The What, How and Why of Wi-Fi Network Design

Fehmi Sakkal | @fsakkal

Ayman Mukaddam | @ayman_mukaddam

If you fail to plan, you plan to fail.

– Benjamin Franklin

Aim of this Workshop

- This workshop will provide a detailed coverage of the key requirements and considerations a Wi-Fi Network "designer" has to study.
- Refresh your Wi-Fi education and get started on the path to becoming Wireless Network Administrators and Designers.
- The workshop will also explore tools that will help in designing, implementing and troubleshooting Wi-Fi networks.

About Us

Fehmi Sakkal
Consulting Systems Engineer
Hewlett Packard Enterprise
CWNE #247

Ayman Mukaddam
Systems Engineer
Hewlett Packard Enterprise
CWNE

Agenda

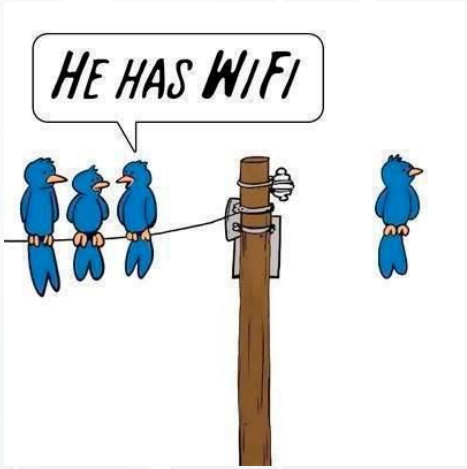
- The Need for Wi-Fi
- Wi-Fi Use Cases
- The Wi-Fi Design Cycle
- RF-Design Considerations & Infrastructure Sizing
- Wi-Fi Design Tools

Everyone's Expectations

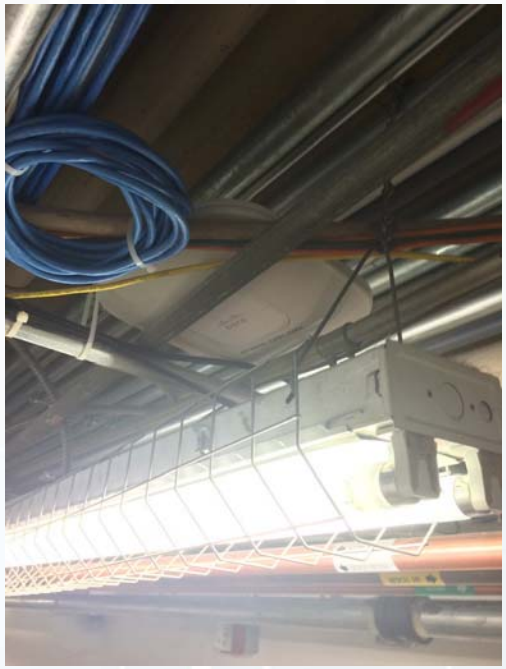
- Wireless is always available
- Wireless works just like at home

Wi-Fi needs Wired Ports

- Proper Design
  - Cheaper to do it right the first time
  - Fail to Plan → Plan to Fail
    - AP Locations (Data Points Distribution)
    - Power/PoE Requirements
    - Proper Design for Distribution System
    - Redundancy

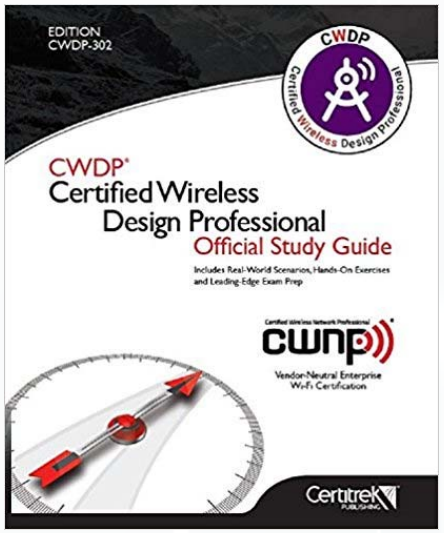


Avoiding Bad-Fi

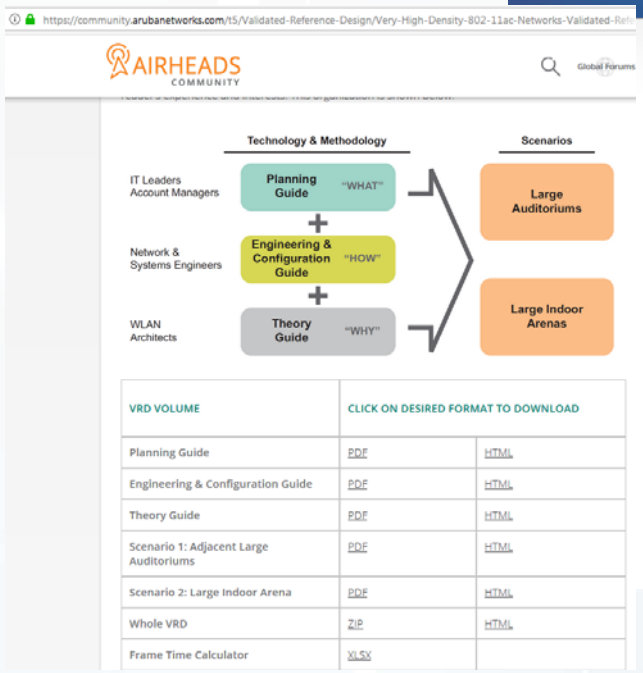


Source: https://badfi.com/

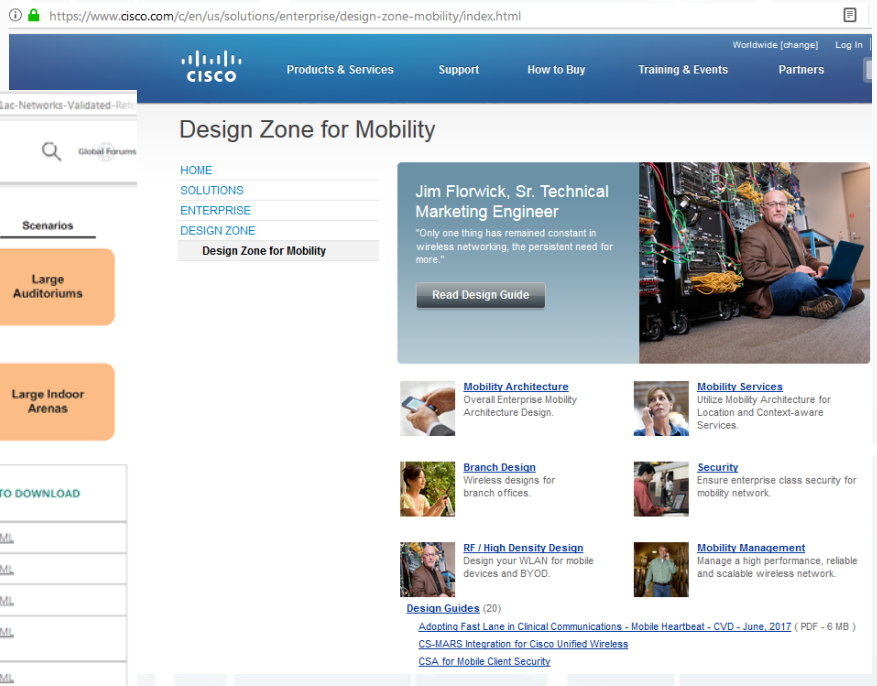
Best Practices



Vendor-Neutral Guides



Aruba Validated Reference Designs



Cisco Design Guides

https://www.cwnp.com/certifications/cwdp
https://community.arubanetworks.com/t5/Validated-Reference-Design/Very-High-Density-802-11ac-Networks-Validated-Reference-Design/ta-p/230891
https://www.cisco.com/c/en/us/solutions/enterprise/design-zone-mobility/index.html

