CAMPUS WIRELESS UPGRADE

Capital Project Proposal

2015-2017



Active Minds Changing Lives

WESTERN WASHINGTON UNIVERSITY

Institution
Western Washington University
Project Title
Campus Wireless Upgrade
Project Location (City)
Bellingham

1. Problem Statement

The Campus Wireless Upgrade will provide ubiquitous wireless access throughout all academic and administrative buildings and selected outdoor coverage in many campus areas. The upgrade will affect the following systems:

Wireless Coverage

- In the years past WWU has only been able to provide wireless on a very small and sporadic scale mainly funded by the Student Technology Fee (a limited, student approved fee) that has focused on student gathering places. Some departments have funded their own Wireless access points for administrative use. The result has been spotty coverage and frustrated students and faculty. While there may be some wireless in most buildings it is very inadequate for the number of devices and throughput required for many areas. Currently our wireless capability amounts to 20% of our actual need. That 20% is spread out over campus, which severely limits many areas with inadequate density and coverage resulting in dropped or slow connections and lost productivity.

Wireless Capacity

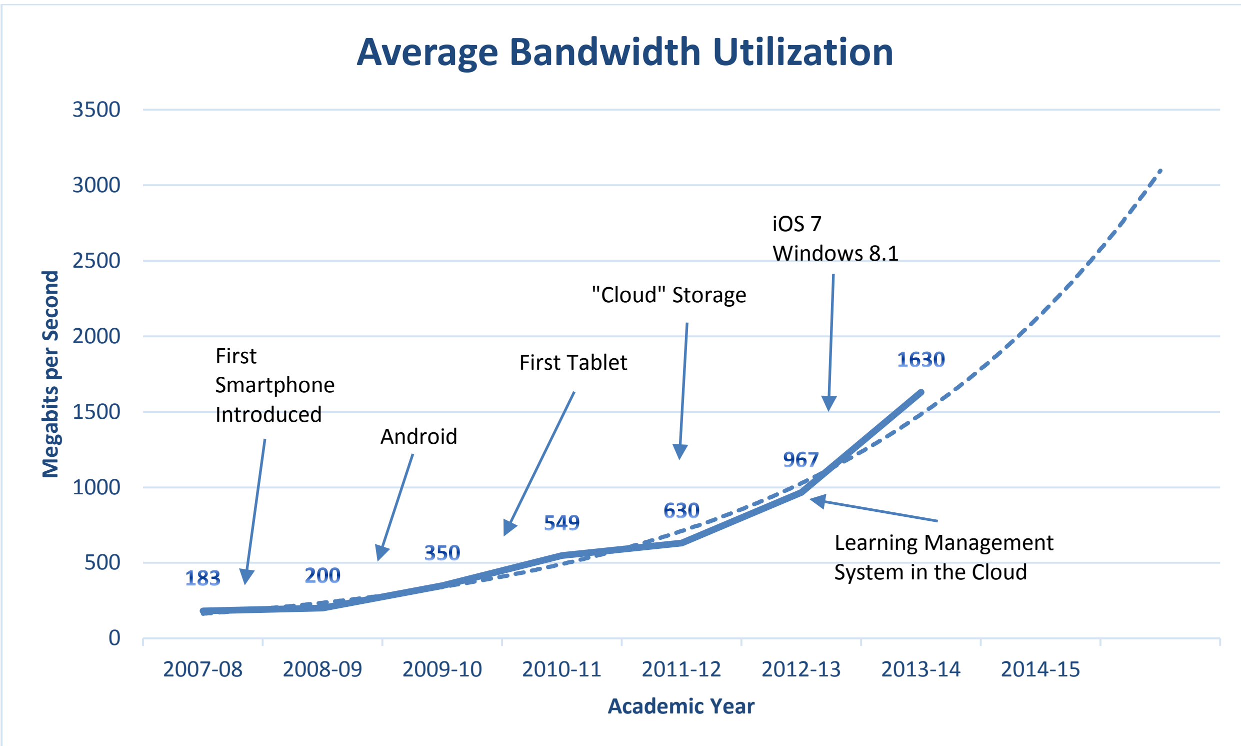
- Wireless coverage is important but as important is the capacity of the wireless network to make connections and provide the bandwidth needed for data. This is especially critical in classrooms and areas like the Library. A new standard called 802.11AC is being ratified to allow increased bandwidth to wireless access points. In order to prepare us for this standard and avoid the costly retrofitting cabling inside of building walls, we will need to provide two Ethernet cables for each access point installed. While this requires some additional labor at the initial time of installation, it would be a huge cost and disruption to users to provide the additional cabling in the future. This new standard also requires additional switches to be installed in each of WWU's telecom closets in order to accommodate the additional ports required. (See Appendix B).
- Wireless coverage and capacity is no less important to our emergency responders in response to fires, active shooters, seismic events, and traffic issues. Responders depend on an ability to send and receive more and more information as fast as possible via portable devices to inform the public and themselves of conditions "on the ground" and to develop strategic responses.
- Additionally, our ability to manage facilities development and operations is becoming more dependent upon mobile devices to perform project management during construction in the field, monitor energy systems for maximizing energy savings, and address utility systems operations.
- Supporting students with disabilities is critical to our mission. More and more solutions that improve their daily experiences relate to portable devices and systems.

Back-end connectivity

- There are two parts to this project: the wireless hardware and the 'back-end' wiring to each wireless access point as described above.

2. History of the project or facility

In the 2011-13 biennia Western requested funds to upgrade its wireless network. This request was not funded. Since the 2011-13 request, the growth in demand for wireless service has continued to expand. Average bandwidth utilization has increased dramatically, mostly due to increased wireless activities from smart phones, tablets and other portable devices which are all vying for the same bandwidth.



3. University programs addressed or encompassed by the project

Most of our administrative and academic work (students, faculty, and staff) occurs using our data network at some point and the proliferation of mobile devices and the need for wireless connectivity is one of the fastest growing areas of technology in the world today.

Educause is the professional society for information technology in higher education and one of their programs is the Educause Center for Applied Research (ECAR). The most recent ECAR Student Technology Survey reports that the average number of wireless devices brought to campus is 2.8 for each student. Most students are bringing a laptop, tablet, and smartphone to campus and expecting all of them to connect through our wireless network simultaneously. This growth has placed significant demand on our wireless network and increased coverage and ‘throughput’ must occur to respond to these needs. (See Appendix C).

Emergency responders, Facilities Development, Facilities Operations, and Facilities Maintenance continue to grow their usage of portable devices to respond to life safety issues, seismic events, energy conservation, utilities support and transportation management.

Western is also in the process of revising its access control system. In order to provide access control where hard wiring is either impractical or cost prohibitive, wireless access devices will be utilized. Potential uses include not only external or internal doors on academic buildings but also student residential areas and parking lot gates.

4. Significant Health, Safety, and Code Issues:

a. There are significant life safety and seismic event response issues since our emergency notification system relies upon email and our website as vectors for emergency information. Most students, faculty, and staff connect their mobile devices to the wireless network when they are on campus. University owned and personal Wi-Fi enabled portable telephones used by first responders can connect to our PBX, VOIP system, and email systems. Ubiquitous wireless coverage assures they are able to receive the notifications and access information throughout campus.

   A campus risk analysis was completed in 2014 with recommendations for campus emergency notifications. A critical part of the campus notification system relies on a functioning IT system. (Appendix information is not provided due to confidentiality requirements related to this type of study).

   We are currently revising our Facility Management System which will require mobile access by Facility personnel including work assignment and time recording. Western would also like to install energy and resource tracking meters as part of its efficiency program. An expanded wireless network simplifies remote meter locations. Significant productivity gains would be made with this capability which will not be possible without a ubiquitous wireless network.

   University Police also rely upon wireless access for some of their data collection and distribution. Our emergency response teams are also able to utilize wireless for communication including transmission of pictures.

   A portion of our Access Control system will utilize wireless connectivity for door control. This has significant security impact for sensitive areas where wired access control cannot be accomplished.

b. The new equipment and installation will be compliant with current standard network protocols, and regulatory standards for network equipment safety, electromagnetic compatibility (EMC), and TIA/EIA telecommunications building wiring standards. Applicable current industry standards include IEEE 802.11a, b, g, n, ac; Wi-Fi Alliance Certified products; applicable TIA/EIA wireless standards, and FCC Wireless Communication Standards.

5. Evidence of increased repairs and/or service interruption:

Significant service interruption occurs as a wireless device moves in and out of limited coverage areas. Not only is the connection broken but often the device must be logged back into the network. This results in wasted time and employee or student frustration. This is critical when emergency responders are relying on wireless connectivity. In a classroom setting, wireless access may function when only a few students are accessing a local antenna but with increasing number of students trying to access service, it will become too slow or may drop, losing an educational opportunity. A modern wireless network would result in a seamless transfer of the wireless signal as people, including first responders moved about campus. More wireless access point in high density areas such as classrooms would provide a better experience with less interference and bandwidth reduction for large numbers of students (including those with disabilities).

6. Impact on Institutional Operations without the Infrastructure Project:

Without a capable and stable wireless network, significant inefficiencies will occur with business processes and access to academic resources. Lack of an effective wireless network could also affect our ability to attract and retain students due to their inability to connect to the university's website and access academic resources such as our learning management system and research data. As discussed in the Educause study of Undergraduate Students and IT, students continue to use technology, and in particular mobile technology, in their everyday experience. (See Appendix C)

Because our current wireless network is not adequate, non-institutional wireless devices are sometimes attached to our network. These "rogue" devices are often not compatible with our network, offer unsecured access, and cause RF interference with nearby legitimate access points, and result in data security breaches or network outages Currently employees need to spend time looking for rogue access points to shut them down. With a ubiquitous network the need for individuals to add these rogue access points would significantly decrease. We estimate a minimum time savings of four hours per week for our network technicians.

7. Reasonable Estimate:

A professional estimator, The Wool-Zee Company, Inc., assisted in development of the project budget. (See Appendix D).

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8. Engineering Study:

The project scope was developed through analysis with university IT technicians and a comprehensive engineering study was performed by Bill Diephuis, P.E. RCDD, K-Engineers, of Lynden, WA. This study identified the need for 1,500 wireless access points to provide full campus wireless coverage. The existing wireless system only includes 400 access points. (See Appendix E).

9. Supports Facilities Plan:

a. Campus/Facilities Master Plan

   With the growth of wireless devices, and their importance to the academic mission and facilities management, the campus wireless network is fast becoming as important as any other utility system on campus. An important part of the campus master plan is assuring that utility services are available to support the mission of the university. (See Appendix F). Additionally, wireless systems installation is standard in any of our new or significantly renovated facilities. Wireless options are continuing to grow for facilities project management, operations and maintenance systems.

b. Ongoing academic and/or research program

   The Campus Wireless Upgrade project supports progress towards all of Western's strategic goals. The wireless network is becoming fundamental to our work and success. As mentioned earlier, students are bringing multiple devices to campus with the expectation of connectivity to their academic resources ‘anytime, anywhere’. A ubiquitous robust wireless network is crucial to faculty and student success, safety and satisfaction.

10. Resource Efficiency and Sustainability:

Energy efficiency is an important aspect of Western’s culture. Western as an institution purchases 100% green electrical power. The replacement wireless antennas proposed for the Wireless Upgrade project will be more efficient than those being replaced. The procurement process that will be utilized will assure new equipment meets State of Washington energy efficiency goals and guidelines. Installation of antennas is much more efficient in providing access to large numbers of student, faculty, and staff than individual hard wired data jacks.

Campus Wireless Upgrade

Appendix Contents

A. Office of Financial Management reports (CBS002 and CBS003)

B. Technical White Paper – 802.11ac: The Fifth Generation of Wi-Fi

C. ECAR Study of Undergraduate Students and Information Technology, 2013 – Educause Center for Analysis and Research.

D. The Wool-Zee Company Inc., Cost Estimate

E. K-Engineers Engineering Study/Campus Wireless Request for Information

F. WWU Institutional Master Plan

Appendix A

OFM

380 - Western Washington University
Capital Project Request
2015-17 Biennium

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Version: WV 2015-17 Working Version

Report Number: CBS002
Date Run: 8/1/2014 9:21AM

Project Number: **30000601**
Project Title: **Campus Wireless Upgrade**
Project Class: **Program**

Description

Starting Fiscal Year: 2016
Agency Priority: 7

Project Summary

The Campus Wireless Upgrade will provide increased wireless coverage throughout campus. The use of the wireless local area network on campus which supports portable computing, telephone devices, emergency responders, mobile energy monitors, etc., has moved from an alternative use to a commonplace and critical use to support the University's educational mission.

Project Description

The University's current wireless network system does not cover significant portions of campus and accessibility has not kept pace with increased demand for this service. Coverage is spotty and not dependable. The University's wireless capability amounts to 20% of our actual need which results in dropped or slowed connections and lost productivity. Average bandwidth has increased dramatically over the last ten years, mostly due to increased wireless activities. The University's emergency response system relies on email and texting notifications that can be severely impacted by the lack of wireless coverage. More and more students, faculty and staff turn to their mobile devices for this kind of information as well as use in their daily academic lives.

ECONOMIC IMPACT - See attachments for OFM Forecasting Division Economic Impact Spreadsheet

Note: Extensive project detail is provided in the Campus Wireless Upgrade project proposal submitted under the Four-Year Higher Education Capital Project Evaluation System (CPES).

Location

City: Bellingham **County:** Whatcom **Legislative District:** 040

Project Type

Intermediate

New Facility: No

Funding

Acct Code	Account Title	Estimated Total	Expenditures: Prior Biennium	Current Biennium	2015-17 Fiscal Period: Reapprops	New Approps
057-1	State Bldg Constr-State	4,700,000				4,700,000
	Total	**4,700,000**	**0**	**0**	**0**	**4,700,000**

		Future Fiscal Periods: 2017-19	2019-21	2021-23	2023-25
057-1	State Bldg Constr-State				
	Total	**0**	**0**	**0**	**0**

Schedule and Statistics

OFM

380 - Western Washington University
Capital Project Request
2015-17 Biennium

*

Version: WV 2015-17 Working Version

Report Number: CBS002
Date Run: 8/1/2014 9:21AM

Project Number: 30000601
Project Title: Campus Wireless Upgrade
Project Class: Program

Schedule and Statistics

	Start Date	End Date
Predesign		
Design	9/1/2015	3/1/2016
Construction	7/1/2016	7/1/2017

	Total
Gross Square Feet:	0
Usable Square Feet:	0
Efficiency:	
Escalated MACC Cost per Sq. Ft.:	0
Construction Type:	Other Schedule B Projects
Is this a remodel?	Yes
A/E Fee Class:	B
A/E Fee Percentage:	12.23%

Cost Summary

		Escalated Cost	% of Project
Acquisition Costs Total		**0**	**0.0%**
Consultant Services			
Pre-Schematic Design Services		0	0.0%
Construction Documents		288,738	6.1%
Extra Services		85,950	1.8%
Other Services		144,965	3.1%
Design Services Contingency		53,220	1.1%
Consultant Services Total		**572,872**	**12.2%**
Maximum Allowable Construction Cost(MACC)	**3,214,661**		
Site work		0	0.0%
Related Project Costs		0	0.0%
Facility Construction		3,214,661	68.4%
GCCM Risk Contingency		0	0.0%
GCCM or Design Build Costs		0	0.0%
Construction Contingencies		321,466	6.8%
Non Taxable Items		0	0.0%
Sales Tax		307,643	6.6%
Construction Contracts Total		**3,843,769**	**81.8%**
Equipment			
Equipment		0	0.0%
Non Taxable Items		0	0.0%

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Report Number: CBS002
Date Run: 8/1/2014 9:21AM

Project Number: 30000601
Project Title: Campus Wireless Upgrade
Project Class: Program

Cost Summary

	Escalated Cost	% of Project
Equipment		
Sales Tax	0	0.0%
Equipment Total	**0**	**0.0%**
Art Work Total	**0**	**0.0%**
Other Costs Total	**64,410**	**1.4%**
Project Management Total	**218,976**	**4.7%**
Grand Total Escalated Costs	**4,700,027**	
Rounded Grand Total Escalated Costs	**4,700,000**	

Operating Impacts

No Operating Impact

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Cost Estimate Summary

2015-17 Biennium

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Cost Estimate Number:	250	**Report Number:**	CBS003
Cost Estimate Title:	Campus Wireless Upgrade	**Date Run:**	8/1/2014 9:41AM
Version:	WV 2015-17 Working Version	**Agency Preferred:**	Yes
Project Number:	30000601		
Project Title:	Campus Wireless Upgrade		
Project Phase Title:			

Contact Info **Contact Name:** Rick Benner **Contact Number:** 360.650.3550

Statistics

Gross Sq. Ft.:	0
Usable Sq. Ft.:	0
Space Efficiency:	
MACC Cost per Sq. Ft.:	0
Escalated MACC Cost per Sq. Ft.:	0
Remodel?	Yes
Construction Type:	Other Schedule B Projects
A/E Fee Class:	B
A/E Fee Percentage:	12.23%

