CISCO VALIDATED DESIGN

Campus LAN and Wireless LAN Design Guide

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Campus Design Introduction

There is a tendency to discount the network as just simple plumbing, to think that all you have to consider is the size and the length of the pipes or the speeds and feeds of the links, and to dismiss the rest as unimportant. Just as the plumbing in a large stadium or high rise has to be designed for scale, purpose, redundancy, protection from tampering or denial of operation, and the capacity to handle peak loads, the network requires similar consideration. As users depend on the network to access the majority of the information they need to do their jobs and to transport their voice or video with reliability, the network must be able to provide resilient, intelligent transport. The reliable network design also needs to incorporate versatility in order to address the changing needs of an organization.

Here are some key concepts that you should address when creating a reliable and versatile network design. The network should be:

- **Self-healing**—Continuously on and available.
- **Self-defending**—Protecting the organization and its users.
- **Self-optimizing**—Adapting to changing needs, beyond the limits of basic standards.
- **Self-aware**—Driving change through insight into network activity.

As you look at a network design, consider the networking trends and future needs of an organization.

- The network must be ready to appropriately scale over time in order to meet the demands of the organization it is supporting.
- Because demands on wireless access points (APs) with the latest 802.11ac Wave 2 technology exceed 1 Gbps, and the IEEE has ratified the 802.3bz standard that defines 2.5 Gbps and 5 Gbps Ethernet, you should deploy a network that is ready to support the demand without requiring an upgrade of the existing copper Ethernet wiring plant. You accommodate these latest demands by deploying network platforms including Cisco® Catalyst Multigigabit technology.
- As you deploy new devices with higher power requirements, such as lighting, surveillance cameras, virtual desktop terminals, remote access switches, and APs, your design should have the ability to support power over Ethernet with 60W per port, offered with Cisco Universal Power Over Ethernet, and the access layer should also provide PoE perpetual power during switch upgrade and reboot events. The Cisco Catalyst 9000 Series access layer switches are perpetual PoE-capable and ready for 100W per port, as that technology becomes available.
- Compliance issues drive a choice of platforms required when you support standards certifications and MACsec. For those cases, you should also be prepared to make analytic data available, using technologies such as NetFlow.
- The Internet of Things and Internet of Everything impacts today's network design. Your network should support TrustSec and other segmentation and virtualization technologies in order to enable the scale and expanded uses and policies for the network driven by these trends.
- Bandwidth needs are doubling potentially multiple times over the lifetime of a network so that the network deployed today needs to be prepared to aggregate using 10 Gbps Ethernet to 40 Gbps to 100 Gbps capacities over time.
- The network platforms deployed today should offer the best longevity into the future, versus selecting the equipment that only meets the limits of today's needs.

- To reduce operational complexity, you can use a centralized controller with open APIs, allowing for very fast, lower-risk deployment of network devices and services through UI and existing orchestration systems—Cisco DNA Center automates this network device configuration and management to achieve your organization's intent.

Cisco Digital Network Architecture (DNA) provides a roadmap to digitization and a path to realize immediate benefits of network automation, assurance, and security. The *campus* local area network (LAN) is the network that supports devices people use within a location to connect to information. The use of the word *campus* does not imply any particular geographic size—the campus LAN can range in size from a single switch at a small remote site up to a large multi-building infrastructure, supporting classrooms, carpeted office space, and similar places where people use their devices for their daily activities. The campus design incorporates both wired LAN and wireless LAN connectivity for a complete network access solution. This guide explains:

- The design of the campus wired LAN foundation.
- How the WLAN extends secure network access for your mobile workforce.
- How the WLAN can provide guest access for contractors and visitors to your facilities.

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Campus LAN and Wireless LAN Design Guidance

Designing a LAN for the campus use case is not a one-design-fits-all proposition. The scale of campus LAN can be as simple as a single switch and wireless AP at a small remote site or a large, distributed, multi-building complex with high-density wired port and wireless requirements. The deployment may require very high availability for the services offered by the network, with a low tolerance for risk, or there may be tolerance for fix-on-failure approach with extended service outages for a limited number of users considered acceptable. Platform choices for these deployments are often driven by needs for network capacity, the device and network capabilities offered, and also the need to meet any compliance requirements that are important to the organization.

You impose most of the campus wired LAN design complexity when aggregating groups of access switches by interconnecting the access layers to the distribution layers. If devices connecting to the access layer have a requirement to communicate with a Layer 2 logical adjacency and those connections cover multiple physical wiring closets connected to a distribution layer, then it is possible to adapt the traditional multilayer campus design to address the Layer 2 adjacency needs. However, the traditional designs drive more complex configurations with additional protocols that must be kept consistent across multiple devices.

To improve the design, there are preferred alternatives that make the deployment easier to manage and less prone to mistakes, while enhancing overall network performance. Such alternatives include the simplified distribution layer option using either a switch stack or a virtual switching system (VSS) or a StackWise Virtual system, which makes deployment and troubleshooting much easier for support staff.

A design alternative is available for organizations that either don't have the need to extend Layer 2 connectivity across an access-to-aggregation boundary or have other means of implementing this functionality, such as when using Campus Fabric technology—an integral part of Cisco Software-Defined Access (SD-Access). The alternative is to extend Layer 3 connectivity to the access layer. The implementation of a well-designed Layer 3 access network ensures consistent, configuration, performance, scalability, and high availability of the network versus the traditional multilayer campus design.

The motivation for the recommended design choices is not that they are the only options available but that the recommendations highlight preferred choices given the scope of the requirements. Even though the traditional multilayer campus design previously mentioned is a widely deployed, valid design choice, the design is not one that is typically recommended in light of better alternatives that are currently available.

When you integrate the wireless components of the campus design with the wired components, the design can often be treated as an overlay that is dependent upon the services provided by the underlying campus infrastructure. This is especially evident for larger networks, because increasing capacity with dedicated devices becomes a requirement. Smaller networks, such as those at small remote sites, offer opportunities for simplification and optimization that are also reflected in the design choices shown below.

The primary design options are grouped by scale, and then appropriate selections are based on the capabilities desired. The selection from the spectrum of capabilities is based on the needs of a specific deployment.

As you go through the design guidance, you should keep the following capabilities in mind when considering which of the previously mentioned categories are most important for your network deployment.

Self-healing

To keep your network continuously on and available, pay attention to the high availability concepts for both a resilient wired switching infrastructure and also for the wireless infrastructure that integrates with it. Resiliency is not only based on the component redundancy and how interconnections are made in the modular campus design but also what capabilities can enhance that physical resiliency.

For example, can you detect and react to RF interference and mitigate its impact in your wireless access network? Can equipment be removed from the network and connectivity for people to information be maintained without interruption?

Resiliency is enhanced by avoiding network impacts to begin with, as described with the next set of capabilities.

Self-defending

To protect the organization and its users from disruptions to their productivity, avoiding the disruptions before they begin is the surest way to keep network services available. There are a range of capabilities to help with this task. For the wired infrastructure, the basic set of Catalyst Infrastructure Security Features include many capabilities to keep intentional and unintentional disruptions from impacting the network, which can be augmented all the way to using enhanced policies through TrustSec segmentation. The wireless network can also defend itself through the implementation of rogue device detection, among other features.

Basic defense mechanisms should be a part of all networks, with the extent of the capabilities chosen based on deployment needs. Once the network can defend itself appropriately, the next step is to optimize itself, as described with the next group of capabilities.

Self-optimizing

To adapt to changing needs, beyond the limits of just the basic published standards, is a key requirement for more advanced networks. Basic standards don’t address a specific organization’s intent for how devices should behave on their network. Mobile phones may have personal uses, but need to have priority access to a limited shared RF resource for the applications that are important to a function of an organization. When choosing from the spectrum of capabilities available, networks with mission critical capabilities can be created that are able to address these needs.

Self-aware

To drive change through insight into network activity, the best networks can report insight into traffic that they transport and how it relates to an organization’s mission. Application visibility from both wired and wireless devices using NetFlow, Network Based Application Recognition (NBAR) and other capabilities, can give insight into how users interact with applications and other users on the network. Besides just reporting information, capabilities such as wireless hyperlocation and analytics enable organizations to provide location-specific services to the users. So in essence the network can provide information for how the users are using the network while at the same time provide or advertise services based on a user’s access to the network.

The capabilities highlighted in these categories are a small sample of the capabilities that are increasingly available as you make your design choices across the spectrum from the foundation to the mission-critical design options, as shown below, for each campus network within the appropriate topology sizing choice.

HIGH-DENSITY LARGE CAMPUS DESIGN

The high-density large campus design has multiple distribution layers connected to a core layer and dense demands in the access layer for wired ports and WLAN devices. The preferred design has capacity for supporting over 15,000 wired and wireless users and devices, is highly available for critical business continuity, and has the capabilities to support advanced features such as NetFlow and network virtualization and segmentation. You may select this design for cases where densities may not be as high as supported; however, the requirements dictate needs for critical business continuity or advanced capabilities.

Campus Core

If there are three or more interconnected distributions or requirements for connectivity at a common location, you use a Layer 3 LAN core in order to simplify the connectivity and management. You use one of the two core options in order to meet the core needs in the high-density large campus design. The flagship platforms for these options:

- **Cisco Nexus 7700 Series**—Family members in the Cisco Nexus Series have a variety of density options and can be segmented into virtual device contexts, allowing the same devices to be used for a campus core and a data center core. When there are requirements for core switches to be independently managed with the ability to have virtual PortChannels between the switches, or a need for high-density 10/40/100 Gigabit Ethernet, these switches are the preferred option.

- **Catalyst 6800 Series with Supervisor 6T**—Family members in the Catalyst Series accommodate a variety of core densities, covering the features commonly used in a campus core. Optionally, you can merge the devices into a VSS mode, with options for redundant supervisors in each member switch offering a highly available configuration, managed as a single device.

Campus Wired Distribution, Wired Access, and Wireless

In the high-density large campus, you make choices for the wired distribution and access based on the most highly available platforms for the role, the highest density and widest selection of interface options, redundant power and modular control plane, with the most advanced software feature capabilities.

In the high density large campus design, centralized wireless is the preferred option, using APs with 802.11ac Wave 2 and CleanAir capabilities.

Table 1 High-density large campus suggested deployment platforms

	Enterprise Class–base foundation network capabilities	Advanced–foundation plus additional network capabilities	Mission Critical–Best in class network capabilities
Core switches	Cisco Nexus 7700 Series with Supervisor 2E or Cisco Catalyst 6807-XL modular chassis pair with Supervisor 6T Option for VSS Quad Supervisor stateful switchover configuration	Cisco Nexus 7700 Series with Supervisor 2E or Cisco Catalyst 6807-XL modular chassis pair with Supervisor 6T Option for VSS Quad Supervisor stateful switchover configuration	Cisco Nexus 7700 Series with Supervisor 2E or Cisco Catalyst 6807-XL modular chassis pair with Supervisor 6T Option for VSS Quad Supervisor stateful switchover configuration
Distribution/aggregation switches	Cisco Catalyst 9500-24Q with StackWise Virtual	Cisco Catalyst 9500-24Q with StackWise Virtual or Cisco Catalyst 6880-X and 6840-X extensible fixed chassis pair VSS configuration	Cisco Catalyst 9500-24Q with StackWise Virtual or Cisco Catalyst 6807-XL modular chassis pair with Supervisor 6T VSS Quad Supervisor stateful switchover configuration
Access switches	Cisco 2960-X and 2960-XR Series with stack modules	Cisco Catalyst 9300 Series stackable switches	Cisco Catalyst 9300 Series stackable switches or Cisco Catalyst 9400 Series
WLAN controller	Centralized Cisco 8500 Series (AireOS) in HA SSO mode	Centralized Cisco 8500 Series (AireOS) in HA SSO mode	Centralized Cisco 8500 Series (AireOS) in HA SSO mode
APs	Cisco 1850 Series	Cisco 2800 Series	Cisco 3800 Series
Key capabilities–wired	1 Gigabit Ethernet access, PoE+	1/10/40 Gigabit Ethernet services, MACsec, TrustSec MPLS, NetFlow, UPOE	Highest availability 1/10/40/100 Gigabit Ethernet services, MACsec, TrustSec MPLS, NetFlow, UPOE
Key capabilities–wireless	2 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80MHz, Transmit Beamforming	5 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80/160MHz, HDX, CleanAir, ClientLink 4.0 + Transmit Beamforming, VideoStream	5 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80/160MHz, mGig+GE, HDX, CleanAir, ClientLink 4.0 + Transmit Beamforming, VideoStream

MEDIUM-DENSITY CAMPUS DESIGN

The medium-density campus design is a single distribution layer, which can be standalone or used as a collapsed core connected to another distribution, or other services, or perhaps connected to WAN router at a remote site that has grown large enough to need an aggregation layer. The demands in the access layer for wired ports and WLAN devices typically number in the hundreds versus the thousands for a large design, with requirements for less than a few groups of 50 or fewer APs. The preferred design strives for typical business continuity needs not requiring every redundant component offered and standard network capabilities.

Campus Wired Distribution, Wired Access, and Wireless

You make choices for the wired distribution and access with a bias towards size and flexibility in order to accommodate the space and power requirements of medium sized installations in a way that can elastically expand as an organization grows. Where densities and advanced software feature capabilities are not as strong of a requirement, options with a more economical and common sparing preference are shown.

The medium-density designs are equivalent to the small-site campus design with the addition of a distribution layer.

Table 2 Medium campus suggested deployment platforms

	Enterprise Class–base foundation network capabilities	Advanced–foundation plus additional network capabilities	Mission Critical–Best in class network capabilities
Distribution/ aggregation switches	Cisco Catalyst 9500-24Q with StackWise Virtual or Cisco Catalyst 3850-X stackable switches	Cisco Catalyst 9500-24Q with StackWise Virtual or Cisco Catalyst 6880-X extensible fixed chassis pair VSS configuration	Cisco Catalyst 9500-24Q with StackWise Virtual configuration
Access switches	Cisco 2960-X and 2960-XR Series with stack modules	Cisco Catalyst 9300 Series stackable switches	Cisco Catalyst 9300 Series stackable switches
Wireless controller	FlexConnect with Cisco 8500/5500 Series remote controller in HA SSO mode or Cisco 3500 Series local controller in HA SSO mode	Cisco 5500/3500 Series local controller in HA SSO mode	Cisco 8500 Series local controller in HA SSO mode
APs	Cisco 1850 Series	Cisco 2800 Series	Cisco 3800 Series
Key capabilities–wired	1/10 Gigabit Ethernet services, MACsec, TrustSec NetFlow	1/10 Gigabit Ethernet services, MACsec, TrustSec NetFlow, UPOE	1/10/40 Gigabit Ethernet services, MACsec, TrustSec, NetFlow, UPOE
Key capabilities–wireless	2 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80MHz, Transmit Beamforming	5 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80/160MHz, HDX, CleanAir, ClientLink 4.0 + Transmit Beamforming, VideoStream	5 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80/160MHz, mGig+GE, HDX, CleanAir, ClientLink 4.0 + Transmit Beamforming, VideoStream

SMALL-SITE CAMPUS DESIGN

The small-site campus design is a single access switch or single access switch stack. The demands in the access layer for wired ports and WLAN devices typically number in the dozens (versus the hundreds in the medium design), with requirements for less than 25 APs. The preferred design strives to minimize cost with minimal numbers of components and features offered, though advanced and mission critical options are available choices for networks that require these capabilities.

Campus Wired Access and Wireless Access

In the small-site campus design, you make choices for the wired access with a bias towards size and flexibility in order to accommodate the space and power requirements of small sites. Densities and advanced software feature capabilities are not as strong of a requirement, so options with the most economical preference are shown.

Table 3 Small campus suggested deployment platforms

	Enterprise Class–base foundation network capabilities	Advanced–foundation plus additional network capabilities	Mission Critical–Best in class network capabilities
Access switches	Cisco 2960-X and 2960-XR Series with stack modules	Cisco Catalyst 9300 Series stackable switches	Cisco Catalyst 9300 Series stackable switches
Wireless controller	FlexConnect with Cisco 8500/5500 Series remote controller in HA SSO mode or Cisco 3500 Series local controller in HA SSO mode	Cisco 5500/3500 Series local controller in HA SSO mode	Cisco 5500/3500 Series local controller in HA SSO mode
APs	Cisco 1850 Series	Cisco 2800 Series	Cisco 3800 Series
Key capabilities–wired	Gigabit Ethernet access	1 Gigabit Ethernet services, MACsec, TrustSec NetFlow, PoE+	Gigabit Ethernet services, MACsec, TrustSec NetFlow, UPOE
Key capabilities–wireless	2 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80MHz, Transmit Beamforming	5 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80/160MHz, HDX, CleanAir, ClientLink 4.0 + Transmit Beamforming, VideoStream	5 Gbps Combined Data, 802.11ac Wave 2, 4x4 MU-MIMO:3SS, 20/40/80/160MHz, mGig+GE, HDX, CleanAir, ClientLink 4.0 + Transmit Beamforming, VideoStream

Campus Wired LAN Design Fundamentals

The LAN is the networking infrastructure that provides access to network communication services and resources for end users and devices spread over a single floor or building. You create a campus network by interconnecting a group of LANs that are spread over a small geographic area. Campus network design concepts are inclusive small networks that use a single LAN switch, up to very large networks with thousands of connections.

The campus wired LAN enables communications between devices in a building or group of buildings, as well as interconnection to the WAN and Internet edge at the network core.

Specifically, this design provides a network foundation and services that enable:

- Tiered LAN connectivity.
- Wired network access for employees.
- IP Multicast for efficient data distribution.
- Wired infrastructure ready for multimedia services.

HIERARCHICAL DESIGN MODEL

The campus wired LAN uses a hierarchical design model to break the design up into modular groups or layers. Breaking the design up into layers allows each layer to implement specific functions, which simplifies the network design and therefore the deployment and management of the network.

