Why The ‘One Access Point Per Classroom’ WLAN Design Approach Doesn’t Work

A White Paper on Wireless LAN Design for the Education Market

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Preface

What is this “One Access Point Per Classroom” issue that we speak of? First, let’s start with a picture, as that will save at least a thousand words, which is important in a ~30-page whitepaper. Referencing the 3D graphic below, you can see that classrooms are often positioned adjacent to each other, in long rows, on either side of a central hallway. Not only do we need to understand this reference model in 2D, but the 3D model is also critical.

I will also mention that this same design issue applies to other similar situations in other vertical markets. Consider the structure of a hospital or large clinic in the healthcare market (as shown below), and further, consider universities. Many other markets have similar building layouts, and the One AP Per Classroom concept could just as easily be generically called One AP Per Room. We’ve chosen the K-12 market as a working example because of their early adopter status and because it’s a market where almost all Wi-Fi manufacturers focus.
To kick off this discussion, we will say that if after going through the proper WLAN design process, the result is a series of classrooms, each with a single Access Point (AP), then more power to you! This scenario is not what we are arguing against in this whitepaper.

We are concerned with the trend of promoting the quick-n-easy methodology of ‘One AP Per Classroom’ that does not take into consideration industry-standard design processes. Compounding this illegitimate approach is the practice of foregoing a post-installation (aka post-deployment) survey to validate the design and performance. It is all-important to understand co-channel contention (CCC) and adjacent-channel interference (ACI) and to understand what other problems might exist or have been created.

We understand that many experienced Wireless LAN (WLAN) designers despise the use of blanket statements or formulaic processes as real-world methodologies, and we agree with this philosophy. Other examples of this are:

- “one AP for every 4,000 square feet of floor space”
- “put an AP every 20 meters in a grid pattern”
- “20% cell overlap”

One AP Per Classroom is a blanket statement, and that approach to defining and designing WLANs will, in most cases, be significantly sub-optimal. If there were only a minor differential between the performance of One AP Per Classroom and the use of industry-standard WLAN design principles, then there would be no need for this whitepaper…yet, here we are.

We are advocating for always performing a proper design, using industry-standard processes, that:

- Includes defining requirements and constraints
- Designing to meet the customer’s requirements, within their constraints
- Validating that the deployed solution meets all of the requirements
We have the collective opinion that promoting a *One AP Per Classroom* “design” results from laziness, ignorance, or greed – depending on who is promoting it. A “1-for-1” approach to WLAN design is most often simply a marketing campaign meant to sell Access Points, and is not a WLAN design methodology. A popular sales technique, used to charge full-scope prices for partial-quality work, is to purposefully confuse the “1:1 initiative” in the education market, that refers to “one device per pupil”, with “1 AP for 1 Classroom.”

The *One AP Per Classroom* approach over-simplifies and improperly shortcuts standard design principles/processes in order to shorten the sales & deployment cycle, to maximize income for a vendor, and to enable unqualified/under-qualified professionals to deploy enterprise WLANs in a way that *sounds good* to the uneducated buyer, but requires no real understanding of RF or the 802.11 protocol. This is simultaneously the greatest weakness of this methodology and why it continues to proliferate among so many integrators.

*Note:* Some have noted that following proper WLAN design process is expensive, and customers may prefer the *One AP Per Classroom* approach in order to save money. *In following this defective methodology, customers usually spend far more money (compared to a proper WLAN design) on costs associated with AP hardware, such as licensing, maintenance contracts, Ethernet ports, cabling, power, and installation costs. These collective costs far exceed design costs on all but the very smallest school.*
K-12 1:1 Confusion

Many in the WLAN industry have taken advantage of the confusion around the often-mentioned 1:1 initiatives within K-12 schools. The premise of “1:1” is based on planning for a minimum of one device per pupil. Many schools are ramping up computer-based education methods, and their WLAN infrastructure must then support as many computing devices within each classroom as there are students and teachers.

In recent years, most schools have experienced a tremendous increase in device count on the WLAN due to the Bring Your Own Device (BYOD) phenomenon. Primary schools frequently have young children bringing smartphones or tablets to school.

Sidebar (Keith):  

At my grandchildren’s elementary school in rural, middle Georgia, the school is moving to a BYOD model. Pupils are strongly encouraged to bring their personally owned devices to class for use in the education process. In fact, school officials sent a letter to all parents a few months ago listing what types of devices would be supported and hinting that these would make great Christmas presents.

In one school district, we were specifically asked by the school board to design their WLAN infrastructure to meet a 5:1 ratio. Their expectation was that the WLAN would someday need to support up to five devices per person (students, staff, & guests). Though we think this is a bit of stretch, we have seen in many of our districts a greater than 2:1 device count today. It’s important to note that even at this device density, it’s important for a WLAN designer to consider how many devices will be simultaneously accessing the network - not how many devices will be carried in a backpack or pocket. These aspects do widen the discussion around proper WLAN design considerations.

Note:  

From a design perspective, there is a significant difference between how one would consider a device that is only associated to Access Point versus how one would consider a device that is actively sending and receiving data across the RF channel. The associated-only device is connected, but consumes near-zero airtime resources. The active device is utilizing airtime, causing channel loading, and possibly causing CCC and/or ACI (depending on many variables, including location), and even raising the noise floor. More on this in a later section.

At the heart of this classroom-centric discussion is device density. Since there are (or will be) lots of students and staff, then there will also be lots of computing devices accessing the WLAN infrastructure. Schools want to be prepared for this onslaught, and they often turn to RFPs or their trusted advisor (oftentimes a local Value Added Reseller (VAR)) in an attempt to get, and stay, ahead of this impending WLAN load.

