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L. Yang
Intel Corp.
P. Zerfos
UCLA
E. Sadot
Avaya

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Architecture Taxonomy for Control and Provisioning of Wireless Access Points (CAPWAP)

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Abstract

This document provides a taxonomy of the architectures employed in the existing IEEE 802.11 products in the market, by analyzing Wireless LAN (WLAN) functions and services and describing the different variants in distributing these functions and services among the architectural entities.

Table of Contents

1. Introduction

As IEEE 802.11 Wireless LAN (WLAN) technology matures, large scale deployment of WLAN networks is highlighting certain technical challenges. As outlined in [2], management, monitoring, and control of large number of Access Points (APs) in the network may prove to be a significant burden for network administration. Distributing and maintaining a consistent configuration throughout the entire set of APs in the WLAN is a difficult task. The shared and dynamic nature of the wireless medium also demands effective coordination among the APs to minimize radio interference and maximize network performance. Network security issues, which have always been a concern in WLANs, present even more challenges in large deployments and new architectures.

Recently many vendors have begun offering partially proprietary solutions to address some or all of the above mentioned problems. Since interoperable systems allow for a broader choice of solutions, a standardized interoperable solution addressing the aforementioned problems is desirable. As the first step toward establishing interoperability in the market place, this document provides a taxonomy of the architectures employed in existing WLAN products. We hope to provide a cohesive understanding of the market practices for the standard bodies involved (including the IETF and IEEE 802.11). This document may be reviewed and utilized by the IEEE 802.11 Working Group as input in defining the functional architecture of an AP.

1.1. IEEE 802.11 WLAN Functions

The IEEE 802.11 specifications are wireless standards that specify an "over-the-air" interface between a wireless client Station (STA) and an Access Point (AP), and also among wireless clients. 802.11 also describes how mobile devices can associate into a basic service set (BSS). A BSS is identified by a basic service set identifier (BSSID) or name. The WLAN architecture can be considered as a type of 'cell' architecture, in which each cell is the Basic Service Set (BSS), and each BSS is controlled by the AP. When two or more APs are connected via a broadcast layer 2 network and all are using the same SSID, an extended service set (ESS) is created.

The architectural component used to interconnect BSSs is the distribution system (DS). An AP is an STA that provides access to the DS by providing DS services, as well as acting as an STA. Another logical architectural component, portal, is introduced to integrate the IEEE 802.11 architecture with a traditional wired LAN. It is possible for one device to offer both the functions of an AP and a portal.

IEEE 802.11 does not specify the details of DS implementations explicitly. Instead, the 802.11 standard defines services that provide functions that the LLC layer requires for sending MAC Service Data Units (MSDUs) between two entities on the network. These services can be classified into two categories: the station service (SS) and the distribution system service (DSS). Both categories of service are used by the IEEE 802.11 MAC sublayer. Station services consist of the following four services:

- Authentication: Establishes the identity of one station as a member of the set of stations that are authorized to associate with one another.

- De-authentication: Voids an existing authentication relationship.

- Confidentiality: Prevents the content of messages from being read by others than the intended recipients.

- MSDU Delivery: Delivers the MAC service data unit (MSDU) for the stations.

  Distribution system services consist of the following five services:

- Association: Establishes Access Point/Station (AP/STA) mapping and enables STA invocation of the distribution system services.

- Disassociation: Removes an existing association.
- Reassociation: Enables an established association (between AP and STA) to be transferred from one AP to another or the same AP.
- Distribution: Provides MSDU forwarding by APs for the STAs associated with them. MSDUs can be either forwarded to the wireless destination or to the wired (Ethernet) destination (or both) using the "Distribution System" concept of 802.11.
- Integration: Translates the MSDU received from the Distribution System to a non-802.11 format and vice versa. Any MSDU that is received from the DS invokes the 'Integration' services of the DSS before the 'Distribution' services are invoked. The point of connection of the DS to the wired LAN is termed as 'portal'.

Apart from these services, the IEEE 802.11 also defines additional MAC services that must be implemented by the APs in the WLAN. For example:

- Beacon Generation
- Probe Response/Transmission
- Processing of Control Frames: RTS/CTS/ACK/PS-Poll/CF-End/CF-ACK
- Synchronization
- Retransmissions
- Transmission Rate Adaptation
- Privacy: 802.11 Encryption/Decryption

In addition to the services offered by the 802.11, the IEEE 802.11 WG is also developing technologies to support Quality of Service (802.11e), Security Algorithms (802.11i), Inter-AP Protocol (IAPP, or 802.11F -- recommended practice) to update APs when a STA roams from one BSS to another, Radio Resource Measurement Enhancements (802.11k), etc.