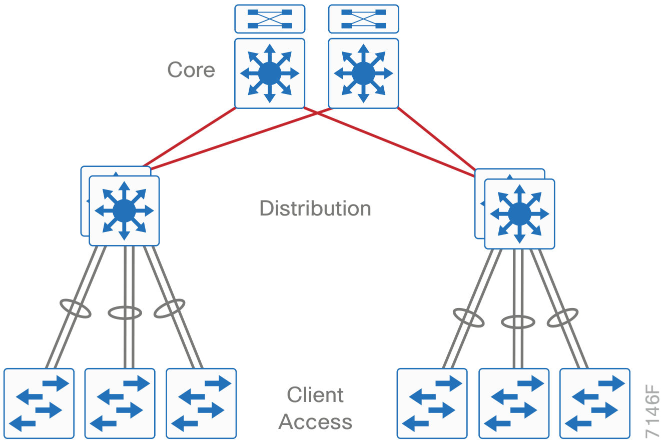
Modularity in network design allows you to create design elements that can be replicated throughout the network. Replication provides an easy way to scale the network as well as a consistent deployment method.

In flat or meshed network architectures, changes tend to affect a large number of systems. Hierarchical design helps constrain operational changes to a subset of the network, which makes it easy to manage as well as improve resiliency. Modular structuring of the network into small, easy-to-understand elements also facilitates resiliency via improved fault isolation.

A hierarchical LAN design includes the following three layers:

- **Access layer**—Provides endpoints and users direct access to the network
- **Distribution layer**—Aggregates access layers and provides connectivity to services
- **Core layer**—Provides connectivity between distribution layers for large LAN environments

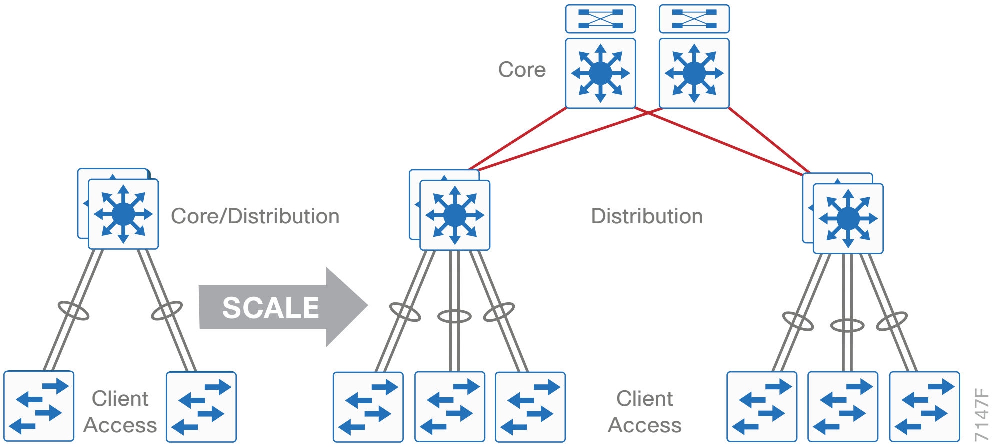
Figure 1 *LAN hierarchical design*



Each layer—access, distribution, and core—provides different functionality and capability to the network. Depending on the characteristics of the deployment site, you might need one, two, or all three of the layers. For example, a site that occupies a single building might only require the access and distribution layers, while a campus of multiple buildings will most likely require all three layers.

Regardless of how many layers are implemented at a location, the modularity of this design ensures that each layer will provide the same services, and in this architecture, will use the same design methods.

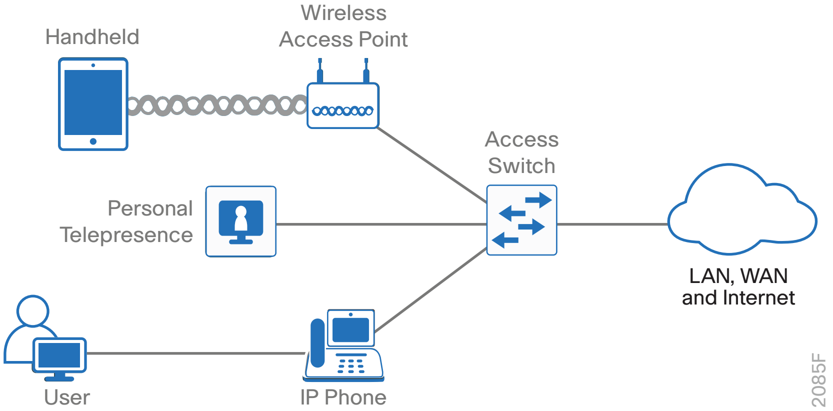
Figure 2 *Scalability by using a modular design*



ACCESS LAYER

The access layer is where user-controlled devices, user-accessible devices, and other end-point devices are connected to the network. The access layer provides both wired and wireless connectivity and contains features and services that ensure security and resiliency for the entire network.

Figure 3 Access layer connectivity



- **Device connectivity**—The access layer provides high-bandwidth device connectivity. To help make the network a transparent part of an end-user's day-to-day job, the access layer must support bursts of high-bandwidth traffic when users perform routine tasks, such as sending large emails or opening a file from an internal web page.

  Because many types of end-user devices connect at the access layer—personal computers, IP phones, wireless APs, and IP video surveillance cameras—the access layer can support many logical networks, delivering benefits for performance, management, and security.

- **Resiliency and security services**—The access-layer design must ensure that the network is available for all users who need it, whenever they need it. As the connection point between the network and client devices, the access layer must help protect the network from human error and from malicious attacks. This protection includes ensuring that users have access only to authorized services, preventing end-user devices from taking over the role of other devices on the network, and, when possible, verifying that each end-user device is allowed on the network.

- **Advanced technology capabilities**—The access layer provides a set of network services that support advanced technologies, such as voice and video. The access layer must provide specialized access for devices using advanced technologies, to ensure that traffic from these devices is not impaired by traffic from other devices and also to ensure efficient delivery of traffic that is needed by many devices in the network.

Access-Layer Platforms

The preferred options for the campus wired LAN include the following Cisco switches as access-layer platforms:

- Cisco Catalyst 9300 Series Switches
- Cisco Catalyst 9400 Series Switches
- Cisco Catalyst 2960-X and 2960-XR Series Switches

DISTRIBUTION LAYER

The distribution layer supports many important services. In a network where connectivity needs to traverse the LAN end-to-end, whether between different access layer devices or from an access layer device to the WAN, the distribution layer facilitates this connectivity.

- **Scalability**—At any site with more than two or three access-layer devices, it is impractical to interconnect all access switches. The distribution layer serves as an aggregation point for multiple access-layer switches.

  The distribution layer can lower operating costs by making the network more efficient, by requiring less memory, by creating fault domains that compartmentalize failures or network changes, and by processing resources for devices elsewhere in the network. The distribution layer also increases network availability by containing failures to smaller domains.

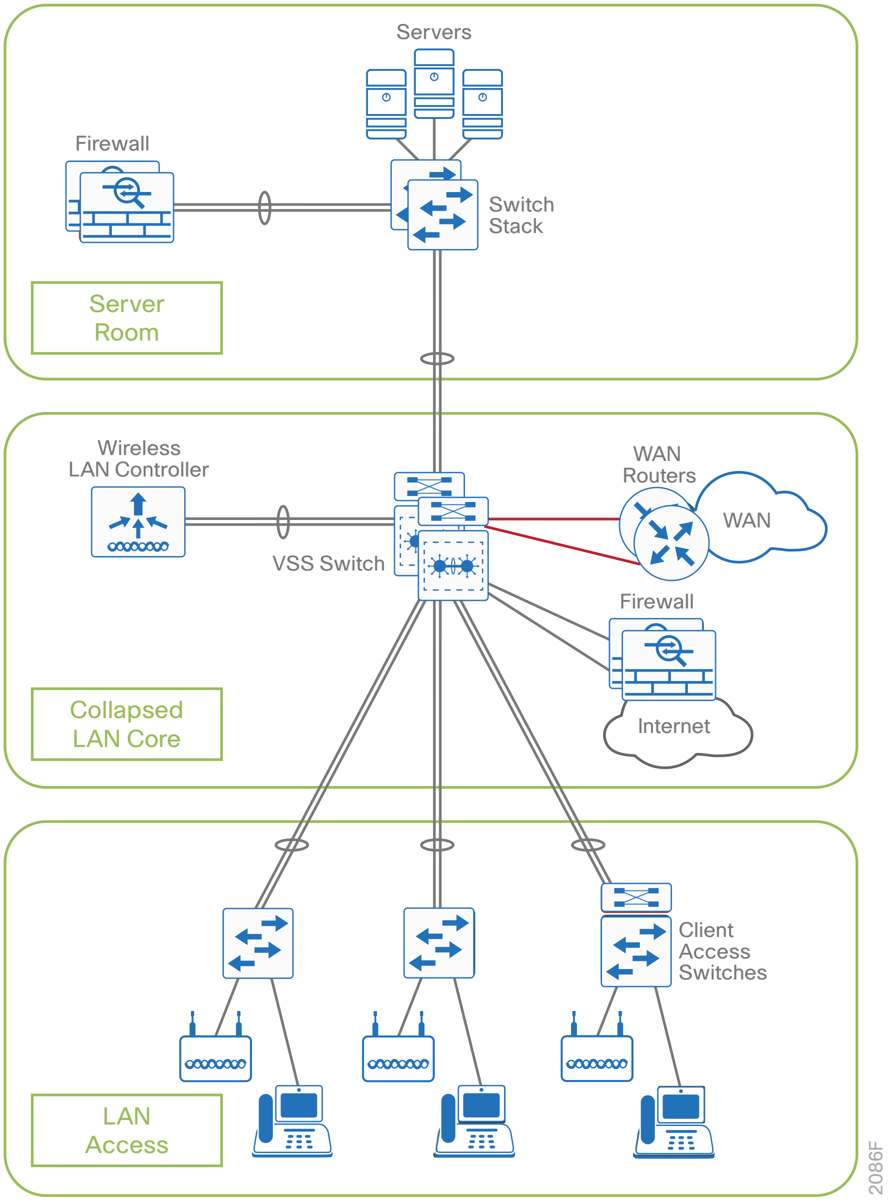
- **Reduce complexity and increase resiliency**—The campus wired LAN has the option to use a simplified distribution layer, in which a distribution-layer node consists of a single logical entity that can be implemented using a pair of physically separate switches operating as one device or using a physical stack of switches operating as one device. Resiliency is provided by physically redundant components like power supplies, supervisors, and modules, as well as stateful switchover to redundant logical control planes.

  This approach reduces complexity of configuring and operating the distribution layer because fewer protocols are required. Little or no tuning is needed to provide near-second or sub-second convergence around failures or disruptions.

Two-Tier Design

The distribution layer provides connectivity to network-based services, to the WAN, and to the Internet edge. Network-based services can include and are not limited to Wide Area Application Services (WAAS) and WLAN controllers. Depending on the size of the LAN, these services and the interconnection to the WAN and Internet edge may reside on a distribution layer switch that also aggregates the LAN access-layer connectivity. This is also referred to as a collapsed core design because the distribution serves as the Layer 3 aggregation layer for all devices.

Figure 4 *Two-tier design: Distribution layer functioning as a collapsed core*



Three-Tier Design

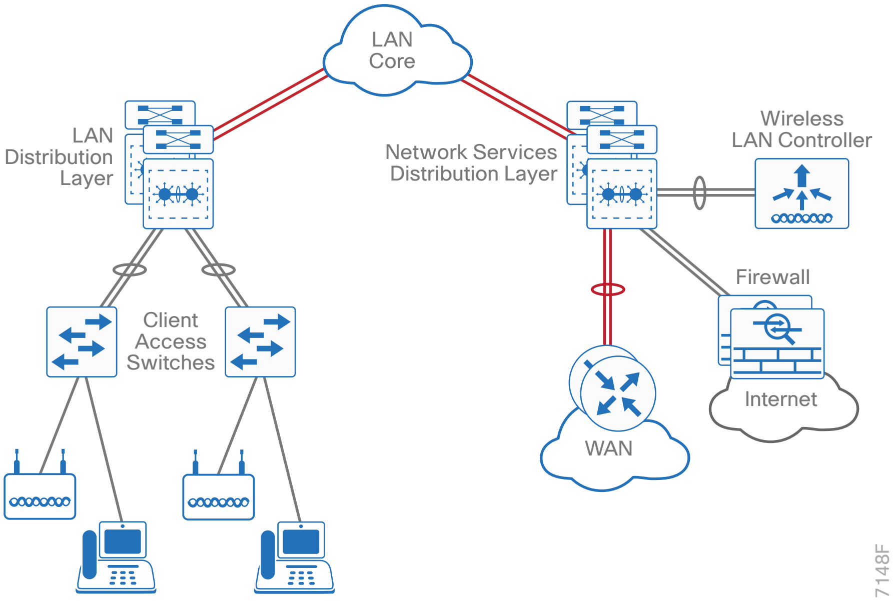
Larger LAN designs require a dedicated distribution layer for network-based services versus sharing connectivity with access layer devices. As the density of WAN routers, WAAS controllers, Internet edge devices, and WLAN controllers grows, the ability to connect to a single distribution layer switch becomes hard to manage. When connecting at least three distributions together, using a core layer for distribution connectivity should be a consideration.

There are a number of factors that drive LAN design with multiple distribution layer modules:

- The number of ports and port bandwidth that the distribution layer platform can provide affects network performance and throughput.
- Network resilience is a factor when all LAN and network-based services rely on a single platform, regardless of that platform's design, it can present a single point of failure or an unacceptably large failure domain.
- Change control and frequency affects resilience. When all LAN, WAN, and other network services are consolidated on a single distribution layer, operational or configuration errors can affect all network operation.
- Geographic dispersion of the LAN access switches across many buildings in a larger campus facility would require more fiber optic interconnects back to a single collapsed core.

Like the access layer, the distribution layer also provides quality of service (QoS) for application flows to guarantee critical applications and multimedia applications perform as designed.

Figure 5 *Three-tier design with a network-services distribution layer*



Distribution-Layer Platforms

The preferred Cisco switches for deploying the distribution layer of the campus wired LAN include:

- Cisco Catalyst 3850-X Series Switches
- Cisco Catalyst 6807-XL Series Switches with Supervisor Engine 6T
- Cisco Catalyst 6880-X Series Switches
- Cisco Catalyst 6840-X Series Switches
- Cisco Catalyst 9500-24Q Switches

CORE LAYER

In a large LAN environment, there often arises a need to have multiple distribution layer switches. One reason for this is that when access layer switches are located in multiple geographically dispersed buildings, you can save potentially costly fiber-optic runs between buildings by locating a distribution layer switch in each of those buildings. As networks grow beyond three distribution layers in a single location, organizations should use a core layer to optimize the design.

Another reason to use multiple distribution layer switches is when the number of access layer switches connecting to a single distribution layer exceeds the performance goals of the network designer. In a modular and scalable design, you can collocate distribution layers for data center, WAN connectivity, or Internet edge services.

In environments where multiple distribution layer switches exist in close proximity and where fiber optics provide the ability for high-bandwidth interconnect, a core layer reduces the network complexity, from N * (N-1) to N links for N distributions, as shown in the following two figures.

Figure 6 *LAN topology with a core layer*

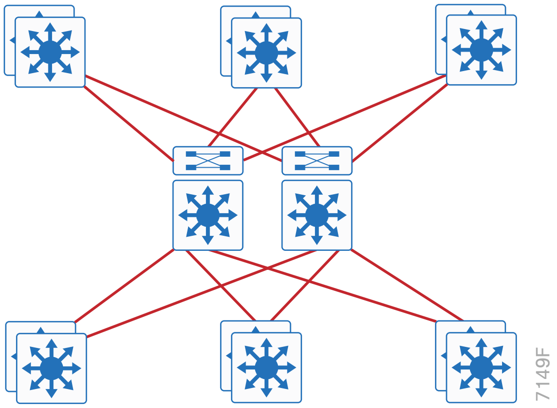
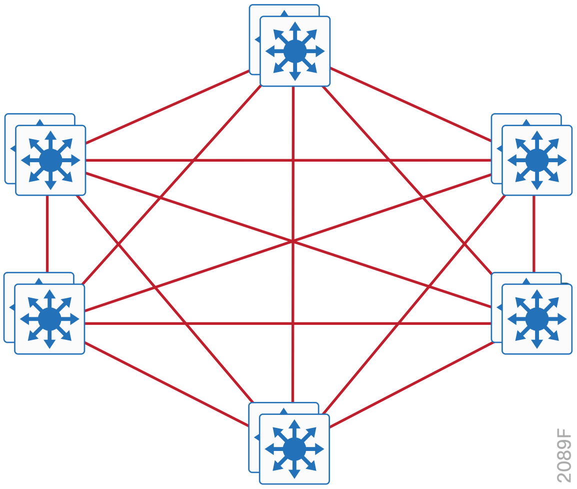


Figure 7 *LAN topology without a core layer*



The core layer of the LAN is a critical part of the scalable network, and yet it is one of the simplest by design. The distribution layer provides the fault and control domains, and the core represents the 24x7x365 nonstop connectivity between them, which organizations must have in the modern business environment where connectivity to resources to conduct business is critical. Connectivity to and from the core is Layer 3–only, which drives increased resiliency and stability.

Core Layer Platforms

The preferred Cisco switches used as campus core-layer platforms are:

- Cisco Nexus 7700 Series Switches with Supervisor 2E
- Cisco Catalyst 6807-XL Switches with Cisco Catalyst 6500 Supervisor Engine 6T

The capacity, density, and features are the primary differences driving platform selection. Both lead platforms have sibling platforms that may be appropriate for the core role in existing networks or networks where the full capabilities of the lead platforms are not required.

CAMPUS WIRED NETWORK DESIGN OPTIONS

When you scale from a single switch in a campus LAN up to a full three-tier campus network, the reliability of the network is increasingly important, because network downtime likely affects a greater user population with a larger workplace and economic significance. To mitigate the concerns about unavailability of network resources, campus designs include additional resiliency options, such as redundant links, switches, and switch components. In traditional multilayer campus designs, the added resiliency comes at a cost of configuration complexity, with most of the complexity introduced from the interaction of the access and aggregation layers of the campus LAN.

