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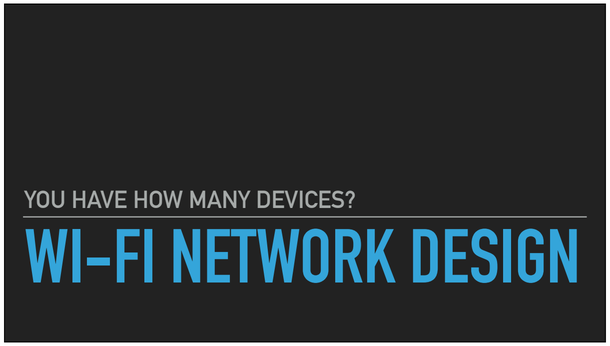

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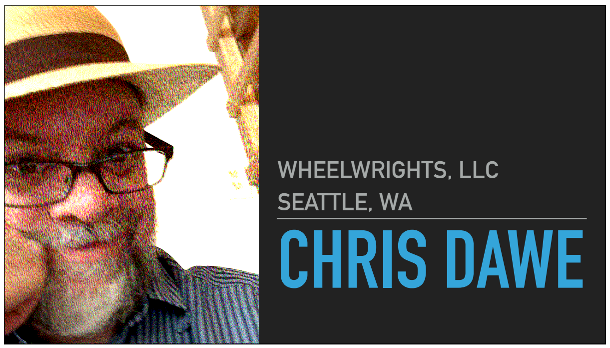
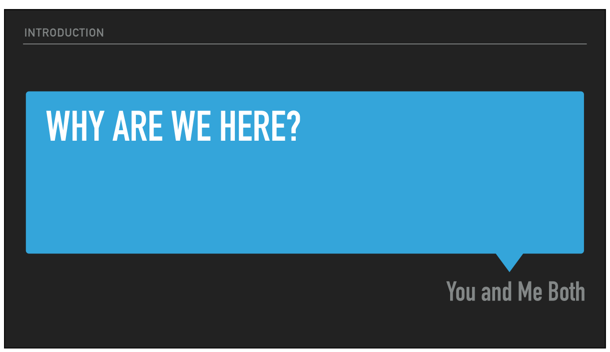
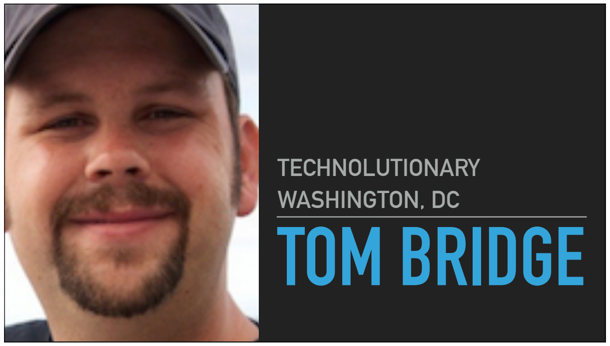


Chris Dawe is a Seattle-based IT consultant specializing in OS X, iOS, and networking for small businesses and K-12 education. Chris also handles project planning and management, and strategic planning consulting.

3



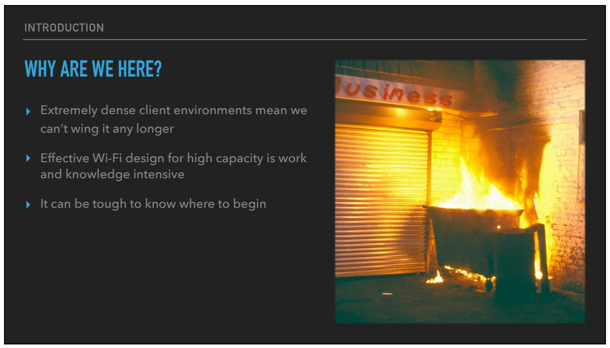
We're here because the rise of iOS and OS X mobility has transformed Wi-Fi from a "nice to have" add-on to to a necessary and critical component of our networks. Because we now have hundreds or thousands of devices, most of which do not connect to an Ethernet cable, and many of which *cannot.*



4

In another sense, we’re here because of this guy.

Two years ago at the Mac Admins 2014, I suggested to my friend and colleague Tom Bridge that I was thinking about submitting a session on the fundamentals of Wi-Fi. Tom called my bluff, and six months later he dragged me kicking and screaming were submitting the proposal for what became 2015’s workshop “Fundamentals of Wi-Fi”. We have since distilled some of what we learned into a presentation at the MacAdUK conference in London, and re-mounted the workshop at Cascadia IT conference in Seattle. In order to re-mount the workshop in Seattle, we compressed the same material into



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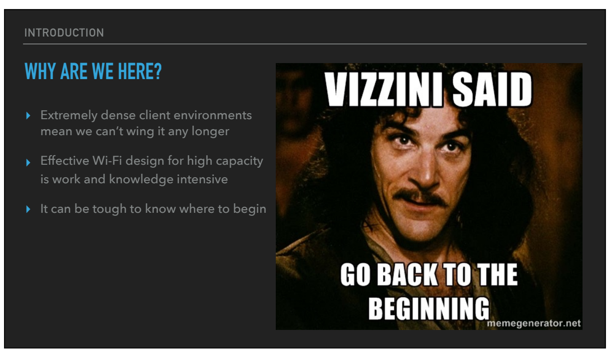


6

So we begin at the beginning.

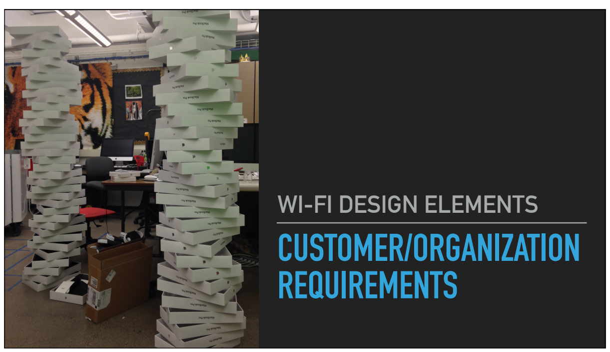
7

We are going to talk about Wi-Fi network design as a complete process with 8 components, many of which you'll deal with before you even order equipment.

1. Customer/organization requirements
2. Understanding your site and its effects on your design
3. Infrastructure requirements
4. Radio frequency (RF) planning
5. Network Capacity Planning

8

6. Design techniques and tools
7. Network installation
8. Testing, validation, and adjustment (finally)



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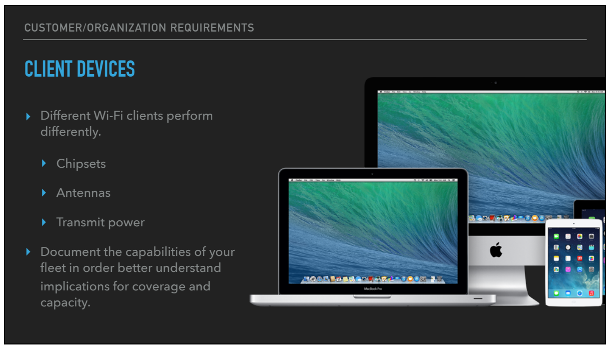
10

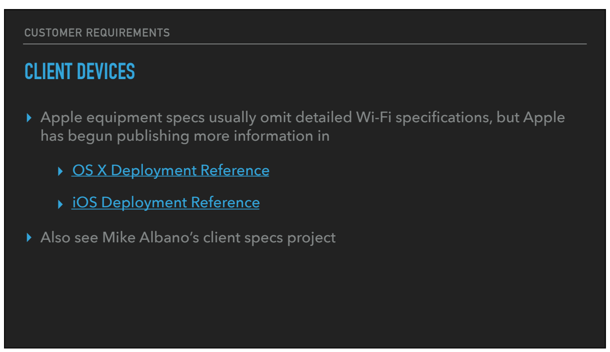
The upshot to a more modern network is the need for more network equipment in order to support the higher performance available in the 5 GHz band. In turn, this requires more money.

