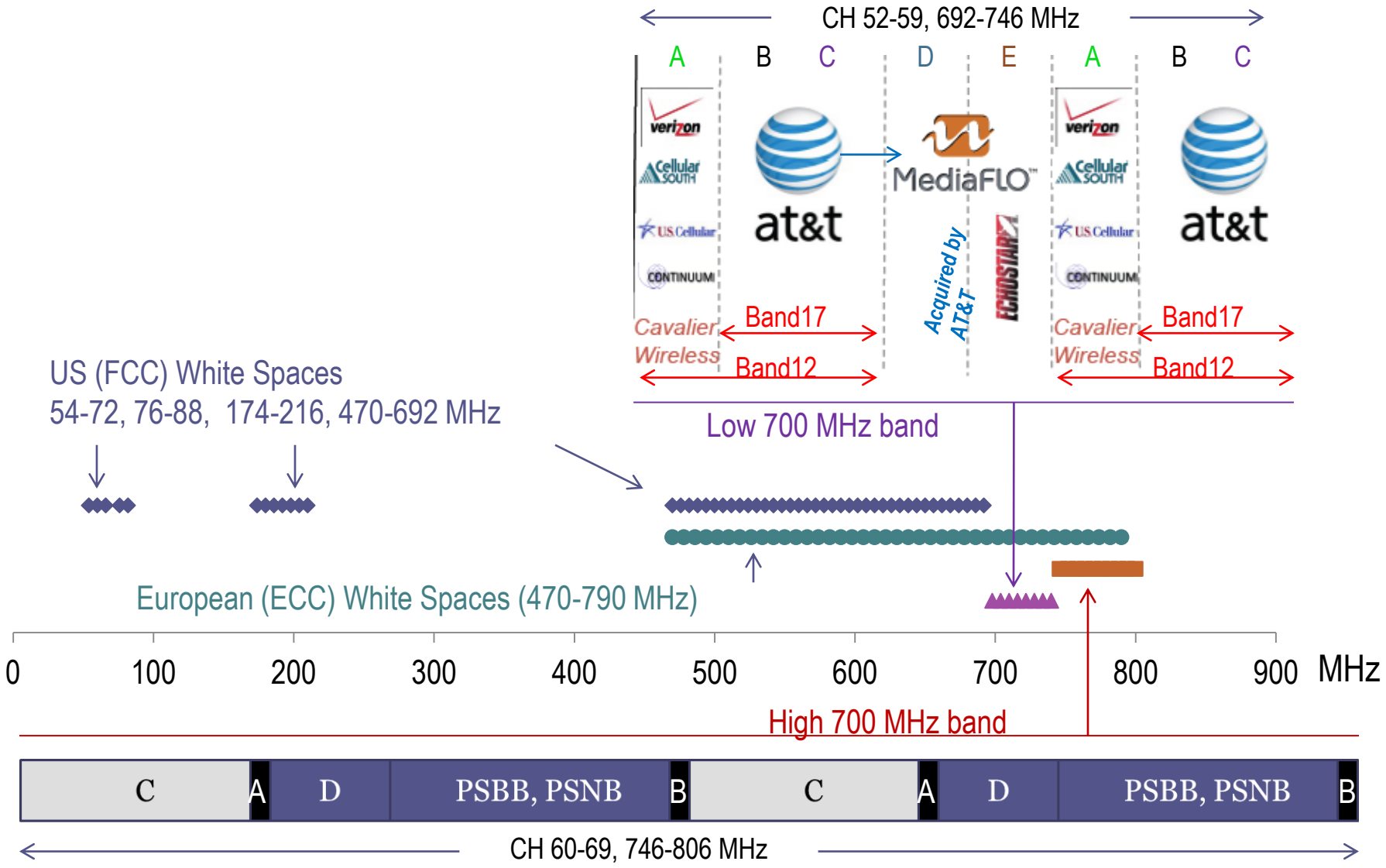


White Space Technologies



FCC has only specified access rules, so Wi-Fi (802.11af), unlicensed LTE and proprietary technologies can use White Spaces via database access.