The primary function of the distribution layer is to aggregate access layer switches in a given building or campus. The distribution layer provides a boundary between the Layer 2 domain of the access layer and the Layer 3 domain that provides a path to the rest of the network. This boundary provides two key functions for the LAN. On the Layer 2 side, the distribution layer creates a boundary for spanning tree protocol (STP), limiting propagation of Layer 2 faults. On the Layer 3 side, the distribution layer provides a logical point to summarize IP routing information when it enters the network. The summarization reduces IP route tables for easier troubleshooting and reduces protocol overhead for faster recovery from failures.

Traditional Multilayer Campus Distribution Layer Design

Traditional LAN designs use a multi-tier approach with Layer 2 from the access layer to the distribution layer, where the Layer 3 boundary exists. The connectivity from the access layer to the distribution layer can result in either a loop-free or looped design.

In the traditional network design, the distribution layer has two standalone switches for resiliency. It is recommended that you restrict a Layer 2 virtual LAN (VLAN) to a single wiring closet or access uplink pair in order to reduce or eliminate topology loops that STP must block and that are a common point of failure in LANs. Restricting a VLAN to a single switch provides a loop-free design, but it does limit network flexibility.

To create a resilient IP gateway for VLANs in the traditional design, you must use first-hop redundancy protocols, which provide hosts with a consistent MAC address and gateway IP for a VLAN. Hot standby routing protocol (HSRP) and virtual router redundancy protocol (VRRP) are the most common gateway redundancy protocols, but they only allow hosts to send data out one of the access uplinks to the distribution layer and require additional configuration for each aggregation switch in order to allow you to distribute VLANs across uplinks. Gateway load-balancing protocol (GLBP) does provide greater uplink utilization for traffic exiting the access layer by balancing load from hosts across multiple uplinks, but you can only use it in a non-looped topology.

All of these redundancy protocols require that you fine-tune the default timer settings in order to allow for sub-second network convergence, which can impact switch CPU resources.

Some organizations require the same Layer 2 VLAN be extended to multiple access layer closets to accommodate an application or service. The looped design causes spanning tree to block links, which reduces the bandwidth from the rest of the network and can cause slower network convergence. The inefficiencies and the increased potential for misconfiguration drive network engineers to look for more appealing alternatives.

Figure 8 *Traditional loop-free design with a VLAN per access switch*

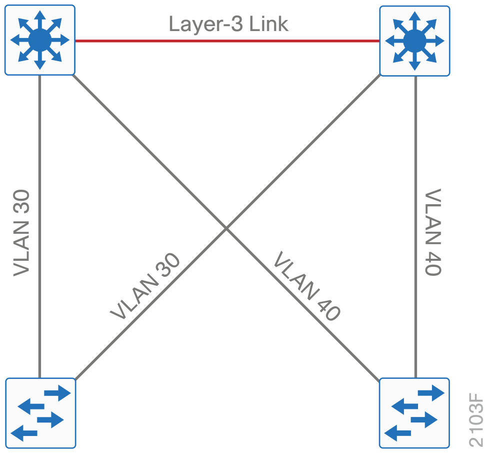
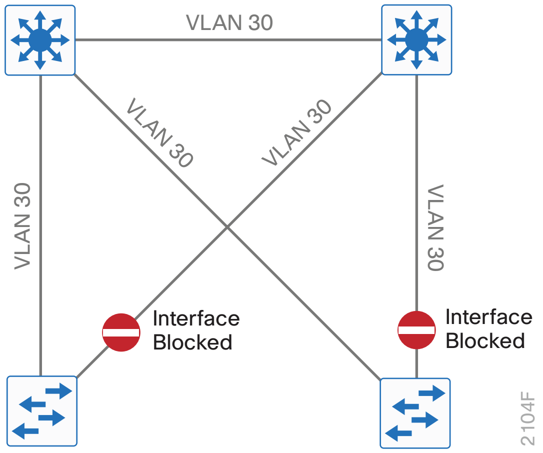


Figure 9 *Traditional looped design with VLANs spanning access switches*



Routed Access Layer to Distribution Design

In another approach to access and distribution layer design, you can use Layer 3 all the way to the access layer. The benefits of this design are that you eliminate spanning tree loops and reduce protocols because the IP gateway is now the access switch. Because there are no spanning-tree blocking links, you can use both uplinks to the access layer and increase effective bandwidth available to the users.

The challenge with the routed access layer design is that the Layer 2 domains are confined to a single access closet, which limits flexibility for applications that require Layer 2 connectivity that extends across multiple access closets.

Software-Defined Access Design

You can overcome the aforementioned Layer 2 limitations of the routed access layer design by adding fabric capability to a campus network that is already using a Layer 3 access network; the addition of the fabric is automated using SD-Access technology. The SD-Access design enables the use of virtual networks (overlay networks) running on a physical network (underlay network) in order to create alternative topologies to connect devices. In addition to network virtualization, SD-Access allows for software-defined segmentation and policy enforcement based on user identity and group membership, integrated with Cisco TrustSec technology. For additional information, see the Software-Designed Access Design Guide.

Simplified Distribution Layer Design

An alternative that can handle Layer 2 access requirements and avoid the complexity of the traditional multilayer campus is called a *simplified distribution layer design*. The design uses multiple physical switches that act as a single logical switch, such as switch stack or a VSS, or the less preferred single, highly-redundant physical switch. One advantage of this design is that spanning tree dependence is minimized, and all uplinks from the access layer to the distribution are active and passing traffic. Even in the distributed VLAN design, you eliminate spanning tree blocked links because of looped topologies. You reduce dependence on spanning tree by using EtherChannel to the access layer with dual-homed uplinks. This is a key characteristic of this design, and you can load-balance up to eight links if needed for additional bandwidth. At the same time, multiple links in an EtherChannel have better performance characteristics versus single independent links.

Figure 10 *Simplified distribution design with a VLAN per access switch*

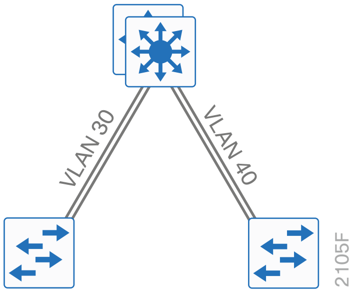
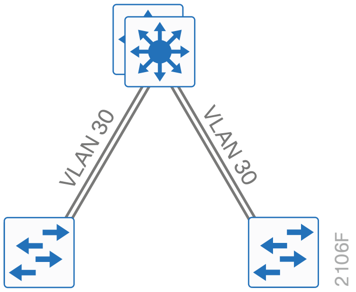


Figure 11 *Simplified distribution design with VLANs spanning access switches*



EtherChannel is a logical interface that can use a control plane protocol to manage the physical members of the bundle. It is better to run a channel protocol instead of using forced-on mode because a channel protocol performs consistency checks for interfaces programmed to be in the channel and provides protection to the system from inconsistent configurations. Cisco Catalyst switches provide both port aggregation protocol (PAgP), which is a widely deployed Cisco designed protocol, and link aggregation protocol (LACP), which is based on IEEE 802.3ad.

There are several other advantages to the simplified distribution layer design. You no longer need IP gateway redundancy protocols such as HSRP, VRRP, and GLBP, because the default IP gateway is now on a single logical interface and resiliency is provided by the distribution layer switch or switches. Also, the network will converge faster now that it is not depending on spanning tree to unblock links when a failure occurs, because EtherChannel provides fast sub-second failover between links in an uplink bundle.

The topology of the network from the distribution layer to the access layer is logically a hub-and-spoke topology, which reduces complexity of design and troubleshooting. The hub-and-spoke topology design provides a more efficient operation for IP Multicast in the distribution layer because there is now a single logical designated router to forward IP Multicast packets to a given VLAN in the access layer.

Finally, by using the single logical distribution layer design, there are fewer boxes to manage, which reduces the amount of time spent on ongoing provisioning and maintenance.

Campus Wireless LAN Design Fundamentals

The campus WLAN provides ubiquitous data and voice connectivity for employees, wireless Internet access for guests, and connectivity for Internet of Things devices. Regardless of their location within the organization—on large campuses or at remote sites—wireless users have the same experience when connecting to voice, video, and data services.

The benefits of the campus WLAN include:

- **Productivity gains through secure, location-independent network access**—Measurable productivity improvements and communication.
- **Additional network flexibility**—Hard-to-wire locations connected wirelessly, without costly construction.
- **Cost-effective deployment**—Adoption of virtualized technologies within the overall wireless architecture.
- **Easy to manage and operate**—From a single pane of glass, centralized control of a distributed wireless environment.
- **Plug-and-play deployment**—Automatic provisioning when an AP is connected to the supporting wired network.
- **Resilient, fault-tolerant design**—Reliable wireless connectivity in mission-critical environments, including complete radio frequency (RF)-spectrum management.
- **Support for wireless users**—Bring-your-own-device (BYOD) design models.
- **Efficient transmission of multicast traffic**—Support for many group communication applications, such as video and push-to-talk.

INFRASTRUCTURE

The campus WLAN is built around these main hardware and software components:

- Cisco WLAN controllers
- Cisco lightweight APs
- Cisco Prime Infrastructure (PI)
- Cisco Mobility Services Engine (MSE)/Cisco Connected Mobile Experiences (CMX)

CISCO WLAN CONTROLLERS

The campus WLAN is a controller-based wireless design, which simplifies network management by using Cisco WLAN controllers (WLCs) to centralize the configuration and control of wireless APs. This approach allows the WLAN to operate as an intelligent information network and to support advanced services. The following are some of the benefits of the controller-based design:

- **Lower operational expenses**—Enables zero-touch configurations for lightweight APs; easy design of channel and power settings and real-time management, including identifying any RF holes in order to optimize the RF environment; seamless mobility across the various APs within the mobility group; and a holistic view of the network, supporting decisions about scale, security, and overall operations.
- **Optimized turn-up—**Enables streamlined configuration of WLAN controller and overall wireless network through the implementation of best practices during initial WLC configuration.
- **Improved return on investment**—Enables virtualized instances of the WLAN controller—for only the virtual wireless LAN controller (vWLC)—reducing the total cost of ownership by leveraging their investment in virtualization.
- **Easier way to scale with optimal design**—Enables the network to scale well, by supporting a centralized (local mode) design for campus environments, and Cisco FlexConnect design for lean remote sites.
- **High availability stateful switchover**—Enables non-disruptive connectivity to wireless client devices during a WLAN controller failure.

Cisco WLAN controllers are responsible for system-wide WLAN functions, such as security policies, intrusion prevention, RF management, QoS, and mobility. They work in conjunction with Cisco lightweight APs in order to support business-critical wireless applications. From voice and data services to location tracking, Cisco WLAN controllers provide the control, scalability, security, and reliability that network managers need to build secure, scalable wireless networks.

The following table summarizes the Cisco WLAN controllers referenced within this guide.

Table 4 WLAN controller platforms

Platform	Deployment Mode	Preferred Topology	Maximum APs	Maximum Clients	Controller Throughput
Cisco 8540	Centralized or FlexConnect	Large Single or Multiple Site	6,000	64,000	40 Gbps
Cisco 5520	Centralized or FlexConnect	Large Single or Multiple Site	1,500	20,000	20 Gbps
Cisco 3504	Centralized or FlexConnect	Small Local Controller Site	150	3,000	4 Gbps
Cisco vWLC (Small)	FlexConnect	Medium Number of Small Sites	200	6,000	500 Mbps
Cisco vWLC (Large)	FlexConnect	Large Number of Small Sites	3,000	32,000	1 Gbps

Because software license flexibility allows you to add additional APs when business requirements change, you can choose the controller that will support your needs long-term, but you purchase incremental access-point licenses only when you need them.

Cisco Lightweight APs

In the Cisco Unified Wireless Network architecture, APs are *lightweight*. This means they cannot act independently of a WLAN controller. When the AP communicates with the WLAN controller, it downloads its configuration and it synchronizes its software or firmware image. The APs can be converted to act in autonomous operation, but autonomous operation requires that each AP be managed individually, therefore it is not covered in this guide.

Cisco lightweight APs work in conjunction with a Cisco WLAN controller in order to connect wireless devices to the LAN while supporting simultaneous data-forwarding and air-monitoring functions. The campus WLAN offers robust wireless coverage with up to nine times the throughput of 802.11a/b/g networks.

The following table summarizes the APs discussed within this guide.

Table 5 Cisco Aironet APs

	1850 Series	2800 Series	3800 Series
Best for	Small to midsize networks	High-density, midsize to large networks	Mission critical, high density, large size networks
Features	802.11ac Wave 2 radio, 4x4 multiple input, multiple output (MIMO), 4 spatial streams	802.11ac Wave 2 radio, 3x4 MIMO, 3 spatial streams	802.11ac Wave 2 radio, 4x4 MIMO, 3 spatial streams
Antennas	Internal & external	Internal & external	Internal & external
HDX support	No	Yes	Yes
CleanAir	No	Yes	Yes
Spectrum Analysis	Yes	Yes	Yes
ClientLink	No (standards-based TxBF)	Yes (4.0)	Yes (4.0)
Combined Data Rate	2 Gbps	5 Gbps	5 Gbps

Support for two key technologies differentiates the APs selected for deployment in the campus WLAN:

- **Cisco CleanAir technology**—Provides IT managers visibility into their wireless spectrum in order to manage RF interference and prevent unexpected downtime. Cisco CleanAir provides performance protection for 802.11 networks. This silicon-level intelligence creates a self-healing, self-optimizing wireless network that mitigates the impact of wireless interference.
- **802.11ac**—The IEEE 802.11ac Wave 2 specification provides for significant enhancements to wireless networking performance.

Mobility Services Engine/Connected Mobile Experiences

Cisco MSE/Cisco CMX is a platform that helps organizations deliver innovative mobile services and improve business processes through increased visibility into the network, customized location-based mobile services, and strengthened wireless security.

MSE/CMX is available in the following form factors:

- Cisco MSE 3365 appliance
- Virtual machine running VMware ESXi 5.1 or later
- CMX Cloud

There are currently two versions of the MSE/CMX with slightly different names. *MSE 8.0* refers to both the MSE platform with CMX software version 8.0 running on it. With CMX release 10.1 and higher, this name has been changed to *CMX*.

The following table summarizes the services offered by the different releases of MSE/CMX.

Table 6 *Services offered by MSE 8.0 and CMX 10.2.2*

Service	MSE 8.0	CMX 10.2.2
Location-based services	Yes	Yes
Cisco Wireless Intrusion Prevention System (wIPS)	Yes	No (planned)
CMX Analytics	Location & presence	Hyperlocation & FastLocate
CMX Connect	Yes	Yes
CMX Mobile App Server & SDK	Yes	No (planned)
Mobile Concierge	Yes	No

WIRELESS DESIGN MODELS

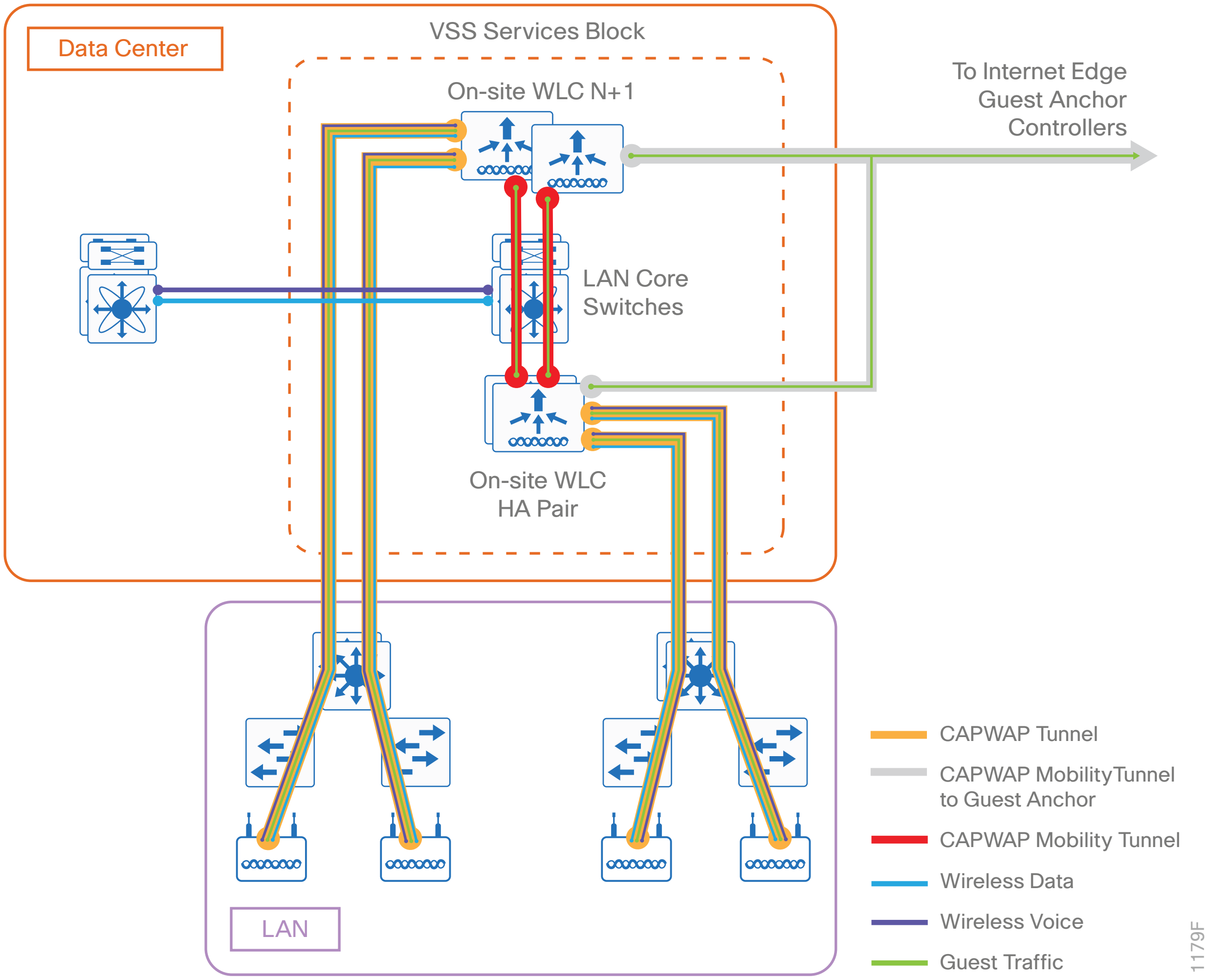
This guide describes the following three design models and their recommended use:

- Centralized (Local-Mode) Design Model
- FlexConnect Design Model
- SD-Access Wireless Design Model

Centralized (Local-Mode) Design Model

A centralized design model, also known as a *local-mode design model,* is recommended primarily for large site deployments. The benefits of a centralized design include IP address management, simplified configuration and troubleshooting, and roaming at scale. In a centralized design model, the WLAN controller and APs are both located within the same site. You can connect the WLAN controller to a data center services block, a separate services block off of the campus core, or a LAN distribution layer. Wireless traffic between WLAN clients and the LAN is tunneled by using the control and provisioning of wireless access points (CAPWAP) protocol between the controller and the AP.