A project that starts with a "budget" prior to the other steps in designing a network will likely prove problematic. It's likely best to move the budget component of the project to a point where you and your institution are more familiar with your technical goals and needs.



11

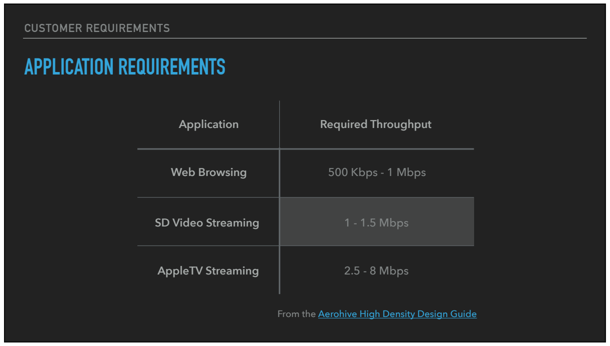
For example, a MacBook Pro may have a 3x3:3 802.11n interface, while a mobile device may be capable of 802.11ac 2x2:2. If your replacement cycle is such that you won't be seeing 802.11ac clients in your organization for another 3 years, consider when it's worth implementing 802.11ac access points.



12

Because Apple tends to aggressively drop models from documentation, you may want to document equipment yourself for later reference.

OS X Deployment Reference: https://help.apple.com/deployment/osx/#/ior1faf9de44
iOS Deployment Reference: https://help.apple.com/deployment/ios/#/ior65f75e248
Mike Albano's Client Specs: http://clients.mikealbano.com



13

Work to document the applications you expect to use. Each application requires different throughput capability, and this will affect the amount of equipment required to serve your devices.

The detailed chart from which this information is taken is found in the Aerohive Design and Configuration Guide for High Density Wi-Fi, by Andrew von Nagy, available from Aerohive at http://docs.aerohive.com/330000/docs/help/english/5.1r2/ref/Aerohive_High-Density_Wi-Fi-Design-Config-Guide_330073-01.pdf

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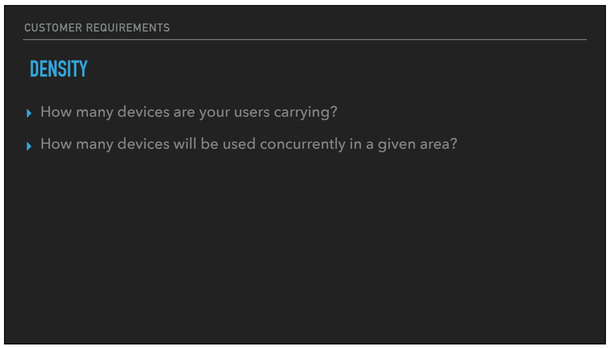

14

The number of devices and users involved, and their usage patterns will prove important to your design.

1. A 600 seat lecture hall is a significant challenge due to the number of people involved.
2. If you have a staff and student body each of whom carry a laptop, tablet, and a phone, the design expectation is going to be very different from an environment where you're designing for the IT and administrative staff.
3. How many devices an AP can handle is a very specific question; there's no real standard for this, and you should be questioning your vendors

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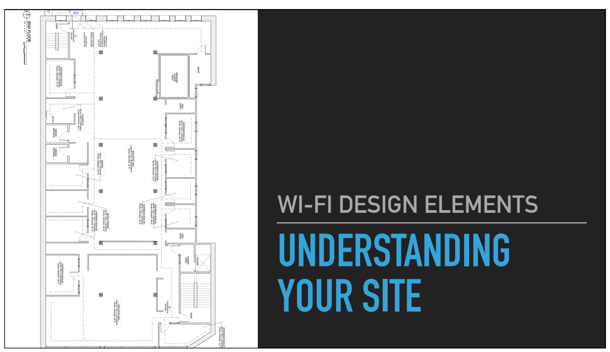

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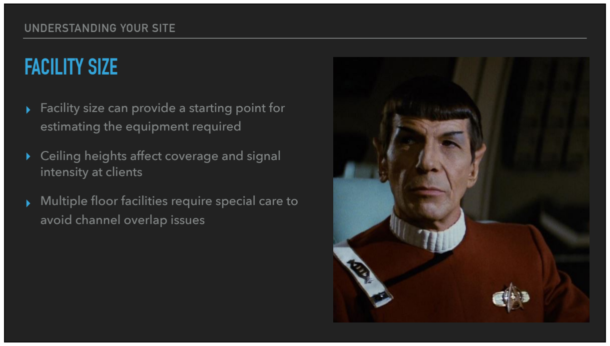
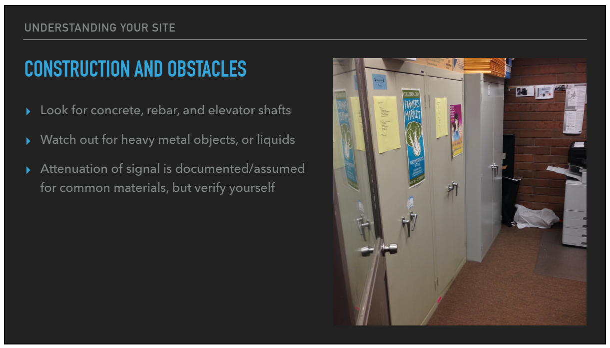


16

Experience will help you avoid two dimensional thinking.

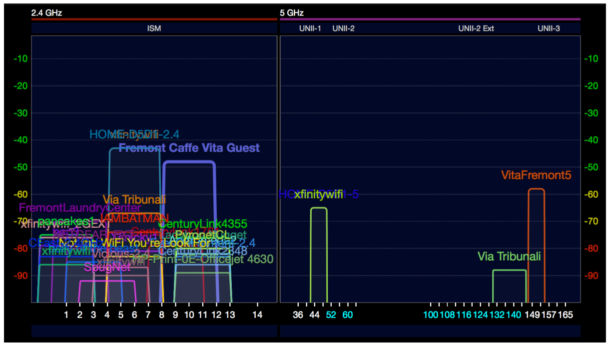


17

One thing to keep in mind is that some objects aren't nailed down, and that staff move things around for their own workflow and convenience. Beer kegs, whiskey barrels, and filing cabinets aren't permanent features, and when they move, your network changes.

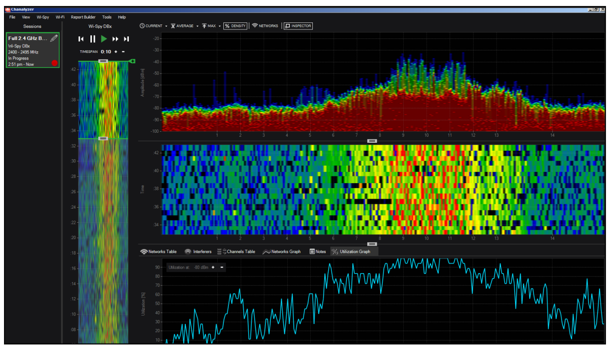
18

You may find that certain spaces are going to be used constantly at a high level, some are going to be used heavily on an intermittent basis, and some are going to be used barely at all. Document these so you know where to focus.



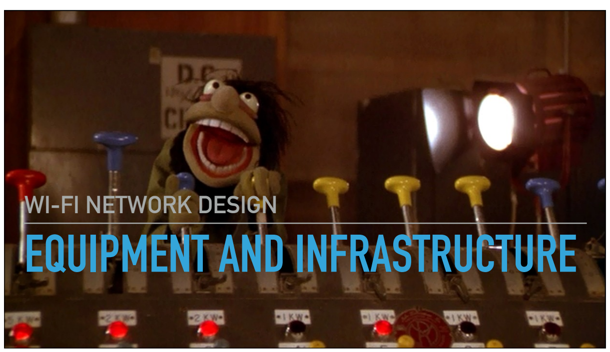
19

Assessing the strength and channel overlap of neighboring networks can help you decide what channels to avoid in your RF planning, but be aware that the environment will change unpredictably.