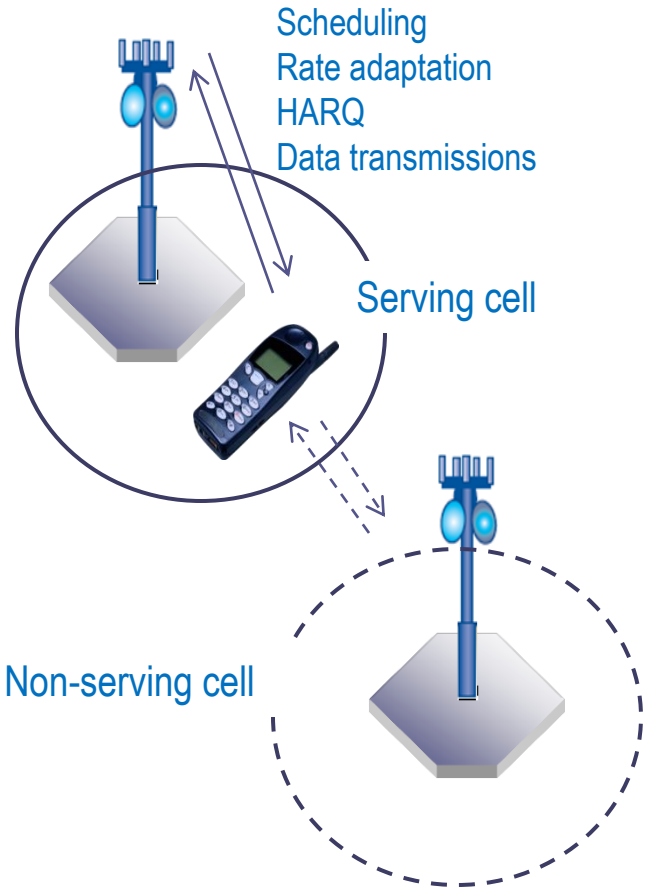
UHF Spectrum, Including White Space Bands