In some cases, even those professionals who write RFPs don’t understand Radio Frequency (RF) behavior or 802.11 WLAN principles. In these cases, it is common for them to lazily use a One AP Per Classroom requirement, or higher, in their requests.

Sidebar (Devin):  

At least a dozen times over the last five years, both inside and outside the U.S., I’ve witnessed WLAN implementations of two 2-radio APs or one 4-8 radio array within each classroom throughout a school facility. Having been fortunate enough to question the project influencer a few times, I’ve found that these scenarios are always sales-driven. Further, in every case I’ve
witnessed, preventing immediate post-deployment testing was a priority for
the selling entity because it lengthens the sales cycle by delaying the close of
a sale.

Once a myth has been perpetrated and proliferated enough, e.g. “but ABC school did it!”, it
becomes trivial to write the buzz-language around 1:1 initiatives into an RFP, especially when the
RFP writers have no real understanding of or frame of reference for RF and 802.11 WLAN
fundamentals. It is our job as WLAN Professionals to follow ubiquitously adopted, industry
standard design principles whenever possible, even if it means that we need to educate our clientele.
Enterprise WLAN Design Processes

In most enterprise WLAN installations, we follow a prescribed design process of:

Define

In this phase, we collect information from the customer and then document a specific set of design requirements and constraints. These may, at a minimum, include:

- Number and type of WiFi-enabled devices
- The physical area to be covered
- The estimated device count growth over time
- Device density in specific areas, and overall
- Applications in use, as much as can be gleaned
- Trouble areas (if a WLAN is already installed)
- Possible interference sources
- Budgetary and time boundaries

See Andrew Von Nagy’s presentation from the 2014 Wireless LAN Professionals Conference (#WLPC). Andrew outlines a recommended WLAN design process for defining requirements and constraints.

Design

In-depth knowledge of RF fundamentals, antenna principles, and a solid understanding of the 802.11 protocol is required to properly accomplish this phase.

Note: There exists weeks of training class material that can help you understand and properly apply RF fundamentals, 802.11 protocols, antennas, surveys, and other basic WiFi concepts. Learning the theory and practical application of these concepts is not something to be taken lightly. Never has the term “garbage in-garbage out” been more applicable.

Using predictive modeling and/or measurements made on-site during a pre-deployment survey, create a draft design. Information gathered should include items like tentative number of APs, type of APs, AP placement/mounting/orientation, power settings, and antenna choices. This data, most often documented as a Pre-Deployment RF Site Survey Report, is used aggregately to determine how to meet the requirements from the Define phase. Do not confuse an RF Site Survey with a WLAN Design. RF Site Surveys have the purpose of gathering and documenting information about the RF environment. A WLAN designer will use information documenting within a RF Site Survey Report to understand all of the variables that should be considered in properly designing the network.

Note: As a cost shortcut, many organizations may try to circumvent the design process by purposefully or ignorantly confusing “Design” and “Survey” and requesting that their trusted technical advisor roll both processes into a “RF Survey/Design”. This is highly discouraged, as it leads to skipping critical steps in the design process, poor deployment, sub-optimal configuration, and oftentimes very poor performance of the WLAN infrastructure. An RF Site
Survey is a sub-set of a WLAN Design and takes into consideration neither the customer’s requirements/constraints nor critical post-install validation steps.

Install

Installation is often the simplest step within the design/deployment process. The first step is having cabling teams install and connect certified Category 6 or better data cables (Cat6a recommended) to each AP location, in accordance with wiring standards and local codes. Next, confirm switch port configurations, mount APs in accordance with the survey report, and test wired-side connectivity, including DHCP if applicable.

Validate

Validation is a critical phase. Do not skip it.

The validation process is the phase where we prove that our WLAN design met the design requirements, within our customer’s constraints. The validation phase is most often accomplished via an RF Site Survey, and most often this type of survey is referred to as a Post-Deployment (or Post-Installation) RF Site Survey.

Note: RF Site Survey tools have matured over the years, and many of them now have integrated connectivity and performance measuring diagnostic tools that can be very helpful during the validation phase. iPerf, jPerf, and custom client/server tools are freely available and often integrated into RF Site Survey software.

The validation phase may (and usually should) include active (moving various data types both uplink and downlink) testing of a customer’s actual client devices.

Monitoring (via controller or wireless network management system (WNMS)) throughput, data/application types, latency/jitter, and other stats on individual APs or network-wide, is suggested. Some WLAN platforms will have more capabilities than others in this area, but when desirable tools are not available within the infrastructure platform or an overlay performance/security monitoring system, laptop-based tools can be used. Performance monitoring should be performed during school hours – preferably when the maximum number of students, staff, and/or guests are using the network (which can often be determined by reviewing trending information within controllers or the WNMS) – or heavily using APs in specific areas.

Note: Some attempt to support their position in favor of One AP Per Classroom by mentioning how many ‘satisfied customers’ they have – who didn’t over-spend on their WLAN. It’s more than likely that the school districts who implemented their WLAN using this methodology never did a post-installation validation survey and documented application layer performance. Design parameters were likely no more than coverage and client counts.

Think of the validation phase as the operational check that any technical system should have before turnover to the customer. Skipping the validation phase, and relying solely on the assumptions made in the design phase, prevents the WLAN designer from ever really knowing how the installed APs react with each other, with client devices, and with their surroundings (e.g. interference sources).
Remediate

The remediation phase is where we optimize a less-than-perfect design by addressing parameters such as AP placement, channel, power, and more. If you need to add, move, or remove APs, or perhaps disable individual radios on specific APs, this is the time to do it. This is the step where we fix anything that doesn’t meet or exceed the original design requirements.
RF and 802.11 Fundamentals

All Wi-Fi devices using the same channel cooperate with each other in order to share the available bandwidth.

