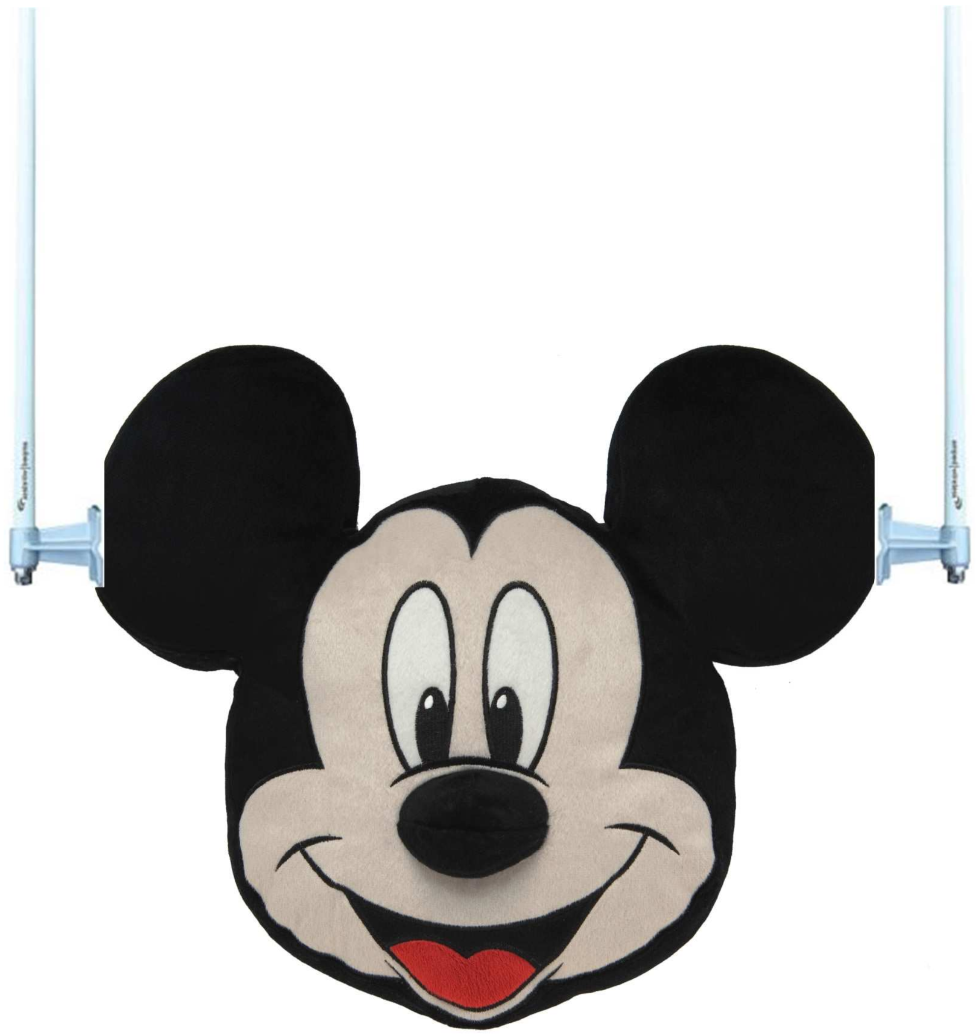
Where Do We Go From Here?
Divergent Philosophies on the Future of Wi-Fi

Jason D. Hintersteiner, CWNE #171

@EmperorWiFi

Welcome to Orlando's CWNP Wi-Fi Trek



About the Speaker

Jason D. Hintersteiner

- **Field Engineer:** Principal network architect and troubleshooter for several hundred networks across numerous venues and verticals
- Well versed with numerous enterprise access point, switch, router, firewall, and controller technologies
- Working 10 years in Wi-Fi industry
  - Vice President, Technology [Spot On Networks]
  - Consultant and Expert Witness [Imperial Network Solutions LLC]
  - Manager, Field Application Engineering [EnGenius Technologies, Inc.]
- Certifications
  - Certified Wireless Network Expert (CWNE #171) & Trainer (CWNT)
  - CompTIA Network+ & Security+
- Professional Organizations
  - IEEE
  - CWNE Board of Advisors
  - Wireless LAN Association (WLA) Technical Committee
- Education
  - Bachelor of Science (BS) & Master of Science [MIT]
  - Master of Business Administration (MBA) [UConn]