20

Spectrum analysis can give you more. In this Chanalyzer Pro screenshot we see something stomping all over the utilization of 2.4 GHz RF spectrum. Busier channels show warmer colors representing utilization over time (at the top) and higher utilization levels (bottom), in this case showing us spectrum that is being overcome by noise. Since a spectrum analyzer gets below the level of WiFi, it shows us radio signals other than Wi-Fi as well as the Wi-Fi itself.



21

So now we've seen that we want to understand organizational requirements *and* understand our facility and environment. As part of this, we also want to understand our equipment and infrastructure.

1. Customer/organization requirements
2. Understanding your site and its effects on your design
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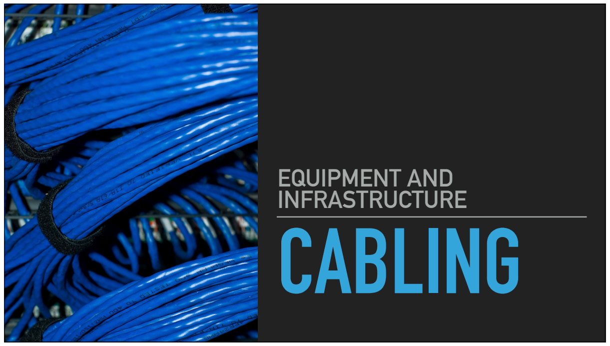
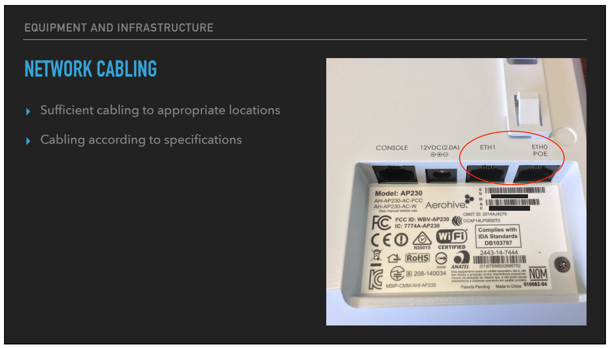


22

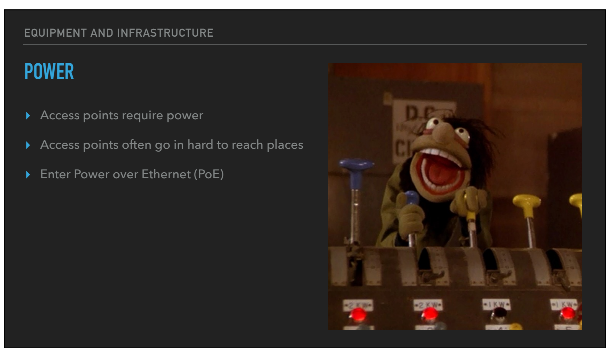
Don't leave cabling to chance by just assuming it will be there. Make sure that you work with your cabling contractor to ensure that they will be available to install your cabling.



23

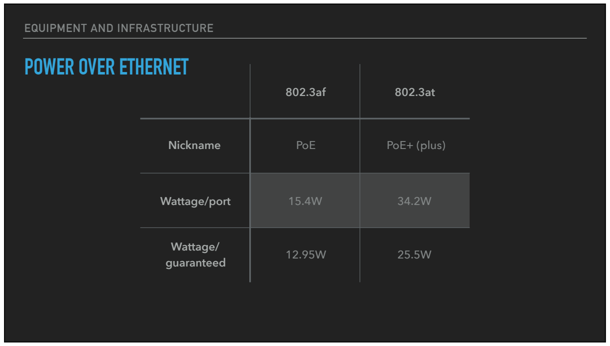
Take the time to make sure that your cabling–whether it's already installed or not–will be sufficient for your equipment. Note that some access points can use more than one Ethernet connection, and that this will likely become more common as faster access points that can overwhelm a gigabit ethernet link arrive on the market.

Also be aware that meeting cable testing specifications is particularly important for PoE. According to more experienced engineers me, the resistance characteristics of older Category 3 cabling can cause unexpected behavior with Power over Ethernet, and should probably be avoided.



24

Now we turn to power and the fact that your access points will require it regardless of their location. Many APs will go into hard-to-reach locations, so it will likely be preferable to deploy power via the Ethernet network connections running from the APs to the network closet.



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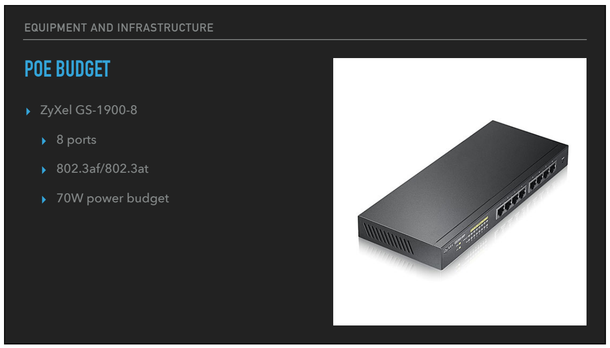
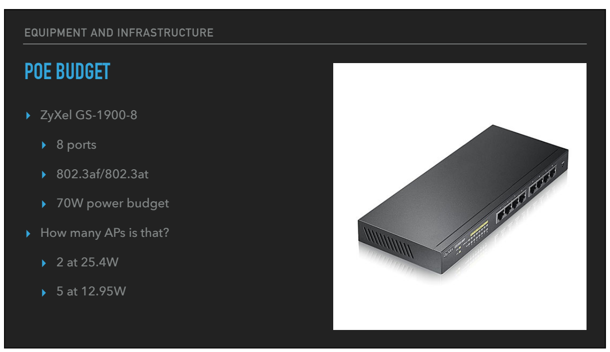
Two different PoE standards exist, providing different amounts of power per-port. Access points specs will usually specify what power standard is required.

802.11n access points will usually work with the lower powered 802.11af PoE standard without issue, but the cutting edge in wireless APs is 802.11ac: 802.11ac access points running 3x3:3 tend to require PoE+ for full functionality; if they don't get it, they step down to a lower performance level, e.g. 2x2:2. In other words, they will usually work with older PoE switches, but may not provide the performance that the vendor markets on the spec sheet.



26

70W is the total amount of power the the switch can output. So with this set of specs, how many APs can we power?



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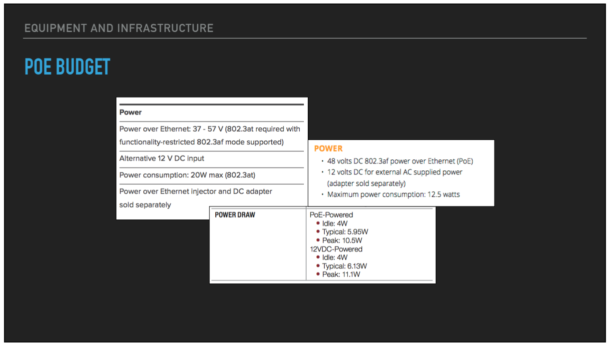
But because this depends on an overly simplistic idea of how much power APs might use (it assumes the maximum), this picture might be inaccurate.



28

You'll find that vendors document the power draw of their equipment in addition to the PoE standard required, adding another wrinkle to your calculations. Clockwise from top-left, these are the power draw figures for a Cisco Meraki MR42, and Aruba AP105, and a Ruckus R500.