The simplest of all WLAN design requirements is coverage (the delivery of RF from the Access Point to the client devices). If we want more coverage, we can either turn up the output power on existing APs or simply add more APs, though coverage is rarely a concern in a properly designed WLAN. The most difficult design requirement is the opposite of coverage: how to control coverage so that we can re-use the limited available frequency space. Controlling coverage is sometimes referred to as minimizing co-channel interference (CCC).

How do we design our wireless networks so that we can conserve and reuse the scarcest of all resources (channels and airtime)? Many take the approach of adding APs, but this method exacerbates CCC and sometimes ACI as well. Some vendors and VARs further compound CCC & ACI issues by discouraging proper design using the promise of free post-install APs in order to make up for any coverage holes.

The problem with CCC is that when more client devices and Access Points share the same channel, they share the channel’s data throughput capacity. As the device density on a channel increases, associated client devices each get a smaller piece of the capacity pie and the negative effects of medium contention (e.g. retransmissions) increase. This further degrades the performance and capacity of the channel and all radios using it.

Note: We’ve learned from professional services experts from Cisco, Aruba, Ruckus, Extreme, and others who have entered the Large Public Venue space that the best way to get more capacity is to find ways of more effectively reusing channels. One of the most effective methods of channel reuse is capitalizing on a building’s materials to help block RF. Yes, that’s right - we want to block undesirable RF propagation.

Marcus Burton wrote an excellent white paper on the IEEE 802.11 protocol contention process.
Designing for High Capacity

There are two key parameters that must be addressed in order to enable increased Wi-Fi network capacity and to successfully handle higher client densities:

**Channel Reuse**

Channel Reuse is the ability to reuse the same channels within areas of desired Wi-Fi coverage. In order to successfully affect channel reuse, we need to consider antenna types, output power, and AP placement (at a minimum) within our design. The goal is to have a desirable amount of RF coverage where we want it and to minimize RF coverage where we don’t want it. This is part of the reason why we consider hallways a *last resort* for AP placement.

When using the 2.4GHz ISM band in North America, only three non-overlapping channels exist: 1, 6 and 11. If you want to limit your use of the 2.4GHz band to a single AP on each of these three channels, with the APs appropriately spaced apart, then that will be a fine design, with the exception that there will be very little data capacity across your enterprise. Even in such an extreme scenario, you may have neighbors who are using 2.4GHz who will interfere (CCC) with at least one (but probably all three) of your APs. If you have a large facility, with very thick walls, and your APs have low output power, low radio sensitivity, low antenna gain, and are spaced as far apart as possible, then you may be OK to have two APs use the same channel (for a total of 6 APs using 2.4GHz within the facility). 2.4GHz ISM signals penetrate quite well, 4.3X better than a 5GHz UNII signal at equal amplitude in open space, and as such is great for a coverage-based design where capacity doesn’t matter. The problem is that capacity matters greatly in K-12 and many other vertical markets. 2.4GHz’s high penetration characteristics are a bad thing for networks designed for capacity because it introduces CCC, which is essentially the “sharing of the channel.”

To illustrate the extent to which CCC is a problem in 2.4GHz, consider the following illustrations. The first graphic shows an Access Point, located in the middle of a football field (360 feet wide including end zones), with a 2.15dBi antenna (minimum gain), using only 2.4GHz, at 1mW output power.
180 feet (60 yards, ~55 meters) away from the AP, at the end of the end zone, we see that we still have -74dBm of signal level. This is good enough signal level, assuming a good SNR (due to a reasonably low noise floor), to achieve fairly high data rates. Consider Cisco’s AP3700 receive sensitivity chart, which shows that the AP can properly decode a 6Mbps transmission at -91dBm. So even if you disable 802.11b data rates (1, 2, 5.5, & 11Mbps), which is a recommended practice for most modern networks, we’re still dealing with -91dBm. Let’s move our AP over to the end of one end zone, and take a look at the signal level (RSSI) at the end of the other end zone.

As you can see, we are still receiving -82dBm. Keep in mind that this is at 1mW of output power, and it’s extremely common to find networks configured for 100mW and a minimum data rate of 1Mbps. Referring back to Cisco’s receive sensitivity chart, 1Mbps transmissions can be decoded with signal levels of -101dBm or greater, and in 2.4GHz, where the noise floor is often -85 to -93dBm, such a receive sensitivity means “if I can hear it, I can decode it.” If an AP can decode the transmission, it will back off, giving way to that transmission. Even at modest output power levels (e.g. 20-50mW), this means that oftentimes, every AP on a channel within a building (depending on the building size, shape, and building materials) can hear every other AP on that channel – one giant collision domain. When doing Wi-Fi performance optimization, it’s our “Prime Directive” to divide collision domains – aka preventing CCC. A good blog post on receive sensitivity is here.

Even when the APs are appropriately powered and spaced, such that they cannot hear each other above the contention threshold (an amount of power that causes them to back off), when clients roam between the two APs, while associated to either AP, all three devices (along with any other client devices that can hear either AP) now share the channel’s contention domain for however long both APs can hear the client device. How often does this happen? Constantly…. continually…. always! There are almost always client devices somewhere between two APs using the same channel. This is why high penetration characteristics are so detrimental. The ideal capacity scenario is for there to be no penetration of walls by the RF. The ideas coverage scenario is to have maximum penetration. As an industry, we transitioned from coverage-based to capacity-based designs more than a decade ago.