Figure 12 *Local-mode design model*



A centralized architecture uses the controller as a single point for managing Layer 2 security and wireless network policies. It also enables services to be applied to wired and wireless traffic in a consistent and coordinated fashion.

In addition to providing the traditional benefits of a Cisco Unified Wireless Network approach, the local-mode design model meets the following customer demands:

- **Seamless mobility**—Enables fast roaming across the campus, so that users remain connected to their session even while walking between various floors or adjacent buildings with changing subnets
- **Ability to support rich media**—Enhances robustness of voice with call admission control and multicast with Cisco VideoStream technology
- **Centralized policy**—Enables intelligent inspection through the use of firewalls, as well as application inspection, network access control, policy enforcement, and accurate traffic classification

If **any** of the following are true at a site, you should consider deploying a controller locally at the site:

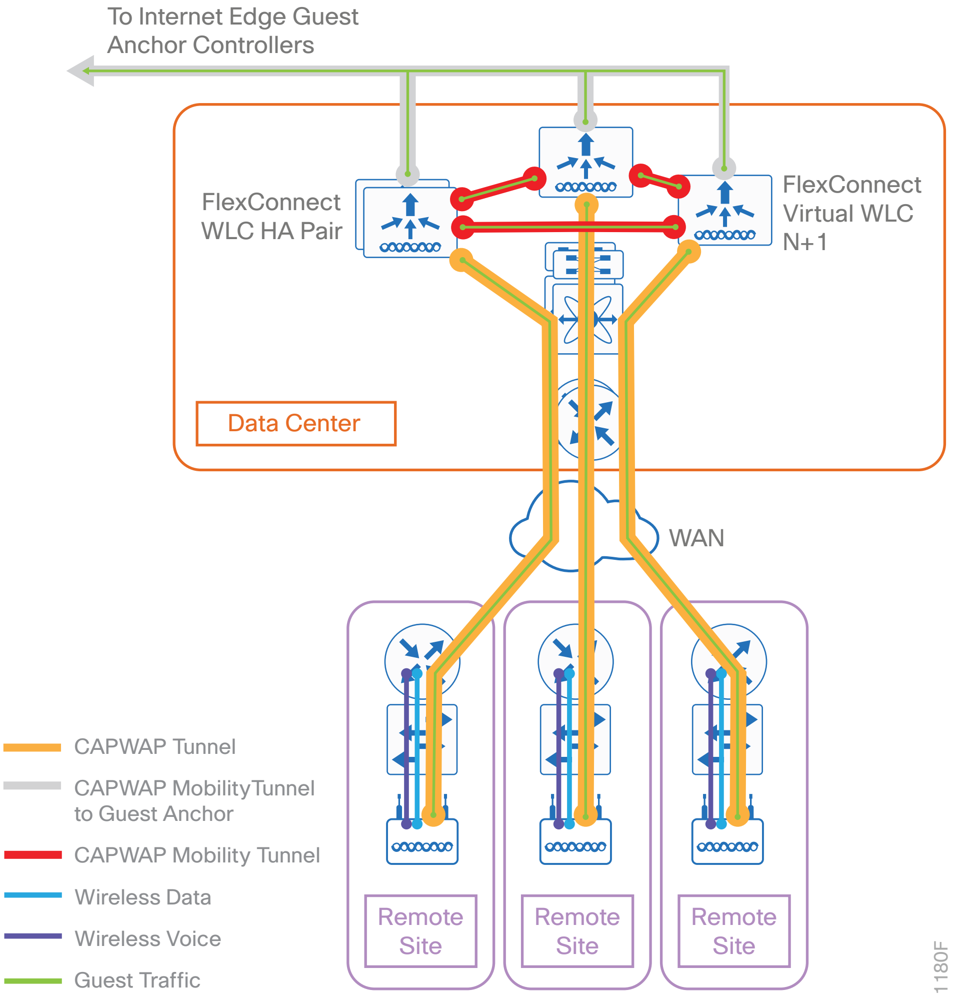
- The site has a data center.
- The site has a LAN distribution layer.
- The site has more than 100 APs.
- The site has a WAN latency greater than 100 ms round-trip to a proposed shared controller.

The recommended platforms for large centralized (local-mode) designs are the Cisco 8540 and 5520 WLAN controllers, due to their scalability and feature support. For smaller sites, you can deploy the Cisco 3504 WLAN controller as a local controller within the site.

Cisco FlexConnect Design Model

Cisco FlexConnect is a wireless solution primarily for deployments that consist of multiple small remote sites (branches) connected into a central site. FlexConnect provides a highly cost-effective solution, enabling organizations to configure and control remote-site APs from the headquarters through the WAN, without deploying a controller in each remote site. Cisco APs operating in FlexConnect mode can switch client data traffic out their local wired interface and can use 802.1Q trunks in order to segment multiple WLANs. The trunk’s native VLAN is used for all CAPWAP communication between the AP and the controller. This mode of operation is referred to as *FlexConnect local switching* and is the mode of operation described in this guide.

Figure 13 *Cisco FlexConnect design model*



Cisco FlexConnect can also tunnel traffic back to the centralized controller, which can be used for wireless guest access. You can use a shared controller pair or a dedicated controller pair in order to deploy Cisco FlexConnect.

In a shared controller model, both local-mode and FlexConnect configured APs share a common controller. A shared controller architecture requires that the WLAN controller support both FlexConnect local switching and local mode. In this guide, the WLAN controllers that support both are the Cisco 8500, 5500, and 3500 Series wireless controllers.

You may be able to use a shared deployment if you meet all of the following requirements:

- You have an existing local-mode controller pair at the same site as your WAN aggregation.
- The controller pair has enough additional capacity to support the Cisco FlexConnect APs.
- The number of FlexConnect groups required matches the capabilities of the controller pair.

If you don't meet the requirements for a shared controller, you can deploy Cisco 8500, Cisco 5500, or Cisco 3500 Series wireless controllers. For highest resiliency, deploy a pair of controllers in high availability (HA) SSO configuration. Alternatively, you can deploy N+1 high availability in order to provide cross-site resiliency if desired.

You can also employ dual, resilient controllers configured in an N+1 HA model using the Cisco vWLC.

If all of the following are true at a site, you should consider deploying Cisco FlexConnect at the site:

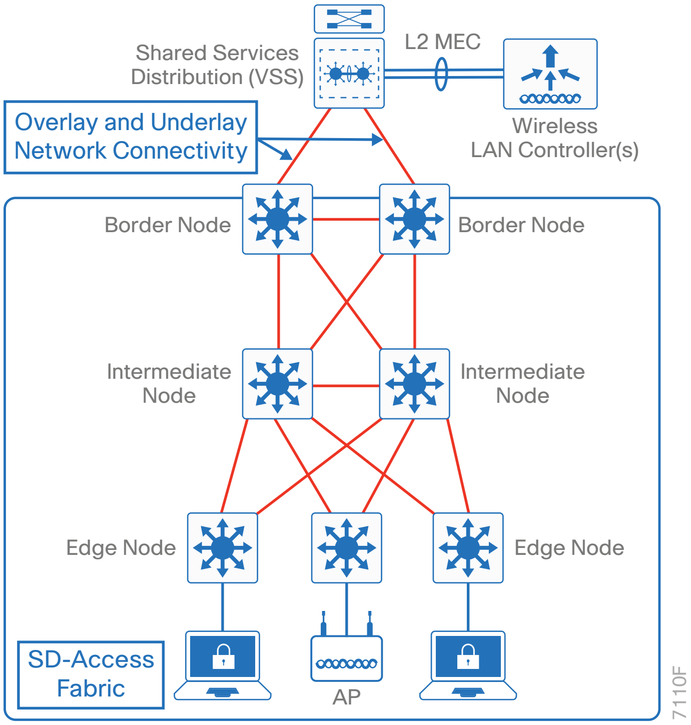
- The site LAN is a single access-layer switch or switch stack.
- The site has fewer than 50 APs.
- The site is one of many small remote sites connected to a central location
- The site has a WAN latency less than 100 ms round-trip to the shared controller.

SD-Access Wireless Design Model

SD-Access Wireless is the fabric-enabled wireless solution that fully integrates with a wired SD-Access Model. The primary benefit of SD-Access Wireless is that customers can have a common policy and unified experience across both wired and wireless. In this model, the fabric WLCs communicate wireless client information to the fabric control plane, and the fabric APs encapsulate traffic into the VXLAN data path.

Tech Tip

SD-Access Wireless control plane traffic is passed to the WLC, while data plane traffic is passed directly into the fabric.



Requirements for deploying SD-Access Wireless

- SD-Access Wired deployment
- Fabric mode supported Access Points directly connected to SD-Access fabric edge nodes
- Fabric mode supported WLC
- 20 ms or less latency between the fabric APs and the fabric WLC

WIRELESS DESIGN CONSIDERATIONS

High Availability

As more devices with critical functions move to the wireless medium, high availability of the wireless infrastructure is becoming increasingly important. Real-time audio, video, and text communication relies on the corporate wireless network, and the expectation of zero downtime is becoming the norm. The negative impacts of wireless network outages are just as impactful as outages of the wired network. Implementing high availability within the wireless infrastructure involves multiple components and functionality deployed throughout the overall network infrastructure, which itself must be designed for high availability. This section discusses high availability specific to the implementation of wireless controller platforms. Platform-level redundancy refers to the ability to maintain wireless service when connectivity to one or more physical WLAN controller platforms within a site is lost.

The methods of high availability discussed within this design guide are as follows:

- High availability SSO
- N+1 high availability
- WLAN controller link aggregation

High Availability SSO

Cisco AireOS supports access-point stateful switchover and client stateful switchover. These two features are collectively referred to as *HA SSO*. For both simplicity and efficacy, HA SSO is the preferred option for providing high availability. By using the cost-effective HA SSO licensing model, Cisco wireless deployments can improve the availability of the wireless network with controller recovery times in the sub-second range during a WLAN controller disruption. In addition, HA SSO allows the resilient WLAN controller to be cost-effectively licensed as a standby resilient controller with its access-point license count automatically inherited from its paired primary WLAN controller. This is accomplished by purchasing a standby resilient controller using the HA SKU available for the Cisco 5500 and 8500 Series WLAN controllers.

The configuration and software upgrades of the primary WLAN controller are automatically synchronized to the resilient standby WLAN controller.

N+1 High Availability

You can use the N+1 HA architecture in order to provide redundancy for WLAN controllers within a single site or across geographically separate sites with lower overall cost of deployment. It is often deployed along with the FlexConnect architecture in order to provide high availability across data centers for remote branches. You can use a single backup WLAN controller in order to provide backup for multiple primary WLAN controllers. HA SSO functionality is not supported for N+1 HA. When the primary controller fails, the AP CAPWAP state machine is restarted.

With N+1 HA, WLAN controllers are independent of each other and do not share configuration or IP addresses on any of their interfaces. Each WLC must be managed separately, can run different hardware, and can be deployed in different datacenters across the WAN link.

It is recommended (but not required) that you run the same software version across WLCs used for N+1 HA, in order to reduce down time as the APs establish CAPWAP sessions to the backup controllers. You can configure APs with a priority with N+1 HA. APs with high priority on the primary controller always connect first to the backup controller, even if they have to push out low priority APs. When a primary WLC resumes operation, the APs fall back from the backup WLC to the primary WLC automatically, if the AP fallback option is enabled.

You can configure an HA-SKU secondary controller as a backup controller for N+1 HA. The HA-SKU unique device identifier provides the capability of the maximum number of APs supported on that hardware. You cannot configure the N+1 Secondary HA-SKU in combination with HA SSO. They are mutually exclusive

WLAN Controller Link Aggregation

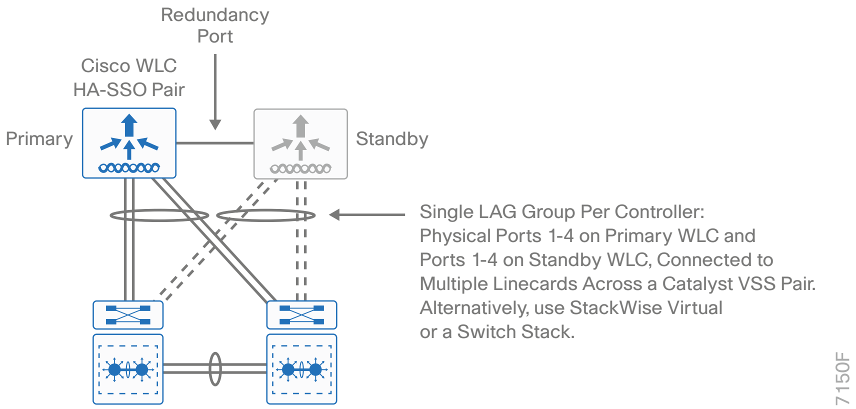
Most Cisco wireless controller appliances have multiple physical 1 or 10 Gigabit Ethernet ports. In typical deployments, one or more WLANs/service set identifiers (SSIDs) are mapped to a dynamic interface, which is then mapped to a physical port. In a centralized design, wireless traffic is backhauled across the network infrastructure and terminated on the physical ports. With the use of a single physical port per WLAN, the throughput of each WLAN is limited to the throughput of the port. Therefore an alternative is to deploy link aggregation (LAG) across the distribution system ports, bundling them into a single high speed interface.

When LAG is enabled, the wireless controller dynamically manages port redundancy and load-balances APs transparently. LAG also simplifies controller configuration because it is no longer necessary to configure primary and secondary ports for each interface. If any of the controller ports fail, traffic is automatically migrated to one of the other ports. As long as at least one controller port is functioning, the wireless controller continues to operate, APs remain connected to the network, and wireless clients continue to send and receive data.

LAG requires an EtherChannel Port Group to be configured on the attached Catalyst switch. The EtherChannel port group can be configured across multiple linecards on the Catalyst switch, or across switches in a Catalyst switch VSS configuration, for additional redundancy. When configured across switches it is referred to as a *multi-chassis EtherChannel*.

The following figure shows an example of wireless controller link aggregation in a high availability configuration to a Catalyst switch VSS pair. Similar connectivity is used when connecting to a distribution switch stack.

Figure 14 *Link aggregation examples*


Redundancy
Port
Cisco WLC
HA-SSO Pair
Primary
Standby
Single LAG Group Per Controller:
Physical Ports 1-4 on Primary WLC and
Ports 1-4 on Standby WLC, Connected to
Multiple Linecards Across a Catalyst VSS Pair.
Alternatively, use StackWise Virtual
or a Switch Stack.
7150F

Spreading the ports from the active and standby WLCs across both switches within the VSS pair is the recommended design. This design minimizes the traffic that crosses the virtual switch link between the Catalyst switches in the VSS pair during normal (non-failure) operation, because both the active and standby WLCs have ports connected to both switches. This design also avoids a switchover from the active WLC to the standby WLC in the event of a switch failure within the VSS pair. However, in the event of a switch failure within the VSS pair, the number of ports connected to the active WLC is reduced by half.

Tech Tip

You set the Catalyst switches unconditionally to LAG (mode-on), because the wireless controller does not support LACP or PAgP.

The following table summarizes high availability support with the various controllers.

Table 7 High availability feature support

Cisco WLC model	HA SSO	N+1 HA	Stack redundancy	LAG
8540	Yes	Yes	–	Yes
5520	Yes	Yes	–	Yes
3504	Yes	Yes	–	Yes
vWLC	No	Yes	–	Through VMware

MULTICAST SUPPORT

Video and voice applications continue to grow as smartphones, tablets, and PCs are added to wireless networks in all aspects of our daily life. In each of the wireless design models, the multicast support to which users are accustomed on a wired network is available wirelessly. Multicast is required in order to enable the efficient delivery of certain one-to-many applications, such as video and push-to-talk group communications. By extending the support of multicast beyond that of the campus and data center, mobile users can now use multicast-based applications.

The campus WLAN supports multicast transmission for the onsite controller through the use of multicast-multicast mode, which uses a multicast IP address in order to more efficiently communicate multicast streams to APs that have wireless users subscribing to a particular multicast group. In this guide, multicast-multicast mode is supported by using the Cisco 3500, 5500, and 8500 Series WLAN Controllers.