Based on our previous calculations, we could power the following number of each model off our Zyxel 8-port switch with its 70 watt power budget:

6 x Aruba AP105
5 x Ruckus R500

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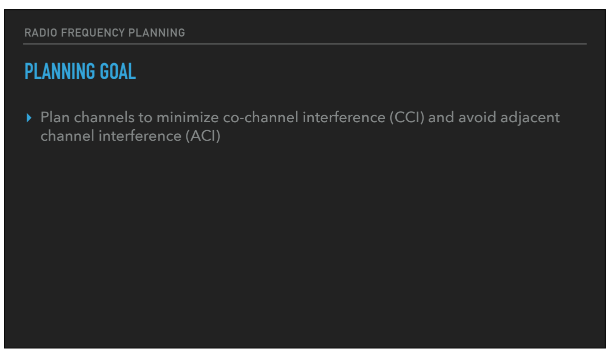


30

Our goal in radio frequency planning is to build a set of radio configurations that minimize co-channel interference and avoid adjacent channel interference.

31

So you're at a party catching up with a friend in a quiet corner of the host's kitchen. Each of you listens and talks in turn. This is a decent analogy for CSMA/CA in a low utilization environment. This works pretty well as you add people to the conversation.

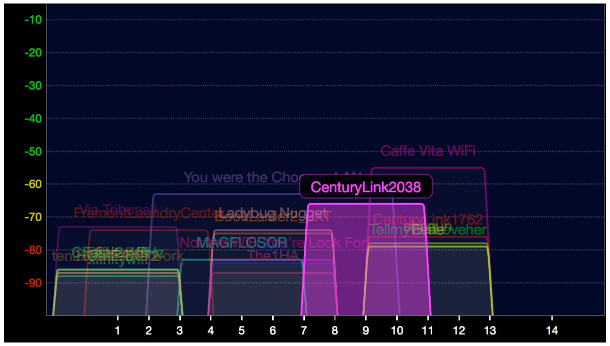
But now consider a number of loud conversations going on around you. That guy over there with his own friends is drunk, loud, and spoiling Game of Thrones, and you can't help but listen, and it's distracting enough that you can't focus on your own conversation as well. *That* is Co-Channel Interference in a nutshell: Every device–client and access point–that is using

32

Adjacent Channel Interference is a bit different. In adjacent channel interference, an environment that has different APs on *different but partially overlapping* channels causes transmission collisions, but because the devices are not using the same channel, they do not communicate with one another. Instead, they collide and simply have to retransmit.

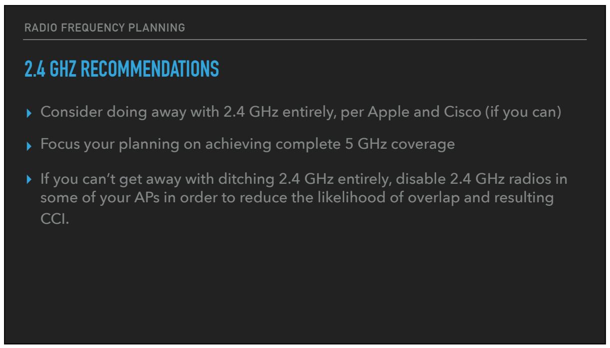
33

The designers of the 802.11 standard in the 2.4 GHz band didn't have a lot of frequency to work with: North America was only given a 50 MHz chunk of spectrum to work with, and as it turned out the channels were 22 MHz wide. Effectively this means that we can assign APs to 1, 6, and 11 without any of them overlapping. All we have to lay out our access points in a neat checkerboard pattern and assign channels carefully, right?



34

The longer effective range of 2.4 GHz signals is such that neighboring networks will impose CCI and ACI from greater distances than you would expect. This is in addition to the fact that 2.4 is subject to interference from more non-Wi-Fi sources. In addition, poor vendor practices such 40 MHz bonded channels and bad default channel assignments effectively guarantee that the 2.4 GHz spectrum is a giant mess in any dense environment.



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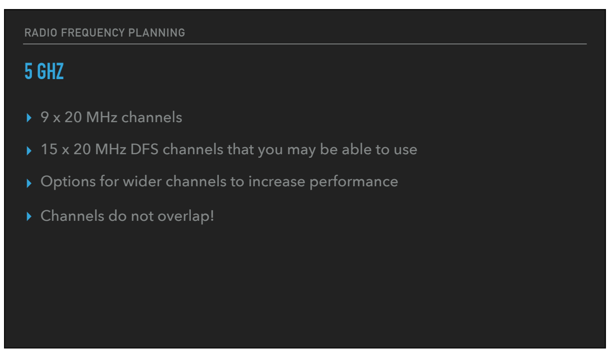
So what do we do? There are a couple of opinions. Apple and Cisco now both recommend doing away with 2.4 GHz entirely and focusing on 5 GHz, which may be feasible in some shops, but support for legacy devices may put the kibosh on it.

If you can't do that, you may be able to adjust your radio plan so that not all of your APs are transmitting in the 2.4 GHz band. Some of the planning tools we'll look at later have the ability to simulate the RF environment that will result.

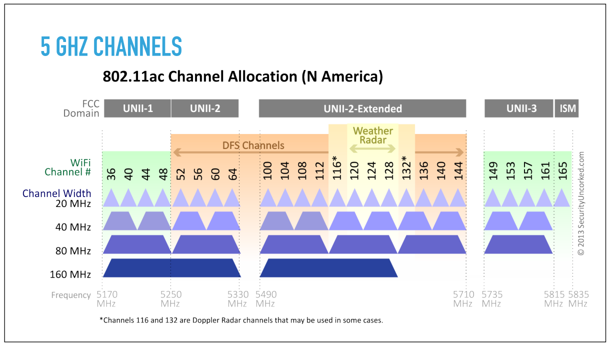


36

We get more channels in 5 GHz, although we'll see that this is more problematic than it looks.

We also get the option to bond channels.

Channels are designed such that they do not overlap, eliminating most adjacent channel interference issues.



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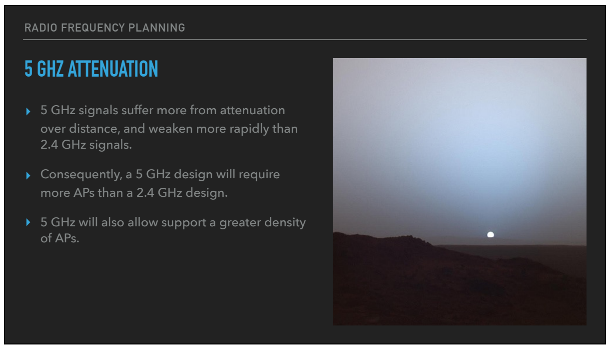
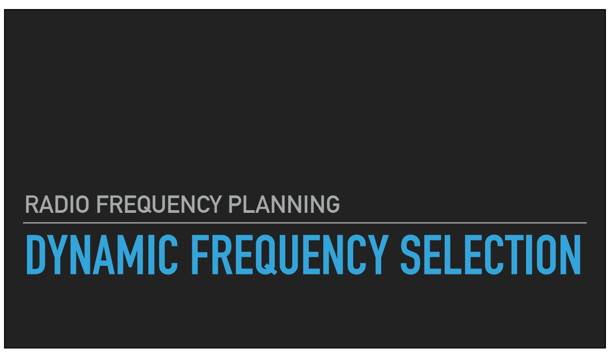
So what do the 5 GHz channels look like?



38

While the channel layout for 5 GHz provides great benefits, physics also taketh away. It's *not* actually true that 5 GHz signal attenuates more rapidly than 2.4 GHz; rather, it's more accurate to say that 5 GHz signals become impossible for systems to interpret more quickly because the requirement are more stringent. The practical consequence is that 5 GHz is usable over shorter distances than 2.4 GHz.