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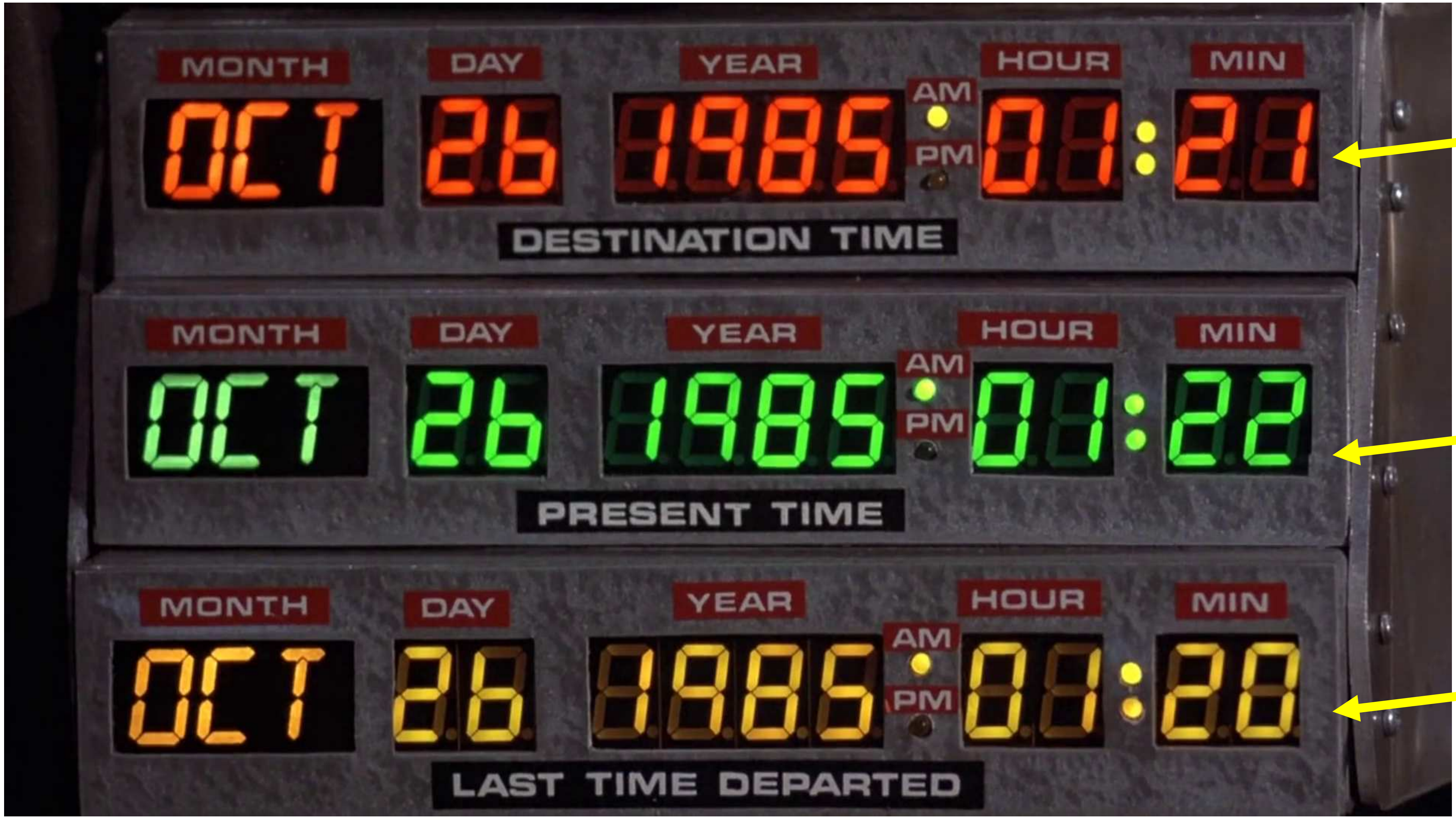
Blog: http://emperorwifi.com

Happy Birthday to Wi-Fi

Wi-Fi Turns 20

https://tse3.mm.bing.net/th?id=OIP.KGGJhWocCYSieKJjWBcefAFNC7&pid=15.1&P=0&w=324&h=183

Agenda



Where we're going

Where we are

Where we were

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A Brief History of RF Communications
1830s to 1920

- 1830's: Early experiments into "wireless telegraphy"
- 1873: James Clerk Maxwell publishes the "Maxwell Equations", showing how electromagnetic waves propagate through free space
- 1893: Nikola Tesla proposes a system for transmitting power and information wirelessly
- 1894: Guglielmo Marconi constructs the first wireless telegraphy system
- 1906: Patents filed for the first crystal detector radios, requiring no external power source
- 1914 – 1921: First radio stations licensed in USA and other countries

A Brief History of RF Communications

1920s to 1940s

- 1922: US Bureau of Standards publishes guide to show people how to build their own radios, brings radio into use by the general public
- Mid-1920s: Vacuum tubes invented, used to enhance performance of radio receivers and transmitters
- 1933: Frequency modulation (FM) radio is patented by Edwin H. Armstrong, shows reduction in static and interference vs. amplitude modulation (AM)
- 1930s: Analog TV starts broadcasting on VHF frequencies using AM (and later FM)
- 1942: Hedy Lamarr & George Antheil patent frequency hopping spread spectrum (FHSS)
- 1946: AT&T commercializes the first mobile telephone service in St. Louis, MO
- 1947: Solid state transistors first manufactured at Bell Labs

A Brief History of RF Communications

1950s to 1980s: Television, Cellular, and GPS

- Early 1950s: Transistor radios are manufactured and commercialized
- 1953: Analog color television introduced
- 1962: Telstar 1, world's first communication satellite, relays the first publicly available live transatlantic TV signal
- 1970s: US Navy starts experimenting with radio (LORAN) and satellite navigation
- 1973: Motorola introduces the first handheld mobile phone
- 1979: First analog cellular system deployed by NTT in Japan
- 1979: Inmarsat - first satellite telephone system introduced
- 1987: First GPS constellation of satellites launched

A Brief History of RF Communications

1970s to 1990s: The Emergence of Wi-Fi

- 1971: Hawaiian islands interconnected with AlohaNET, early version of the Ethernet and Wi-Fi protocols
- 1985: FCC opens up the ISM bands (including 900 MHz, 2.4 GHz and 5.8 GHz) to unlicensed use
- 1988: NCR and AT&T introduce WaveLAN for wireless cash registers (900 MHz & 2.4 GHz)
- 1997: Original 802.11 Wi-Fi introduced to allow multiple vendors to manufacture devices that will intercommunicate via standards-based protocols. (2.4 GHz, up to 2 Mbps)
  - Best effort (not for performance or mission critical applications)
  - Low data rates

Wi-Fi Technology Generations

History of Wi-Fi Generations (1997-2016)