Schedule

	Start Date	End Date
Predesign:		
Design:	09-2015	03-2016
Construction:	07-2016	07-2017
Duration of Construction (Months):	12	

Cost Summary Escalated

Acquisition Costs Total			**0**
Pre-Schematic Design Services		0	
Construction Documents		288,738	
Extra Services		85,950	
Other Services		144,965	
Design Services Contingency		53,220	
Consultant Services Total			**572,872**
Site work		0	
Related Project Costs		0	
Facility Construction		3,214,661	
Construction Contingencies		321,466	
Non Taxable Items		0	
Sales Tax		307,643	
Construction Contracts Total			**3,843,769**
Maximum Allowable Construction Cost(MACC)	**3,214,661**		
Equipment		0	
Non Taxable Items		0	
Sales Tax		0	
Equipment Total			**0**
Art Work Total			**0**
Other Costs Total			**64,410**
Project Management Total			**218,976**
Grand Total Escalated Costs			**4,700,027**
Rounded Grand Total Escalated Costs			**4,700,000**

Additional Details

Alternative Public Works Project: No

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Cost Estimate Summary

2015-17 Biennium

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Cost Estimate Number:	250	**Report Number:**	CBS003
Cost Estimate Title:	Campus Wireless Upgrade	**Date Run:**	8/1/2014 9:41AM
Version:	WV 2015-17 Working Version	**Agency Preferred:**	Yes
Project Number:	30000601		
Project Title:	Campus Wireless Upgrade		
Project Phase Title:			

Contact Info **Contact Name:** Rick Benner **Contact Number:** 360.650.3550

Additional Details

State Construction Inflation Rate:	3.08%
Base Month and Year:	03-2014
Project Administration By:	AGY
Project Admin Impact to DES that is NOT Included in Project Total:	$0

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Cost Estimate Detail

2015-17 Biennium

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Cost Estimate Number:	250	**Analysis Date:**	March 13, 2014
Cost Estimate Title:	Campus Wireless Upgrade		
Detail Title:	Wireless Upgrade		
Project Number:	30000601		
Project Title:	Campus Wireless Upgrade		
Project Phase Title:			
Location:			

Contact Info **Contact Name:** Rick Benner **Contact Number:** 360.650.3550

Statistics

Gross Sq. Ft.:
Usable Sq. Ft.:
Rentable Sq. Ft.:
Space Efficiency:
Escalated MACC Cost per Sq. Ft.:
Escalated Cost per S. F. Explanation

Construction Type:	Other Schedule B Projects
Remodel?	Yes
A/E Fee Class:	B
A/E Fee Percentage:	12.23%
Contingency Rate:	10.00%
Contingency Explanation	
Projected Life of Asset (Years):	
Location Used for Tax Rate:	
Tax Rate:	8.70%
Art Requirement Applies:	No
Project Administration by:	AGY
Higher Education Institution?:	Yes
Alternative Public Works?:	No

Project Schedule

Project Schedule	Start Date	End Date
Predesign:		
Design:	09-2015	03-2016
Construction:	07-2016	07-2017
Duration of Construction (Months):	12	
State Construction Inflation Rate:	3.08%	
Base Month and Year:	3-2014	

Project Cost Summary

MACC:	$ 2,949,500
MACC (Escalated):	$ 3,214,661
Current Project Total:	$ 4,324,758
Rounded Current Project Total:	$ 4,325,000
Escalated Project Total:	$ 4,700,027
Rounded Escalated Project Total:	$ 4,700,000

ITEM	Base Amount	Sub Total	Escalation Factor	Escalated Cost
CONSULTANT SERVICES				
Construction Documents				
A/E Basic Design Services				273,789
SubTotal: Construction Documents				**288,738**
Extra Services				
Commissioning (Systems Check)	15,000			
Testing	5,000			
Travel & Per Diem	40,000			
Document Reproduction	5,000			
Advertising	3,500			
Verifying Existing Conditions	13,000			
SubTotal: Extra Services		**81,500**	1.0546	**85,950**
Other Services				
Bid/Construction/Closeout				123,007
On-Site Rep.	10,000			
		133,007	1.0899	
SubTotal: Other Services				**144,965**
Design Services Contingency				
Design Services Contingency	48,830			
SubTotal: Design Services Contingency		**48,830**	1.0899	**53,220**
Total: Consultant Services		**537,126**	1.0666	**572,872**
CONSTRUCTION CONTRACTS				
Facility Construction				
Total Cost	2,949,500			
SubTotal: Facility Construction		**2,949,500**	1.0899	**3,214,661**
Maximum Allowable Construction Cost (MACC)		**2,949,500**	1.0900	**3,214,661**
Construction Contingencies				
Allowance for Change Orders	294,950			
SubTotal: Construction Contingencies		**294,950**	1.0899	**321,466**
Sales Tax		**282,268**	1.0899	**307,643**
Total: Construction Contracts		**3,526,718**	1.0899	**3,843,769**
OTHER COSTS				
Permits/Plan Review	40,000			
M&O Assist	20,000			
Total: Other Costs		**60,000**	1.0735	**64,410**
PROJECT MANAGEMENT				
Agency Project Management	200,914			
Total: Project Management		**200,914**	1.0899	**218,976**

Appendix B

White Paper

802.11ac: The Fifth Generation of Wi-Fi

Technical White Paper

August, 2012

Contents

1. Executive Summary

802.11ac, the emerging standard from the IEEE, is like the movie **The Godfather Part II**. It takes something great and makes it even better. 802.11ac is a faster and more scalable version of 802.11n. 802.11ac couples the freedom of wireless with the capabilities of Gigabit Ethernet.

Wireless LAN sites will see significant improvements in the number of clients supported by an access point (AP), a better experience for each client, and more available bandwidth for a higher number of parallel video streams. Even when the network is not fully loaded, users see a benefit: their file downloads and email sync happen at low-lag gigabit speeds. Also, device battery life is extended, since the device's Wi-Fi interface can wake up, exchange data with its AP, then revert to dozing that much more quickly.

802.11ac achieves its raw speed increase by pushing on three different dimensions:

- More channel bonding, increased from the maximum of 40 MHz in 802.11n, and now up to 80 or even 160 MHz (for 117% or 333% speed-ups, respectively)
- Denser modulation, now using 256 quadrature amplitude modulation (QAM), up from 802.11n's 64QAM (for a 33% speed burst at shorter, yet still usable, ranges)
- More multiple input, multiple output (MIMO). Whereas 802.11n stopped at four spatial streams, 802.11ac goes all the way to eight (for another 100% speed-up).

The design constraints and economics that kept 802.11n products at one, two, or three spatial streams haven't changed much for 802.11ac, so we can expect the same kind of product availability, with first-wave 802.11ac products built around 80 MHz and delivering up to 433 Mbps (low end), 867 Mbps (midtier), or 1300 Mbps (high end) at the physical layer. Second-generation products promise still more channel bonding and spatial streams, with plausible product configurations operating at up to 3.47 Gbps.

802.11ac is a 5 GHz-only technology, so dual-band APs and clients will continue to use 802.11n at 2.4 GHz. However, 802.11ac clients operate in the less crowded 5 GHz band.

Second-generation products should also come with a new technology, multiuser MIMO (MU-MIMO). Whereas 802.11n is like an Ethernet hub that can only transfer a single frame at a time to all its ports, MU-MIMO allows an AP to send multiple frames to multiple clients at the same time over the same frequency spectrum. That's right: with multiple antennas and smarts, an AP can behave like a wireless switch. There are technical constraints, and so MU-MIMO is particularly well suited to bring-your-own-device (BYOD) situations where the devices such as smartphones and tablets might only have a single antenna.

802.11ac-enabled products are the culmination of efforts at the IEEE and Wi-Fi Alliance pipelines. IEEE 802.11ac delivered an approved Draft 2.0 amendment in January 2012 and a refined Draft 3.0 in May 2012, with final ratification planned for the end of 2013. In parallel, the Wi-Fi Alliance is expected to take an early IEEE draft, most likely Draft 3.0, and use that as the baseline for an interoperability certification of first-wave products in early 2013. Later, and more in line with the ratification date of 802.11ac (that is, after December 2013), the Wi-Fi Alliance is expected to refresh its 802.11ac certification to include testing of the more advanced 802.11ac features. This second-wave certification should include features such as channel bonding up to 160 MHz, four spatial streams, and MU-MIMO. Overall, this arrangement closely follows how 802.11n was rolled out.

Enterprise networks considering an investment in infrastructure Wi-Fi have two excellent choices: (1) buy 802.11n APs, since they deliver a remarkable level of performance, they are available today, and 802.11n is widely deployed in client products, or (2) wait for 802.11ac APs and their state-of-the-art performance. Then there is option (3), which avoids the wait: invest in a modular 802.11n AP such as the Cisco® Aironet® 3600 Access Point that is readily field-upgradable to 802.11ac.

Meanwhile, consumer-grade products might be launched earlier, in 2012, but before Wi-Fi Alliance certification is available. However, we **strongly** recommend that all enterprises wait for products that are certified by the Wi-Fi Alliance as interoperable (that is, in 2013).

802.11ac, when it arrives, has a few new effects on existing 802.11a/11n deployments even if the deployment is not upgraded to 802.11ac immediately: (1) the wider channel bandwidths of neighboring APs require updates to radio resource measurement, or RRM (and in particular the dynamic channel assignment algorithm), and (2) 802.11a/11n wireless intrusion protection systems (WIPS) can continue to decode most managements frames such as beacon and probe request/response frames (that are invariably sent in 802.11a format) but do not have visibility in data sent in the new 802.11ac packet format.

One thing not to worry about is compatibility. 802.11ac is designed in a deep way to coexist efficiently with existing 802.11a/n devices, with strong carrier sense, a single new preamble that appears to be a valid 802.11a preamble to 802.11a/n devices, and extensions to request-to-send/clear-to-send (RTS/CTS) to help avoid collisions with users operating on slightly different channels.

2. What Is 802.11ac?

First, 802.11ac is an evolution of 802.11n. If you want to learn more about 802.11n, jump to the appendix. If you are already familiar with the channel bonding, MIMO, and aggregation introduced by 802.11n and you don't need a refresher, then read on.

2.1 Drivers for 802.11ac

802.11ac is an evolutionary improvement to 802.11n. One of the goals of 802.11ac is to deliver higher levels of performance that are commensurate with Gigabit Ethernet networking:

- Seemingly "instantaneous" data transfer experience
- A pipe fat enough that delivering high quality of experience (QoE) is straightforward

In the consumer space, the target is multiple channels of high-definition content delivered to all areas of the house. The enterprise has different challenges:

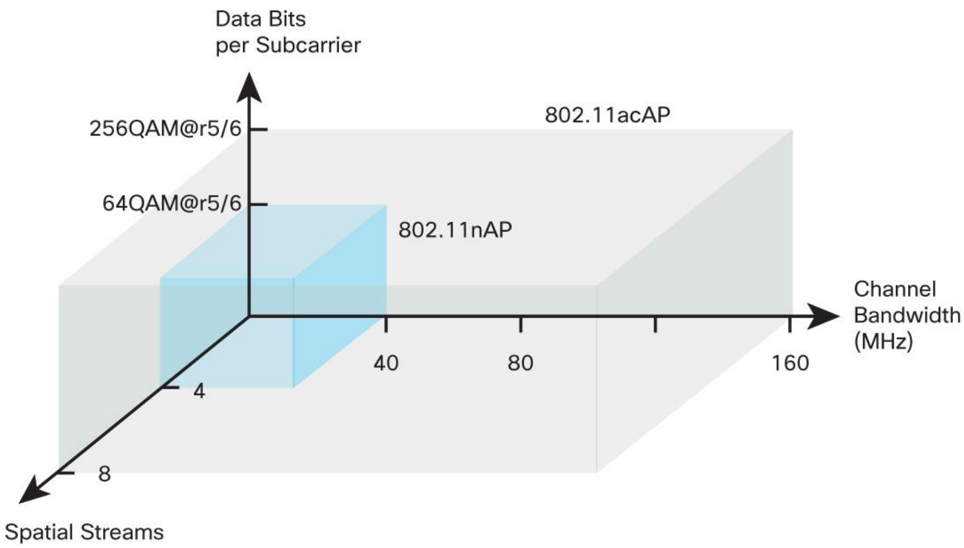
- Delivering network with enterprise-class speeds and latencies
- High-density environments with scores of clients per AP
    - Which are exacerbated by the BYOD trend such that one employee might carry two or even three 802.11 devices and have them consuming network resources all at once
- The increased adoption of video streaming

802.11ac is about delivering an outstanding experience to each and every client served by an AP, even under demanding loads.

Meanwhile 802.11 is integral to hugely broad range of devices, and some of them are highly cost, power, or volume constrained. One antenna is routine for these devices, yet 802.11ac must still deliver peak efficiency.

The one thing that 802.11ac has in its favor is the evolutionary improvement to silicon technology over the past half-dozen years: channel bandwidths can be wider, constellations can be denser, and APs can integrate more functionality.

Figure 1. How 802.11ac Accelerates 802.11n



2.2 How Does 802.11ac Go So Fast?

Wireless speed is the product of three factors: channel bandwidth, constellation density, and number of spatial streams. 802.11ac pushes hard on the boundaries on each of these, as shown in Figure 1.

For the mathematically inclined, the physical layer speed of 802.11ac is calculated according to Table 1. For instance, an 80 MHz transmission sent at 256QAM with three spatial streams and a short guard interval delivers 234×3×5/6×8 bits/3.6 μs = 1300 Mbps.

Table 1. Calculating the Speed of 802.11n and 802.11ac

PHY	Bandwidth (as Number of Data Subcarriers)		Number of Spatial Streams		Data Bits per Subcarrier		Time per OFDM Symbol		PHY Data Rate (bps)
11n or 11ac	56 (20 MHz)		1 to 4		Up to $5/6 \times \log_2(64) = 5$		3.6 μs (short guard interval)		
	108 (40 MHz)	×		×		÷	4 μs (long guard interval)	=	
11ac only	234 (80 MHz)		5 to 8		Up to $5/6 \times \log_2(256) \approx 6.67$				
	2×234 (160 MHz)								

Immediately we see that increasing the channel bandwidth to 80 MHz yields a 2.16 times speed-up, and 160 MHz offers a further doubling. Nothing is for free: it does consume more spectrum, and each time we're splitting the same transmit power over twice as many subcarriers, so the speed doubles, but the range for that doubled speed is slightly reduced (for an overall win).

Going from 64QAM to 256QAM also helps, by another 8/6 = 1.33 times. Being closer together, the constellation points are more sensitive to noise, so 256QAM helps most at shorter range where 64QAM is already reliable. Still, 256QAM doesn't require more spectrum or more antennas than 64QAM.

Then the speed is directly proportional to the number of spatial streams. More spatial streams require more antennas, RF connectors, and RF chains at transmitter and receiver. The antennas should be spaced 1/3 wavelength (3/4”) or more apart, and the additional RF chains consume additional power. This drives many mobile devices to limit the number of antennas to one, two, or three.

Collectively, these three speed-ups are significant. From Figure 2 and Table 2, the minimum allowed 802.11ac product is 4.4× faster than the corresponding 802.11n product, and the midtier and high-end wave 1 products are nearly 3× faster, reaching up to 1.3 Gbps PHY data rates. Actual throughput will be a function of MAC efficiency (rarely better than 70%) and the device capabilities at each end of the link.