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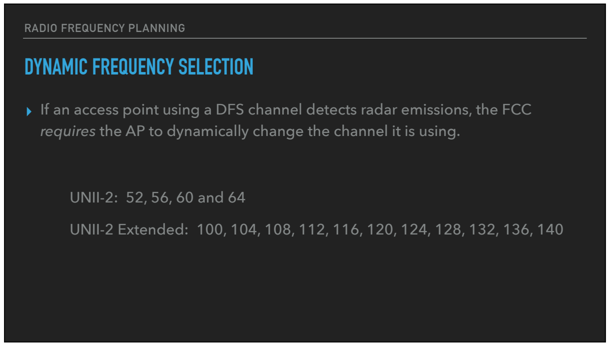

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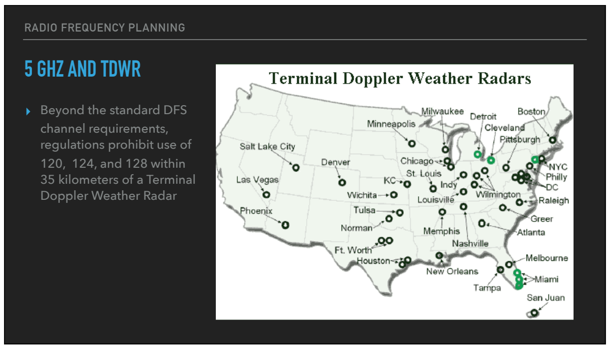
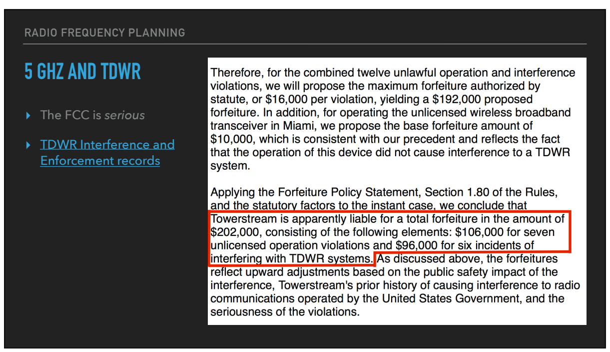
Portions of the 5 GHz frequency band share utilization with a variety of radar, and the FCC rules that grant Wi-Fi access to the spectrum also dictate that radar has priority over Wi-Fi. FCC regulations *require* vendors to implement mechanisms to force wireless access points to switch to a new channel in the event that radar is detected. This slide lists the channels subject to DFS rules as of early 2016.



41

The most specific and severe use case for DFS involves Terminal Doppler Weather Radar, a technology that the Federal Aviation Administration began implementing in the 1980s following several catastrophic air crashes caused by wind shear. As of 2014, there were 45 operational TDWR radars in major metropolitan locations across the United States and Puerto Rico.

The FCC *entirely* prohibits the use of several of the DFS channels within 35 kilometers of a TDWR. The FCC wants to avoid any interference with the TDWR, and they're *serious about it.*



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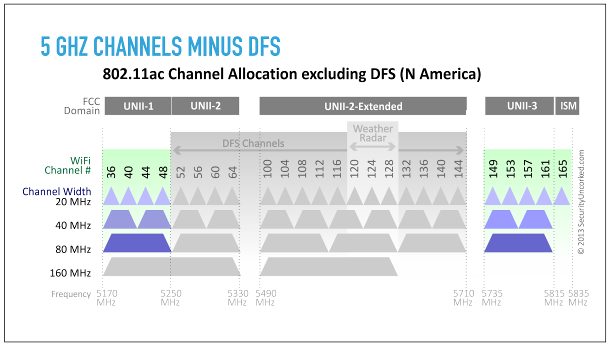
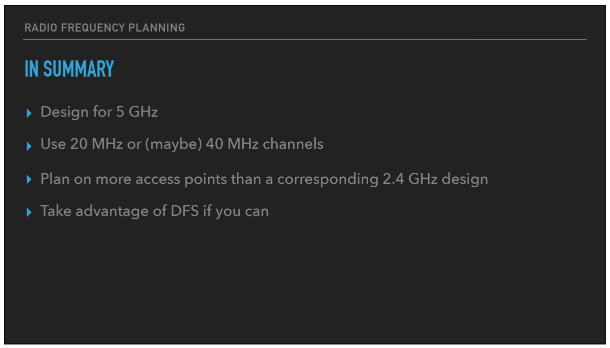
Find full documentation of violation and enforcement measures at https://www.fcc.gov/general/u-nii-and-tdwr-interference-enforcement



43

Take DFS channels away completely, and the 24 x 20 MHz channels we had falls to 9, which we can combine to create 4 x 40 MHz channels.



44

45

And then you can start thinking about planning for capacity. Planning for capacity has superseded coverage as the holy grail of Wi-Fi network design, because as we'll see, coverage is no longer enough to guarantee reliability.

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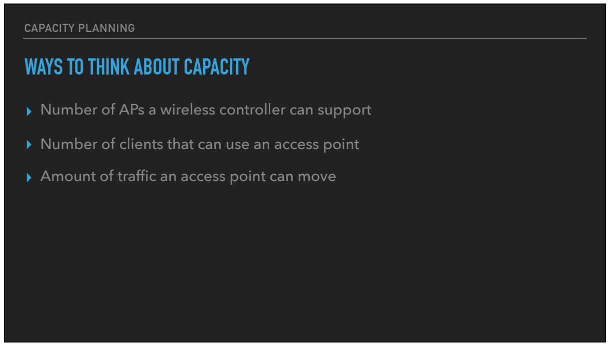

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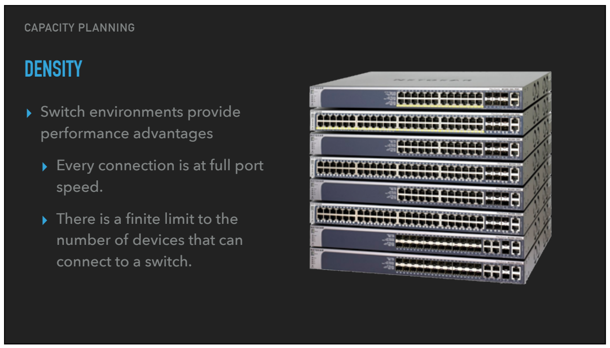
There are a number of different ways to understand capacity. Vendor hardware controllers are often licensed for a certain number of APs, and controller hardware has a certain amount of processing oomph and can handle only so much traffic.

But what we're going to focus on today is how many clients can use access points, and how much traffic can move in a given period of time.

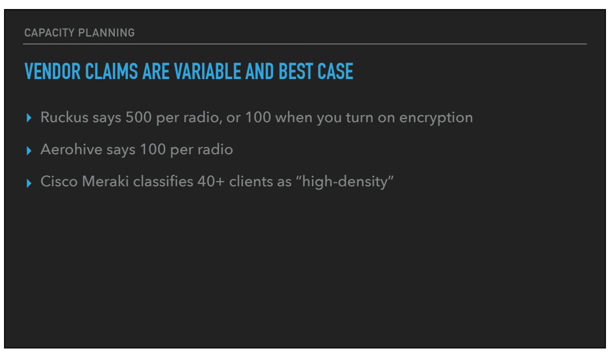
- There's no standard for the number of clients that can use an AP
- Vendor controllers are often licensed for a number of access points, and



47

Keep in mind that Wi-Fi is a little weirder than traditional Ethernet. Assuming that the cabling is within spec, every client connected to an Ethernet switch gets a dedicated connection at full port speed. In addition, Ethernet switches have hard limits to the number of devices that can be connected–they are constrained by the number or ports.

Neither of these things is true of Wi-Fi.



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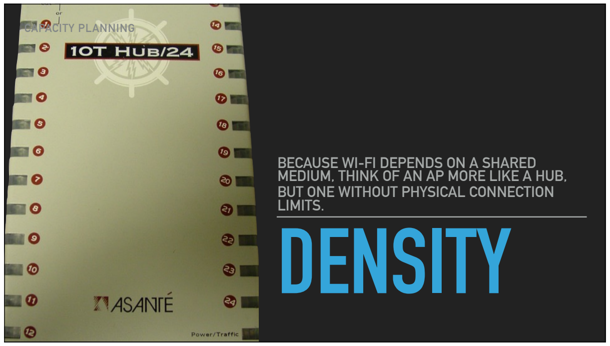
First of all rather than finding a hard limit of devices that can be physically connected, you will find that vendors estimate the maximum number of devices that can effectively use an access point. Nothing stops additional devices from connecting, and there aren't really standards for this. Different vendors discuss access point capacity in different ways.