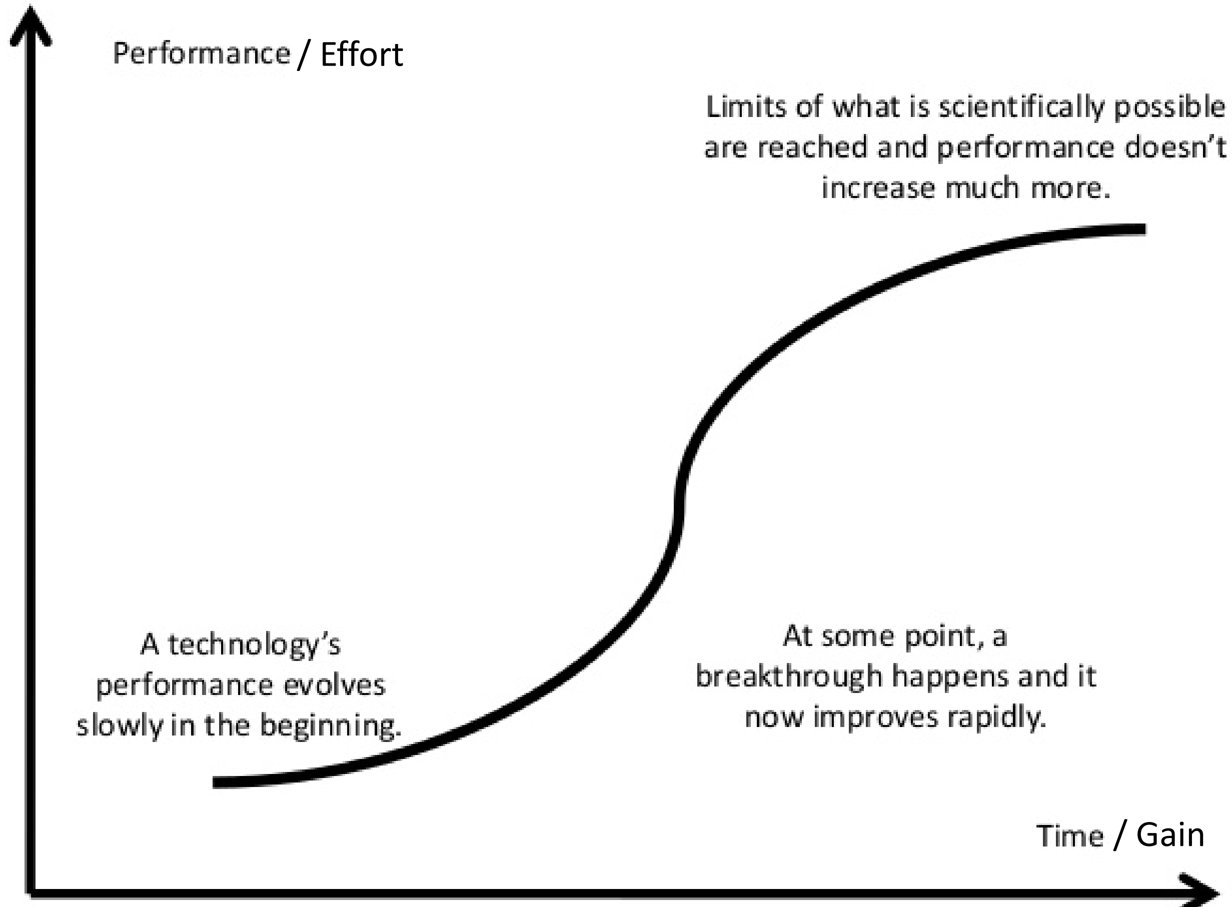
Wi-Fi Technology	Year Introduced	2.4 GHz	5 GHz	Max Channel Size	Max Spatial Streams (MIMO)	Maximum Modulation & Coding (MCS)	Max Half Duplex Data Rate
802.11 (Clause 15: DSSS)	1997	■		22 MHz	1x1:1	DPSK / Barker	2 Mbps
802.11a (Clause 17: OFDM)	1999		■	20 MHz	1x1:1	OFDM (64 QAM, 3/4)	54 Mbps
802.11b (Clause 18: HR/DSSS)	1999	■		22 MHz	1x1:1	QPSK / CCK	11 Mbps
802.11g (Clause 19: ERP-OFDM)	2003	■		20 MHz	1x1:1	OFDM (64 QAM, 3/4)	54 Mbps
802.11n (Clause 20: HT)	2009	■	■	40 MHz	4x4:4 (MIMO)	OFDM (64 QAM, 5/6)	600 Mbps
802.11ac (Clause 21: VHT)	2014 (wave 1)		■	80 MHz	4x4:4 (MIMO)	OFDM (256 QAM, 5/6)	1.3 Gbps
	2016 (wave 2)		■	160 MHz	8x8:8 (MIMO & MU-MIMO)	OFDM (256 QAM, 5/6)	6.9 Gbps

Wi-Fi Technology Generations

Growth of Wi-Fi Capabilities

- How has Wi-Fi been able to expand its capabilities by >1000x?
- Cannot break the laws of physics
- Answer: *Math*
  - Sufficiently complex algorithms running on sufficiently capable computer processors can “bend” the laws of physics
  - New techniques to squeeze additional bandwidth
    - Multiple streams (MIMO)
    - Wider channels
    - More sophisticated modulation & coding techniques
  - Each generation: increase *complexity*
    - Price: Increased *sensitivity* and *fragility*
    - Wi-Fi design becomes increasingly more important

Wi-Fi Technology Generations
The Technology S-Curve



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Over time, it takes larger efforts to make smaller gains.

Wi-Fi Technology Generations

Industry Trends

- “At the end of 2013, there were more mobile devices than people on Earth.” -- SAP
- “By 2020, it is predicted that 24 billion devices will be connected to the Internet. The vast majority will use some form of wireless for access.” -- Gigacom, 2014
- “The 2.4 GHz and 5 GHz RF spectrum is estimated to be fully saturated by 2020, leading to the need for more spectrum, such as 900 MHz and 60 GHz.” – Wi-Fi Alliance, April 2017

Wi-Fi Technology Generations

We are an Industry Obsessed with “Speed”

http://forums.riftgame.com/attachments/general-discussion/22879d1427336184-black-teir-loyalty-spaceballs-plaid.jpg

- Easy to market the concept of *throughput*
- Ever-increasing demand for bandwidth
  - More devices
  - More bandwidth consumption per device
- Problem: We’re out of mathematical tricks to cheat the physics
  - Channel Size: Bandwidth limitations make wider channels impractical
  - MIMO: Adding more spatial streams impractical, due to power and size limitations on client devices
  - Overhead: Protocol fairly optimized in 802.11n/ac with frame aggregation

In summary: We really can no longer go “faster”.