Wireless Everywhere

Education – K12

Education – Universities

Enterprise

Warehouse

Hospitality

Retail

Healthcare

LPV: Airports

Images:
https://www.engaging-technologies.com/product/mimiostudio-interactive-software/
http://www.puterea.ro/social/centru-de-pregatire-pentru-elevii-informaticieni-84848.html
http://hospitalityriskupdate.com/2014/06/13/should-your-hotel-offer-free-wifi/
https://marketingland.com/power-wi-fi-using-mobile-drive-customer-acquisition-loyalty-133602
https://www.performancenetworks.co.uk/blog/post/wifi-network-can-help-transform-business/
https://smallbiztrends.com/2014/10/hospital-wifi.html
https://gizmodo.com/thanks-tsa-airport-security-lines-are-now-3-hours-long-1777073373
https://rmsomega.com/pla-voicepicking-forklift/

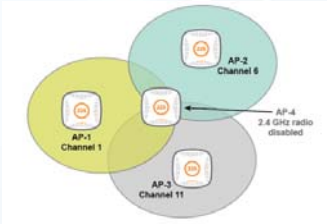
Bicsi MIDDLE EAST & AFRICA

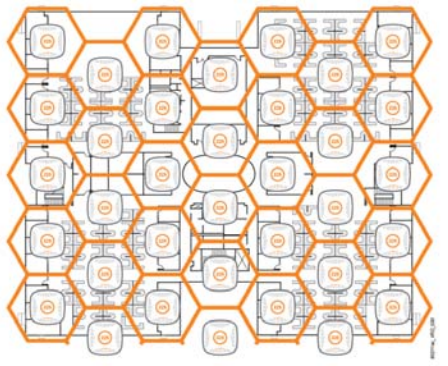
Wireless Use Cases

- Standard Deployments (Carpeted Space)
- Complex Deployments
  - Auditorium & Large Public Venue
  - Warehouse
- Outdoor Use Cases

Wireless Use Cases – Carpeted Space

- A standard environment
  - Distance between two APs should be approximately 12 to 20 meter
  - Minimum RSSI should be -65 dBm throughout the coverage area
  - SNR should be greater than 25 dB
  - Typically less than 20 to 30 devices per cell
  - Many 2.4 GHz radios might be disabled

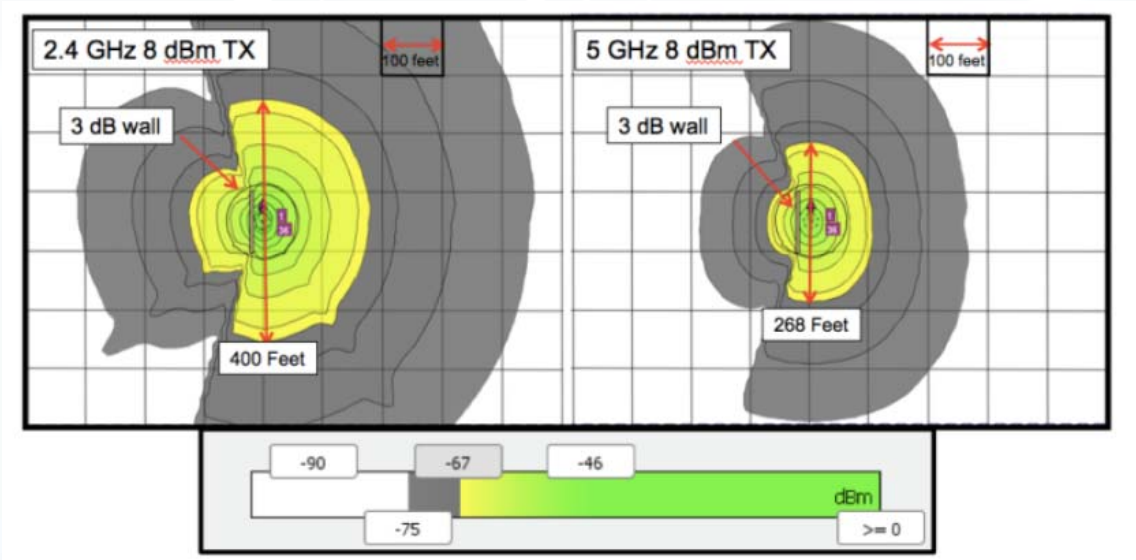




https://www.cisco.com/c/en/us/products/collateral/wireless/aironet-1250-series/design_guide_c07-693245.html
https://community.arubanetworks.com/t5/Validated-Reference-Design/Aruba-802-11ac-Networks/ta-p/242637

Wireless Use Cases – Carpeted Space

- A standard environment – Design for 5 GHz



https://www.cisco.com/c/en/us/td/docs/wireless/controller/8-1/Enterprise-Mobility-8-1-Design-Guide/Enterprise_Mobility_8-1_Deployment_Guide/wlanrf.pdf