IEEE 802.11 does not specify exactly how these functions are implemented, nor does it specify that they be implemented in one physical device. It only requires that the APs and the rest of the DS together implement all these services. Typically, vendors implement not only the services defined in the IEEE 802.11 standard, but also a variety of value-added services or functions, such as load balancing support, QoS, station mobility support, and rogue AP

detection. What becomes clear from this document is that vendors take advantage of the flexibility in the 802.11 architecture, and have come up with many different flavors of architectures and implementations of the WLAN services.

Because many vendors choose to implement these WLAN services across multiple network elements, we want to make a clear distinction between the logical WLAN access network functions and the individual physical devices by adopting different terminology. We use "AP" to refer to the logical entity that provides access to the distribution services, and "WTP" (Wireless Termination Point) to the physical device that allows the RF antenna and 802.11 PHY to transmit and receive station traffic in the BSS network. In the Centralized Architecture (see section 5), the combination of WTPs with Access Controller (AC) implements all the logical functions. Each of these physical devices (WTP or AC) may implement only part of the logical functions. But the DS, including all the physical devices as a whole, implements all or most of the functions.

1.2. CAPWAP Functions

To address the four problems identified in [2] (management, consistent configuration, RF control, security) additional functions, especially in the control and management plane, are typically offered by vendors to assist in better coordination and control across the entire ESS network. Such functions are especially important when the IEEE 802.11 WLAN functions are implemented over multiple entities in a large scale network, instead of within a single entity. Such functions include:

- RF monitoring, such as Radar detection, noise and interference detection, and measurement.
- RF configuration, e.g., for retransmission, channel selection, transmission power adjustment.
- WTP configuration, e.g., for SSID.
- WTP firmware loading, e.g., automatic loading and upgrading of WTP firmware for network wide consistency.
- Network-wide STA state information database, including the information needed to support value-added services, such as mobility and load balancing.
- Mutual authentication between network entities, e.g., for AC and WTP authentication in a Centralized WLAN Architecture.

The services listed are concerned with the configuration and control of the radio resource ('RF Monitoring' and 'RF Configuration'), management and configuration of the WTP device ('WTP Configuration', 'WTP Firmware upgrade'), and also security regarding the registration of the WTP to an AC ('AC/WTP mutual authentication'). Moreover, the device from which other services, such as mobility management across subnets and load balancing, can obtain state information regarding the STA(s) associated with the wireless network, is also reported as a service ('STA state info database').

The above list of CAPWAP functions is not an exhaustive enumeration of all additional services offered by vendors. We included only those functions that are commonly represented in the survey data, and are pertinent to understanding the central problem of interoperability.

Most of these functions are not explicitly specified by IEEE 802.11, but some of the functions are. For example, the control and management of the radio-related functions of an AP are described implicitly in the MIB, such as:

- Channel Assignment
- Transmit Power Control
- Radio Resource Measurement (work is currently under way in IEEE 802.11k)

The 802.11h [5] amendment to the base 802.11 standard specifies the operation of a MAC management protocol to accomplish the requirements of some regulatory bodies (principally in Europe, but expanding to others) in the following areas:

- RADAR detection
- Transmit Power Control
- Dynamic Channel Selection

1.3. WLAN Architecture Proliferation

This document provides a taxonomy of the WLAN network architectures developed by the vendor community in an attempt to address some or all of the problems outlined in [2]. As the IEEE 802.11 standard purposely avoids specifying the details of DS implementations, different architectures have proliferated in the market. While all these different architectures conform to the IEEE 802.11 standard as a whole, their individual functional components are not standardized.

Interfaces between the network architecture components are mostly proprietary, and there is no guarantee of cross-vendor interoperability of products, even within the same family of architectures.

To achieve interoperability in the market place, the IETF CAPWAP working group is first documenting both the functions and the network architectures currently offered by the existing WLAN vendors. The end result is this taxonomy document.

After analyzing more than a dozen different vendors' architectures, we believe that the existing 802.11 WLAN access network architectures can be broadly categorized into three distinct families, based on the characteristics of the Distribution Systems that are employed to provide the 802.11 functions.

- Autonomous WLAN Architecture: The first architecture family is the traditional autonomous WLAN architecture, in which each WTP is a single physical device that implements all the 802.11 services, including both the distribution and integration services, and the portal function. Such an AP architecture is called Autonomous WLAN Architecture because each WTP is autonomous in its functionality, and no explicit 802.11 support is needed from devices other than the WTP. In such architecture, the WTP is typically configured and controlled individually, and can be monitored and managed via typical network management protocols like SNMP. The WTPs are the traditional APs with which most people are familiar. Such WTPs are sometimes referred to as "Fat APs" or "Standalone APs".