Wi-Fi Technology Generations

We are an Industry Obsessed with "Ease"

- We've sold consumers for 20 years on how *simple* it is to install Wi-Fi.
  - Put the APs wherever you want
  - Connect whatever client devices you want
- This perception of "*Wi-Fi is easy*" carries over into SMB & Enterprise
- Problem: *Bad-Fi!*
  - Increased complexity makes Wi-Fi harder, not easier.
  - Consumers, SMB, and Enterprise have both *higher dependencies* on and *higher expectations* for Wi-Fi
  - We focus on *cloud controllers* and *pretty dashboards*
  - We build *complex algorithms* to compensate for poor deployments, i.e. radio resource management (RRM) a.k.a. auto-channel & auto-power
  - There is *no motivation* for client device manufacturers to make "good" clients.

Wi-Fi Technology Generations

We are an Industry Focused on Selling Products, not Applications

- "WLAN resellers and implementers are trained to *install specific vendor solutions* and prioritize such practices *rather than try to understand the end-user experience* that is needed to optimize business application productivity" - Gartner, May 2017 (https://www.gartner.com/doc/reprints?id=1-44HED1A&ct=170628&st=sb)

- Problem: We don't understand customer's applications and devices.
  - We're in the business of selling *SKUs*, not *solutions*
  - Motivated to sell *more* vs. selling *right*
  - Help author RFPs based on *product specs*, not *customer needs*
  - We're all focused on *our own little piece* of the puzzle, not the *whole solution*

Understanding the Customer's Needs
Focus on the Applications, Not the Products

When you have this....

http://diyinahour.com/diy/wp-content/uploads/2013/03/Hammer.jpg

Everything looks like this...

http://www.usifaz.com/Web%20Site%20Pics/Anchors%20%26%20Loose%20Nails/roofing%20nail.gif

Including this...

http://skyrunner.com/img/p_screw.jpg

and this...

http://www.homedepot.com/catalog/productImages/1000/a8/a82b9667-8135-4296-bf0c-37b63d101f08_1000.jpg

but also this...

http://www.falknertech.com/images/iphone6-cracked.png

Wi-Fi Technology Generations

If we Cannot go “Faster”, Let’s Talk in Parallel

- Most of those 24 billion devices *don’t need* raw bandwidth
  - Internet of Things (IoT) still focuses on a plethora of “smart appliances” and other applications that do not require a lot of bandwidth
  - Even for real-time streaming video, there is a practical “human limit” of how much real-time data we really need
- Wi-Fi technology now focused on maximizing *airtime capacity* to handle more devices
- Airtime capacity *isn’t sexy*
  - Neither faster nor easier
  - Too complex a concept to communicate to the average customer

This upends 20 years of conventional “sales wisdom”. It will be a hard pill to swallow in the marketplace.

Wi-Fi Technology Generations

The Networks are Only as Good as the Clients

- Client devices are sold on individual performance
- Almost all IoT devices are only 2.4 GHz
  - Maximize compatibility and ease of use
  - Focused on their front end function, not on optimizing the Wi-Fi backhaul
- For 20 years, our industry told everyone to put any bad client on our Wi-Fi networks and expect great performance!

@EmperorWiFi, 9/27/2017

The golden rule: The Wi-Fi network will always be to blame! Our networks, however, are at the mercy of the worst client devices.

Internet of Things (IoT)

Client Devices of the Present (and the Future)

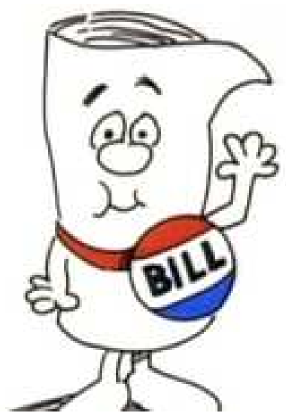
What Is It?

- Very overhyped vaporware
- Sensors and Actuators
- Battery powered / house powered
- Wireless Backhaul (but invariably ***really bad*** 2.4 GHz only Wi-Fi)
- Critical Requirements
  - Easy to install and use
  - Low power (if battery operated)
  - Relatively inexpensive
  - Low bandwidth

What Verticals are You Likely To See It?

- Consumer
  - Home security
  - Baby monitoring
  - Home entertainment / lighting control (e.g. SONOS, Control4, etc.)
  - Smart appliances / smart metering
- Elder care
  - Home health care / medical devices
  - Assisted living / nursing care
  - Asset tracking
- Other Applications?

Much of this space still consists of solutions looking for problems to solve.



How a Spec Becomes a Feature

How a Spec Becomes a Feature

Step 1: The 802.11 Spec is Officially Created

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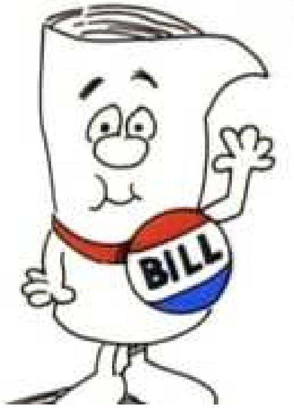
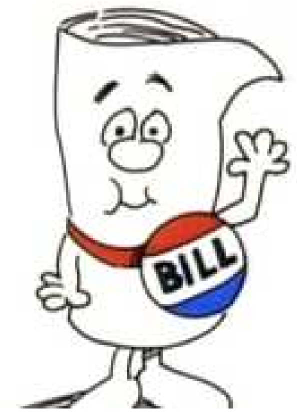


- IEEE 802.11 Working Groups
  - https://standards.ieee.org
  - Develop the official standards by committee
  - Technically open to everyone
  - Generally represented by the largest equipment and client device vendors
  - Have a cadre of highly intelligent RF physicists and academicians
- Issues
  - Long and bureaucratic process; can take several years to publish
  - Many of the specs are compromises
    (e.g. four "optional" implementations of TxBF in IEEE 802.11n)
  - Many of the specs are quite impractical for real-world implementation