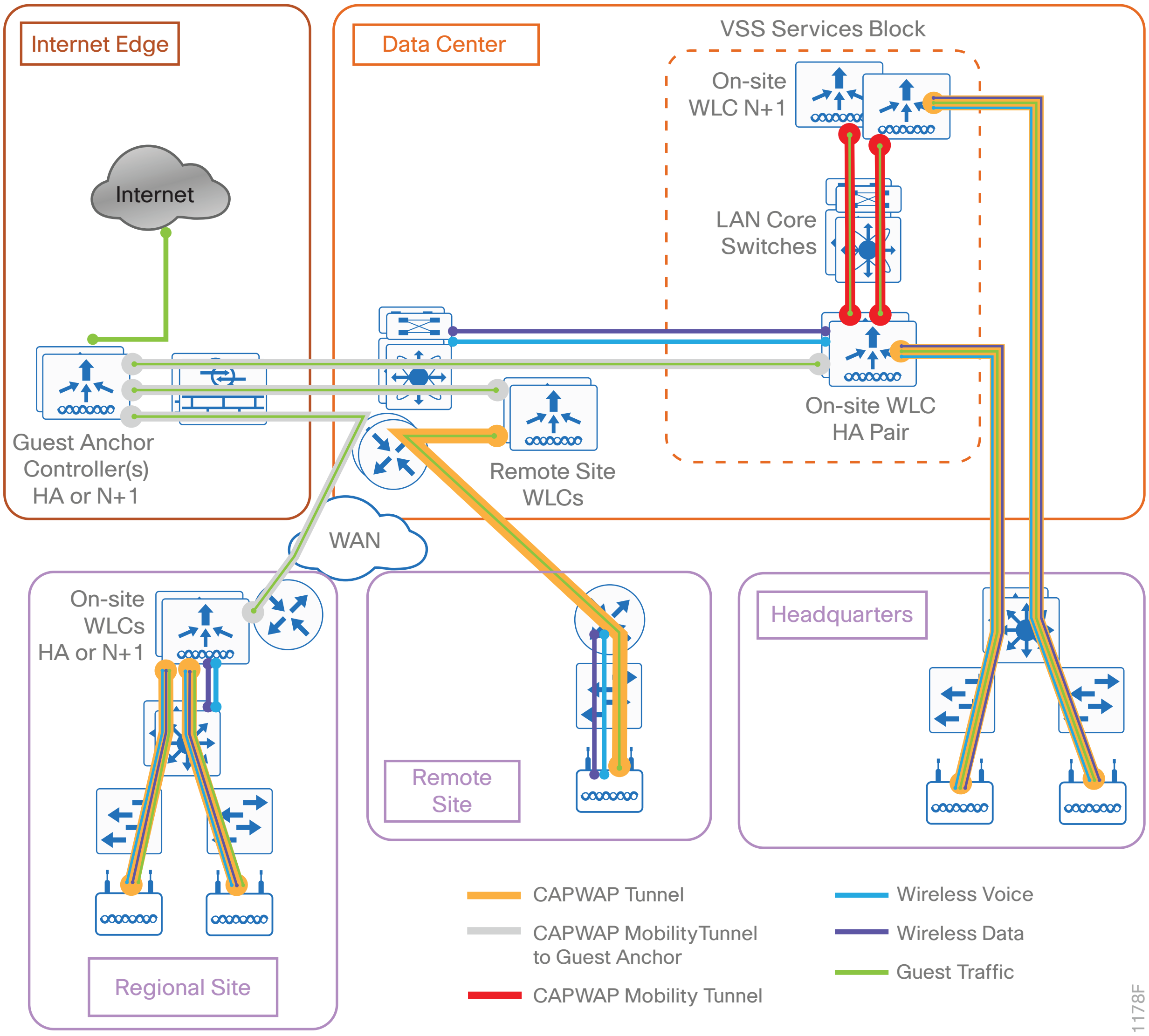
Remote sites that use the Cisco vWLC using Cisco FlexConnect in local switching mode can also benefit from the use of multicast-based applications. Multicast in remote sites leverages the underlying WAN and LAN support of multicast traffic. When combined with APs in FlexConnect mode using local switching, subscribers to multicast streams are serviced directly over the WAN or LAN network with no additional overhead being placed on the WLAN controller.

Guest Wireless

Using the existing campus wired and wireless infrastructure for guest access provides a convenient, cost-effective way to offer Internet access for visitors and contractors. The wireless guest network provides the following functionality:

- Provides Internet access to guests through an open wireless SSID, with web authentication access control
- Supports the creation of temporary authentication credentials for each guest by an authorized internal user
- Keeps traffic on the guest network separate from the internal network in order to prevent a guest from accessing internal network resources
- Supports centralized and Cisco FlexConnect design models

Figure 15 *Wireless architecture overview*



If you have a single controller pair for the entire organization and that controller pair is connected to the same distribution switch as the Internet edge firewall, you can use a shared deployment.

In a shared deployment, a VLAN is created on the distribution switch in order to logically connect guest traffic from the WLAN controllers to the demilitarized zone (DMZ). The DMZ Guest VLAN will not have an associated Layer 3 interface or switch virtual interface. As such, each wireless client on the guest network will use the Internet edge firewall as their default gateway.

If you don't meet the requirements for a shared deployment, you can use Cisco 5500 or Cisco 3500 Series Wireless LAN Controllers in order to deploy a dedicated guest controller. The controller is directly connected the Internet edge DMZ, and guest traffic from every other controller in the organization is tunneled to this controller. Other controllers can provide guest anchoring services as described but are not covered in this guide.

In both the shared and dedicated guest wireless design models, the Internet edge firewall restricts access from the guest network. The guest network is only able to reach the Internet and the internal DHCP and DNS servers.

Most organizations' IT departments choose to have guest wireless users authenticate first, before allowing access to the Internet. This step is sometimes accompanied with the guest user reading and agreeing to an acceptable use policy (AUP) or end-user agreement (EUA) before accessing the Internet. Since the organization's IT department typically has no control over the hardware or software capabilities of guest wireless devices, the authentication and authorization decision is often based on only a guest userid and password. In other words, the device with which the guest is accessing the network may not be considered for any policy decision. A typical way of implementing guest user authentication is through the guest user's web browser, a method known as *web authentication* or *WebAuth*. With this method of authentication, the wireless guest must first open his or her web browser, or mobile app with embedded browser, to a URL located somewhere within the Internet. The browser session is re-directed to a web portal that contains a login page that requests login credentials. Upon successful authentication, the guest user is either allowed access to the Internet or redirected to another web site. This authentication method is also known as a *captive portal*.

There are multiple ways of authenticating guests on WLANs, such as the following:

- **Local WebAuth**—With this method, the web session of the guest device is redirected by the guest wireless controller to a web portal containing the login screen within the guest wireless controller. The guest's credentials are then checked against the local database within the guest wireless controller. The advantage of this option is that the entire management of guest wireless access is confined to the guest wireless controller within the DMZ. The downside of this option is that guest credentials are maintained separately within the guest wireless controller.

- **Central web authentication**—With this method, the web session of the guest device is redirected by the guest wireless controller to an external web portal containing the login screen. The guest's credentials are then checked against an external database within an authentication, authorization, and accounting (AAA) server. Cisco Identity Services Engine (ISE) can provide both the external web portal and AAA server functionality. By positioning the WebAuth login portal in a central server, the network administrator can provide one unified login page—with an optional AUP or EUA—for all wireless guest access without having to create a separate login page on each guest wireless controller. By moving the guest credential database and guest sponsor portal to an AAA server, the network administrator can provide one central place for creating and managing guest credentials, versus having to create guest credentials on each guest wireless controller.

- **CMX-based guest-onboarding**—CMX-based guest-onboarding is often implemented by organizations who wish to provide free Internet access within their venue, in exchange for collecting some information from customers who visit the site. With this method, guests are allowed to use the wireless network and access the Internet from the venue by logging in using their existing social media credentials. The venue owner may also choose to allow anonymous login to the wireless network. The venue owner may also optionally choose to display a splash page and registration form, customized for that particular venue location. You can accomplish CMX-based guest-onboarding by deploying the Cisco CMX platform (also known as the *Mobility Services Engine*). You can deploy the Cisco Enterprise Mobility Services Platform along with CMX in order to go beyond simply providing connectivity—by engaging the visitor via a web browser or mobile application deployed on the mobile device.

Cisco OfficeExtend

For the home-based teleworker, it is imperative that access to business services be reliable and consistent, providing an experience that is comparable to being on campus. But on the commonly used 2.4-GHz wireless band, residential and urban environments have many potential sources of congestion, such as cordless handsets, smartphones, tablets, and baby monitors. To support users whose technical skills vary widely, a teleworker solution must provide a streamlined and simplified way to implement devices that allow for secure access to the corporate environment.

IT operations have a different set of challenges when it comes to implementing a teleworking solution, including properly securing, maintaining, and managing the teleworker environment from a centralized location. Because operational expenses are a constant consideration, IT must implement a cost-effective solution that protects an organization's investment without sacrificing quality or functionality.

The Cisco OfficeExtend satisfies the ease-of-use, quality-of-experience, and operational-cost requirements. The Cisco OfficeExtend solution is built around two main components:

- Cisco 3500 Series or Cisco 5500 Series or Cisco 8500 Series Wireless LAN Controller
- Cisco Aironet 1810W Series OfficeExtend Access Point

Cisco WLAN Controllers

Cisco WLAN controllers work in conjunction with Cisco OfficeExtend APs in order to support business-critical wireless applications for teleworkers. Cisco WLAN controllers provide the control, scalability, security, and reliability that network managers need to build a secure, scalable teleworker environment.

A standalone controller can support up to 500 Cisco OfficeExtend sites. For a resilient solution, Cisco recommends deploying controllers in pairs.

The following controllers are preferred options for Cisco OfficeExtend:

- Cisco 3500 Series Wireless LAN Controller
- Cisco 5500 Series Wireless LAN Controller

Because software license flexibility allows you to add additional APs as business requirements change, you can choose the controller that will support your needs long-term, enabling you to only pay for what you need, when you need it.

To allow users to connect their endpoint devices to either the organization's on-site wireless network or their at-home teleworking wireless networks without reconfiguration, Cisco OfficeExtend uses the same wireless SSIDs at teleworkers' homes as those that support data and voice inside the organization.

Cisco OfficeExtend Access Points

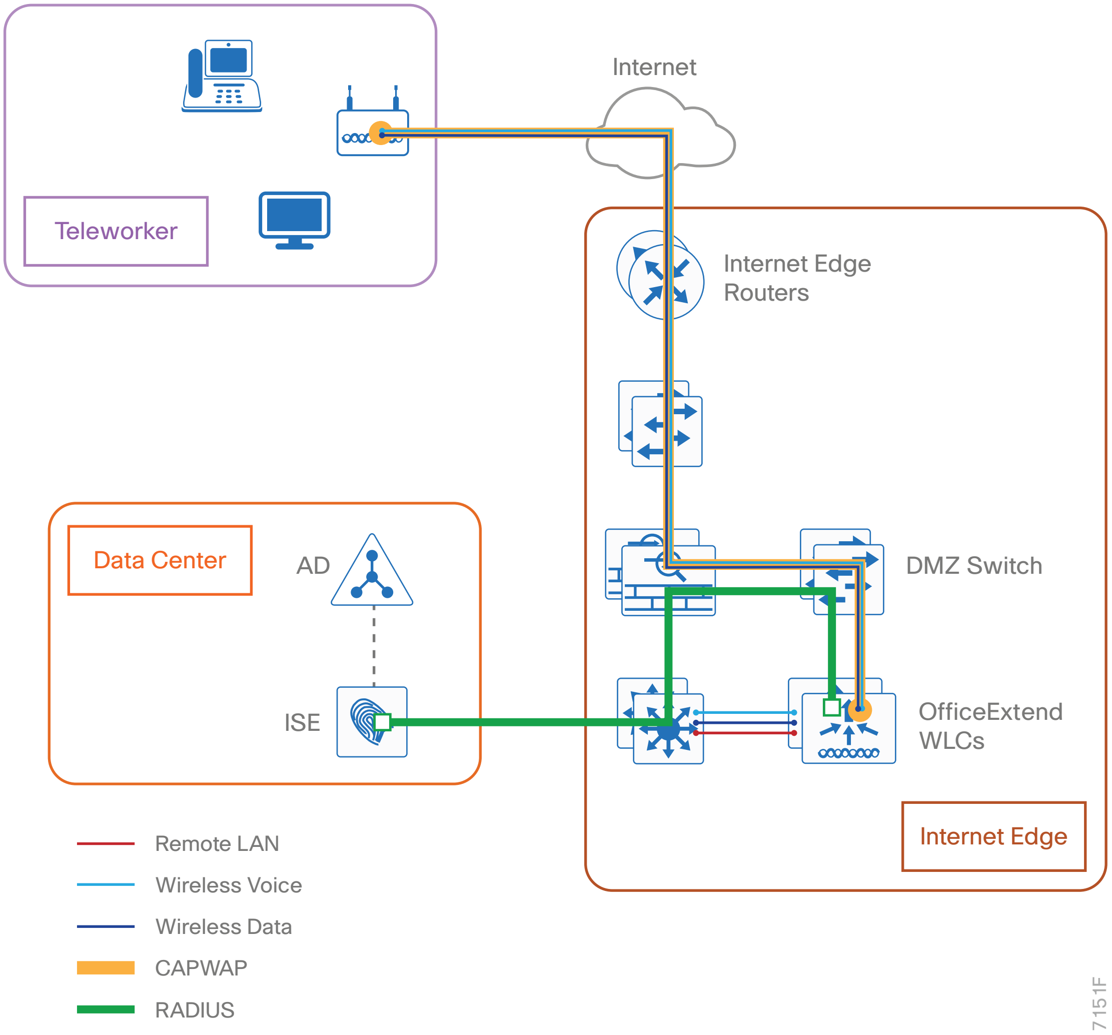
The Cisco Aironet 1810W Series OfficeExtend Access Point is lightweight, meaning it cannot act independently of a WLAN controller. To offer remote WLAN connectivity by using the same profile as at the corporate office, the AP validates all traffic against centralized security policies. By using WLAN controllers for the centralization of policies, Cisco OfficeExtend minimizes the management overhead associated with home-based firewalls. A datagram transport layer security connection secures communications between the AP and the WLAN controller.

Cisco OfficeExtend delivers 802.11ac wireless performance and avoids congestion caused by residential devices because it operates simultaneously in the 2.4-GHz and the 5-GHz RF bands. The AP also provides wired Ethernet connectivity in addition to wireless. The Cisco OfficeExtend Access Point provides wired and wireless segmentation of home and corporate traffic, which allows for home device connectivity without introducing security risks to corporate policy.

OfficeExtend Design Models

For the most flexible and secure deployment of Cisco OfficeExtend, deploy a dedicated controller pair for Cisco OfficeExtend using the Cisco 5500 or 3500 Series Wireless LAN Controllers. In the dedicated design model, the controller is directly connected to the Internet edge DMZ and traffic from the Internet is terminated in the DMZ (as opposed to on the internal network), while client traffic is still directly connected to the internal network.

Figure 16 *Cisco OfficeExtend dedicated design model*



Multicast Domain Name Services and Bonjour Gateway

Bonjour is Apple's zero-configuration protocol for advertising, discovering, and connecting to network services such as file sharing, print sharing, and media sharing. The Bonjour protocol was originally designed for home network use and uses multicast domain name services (mDNS) via link-local multicasting to share network services. Although this approach works well in home networks, a limitation of link-local multicasting is that these network services will only be shared within a single Layer 2 domain (such as a VLAN or WLAN). In a WLAN enterprise scenario, you use different WLANs and VLANs for different classes of devices, including corporate devices, employee devices, personal devices, and guest devices (as well as quarantine WLANs for unapproved devices). As such, basic Bonjour operations—such as printing to a wired printer from a WLAN—may not be natively supported.

To address this limitation and to meet user demand for BYOD Apple devices within the enterprise, Cisco developed the Bonjour Gateway feature for its WLCs. This feature solves the Layer 2 domain limitation for Bonjour by allowing the WLC to snoop, cache, and proxy-respond to Bonjour service requests that may reside on different Layer 2 domains. Additionally, these responses may be selectively controlled by administrative policies, so that only certain Bonjour services will be permitted in specific Layer 2 domains.

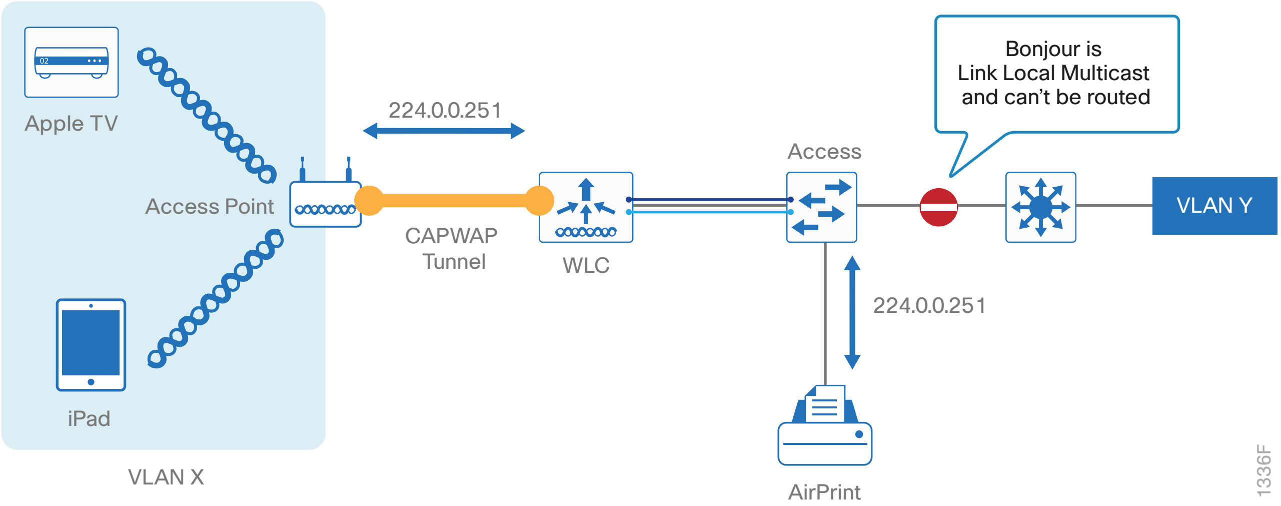
The Bonjour protocol uses mDNS queries. These queries are sent over UDP port 5353 to these reserved group addresses:

- IPv4 Group Address: 224.0.0.251
- IPv6 Group Address: FF02::FB

It is significant to highlight that mDNS addresses used by Bonjour are link-local multicast addresses and are only forwarded within the local Layer 2 domain, because link-local multicast is meant to stay local by design. Furthermore, routers cannot even use multicast routing to redirect the mDNS queries, because the time-to-live (TTL) of these packets is set to 1.