Ruckus note at https://forums.ruckuswireless.com/ruckuswireless/topics/max_client_per_ap
Aerohive note at https://community.aerohive.com/aerohive/topics/ap230_maximum_concurrent_user



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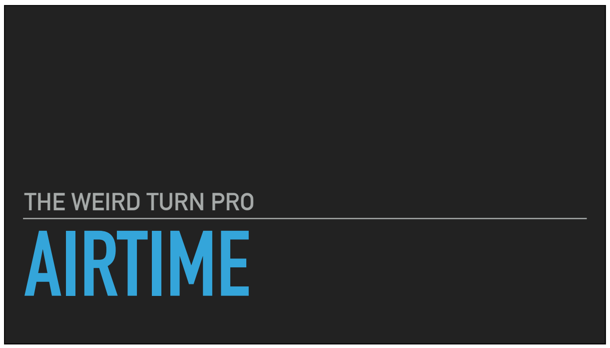
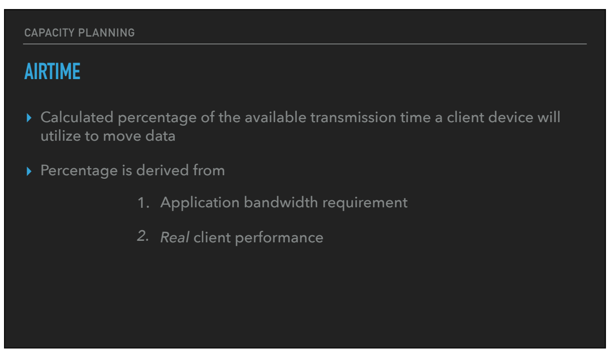
But it's worse than just a potentially large number of connections, because as we saw in the troubleshooting section, Wi-Fi is a shared medium, and APs behave more like an Ethernet hub from the 1990s. Remember that each device has to wait its turn to talk, which in turn means that more devices mean slower per-device performance.

It gets weirder than that, though.



50

The concept of airtime lends an additional layer of complexity to you network. Understanding Airtime is key to understanding how different devices interact with the Wi-Fi network and how those different devices further affect the performance and capacity of a network. As we talk about airtime, you'll see why depending on what clients you documented at the beginning of your project could demonstrate that even the highest-end access points can not save you.



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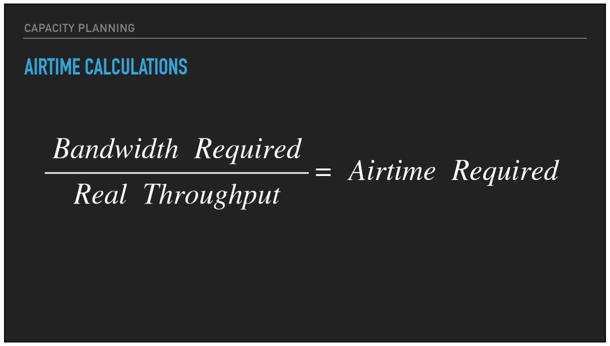
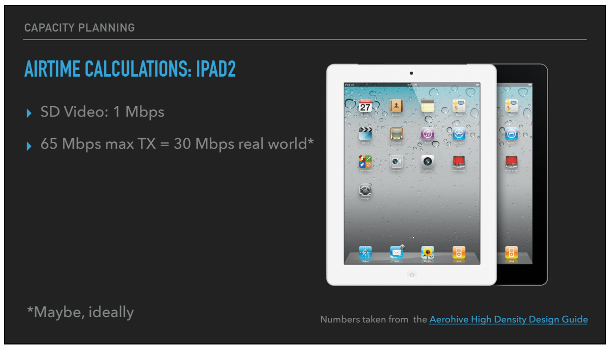


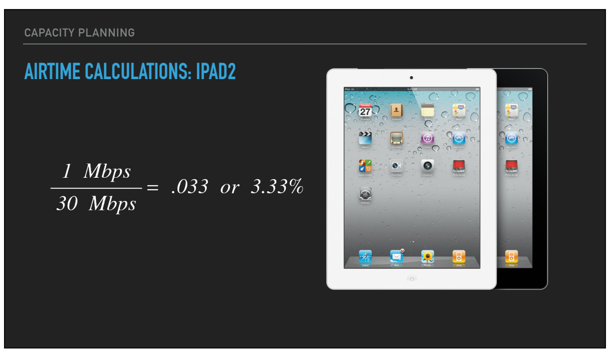
52

Divide the bandwidth that an application requires by the real throughput of a device, and you get the percentage of available a time that a device requires to move its data. Everybody follow that?



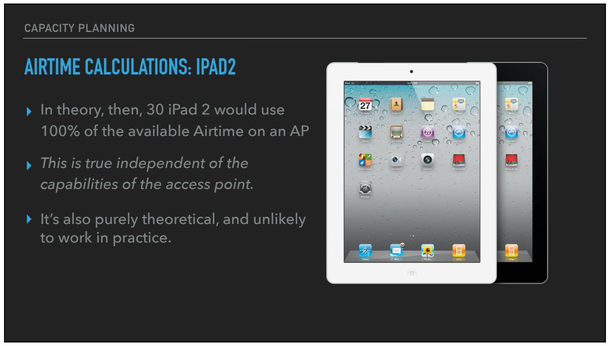
53

No? Okay, so an example using the venerable Apple iPad 2.



54

1 megabit divided by 30 megabits gives us approximately 3.33% airtime required.



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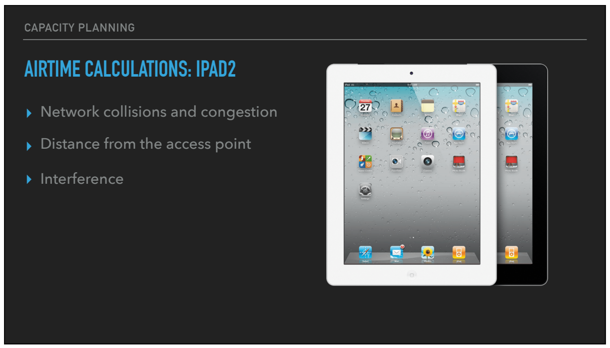
In theory, then, we can show that 30 iPads will use 100% of the available airtime on an AP.

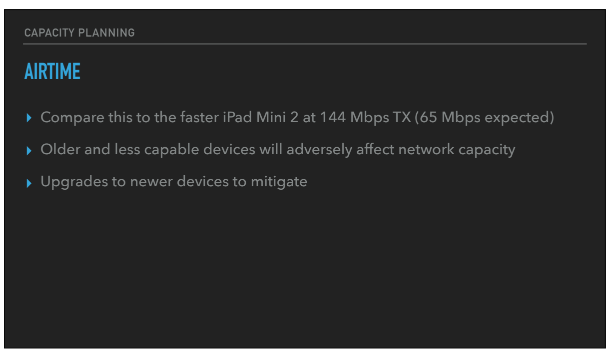


56

There are a few things that militate against this perfect scenario.

1. Network collisions will force retransmits, reducing efficiency on the channel.
2. Distance from the access point reduces client transmit (TX) rate, rendering your math moot.
3. Interference will reduce the overall efficiency of the channel utilization.

The upshot here is that using the iPad 2 will likely to force you to two access points for those 30 connections.



57

The iPad Mini 2 can move data approximately twice as quickly, so that it takes approximately half the amount of time to move the same data as the iPad 2.