How a Spec Becomes a Feature

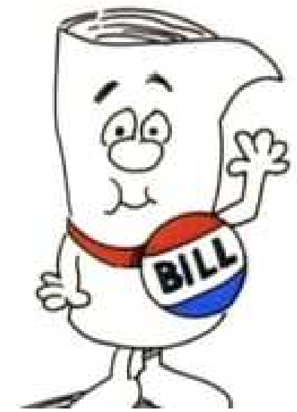
Step 2: The AP Chipset is Built



- Chipset Manufacturers
  - Used to be many, now only a few (i.e. Qualcomm / Broadcom)
  - Determine what in IEEE spec can be implemented, and when (why we have "wave 1" and "wave 2" in 802.11ac)
  - They also create their own competitive features that aren't part of the IEEE spec (most notable examples: WDS bridging, tri-band, 1024-QAM)
  - Provide drivers to the AP manufacturers to use the chipset functionality
- Issues
  - Chipset vendors have all the power in terms of the core features available and the innovations that get made
  - Every AP manufacturer essentially uses the same "engine" to run their APs

How a Spec Becomes a Feature

Step 3: The Access Point is Made



- Access Point Manufacturers
  - Distinguish themselves via branding and marketing
  - Create new features not part of the IEEE spec or the chipset (notable examples: band steering, radio resource management)
  - Compete on higher-level software (management and control / ease of use, vertical-specific features, etc.)
  - Compete on other add-ons (e.g. customer support, related hardware, etc.)
- Issues
  - Enterprise, competition is focused on making APs feature-rich to command premium prices and capture sticky customers
  - In SMB, APs are becoming commoditized as the core engine (chipset) is commoditized, and pricing is on a “race to the bottom”
  - There’s a large grey battleground area in the “M” portion of SMB, as they don’t need the features nor do they want to pay the premium

Some Hot Topics in the Wi-Fi World

Spectrum Sharing

The Carriers are Coming for Our Spectrum

- The cellular carriers are developing several technologies to utilize portions of the 5 GHz band for data offload (LAA-LTE, LTE-U)
- All of these will have some, if not a lot, of impact on Wi-Fi throughputs

Ekahau Webinar, August 2017

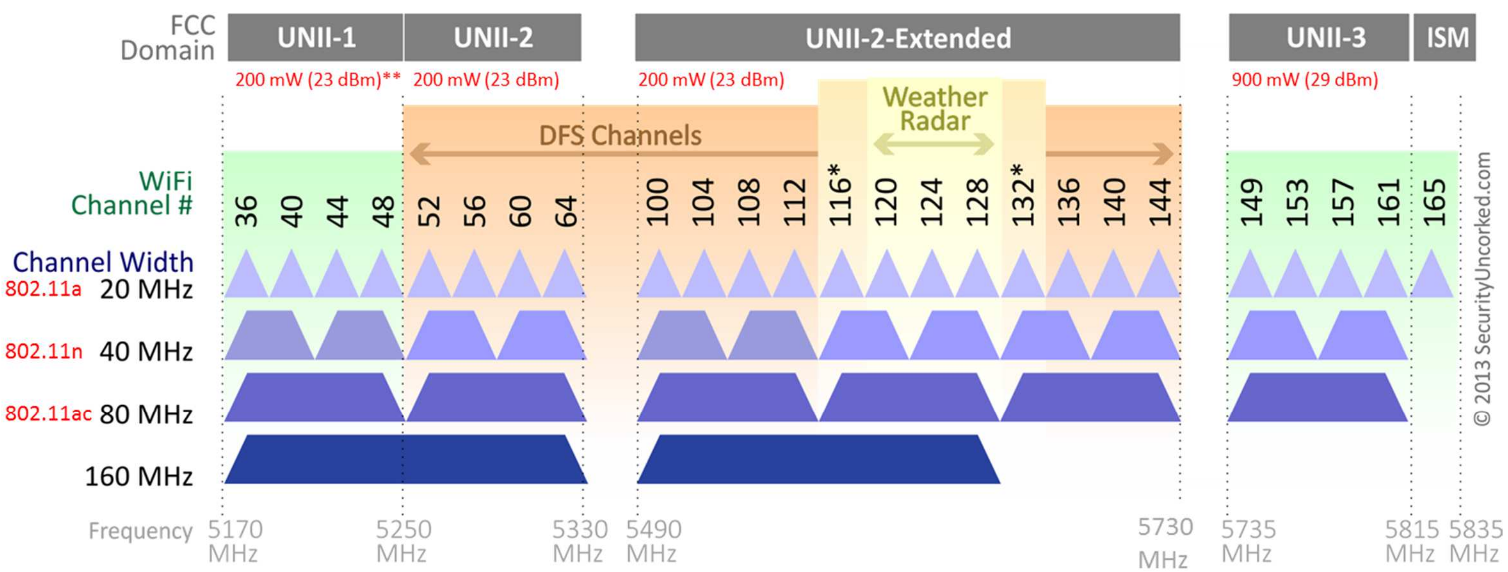
Source: google

Spectrum Sharing

5 GHz Channels: DFS

- Larger band: 660 MHz total width of 5 GHz band in USA
- Larger channels → signal is more prone to interference

802.11ac Channel Allocation (N America)



* Channels 116 – 144 used for Doppler radar. Channels 132 – 144 not yet available in USA
** Allowed Power for UNII-1 band increased by FCC from 40 mW to 200 mW in 2014

- DFS: Dynamic Frequency Selection
  - Channels in this range in use by US military radar and weather radar systems
  - Channels impacted: UNII-2 (52-64) and UNII-2e (100-144)
- DFS Operational Requirement by FCC
  - Wi-Fi stations (APs and client devices) must be able to detect known radar energy signatures & vacate the channel
  - Many consumer APs & client devices (e.g. USB sticks) avoid this by not using DFS channels, sticking only to UNII-1 (36-48) and UNII-3 (149-165).
  - http://clients.mikealbano.com is best online reference

The Issues with DFS

Ill-conceived FCC Rules Results in Poor DFS Utilization

- Some client devices outright *avoid* DFS channels altogether
  - Option 1: Avoid DFS channels in an AP channel plan
  - Option 2: Accept effective coverage holes in the network for client devices that cannot see APs on DFS channels
- Clients that use DFS channels only do *passive scanning*
  - This creates roaming and performance issues for client devices
  - It takes a comparatively long time to detect and roam to an AP set to a DFS channel vs. a non-DFS channel
- DFS tends to only be practical in point-to-(multi)point links in residential neighborhoods, where non-DFS channels are saturated
  - Ironically, DFS events are most likely to occur outdoors

We could be utilizing the DFS spectrum a lot better than we are!