Bonjour was originally developed for typical home networks, with a single Layer 2 domain, where this link-local limitation of mDNS rarely posed any practical deployment constraints. However, in an enterprise campus deployment—where large numbers of wired and wireless Layer 2 domains may exist—this limitation severely limits Bonjour functionality, because Bonjour clients only see locally-hosted services and do not see or connect to services hosted on other subnets. This link-local multicast limitation of Bonjour mDNS is illustrated in the following figure.

Figure 17 *Bonjour deployment limitation in enterprise networks*



The Bonjour Gateway feature (the mDNS gateway feature most often enabled for Bonjour) snoops and caches all Bonjour service advertisements across multiple VLANs and can be configured to selectively reply to Bonjour queries.

Bonjour Gateway Service Policy Deployment Options

A key functional advantage of the Bonjour gateway is that it can be configured to selectively reply to Bonjour service requests, thus allowing for administrative control of Bonjour services within the enterprise. Bonjour policies can be applied on the following basis:

- Per WLAN
- Per VLAN
- Per Interface/Interface-Group

Cisco Application Visibility & Control

The Cisco Application Visibility and Control (AVC) solution—already supported on Cisco routing platforms such as the Cisco ASR 1000 and Cisco ISR—is available on WLC platforms, including the Cisco 3500, 5500, and 8500 WLCs in central switching mode.

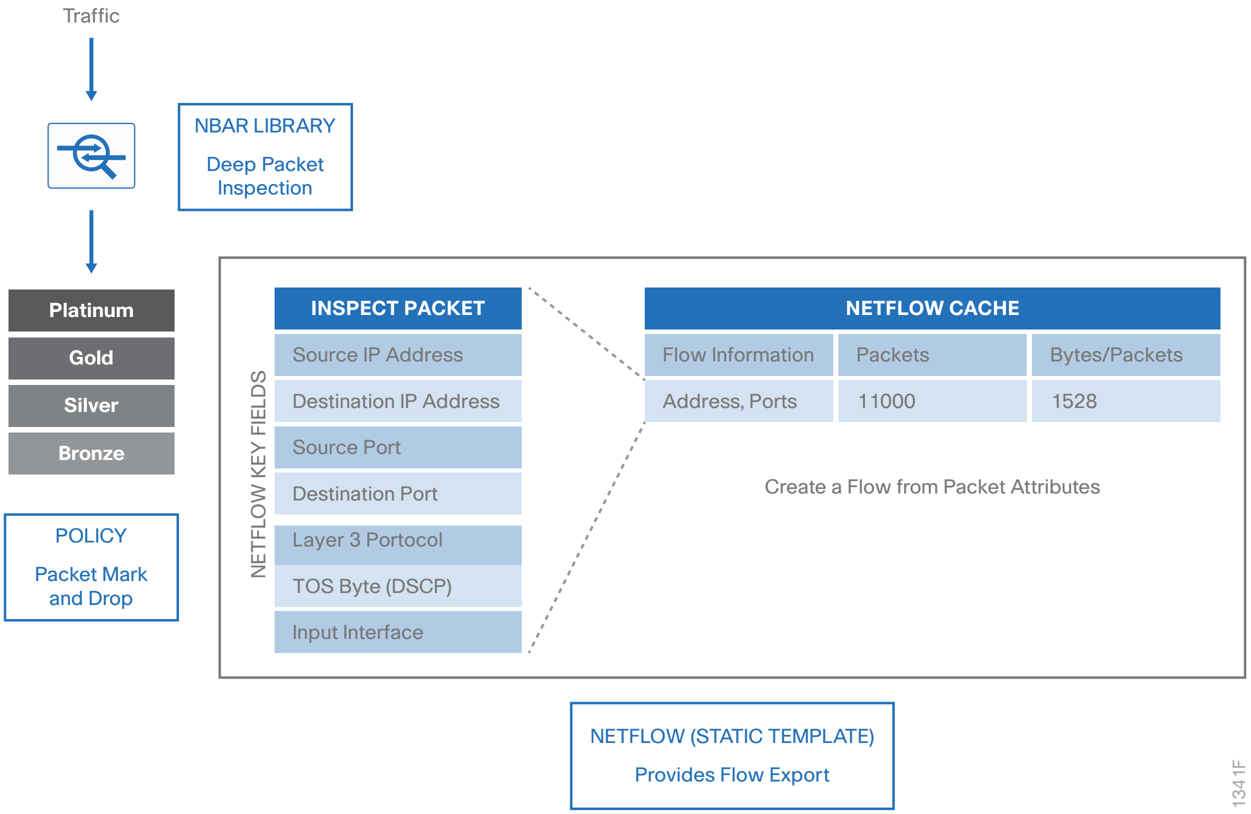
The Cisco AVC feature set increases the efficiency, productivity, and manageability of the wireless network. Additionally, the support of AVC embedded within the WLAN infrastructure extends Cisco's application-based QoS solutions end-to-end.

AVC includes these components:

- Next-generation deep packet inspection (DPI) technology called *Next Generation Network-Based Application Recognition* (NBAR2), which allows for identification and classification of applications. Available on Cisco IOS-based platforms, NBAR2 is a deep-packet inspection technology that includes support of stateful L4-L7 classification.
- Ability to remark applications using DiffServ, which you can then use to prioritize or de-prioritize applications for QoS treatment over both the wired and wireless networks.
- A template for Cisco NetFlow v9 to select and export data of interest to Cisco PI or a third-party NetFlow collector to collect, analyze, and save reports for troubleshooting, capacity planning, and compliance purposes.

These AVC components are shown in the following figure.

Figure 18 Cisco AVC components



Cisco AVC on the WLC inherits NBAR2 from Cisco IOS that provides DPI technology in order to classify stateful L4-L7 application classification. This is critical technology for application management because it is no longer a straightforward matter of configuring an access list based on the TCP or UDP port number(s) to positively identify an application. In fact, as applications have matured—particularly over the past decade—an ever-increasing number of applications have become opaque to such identification. For example, HTTP protocol (TCP port 80) can carry thousands of potential applications within it and in today's networks seems to function more as a transport protocol, rather than as the OSI application-layer protocol that it was originally designed to be. Therefore, to identify applications accurately, DPI technologies such as NBAR2 are critical.

After the NBAR engine recognizes applications by their discrete protocol signatures, it registers this information in a Common Flow Table so that other WLC features can leverage this classification result. Features include QoS, NetFlow, and firewall features, all of which can take action based on this detailed classification.

Cisco AVC provides:

- Application Visibility on the Cisco WLC by enabling Application Visibility for any WLAN configured. Once you turn Application Visibility on, the NBAR engine classifies applications on that particular WLAN. You can view Application Visibility on the WLC at an overall network level, per WLAN or per client.
- Application Control on the Cisco WLC by creating a AVC profile (or policy) and attaching it to a WLAN. The AVC Profile supports QoS rules per application and provides the following actions to be taken on each classified application: Mark (with DSCP), Permit (and transmit unchanged) or Drop.

Key business use cases for Cisco AVC include:

- **Classifying and marking wireless mobile device applications**—Identifying and differentiating real-time voice, video, or business-critical applications from less important (but potentially bandwidth-hungry) applications in order to prioritize, de-prioritize, or drop specific application traffic.
- **Capacity planning and trending**—Baselining the network to gain a clearer understanding of what applications are consuming bandwidth and trending application use in order to help network administrators plan for infrastructure upgrades.

Wireless Intrusion Prevention System

The Cisco wIPS solution offers a flexible and scalable, 24x7x365-based full time wireless security solution to meet each customer's needs. Security is a huge factor in today's WLAN deployments, and Cisco wIPS system is designed to meet all Layer 1, 2, and 3 security challenges of a WLAN deployment. Using a Cisco solution of a WLC, PI, and MSE with context aware location services, wIPS can locate, mitigate, and contain attacks in campus environments. The various types of attacks that wIPS can support are shown.

Table 8 wIPS attacks and Cisco solution

wIPS attacks and threats	Cisco solution
On-wire attacks Rogue wireless APs Ad-hoc wireless bridge	WLC, PI, and MSE with Context-Aware detects, locates, mitigates, and contains these attacks.
Over-the-Air Attacks Evil twin/honey pot AP Denial of service Reconnaissance Cracking tools	WLC, PI, and MSE with a wIPS detect and send alerts for these attacks.
Non-802.11 Threats Tampered rogues Bluetooth, microwave RF jammers	CleanAir AP, WLC, PI and MSE with Context-Aware detects locates and sends an alert for these attacks.

On-wire Attacks

An AP in wIPS-optimized mode will perform rogue threat assessment and mitigation by using the same logic as current Cisco Unified Wireless Network implementations. This allows a wIPS AP to scan, detect, and contain rogue APs and ad hoc networks. Once discovered, this information regarding rogue wireless devices is reported to Cisco PI, where rogue alarm aggregation takes place. However, with this functionality comes the caveat that if a containment attack is launched using a wIPS mode AP, its ability to perform methodical attack-focused channel scanning is interrupted for the duration of the containment.

Over-the-Air Attacks

Cisco Adaptive wireless IPS embeds complete wireless threat detection and mitigation into the wireless network infrastructure to deliver the industry's most comprehensive, accurate, and operationally cost-effective wireless security solution.

Non-802.11 Threats

Cisco CleanAir technology detects non-802.11 threats. CleanAir technology is an effective tool to monitor and manage your network's RF conditions. Cisco MSE extends those capabilities.

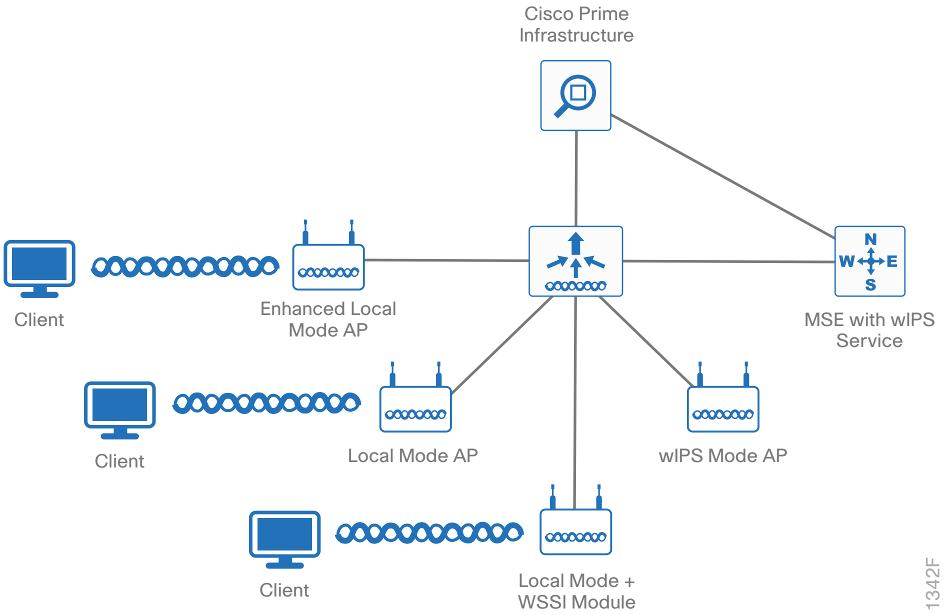
Cisco Adaptive wIPS system

The basic system components for a Cisco Adaptive wIPS system include:

- APs in Cisco wIPS monitor mode, in enhanced local mode, or with Cisco WSM
- WLAN controller(s)
- Cisco MSE running the Cisco wIPS service
- Cisco Prime Infrastructure

An integrated wIPS deployment is a system design in which non-wIPS mode APs and wIPS mode APs are intermixed on the same controller(s) and managed by the same Prime Infrastructure. This can be any combination of local mode, FlexConnect mode, enhanced local mode, monitor mode, and modular APs that support the WSM. By overlaying wIPS protection and data shares using WSM on the APs, you can reduce infrastructure costs.

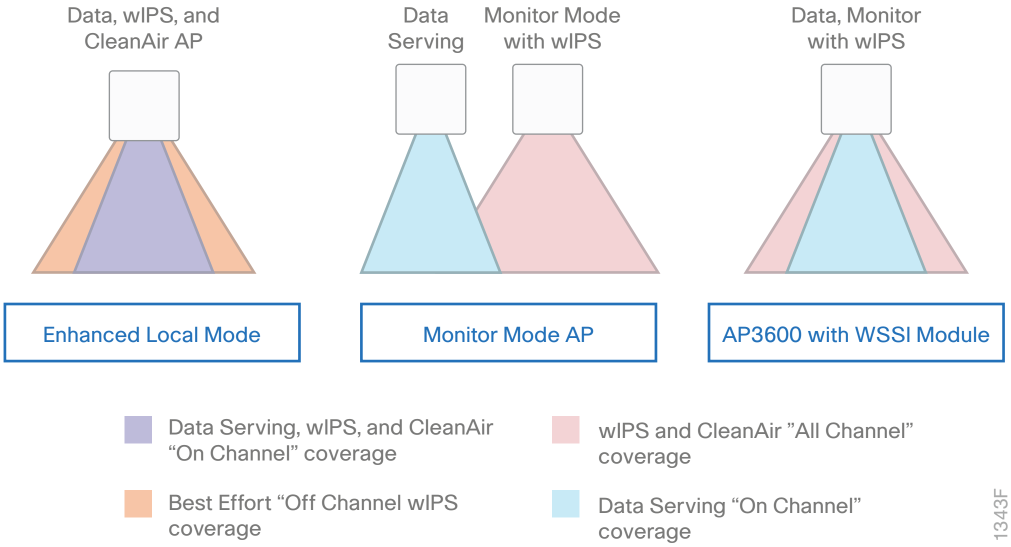
Figure 19 *wIPS operation with Cisco MSE*



wIPS Deployment Modes

Cisco Adaptive Wireless IPS has three options for wIPS mode APs. To better explain the differences between the wIPS mode APs, this section describes each mode.

Figure 20 *wIPS operation modes*


Data, wIPS, and CleanAir AP
Data Serving
Monitor Mode with wIPS
Data, Monitor with wIPS
Enhanced Local Mode
Monitor Mode AP
AP3600 with WSSI Module
Data Serving, wIPS, and CleanAir "On Channel" coverage
Best Effort "Off Channel wIPS coverage
wIPS and CleanAir "All Channel" coverage
Data Serving "On Channel" coverage
1343F

Enhanced Local Mode

ELM provides wIPS detection *on-channel,* which means attackers are detected on the channel that is serving clients. For all other channels, ELM provides best-effort wIPS detection. This means that every frame the radio will go off-channel for a short period of time. While the radio is off-channel, if an attack occurs while that channel is scanned, the attack will be detected.

As an example of enhanced local mode on a 3800 Series AP, assume the 2.4 GHz radio is operating on channel 6. The AP will constantly monitor channel 6 and any attacks on channel 6 will be detected and reported. If an attack occurs on channel 11 while the AP is scanning channel 11 off-channel, the attack will be detected.

ELM features include:

- wIPS security scanning for 7x24 on- channel scanning (2.4 GHz and 5 GHz), with best effort off-channel support.
- AP additionally serving clients and with Cisco Aironet 2nd generation (G2) Series Access Points, CleanAir spectrum analysis is enabled on-channel (2.4 GHz and 5 GHz).
- Adaptive wIPS scanning in the data channel serving local and FlexConnect APs.
- Protection without requiring a separate overlay network.
- Support for PCI compliance for the WLANs.
- Full 802.11 and non-802.11 attack detection.
- Forensics and reporting capabilities.
- Flexibility to set integrated or dedicated Monitor Mode APs.
- Pre-processing at APs, which minimizes data backhaul (that is, works over very low bandwidth links).
- Low impact on the AP serving client data.

Monitor Mode

Monitor mode provides wIPS detection off-channel, which means the AP will dwell on each channel for an extend period of time, allowing the AP to detect attacks on all channels. The 2.4 GHz radio scans all 2.4 GHz channels, while the 5 GHz channel scans all 5 GHz channels. An additional AP would need to be installed for client access.

Some of the features of monitor mode:

- The monitor mode access point (MMAP) is dedicated to operate in monitor mode and can optionally add wIPS security scanning of all channels (2.4 GHz and 5 GHz).
- For Cisco Aironet G2 Series APs, CleanAir spectrum analysis is enabled on all channels (2.4 GHz and 5 GHz).
- MMAPs do not serve clients.
- A Cisco AP with the WSM module uses a combination of on-channel and off-channel operation. This means that the AP 2.4 GHz and 5 GHz internal radios will scan the channel with which they are serving clients and the WSM module will additionally operate in monitor mode and scan all channels.