Wireless Use Cases – Carpeted Space

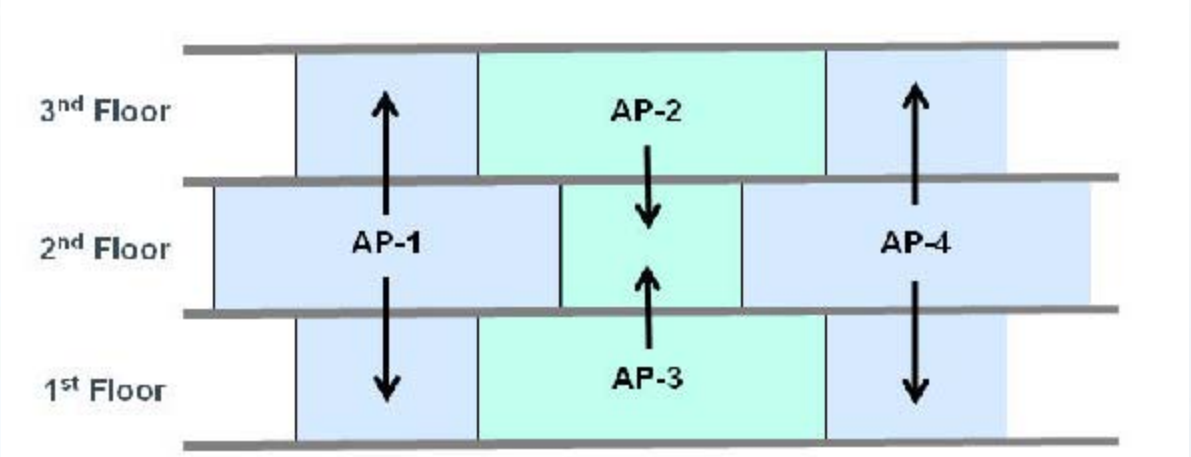
- A standard environment

Indoor Environment	Attenuation in 2.4 GHz	Attenuation in 5 GHz
Fabric, blinds, ceiling tiles	Approximately 1 dB	Approximately 1.5 dB
Interior drywall	3–4 dB	3–5 dB
Cubicle wall	2–5 dB	4–9 dB
Wood door (Hollow –Solid)	3–4 dB	6–7 dB
Brick/concrete wall	6–18 dB	10–30 dB
Glass/window (not tinted)	2–3 dB	6–8 dB
Double-pane coated glass	13 dB	20 dB
Steel/fire exit door	13–19 dB	25–32 dB

https://community.arubanetworks.com/t5/Validated-Reference-Design/Aruba-802-11ac-Networks/ta-p/242637

Wireless Use Cases – Carpeted Space

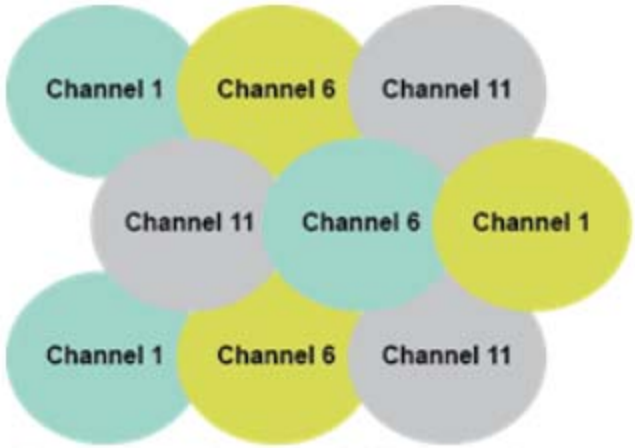
- A standard environment



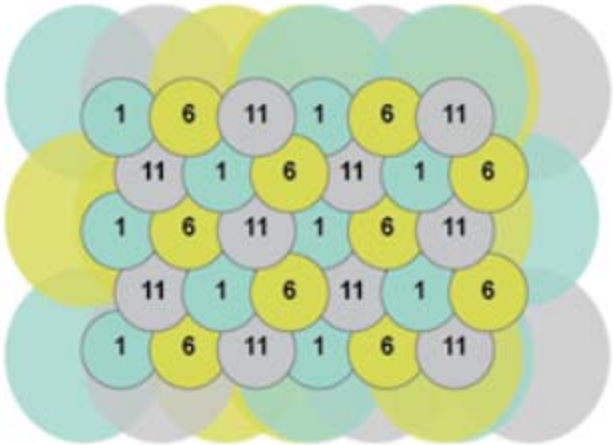
http://www.wi-fiplanet.com/tutorials/article.php/3811421/How-to-Optimize-Wi-Fi-Coverage-in-Multi-Floor-Facilities.htm