The Issues with DFS

DFS Better Be Fixed Before More Spectrum is Added

- Wi-Fi Alliance and others have proposed opening up additional spectrum for Wi-Fi
  - 5.325 GHz – 5.500 GHz (Channels 68-96)
  - 5.9 GHz (above Channel 165)
  - 6 GHz and 7 GHz
- Proposals are to use “DFS-like” mechanisms to protect the radio systems already on these bands
- We need better guidelines for using this spectrum

We need to add spectrum, but we first need to <u>fix DFS</u> so we can actually <u>use</u> this spectrum!

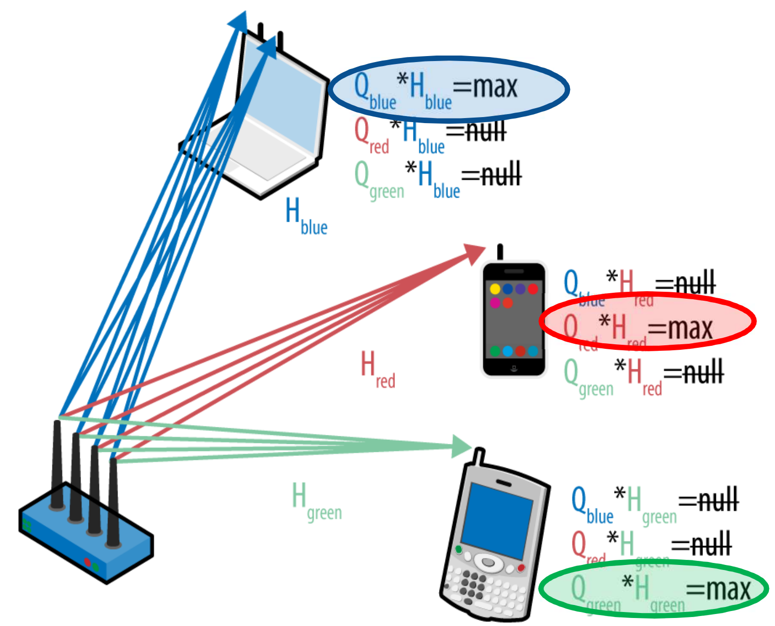
Multi-User MIMO

802.11ac wave 2

- Simultaneous downstream communication: AP to multiple clients
- Utilizes transmit beam forming to direct individual traffic to particular client devices across multiple antennas
- “Potentially useful” in dense client environments
  - *Clients must provide position feedback (≥ 802.11ac wave 2)*
  - *Clients must be spatially separated from each other*
  - *Clients must have similar data transmission times (MCS data rates + data quantity)*

Received Signal per Antenna | *Client Position Feedback* | *Transmitted Signal per Antenna*

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & Q_{14} \\ Q_{21} & Q_{22} & Q_{23} & Q_{24} \\ Q_{31} & Q_{32} & Q_{33} & Q_{34} \\ Q_{41} & Q_{42} & Q_{43} & Q_{44} \end{bmatrix} \begin{bmatrix} H_1 \\ H_2 \\ H_3 \\ H_4 \end{bmatrix}$$



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Multi-User MIMO

Client Support ...or Lack Thereof

USB Adapter Support for MU-MIMO

- Linksys WUSB6100M
- Linksys WUSB6400M
- Edimax EW-7822ULC
- Asus USB-AC53 Nano

Several USB devices support MU-MIMO.

These aren't the devices that are usually mobile in high density environments.

Smartphone Support for MU-MIMO

- Samsung Galaxy Note 7

●●○○○ VZW Wi-Fi VPN 5:54 PM 65%
samsung.com

Galaxy Note8 PRE-ORDER

S PEN CAMERA PERFORMANCE PHONE+ ACCESSORIES SPECS

Network & Connectivity

LTE Cat.16

*May differ by markets and mobile operators.

Wi-Fi 802.11 a/b/g/n/ac (2.4/5GHz), VHT80 MU-MIMO, 1024QAM
Bluetooth® v 5.0 (LE up to 2Mbps), ANT+, USB Type-C, NFC, Location (GPS, Galileo, Glonass, BeiDou)

*Galileo and BeiDou coverage may be limited. BeiDou may not be available for certain countries.

Expar

●●●○○ VZW Wi-Fi VPN 10:18 PM 100%
Apple Inc.

iPhone 8 Pre-order

Model A1905*

Model A1897*

Models A1905 and A1897 do not support CDMA networks, such as those used by Verizon and Sprint.

FDD-LTE (Bands 1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 29, 30, 66)

TD-LTE (Bands 34, 38, 39, 40, 41)

UMTS/HSPA+/DC-HSDPA (850, 900, 1700/2100, 1900, 2100 MHz)

GSM/EDGE (850, 900, 1800, 1900 MHz)

All models

802.11ac Wi-Fi with MIMO

Bluetooth 5.0 wireless technology

NFC with reader mode

Location

●●●○○ VZW Wi-Fi VPN 10:42 AM 92%
Apple Inc.

iPhone X Models and Pricing

1700/2100, 1900, 2100 MHz)

GSM/EDGE (850, 900, 1800, 1900 MHz)

Model A1901*

Model A1901 does not support CDMA networks, such as those used by Verizon and Sprint.

FDD-LTE (Bands 1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 29, 30, 66)

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All models

802.11ac Wi-Fi with MIMO

Bluetooth 5.0 wireless technology

NFC with reader mode

Conclusion: MU-MIMO is dead!