If we take this a step further, we notice that 2.4GHz has no perfect solution for handling capacity. Trying to maximize capacity across 2.4GHz is like applying a couple of boxes of Band-Aids to a neck laceration. If APs can hear each other or client devices that are located between APs on the same channel, we will have one big collision domain across those two APs and all of their
collective clients. The same could hold true of 10 APs within the same facility due to output power, wall penetration, physical proximity of the APs, and receive sensitivity.

Typically “experts” will instruct you to turn down the power on the 2.4GHz radios, but turning down the output power can lower the data rates that will be used by the AP & clients. Using lower data rates results in more airtime utilization by each client, which limits the capacity of the channel. Turning down the output power often doesn’t help with the CCC problem at all unless it’s also used in conjunction with disabling lower orders of modulation (e.g. turning off data rates like 1, 2, 5.5, 11, 6, and 9 Mbps – at a minimum) and using physical spacing and building materials to divide the collision domains. Use of lower order modulation often results in sticky clients, which will refuse to roam to a better AP in an appropriate manner. This can cause very large collision domains.

If an improper design is implemented, as represented in the Single Channel Architecture (SCA) below, higher output power will increase the size of the collision domain, which will cause lower throughput due to more devices sharing the same channel.

This same CCC problem is experienced when client devices roam between APs using the same channel (channels are represented by various colors in the graphic below) while associated to either one of them. The client device essentially joins the two contention domains into one.
When using an optimal channel reuse design, APs can use higher output power, which will result in higher SNR, which will mean higher data rates (due to use of higher order modulation), and typically means lower retry rates. This is all good.

By placing one AP within each classroom, it is almost guaranteed that CCC will be a problem in 2.4GHz, which will always result in lower throughput capability (capacity) due to greater contention. The common and unproven argument, from those who are in favor of One AP Per Classroom, is, “We will just let the vendor’s automated radio resource management algorithm turn down the 2.4GHz radio power as necessary.” We challenge anyone to show us a network where One AP Per Classroom has been implemented, with all 2.4GHz radios enabled, that doesn’t have a significant CCC problem in 2.4GHz.

The next point that is often surfaced is when the classroom walls are made of substances such as poured concrete or cinder block, which partially acts as an RF absorber. The average cinder block wall or poured concrete wall drops 20-30 dB, depending on thickness (e.g. one or two cinder blocks thick). Even when these types of walls are present, they may only be present between classrooms and the hallway – not between each adjacent classroom. It would still be important to disallow adjacent classrooms or classrooms above/below to use the same 2.4GHz channel (because client devices between them would adjoin the collision domains). Classrooms have doors, and often windows as well, which would allow RF, even when the walls are cinder block, to escape at an amplitude high enough to cause contention with other APs on the same channel, especially if any of those APs are in hallway areas.

When APs are deployed in every classroom (without adhering to a proper design), with many of the 2.4GHz radios disabled to avoid CCC, it can waste quite a bit of money. Turning those unnecessary 2.4GHz radios into WIPS sensors isn’t good enough, because security and performance monitoring would be limited only to 2.4GHz. Do intruders not use 5GHz also? Does the 5GHz spectrum not also need monitoring? Further, each AP has a set of associated costs, which includes the AP itself, cabling, installation/configuration, switch port, management licensing, and support/maintenance. After spending all of that money, you’re going to turn off radios in 2/3rds of the APs? It makes more sense to design and deploy according to a proper design plan, and if full-time performance/security scanning is desirable, then use separate, dual-band APs/Sensors within hallways. Standard practice in this scenario is to deploy approximately 1 sensor for every 4 APs.

Data Rates

In order to maximize efficient use of a channel, we need to ensure that each client uses the highest possible data rate at any given times. Part of the methodology of ensuring that clients connect at the
highest data rates is to set a medium (12 or 18 Mbps) or high (24 or 36 Mbps) minimum Basic Rate (required data rate) and disabling legacy PHY rates (e.g. 1, 2, 5.5, & 11 Mbps) and lower OFDM rates when possible.

Slow data rates and high retry rates (due to interference and collisions) can yield poor overall performance (increased channel utilization and decreased channel capacity) while also causing:

- Sticky clients
- Poor roaming
- High latency
Why One AP Per Classroom is Seductive

Some may be seduced by the One AP Per Classroom approach, especially as a starting point for WLAN design. We agree that it’s a simple concept, easy to understand and communicate, easy to build a Bill of Materials (BoM) around, easy to install, and of course….easy to sell.

The One AP Per Classroom approach is seductive both for buyer and seller. Sellers get to sell additional APs without explaining anything to the buyer (usually a school district). No time is spent on design, and only a simple BoM is produced in order to move the project forward. Buyers have it easy as well. They don’t have to consider their real needs, but rather can simply count the number of classrooms and find a cabling contractor. All done.

**We would like to be clear on this matter:** regardless of the enticing description above, any WLAN deployed apart from following industry design best practices will significantly under-perform its potential.

While the simplicity of One AP Per Classroom may be seductive, a low-performance network is not – especially considering the cost of a WLAN and all of its associated costs (as previously mentioned).

The most tempting part of this approach is that after installation, it actually functions! The One AP Per Classroom approach doesn’t yield a high-performance Wi-Fi network, but it does function well enough to hide its flaws from the non-discerning eye. This often allows VARs and consultants to over-sell equipment without accountability.