Wireless Use Cases – Carpeted Space

- Coverage vs Capacity



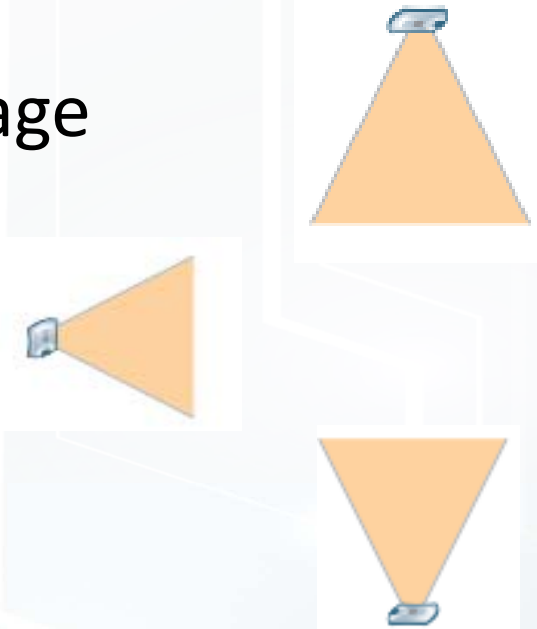
Coverage design with 7.2 Mb/s cell edge



Coverage design with 216.7 Mb/s cell edge

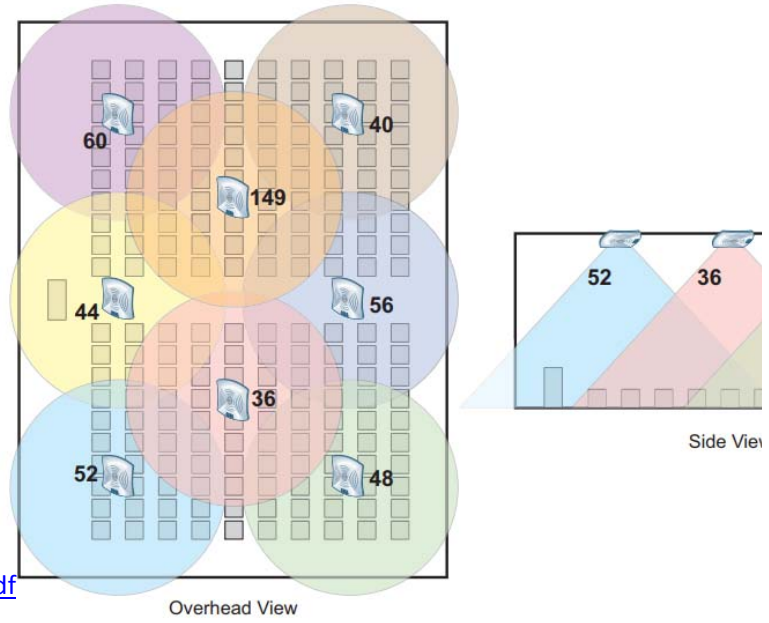
Wireless Use Cases - Auditoriums

- Overhead Coverage
- Side Coverage
- Floor Coverage



Wireless Use Cases - Auditoriums

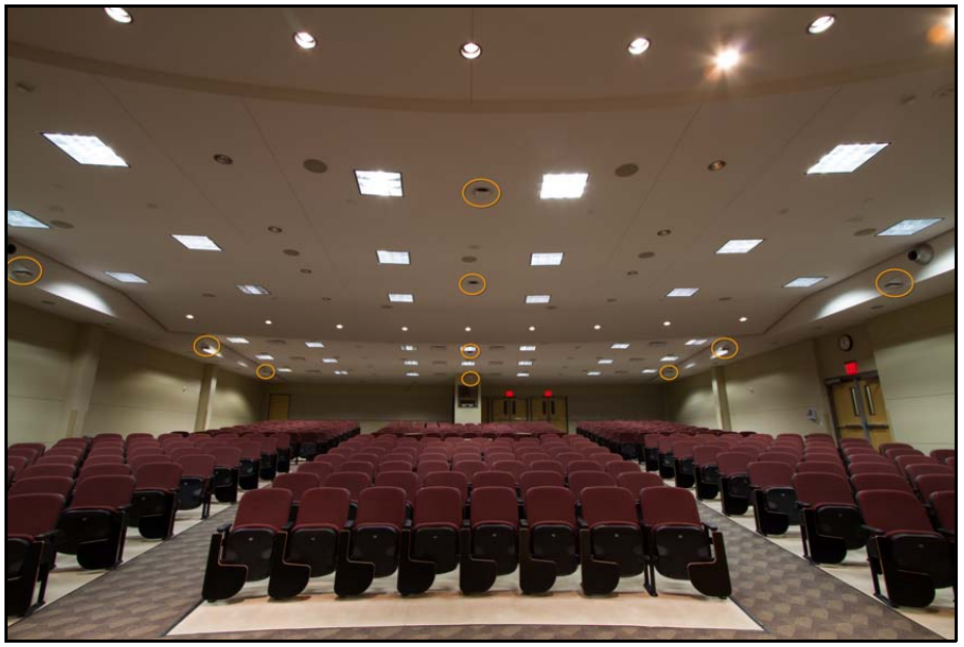
- Overhead Coverage
  - APs on the ceiling above the seats in the auditorium (Low Gain Antenna)
  - RF Channel Reuse is not possible
  - Signal is more uniform (APs evenly distributed)
  - Cell Size Not less than 300 seats (150m^2)
  - Better to use down-tilt antenna (No Need for External A
  - Might be hard to pull cables
  - Maintenance might be hard
  - Hard to control CCI/ACI
  - Aesthetics



http://www.arubanetworks.com/assets/vrd/Aruba_VHD_VRD_Scenario1_Large_Auditoriums.pdf

Wireless Use Cases - Auditoriums

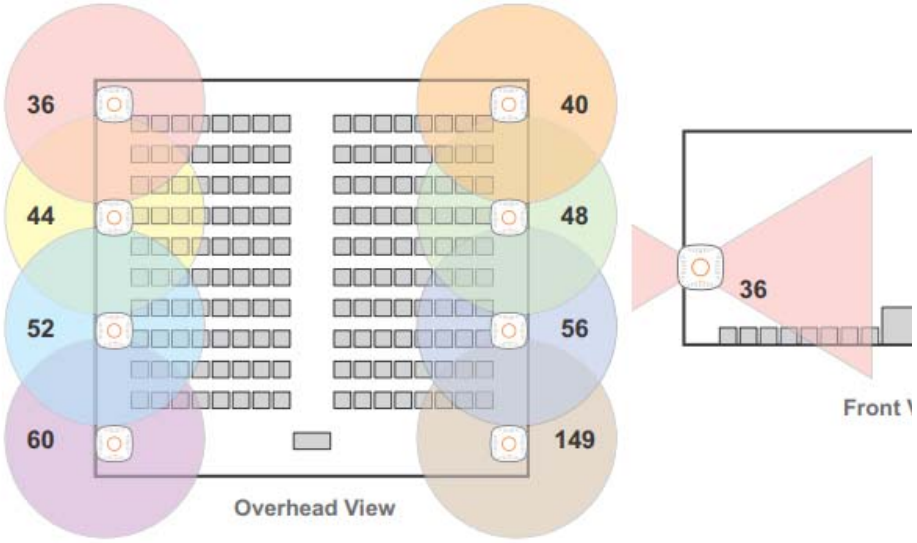
- Overhead Coverage Example



http://www.arubanetworks.com/assets/vrd/Aruba_VHD_VRD_Scenario1_Large_Auditoriums.pdf

Wireless Use Cases - Auditoriums

- Side Coverage
  - The AP is mounted to walls and/or pillars that exist in the auditorium, generally no more than 12 ft (4 m) above the floor
  - RF Spatial Reuse Not Possible
  - Signal in Center Less than sides
  - Cell Size Not less than 300 seats (150m^2)
  - Easier & Cheaper installation
  - Easier Access to AP
  - Hard to control CCI/ACI
  - Aesthetics



http://www.arubanetworks.com/assets/vrd/Aruba_VHD_VRD_Scenario1_Large_Auditoriums.pdf

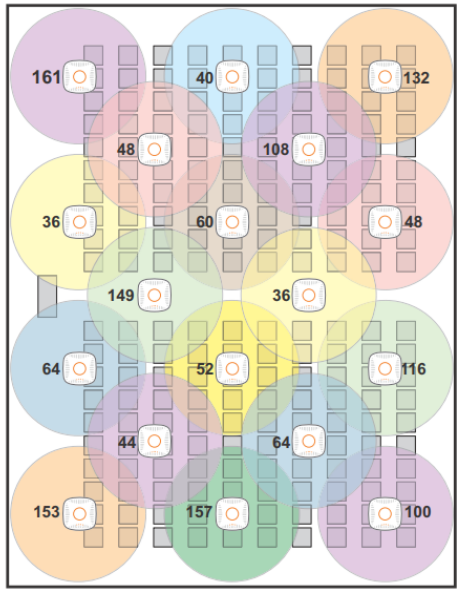
Wireless Use Cases - Auditoriums/LPV

- Side Coverage Example

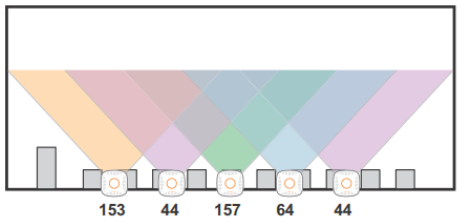
http://www.arubanetworks.com/assets/vrd/Aruba_VHD_VRD_Scenario1_Large_Auditoriums.pdf

Wireless Use Cases - Auditoriums/LPV

- Floor Coverage (Underseat)
  - The AP is mounted under the seat
  - RF Spatial
  - Signal is m
  - Cell Size ca
  - More Cost
  - Very Easy
  - Hard to co



Overhead View



Side View

http://www.arubanetworks.com/assets/vrd/Aruba_VHD_VRD_Scenario1_Large_Auditoriums.pdf

Wireless Use Cases - Auditoriums/LPV

- Floor Coverage (Underseat)

http://www.arubanetworks.com/assets/vrd/Aruba_VHD_VRD_Scenario1_Large_Auditoriums.pdf