Rogue Detection

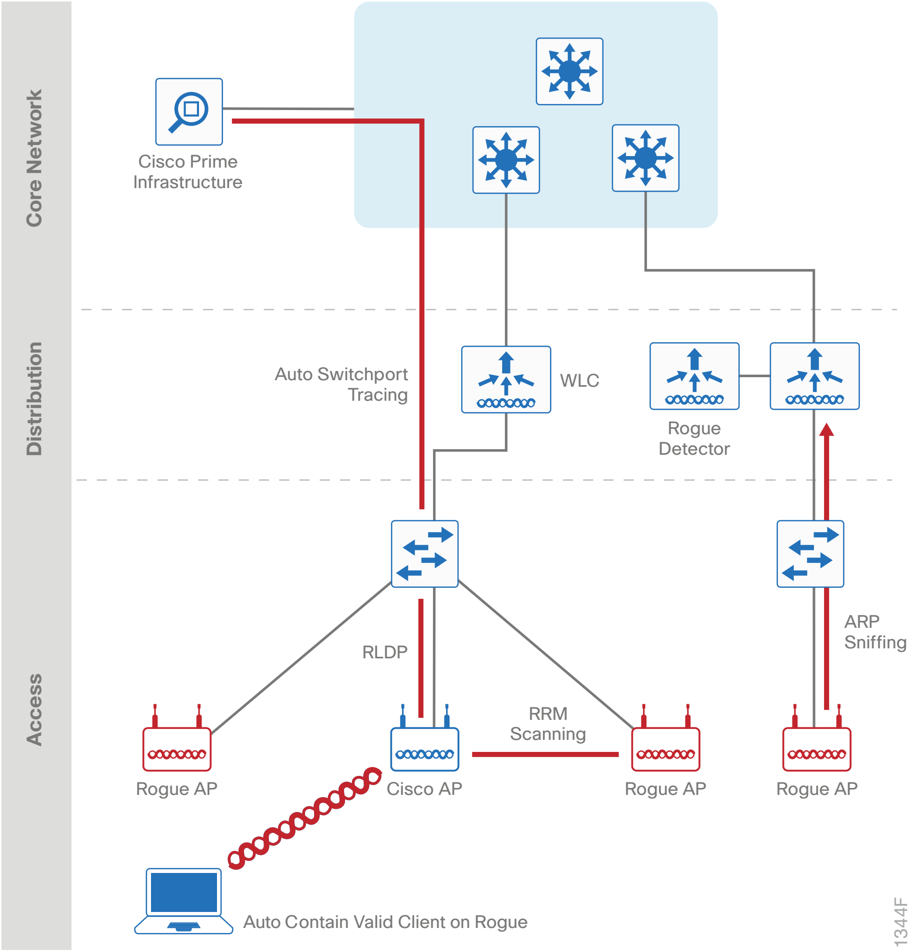
You can regard any device that shares your spectrum and that you are not managing as a rogue device. A rogue becomes dangerous in the following scenarios:

- Rogue AP with the same SSID as your network (honeypot)
- Rogue AP device also on the wired network
- Ad-hoc rogues
- Rogues set up by an outsider with malicious intent

There are three main phases of rogue device management in the CUWN solution:

- **Detection**—The solution uses RRM scanning in order to detect the presence of rogue devices.
- **Classification**—The solution uses rogue location discovery protocol, rogue detectors, and switch port tracing in order to identify whether the rogue device is connected to the wired network. Rogue classification rules also assist in filtering rogues into specific categories based on their characteristics.
- **Mitigation**—The solution used switch port trace and shutting down, rogue location, and rogue containment in order to track down physical location and nullify the threat of rogue devices.

Figure 21 Cisco rogue management



For additional information about a range WLAN controller versions, visit cisco.com and search for "Wireless Rogue Management."

Radio Resource Management

To optimize efficiency, RRM software embedded in the Cisco Wireless LAN Controller acts as a manager to constantly monitor over-the-air metrics and control the RF transmitted. It measures:

- **Signal**—Your own APs belonging to the same RF network.
- **Interference**—Other 802.11 devices operating nearby that can be heard by your network.
- **Noise**—Any energy in the RF spectrum that cannot be demodulated as 802.11 protocol.
- **Load**—Instantaneous user load on the network.
- **Coverage**—The RSSI and signal-to-noise ratio estimated by the system for clients attached to your network.

Using this information, RRM can periodically reconfigure the 802.11 RF network for best efficiency. To do this, RRM performs these functions:

- **Radio resource monitoring**—Collecting the metrics
- **Transmit power control**—Adjusting for optimal power levels
- **Dynamic channel assignment (DCA)**—Ensuring that channel assignments do not overlap
- **Coverage hole detection and correction**—Ensuring that you have adequate coverage and detecting clients that may be in a coverage hole

RRM automatically detects and configures new Cisco WLCs and lightweight APs as they are added to the network. It then automatically adjusts associated and nearby lightweight APs to optimize coverage and capacity.

For more detailed information about what RRM does and how it takes its measurements, visit cisco.com and search for the latest Radio Resource Management White Paper.

Transmit Power Control

The Cisco WLC dynamically controls AP transmit power based on real-time WLAN conditions. You can choose between two versions of transmit power control: TPCv1 and TPCv2. With TPCv1, typically power can be kept low to gain extra capacity and reduce interference. With TPCv2, transmit power is dynamically adjusted with the goal of minimum interference. TPCv2 is suitable for dense networks. TPCv1 is the default setting and is well suited for use in most deployments.

Overriding the TPC Algorithm with Minimum and Maximum Transmit Power Settings

The TPC algorithm balances RF power in many diverse RF environments. However, it is possible that automatic power control will not be able to resolve some scenarios in which an adequate RF design was not possible to implement due to architectural restrictions or site restrictions—for example, when all APs must be mounted in a central hallway, placing the APs close together but requiring coverage out to the edge of the building.

In these scenarios, you can configure maximum and minimum transmit power limits to override TPC recommendations. The maximum and minimum TPC power settings apply to all APs belonging to the same AP Group through use of an RF profile. When used as a global configuration option, the settings apply to all APs attached to the specific controller.

If you configure a minimum transmit power, RRM does not allow any AP attached to the controller to go below this transmit power level, regardless of which function is directing the power change (RRM TPC or coverage hole detection). For example, if you configure a minimum transmit power of 11 dBm, then no AP will transmit below 11 dBm, unless the AP is configured manually and no longer under control of RRM.

For additional details about the TPC algorithm that is part of RRM, visit cisco.com and search for the latest Radio Resource Management White Paper.

Dynamic Channel Assignment

The 802.11 specification defines multiple channels for operation. The channels are essentially different frequency ranges that are non-overlapping and can be assigned using a channel designator. The behavior is analogous to lanes on a highway—you only get the full benefit of the lane if it is completely separate from another lane on the same highway. If the lanes overlap each other (or worse, merge into a single lane), then the highway slows to a crawl.

Channels in an RF network work similarly. However, there is an additional consideration of power, equivalent to making lane wider or narrower (the coverage of the AP). The job of Dynamic Channel Assignment is to track the available lanes (channels), which differ by regulations depending on the country of installation. Secondly, DCA assigns channels to APs that do not conflict with channels already assigned. For a given AP, potential throughput is dependent upon interference free operation. DCA is aware of what channels on which you are allowed to operate and assigns these channels to be as interference-free as possible, based on over-the-air observations.

After all access points have been installed, it is a best practice to then calibrate DCA by invoking the RRM start-up mode. The RRM startup mode is invoked in the following conditions:

- In a single-controller environment, the RRM startup mode is invoked after a successful upgrade of the controller software; otherwise, it is manually initiated (see below).
- In a multiple-controller environment, the RRM startup mode is invoked after an RF Group leader has successfully upgraded the software; otherwise, it is manually invoked from the CLI.

You can trigger RRM startup mode from CLI, using the following command:

```
config 802.11a/b channel global restart
```

RRM startup mode runs for 100 minutes (10 iterations at 10-minute intervals). The startup mode consists of 10 DCA runs with high sensitivity and no dampening (making channel changes easy and sensitive to the environment) to converge to a steady state channel plan. After the startup mode is finished, DCA continues to run at the interval and sensitivity as specified by the organization.

For additional details about the DCA algorithm that is part of RRM, visit cisco.com and search for the latest Dynamic Channel Assignment White Paper.

Coverage Hole Detection and Correction

The RRM coverage hole detection algorithm can detect areas of weak radio coverage in a WLAN that are below the level needed for robust radio performance. This feature can alert you to the need for an additional (or relocated) lightweight AP.

If clients on a lightweight AP are detected at threshold levels lower than those specified in the RRM configuration, the AP sends a “coverage hole” alert to the controller. The thresholds include RSSI, failed client count, percentage of failed packets, and number of failed packets. The alert indicates the existence of an area where clients are continually experiencing poor signal coverage without having a viable AP to which to roam. The controller discriminates between coverage holes that can and cannot be corrected. For coverage holes that can be corrected, the controller mitigates the coverage hole by increasing the transmit power level for that specific AP. For clients that are making poor roaming decisions (referred to as "sticky clients"), the Coverage Hole Algorithm reports a false positive. The system validates to ensure that a client is heard better on another AP and is not unnecessarily moving to another AP for an arbitrary reason.

For additional details about the Coverage Hole detection and mitigation, visit cisco.com and search for the latest Coverage Hole Detection and Mitigation Algorithm discussion in the Radio Resource Management White Paper.

Benefits of RRM

RRM produces a network with optimal capacity, performance, and reliability. It frees you from having to continually monitor the network for noise and interference problems, which can be transient and difficult to troubleshoot. RRM ensures that clients enjoy a seamless, trouble-free connection throughout the Cisco unified wireless network.

BAND SELECT

Most consumer devices being released today operate in one or both of two frequency ranges, or *bands* Dual-band devices are quite common; however, the bands supported by the devices are not created equally. The properties and number of frequencies available for 2.4 GHz and 5 GHz devices differ significantly, with 5 GHz having as much as 8 times the available bandwidth as 2.4 GHz. Even so, the 2.4 GHz physical properties allow a device to be heard much further (1.5 times as much) than 5 GHz devices operating at the same power level.

Band Select allows identification of dual-band clients and helps the devices make informed decisions about which frequency range and AP to select. The system does this by simply not answering the 2.4 GHz probes from a client and by immediately answering the client when the client uses 5 GHz probes. This system behavior encourages clients to use the available superior bandwidth in 5 GHz and increases the overall network capacity.

Organizations are advised to enable Band Select in all environments. For more information on configuring Band Select, visit cisco.com and search for "Wireless Controller Configuration 802.11 Bands."

FLEXIBLE RADIO ASSIGNMENT

Flexible Radio Assignment (FRA) is a new feature that takes advantage of hardware choices available in the Cisco 2800/3800 series access points. Note from the Band Selection discussion that there are limitations to 2.4 GHz. If you are deploying APs for optimal 5 GHz coverage and density, you will likely have an unnecessarily high density of 2.4 GHz radios and their limited channel selection options, which will cause interference issues. FRA measures this and identifies APs whose 2.4 GHz radio can be selectively assigned to a role that optimizes the use of the RF spectrum.

FRA first identifies redundant APs and then manages changing the single XOR radio to another band. FRA relies on capable hardware as well as existing DCA in order to manage the switching of interface roles. FRA also provides a new metric, Coverage Overlap Factor, that admins can use to manually select and configure redundant radios within the deployment.

For a campus admin deploying Cisco 2800i/3800i models, FRA in auto mode is very conservative and will do a fine job of ensuring that coverage is dense enough without driving it to levels where interference again becomes a problem.

For those deploying Cisco 2800i/3800i models, the recommendation is to leave the APs in auto-FRA and enable auto-FRA from the GUI.

For additional details about configuring FRA, visit cisco.com and search for "Flexible Radio Assignment and Redundant Radios."

CISCO CLIENTLINK

Cisco ClientLink wireless networking technology uses beamforming in order to improve the signal-to-noise ratio for all wireless clients and is not limited to those that support the 802.11n standard (which has minimal client implementation adoption) or the 802.11ac standard.

All Cisco 2800 Series and 3800 APs support Cisco ClientLink, which is automatically enabled and provides for a higher perceived signal-to-noise ratio for all clients (even legacy 802.11a,b,g). As a result, the network enables higher data rates and increased airtime efficiency. In short, communication is faster, so more time is available for all.

ClientLink is a Cisco innovation available since 2010 to make 802.11 networks more robust. The ClientLink implementation is unique because it has no requirement for client-side support, which means it does not rely upon the client manufacturer to implement anything to achieve the ClientLink benefits.

A client-side standard was introduced for beamforming with 802.11n; however, the standard was never widely implemented in the market. With 802.11ac, client-side beamforming is a requirement that is well supported, but only for the newest certified clients. ClientLink bridges the support gap and allows for all clients to see benefits in performance.

For additional details about ClientLink, visit cisco.com and search for "Cisco ClientLink: Optimizing Device Performance with 802.11n."

DYNAMIC BANDWIDTH SELECTION—DBS

With the introduction of 802.11n, and later with 802.11ac Wave 1 and Wave 2, you have the ability to use multiple channels together as a single assignment on a given AP. This increases the amount of bandwidth available for a given channel and improves the throughput and apparent speed perceived by the client. However, to use these combined channels, an AP and a client must both support the capability, which is not the possible with 802.11n clients. Feature-sparse clients and almost all 802.11n smartphones are limited to a 20 MHz channel width; whereas an 802.11ac client must support up to 80 MHz channel width in order to be certified.

The clients in most networks today are largely 802.11n devices, along with some 802.11ac clients. This mixed environment is expected to be common for some time yet in the market.

Bonding channels—using multiple single channels to create a single super channel—has the advantage of providing more usable throughput to a client with the capability to use the channel. However, in using multiple channels to create a single one, larger chunks of the spectrum are consumed, decreasing the overall number of non-interfering channels to use with DCA. This can result in aggressive channel re-use if there are enough APs (each one requires an operating channel) and increased co-channel interference (the very opposite of efficiency).

Dynamic Bandwidth Selection works with the DCA algorithm to monitor the APs and the client types and capabilities using the APs. Based on this analysis, DBS assigns appropriate channel widths to APs to dynamically balance the bandwidth selection for the types of clients and traffic that each AP uses.

DBS allows appropriately sized bandwidth to be used for the clients being served, avoids wasting multiple channels for devices that likely could not use the added capacity, and avoids the associated interference created by those devices. For these reasons, you should run DCA in DBS mode.

For additional details, visit cisco.com and search for "High Density Experience (HDX) Deployment Guide."

CAMPUS WIRELESS CLEANAIR

Cisco CleanAir is a spectrum intelligence solution—designed to proactively manage non-Wi-Fi interference—that also operates in the 2.4 and 5 GHz spectrums. Many consumer devices also use the same frequencies that you use in 802.11 Wi-Fi. Devices such as Bluetooth headsets, microwave ovens, and many new IOT devices use different protocols but occupy the same frequencies required for operation of the WLAN.

Cisco CleanAir is an innovation available only when implemented in the silicon of CleanAir-capable APs. CleanAir is dedicated to detecting and identifying sources of interference that otherwise would simply appear as noise to a Wi-Fi chipset.

All Cisco 2800 Series and 3800 Series APs include the CleanAir chipset. The technology was released in 2010 and has continuously adapted to keep pace with the market and changing nature of the WLAN spectrum. CleanAir monitors the full channel bandwidth capability of a CleanAir-capable AP regardless of the deployment requirements, and as a result, it monitors the range of 20 MHz-160 MHz channels.

CleanAir can report analysis and findings through the WLAN controller. You can use certain CMX implementations and Cisco Prime to map both the interference and the impact of the interference for easy analysis and troubleshooting.

At the controller level, you can use two mitigation strategies to help maintain your network and prevent outages associated with common non-Wi-Fi interference sources:

- **Persistent Interference Avoidance**—Allows the WLC to track and report non-Wi-Fi interferers to DCA. For instance, there may be a microwave oven that becomes quite active around lunchtime every day. Persistent Interference Avoidance remembers this device and instructs DCA to pick channels for the affected APs that will not be interfered with by this periodic interference source.
- **ED-RRM**—Helps mitigate disruptions from interference sources (perhaps a video camera) that use 100% of the available airtime when enabled. Because this interference is not recognizable as anything other than noise to the 802.11 chipset, all clients and APs typically wait for the channel to become less busy. ED-RRM provides a safety net by doing two things:
    - Recognizing that something is not noise but instead is intentionally transmitting and interfering with the network operations.
    - Forcing the AP away from the problematic channel to a channel where operations can resume. The resolution is very fast acting (30 seconds or less), and the information about the interference is incorporated into RRM through DCA, alerting DCA about interference disruptions related to the channel just abandoned.

As a best practice, you should enable CleanAir, Persistent Device Avoidance, and ED-RRM.

For additional details, visit cisco.com and search for the Cisco CleanAir Technology: Intelligence in Action White Papers.

SECURE WLANS

Wireless devices should connect to the network infrastructure securely where possible. In an enterprise environment, you should configure WLANs to support WPA2 with AES-CCMP encryption, and 802.1x authentication of devices. This is sometimes referred to as WPA Enterprise on wireless devices. Most modern wireless devices support WPA2. The use of older security methods, such as WEP or WPA, is not recommended due to known security vulnerabilities. 802.1x authentication requires an AAA server—such as Cisco ISE—that provides centralized policy-based management and control for end-users accessing the wireless network.

Typically the AAA server will implement the RADIUS protocol between itself and the WLC. Authentication of end-users is accomplished via an extensible authentication protocol (EAP) session between the wireless device and the AAA server. The EAP session is transported via RADIUS between the WLC and the AAA server. Depending upon the capabilities of wireless device, the capabilities of the AAA server, and the security requirements of the organization, multiple variants of EAP, such as PEAP and EAP-TLS, may be implemented. PEAP makes use of standard user credentials (userid & password) for authentication. EAP-TLS makes use of digital certificates for authentication.

It is highly recommended that you deploy redundant AAA servers for high availability in case one or more servers become temporarily unavailable. Often the AAA server is configured to reference an external directory or data store such as Microsoft's Active Directory (AD). This allows the network administrator to leverage existing AD credentials instead of duplicating them within the AAA server. This can also be extended to provide role-based access control (RBAC) for end-users through the use of AD groups. For example, it may be desirable to provide restricted network access to long-term contractors, as opposed to the access granted employees. The use of an external directory or data store can also provide a single point for granting or revoking credentials, not only for access to the network infrastructure, but for access to other resources within the organization. The AAA server itself can apply additional policy-based rules for authorization to the network, such device type, time of day, location, etc., depending upon the capabilities of the AAA server. AAA logs and accounting may be used to provide an audit trail of each employee's access to the wireless network infrastructure.

The use of WPA2 with AES-CCMP encryption on the WLAN does not extend to management frames. Therefore, the optional use of protected management frames (PMF) is advisable for WLANs where possible. PMF is part of the IEEE 802.11 standard, which provides a level of cryptographic protection to robust management frames such as de-authentication and dissociation frames, preventing them from being spoofed. It should be noted that the benefits of PMF does require wireless clients to support PMF. Cisco also offers an earlier version of Management Frame Protection (MFP) that has both infrastructure and client components.