Multi-User MIMO

- MU-MIMO is only potentially effective…

  …in *high density* environments

  …with a preponderance of *supporting client devices*

  …that are *radially separated* relative to the AP

  …that have roughly *equal amounts of data* to receive

- Most smartphone devices still don't support MU-MIMO
  - They *don't need to* support MU-MIMO in order to sell
  - MU-MIMO does *nothing to enhance speed* of an individual client device

MU-MIMO is dead because client devices will not be sold on the basis of their ability to resolve a network capacity problem.

This will never be a viable market solution!

Why the Death of MU-MIMO is Bad News for 802.11ax

IEEE 802.11ax requires *even more* to go just right…

- Multiple enhancements, including bi-directional MU-MIMO, coloring, multiple NAVs, dynamic fragmentation, and adaptive power
- Key enhancement: OFDMA: Orthogonal frequency division multiple access
  - Multiple subcarriers (down to 2 MHz)
  - Time-domain multiplexing (i.e. variant of TDMA)
  - Requires the AP to *maintain complete control* of the channel, as in cellular LTE networks (and PCF)

802.11ax is an order of magnitude more complex than what has come before in Wi-Fi. It takes the principle of using math to cheat physics to new depths!

Why the Death of MU-MIMO is Bad News for 802.11ax

IEEE 802.11ax requires ***even more*** to go just right…

- Fundamental flaw:
  - Wi-Fi is *unlicensed,* whereas cellular LTE is licensed
  - By definition, *the AP does not have control of the channel!*
- Can it be made to work in the lab? Probably
- Can it be made to work in the real world? Very rarely, if at all!
- Why?
  - Like MU-MIMO, any neighboring legacy Wi-Fi network or legacy Wi-Fi clients will constrain any possible 802.11ax gains
  - OFDMA and bi-directional MU-MIMO requires client device support
    - Client device manufacturers not motivated: they *don't need* it in order to sell
    - 802.11ax does *nothing to enhance speed* of an individual client device

Conclusion: 802.11ax is dead!

Why the Death of MU-MIMO is Bad News for 802.11ax

IEEE 802.11ax requires *even more* to go just right…

The Emperor's Prediction that this is the only "ax" that the Apple® iPhone™ is likely to support…

http://www.facebook.com/HaerteTest

Tri-Band APs

A More Practical Alternative to MU-MIMO and 802.11ax?

EnGenius EAP2200

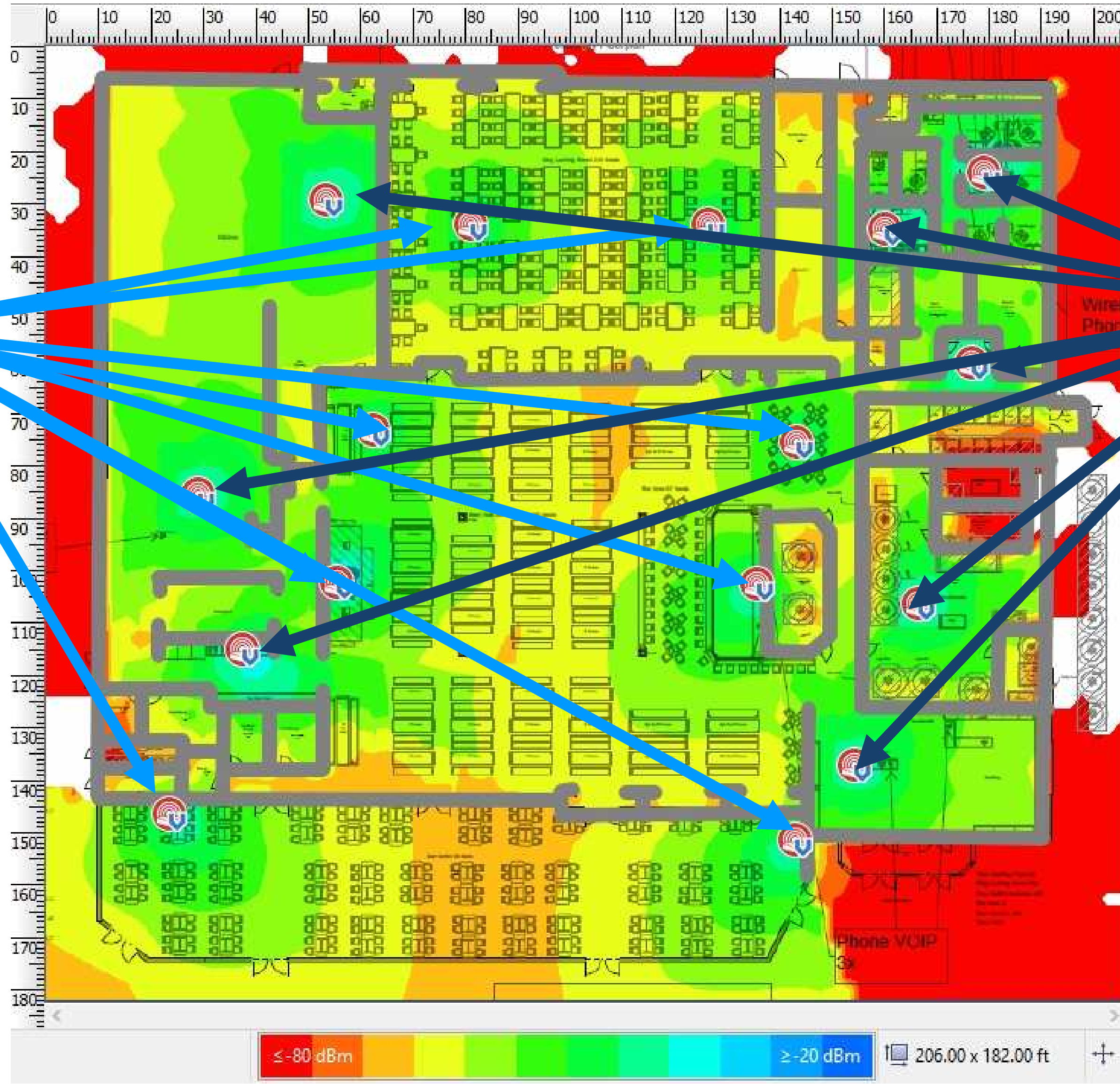
- Radios
  - 2.4 GHz, 5 GHz Low-Band (36-64), 5 GHz High-Band (100-165)
  - Shielding done at chipset level
- Advantages over MU-MIMO
  - Supports all 5 GHz clients *without additional client device support*
  - Supports bi-directional communication with two 5 GHz clients simultaneously
- Applications
  - High density environments (lecture halls, auditoriums, conference centers, etc.)
- Challenges
  - Client steering (i.e. load balancing between 5 GHz radios)
  - Channel planning (each AP takes two 5 GHz channels)