Wireless Use Cases – Auditoriums/LPV

- Use one strategy per area
- Choose the right AP models (High Density)
- Minimum AP to AP spacing 5m (integrated antenna) and 2m (highly directional antenna)
- Functionality at the expense of Aesthetics

http://www.arubanetworks.com/assets/vrd/Aruba_VHD_VRD_Scenario1_Large_Auditoriums.pdf

Wireless Use Cases - Warehouse

- Warehouse Characteristics
  - Low Throughput Requirement ices)
  - High Ceilings
  - Shelves with varying density a
  - Different client devices with d ies
  - Limited LOS
  - Vertical Coverage is needed
  - Varying Stock Levels

http://community.arubanetworks.com/t5/WLAN-Professionals-Summit-2014/Hostile-Environments-Wireless-LAN-Design-for-Warehouses/gpm-p/139077

Wireless Use Cases - Warehouse

- Absorption Goods like
  - Paper
  - Plastic
  - Water
- Reflection Goods like
  - Metal

http://community.arubanetworks.com/t5/WLAN-Professionals-Summit-2014/Hostile-Environments-Wireless-LAN-Design-for-Warehouses/gpm-p/139077

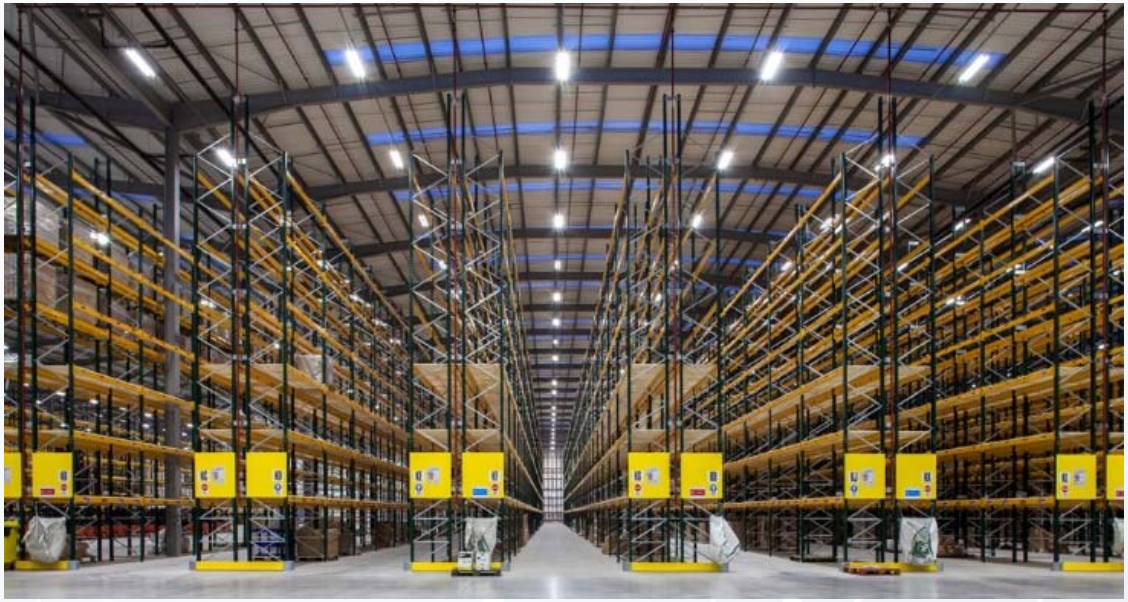
Wireless Use Cases - Warehouse

- AP Locations and Antenna Selection
  - Overhead Low Gain Down-tilt Antenna (Low Absorption)
    - Limit Cell Coverage
    - Better Signal at Ground Level
    - Less AP to AP Interference
  - Side Coverage Low Gain Directional Antenna (High Absorption)

https://www.securedgenetworks.com/blog/9-common-warehouse-wifi-problems-and-what-you-can-do-to-fix-them

Wireless Use Cases - Warehouse

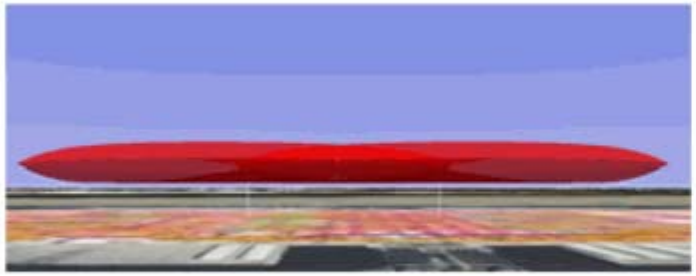
- AP Locations and Antenna Selection



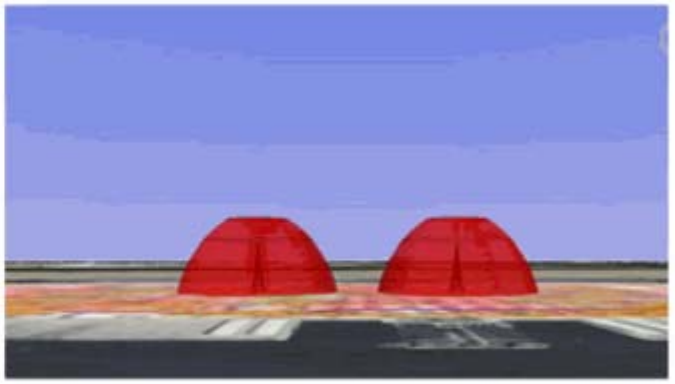
http://luxreview.com/article/2016/03/lighting-in-warehouses