Figure 2. Evolution of Cisco APs with 802.11 Physical Layer Amendments

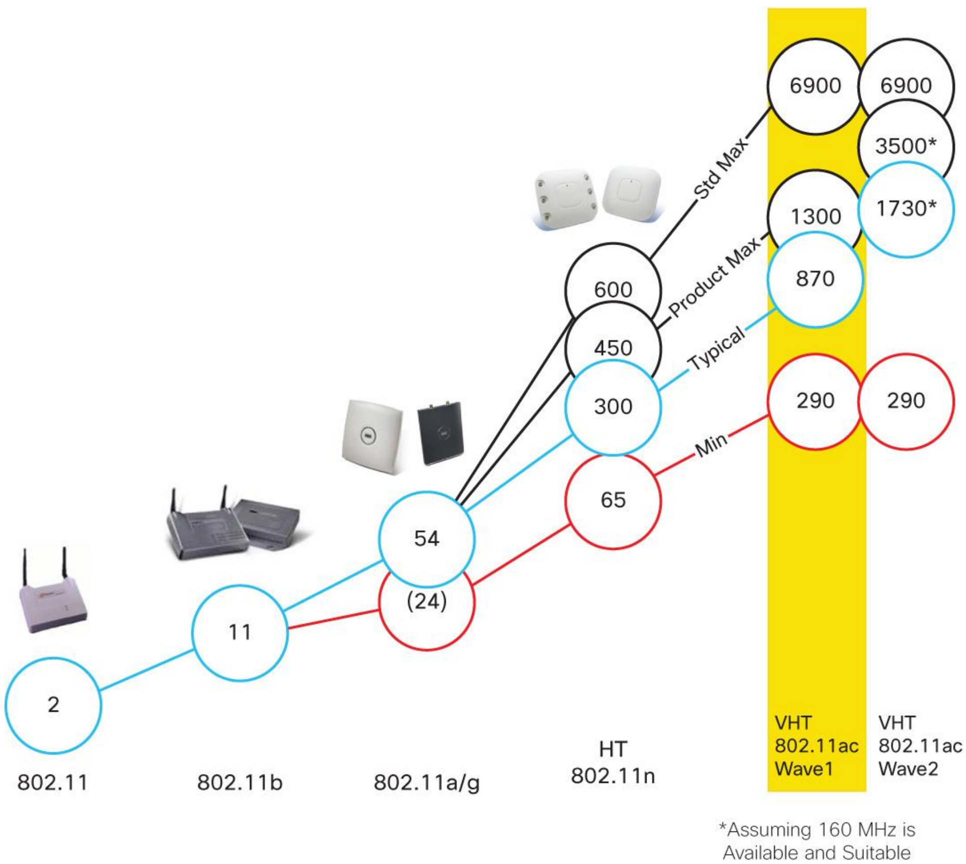


Table 2. Important Data Rates of 802.11a, 11n, and 11ac

Nominal Configuration	Bandwidth (MHz)	Number of Spatial Streams	Constellation Size and Rate	Guard Interval	PHY Data Rate (Mbps)	Throughput (Mbps)*
802.11a						
All	20	1	64QAMr3/4	Long	54	24
802.11n						
Min	20	1	64QAMr5/6	Long	65	46
Low-end product (2.4 GHz only+)	20	1	64QAMr5/6	Short	72	51
Midtier product	40	2	64QAMr5/6	Short	300	210
Max product	40	3	64QAMr5/6	Short	450	320

Nominal Configuration	Bandwidth (MHz)	Number of Spatial Streams	Constellation Size and Rate	Guard Interval	PHY Data Rate (Mbps)	Throughput (Mbps)*
Amendment max	40	4	64QAMr5/6	Short	600	420
802.11ac wave 1						
Min	80	1	64QAMr5/6	Long	293	210
Low-end product	80	1	256QAMr5/6	Short	433	300
Midtier product	80	2	256QAMr5/6	Short	867	610
High-end product	80	3	256QAMr5/6	Short	1300	910
80 MHz amendment max	80	8	256QAMr5/6	Short	3470	2400
802.11ac wave 2						
Low-end product	160	1	256QAMr5/6	Short	867	610
Midtier product	160	2	256QAMr5/6	Short	1730	1200
High-end product	160	3	256QAMr5/6	Short	2600	1800
Ultra-high-end product	160	4	256QAMr5/6	Short	3470	2400
Amendment max	160	8	256QAMr5/6	Short	6930	4900

*Assuming a 70% efficient MAC, except for 802.11a, which lacks aggregation.
+Assuming 40 MHz is not available due to the presence of other APs.

2.3 How Do We Make 802.11ac Robust?

The sticker on the box that shows maximum data rate doesn't help us much in the real world, where devices have to contend with interference from non-802.11 devices, preexisting APs that might only use 20 or 40 MHz, multipath fading, few antennas on mobile devices, weak signals at range, and so forth. What makes the raw speed of 802.11ac so valuable are the extensions that help to deliver reliable throughput under realistic conditions.

2.3.1 Technology Overview

By design, 802.11ac is intended to operate only in the 5 GHz band, as shown in Table 3. This avoids much of the interference at 2.4 GHz, including Bluetooth headsets and microwave ovens, and provides a strong incentive for users to upgrade their mobile devices (and hotspot APs) to be dual band so that the 5 GHz band is more universally usable. This choice also streamlines the IEEE process by avoiding the possibility of contention between 802.11 and 802.15 proponents. And there is barely 80 MHz of bandwidth at 2.4 GHz anyway.

As we've already seen, 802.11 introduces higher order modulation, up to 256QAM; additional channel bonding, up to 80 or 160 MHz; and more spatial streams, up to eight. There is an alternative way to send a 160 MHz signal, known as "80+80" MHz, discussed later (see section 2.3.6).

802.11ac continues some of the more valuable features of 802.11n, including the option of short guard interval (for a 10% speed bump) and incrementally better rate at range using the advanced low-density parity check (LDPC) forward error-correcting codes. These LDPC codes are designed to be an evolutionary extension of the 802.11n LDPC codes, so implementers can readily extend their current hardware designs.

Various space time block codes (STBCs) are allowed as options, but (1) this list is trimmed from the overrich set defined by 802.11n, and (2) STBC is largely made redundant by beamforming. 802.11n defined the core STBC modes of 2×1 and 4×2 and also 3×2 and 4×3 as extension modes, but the extension modes offered little gain for their additional complexity and have not made it to products. Indeed, only the most basic mode, 2×1, has been certified by the Wi-Fi Alliance. With this experience, 802.11ac only defines the core 2×1, 4×2, 6×3, and 8×4 STBC modes, but again only 2×1 is expected to make it to products: if you had an AP with four antennas, why would you be satisfied with 4×2 STBC when you could - and should - be using beamforming?

What 802.11ac also gets right is to define a single way of performing channel sounding for beamforming: so-called explicit compressed feedback. Although optional, if an implementer wants to offer the benefits of standards-based beamforming, there is no choice but to select that single mechanism, which can then be tested for interoperability.

Table 3. Primary Ingredients of 802.11ac

Parameter	802.11ac D3.0 Likely Wave 1 Wi-Fi Alliance Certification	802.11ac (Later Draft) Potential Wave 2 Wi-Fi Alliance Certification	802.11ac Complete Amendment
Spectrum	5 GHz (varied support by regulatory domain; nearly 600 MHz in the United States)		<6 GHz excluding 2.4 GHz
Bandwidth	Mandatory: 20, 40, and 80 MHz	Mandatory: 20, 40, and 80 MHz Optional: 160 and 80+80 MHz	
Modulation	Mandatory: BPSK, QPSK, 16QAM, 64QAM Optional: 256QAM		
Number of spatial streams	Mandatory: 2 (non mobile APs*), 1 (others) Optional: up to 3 spatial streams	Mandatory: 2 (non mobile APs*), 1 (others) Optional: up to 4 spatial streams	Mandatory: 1 Optional: 2-8
Forward error correction	Mandatory: BCC Optional: LDPC		
STBC	Optional: 2×1 AP to client		Optional: 2×1, 4×2, 6×3, 8×4
Short guard interval	Optional		
Sounding (a single interoperable protocol)	Optional		
CTS in response to RTS with bandwidth indication	Mandatory		
RTS with bandwidth indication	Optional		
Aggregation	Mandatory: TX and RX of A-MPDU Optional: RX A-MPDU of A-MSDU	Mandatory: TX and RX of A-MPDU TBD: RX A-MPDU of A-MSDU	A-MDPU, A-MDPU of A-MSDU
MU-MIMO	-	Optional	
*Additional requirement introduced by the Wi-Fi Alliance.			

Because of the wider channel bandwidths of 802.11ac, it is much more likely that an 80 MHz AP will overlap with another 20 or 40 MHz AP - and similarly an 80 or 160 MHz AP - or even several of them, all potentially on different channels. To enable reliable operation amid this complexity, 802.11ac mandates extensions to the RTS/CTS mechanism, stronger clear-channel assessment (CCA) requirements, and new primary channel selection rules. See section 2.3.4.

802.11ac also introduces a valuable new technology called multiuser MIMO. This is challenging to get right, so is deferred until the second wave of 802.11ac products and is optional. More on this later in section 2.3.9.

2.3.2 Differences Between 802.11ac and 802.11n

802.11ac has avoided the battles of 802.11n and instead has focused on extending the tremendous advances made in 802.11n to deliver the next generation of speed and robustness.

For instance, 802.11n pioneered aggregation through the selective use of A-MPDU, A-MSDU, and A-MPDU of A-MSDU (see Appendix). 802.11ac actually **requires** every 802.11ac transmission to be sent as an A-MPDU aggregate. This is due in part because of the intrinsic efficiency of A-MPDU and for some other reasons too (see section 2.3.5).

In a further example, 802.11ac extends the 802.11n channel access mechanism: virtual carrier sense and backoff occur on a single 20 MHz primary channel; then CCA is used for the remaining 20 MHz subchannels immediately before transmitting on them.

Given the power of A-MPDU and the 802.11n channel access mechanism, 802.11ac actually didn't need to innovate much in the MAC. Indeed, extensions to the RTS/CTS mechanism are the only new mandatory MAC feature.

802.11n does include many options with reduced value. 802.11ac takes a very pragmatic approach to them. If a "useless" option is used and affects a third-party device, then typically 802.11ac forbids an 802.11ac device (operating in 802.11ac mode) from using the option. If a "useless" option has not been used in 802.11n products or only affects the devices that activate the option, then the feature is not updated for 802.11ac but is instead "left to die."

For instance, there is no 802.11ac version of the "802.11n greenfield" preamble format. 802.11ac only defines one preamble format, which, to legacy 802.11a/11n devices, will look safely like an 802.11a preamble followed by a payload with a bad CRC. This means that legacy devices don't try to transmit over the top of the 802.11ac transmission, nor do they attempt to send a bad payload up the stack.

802.11n introduced a "reduced interframe spacing," which reduces overheads between consecutive transmissions, but experience has shown that A-MDPU solves much the same problem, but even more efficiently. 802.11ac devices operating in 802.11ac mode are not permitted to transmit RIFS (as of Draft 3.0).

802.11n features that are not updated for 11ac (or explicitly forbidden for 802.11ac devices operating in 802.11ac mode) include all the 802.11n sounding options, including extension LTFs, the calibration procedure, antenna selection, PCO, LSIG TXOP protection, unequal modulation, 4×3 and 3×2 STBC modes, MCS32, and dual CTS protection. If you don't know these terms, then no problem, because almost certainly you'll never need to know them.

2.3.3 Standards-Based Beamforming

Any device (with multiple antennas) can beamform to any other device at any time. What 802.11ac adds is the opportunity for the receiver to help the beamforming transmitter to do a better job of beamforming. This is called "sounding," and it enables the beamformer to precisely steer its transmitted energy toward the receiver. 802.11ac defines a single, though optional, protocol for one 802.11ac device to sound other 802.11ac devices. The protocol selected closely follows the 802.11n "explicit compressed feedback" protocol, as follows.

A device, typically an AP, sends a "VHT Null Data Packet (NDP) Announcement" frame. Its only purpose is to contain the address of the AP and of the target recipients. The VHT NDP Announcement frame is immediately followed by a "VHT Null Data Packet" (VHT NDP) intended for those target recipients. Each intended recipient measures the RF channel from AP to itself using the preamble of the VHT NDP and compresses the channel. The first intended recipient responds with the compressed channel information in a VHT Compressed Beamforming frame immediately, and other recipients respond when they are polled by the AP. The VHT NDP Announcement frame, the VHT NDP, and the VHT Compressed Beamforming frame are all similar to features in 802.11n. However, because of some subtle differences, the 802.11ac sounding is not backward compatible with 802.11n devices.

Also, to support this new MU-MIMO feature (see section 2.3.9), the channel feedback can contain an extra level of detail.

Explicit compressed feedback (ECFB) is known to provide the most precise estimate of the channel that takes into account all the imperfections at transmitter and receiver.

However, ECFB comes with a lot of overhead: the VHT NDP Announcement frame, the VHT NDP itself, and the frame carrying the compressed feedback. For an AP with four antennas, the compressed feedback varies from 180 to 1800 bytes, depending on the number of client antennas and level of compression. Sounding just one single-antenna 80 MHz client takes about 250 microseconds. When devices can transmit at 433 Mbps, this is expensive, since that same time could have instead been used to send an extra 13,000 bytes.

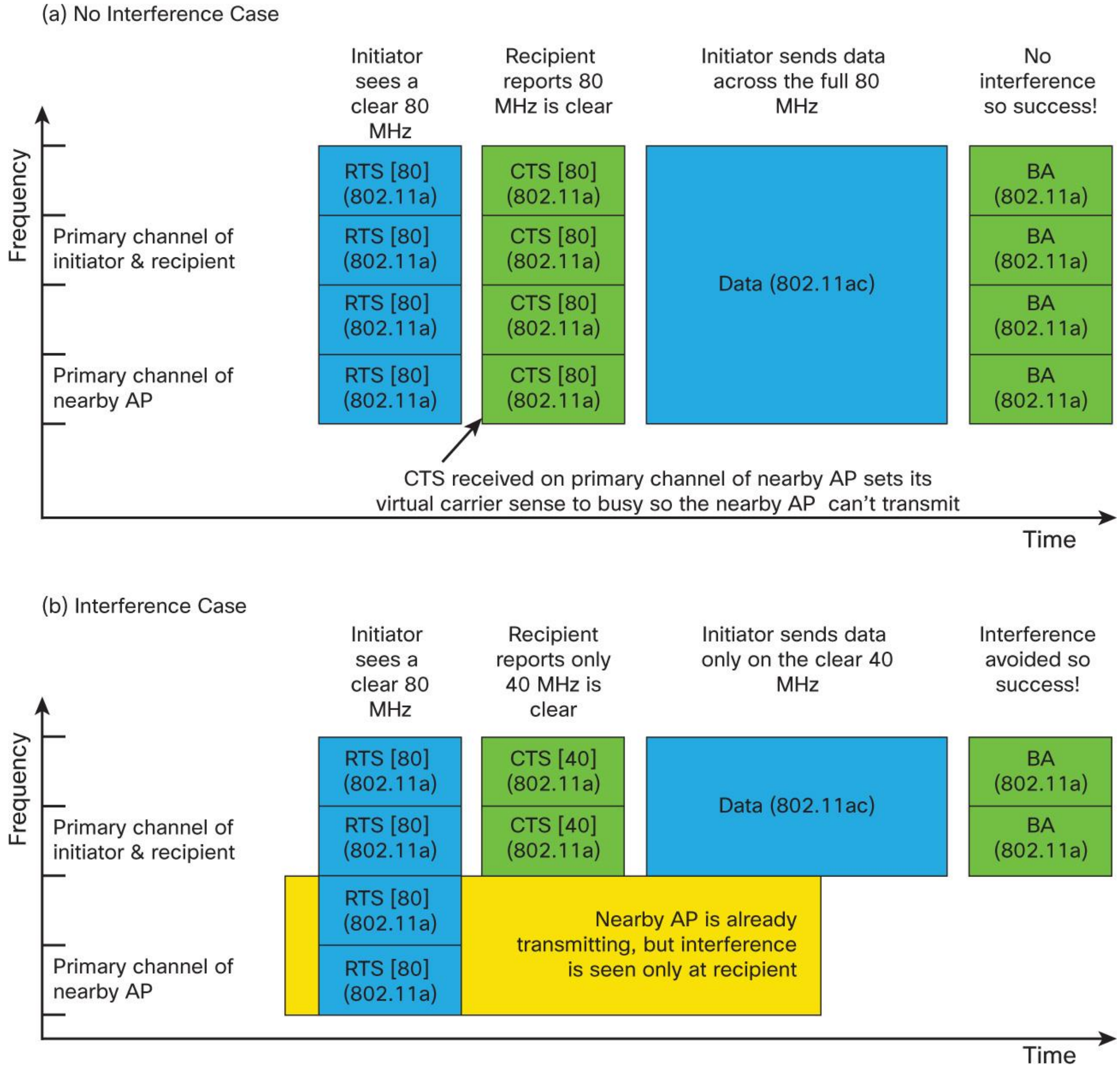
And so technologies that solve the problem of sounding without depending on client assistance (such as Cisco's family of ClientLink technologies) continue to add genuine value. They (1) still help legacy 802.11a/n clients, (2) still help those 802.11ac clients that do not support 802.11ac sounding, (3) still help clients at 2.4 GHz, and (4) can avoid the overhead of standards-based explicit sounding when it is not actually necessary.

2.3.4 RTS/CTS with Bandwidth Indication

An 802.11ac AP operating on 80 MHz (or 160 MHz and so on) should still be capable of allowing 802.11a or 802.11n clients to associate. Thus beacons are sent on one 20 MHz channel, known as the primary channel, within that 80 MHz. The AP and all clients associated to the AP receive and process every transmission that overlaps this primary channel and extract virtual carrier sense from the frames they can decode.

However, the AP could be nearby other uncoordinated APs. Those APs could be preexisting 802.11a or 802.11n APs, and their primary channels could be any 20 MHz within the 80 MHz of the 802.11ac AP. Then the different APs and their associated clients have a different virtual carrier sense, so can transmit at different times on the different subchannels, including overlapping times. With the wide 802.11ac channel bandwidths, this scenario becomes much more likely than with 802.11n.

Figure 3. RTS/CTS Enhanced with Bandwidth Signalling



For this reason, 802.11ac defines an enhanced RTS/CTS protocol. RTS/CTS can be used to find when channel bandwidth is clear and how much, around both the initiator and the responder, as shown in Figure 3.

First, when an 802.11ac device sends an RTS, (1) this initiating device has to verify that the 80 MHz channel is clear in its vicinity, (2) the RTS is normally sent in an 802.11a PPDU format, and (3) the basic 802.11a transmission, which is 20 MHz wide, is replicated another three times to fill the 80 MHz (or another seven times to fill 160 MHz). Then every nearby device, regardless of whether it is an 802.11a/n/ac device, receives an RTS that the device can understand on its primary channel. And every device that hears the RTS has its virtual carrier sense set to busy (see Figure 3(a)). To make the protocol robust, the replication bandwidth of the RTS is reported inside the 802.11a PPDU[1].