*Analogy:* You purchase a Ferrari for $200,000. To validate that you’ve made a good decision in purchasing this high-performance automobile, you take your new prized race car onto the city streets for a test drive. There on your city streets, you can go up to 55 MPH before being hindered by traffic and speeding laws. You then assume that because your Ferrari is functional, it’s also high performing. This sadly isn’t the case, and you won’t know to what extent your new car is under-performing until you need it to go fast. Further, if you’re only ever going to drive your Ferrari on the city streets, at/below 55 MPH, then you could’ve saved a bit of money by buying a Toyota Corolla instead.

The functionality experienced in a One AP Per Classroom deployment is a testament to the inherent resilience integrated into the 802.11 protocol. This same approach is used in many enterprise WLANs outside the education market, especially in the healthcare market. The system gets installed without a proper design (i.e. APs in the hallways), and in the beginning, works to an acceptable level due to very low performance requirements. As an increasing load (client density, applications that are time/latency sensitive, applications that require high throughput, etc.) is placed on the WLAN, performance declines sharply along with user experience. The solution to this performance...
problem almost always includes removal (or disabling) of APs, and by this time, the VAR or consultant who installed the WLAN is often out of the picture.

*Note:* Some have commented and predicted that having One AP Per Classroom will ‘future-proof’ the school district. This reasoning ignores WLAN industry best practices, such as defining the customer’s current and future needs and constraints before specifying the design requirements. A properly designed WLAN will also meet the future needs of a school, but without needlessly overspending on Access Points and their significant associated costs.

Many of education’s early adopters of the One AP Per Classroom opted for this approach before they began adoption of “1:1 computer/pupil” and “BYOD” on their campuses. A system with too many APs will function well enough to mask its design flaws until scenarios like high client density with high throughput requirements are brought to bear. This is when CCC & ACI rear their ugly heads and the expected high performance cannot be found.

*Question:* If a school buys more APs than it needs, and the WLAN adequately performs for only a short period of time, was it a good investment? Did they consider the associated costs of the unnecessary AP hardware, such as licensing, maintenance/support contracts, Ethernet ports, cabling, power, and installation costs?
What about 5GHz?

5GHz has far more available spectrum (and thus available channels), with much less utilization in most environments, with lesser penetration characteristics than with 2.4GHz. This is an all-around win for network designers.

Note: Some older client devices are not capable of using DFS channels (UNII-2 and UNII-2e) or the 5GHz ISM band (now being phased out), and when that is the case, network designers are left with only 8 channels (within UNII-1 and UNII-3) to work with. While the April 2014 FCC Report & Order rearranged and added spectrum (UNII-1 through UNII-4), there is currently no equipment available on the market capable of taking advantage of this new spectrum.

It’s a recommended practice to check all of your 5GHz capable client devices and APs to assure that they are capable of using UNII-2 and UNII-2e channels. Note that if your infrastructure is capable and configured to use these two 5GHz bands, and some of your client devices are not DFS capable, then these specific client devices will experience coverage gaps.

Note: It’s important to the industry at large, that everyone purchase only devices that support all 5GHz UNII bands. There is no added expense, network capacity is greatly enhanced, and it allows network designers to more quickly and successfully move networks away from 2.4GHz for mission-critical users/devices.

We aren’t downplaying having only eight 20MHz channels, but it’s hard to disregard the scalability of having 25 channels (currently, including DFS channels) with an additional 12 channels forthcoming. It’s channivana! (That’s not really a word, but it should be.) This amount of channel space, and the lesser penetration characteristic means a proper design can yield far less CCC.

With the monstrous (comparably speaking) amount of non-overlapping channel space in 5GHz, combined with 5GHz’s lesser penetration characteristics and the right types of walls (e.g. cinder block or poured concrete, which drops 20-30dB), having One AP Per Classroom might meet proper design requirements, provided 2.4GHz client devices will not be supported. That is to say that the 2.4GHz AP radios would be disable or used for scanning or other passive tasks. Rather than completely disable all 2.4GHz radios, a compromise is to properly design the 2.4GHz portion of the deployment for minimal CCC (which typically requires that many (or most) 2.4GHz radios are disabled). Part of such a design is assuring that 2.4GHz radio power is turned down and band steering functionality aggressively steers clients to 5GHz.
Designing to Meet Requirements

Consider what you would think of a public school district who built two football stadiums for a single high school. What if they built a cafeteria and commercial kitchen with three times the capacity of their current student body. Over-building to this degree would be a shameful waste of taxpayer money. In the same way, purchasing and deploying twice as many APs as needed for their 1:1 and/or BYOD initiatives just doesn’t make sense. Sure, we design for future growth – as any good network designer would. More students, more staff, and more guests are expected and that means more devices and heavier network use. There is almost always some level of expansion as we move forward. It’s how you scale and to what extent that is important.

Meeting scalability requirements for high-density deployments is not based on AP counts, but rather on effective channel reuse. Once a channel is saturated, adding additional APs doesn’t yield additional capacity. It has been our experience, across a variety of states and countless schools, that no more than one AP per two classrooms is needed to meet 5GHz coverage/capacity goals. However, as previously mentioned, based on the building materials, future capacity design requirements, budget, and removal of 2.4GHz, one 5GHz-only AP per classroom may be acceptable.

**Rule-of-thumb:** A Wi-Fi design rule-of-thumb for schools who are implementing 1:1 initiatives and allow 1 additional BYOD device per pupil, is to design for -65dBm at 5GHz from two APs. This then virtually guarantees that at least four radios (2 x 5GHz and 2 x 2.4GHz) are covering all areas with high RSSI.