Wireless Use Cases - Overhead

- Overhead Coverage

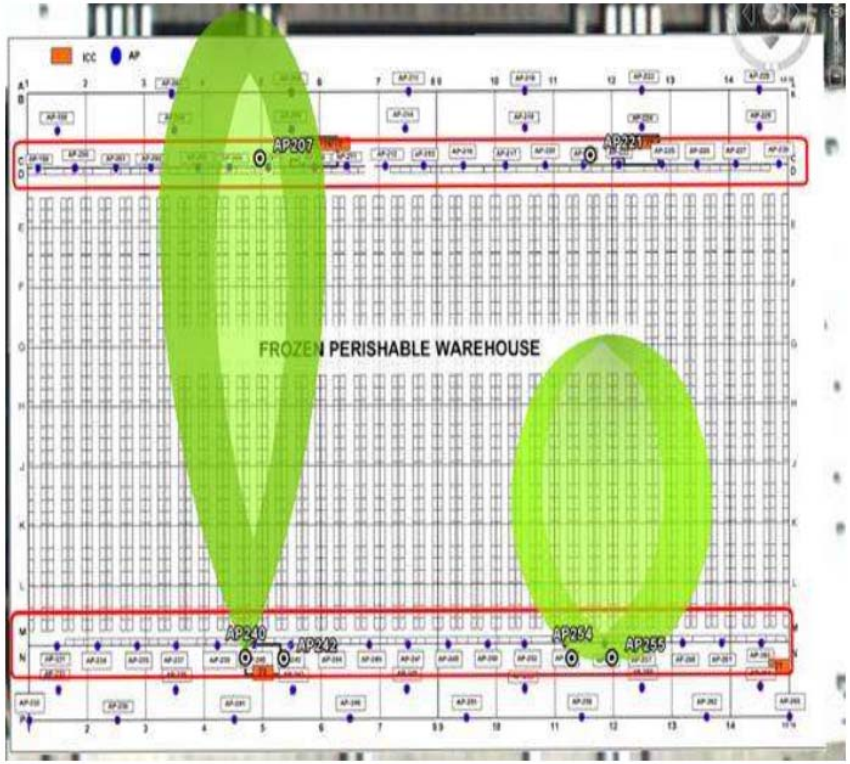


10dBi “Stick” Omni



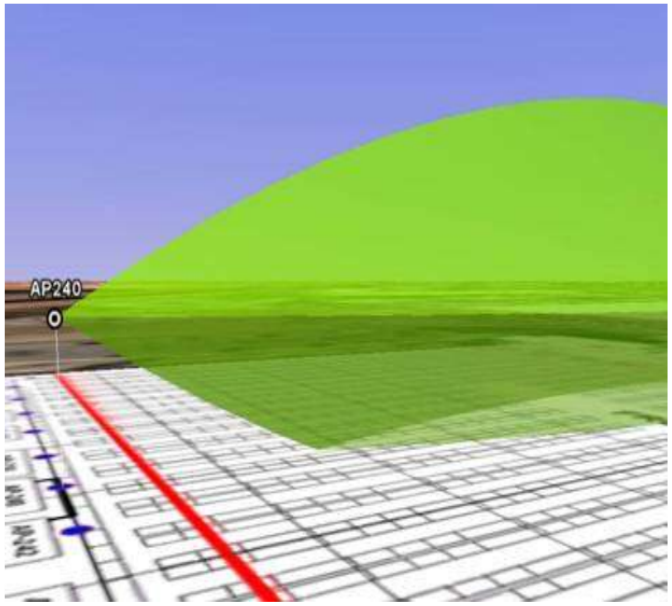
3dBi “Squint” Omni

Wireless Use Cases - Warehouse

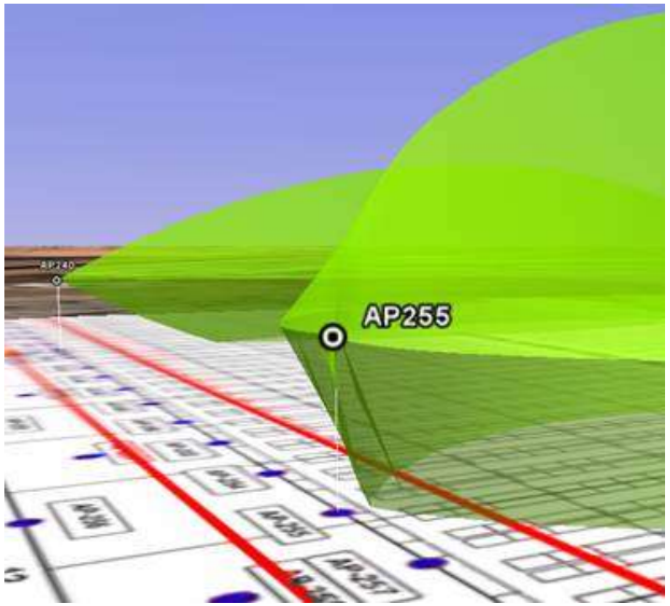


http://community.arubanetworks.com/t5/WLAN-Professionals-Summit-2014/Hostile-Environments-Wireless-LAN-Design-for-Warehouses/gpm-p/139077

Wireless Use Cases - Warehouse



High Gain Antenna Pattern
(narrow vertical beamwidth)



Low Gain Antenna Pattern
(wide vertical beamwidth)

http://community.arubanetworks.com/t5/WLAN-Professionals-Summit-2014/Hostile-Environments-Wireless-LAN-Design-for-Warehouses/gpm-p/139077

Outdoor Use Cases

- Client Coverage
- Wireless Mesh
  - Point-to-Point
  - Point-to-Multipoint
  - Multi-hop Mesh

WLAN Design Cycle

- Like anything else, it's good to have a methodology and framework for the wireless network design.
- The building blocks are the same as any design cycle.
- These building blocks can be integrated into the relevant project management plan and approach and in the relevant order, including initiation, planning, execution, checking/control and closing of the WLAN project.

Design Cycle Building Blocks

Initiation	Planning	Execution	Check/Control	Closing
• Use-cases • Scope requirements	• Hardware Selection • Site Surveys • Documentation			

Gathering & Analyzing Requirements

- MEET the customer! And identify key decision makers and participants
- Identify a high-level scope
- Understand the customer’s expertise and expectations
- Gather requirements: both technical and business
- Consider constraints: time, money, politics…etc
- Create CRD and SoW

CRD & SoW

- Customer Requirements Document: summary of requirements that have been gathered through the discovery phase and interview process. The purpose of this document is to ensure that both parties are in agreement regarding the project requirements

- SoW: The statement of work (SOW) is the formal agreement that is reached between the designer and customer. It should explicitly detail the deliverables, timelines, scope of the project, and pricing. A well - written SOW will clearly define which tasks the customer should complete and which tasks the designer should complete.

Site Surveys

- Common to planning, implementation, and design post-checks
- Should range:
- From an actual site walkthrough during planning to understand the environment
- To design and implementation survey, heatmap measurements and tests
- To the actual survey post-installation
- Plan for contact information, facility access, H&S, security clearance…etc
- Utilize the proper tools

WLAN Installation

- Agreement on Proper roll-out Plan and Site Access
- Green-field vs Brown-field Deployments
- Who is carrying out the implementation/installation?
- Documentation to turn implementation into operation

Check/Control

- Post-installation tasks including:
  - RF-assessment
  - Configuration validation
  - Security testing
  - Client connectivity testing, roaming, application, load and performance testing
- Troubleshooting & analysis: RF, Network, Security, and QoS Analysis
- Updating documentation with design/configuration changes

Closing

- UAT and Document/project Sign-off
- Transfer of Information, Credentials, Documentation, Escalation Processes, and Training

Data Rates 101

- ***Data Rate*** is the speed at which data is transferred between two devices generally measured in megabits per second (Mbps)
- ***Data Rate*** is the number of bits per second the PHY layer carries during a single-frame transmission.
- ***Data Rate*** is the modulation rate at which a frame is sent at depending on a “million environmental variables”.

Data Rates = Actual Rates?

Data Rates 101

- ***Data Rate*** is the speed and not actual throughput.
- ***Aggregate throughput*** is usually 30-50% of data rate speed due to medium access methods and overhead.
- MCS variables control the **data rate *"bandwidth"*** at which a radio can transmit. Medium contention and RF environmental variables determine what the actual TCP throughput is for the radio.