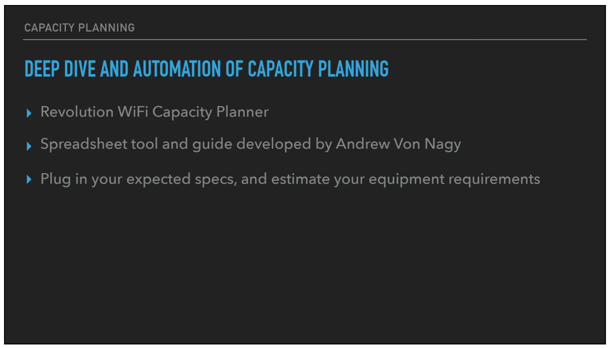
The discussion of airtime forces us to consider the cost of retaining older Wi-Fi client devices. You may not have the budget to upgrade your iPad 2s at this time, but as you design your network, consider that airtime dictates that iPad 2s may require twice as much access point infrastructure to support, and that upgrading to newer clients could mitigate some of the cost of network equipment.

58

Based on everything you've seen so far, I wouldn't blame you if you ran screaming for the exit. Gathering and analyzing all of the information I've described above by hand will do that, because the work is incredibly arcane and time consuming, and there's no way around it other than guessing and probably failing.

Thankfully, there are tools available to lighten the load.

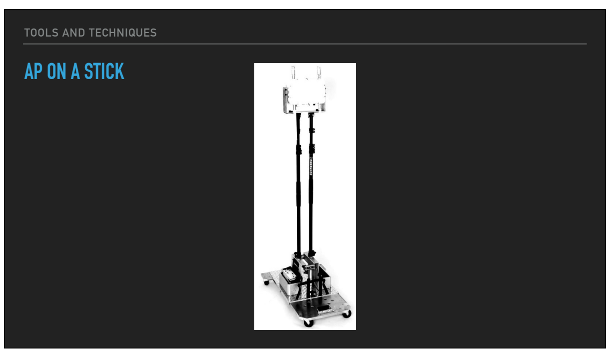
1. Customer/organization requirements
2. Understanding your site and its effects on your design



59

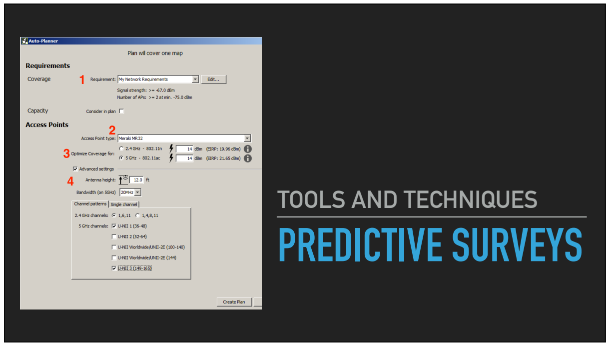
If you think that airtime is complicated, you're not wrong. It gets more complicated when you deal with a diverse fleet of client devices with different wi-fi performance characteristics. In turn, this leads to a lot more work attempting to estimate your equipment needs in order to meet a capacity requirement.

Fortunately, Andrew von Nagy at Revolution Wifi (revolutionwifi.net) has created a tool to help with this. His capacity planner allows you to input a variety of factors affecting your wi-fi network and generate estimates of equipment required, helping you along on the road to your design.



60

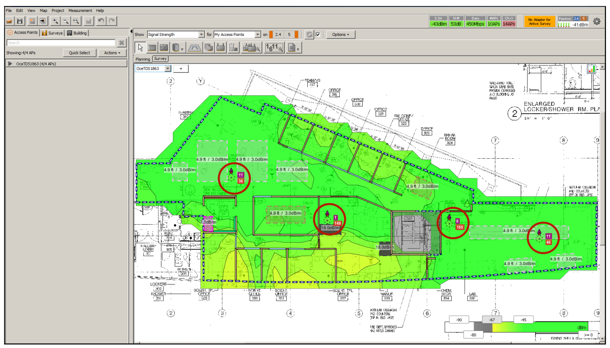
In the early days of Wi-Fi, "AP on a Stick" was often used for a survey to determine how many APs would be required for a facility. A Wi-Fi engineer would simulate installation of an AP on some form of pole, and would move it into the facility and take measurements. This works reasonably well to document basic coverage, but suffers from being a labor-intensive process that also proves cumbersome if your goals include documenting coverage for secondary APs (your goals should).



61

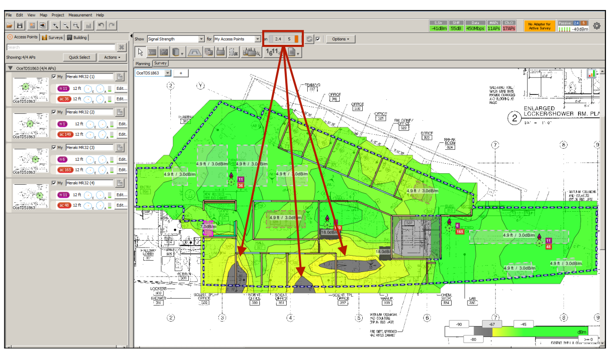
A predictive survey application allows you to try to plug information about your environment into a piece of software that takes the information you give it and attempts to build a design from it. The screen shots shown are from Ekahau Site Survey Pro, including but not limited to Tamograph Site Survey Pro, Netscout (formerly Fluke) Airmagnet, and several others.

Start by plugging in a floor plan and scaling it. Then use the software to draw the areas you wish to cover. known obstacles onto the floor plan so that the software can estimate signal attenuation within the facility. This includes drawing walls of various kinds, doors, windows, cubicles, and so on. This is



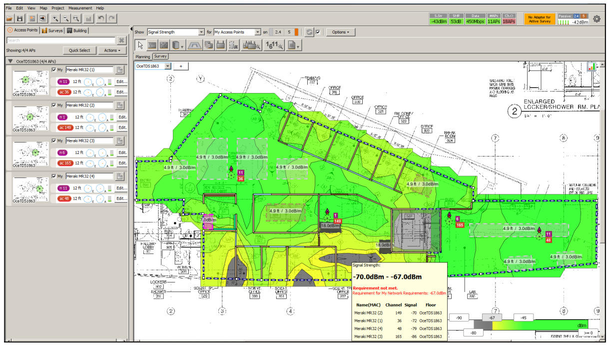
62

In this case, the predictive survey proposes using 4 x Cisco Meraki MR32 access points distributed across the facility, and shows complete coverage of the facility. However, there are some areas of lower signal (yellow color) suggested on the plan.



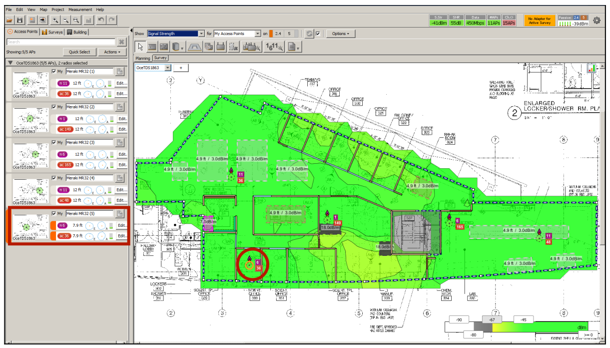
63

I notice that the plan includes 2.4 GHz signal, and use the button at the top to disable visualization of the 2.4 GHz band. When I do, several areas turn grey, indicating insufficient signal.



64

Mousing over an area of the map, I find that ESS pops up a notification that my design requirements are not met in those areas, and shows me the estimated RSSI for the four access points it automatically placed on the map.