At the end of this whitepaper, we have provided a more comprehensive list of common Wi-Fi design requirements and metrics. The rule-of-thumb above has proven effective as a design bellwether to determine whether other design requirements are being met simultaneously.
Association vs. Throughput

Some manufacturers tout monstrous “concurrent station capacity”, like 500 clients per AP. Don’t you love the embedded spin in that type of terminology? Hey, it’s the “best version of the truth”, don’t you think? Ha! Let’s discuss this terminology for a moment because it is completely relevant to good network design.

There are two important numbers to consider in capacity planning:
- The number of client devices associated to an AP
- The average number of simultaneous transmitters within a BSS

Both of these numbers can be important, depending on the audience being served. For example, within K-12 environments, classrooms may have an average of ~30 students. If one AP is serving two of these classrooms, then the AP has ~60 associated clients.

Note: We’re speaking in rough numbers here because the client devices control which AP to associate with, and thus some APs could be more loaded than others. Features exist (depending on vendor), such as band steering, load balancing, spectrum balancing, and others that help evenly distribute client load (based on channel duty cycle (aka airtime), client count, and others) across APs.

In this environment, there’s a reasonable potential for at least one of the two classrooms (and thus ~30 clients) to use the AP at any given time, and you can’t rule out times when both classrooms will use the AP simultaneously. It really comes down to understanding classroom computer use patterns and a bit of probability consideration. For example, it’s highly unlikely that both classrooms would simultaneously decide to stream an hour-long, unicast, high-definition video stream to each of 60 client devices. It’s much more likely that one classroom would load or copy a PDF eBook from a local server while another classroom watches a standard definition, unicast video clip for 30 seconds or 10 minutes.

5GHz-only

You may be thinking, “Who cares! I have two radios!”, but there’s a strong move toward 5GHz-only environments happening, so there will be more and more K-12 environments where one 5GHz radio will serve those two classrooms. Making the assumption, for simplicity’s sake, that one AP radio is serving those two classrooms, then setting the maximum number of associations to something like 75 would offer sufficient headroom, while also manually assisting the load balancing mechanisms within the system (by causing clients to seek out a different nearby AP). This is a common scenario where “500 clients per AP” has no meaning.

Public Venues

In public venues such as arenas, amphitheaters, stadiums, parks, city-wide public Wi-Fi deployments, and other similar scenarios where Wi-Fi is an open/public service, there’s the potential to hit that “500 clients per AP” limit. In such use cases, there’s really no reason to add many additional APs because most of those client devices are not trying to send data to the AP at any given moment. It’s entirely possible that many of the devices connecting to APs in these scenarios are doing so automatically from peoples’ purses and pockets, with no user interaction. The client associates, pulls an IP address, and then sits idle. For this reason, sufficiently large DHCP scopes must be available in these scenarios.
We took the time to explain this so that there’s clarity around this terminology. If any significant portion of those 500 devices tried to transmit simultaneously, the airtime would instantly become saturated (high duty cycle) and retransmissions would skyrocket due to collisions. Keep in mind that each of the associated devices, plus the AP, plus any nearby APs that can be heard (at a sufficient signal strength), plus clients associated to those nearby APs, are all within the same collision (contention) domain. In very high-density environments, it’s desirable to get the client devices on and off the channel as fast as possible because airtime is your most valuable resource. High data rates and low retry counts are your goals here.

Note: While the 802.11-2012 standard allows for 2007 Association Identifiers (AIDs), all Wi-Fi radio manufacturers limit the number of associations to their radios. This limitation varies by manufacturer, but typically ranges from 100-250 associations per radio within an AP. Depending on your use case, it may (or may not) be important to check this AP specification parameter (on the AP’s datasheet).

In any good design, it’s important in making good design decisions to understand the average number of simultaneous transmitters and what type of applications are commonly used.

Predicting Needs

Telecommunications companies use various methods of predicting customer behavior in order to prepare for anticipated loads. One prediction technique is called an Erlang function. A simple example is a phone company that wants to understand how many phone lines to bring into an apartment complex. They understand that all of the apartment dwellers won’t be accessing their line simultaneously, so they want to understand the over-subscription ratio. The same is done for DSL, cable, and other Internet services. Using some average number of minutes per day numbers, combined with peak load time information, we can anticipate a number of trunk lines to run from the central office to the apartment complex. This can be as low as 5%-10%. This process works great until the morning of Mother’s Day, when everyone wants to call home at the same time. The phone industry doesn’t design for Mother’s Day, but rather for a normal day. As such, they install a ‘Sorry, All Lines Are Busy’ recording for use on Mother’s Day.

Fortunately for the WLAN industry, this same approach applies to Wi-Fi network design. There’s a low probability that all client devices in adjacent classrooms will simultaneously access network resources, and even if they did, there would be even less of a probability of all client devices performing high-utilization functions such as streaming HD video or large file copies. We don’t design networks around sub-1% “corner cases” because it’s not necessary or cost-effective. In other words, we don’t need to design and build a network that can support the simultaneous combination of: 1) the maximum expected number of BYOD devices, 2) the maximum expected number of guest devices, 3) the maximum expected number of students, teachers, and staff and 4) the maximum anticipated headroom for future organization & network growth. The cost and complexity would be way over-the-top for such a design/deployment, so we design for a reasonable subset of these maximums. This is why it’s important to gather network design requirement and constraint information (the Define phase) before beginning a deployment.
Providing Wi-Fi For 1:1 Initiative Needs

In the previously-mentioned “rule-of-thumb” design methodology, we provided for four-radio coverage in all areas. With typical density capabilities of 100 clients per radio (or more), that’s 400+ devices associated to the WLAN infrastructure within a given physical area. That far exceeds the normal requirements for K-12, and offers the aggregate throughput of those four radios in a given area (provided there is a proper design and minimal interference sources). Depending on variables such as device types, applications (very important!), data rates in use, and interference, it’s typical to see at least 100Mbps of aggregate throughput capacity for a given area.