[1] Since the 802.11a PPDU format doesn't contain a bandwidth indication, 802.11ac has to play some tricks to maintain backward compatibility. The bandwidth indication is encoded in the scrambling sequence, and also the individual/group bit in the transmitter MAC address in the RTS frame is changed from "individual" to "group." This last change will be visible in sniffer traces.

Second, before the device addressed by the replicated RTS responds with a CTS, the recipient device checks to see if there is anyone transmitting near itself, on its primary channel or on **any other** 20 MHz within the 80 MHz. If a portion of the bandwidth is in use nearby, then the recipient only responds with a CTS on the available and "usable" 20 MHz subchannels and also reports the bandwidth of the replicated CTS inside the CTS's PPDU. Here "usable" subchannels means the subchannels on which the initiating device is allowed to send something, such as a 20, 40, or 80 MHz (but not 60 MHz) transmission. This is shown in Figure 3(b).

Third, the CTS is sent, like the RTS, in an 802.11a PPDU format, replicated in 20 MHz chunks across the available and useful bandwidth. Again every nearby device receives a CTS that the device can understand on its primary channel.

There are other variations on this protocol, for when the initiator is incapable of switching to a narrower bandwidth on the fly and so forth, but the previous description captures the essence of the enhancement: the recipient can say "these subchannels are busy - don't use them."

2.3.5 All A-MPDUs

802.11 defines that every 802.11 PPDU transmission is an A-MPDU, yet the A-MPDU might only contain a single MPDU. Why? The short answer is that it's complicated.

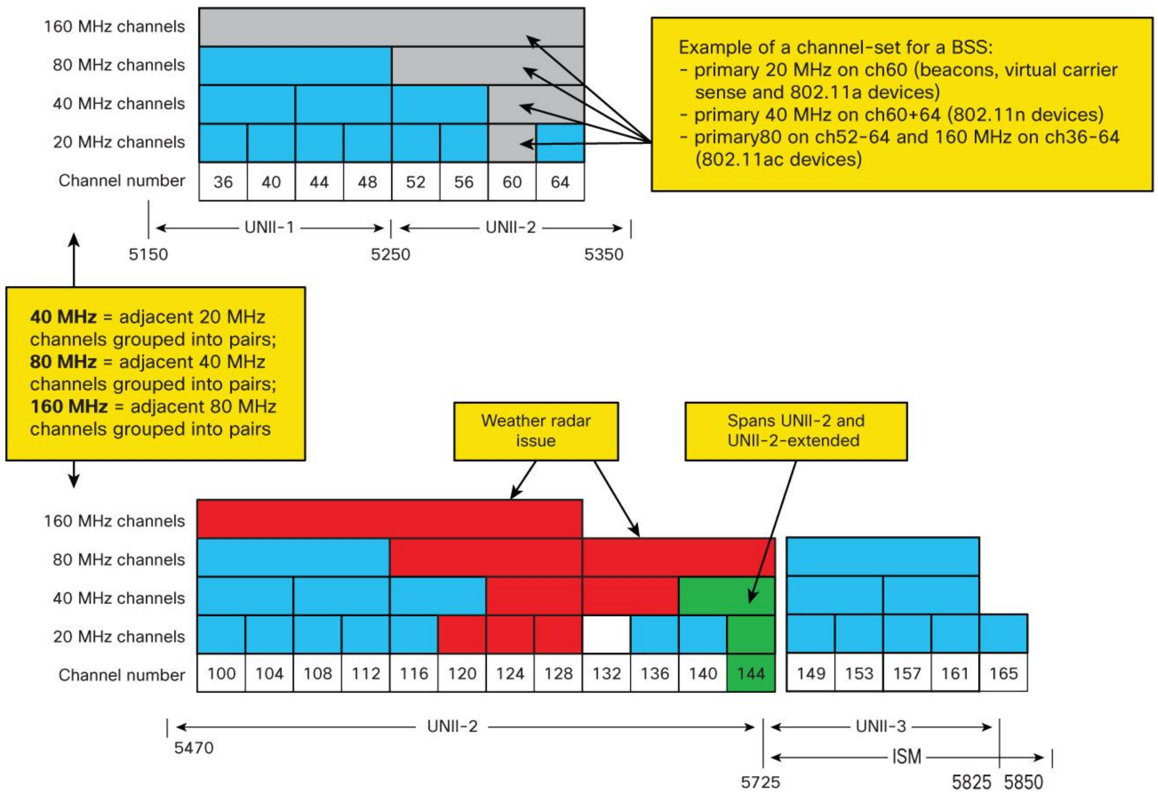
Long answer: There are three reasons: (1) In 802.11a/n, the duration of the transmission is set by the number of octets and the data rate for the transmission. But for a maximum-length 5.5 ms transmission at 6.93 Gbps, there could be over 4 million bytes, and this takes 23 bits to represent. These bits would be sent at the lowest MCS rate at the start of **every** 802.11ac transmission and so practically would add 4 µs each time. Instead, the length of an 802.11ac transmission is constrained to be a multiple of the number of data bits per OFDM symbol, and then only the number of OFDM symbols needs to be signaled. Moreover, the number of (assumed to be) 4 µs-long OFDM symbols is already implicitly available in the legacy portion of the preamble, so this signaling comes almost "for free."[2] Then we need a way to completely fill even the last OFDM symbol with data. A-MDPU makes this easy: send the data as MDPUs within MDPU subframes in an A-MDPU, then pad the A-MDPU with enough null MDPU subframes to fill up the last OFDM symbol. (2) This same padding mechanism will come in handy for the new MU-MIMO feature. (3) A-MDPU is in general a good idea to increase reliability for long payloads.

2.3.6 Channelization and 80+80 MHz

802.11ac adopts a keep-it-simple approach to channelization. Adjacent 20 MHz subchannels are grouped into pairs to make 40 MHz channels, adjacent 40 MHz subchannels are grouped into pairs to make 80 MHz channels, and adjacent 80 MHz subchannels are grouped into pairs to make the optional 160 MHz channels, as shown in Figure 4. A BSS (that is, AP plus clients) uses the different bandwidths for different purposes, but the usage is principally governed by the capabilities of the clients.

[2] Just a single bit is needed to disambiguate the number of actual OFDM symbols present if the transmission instead uses the short guard interval and the OFDM symbols are actually 3.6 µs long.

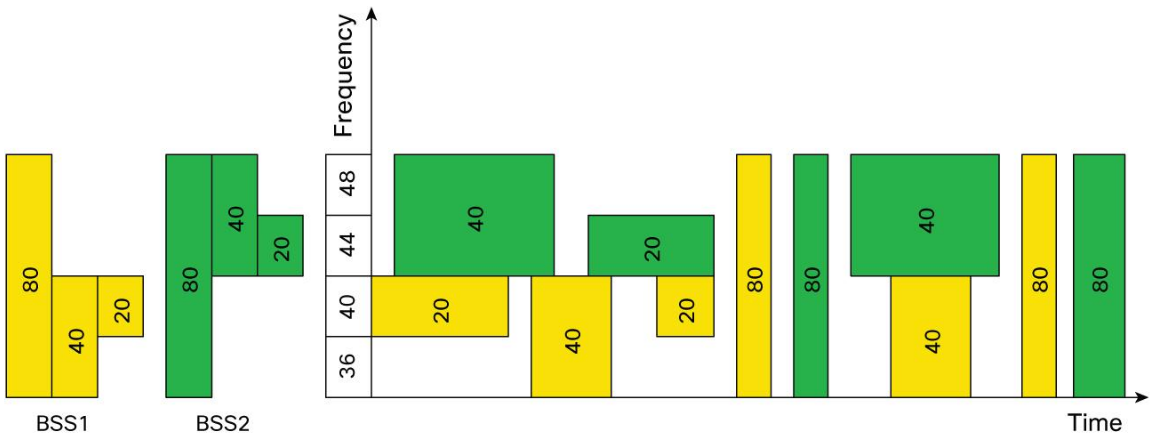
Figure 4. 802.11ac Channelization (United States)



We see that in the United States, there are 20 to 25 20 MHz channels, 8 to 12 40 MHz channels, 4 to 6 80 MHz channels, and 1 or 2 160 MHz channels. These numbers are ranges because of the evolving regulatory issues surrounding the different spectrum noted in Figure 4.

What if most clients at a deployment are still 802.11n clients with 40 MHz maximum? Does deploying 802.11ac APs mean fewer channels and more interference? As you would expect from an IEEE standard, the answer is a resounding “no.” It is entirely allowed for two 80 MHz 802.11ac APs to select the same 80 MHz channel bandwidth but one AP to put its primary 20 MHz channel within the lower 40 MHz and the other AP to put its primary 20 MHz channel within the upper 40 MHz. What this means is that 802.11n clients associated to the first AP can transmit 20 or 40 MHz as usual, at the same time as 802.11n clients associated to the second AP can transmit 20 or 40 MHz in parallel. What is new in 802.11ac is the ability for any 802.11ac client that sees that the whole 80 MHz as available to invoke a very high-speed mode and to transmit across the whole 80 MHz. This is shown in Figure 5.

Figure 5. Example of Parallel Transmissions with Two BSSs on the Same 80 MHz but with Different Primary 20-MHz Subchannels



The ability to have overlapped APs but different primary channels is made possible by:

- The enhanced secondary CCA thresholds mandated by 802.11ac, which are up to 13 dB more stringent than the secondary channel CCA thresholds defined by 802.11n
- The addition of a bandwidth indication to the RTS/CTS exchange (see section 2.3.4)

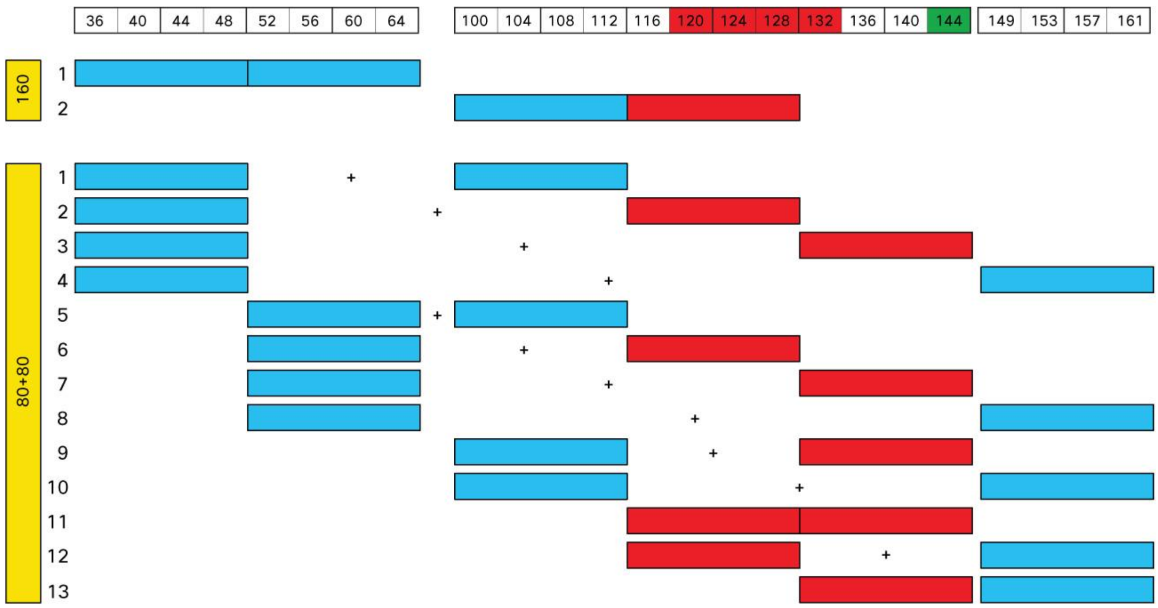
Over time, clients will transition from 802.11n to 802.11ac, so that 80 MHz is used more and more. In this environment APs should change to align their primary 20 MHz channels.

The capability of 80 MHz channels is markedly increased over narrower bandwidths. And this offers a lot of value in many typical scenarios: a few clients transferring a lot of traffic associated to a 40 MHz AP are speed limited to 802.11n's 300 or 450 Mbps. This is true even if the APs on the adjacent 40 MHz are all lightly loaded. With the wider channel, more clients get to transfer their data more quickly. and they can complete their transmissions that much sooner. Overall, less battery energy is consumed, and other clients don't have as long to wait (for better QoS). This discussion all comes under the umbrella of "statistical multiplexing," where more multiplexing is more efficient for bursty traffic.

Since the number of 160 MHz channels is tiny, 160 MHz is unsuited to typical enterprise use. In the home, every 160 MHz channel is subject to difficult radar detection regulatory requirements. Thus 802.11ac also introduces a noncontiguous 80+80 MHz mode. As can easily be imagined from the name, it is the 160 MHz waveform, but transmitted in two separate 80 MHz frequency segments, where each 80 MHz segment can lie on any allowed 80 MHz channel. To make this feasible, it is still a time-division-duplex system, in that APs and clients only ever transmit on 80+80 or receive on 80+80; they are never expected to transmit on one 80 MHz segment and receive on the second 80 MHz segment.

In lightly and moderately used spectrum, this appears to provide vastly more flexibility to avoid interference, as shown in Figure 6. 80+80 MHz has 13 options versus the two options for 160 MHz (ignoring regulatory issues). Unfortunately, an 80+80 MHz device is much more complicated than a 160 MHz device, since the 80+80 MHz device needs twice as many RF chains. A device might operate either as a two-spatial stream 80 MHz device or as a one-spatial stream 80+80 MHz device. In this case, 80+80 MHz allows the use of more spectrum but only uses that spectrum half as efficiently.

Figure 6. Channel Options for 160 MHz and 80+80 MHz



Neither 160 MHz nor 80+80 MHz are recommended for typical enterprises given the currently available spectrum.

From Figure 4, RRM becomes a much more complicated task. It must:

- Avoid channels with radar (if present).
- Uniformly spread the channel bandwidth used by each AP and preferably spread the AP's primary 20 MHz channel too.
- Tend to avoid a channel that overlaps with other 20, 40, 80, 160, or 80+80 MHz APs nearby.
- Within an 80 MHz channel bandwidth (for example), decide whether to align primary 20 MHz channels with other APs or deliberately not to align primary channels. This is not a clear-cut choice:
  - If the primary channels are aligned, then virtual carrier sense works completely, yet all 20/40 MHz traffic (including broadcast, multicast, and data traffic to 802.11a/n devices) is sent in series. During these times, 40 or 60 MHz of bandwidth is unused. Still, if the clients are predominantly 802.11ac, then this is generally the best approach in terms of throughput and airtime fairness.
  - Conversely, if one AP's primary channel is assigned to the lower 40 MHz and another AP's channel is assigned to the upper 80 MHz, then 20/40 MHz traffic can be parallelized (as per Figure 5). If clients are predominantly 802.11a/802.11n, then this is the better choice. And when the whole 80 MHz is free, as measured by physical carrier sense and/or RTS/CTS with bandwidth indication, then 80 MHz communication between 802.11ac devices is still allowed.

Certainly it is difficult to get the most out of 802.11ac without coordination of AP channel assignment, typically under the aegis of an effective centralized RRM algorithm.

2.3.7 Rate at Range

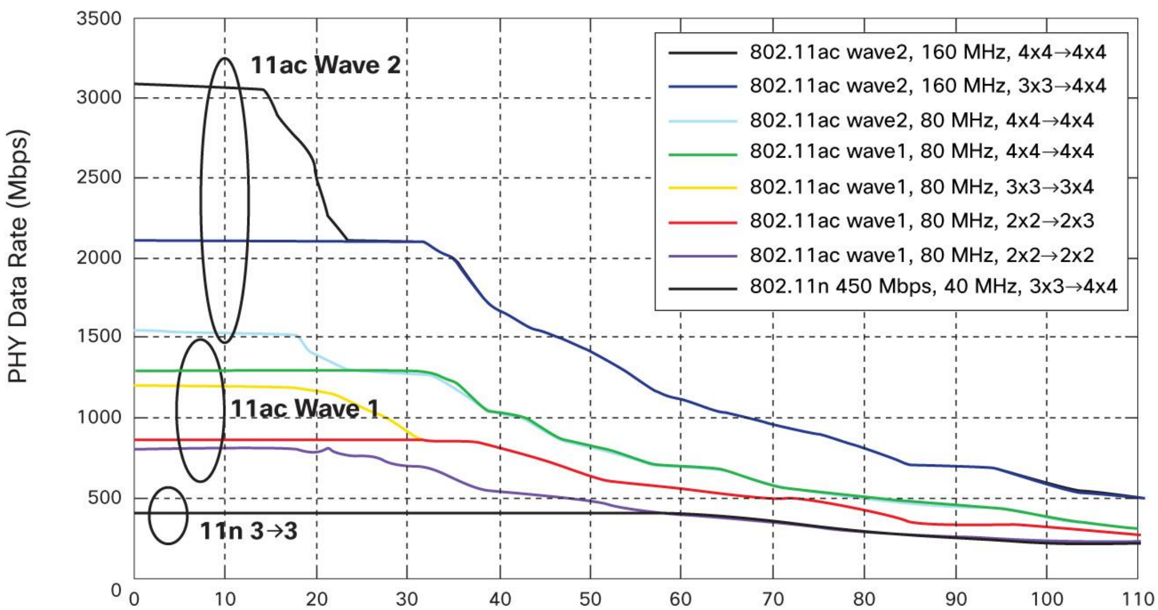
As well as offering higher speeds, 802.11ac also delivers greater robustness than 802.11a or 802.11n.