- Centralized WLAN Architecture: The second WLAN architecture family is an emerging hierarchical architecture utilizing one or more centralized controllers for managing a large number of WTP devices. The centralized controller is commonly referred to as an Access Controller (AC), whose main function is to manage, control, and configure the WTP devices that are present in the network. In addition to being a centralized entity for the control and management plane, it may also become a natural aggregation point for the data plane since it is typically situated in a centralized location in the wireless access network. The AC is often co-located with an L2 bridge, a switch, or an L3 router, and may be referred to as Access Bridge or Access Router in those particular cases. Therefore, an Access Controller could be either an L3 or L2 device, and is the generic term we use throughout this document. It is also possible that multiple ACs are present in a network for purposes of redundancy, load balancing, etc. This architecture family has several distinct characteristics that are worth noting. First, the hierarchical architecture and the

centralized AC affords much better manageability for large scale networks. Second, since the IEEE 802.11 functions and the CAPWAP control functions are provided by the WTP devices and the AC together, the WTP devices themselves may no longer fully implement the 802.11 functions as defined in the standards. Therefore, it can be said that the full 802.11 functions are implemented across multiple physical network devices, namely, the WTPs and ACs. Since the WTP devices only implement a portion of the functions that standalone APs implement, WTP devices in this architecture are sometimes referred to as light weight or thin APs.

- Distributed WLAN Architecture: The third emerging WLAN architecture family is the distributed architecture in which the participating wireless nodes are capable of forming a distributed network among themselves, via wired or wireless media. A wireless mesh network is one example within the distributed architecture family, where the nodes themselves form a mesh network and connect with neighboring mesh nodes via 802.11 wireless links. Some of these nodes also have wired Ethernet connections acting as gateways to the external network.

1.4. Taxonomy Methodology and Document Organization

Before the IETF CAPWAP working group started documenting the various WLAN architectures, we conducted an open survey soliciting WLAN architecture descriptions via the IETF CAPWAP mailing list. We provided the interested parties with a common template that included a number of questions about their WLAN architectures. We received 16 contributions in the form of short text descriptions answering those questions. 15 of them are from WLAN vendors (AireSpace, Aruba, Avaya, Chantry Networks, Cisco, Cranite Systems, Extreme Networks, Intoto, Janusys Networks, Nortel, Panasonic, Trapeze, Instant802, Strix Systems, Symbol) and one from the academic research community (UCLA). Out of the 16 contributions, one describes an Autonomous WLAN Architecture, three are Distributed Mesh Architectures, and the remaining twelve entries represent architectures in the family of the Centralized WLAN Architecture.

The main objective of this survey was to identify the general categories and trends in WLAN architecture evolution, discover their common characteristics, and determine what is performed differently among them and why. In order to represent the survey data in a compact format, a "Functional Distribution Matrix" is used in this document, (mostly in the Centralized WLAN architecture section), to tabulate the various services and functions in the vendors' offerings. These services and functions are classified into three main categories:

- Architecture Considerations: The choice of the connectivity between the AC and the WTP. The design choices regarding the physical device on which processing of management, control, and data frames of the 802.11 takes place.

- 802.11 Functions: As described in Section 1.1.

- CAPWAP Functions: As described in Section 1.2.

For each one of these categories, the mapping of each individual function to network entities implemented by each vendor is shown in tabular form. The rows in the Functional Distribution Matrix represent individual functions that are organized into the above mentioned three categories. Each column of the Matrix represents one vendor's architecture offering in the survey data. See Figure 7 as an example of the Matrix.

This Functional Distribution Matrix is intended for the sole purpose of organizing the architecture taxonomy data, and represents the contributors' views of their architectures from an engineering perspective. It does not necessarily imply that a product exists or will be shipped, nor an intent by the vendor to build such a product.

The next section provides a list of definitions used in this document. The rest of this document is organized around the three broad WLAN architecture families that were introduced in Section 1.3. Each architecture family is discussed in a separate section. The section on Centralized Architecture contains more in-depth details than the other two families, largely due to the large number of the survey data (twelve out of sixteen) collected that fall into the Centralized Architecture category. Summary and conclusions are provided at the end to highlight the basic findings from this taxonomy exercise.

2. Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [3].