To illustrate the importance of frequency reuse, and the detriment of channel saturation (aka high duty cycle or airtime utilization), we will offer two specific examples.

Example #1

One of our K-12 customers were conducting a teacher training day to bring teachers up-to-speed on Chromebooks. Throughout the day, the school thought that the 150 Chromebooks were associated to a 12-radio array. (Note, this is not a dig against a manufacturer, but rather only an illustration of a concept) Later, while attempting to ascertain event analytics (e.g. client count, throughput, etc), the school administrator realized that the array had been powered off the entire day. Further, it was realized that a single AP had been sufficiently handling all 150 Chromebooks. Given that Chromebooks primarily use a browser (http), the channel load is often minimal unless there are streaming videos or similar. This concept points back to our earlier discussion on the Erlang function.

Example #2

During the WLAN Pros 2013 Wi-Fi Stress Test, we found that we could “break” any AP by streaming multiple unique high-definition videos to no more than 20 tablets per AP. Once the channel was saturated (typically at 80-85% duty cycle), no more additional data could be sent.
Designing to Meet All Requirements

A big flaw in the One AP Per Classroom approach is failing to validate that design parameters were sufficiently met. When using the One AP Per Classroom approach, coverage is often a multiple of what’s necessary for a good design, so coverage itself is never an issue. Since it’s an important parameter that is fairly easy to measure, and should be part of any post-deployment validation, let’s take CCC measurement as an example.

Conduct a passive post-deployment RF Site Survey (scanning all channels). In your Site Survey software, identify locations where you have more than two APs at >-85dBm of signal strength (RSSI) on the same channel. These will be areas you need to make adjustments.

**Note:** Some engineers use -80dBm, others -85dBm, and still others -87dBm for this “trigger point”, but it’s important to understand that the actual number is based on the Clear Channel Assessment (CCA) threshold in each device (whether AP or Client). We prefer -85dBm due to our own personal experience, but there’s no perfect answer. Some AP manufacturers allow configuration of this threshold, essentially lowering the AP’s receive sensitivity. This feature is meant to allow manipulation of what signal level will cause a device to back off (defer).

In a *One AP Per Classroom* environment, the typical CCC is quite large and severe.
Conclusion

When planning a WLAN for a K-12 1:1 program, take the time to thoughtfully understand your customer’s requirements and constraints and then diligently focus on industry standard design principles. If your IT solutions provider or Value Added Reseller (VAR) is making WLAN design services cost prohibitive, or resorting to a One AP Per Classroom approach, they are doing the school district an disservice.
Review of Design Requirements

Here is a short list of some of the requirements we design for, and measure against, when designing WLANs. There are many diagnostic tools available to measure & report on these metrics, such as those available from Fluke Networks (AirMagnet), Tamosoft, Wildpackets, MetaGeek, Ekahau, and Wireshark.

**First “Primary” Access Point RSSI**
Typically between -65dBm and -67dBm for voice-grade deployments using 20MHz channels at MCS 0-7. Higher output power, depending on desired MCS and channel widths to be supported, may be necessary at times.

**Second “Backup” Access Point RSSI**
Typically between -65dBm and -67dBm for voice-grade deployments using 20MHz channels at MCS 0-7. Some people call this ‘overlap’ but it’s not measured in percent of coverage area, but rather in dBm for the ‘backup’ coverage. You can’t measure the ‘overlap’ in percentage, but you can measure ‘backup coverage’ in dBm.

**Signal to Noise (SNR) Ratio**
Typically 25dB or higher in all areas that are planned to support VoIP over WLAN (VoWiFi) using 20MHz channels at MCS 0-7. When using wider channels (40 MHz) with up to MCS9, an SNR of 35dB should be targeted.

**Co Channel Contention (CCC)**
Any radio – but specifically Access Points stronger than –85dBm on same channel equals Co-Channel Interference, or Co-Channel Contention. The area where two or more Access Points would defer to each other, thus sharing the available bandwidth on the frequency.

**Channel Utilization (Duty Cycle)**
Channel Utilization can be caused by modulated and unmodulated RF signals on the channel frequencies that you are trying to use for Wi-Fi. It’s industry best practice to target keeping channel utilization under 50% to avoid latency and high retransmissions.

**Client Density**
The typical number of clients associated (and actively moving data) to an AP is usually between 20-30 for laptop users and 5-10 for most VoWiFi handsets. Check with your voice handset vendor for their actual recommendations if you are doing a voice deployment, as many recommend no more than 7 handsets per AP. It is recommended to do an Erlang analysis to discovery the average call minutes per hour to understand the recommended number of simultaneously associated handsets per AP. It is recommended to measure and validate the appropriate number of APs for your client device loads.

**High Density**
Sometimes there are areas where there is an abnormally high concentration of client devices (e.g. auditoriums and cafeterias). In these areas, it is recommended to calculate and validate the necessary number and type of APs. High-density areas need to be highlighted on floor plans during the definition stage of the WLAN design process.

**Data Throughput (aka Goodput)**
Data Throughput, which is sometimes called Goodput (referring to successful throughput), is a measure of the amount of data that can be moved by a client across an AP. While Data Throughput is related to Data Rate, they are not the same thing. Throughput is the result of Data Rate and other
factors (e.g. retransmissions) combined. Throughput capability for specific clients should be known for uplink (to AP) and downlink (from AP), using TCP and UDP based protocols. Applications such as iPerf can be used for this purpose.