Consider that, to deliver 450 Mbps, 802.11n has to use 3 spatial streams maxed out at the sensitive 64QAM constellation, and with little multipath immunity: short guard interval and very little coding gain (a rate 5/6 code, so

20% allocated to redundancy). Yet, by going from 40 to 80 MHz, 802.11ac achieves 530 Mbps using only a long guard interval, 16QAM, and rate-3/4 coding (that is, 33% redundancy).

We see this improvement in Figure 7, where 80 MHz links offer higher data rates close in and farther out. In wave 1, different product configurations offer different benefits, but all are a marked step up from 802.11n. Meanwhile wave 2, and especially 160 MHz, offers still greater speeds. However, this improvement is not immediately useful, especially in the enterprise, due to the very limited number of 160 MHz channels that are available.

Figure 7. Simulation of Rate at Range for 802.11ac



2.3.8 Regulatory

Regulatory considerations and 802.11ac intersect in five respects:

- In some regulatory domains, new rules are needed for devices to transmit 80, 160, and/or 80+80 MHz waveforms at all:
  - Effective March 2012, >40 MHz operation is allowed in the United States, the European Union, Australia, New Zealand, Brazil, and South Africa, and no obstacle is expected in multiple other countries.
  - A few countries might only allow 80 MHz or 802.11ac operation after it is ratified by IEEE.
- In some regulatory domains, new tests are needed for devices that 160 and/or 80+80 MHz waveforms across adjacent subbands where the present rules allow this (for example, 5.15-5.25, 5.25, and 5.35 GHz).
- In some regulatory domains, new rules are needed to allow the transmission of waveforms across adjacent subbands where the rules presently don't allow this (for example, below and above 5.725 GHz, also known as channel 144).
- 802.11ac devices (and other unlicensed devices) suffer from reduced access to spectrum containing time domain weather radars in and around 5.6-5.65 GHz.
- Due to the wider bandwidth of 802.11ac, there are strong market desires to open up new spectrum, for instance, in the 5.35-5.47 GHz band (which enables two new 80 MHz channels and one new 160 MHz channel):

- See, for instance, U.S. Act of Congress HR 3630, which empowers the NTIA to study opening up this band to unlicensed use.

Due to the fact that regulations around the world are continually evolving, it is difficult to comment on this topic in detail in this white paper.

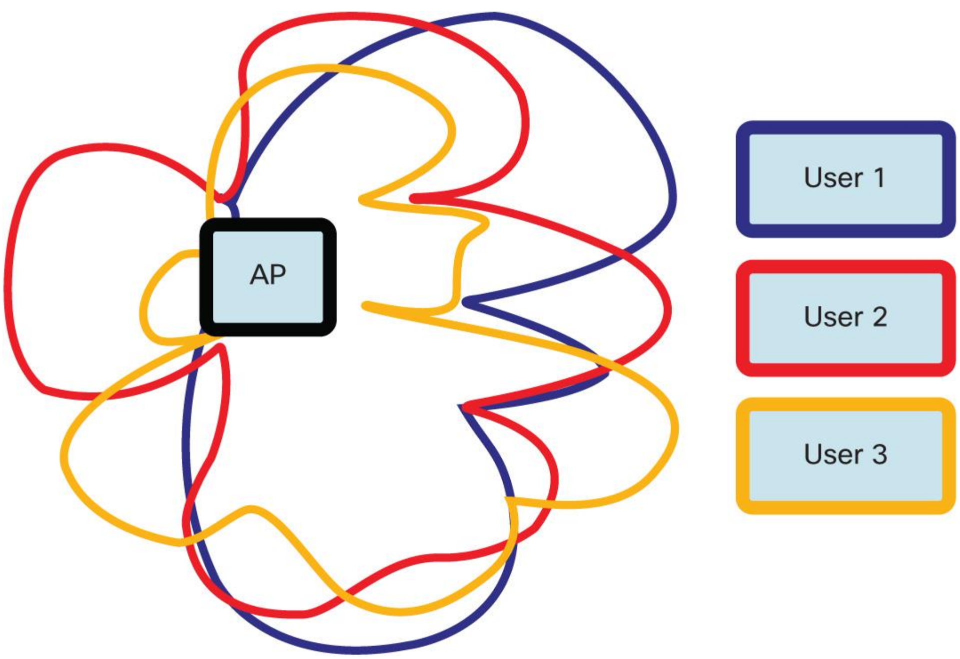
2.3.9 MU-MIMO

With 802.11n, a device can transmit multiple spatial streams at once, but only directed to a **single** address. For individually addressed frames, this means that only a single device (or user) gets data at a time. We call this single-user MIMO (SU-MIMO). With the advent of 802.11ac, a new technology is defined, called multi-user multiple input, multiple output (MU-MIMO). Here an AP is able to use its antenna resources to transmit multiple frames to different clients, all at the same time and over the same frequency spectrum. If 802.11n is like a hub, then 802.11ac can be thought of as a wireless switch (on the downlink).

However, MU-MIMO is a challenging technology to implement correctly and won't be available in the first wave of AP products. And even when available, MU-MIMO does come with caveats.

Figure 8 shows one piece of the puzzle. To send data to user 1, the AP forms a strong beam toward user 1, shown as the top-right lobe of the blue curve. At the same time the AP minimizes the energy for user 1 in the direction of user 2 and user 3. This is called "null steering" and is shown as the blue notches. And at the same time, the AP is also sending data to user 2 and forms a beam toward user 2 and forms notches toward users 1 and 3, as shown by the red curve. Then the yellow curve shows a similar beam toward user 3 and nulls toward users 1 and 2. In this way, each of users 1, 2, and 3 receives a strong copy of the desired data that is only slightly degraded by interference from data for the other users.

Figure 8. MU-MIMO Using Combination of Beamforming and Null Steering to Multiple Clients in Parallel



For all this to work properly, especially the deep nulls, the AP has to know the wireless channel from itself to all of the users very accurately. And since the channel changes over time, the AP has to keep measuring the channel, which adds overhead. Some APs might use the higher overhead 802.11ac sounding protocol only, but the greatest benefit of MU-MIMO comes if the AP can minimize the number of explicit sounding exchanges, such as with the ClientLink mechanisms.

Meanwhile, the client is receiving its desired signal distorted by some interference from the signals intended for other users. This interference makes the highest constellations such as 256QAM infeasible within an MU-MIMO transmission.

In summary, MU-MIMO allows an AP to deliver appreciably more data to its associated clients, especially for small form-factor clients (often BYOD clients) that are limited to a single antenna. If the AP is transmitting to two or three clients, the effective speed increase varies from a factor of unity[3] (no speed increase) up to a factor of two or three times, according to wireless channel conditions.

2.3.10 802.11ac Project Authorization Request

The 802.11ac project authorization request (PAR) that kicked off 802.11ac includes some throughput numbers: 500 Mbps single-user throughput and 1 Gbps multiuser throughput. These numbers are requirements on the 802.11ac **amendment** (that is, the document), not on individual products. The amendment defines that the minimum product allowed to call itself 802.11ac can operate at 290 Mbps single user and not support multiuser at all.

3. When Is 11ac Happening?

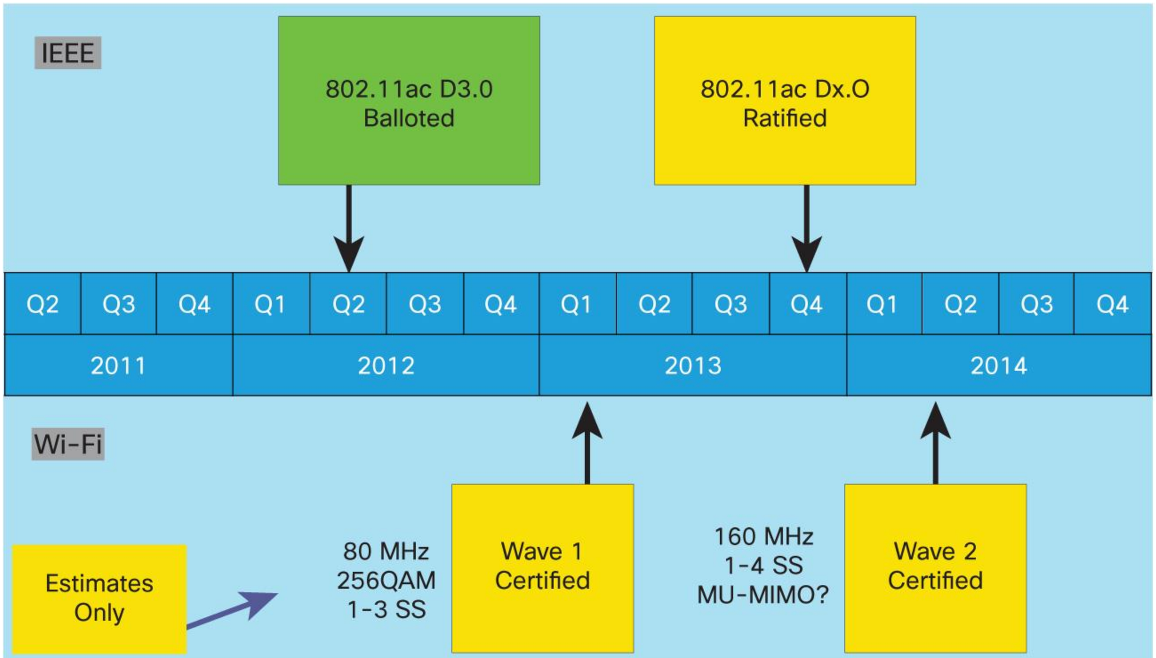
802.11ac is being aggressively standardized, as shown in Figure 9. A mature Draft 3.0 was completed in May 2012, at over 300 pages. It is estimated that the Wi-Fi Alliance will use this draft as the basis for an initial “wave 1” certification in early 2013. 802.11ac products might be released ahead of the certification date, but these are typically consumer-grade products targeting the back-to-school or Christmas markets and don’t come with Wi-Fi Alliance testing of interoperability. Enterprise customers are strongly advised to wait until products certified by the Wi-Fi Alliance become available.

IEEE will continue to refine the 802.11ac amendment based on a continuous improvement process driven by the industry experts. This process creates a sequence of drafts and culminates in the publication of the ratified version. This process is anticipated to complete by the end of 2013.

In parallel, the Wi-Fi Alliance is expected to develop a wave 2 certification that encompasses a wider range of 802.11ac features, such as four spatial streams, 160 MHz operation, and MU-MIMO. The launch date of this is likely to be loosely aligned with the ratification of IEEE 802.11ac, as shown in Figure 9.

[3] If the speed-up factor drops below unity, the AP uses SU-MIMO instead.

Figure 9. Timeline for 802.11ac Standardization and Certification



4. How Does 11ac Affect Me?

4.1 Compatibility

One effect **not** to worry about is compatibility.

802.11ac is carefully designed to be maximally forward and backward compatible with 802.11a/n devices. In fact, the 802.11ac design is even simpler and more thorough than 802.11n compatibility with 802.11a devices, as shown in Table 4.

An 802.11ac device must support all the mandatory modes of 802.11a and 802.11n. So an 802.11ac AP can communicate with 802.11a and 802.11n clients using 802.11a or 802.11n formatted packets. For this purpose it is as if the AP were an 802.11n AP. Similarly, an 802.11ac client can communicate with an 802.11a or 802.11n AP using 802.11a or 802.11n packets. Therefore, the emergence of 802.11ac clients will not cause issues with existing infrastructure.

Table 4. Compatibility and Coexistence of 802.11a, 802.11n, and 802.11ac Devices

Receiver Role	Transmitter Receiver	802.11a	802.11n	802.11ac
Intended recipient	802.11a	☑	☑ 802.11n device drops down to 802.11a PPDUs	☑ 802.11ac device drops down to 802.11a PPDUs
	802.11n	☑	☑	☑ 802.11n device drops down to 802.11n PPDUs
	802.11ac	☑	☑	☑

Receiver Role	Transmitter Receiver	802.11a	802.11n	802.11ac
Third-party recipient	802.11a	☑	☑ For transmitted HT_MM PPDUs, the third party waits for the packet length as indicated in the legacy portion of the preamble, then an extra EIFS (so no collisions) ☐ HT_GF PPDUs, preamble should only be transmitted if preceded by MAC protection (for example, RTS/CTS or CTS-to-self) sent using 802.11a format PPDUs (so no collisions)	☑ The third party waits for the packet length indicated in the legacy portion of the preamble, then an extra EIFS (so no collisions)
	802.11n	☑	☑	☑ The third party waits for the packet length indicated in the legacy portion of the preamble, then an extra EIFS (so no collisions)
	802.11ac	☑	☑	☑

Furthermore, the preamble of the 802.11ac formatted packet is identical to an 802.11a formatted packet, so the CCA mechanism kicks in for third-party both 802.11a and 802.11n devices. As soon as these third-party devices see the 802.11ac preamble, they know the duration of the packet and know not to transmit during that time. Also, since the packet is typically followed by an Ack or Block Ack frame sent in an 802.11a frame, the third-party devices can correctly receive the Ack or Block Ack and then can continue to try to transmit as usual. In the worst case, a third-party device hears the 802.11ac frame but is out of range of the transmitter of the Ack or Block Ack. But even here the third party must wait for an extended duration (called EIFS) to allow time for the Ack or Block Ack to be transmitted without fear of collision.

Because of this preamble-level compatibility, there is no need for 802.11ac devices to precede their 802.11ac transmissions by CTS-to-self or RTS/CTS. The kinds of inefficiencies associated with sending 802.11g packets in the presence of 802.11b devices are completely avoided at 5 GHz.

4.2 When to Upgrade to 802.11ac?

IT administrators are in the fortunate position to be able to pick between two great technologies: (1) 802.11n with A-MPDU, MIMO, beamforming, and speeds from 65 to 450 Mbps within 40 MHz, and (2) 802.11ac with A-MPDU, MIMO, beamforming, and speeds from 290 to 1300 Mbps within 80 MHz.

802.11n is available today and is sufficient for a lot of customer use cases.

802.11ac is the future of wireless LANs, but Wi-Fi-certified 802.11ac APs are not yet available. 802.11ac can provide full HD video at range to multiple users, higher client density, greater QoS, and higher power savings from getting on and off the network that much more quickly.

Most IT administrators deploy new APs at the same time as they fit out a building or retrofit a space. For these, we recommend installing 802.11n APs today, because of the sheer value of 802.11n. Further, for investment protection, it is most desirable to install modular APs that are readily field-upgradable to 802.11ac. As 802.11ac APs become available, these users should automatically start installing 802.11ac APs since the incremental value of 802.11ac exceeds any reasonable price differential.

Also, IT administrators typically upgrade their APs on a three-, four-, or five-year schedule. These IT administrators should continue to upgrade their APs on schedule, since the capability of today's APs significantly exceeds the capabilities of previous generations of APs. Until 802.11ac APs become available, we do recommend that modular 802.11n APs be installed, so as to provide an upgrade path to 802.11ac.

4.3 Radio Resource Management and WIPS Effects

802.11a/11n deployments not upgraded to 802.11ac still have to consider the effect of 802.11ac introduced by neighbors in the normal way and the additional exploits available to attackers.

802.11ac affects RRM since overlapped devices can now transmit over 80 or even 160 MHz. With a software upgrade, it is possible for existing RRM systems to detect the presence of 802.11ac APs from the new 802.11ac fields in beacon frames and extract the affected bandwidth. With this knowledge, the RRM system can mitigate the effect from nearby 802.11ac APs. The RRM system has to work harder since (1) a single overlapped 802.11ac AP affects a wider bandwidth, and (2) the effect on any 20 MHz subchannel depends on whether or not the primary 20 MHz subchannels of the in-network and overlapped APs are aligned (see section 2.3.6).

Users should verify that their APs are capable of using all the available channels, even those subject to radar detection (DFS) requirements. (Many consumer-grade and some enterprise-grade APs are not certified by regulators to operate on DFS channels. This is unfortunate since in the United States, for example, 63% of 20 MHz channels are DFS channels.)

In general, the wireless intrusion protection system of an 802.11a/11n deployment can detect and mitigate many attacks by 802.11ac devices, particularly when considering naïve attackers. This is because the 802.11ac device communicates using 802.11a/11n format packets when communicating with 802.11a/11n devices, and 802.11ac devices invariably continue to transmit beacons, probe requests, and probe responses at 802.11a rates. However, packets sent using 802.11ac format cannot be decoded by 802.11a/n devices. The recommended countermeasure against such attacks is to provide a sprinkling of 802.11ac APs operating full-time WIPS (for example, one 802.11ac WIPS AP for five or six serving 802.11a/n APs) or a full upgrade of all APs.