In a home-office environment, it may be necessary to configure a WLAN to support WPA2 with pre-shared key (PSK). This is sometimes referred to as *WPA Personal* on wireless devices. This may be necessary because the implementation of an AAA server is not cost-effective for the number of end-users who access the WLAN. This may also be necessary in other environments if there is no end-user associated with a wireless device, the wireless device does not support the ability to configure a userid & password, or the wireless device cannot support a digital certificate. Since the PSK is shared among all devices that access the wireless infrastructure, it may be necessary to change the PSK if an employee who knows the PSK leaves the organization. Furthermore, with WPA PSK, there is no easy audit trail of each employee's access to the network.

The use of a dedicated, open WLAN is still common, but not ideal, for wireless guest access. Therefore, the configuration of an unsecure WLAN on the network infrastructure may still be necessary. Open access guest WLANs are often implemented in order to minimize the complexity of onboarding a guest who needs only temporary wireless network connectivity. Typically, the guest WLAN is terminated outside the corporate firewall, which allows no access inbound to corporate resources, so guests may be allowed access to the Internet only. Depending upon the requirements of the organization, guests may be required to authenticate before being allowed to access the Internet. Typically, a captive-portal model is used with WebAuth, in which guest web sessions are redirected to a portal, which authenticates the guest before allowing Internet access.

Administrative Access Control

It is recommended that you implement secure administrative access control to wireless infrastructure components in order to mitigate against unauthorized access. You can typically implement administrative access control via the local user database in each infrastructure device, or via a centralized AAA server—such as Cisco ISE.

For a small number of network infrastructure devices, configuring individual local administrator accounts on each infrastructure device may be acceptable. It is recommended that the number of administrators be limited and that each administrator have a unique account. A shared administrator account limits the ability to audit who accessed a particular network device and potentially made configuration changes. When employees leave the organization, or move to other groups, their administrative access should be immediately revoked. With individual administrator accounts, only the account for the particular employee needs to be revoked.

As the number of infrastructure devices within the network grows, the administrative burden of configuring individual local administrator accounts on each infrastructure device can become unmanageable. It is therefore recommended that you control administrative access via an AAA server, which provides centralized policy-based management and control. It is recommended that you deploy redundant AAA servers for high availability in case one or more servers become temporarily unavailable. Network administrators may still configure an individual local administrator account on each infrastructure device for local access via the console port, should all network access to the infrastructure device be lost.

The AAA server may itself reference an external directory or data store such as AD. This allows the network administrator to leverage existing AD credentials instead of duplicating them within the AAA server. This can also be extended to provide RBAC for administrators through the use of AD groups. The use of an external directory or data store can also provide a single point to grant or revoke credentials, not only for administrative access control to multiple infrastructure devices, but for access to other resources within the organization.

Where possible, the selection of a strong password—consisting of a minimum length, and combination of letters, numbers, and/or special characters—should be enforced. Where possible, a maximum number of unsuccessful attempts to access the device, before the account is disabled for a period of time, should also be enforced. Successful and unsuccessful attempts should be logged either locally or to a central logging server. This helps mitigate against (and/or alert appropriate network operations staff about) brute force attempts to gain access to infrastructure devices. Where multiple levels of administrative access are supported, it is recommended you enforce them, with administrators having the minimum access level required for performing their respective tasks. It is also recommended that you limit the number of concurrent logins from a single username.

It may be advantageous to limit where access to the wireless infrastructure device is initiated from and what protocols are allowed. You can accomplish this in multiple ways. For example, you can deploy the management interface of WLAN controllers on a separate VLAN (and therefore a separate IP subnet) from wireless client traffic. In such a deployment, an access-control list (ACL) deployed on the Layer 3 switch adjacent to the WLAN controller can limit access to the management interface. This shifts the CPU burden of an ACL off the WLAN controller to the Layer 3 switch. Alternatively, you can configure a CPU ACL on the WLAN controller to filter management protocols. You can also disallow management of the WLAN controller via a wireless device, a method that may also provide additional security if the intention is to manage the wireless infrastructure from a central network operations center.

Access to wireless infrastructure devices should be via secure protocols such as HTTPS and SSHv2 where possible. Access via non-encrypted protocols such as HTTP and Telnet should be disabled where possible. This protects the confidentiality of the information within the management session. When using SNMP, it is recommended that you enable SNMPv3 where possible. SNMPv2c relies on a shared community string that is sent in clear text across the network. Take caution when using SNMPv2c, particularly when using SNMP for read/write access. SNMPv3 uses unique credentials (userid/password) and can also provide encryption and data authentication services to SNMP traffic.

Local Profiling

Cisco ISE currently offers a rich set of features that provide device identification, onboarding, posture, and policy. As an alternative, local profiling on the WLC does the profiling of devices based on protocols such as HTTP and DHCP in order to identify the end devices on the network. The user can configure the device-based policies and enforce per user or per device policy on the network. The WLC will also display statistics based on per-user or per-device endpoints and policies applicable per device. With local profiling you can implement BYOD on a small scale within the WLC itself.

The profiling and policy enforcement are configured as two separate components. The configuration on the WLC is based on defined parameters specific to clients joining the network. The policy attributes that are of interest are:

- **Role**—Defines the user type or the user group to which the user belongs (Examples: Student or Employee)
- **Device**—Defines the type of device (Examples: Windows machine, smart phone, or Apple device)
- **Time of day**—Allows configuration to be defined at the time-of-day that endpoints are allowed on the network
- **EAP Type**—Checks the EAP method used by the client

The above parameters are configurable as policy match attributes. After the WLC has a match corresponding to the above parameters per end-point, the policy enforcement comes into picture. Policy enforcement will be based on session attributes such as:

- VLAN
- ACL
- Session timeout
- QoS
- Sleeping client
- FlexConnect ACL
- AVC profile (added in 8.0 release)
- mDNS profile (added in 8.0 release)

The user can configure these policies and enforce end-points with specified policies. The wireless clients are profiled based on the MAC OUI, DHCP, and HTTP user agent (valid Internet required for successful HTTP profiling). The WLC uses these attributes and predefined classification profiles to identify the device.

BEST PRACTICES CHECKLIST

For convenience of network deployment engineers, starting with CUWN (AireOS) software 8.1 release, a best practices checklist is available within the dashboard for WLAN controllers. The checklist is used to fine-tune WLC configuration to match the best practices as suggested by Cisco. The checklist compares the local configuration on the controller with recommended best practices and highlights all of the features that differ. The check also provides a simple configuration panel to turn on the best practices. Use of best practices is highly recommended for a WLAN deployment involving WLCs.

Common Components in Campus Designs

DEVICE MANAGEMENT USING CISCO ISE

Without a centralized access and identity policy enforcement point, it's difficult to ensure the reliability of a network as the number of network devices and administrators increases.

Cisco ISE operates as a centralized AAA server that combines user authentication, user and administrator access control, and policy control in a single solution. Cisco ISE uses a rule-based policy model, which allows for security policies that grant access privileges based on many different attributes and conditions in addition to a user's identity.

The capabilities of Cisco ISE coupled with an AAA configuration on the network devices reduce the administrative issues that surround having static local account information on each device. Cisco ISE can provide centralized control of authentication, which allows the organization to quickly grant or revoke access for a user on any network device.

Rule-based mapping of users to identity groups can be based on information available in an external directory or an identity store such as Microsoft Active Directory. Network devices can be categorized in multiple device groups, which can function as a hierarchy based on attributes such as location, manufacturer, or role in the network. The combination of identity and device groups allows you to easily create authorization rules that define which network administrators can authenticate against which devices.

These same authorization rules allow for privilege-level authorization, which can be used to give limited access to the commands on a device. For example, a rule can give network administrators full access to all commands or limit helpdesk users to monitoring commands.

CISCO DIGITAL NETWORK ARCHITECTURE CENTER

DNA Center is a controller for planning, preparation, installation, and integration. SD-Access is one of the many software application packages that run on DNA Center.

DNA Center centrally manages four major workflow areas.

- **Design**—Configures device global settings, network site profiles for physical device inventory, DNS, DHCP, IP addressing, software image management, plug-and-play, and user access.
- **Policy**—Defines business intent for provisioning into the network, including creation of virtual networks, assignment of endpoints to virtual networks, and policy contract definition for groups.
- **Provision**—Provisions devices for management and creates fabric domains, control plane nodes, border nodes, edge nodes, fabric wireless, CUWN wireless, and external connectivity.
- **Assurance**—Enables health scores dashboard, client/device 360° views, node, client, and path traces.

DNA Center supports integration using APIs. For example, Infoblox IP address management and policy enforcement integration with ISE are available through DNA Center. A comprehensive set of northbound REST APIs enables automation, integration, and innovation.

- All controller functionality is exposed through northbound REST APIs.
- Organizations and ecosystem partners can easily build new applications.
- All northbound REST API requests are governed by the controller RBAC mechanism.

DNA Center is key to enabling automation of device deployments into the network providing the speed and consistency required for operational efficiency. Organizations using DNA Center are able to benefit from lower cost and reduced risk when deploying and maintaining their networks.

CAMPUS DEPLOYMENT USING CISCO PRIME INFRASTRUCTURE

As networks and the number of services they support continue to evolve, the responsibilities of network administrators to maintain and improve their efficiency and productivity also grow. Using a network management solution can enable and enhance the operational efficiency of network administrators.

Cisco Prime Infrastructure is a sophisticated network management tool that can help support the end-to-end management of network technologies and services that are critical to the operation of your organization; it aligns network management functionality with the way that network administrators do their jobs. Cisco Prime Infrastructure provides an intuitive, web-based GUI that can be accessed from anywhere from within the network and gives you a full view of a network use and performance.

With a campus network and the services that it can support, Cisco Prime Infrastructure can play a critical role in day-to-day network operations.

Device Work Center

Cisco Prime Infrastructure includes the Device Work Center. Some of the features found in the Device Work Center are:

- **Discovery**—Builds and maintains an up-to-date inventory of managed devices, including software image information and device configuration details.
- **Configuration Archives**—Maintains an active archive of multiple iterations of configuration files for every managed device.
- **Software Image Management**—Enables a network administrator to import software images from Cisco.com, managed devices, URLs, or file systems, and then distribute them to a single device or group of devices.

Configuration Templates and Tasks

Using the Configuration Tasks feature to apply configuration templates to many devices, administrators can save many hours of work. Cisco Prime Infrastructure provides a set of templates and you can use them to create a configuration task, providing device-specific values as needed. For other configuration needs, Cisco Prime Infrastructure enables you to define your own templates.

Alarms, Events, and Syslog Messages

Cisco Prime Infrastructure provides the Alarms and Events feature, which is a unified display with detailed forensics. The feature provides actionable information and the ability to automatically open service requests with the Cisco Technical Assistance Center.

Reporting

Cisco Prime Infrastructure provides you a single launch point for all reports that you can configure, schedule, and view. The Report Launch Pad page provides access to over 100 reports, each of which you can customize as needed.

CleanAir Support

Cisco Prime Infrastructure supports the management of CleanAir enabled wireless APs, enabling administrators to see interference events.

Network Analysis Module Support

For increased visibility into your network, Cisco Prime Infrastructure supports management and reporting for Cisco Network Analysis Module products.

CAMPUS QUALITY OF SERVICE

Because real-time communication traffic is very sensitive to delay and drop, the network must ensure that this type of traffic is handled with priority so that the stream of audio or video is not interrupted. QoS is the technology that answers this need.

The primary role of QoS in rich-media campus networks is to manage packet loss, where high-bandwidth links with instantaneous congestion on the order of milliseconds can cause buffer overruns and a poor user experience. Another goal of campus QoS is to apply policies to at the edge to allow consistent treatment of traffic for a predictable user experience across the entire enterprise network.

QoS allows an organization to define different traffic types and to create more deterministic handling for real-time traffic. QoS is especially useful in congestion handling, where a full communications channel might prevent voice or video streams from being intelligible at the receiving side. Congestion is common when links are over-subscribed by aggregating traffic from a number of devices, and also when traffic on a link to a device has come from upstream links with greater bandwidth. Rather than creating bandwidth, QoS takes bandwidth from one class and gives it to another class.

Within the campus wired LAN, Cisco keeps the QoS profiles as simple as possible while ensuring support for applications that need special delivery. This approach establishes a solid, scalable, and modular framework to implement QoS across the entire network.

The primary goals of implementing QoS within the network are:

- Expedited delivery service of communications for supported, real-time applications.
- Business continuance for business-critical applications.
- Fairness among all other applications when congestion occurs.
- Deprioritized background applications and non-business entertainment-oriented applications so that these do not delay interactive or business-critical applications.
- A trusted edge around the network to guarantee that users cannot inject their own arbitrary priority values and to allow the organization to trust marked traffic throughout the network.

To accomplish these goals, the design implements QoS across the network as follows:

- Establish a limited number of traffic classes (that is, four to twelve classes) within the network that need special handling (for example, real-time voice, real-time video, high-priority data, interactive traffic, batch traffic, and default classes).
- Classify applications into the traffic classes.
- Apply special handling to the traffic classes to achieve intended network behavior.

To deploy QoS, use the EasyQoS feature in DNA Center to configure quality of service on the discovered devices in your network. EasyQoS allows you device-grouping and class-of-service assignment. Cisco DNA Center translates your QoS selections into proper device configurations and deploys the configurations to the devices.

For additional information, visit cisco.com and search for “EasyQOS”

Appendix—Glossary

3SS	three spatial streams
AAA server	authentication, authorization, and accounting server
ACL	access control list
ACS	Cisco Access Control Server
AP	access point
AQ	air quality
AUP	acceptable use policy
AVC	Cisco Application Visibility and Control
BYOD	bring your own device
CAPWAP	control and provisioning of wireless access points protocol
CMX	Cisco Connected Mobile Experiences
CUWN	Cisco Unified Wireless Network
DCA	dynamic channel assignment
DFS	dynamic frequency selection
DMZ	demilitarized zone
DNA	Cisco Digital Network Architecture
DPI	deep packet inspection
EAP	extensible authentication protocol
EUA	end-user agreement
FRA	Flexible Radio Assignment
G2	second generation
GLBP	gateway load-balancing protocol
HA	high availability
HA SSO	high availability stateful switchover
HSRP	hot standby routing protocol
ISE	Cisco Identity Services Engine
ISM	industrial, scientific, and medical band
LACP	link aggregation protocol
LAG	link aggregation
LAN	local area network
mDNS	multicast domain name services
MFP	Management Frame Protection

MIMO multiple input, multiple output design

MMAP monitor mode access point

MSE Cisco Mobility Services Engine

NBAR2 Next Generation Network-Based Application Recognition

PAgP port aggregation protocol

PHY physical layer

PI Cisco Prime Infrastructure

PMF protected management frames

PSK pre-shared key

QAM quadrature amplitude modulation

QoS quality of service

RBAC role-based access control

RF radio frequency

RRM radio resource management

RSSI received signal strength

SD-Access Software-Defined Access

SSID service set identifier

SSO stateful switchover

STP spanning tree protocol

SVL StackWise Virtual Link

TPC transmit power control

TTL time-to-live

TxBF standards-based transmit beamforming

UPOE Cisco Universal Power Over Ethernet

VLAN virtual local area network

VRRP virtual router redundancy protocol

VSS virtual switching system

VSW Virtual StackWise

vWLC virtual wireless local area network controller

WAAS Wide Area Application Services

WAN wide area network

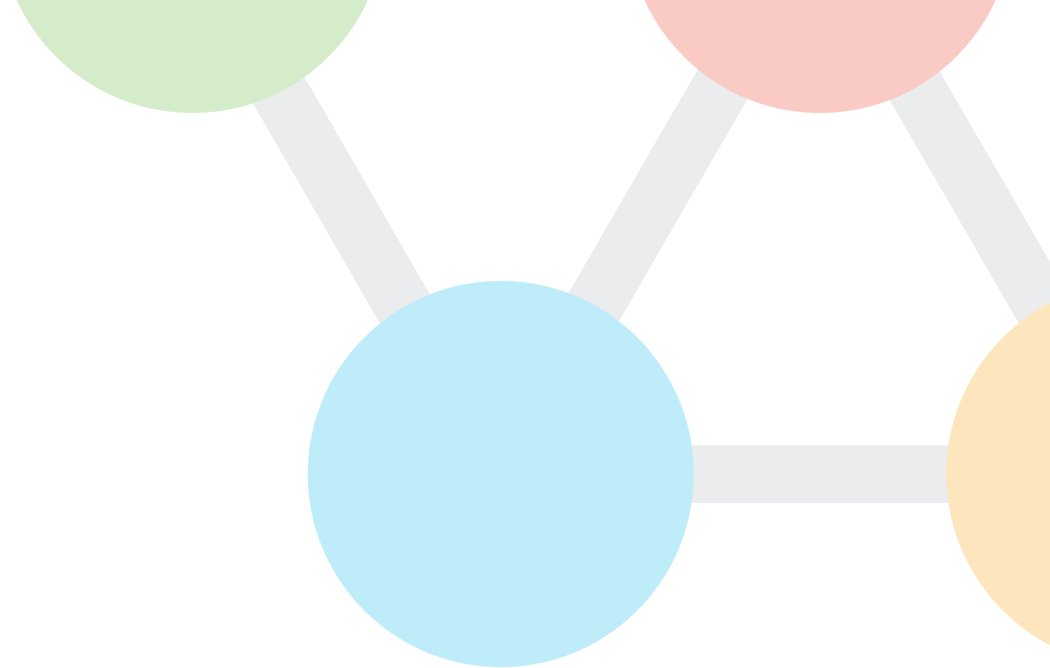
WIDS wireless intrusion detection system

wIPS Cisco Wireless Intrusion Prevention System

WLAN wireless local area network

WLC wireless local area network controller

WSM Wireless Security Module



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