**Minimum Basic Data Rates**
The Minimum Basic Data Rate is the lowest mandatory Data Rate. This is used for Beacons and Probe Responses (among other things) and can drastically affect channel duty cycle, client stickiness, and network performance. It’s typical to set 12 or 24 as the Minimum Basic Data Rate (with all rates below it disabled and all rates above it set for Optional) in both 2.4GHz and 5GHz. This of course means disabling 1, 2, 5.5, and 11 Mbps (HR/DSSS), which disables support of 802.11 Prime and 802.11b clients.

**Jitter**
Jitter is a measure of the delay variance between packets. Jitter of less than 5ms is important for VoIP deployments. It’s recommended to measure both upstream and downstream jitter during a two-way conversation in progress. □

**Latency**
Latency is a measure of end-to-end delay and should typically be less than 50ms end-to-end, one way.

**Packet Loss**
Wi-Fi networks supporting VoIP should typically support less than 1% packet loss.

**CODEC**
Use a voice codec that has the highest potential MOS score. Avoid compressed codecs unless calls will traverse WAN links. We have lots of bandwidth in today’s Wi-Fi networks, and the quality of uncompressed codecs are typically better.

**Roaming**
Roaming is the function of a client device moving between APs. It’s important to understand the difference between portability (start computing, stop computing, move, start computing again) and mobility (computing while on-the-move), as each has different requirements within Wi-Fi design. Handoff between Access Points is typically 30-100ms in an open or fast/secure roaming environment, depending on channel congestion. When testing, set a baseline by testing with an Open System Authentication (no encryption) environment. Evaluate the best fast/secure roaming protocols (Voice-Enterprise, OKC), and authentication mechanisms (WPA2-PSK, WPA2-Ent, PPSK/DPSK, PSK, etc.).

**Authentication / Encryption**
Open System Authentication, without encryption, is the fastest for supporting VoWiFi, but has no security. WPA2 Passphrase (aka WPA2-PSK) requires a key exchange (called the 4-way handshake) upon roaming. WPA2-Enterprise (aka 802.1X/EAP) will require a full RADIUS authentication upon roaming unless a fast/secure roaming protocols (such as Voice-Enterprise or Opportunistic Key Caching) are supported both on the client device and AP.

**Beacon Interval**
Normally set to ~10 beacons per second (~100ms). Very rarely is it a good idea to change the manufacturer’s default Beacon Interval setting.

**DTIM Interval**
Check with your handset vendor on a voice deployment. This is typically configured for 2.
Coverage Areas
Data-only designs will include areas where laptops typically go (e.g. carpeted or vinyl floors). Voice designs also need to cover elevators, stairwells, restrooms, parking structures, and more.

Location Services (aka RTLS)
Location Services (also called Real Time Location Services) are used within the Wi-Fi infrastructure or an overlay system to track items within the RF coverage area. It’s typical that more APs are required to yield the granularity needed for accurate location services.

Collision Domains
All Wi-Fi devices that can hear each other (or interfering devices) on the same channel (or across channels) share a collision domain. The more devices (and sources of interference) you have within a collision domain, the worse your performance will be. Wi-Fi (IEEE 802.11) uses defined, shared channels. Design accordingly.

Quality of Service (QoS)
Within Wi-Fi networking, there are various QoS protocols, methods of implementing QoS, and areas within the network where QoS can be implemented. When we refer to QoS in Wi-Fi, we are most often referring to the Wi-Fi Alliance WMM certification, which defines 4 queues: Voice (VO), Video (VI), Best Effort (BE), and Background (BK). Applications mark User Priority (UP) at Layer-7, which are then mapped to WMM queues at Layer-2. WMM works similarly to Weighted Fair Queuing, which offers a statistical advantage to various traffic types such that no queue is prevented from gaining access to the medium. With WMM, any application not marked with a UP will go into the BE queue. All APs can client devices within your environment should support the same QoS protocol. Check with your application vendor for QoS setting recommendations. Some applications may work fine without any QoS tuning. Validate that QoS is end-to-end.

Error Rates
It’s important to understand and set design parameters for Retransmission (“Retry”) Rates and CRC (“Error”) Rates on your WLAN. Voice implementations are especially sensitive to environments with high error counts.

Traffic Flows
Understand your traffic flows and patterns – uplink, downlink, peak time of day, TCP/UDP, big/small frame sizes, types of applications, etc. Pay special attention to any potential delays arising from controller tunneling (if applicable). Determine the appropriate architecture and deployment method to suit your needs.

Protection Mode
When designing around mixed PHYs (physical layer specifications), protection mechanisms at the physical and MAC layers add significant overhead to every frame exchange. Removing legacy (802.11a, b, & g) clients from your network (and even within range of your network) will greatly boost performance due to the removal of protection mechanisms. If you must support legacy client devices, set performance expectations accordingly. It’s common to lose 40-50% of an AP’s capacity due to protection mechanisms.

Power Management
It’s advisable, in most situations, to use the most efficient Power Mode supported by your APs and client devices. Some of the older versions (Power Save Poll) were inefficient, and not effective for voice deployments. Newer power management protocols (e.g. WMM Power Save) are much more effective in saving battery life.
**SSIDs & VLANs**

When configuring a unique SSID/VLAN for voice, confirm use of the correct VLAN/Subnet and keep in mind that adding a VLAN to Wi-Fi **does not** divide broadcast domains. Even with a separate VLAN (on the Ethernet), Wi-Fi devices using the same channel are still in the same collision and broadcast domains if they are within reception range.

**Administrative Security**

It’s recommended that there be no administrative access to the WLAN infrastructure from Wi-Fi devices and all controllers and APs should be managed from the management VLAN.