5. Summary

802.11ac is an exciting new step for wireless LANs that will be embraced by the industry starting late 2012 (consumer) and from early 2013 (enterprise). 802.11ac is an improved version of 802.11n offering higher speeds over wider bandwidths. 802.11ac is worth having when it is available, and especially when the client mix converges to being dominated by 802.11ac devices. In the meantime, 802.11n offers many of the same technologies, albeit at lower speeds, and is available today. IT administrators looking to invest in wireless LANs in the near term should strongly consider 802.11n APs that are field upgradable to 802.11ac.

Appendix: What Is 802.11n?

802.11n was a major advance over 802.11a. 802.11n introduced several major Medium Access Control (MAC) sublayer and Physical (PHY) layer advances, namely:

- **Multiple input, multiple output (MIMO)**. MIMO brings with it a host of benefits:
    - Greater speed without an increase in spectrum consumption using spatial multiplexing (SM). SM splits up the data into pieces and sends each piece along parallel “spatial” channels in a fraction of the time that it would take to send the same data serially. Without SM, 802.11n maxes out at 150 Mbps. With SM, 300 and 450 Mbps are available as long as both transmitter and receiver have at least two and three antennas (and RF chains), respectively.

- Greater uplink reliability. Due to multipath, an AP with four antennas receives four copies of a client's signal. Each copy is distorted (constructively or destructively) in four very different ways, so the likelihood that all copies are destructively faded all at the same time is very low. Thus the MIMO equalizer within the receiver can gather all these copies, cleverly combine them, and achieve greater reliability, delivering more predictable data rates and fewer retries. Of course an AP with fewer antennas can't do as well, particularly when the number of spatial streams climbs up toward the number of receive antennas.
- Greater downlink reliability (maybe). Here 802.11n offers beamforming (with outstanding benefits), space time block coding (useful benefits but inferior to beamforming), and cyclic delay diversity (with very modest benefits). Yet 802.11n offers many incompatible flavors of beamforming, each involving client assistance, and the industry has never put its weight behind any one of them. Thus beamforming is only practically available from techniques that don't expect assistance from the client such as Cisco ClientLink. Beamforming is particularly valuable due to the vulnerability of low-antenna count devices to destructive fading.

This is all described in much greater detail in a companion white paper.

- **Channel bonding**. By doubling the channel bandwidth from 20 to 40 MHz, a single transmission can carry twice as much data in the same time. Actually, the gain is slightly more than two times since the guard band between the two traditional 20 MHz channels can be used as well.
- **Aggregation**. If the PHY is the engine of a car that generates great power, the MAC is like the car transmission, which is responsible for efficiently delivering the power to the wheels.

  Before 802.11n, each 802.11a data frame comes with various overheads such as the preamble for the frame, often an acknowledgement frame, and any time gaps between and around these transmissions. When the data size gets smaller than this overhead, then speeding up the data payload doesn't increase the effective speed by that much. The MAC is throwing away the power.

Figure 10. Forms of Aggregation Introduced by 802.11n

802.11n addressed this concern using two aggregation techniques: the "intuitively" named A-MSDU and A-MPDU, which can also be combined together, as in "A-MPDU of A-MSDU." With aggregation, the data is packed together in a single unit that is sent with one preamble and acknowledged in one transmission. A-MSDU aggregates MSDUs (for example, LLC+IP+TCP+data) at the top of the MAC transmission path, so an individual MSDU in an A-MSDU lacks a MAC header/footer, such as a sequence number or frame check sequence. This is good for efficiency yet makes retries at the individual MSDU level impossible. Meanwhile, A-MPDU aggregates MPDUs at the bottom of the MAC, so each MPDU in an A-MDPU contains its own MAC header. Efficiency is not quite as good, especially for short MSDUs, but if a packet fails to get through the wireless link - for example, from a single isolated bit error - then the other MDPUs can still be received correctly, and only the erroneous packet needs to be retried. This is shown in Figure 10.

- **Channel access for 40 MHz**. Perhaps the fundamental reason for the success of 802.11 is that anyone can install an AP or use a client, regardless of what other 802.11 devices are already nearby, and mostly it all "just works."

  This comes from a MAC design goal that channel access be reasonably efficient and fair to all, regardless of number of devices, distance to AP, device capability, and so forth - put succinctly as "your packet is as important as my packet." We see the efficiency goal in the range of MAC techniques to reduce collisions, such as physical carrier sense (don't transmit if you hear a lot of energy) and virtual carrier sense (don't transmit while someone told you they'd be transmitting or receiving). We see the fairness goal in that each device is only permitted to transmit after meeting the same carrier sense and collision avoidance requirements.

  However, 40 MHz brings real challenges to both collision avoidance and fairness since it is either cost-prohibitive or impossible to maintain accurate physical carrier sense and virtual carrier sense on two 20 MHz subchannels in parallel. Instead a "primary" 20 MHz channel is defined with the usual tight requirements on carrier sense and collision avoidance, augmented by a degraded physical carrier sense on the "secondary" 20 MHz. When a device wants to transmit, it performs channel access in the usual way[4] - all on the **primary** 20 MHz subchannel. Also, immediately before the device can transmit a 40 MHz packet, the device inspects the physical carrier sense state of the secondary channel for a short duration to make sure that the secondary channel is clear too. If clear, the 20 MHz packet is sent; otherwise the device can either (1) transmit a 20 MHz packet on the primary 20 MHz channel or (2) back off again, then recheck if the full 40 MHz is clear. Remarkably, this simple scheme is reasonably fair, and option (1) is reasonably efficient.

  Still, in some topologies, devices on the secondary 20 MHz are treated unfairly with respect to the 40 MHz devices, and so 802.11n has additional channel selection rules to try to avoid this scenario in the first place. These rules work pretty well given the large number of 40 MHz channels available at 5 GHz.

802.11n was notorious in the standards community for its slow progress. There were three causes: (1) The process that 802.11n chose to select the winning proposal invited contention. (2) 802.11n was loved to near-death, in that many experts wanted to help and to contribute their technology. It took a long time to work through the contention by adopting many optional modes and then a long time to refine all the optional modes. (3) Operation of 802.11 systems at 2.4 GHz using 40 MHz channel widths in the proximity of 802.15 systems (such as Bluetooth) raised concerns among parts of the 802.15 community.

[4] That is, the device checks carrier sense and, if the channel is busy, waits until it is clear, randomly backs off a number of slots, and waits while it counts off those slots.

Americas Headquarters
Cisco Systems, Inc.
San Jose, CA

Asia Pacific Headquarters
Cisco Systems (USA) Pte. Ltd.
Singapore

Europe Headquarters
Cisco Systems International BV Amsterdam,
The Netherlands

Cisco has more than 200 offices worldwide. Addresses, phone numbers, and fax numbers are listed on the Cisco Website at **www.cisco.com/go/offices.**

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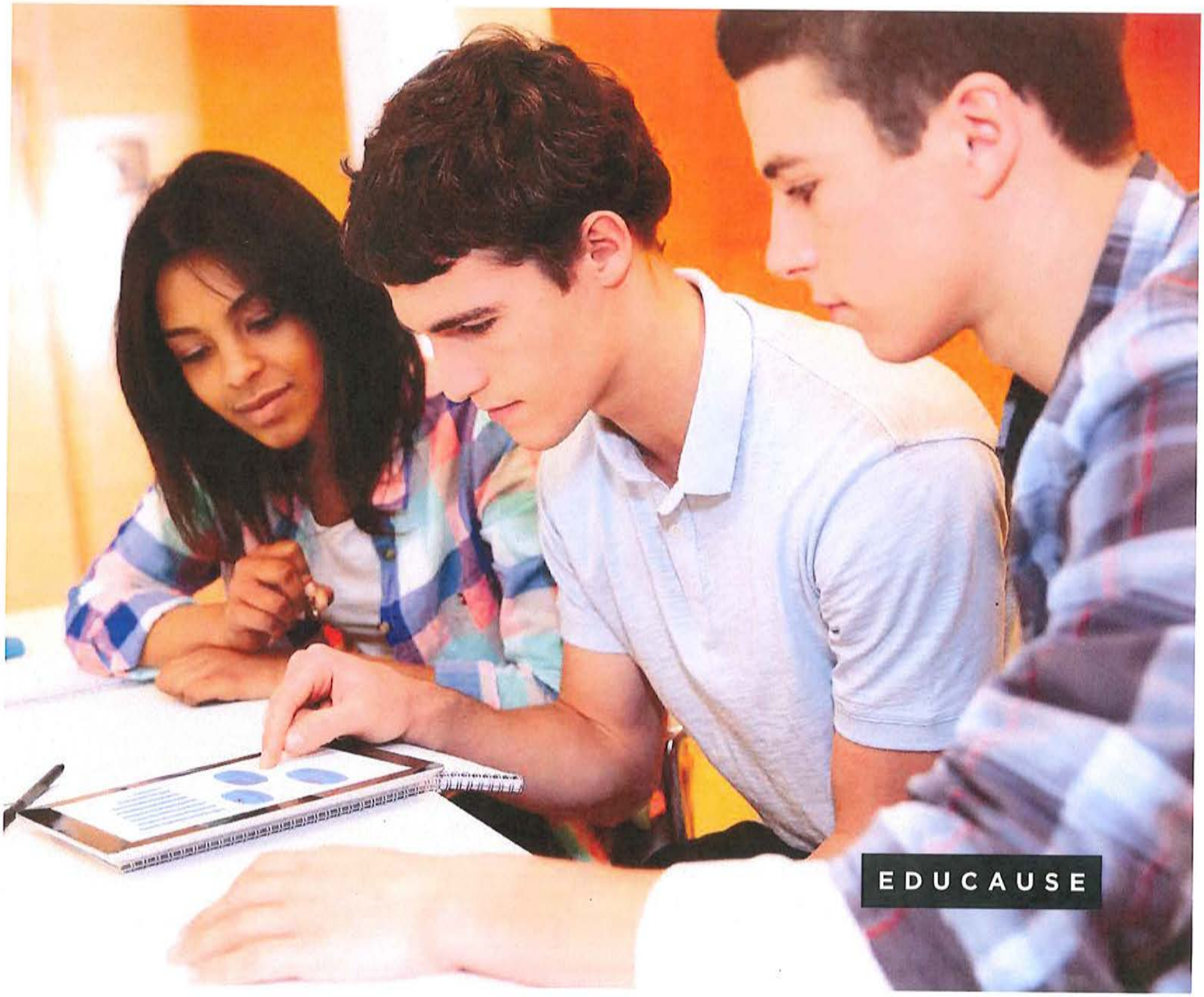
Appendix C

EDUCAUSE CENTER FOR ANALYSIS AND RESEARCH

ECAR Study of Undergraduate Students and Information Technology, 2013



EDUCAUSE

Contents

Authors

Eden Dahlstrom, EDUCAUSE Center for Analysis and Research

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Charles Dziuban, Director, Research Initiative for Teaching Effectiveness, University of Central Florida

Citation

Dahlstrom, Eden, J.D. Walker, and Charles Dziuban, with a foreword by Glenda Morgan. *ECAR Study of Undergraduate Students and Information Technology, 2013* (Research Report). Louisville, CO: EDUCAUSE Center for Analysis and Research, September 2013, available from http://www.educause.edu/ecar.

EDUCAUSE

EDUCAUSE is a nonprofit association and the foremost community of IT leaders and professionals committed to advancing higher education. EDUCAUSE programs and services are focused on analysis, advocacy, community building, professional development, and knowledge creation because IT plays a transformative role in higher education. EDUCAUSE supports those who lead, manage, and use information technology through a comprehensive range of resources and activities. For more information, visit http://www.educause.edu.

Foreword

Why do we study student technology choices and preferences? With the first student study launched in 2004 we had an instinctive sense of why the exercise was valuable. Several campuses had been collecting data on student technology use—some of them for quite a while—but this included little broad and generalizable data about how students in higher education were adapting to and using technology. There was speculation but little real data-driven insight. The first ECAR student study brought a larger perspective to what technologies students were using and to what they were thinking about and doing with respect to technology.

But at the time I am not sure that we fully understood just how valuable the product and the process that we created would become. The value has both grown and become more evident over time. The body of longitudinal data that we have built and the insight it brings us about trends reflect the rate at which technology has changed over the past decade. In 2004 there was no YouTube or easily accessible video, mobile devices had made little impact, *blended learning* was a relatively new term, the consumerization of technology had not really taken hold, and MOOCs (massive open online courses) and digital badges were yet to be encountered.

One feature common to all of these technology changes is the way they empower the individual user. This makes it imperative that we have the kind of data that the ECAR study gathers and with the large and varied sample that it is able to muster. If technology is personalized and if students are bringing their own devices and using consumer-grade tools, then we need to know what they use and to what ends. We need to think through some of the implications of this usage for faculty, administrators, and technology support staff.

While changes in technology over the decade chronicled by the ECAR student study have been profound, there is an amazing sturdiness to student attitudes and preferences about technology and in its corresponding patterns of use. From the beginning students saw promise and utility in technology (though perhaps less direct relevance to their academic success than we might like), but clearly they had some reservations about it and some clear boundaries for its use. Reviewing 10 years of the study shows how students are generally slow to adapt to new technologies and practices, especially where it relates to their academics. There is an apparent disconnect between the technology students have and use and the practical application of these technologies "in the classroom." Doing more to facilitate use of technology in creative and meaningful ways—ways that encourage and support the use of technology for academics—is something that each of us has a certain level of responsibility for to improve students' technology experiences.

Glenda Morgan, University of Illinois at Urbana-Champaign

Executive Summary

Since 2004, ECAR has partnered with higher education institutions to investigate the technologies that matter most to students by exploring technology ownership, use patterns, and perceptions of technology among undergraduate students. In 2013, the ECAR technology survey was sent to approximately 1.6 million students at 251 college/university sites, yielding 113,035 respondents across 13 countries. This year's findings are organized into four main themes to help educators and higher education institutions better understand students' current experiences:

- Students' relationship with technology is complex—they recognize its value but still need guidance when it comes to better using it for academics.
- Students prefer blended learning environments while beginning to experiment with MOOCs.
- Students are ready to use their mobile devices more for academics, and they look to institutions and instructors for opportunities and encouragement to do so.
- Students value their privacy, and using technology to connect with them has its limits.

These themes not only inform us about undergraduate students' opinions concerning technology, but they can also provide insight about the technology needs and expectations of tomorrow.

Summary of Findings

Students' relationship with technology is complex. They recognize its value but still need guidance when it comes to better using it for academics. The affinity of undergraduates for multimedia, mobile devices, and multitasking is well documented. What is less well recognized is the circumspect way in which students think about integrating technology into their academic lives, a characteristic of college students that has persisted for many years. Educational technology need not be flashy in order for them to value it (e.g., the course management system [CMS], asynchronous discussions, and online course content), and even the most dedicated technophiles want to know how the latest innovation will help them in their classes and in their undergraduate experience generally.

- Students value the ways in which technology helps them achieve their academic goals and prepares them for their future academic and workplace activities.
- Students are generally confident in their preparedness to use technology for coursework, but those who are interested in more technical training favor "in class" guidance over separate training options.
- Basic technology resources, such as the institution's website and the CMS, are the most pervasive and most valued.

- Freely available course content/open educational resources, e-books, simulations and education games, and e-portfolios are still in the experimental stages for most students.

Students prefer blended learning environments while beginning to experiment with MOOCs. When it comes to modality, college students seem to recognize effectiveness when they see it. Their preference for blended learning environments tracks well with the findings of recent large meta-analyses of the efficacy of different ways of integrating technology into higher education (e.g., the analysis by Barbara Means et al., 2010[1]). And students' long-standing desire to retain some degree of face-to-face contact with their professors persists, even with the increasing sophistication of online methods of interaction. Even for people who have never known a world without the Internet, the human touch is valuable.

- Although not fully mainstream, blended learning persists as the preferred modality.
- More students are taking online-only courses; however, few undergraduates have taken a MOOC.
- Few students say they'd use a digital badge (common in MOOC credentialing) in their application portfolio for an employment interview.

Students are ready to use their mobile devices more for academics, and they look to institutions and instructors for opportunities and encouragement to do so. Students and faculty gain sophistication with technology each year, and each year there is greater expectation for technology to be used as a teaching and learning tool. Students look to their instructors and their institutions for guidance about how to best use the technology they own to enhance their college/university experience, not only from an academic standpoint but also from an experiential standpoint. Finding how to best incorporate technology into the academic environment will require a partnership involving students, their instructors, and the institution. Mobile devices present a conundrum in this regard, because in the classroom, they can easily and indistinguishably be used for both class-related and extracurricular activities.