ECC = Electronic Communications Committee

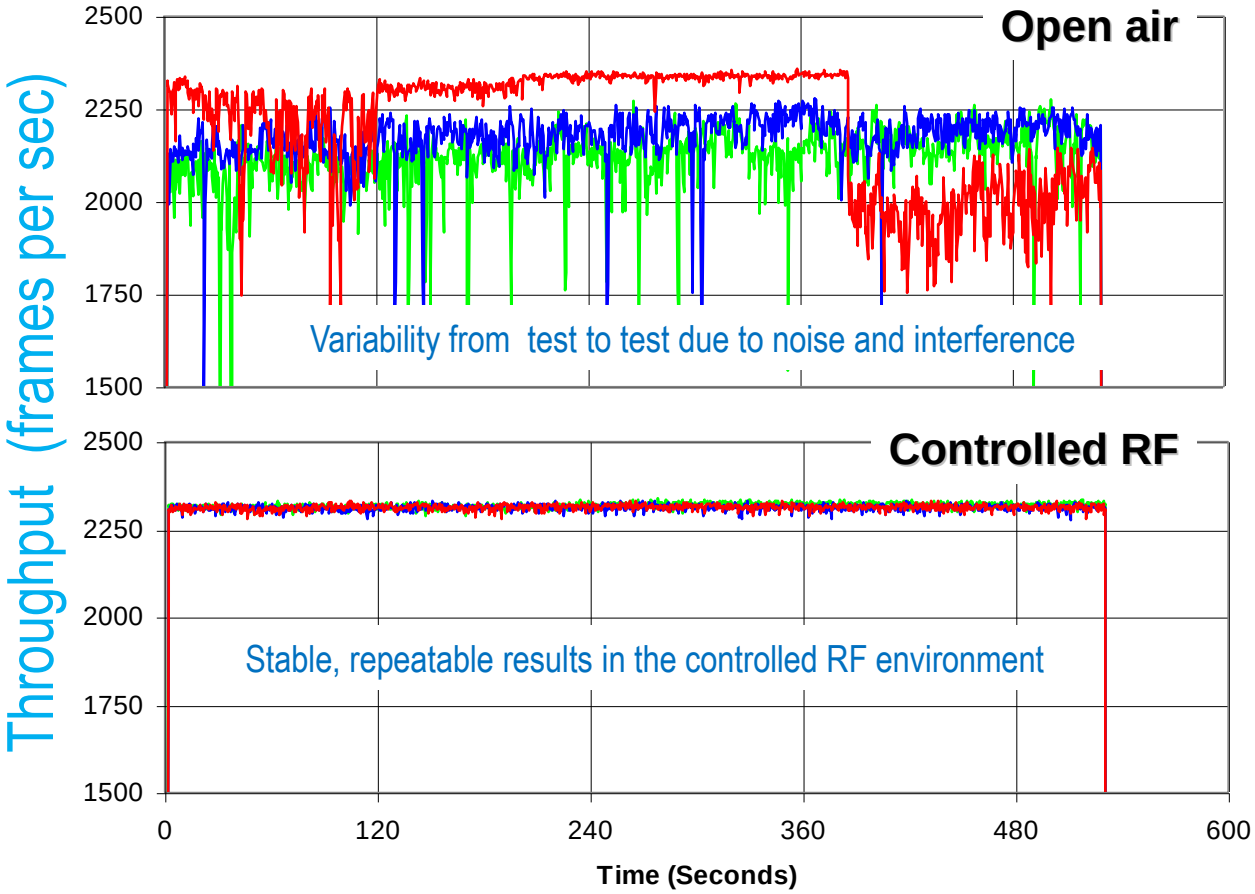
Dealing with Escalating Complexity

- **Complex MIMO radio technology**
  - Spatial multiplexing, TX/RX diversity, beamforming, MU-MIMO
  - Multiple radio networks (2G/3G/LTE, Wi-Fi)
- **Complex protocols**
  - Mobility management (handover)
  - Cell-edge interference avoidance
  - Self-organizing behavior
- **Require new generation sophisticated test methodologies to ensure devices and systems work in the field**



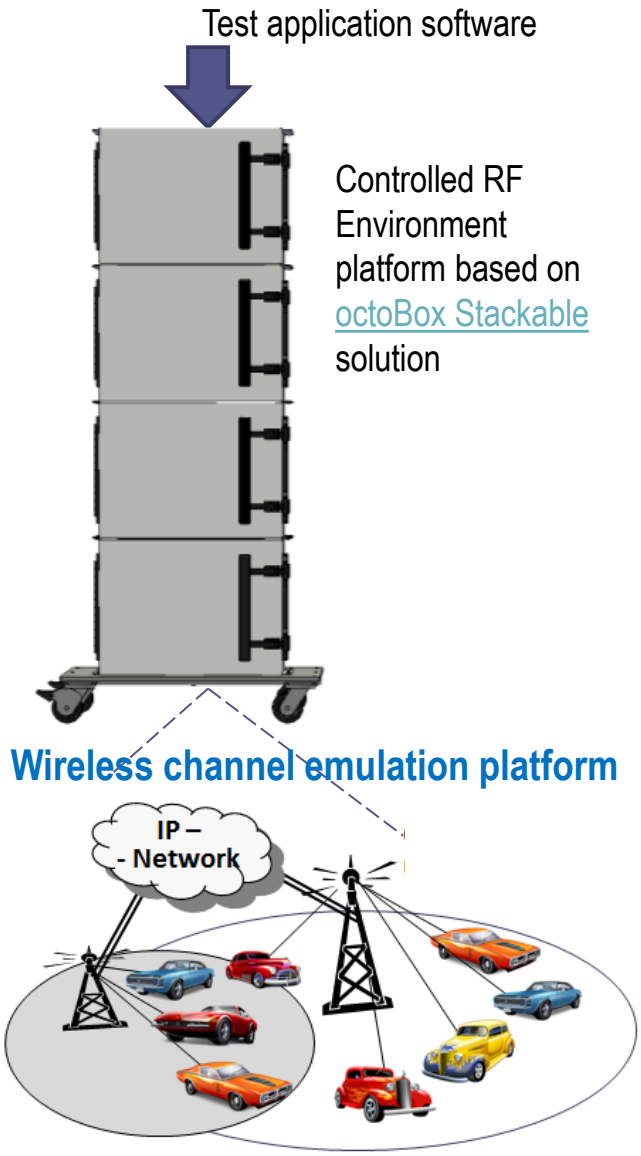
MU = multi-user
MIMO = multiple input multiple output
HARQ = Hybrid Automatic Repeat ReQuest

Open Air Testing vs. Controlled RF Environment



Emulate Wireless Systems In a Box

- **Emulate wireless network conditions in a controlled laboratory environment allowing testing of wireless device and system performance, such as**
  - Range
  - Roaming
  - Adaptive modulation techniques
  - MIMO techniques
  - Mesh algorithms
  - Routing
- **Emulate real-world wireless network conditions, including**
  - Motion
  - Distance
  - Data traffic
  - Interference



Summary

- **Wireless networks are growing more diverse and more complex**
- **2G/3G/LTE and Wi-Fi are now set to dominate the indoor and outdoor spaces**
- **Powerful test solutions emulating a variety of operating conditions in the lab will help deliver reliable wireless products to consumers**

For More Information

- White papers, presentations, articles and test reports on a variety of wireless topics

www.octoscope.com