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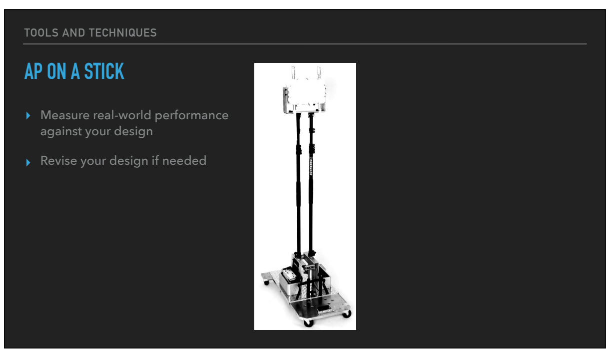
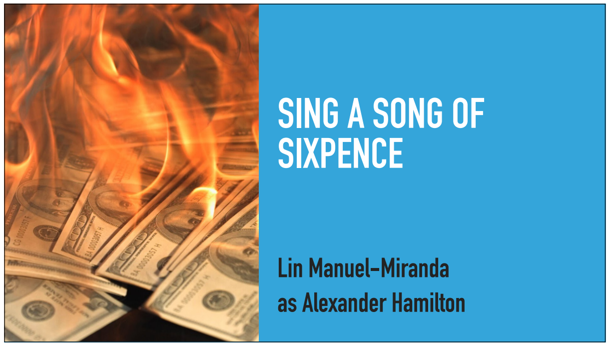
To compensate, I then add and place a 5th MR32 access point, which appears to fill in the gaps in the 5 GHz band. I will have to verify that the AP's configuration does not conflict with the remainder of the network, and I will have to validate the network once installed.



66

Once you have a predictive survey, you can use AP on a stick to verify the veracity of the survey's preditions. Obtain one of the access points and use a "stick" or specialized cart to simulate the installation location of the AP, then take measurements and compare to what's predicted. Doing this with several APs and comparing your measurements can give you insight into whether your predicted results will dovetail with a real installation.

If they do, you now have a more concrete idea of what equipment is going to be required, which in turn allows you to build the budget that we talked about at the beginning.



67

The upshot to a more modern network is the need for more network equipment in order to support the higher performance available in the 5 GHz band. In turn, this requires more money.

Once you have planned out your network and estimated equipment, you are more equipped to create a budget for the project.

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1. Customer/organization requirements
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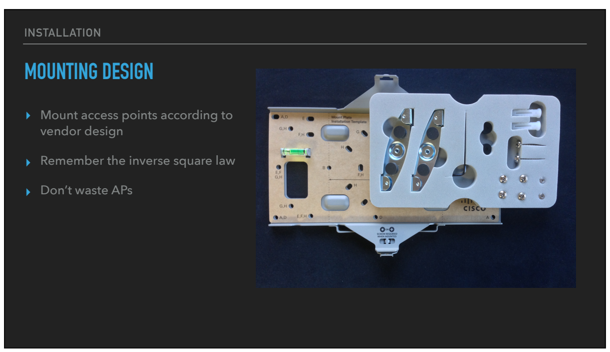
4. Radio frequency (RF) planning
5. Network Capacity Planning
6. Design techniques and tools
7. **Network installation**
8. Testing, validation, and adjustment (finally)



69

Vendors design the majority of access points with omnidirectional antennas oriented such that the optimal mounting for an access point is horizontal on the ceiling. This configuration maximizes coverage, and mounting in other ways can reduce the coverage an AP provides, or bleed it into an unexpected area such as the suite upstairs.

Because of the inverse square law, your signal strength falls with distance; a very common small business and residential mistake is to place the single access point in the closet at the back of the building where your ISP brought your cable modem in, which in turn reduces coverage at the front of the

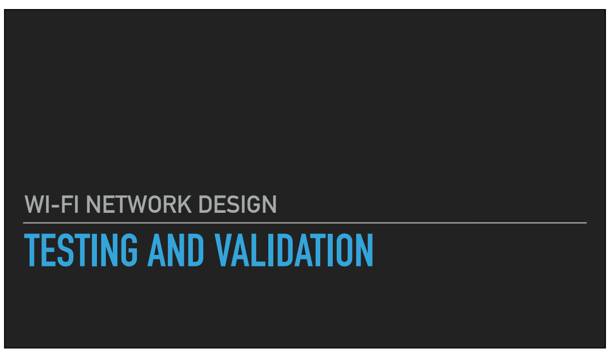
70

This is an Aerohive AP120 mounted to the ceiling of my office. Because do as I do.

71

All of the Airport base stations pictured are installed in less-than-optimal locations.

The AP on the left sits on a desktop between a copier and a stack of paper.
The AP in the middle is located in a linen closet where a medical practice washes treatment robes. It is far away from the actual wireless users in the back of the building.
The Airport Express on the right is underneath a liquor cabinet, and the cabinet is full of glass and topped with bottles.



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1. Customer/organization requirements
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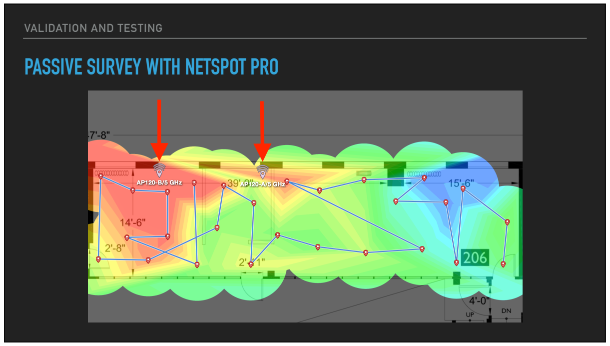
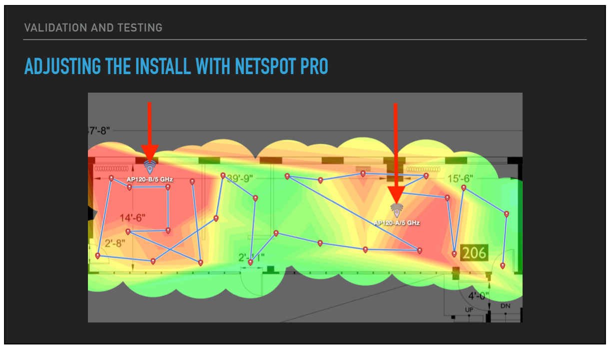


73 Just like anyone else, I've done some "wing it" installs when I felt it wasn't really necessary to put too much effort in. At my office, this resulted in two APs being installed on available flat surfaces. A passive survey with Netspot Pro showed that this *ad hoc* installation resulted in an area of poor signal to noise ratio (blue). The results of the survey suggest that more even distribution of APs will provide more complete coverage.



74 Moving one AP to the ceiling in the front of the office, I then re-survey my facility and see that indeed my overall coverage has improved. Perhaps the second AP could also be moved to a more optimal location, but for the purposes of my usage, this move proves sufficient.

75

> THE EXACT QUOTATION? ALAS, THAT WOULD BE FOUND IN A BOOK BORROWED BY A FRIEND WHO NEVER RETURNED IT, MARKED BY A SLIP OF PAPER THAT FELL OUT LONG AGO.

Nigel Strangeways, Babblings of a Bibliophile

76

TEXTS AND DOCUMENTS

- CNWA Study Guide
- Enterprise Best Practices for Apple Devices on Cisco Wireless LAN
- Aerohive High Density Design Guide
- Cisco Meraki High Density Design Guide

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APPLE KBASE ARTICLES AND ONLINE HELP DOCUMENTS

- About OS X wireless roaming for enterprise customers (Mac OS X)
- Wireless roaming reference for enterprise customers (iOS 8 and later)
- Mac OS Deployment Reference (online guide)
- iOS Deployment Reference (online guide)

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RESOURCES

BLOGS AND COMMUNITY TOOLS

- Mike Albano's Client List
- Revolution Wi-Fi
- Revolution Wi-Fi Capacity Planner

79

WI-FI NETWORK DESIGN

IS THERE EVEN TIME FOR QUESTIONS?

80

HTTPS://BIT.LY/PSUMAC2016-89

FEEDBACK URL

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