Evolution of Data Rates

- **IEEE 802.11 Wi-Fi protocol summary**

Protocol	Frequency	Signal	Maximum data rate
Legacy 802.11	2.4 GHz	FHSS or DSSS	2 Mbps
802.11a	5 GHz	OFDM	54 Mbps
802.11b	2.4 GHz	HR-DSSS	11 Mbps
802.11g	2.4 GHz	OFDM	54 Mbps
802.11n	2.4 or 5 GHz	OFDM	600 Mbps
802.11ac	5 GHz	256-QAM	1.3 Gbps
802.11ax	2.4 or 5 GHz	1024-QAM	9.6 Gbps

Data Rate Selection

- **IEEE 802.11-2016:** If no protection mechanism, “a non-DMG STA shall transmit the frame using a rate that is in accordance with rules defined in 10.7.5 and 10.7.6.”
- “Generally”, **management** and **control** frames are sent at low frame rates, so that all STAs will understand them.
- “Generally”, **data** frames are sent at faster frame rates.

Data Rate Selection

- It would be ideal for all Wi-Fi infrastructure to use the highest data rates, but that doesn't happen.
- So what affects Data Rate Selection?

Rate Selection/Shifting

- Also known as Dynamic Rate Shifting, Adaptive Rate Shifting, Adaptive Rate Selection, Automatic Rate Selection…etc
- **IEEE 802.11-2016:** "The algorithm for performing rate switching is beyond the scope of this standard…"
- Vendor's "secret sauce" algorithms do this.
- Objective of DRS is upshifting and downshifting for improved performance and rate optimization.

DRS: The More You Know

- DRS usually determined by RSSI, SNR, packet error rates, retransmissions.
- DRS works with ALL 802.11 PHYs !
- DRS algorithm may dynamically shift coding, modulation and channel width (not good) in order to keep rate high or to keep connection solid (according to vendor)

Who makes the DRS decision? Client or AP?

Data Rate: What Else?

- RF noise (interference, raises noise floor, lowers SNR)
- Channel utilization (CCI, low basic rates, high traffic)
- Retries/retransmissions (takes longer xmit same data)
- WLAN clients:
  - Some clients “hear and talk” better than others
  - Number of Tx/Rx antennas and spatial streams
- WLAN client drivers!!!
- WLAN client locations (distance, conditions from client to AP)

Recommendation for Faster Rates

- Smaller cell sizes: Will help load balance
- Smaller cell sizes: Encourages STAs to roam
  - to another AP
- “Smaller” cell sizes: Disable low basic rates

Data Rate & Range Myths

- Disabling low data rates does NOT decrease RF cell size
- Increasing data rates does NOT decrease RF cell size

MCS & Wi-Fi Rates

- MCS (*modulation* and *coding scheme*) is defined in 802.11n and is based upon factors of:
  - modulation
  - number of spatial streams
  - channel size
  - guard interval
- MCS also affected by SNR:
  - For every additional 20 MHz bonding, noise floor increases 3 dB.
  - If noise floor is -98 dBm for 20 MHz, then it is -95 dBm for 40 MHz and -92 dBm for 80MHz

802.11n/HT and 802.11ac/VHT MCS, SNR and RSSI

HT MCS	VHT MCS	Modulation	Coding	20MHz				40MHz				80MHz				160MHz			
				Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI
				800ns	400ns			800ns	400ns			800ns	400ns			800ns	400ns		
1 Spatial Stream																			
0	0	BPSK	1/2	6.5	7.2	2	-82	13.5	15	5	-79	29.3	32.5	8	-76	58.5	65	11	-73
1	1	QPSK	1/2	13	14.4	5	-79	27	30	8	-76	58.5	65	11	-73	117	130	14	-70
2	2	QPSK	3/4	19.5	21.7	9	-77	40.5	45	12	-74	87.8	97.5	15	-71	175.5	195	18	-68
3	3	16-QAM	1/2	26	28.9	11	-74	54	60	14	-71	117	130	17	-68	234	260	20	-65
4	4	16-QAM	3/4	39	43.3	15	-70	81	90	18	-67	175.5	195	21	-64	351	390	24	-61
5	5	64-QAM	2/3	52	57.8	18	-66	108	120	21	-63	234	260	24	-60	468	520	27	-57
6	6	64-QAM	3/4	58.5	65	20	-65	121.5	135	23	-62	263.3	292.5	26	-59	526.5	585	29	-56
7	7	64-QAM	5/6	65	72.2	25	-64	135	150	28	-61	292.5	325	31	-58	585	650	34	-55
	8	256-QAM	3/4	78	86.7	29	-59	162	180	32	-56	351	390	35	-53	702	780	38	-50
	9	256-QAM	5/6			31	-57	180	200	34	-54	390	433.3	37	-51	780	866.7	40	-48
2 Spatial Streams																			
8	0	BPSK	1/2	13	14.4	2	-82	27	30	5	-79	58.5	65	8	-76	117	130	11	-73
9	1	QPSK	1/2	26	28.9	5	-79	54	60	8	-76	117	130	11	-73	234	260	14	-70
10	2	QPSK	3/4	39	43.3	9	-77	81	90	12	-74	175.5	195	15	-71	351	390	18	-68
11	3	16-QAM	1/2	52	57.8	11	-74	108	120	14	-71	234	260	17	-68	468	520	20	-65
12	4	16-QAM	3/4	78	86.7	15	-70	162	180	18	-67	351	390	21	-64	702	780	24	-61
13	5	64-QAM	2/3	104	115.6	18	-66	216	240	21	-63	468	520	24	-60	936	1040	27	-57
14	6	64-QAM	3/4	117	130.3	20	-65	243	270	23	-62	526.5	585	26	-59	1053	1170	29	-56
15	7	64-QAM	5/6	130	144.4	25	-64	270	300	28	-61	585	650	31	-58	1170	1300	34	-55
	8	256-QAM	3/4	156	173.3	29	-59	324	360	32	-56	702	780	35	-53	1404	1560	38	-50
	9	256-QAM	5/6			31	-57	360	400	34	-54	780	866.7	37	-51	1560	1733.3	40	-48
3 Spatial Streams																			
16	0	BPSK	1/2	19.5	21.7	2	-82	40.5	45	5	-79	87.8	97.5	8	-76	175.5	195	11	-73
17	1	QPSK	1/2	39	43.3	5	-79	81	90	8	-76	175.5	195	11	-73	351	390	14	-70
18	2	QPSK	3/4	58.5	65	9	-77	121.5	135	12	-74	263.3	292.5	15	-71	526.5	585	18	-68
19	3	16-QAM	1/2	78	86.7	11	-74	162	180	14	-71	351	390	17	-68	702	780	20	-65
20	4	16-QAM	3/4	117	130	15	-70	243	270	18	-67	526.5	585	21	-64	1053	1170	24	-61
21	5	64-QAM	2/3	156	173.3	18	-66	324	360	21	-63	702	780	24	-60	1404	1560	27	-57
22	6	64-QAM	3/4	175.5	195	20	-65	364.5	405	23	-62			26	-59	1579.5	1755	29	-56
23	7	64-QAM	5/6	195	216.7	25	-64	405	450	28	-61	877.5	975	31	-58	1755	1950	34	-55
	8	256-QAM	3/4	234	260	29	-59	486	540	32	-56	1053	1170	35	-53	2106	2340	38	-50
	9	256-QAM	5/6	260	288.9	31	-57	540	600	34	-54	1170	1300	37	-51			40	-48