- Students hold high expectations for anytime, anywhere access to course materials and for leveraging the use of their personal digital devices inside and outside class.
- Undergraduates own two to three Internet-capable devices, and ownership of smartphones and tablets jumped the most (among all devices) from 2012 to 2013.
- Laptops are still cited as the most used and most important device for academics, but more students are beginning to use smartphones and tablets for academic purposes.
- In-class use of smartphones and tablets is not yet common; students say they are often prevented or discouraged from using these devices while in class.
- Mobile-device access to institutionally provided services, applications, and websites is up, though performance ratings are waning a bit compared with 2012.

Students value their privacy, and using technology to connect with them has its limits. The nature and degree of undergraduates' expectations of privacy is the subject of some debate. What is beyond doubt is that students are extremely sensitive to the boundaries between their personal and their academic lives. Even when safeguards are promised, students resist the integration into education of technologies that they perceive to be primarily personal, clearly indicating that because some technology is used widely by students does not mean that it should be leveraged for academic use.

- Technology makes the connected age possible, but using technology to help students *feel* more engaged in their classes (or campus life) and connected with others on campus can be challenging.
- Students prefer to keep their social and academic lives separate, and they maintain those boundaries in their use of technology.
- Students are only moderately interested in early-alert learner analytics and guidance about course offerings.
- Students prefer face-to-face interactions, e-mail, and the CMS as ways to communicate more with their instructors.

The Connected Age

For higher education, the "connected age" describes the technology-assisted hyperconnectivity of learners, faculty, and institutions to those around them.

Appendix D

WWU CAPITAL IMPROVEMENTS, INTERMEDIATE- CAMPUS WIRELESS UPGRADES

This is an Opinion of Probable Cost

DATE:	March 12, 2014
A/ E:	**RMC Architects**
ESTIMATE:	Conceptual Estimate
BY:	Matthew M. Woolsey, The Wool-Zee Company, Inc.
SPECIFICS:	**Improve & Increase Wireless Coverage**
LOCATION:	**Campus**

ITEM #	TITLE		TOTAL
1	A/S/C WORK (5% OF ELECTRICAL)		$110,000
2	ELECTRICAL		$2,177,500
3	MECHANICAL		$0
	PROJECT TOTAL Bare Costs		**$2,287,500**
	Estimate Contingency	10%	$228,750
	PROJECT SUBTOTAL		**$2,516,250**
	General Requirements	10%	$251,625
	PROJECT SUBTOTAL		**$2,767,875**
	GC Overhead & Profit	8%	$221,430
	PROJECT TOTAL		**$2,989,305**

Exclusions and Assumptions:

1 Estimate Does NOT Include State/Local Taxes

WWU Capital Project Request Budget Estimates

This is an Opinion of Probable Cost

DATE:	12-Mar-14
A/ E:	**RMC Architects**
BY:	K Engineers, Inc.
SPECIFICS:	**Intermediate Capital Project Project Estimates**

Item #	Description	Quantity	Units	UNIT & EXTEND COST Unit Cost	 Extended	TOTALS
	Campus Wireless Upgrade					
1	Access Point Devices	**1,100**	EA	1,100.00	**$1,210,000**	**$1,210,000**
2	Access Points Installation	**1,100**	EA	175.00	**$192,500**	**$192,500**
3	Access Point Licenses	**500**	EA	10.00	**$5,000**	**$5,000**
4	CAT6 wiring (installed)	**1,100**	EA	450.00	**$495,000**	**$495,000**
5	Network Switch ports	**1,100**	EA	250.00	**$275,000**	**$275,000**
	SUBTOTAL (Electrical contractor)					**$2,177,500**

Commentary:
Campus has 400 existing radios existing which would remain.
Reported that existing radios provide approximately 20% of adequate coverage
University has 1500 licenses for up to 1500 devices. An additional 500 licenses are included.
Based on Cisco 3702 AP's
Existing management software is adequate

Appendix E

K ENGINEERS, INC. 208 Third Street, Lynden, WA 98264
ELECTRICAL ENGINEERING Tel (360) 354-4757 Fax (360) 354-6794

July 10, 2014

Western Washington University
Facilities Development and Capital Budget
Bellingham, WA

Mr. Ed Simpson

Re: Campus Wireless Upgrade Study

Introduction:

The purpose of this study is to provide an engineering analysis and report regarding the implementation of a comprehensive wireless network upgrade for the academic buildings at Western Washington University campus.

Existing Conditions:

There are 43 existing academic buildings on and off campus that are considered in this study. The buildings are a variety of ages, sizes and building construction and are used in a variety of ways, including office space, classrooms, labs, utility space, common areas, food service, gymnasiums, etc.

Existing wireless coverage across campus is inadequate to serve the current desired usage by the occupants of the buildings. WWU Telecom department reports that there are approximately 400 existing radios across campus and these radios cover approximately 20% of the building areas. Wireless handheld devices are becoming ubiquitous and therefore wireless networking is critically important for the current and future needs of the occupants of the buildings across campus.

Calculation Methodology:

In order to achieve full wireless network coverage across campus, access points will need to be added. The current standard access point device that is used by WWU Telecom is a Cisco AIR-3702 radio, which is a dual radio, controller based system. The radios are powered by Power over Ethernet technology and receive power from the switches in the telecom room.

In determining the quantity of radios that will be required for full campus coverage, one must determine the amount of building area that each access point can adequately cover. Access points are limited spatially (distance from the access point) and, more importantly, by quantity of users. When the quantity of users on an access point increases, the speed of throughput decreases. Therefore, in higher density areas of buildings (classrooms, labs, common areas, etc) there will need to be higher quantity of access points. In lower density areas of buildings (offices, gyms, utility spaces, etc.) the quantity of access points can be less. Each access point should not serve more than 20-30 users concurrently, according to the manufacturer's recommendations.

In the schedule below, each of the buildings was approximately evaluated based on the type of occupancy and assigned an approximate square footage that could reasonably be covered by a single access point. It was assumed that, on average, a building will have an actual occupancy of approximately one person per 50 square feet.

This method was used to estimate the total quantity of access points that would be needed for full coverage, however a complete site survey of each building will be necessary during the design phase of work to determine the actual quantity and location of devices that will be required. This estimate indicates that approximately 1400 total access points will be required, however, it would be prudent to allow for an additional 100 devices to accommodate site variances that are found during design.

Therefore, the total quantity of 1,500 access points, less the existing 400 access points gives a total of 1,100 new access points will be required.

ACCESS POINT QUANTITY CALCULATION

PER SQUARE FOOT METHOD

Building Common Name	Building Code	Gross Square Footage	Coverage Area Per Access Point	Quantity of Access Points
ART ANNEX	AA	15,586	1200	13
ADMINISTRATIVE SERVICES BUILDING	AC	30,035	1200	25
ARNTZEN HALL	AH	98,337	1400	70
ACADEMIC INSTRUCTION CENTER	AI	130,649	1600	82
ALUMNI HOUSE	AL	2,623	1500	2
BIOLOGY GREENHOUSE	BG	2,092	1500	1
BOND HALL	BH	91,168	1400	65
BIOLOGY BUILDING	BI	81,120	1800	45
CANADA HOUSE	CA	5,866	1600	4

CHEMISTRY BUILDING	CB	77,226	1800	43
COMMUNICATIONS FACILITY	CF	131,365	1400	94
COLLEGE HALL	CH	32,917	1600	21
COMMISSARY	CM	37,121	2000	19
CAMPUS SERVICES FACILITY	CS	34,698	1600	22
CARVER GYMNASIUM	CV	110,700	2400	46
EDENS HALL	EH	63,662	1600	40
ENVIRONMENTAL STUDIES CENTER	ES	111,145	1200	93
ROSS ENGINEERING TECHNOLOGY	ET	77,592	1800	43
FAIRHAVEN COLLEGE	FA	51,529	1600	32
FINE ARTS BUILDING	FI	59,300	1800	33
FRASER HALL (LECTURE HALLS)	FR	13,562	1200	11
HAGGARD HALL	HH	107,971	1800	60
HIGH STREET HALL	HS	9,918	2000	5
HUMANITIES	HU	33,342	1600	21
	L1		1500	2
	LW		1500	5
SHANNON POINT MARINE LAB	MC	12,845	1400	9
SHANNON POINT MARINE EDUCATION	ME	11,978	1800	7
MILLER HALL	MH	133,117	1800	74
MARSHALLING YARD	MY	4,940	2000	2
OLD MAIN	OM	145,474	1600	91
PERFORMING ARTS CENTER	PA	128,649	2000	64
PARKS HALL	PH	56,109	1400	40
PHYSICAL PLANT	PP	24,164	2500	10
SHANNON POINT COMMONS BUILDING	SC	2,600	1400	2
SMATE HALL	SL	40,144	1200	33
SHANNON POINT MODULAR	SM	3,656	1500	2
STEAM PLANT	SP	13,071	2500	5
STUDENT RECREATION CENTER	SV	98,300	2500	39
VIKING UNION	VU	65,342	1400	47
WILSON LIBRARY	WL	141,243	2000	71
Total		**2,291,156**	**1646**	**1392**

Cost Estimate:

The following cost estimate includes new access point devices, access point licenses, and the required wiring infrastructure to those devices. (Note that the University owns access point licenses currently and that only 500 additional licenses would be required) It also includes new PoE networks switches in the telecom rooms in order to serve the access points. Installation and configuration of the system by a vendor is included.

Campus network core systems will also need to be upgraded with new wireless controllers in order to manage the new access points.

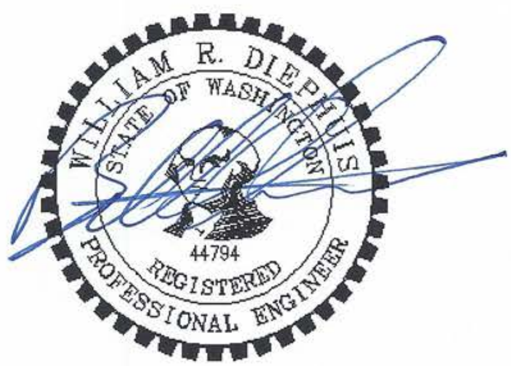
K ENGINEERS, INC.
ELECTRICAL ENGINEERING
208 Third Street, Lynden, WA 98264
Tel (360) 354-4757 Fax (360) 354-6794

COST ESTIMATE - CAMPUS WIRELESS NETWORK UPGRADE

Description	Qty	Unit	Cost	Total
Access Point Devices	1,100	EA	875.00	$962,500
Access Points Installation	1,100	EA	225.00	$247,500
Access Point Licenses	500	EA	10.00	$5,000
CAT6 wiring (installed)	1,100	EA	500.00	$550,000
Access Switches	77	EA	2,500.00	$192,500
Wireless Controllers	4	EA	30,000.00	$120,000
System Integration	1	LS	100,000.00	$100,000
TOTAL				$2,177,500

Notes:
Costs are intended to be contractor pricing only.
A&E fees and soft costs not included.
WWST not included.
No escalation is included

Sincerely,



Bill Diephuis, P.E., RCDD
K Engineers, Inc.

WA STATE CISCO CONTRACT
T06-MST-642

WSCA CISCO CONTRACT
T10-MST-325

WSCA NETAPP CONTRACT
A11-MST-487

CAMPUS WIRELESS

Western Washington University

July 22, 2014

Request for Information

Post Falls, Idaho
971 South Clearwater Loop
Post Falls, ID 83854
T (208) 777-4709
F (208) 777-4708

Boise, Idaho
950 W Bannock • Suite 1153
Boise, ID 83702
T (208) 501-0030
F (208) 777-4708

Bellevue, Washington
3025 112th Ave NE • Suite 120
Bellevue, WA 98004
T (425) 691-3700
F (425) 691-3696

Corvallis, Oregon
1445 NW 11th Street
Corvallis, OR 97330
T (888) 809-4609
F (208) 777-4708

Table of Contents

Summary

WLAN Site Surveys (100% Onsite)*	$114,075
Network Switches	$932,682
Wireless Product	$2,459,690
Cabling and WAP Install	$750,000
Services	$95,000
Total	**$4,351,446**

*100% Software Option is also available for $24,764.
Hybrid options can be achieved by changing % of Software vs. On-Site surveys

WLAN Site Surveys

We provide 2 site survey options: **On-Site** and **Software:**

On-Site Project Summary: Ednetics will visit the WWU campus to conduct the survey. The purpose of the survey will be to produce a wireless network design, including equipment bill of materials and Wireless Access Point (WAP) install location maps. The survey process will product a report for each building that will indicate any conclusions reached during the process as well as anticipated radio frequency (RF) 'heat-maps' for wireless coverage.

Software Project Summary: Ednetics perform a simulated wireless network survey using survey software, customer provided maps and building information. The purpose of the survey is to determine required quantity of Wireless Access Points (WAPs), their approximate mounting locations and the anticipated coverage patterns they will provide. Ednetics will use our own expertise working with wireless in schools and the building maps to choose WAP locations. The software will then produce approximate coverage areas for each WAP, creating a radio frequency (RF) 'heat map'. This is an iterative process until the desired coverage and density are achieved.

Building	WAPs	Cost Estimate: On-Site	Cost Estimate: Software
ACADEMIC INSTRUCTION CENTER -East	68	$5,100.00	$1,088.00
ACADEMIC INSTRUCTION CENTER -West	29	$2,175.00	$464.00
ADMINISTRATIVE SERVICES BUILDING	26	$1,950.00	$416.00
ALUMNI HOUSE	3	$500.00	$150.00
ARNTZEN HALL	77	$5,775.00	$1,232.00
ART ANNEX	12	$900.00	$192.00
BIOLOGY BUILDING	55	$4,125.00	$880.00
BIOLOGY GREENHOUSE	2	$500.00	$150.00
BOND HALL	69	$5,175.00	$1,104.00
BOOKSTORE	11	$825.00	$176.00
CAMPUS SERVICES FACILITY	16	$1,200.00	$256.00
CANADA HOUSE	6	$500.00	$150.00
CARVER GYMNASIUM	52	$3,900.00	$832.00
CHEMISTRY BUILDING	49	$3,675.00	$784.00
COLLEGE HALL	29	$2,175.00	$464.00
COMMISSARY	17	$1,275.00	$272.00
COMMUNICATIONS FACILITY	85	$6,375.00	$1,360.00
ENVIRONMENTAL STUDIES CENTER	80	$6,000.00	$1,280.00
FAIRHAVEN COLLEGE	24	$1,800.00	$384.00
FINE ARTS BUILDING	28	$2,100.00	$448.00
FRASER HALL (LECTURE HALLS)	12	$900.00	$192.00
HAGGARD HALL	62	$4,650.00	$992.00
HIGH STREET HALL	11	$825.00	$176.00
HUMANITIES	28	$2,100.00	$448.00
LAKEWOOD STUDENT CENTER	5	$500.00	$150.00
MAINTENANCE WAREHOUSE	6	$500.00	$150.00
MARSHALLING YARD	4	$500.00	$150.00
MILLER HALL	74	$5,550.00	$1,184.00
OLD MAIN	87	$6,525.00	$1,392.00
PARKS HALL	67	$5,025.00	$1,072.00
PERFORMING ARTS CENTER	81	$6,075.00	$1,296.00
PHYSICAL PLANT	18	$1,350.00	$288.00
ROSS ENGINEERING TECHNOLOGY	56	$4,200.00	$896.00
SHANNON POINT COMMONS BUILDING	3	$500.00	$150.00
SHANNON POINT MARINE EDUCATION	6	$500.00	$150.00
SHANNON POINT MARINE LAB	17	$1,275.00	$272.00
SHANNON POINT MODULAR	4	$500.00	$150.00
SMATE HALL	29	$2,175.00	$464.00
STEAM PLANT	7	$525.00	$150.00
STUDENT RECREATION CENTER	36	$2,700.00	$576.00
VIKING COMMONS	21	$1,575.00	$336.00
VIKING UNION	51	$3,825.00	$816.00
WILSON LIBRARY	77	$5,775.00	$1,232.00
Total		**$114,075.00**	**$24,764.00**

Network Switches

Building_MDF

WS-C4503E-S7L+48V+	4503-E Chassis One WS-X4648-RJ45V+E Sup7L-E LAN Base	77	$	7,150.00	$	550,550.00
PWR-C45-1300ACV	Catalyst 4500 1300W AC PS (Data and PoE)	77	$	646.75	$	49,799.75
PWR-C45-1300ACV/2	Catalyst 4500 1300W AC PS (Data and PoE)	77	$	646.75	$	49,799.75
WS-X4648-RJ45V+E	Catalyst 4500 E-Series 48-Port 10/100/1000 (RJ45)	77	$	3,571.75	$	275,024.75
SFP-H10GB-CU1M=	Cisco Cisco SFP+ Copper Twinax Cable 1M	77	$	97.50	$	7,507.50
SFP-H10GB-CU5M=	Cisco Cisco SFP+ Copper Twinax Cable 5M	0	$	169.00	$	-
SFP-10G-LRM=	10GBASE-LRM SFP+ Module	0	$	841.75	$	-
			Subtotal		**$**	**932,681.75**

Building_IDF1

WS-C4503E-S7L+48V+	4503-E Chassis One WS-X4648-RJ45V+E Sup7L-E LAN Base	0	$	7,150.00	$	-
PWR-C45-1300ACV	Catalyst 4500 1300W AC PS (Data and PoE)	0	$	646.75	$	-
PWR-C45-1300ACV/2	Catalyst 4500 1300W AC PS (Data and PoE)	0	$	646.75	$	-
WS-X4648-RJ45V+E	Catalyst 4500 E-Series 48-Port 10/100/1000 (RJ45)	0	$	3,571.75	$	-
SFP-H10GB-CU1M=	Cisco Cisco SFP+ Copper Twinax Cable 1M	0	$	97.50	$	-
SFP-H10GB-CU5M=	Cisco Cisco SFP+ Copper Twinax Cable 5M	0	$	169.00	$	-
SFP-10G-LRM=	10GBASE-LRM SFP+ Module	0	$	841.75	$	-
			Subtotal		**$**	**-**

Building_IDF2

WS-C4503E-S7L+48V+	4503-E Chassis One WS-X4648-RJ45V+E Sup7L-E LAN Base	0	$	7,150.00	$	-
PWR-C45-1300ACV	Catalyst 4500 1300W AC PS (Data and PoE)	0	$	646.75	$	-
PWR-C45-1300ACV/2	Catalyst 4500 1300W AC PS (Data and PoE)	0	$	646.75	$	-
WS-X4648-RJ45V+E	Catalyst 4500 E-Series 48-Port 10/100/1000 (RJ45)	0	$	3,571.75	$	-
SFP-H10GB-CU1M=	Cisco Cisco SFP+ Copper Twinax Cable 1M	0	$	97.50	$	-
SFP-H10GB-CU5M=	Cisco Cisco SFP+ Copper Twinax Cable 5M	0	$	169.00	$	-
SFP-10G-LRM=	10GBASE-LRM SFP+ Module	0	$	841.75	$	-
			Subtotal		**$**	**-**

Total Network Switches	**$**	**932,681.75**

Confirm and update parts, closet details, quantities…..