http://www.emperorwifi.com/2017/08/the-emergence-of-tri-band-aps.html

Tri-Band APs

Design Example: Restaurant / Brewery / Banquet Hall

Tri-Band APs (front of house)

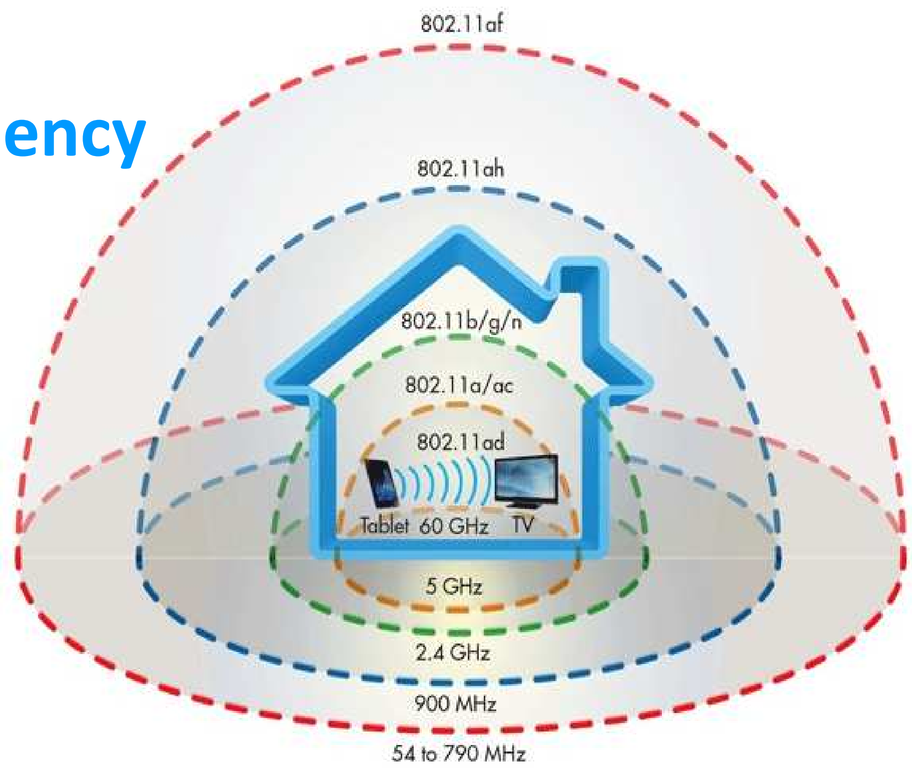


Dual-Band APs (back of house)

- Still have design constraints of cabling restrictions, building materials
- New channel planning and transmit power considerations

Alternative Wi-Fi Technologies

Breaking out Applications by Unlicensed Frequency



http://pocketnow.com/2016/01/12/wifi-802-11-ad-802-11-ah-802-11-af-halow

- WiGig: 802.11ad
  - 60 GHz [DMG PHY]
  - Single room only
  - Ultra high bandwidth
  - Target: Multimedia, Short Distance PTP
- White-Fi: 802.11af
  - 54-790 MHz (VHF/UHF) [TVHT PHY]
  - Good penetration through walls
  - Moderate bandwidth
  - Target: IoT
- HaLow: 802.11ah
  - 900 MHz [S1G PHY]
  - Good penetration through walls
  - Low bandwidth
  - Target: IoT
- Li-Fi: 802.15.7
  - Visible Light (430-750 THz)
  - Single room only
  - Very high bandwidth
  - Avoids electromagnetic interference

Where Do We Go From Here

Start With Requirements

Functional Requirements (WLA Red Book)

- FR1: Usage
  - What *devices* are using the network?
  - What *frequencies* do they operate on?
  - Are there multiple types of users w/ different capabilities, security, & access rights?
- FR2: Coverage
  - What areas of the facility need to be covered?
  - What are the physical and logical constraints?
- FR3: Capacity
  - How many devices need simultaneous access?
  - How much bandwidth will be consumed?

Design Parameters

- DP1: Access Point Model and Antenna
  - AP vendor and model
  - Number of bands and radio chains
  - Antenna type and direction
- DP2: AP Location
  - Where are APs physically located
  - Where are they relative to one another
- DP3: AP Channel Settings
  - AP channel settings per band
  - AP channel width per band
- DP4: AP Transmit Power Settings
  - AP transmit power settings, per band

The Call to Action

- The Future of Wi-Fi depends upon the *client devices*
  - Client devices will continue to have the cheapest possible components, and will continue to be the worst possible actors on our networks
  - We need to invest in AP technologies that are *tolerant* of poor client devicess
  - We could use *help from WFA and others* to push for *minimum client standards*
- We must design our networks for *robustness*
  - We can *no longer rely* upon boosting speed by using math to cheat physics
  - We must *adapt to working in different RF domains* (900 MHz, 2.4 GHz, 5 GHz, 60 GHz, 430-750 THz) for different applications
- We must push for appropriate regulation
  - Develop spectrum sharing strategies that *don't overly hamper* Wi-Fi performance
  - Workable *DFS rules* that make additional spectrum actually usable

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