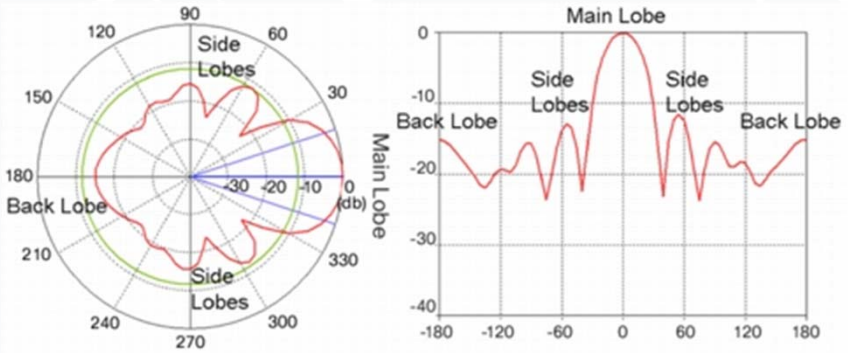
RF Domain & Restrictions

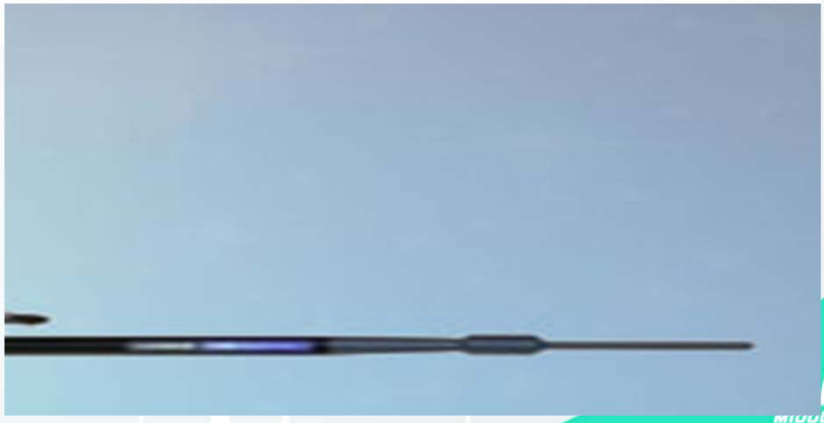
- TRA Regulatory Domain
- Power & Antenna Gain Restrictions

RF Patterns: This…. Will NOT Make It!

Antenna Application Myths

- Work with antennas only if you know what you are doing.
- Consider different antennas for different applications
- Antenna placement & alignment is key
- Antennas don't create extra energy!
- "An antenna's gain or is a key performance number which combines the antenna's directivity and electrical efficiency" - Wikipedia





Demo MCS & Wi-Fi Rate

Demo Chanel Planning and Wi-Fi Equipment Types

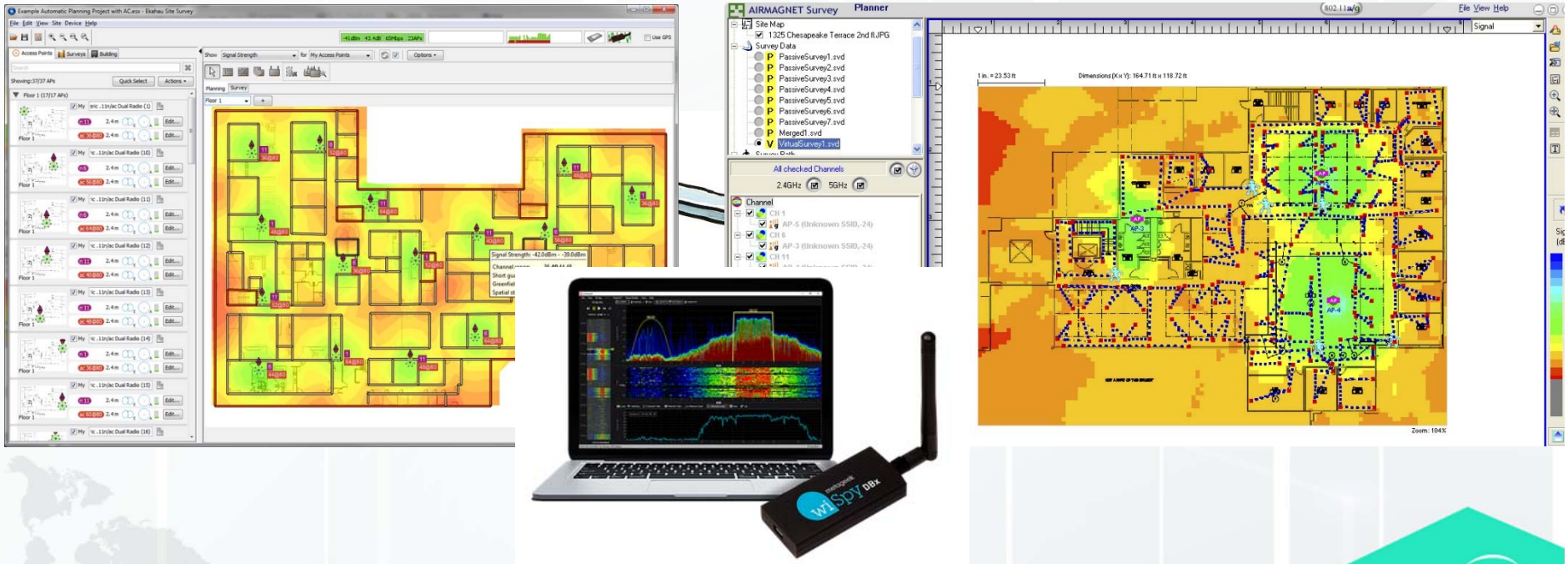
Bicsi
MIDDLE EAST
& AFRICA

Equipment Selection Whiteboard Discussion

Use the Right Tool for the Right Job

https://www.ekahau.com/

https://www.airmagnet.com/



https://www.metageek.com/products/wi-spy/

Planning & Survey Types

- Predictive modeling
- Pre-deployment (aka “AP-on-a-stick”) surveys
- Post-deployment surveys

- Active Site Survey
- Passive Site Survey

Survey Toolset

- Clear Map with Proper Scale (Better if Autocad)
- Survey Mapping Software + Wifi Adapters
- APs
- Power Source: Batteries/ PoE Injectors/Switch
- Phone / Camera
- Duct Tape / Cable Ties
- Mounting Poles / AP on a Stick

- Optional: http://connect-a-desk.com/

Tools Demonstration