Wireless Product

Access Points

AIR-CAP3702I-AK910	Cisco Aironet 802.11AC 4X4:3SS - 10 Pack	150	$	9,717.50	$	1,457,625.00
AIR-CAP3702I-A-K9	Cisco Aironet 802.11AC 4X4:3SS	6	$	971.75	$	5,830.50
AIR-CAP2602I-A-K9	Cisco Aironet 802.11N 3X3:3SS	0	$	711.75	$	-
AIR-CAP1602I-A-K9	Cisco Aironet 802.11N 3X3:2SS	0	$	451.75	$	-
			Subtotal		**$**	**1,463,455.50**

Contoller

AIR-CT5760-1K-K9	Cisco 5760 WLAN Controller w/1000 WAP Licenses	1	$	130,000.00	$	130,000.00
CON-SNT-CT57601K	SMARTNET 8X5XNBD Cisco 5700 1K - 12 months	5	$	19,500.00	$	97,500.00
AIR-CT5760-500-K9	Cisco 5760 WLAN Controller w/500 WAP Licenses	1	$	78,000.00	$	78,000.00
CON-SNT-CT576500	SMARTNET 8X5XNBD Cisco 5700 500 - 12 months	5	$	11,700.00	$	58,500.00
AIR-CT5760-HA-K9	Cisco 5700 Series Wireless Controller - high availability	1	$	78,000.00	$	78,000.00
CON-SNT-CT5760HA	SMARTNET 8X5XNBD Cisco 5700 HA - 12 months	5	$	1,950.00	$	9,750.00
PWR-C1-350WAC/2	350WAC Power Supply Bay 2	3	$	325.00	$	975.00
AIR-CT5760-RK-MNT	5760 Wireless Controller Rack mount kit	3	$	61.75	$	185.25
SFP-10G-SR=	10GBASE-SR SFP Module	0	$	646.75	$	-
SFP-10G-LR=	10GBASE-LR SFP Module	0	$	2,596.75	$	-
SFP-H10GB-CU5M=	Cisco Cisco SFP+ Copper Twinax Cable	0	$	169.00	$	-
			Subtotal		**$**	**452,910.25**

Prime Infrastructure Management

L-PI12-LF-1K	Cisco Prime Infrastructure Lifecycle 1000 Device	1	$	44,850.00	$	44,850.00
UCSS-UPIL-1-1K	Prime Infra Lifecycle 1K PASS-1yr UCSS	5	$	4,485.00	$	22,425.00
CON-ESW-PI2XLF1K	ESSENTIAL SW PI 2.x - Lifecycle - 1K Device Lic - 1yr	5	$	6,727.50	$	33,637.50
L-PI2X-AS-25	Prime Infrastructure 2.x - Assurance - 25 Device Lic	1	$	1,946.75	$	1,946.75
UCSS-UPIA-1-25	Prime Infra Assurance 25 PASS-1yr	5	$	195.00	$	975.00
CON-ESW-PI2XAS25	ESSENTIAL SW PI 2.x - Assurance - 25 Device Lic - 1yr	5	$	291.75	$	1,458.75
UCSC-C220-for PI	Prime Infra Server Hardware with Vmware	1	$	22,100.00	$	22,100.00
CON-SNT	Smartnet for PI server and Vmware - 1yr	5	$	900.00	$	4,500.00
			Subtotal		**$**	**131,893.00**

Mobility Services Engine

L-AD-LS-100AP	100 AP CMX License (Advanced Location Services)	5	$	11,046.75	$	55,233.75
L-AD-LS-1000AP	1000 AP CMX License (Advanced Location Services)	1	$	97,496.75	$	97,496.75
L-WIPS-ELM-1000AP	1000 AP WIPS Enhanced Local Mode licenses	1	$	51,996.75	$	51,996.75
L-WIPS-ELM-100AP	100 AP WIPS Enhanced Local Mode licenses	5	$	5,846.75	$	29,233.75
AIR-MSE-3355-K9	MSE 3355 Hardware SKU	3	$	14,296.75	$	42,890.25
CON-SNT-MSE3355	SMARTNET 8X5XNBD MSE 3355 Hardware SKU - 1yr	15	$	3,478.50	$	52,177.50
			Subtotal		**$**	**329,028.75**

Identity Services Engine

SNS-3495-M-ISE-K9	SNS 3495 Migration Server: Loaded with ISE Software	2	$	12,343.50	$	24,687.00
L-ISE-BSE-10K=	Cisco Identity Services Engine 10000 EndPoint Base Lic	2	$	16,250.00	$	32,500.00
CON-SNT-SNS3495	SMARTNET 8X5XNBD Large Secure Server	10	$	2,521.50	$	25,215.00
			Subtotal		**$**	**82,402.00**

Total Wireless	**$**	**2,459,689.50**

Confirm and update parts, closet details, quantities…..

Cabling and Installation of WAPs

Per the request we will provide installation of CAT 6 CMR cabling and mounting of wireless access points.

- We will supply and install materials to support an open pathway, such as J-hooks and hangers where possible.
- Costs for EMT conduit, cable tray, core drills, network equipment (switches and WAPs) are excluded.
- We will terminate data cables within MDF/IDF location as specified to new 24/48prt Cat6 patch panels as needed.
- We will terminate data cables at workstation with Cat6 RJ45 insert.
- We will install and mount wireless access points (including WAP patch cable).
- Create final documentation upon completion of project.

Building	WAPs	Cabling Cost/Building
ACADEMIC INSTRUCTION CENTER -East	68	$34,000.00
ACADEMIC INSTRUCTION CENTER -West	29	$14,500.00
ADMINISTRATIVE SERVICES BUILDING	26	$13,000.00
ALUMNI HOUSE	3	$1,500.00
ARNTZEN HALL	77	$38,500.00
ART ANNEX	12	$6,000.00
BIOLOGY BUILDING	55	$27,500.00
BIOLOGY GREENHOUSE	2	$1,000.00
BOND HALL	69	$34,500.00
BOOKSTORE	11	$5,500.00
CAMPUS SERVICES FACILITY	16	$8,000.00
CANADA HOUSE	6	$3,000.00
CARVER GYMNASIUM	52	$26,000.00
CHEMISTRY BUILDING	49	$24,500.00
COLLEGE HALL	29	$14,500.00
COMMISSARY	17	$8,500.00
COMMUNICATIONS FACILITY	85	$42,500.00
ENVIRONMENTAL STUDIES CENTER	80	$40,000.00
FAIRHAVEN COLLEGE	24	$12,000.00
FINE ARTS BUILDING	28	$14,000.00
FRASER HALL (LECTURE HALLS)	12	$6,000.00
HAGGARD HALL	62	$31,000.00
HIGH STREET HALL	11	$5,500.00
HUMANITIES	28	$14,000.00
LAKEWOOD STUDENT CENTER	5	$2,500.00
MAINTENANCE WAREHOUSE	6	$3,000.00
MARSHALLING YARD	4	$2,000.00
MILLER HALL	74	$37,000.00
OLD MAIN	87	$43,500.00
PARKS HALL	67	$33,500.00
PERFORMING ARTS CENTER	81	$40,500.00
PHYSICAL PLANT	18	$9,000.00
ROSS ENGINEERING TECHNOLOGY	56	$28,000.00
SHANNON POINT COMMONS BUILDING	3	$1,500.00
SHANNON POINT MARINE EDUCATION	6	$3,000.00
SHANNON POINT MARINE LAB	17	$8,500.00
SHANNON POINT MODULAR	4	$2,000.00
SMATE HALL	29	$14,500.00
STEAM PLANT	7	$3,500.00
STUDENT RECREATION CENTER	36	$18,000.00
VIKING COMMONS	21	$10,500.00
VIKING UNION	51	$25,500.00
WILSON LIBRARY	77	$38,500.00
Total		**$750,000.00**

Services

Wireless Network Implementation - Please see scope of work	$	95,000.00
Subtotal	**$**	**95,000.00**
Total	**$**	**95,000.00**

Scope of Services

WWU Wireless Network Scope of Services

Wireless Network Deployment Scope of Services:

Ednetics will work with WWU to deploy a Cisco wireless network solution. This project will consist of staging, configuration and deployment of Wireless Access Points to designated locations throughout WWU. Ednetics will configure SSIDs for client connections. The exact SSIDs and methods of authentication will need to be discussed and finalized. This will also include the deployment of a Cisco Mobility Services Engine (MSE) for live and historical tracking of client location data, Cisco Prime Infrastructure (CPI) for management, and Cisco Identity Services Engine (ISE) for 802.1x services.

WWU Responsibilities:

- Provide any necessary electrical facilities (power outlets etc.)
- Ensure that there is adequate rack space for new equipment
- Network equipment programming; switch, switchport, router, firewall (Ednetics can consult)
- Provide environmental cooling for new equipment
- Provide compatible hardware and software (VMware) for a virtual machine for Mobility services Engine (MSE).
- Complete Ednetics provided customer templates
- Provide Ednetics with configuration templates for all project equipment
- Provide Ednetics with timely access to all network closets included in the project
- Provide any required closet side patch cords (copper and fiber)
- Ednetics requests that WWU provide a fully functional IPSEC VPN for remote access to network equipment to remain in place while the project or any subsequent support contracts are in effect.

Ednetics Responsibilities:

- Install Wireless LAN Controllers (WLCs) / WiSM
- Work with WWU to create a plan for any new SSIDs and methods of authentication
- Receive all project relate equipment at our facility for staging as specified
- Create an asset sheet for the equipment involved in the installation
- Label all equipment with Ednetics or WWU labeling standards
- Affix any WWU provided asset tags, scan to asset sheet
- Associate customer SMARTnet contracts to Ednetics' and WWU' profile
- Download the latest recommended IOS files for all project related equipment
- Documentation, testing, training and support:
    - Provide asset sheet
    - Work with WWU to test access and connectivity to project SSIDs
    - Provide on-site training as required; up to two (2) hours of administrative training on operation of Wireless LAN Controllers
    - Provide thirty (30) days of up and running technical support for configurations performed during the project. Manufacturer warranties are provided as part of this response for ongoing support.

Cisco Prime Infrastructure Scope of Services:

Ednetics will install a new CPI appliance. Ednetics will transfer WWU preconfigured data such as templates, building maps and WAP locations to the new CPI server. Ednetics will import all WAPs and controllers, rename and configure maps and WAP placement.

Anticipated WWU Responsibilities:

- Provide any necessary electrical facilities (power outlets etc.)
- Ensure that there is adequate rack space for new equipment
- Network equipment programming; switch, switchport, router, firewall (Ednetics can consult)
- Provide environmental cooling for new equipment
- Complete Ednetics provided customer templates
- Provide Ednetics with configuration templates for all project equipment
- Provide Ednetics with timely access to all network closets included in the project
- Provide any required closet side patch cords (copper and fiber)
- Ednetics requests that WWU provide a fully functional IPSEC VPN for remote access to network equipment to remain in place while the project or any subsequent support contracts are in effect.

Anticipated Ednetics Responsibilities:

- Associate customer CPI SMARTnet contracts to Ednetics' and WWU profile
- License and register the CPI server software
- Obtain the latest CPI software and updates.
- Rack and connect the CPI appliance
- Install the new CPI appliance (licensing, service activation, and networking parameters)
- Program CPI server including, passwords, networking device entries, and user accounts.
- Import preconfigured existing CPI templates into the new CPI system
- Import wireless controllers and WAPs, rename, import maps, place WAPs, push templates
- Documentation, testing, Training and Support:
  - Provide asset sheet
  - Compare the post-upgrade dashboard to the pre-upgrade dashboard
  - Confirm that reporting is operating properly
  - Provide on-site training as required; up to two (2) hours of administrative training on operation of Cisco Prime Infrastructure
  - Provide thirty (30) days of up and running technical support for configurations performed during the project. Manufacturer warranties are provided as part of this response for ongoing support.

ISE Basic Licensing Scope of Services:

Ednetics will configure the ISE server to integrate with existing Active Directory and act as a RADIUS server for 802.1x authentications via AD machine groups, AD user security groups or MAC. Multiple options exist for authentication of users or machines per SSID depending on intended function. Ednetics would like to consult with WWU to determine desired SSIDs, functions and network access levels by VLAN and ACL. Ednetics will also configure ISE as a RADIUS server for management authentication to network switching. For wired authentications is assumed that Ednetics would assist with the design and initial system configurations in a limited test deployment, with WWU to scale-out if functions are adopted.

Anticipated WWU Responsibilities:

- Provide any necessary electrical facilities (power outlets etc.)
- Ensure that there is adequate rack space for new equipment
- Network equipment programming; switch, switchport, router, firewall (Ednetics can consult)
- Provide environmental cooling for new equipment
- Any necessary client-side configurations, changes or upgrades
- Deployment of any necessary switch configuration changes for 802.1x
- Mobile Device Management (MDM) deployments, changes, etc.
- Any necessary Active Directory configurations, changes or updates
- Creation and management of any MAC lists or databases used in the deployment
- Provide any necessary hardware and software for configuration backups

Anticipated Ednetics Responsibilities:

- Rack, install and connect the ISE appliance
- Obtain any recommended software updates
- Work with Customer Technical Staff to determine post install testing procedures
- Integrate Cisco Identity Services Engine to Active Directory or LDAP server
- Create 802.1x authentication policies for wireless clients to authenticate using AD machine group, security groups or MAC
- Configure RADIUS authentication for management of network switching
- Documentation, testing, Training and Support:
    - Provide documentation including asset sheet and verification of configuration backup.
    - Provide on-site training as required; up to two (2) hours of administrative training on operation of Cisco Identity Services Engine
    - Provide thirty (30) days of up and running technical support for configurations performed during the project. Manufacturer warranties are provided as part of this response for ongoing support.

Appendix F

Western Washington University
Institutional Master Plan

An Addendum to the Western Washington University Neighborhood Plan

Adopted by the City of Bellingham, September 24, 2001
Ordinance #2001-09-068

Approved by WWU Board of Trustees, October 5, 2001

WESTERN
WASHINGTON UNIVERSITY

Parking and Transportation, Visitors Information Center, Alumni House, and High Street Hall.

- Steam is distributed primarily in the tunnel system with some radial feeds in utilidors.
- The Steam Plant has capacity for expected growth.
- The condensate system in many areas is at the end of its expected life and should be replaced within 20 years. (Condensate is the hot water return system for the steam.)
- The anticipated growth may require increasing steam pressure in the existing lines to meet future needs.
- Increasing pressure would increase maintenance requirements and may require changing condensate piping, insulation, and pressure reducing valve settings.
- It is recommended that buildings south of the Academic Zone District not be served with steam due to the decrease in efficiency levels.

Telecommunications

- The University is in the process of completing its Integrated Signal Distribution System (ISDS). This system is a fiber optic backbone for transporting information.
- The ISDS lines are fiber optic cables and carry data communications, fire and life safety communications, building controls and automation communication, and television.
- The telecommunication systems are run through campus in the tunnel system or ductbanks to all buildings.
- The telephone system (voice communications) runs on copper cable to a main switch in Bond Hall. Private companies currently provide public switched network access and long-distance carrier services.

- A satellite communication system is also located at the Physical Plant and connects to the ISDS system.
- The campus has an emergency telephone system throughout campus. The emergency phones use cell technology and connect to University Police.
- There is a need for cellular telephone and communication technology to serve the campus and neighbors.