3. Definitions

3.1. IEEE 802.11 Definitions

Station (STA): A device that contains an IEEE 802.11 conformant medium access control (MAC) and physical layer (PHY) interface to the wireless medium (WM).

Access Point (AP): An entity that has station functionality and provides access to distribution services via the wireless medium (WM) for associated stations.

Basic Service Set (BSS): A set of stations controlled by a single coordination function.

Station Service (SS): The set of services that support transport of medium access control (MAC) service data units (MSDUs) between stations within a basic service set (BSS).

Distribution System (DS): A system used to interconnect a set of basic service sets (BSSs) and integrated local area networks (LANs) to create an extended service set (ESS).

Extended Service Set (ESS): A set of one or more interconnected basic service sets (BSSs) with the same SSID and integrated local area networks (LANs), which appears as a single BSS to the logical link control layer at any station associated with one of those BSSs.

Portal: The logical point at which medium access control (MAC) service data units (MSDUs) from a non-IEEE 802.11 local area network (LAN) enter the distribution system (DS) of an extended service set (ESS).

Distribution System Service (DSS): The set of services provided by the distribution system (DS) that enable the medium access control (MAC) layer to transport MAC service data units (MSDUs) between stations that are not in direct communication with each other over a single instance of the wireless medium (WM). These services include the transport of MSDUs between the access points (APs) of basic service sets (BSSs) within an extended service set (ESS), transport of MSDUs between portals and BSSs within an ESS, and transport of MSDUs between stations in the same BSS in cases where the MSDU has a multicast or broadcast destination address, or where the destination is an individual address, but the station sending the MSDU chooses to involve DSS. DSSs are provided between pairs of IEEE 802.11 MACs.

Integration: The service that enables delivery of medium access control (MAC) service data units (MSDUs) between the distribution system (DS) and an existing, non-IEEE 802.11 local area network (via a portal).

Distribution: The service that, by using association information, delivers medium access control (MAC) service data units (MSDUs) within the distribution system (DS).

3.2. Terminology Used in This Document

One of the motivations in defining new terminology is to clarify ambiguity and confusion surrounding some conventional terms. One such term is "Access Point (AP)". Typically, when people talk about "AP", they refer to the physical entity (box) that has an antenna, implements 802.11 PHY, and receives/transmits the station (STA) traffic over the air. However, the 802.11 Standard [1] describes the AP mostly as a logical entity that implements a set of logical services so that station traffic can be received and transmitted effectively over the air. When people refer to "AP functions", they usually mean the logical functions the whole WLAN access network supports, and not just the subset of functions supported by the physical entity (box) that the STAs communicate with directly. Such confusion can be especially acute when logical functions are implemented across a network instead of within a single physical entity. To avoid further confusion, we define the following terminology:

CAPWAP: Control and Provisioning of Wireless Access Points

IEEE 802.11 WLAN Functions: A set of logical functions defined by the IEEE 802.11 Working Group, including all the MAC services, Station Services, and Distribution Services. These logical functions are required to be implemented in the IEEE 802.11 Wireless LAN (WLAN) access networks by the IEEE 802.11 Standard [1].

CAPWAP Functions: A set of WLAN control functions that are not directly defined by IEEE 802.11 Standards, but deemed essential for effective control, configuration, and management of 802.11 WLAN access networks.

Wireless Termination Point (WTP): The physical or network entity that contains an RF antenna and 802.11 PHY to transmit and receive station traffic for the IEEE 802.11 WLAN access networks. Such physical entities were often called "Access Points" (AP), but "AP" can also refer to the logical entity that implements 802.11 services. We recommend "WTP" as the generic term that explicitly refers to the physical entity with the above property (e.g., featuring an RF antenna and 802.11 PHY), applicable to network entities of both Autonomous and Centralized WLAN Architecture (see below).

Autonomous WLAN Architecture: The WLAN access network architecture family in which all the logical functions, including both IEEE 802.11 and CAPWAP functions (wherever applicable), are implemented within each Wireless Termination Point (WTP) in the network. The WTPs in

such networks are also called standalone APs, or fat APs, because these devices implement the full set of functions that enable the devices to operate without any other support from the network.

Centralized WLAN Architecture: The WLAN access network architecture family in which the logical functions, including both IEEE 802.11 and CAPWAP functions (wherever applicable), are implemented across a hierarchy of network entities. At the lower level are the WTPs, while at the higher level are the Access Controllers (ACs), which are responsible for controlling, configuring, and managing the entire WLAN access network.

Distributed WLAN Architecture: The WLAN access network architecture family in which some of the control functions (e.g., CAPWAP functions) are implemented across a distributed network consisting of peer entities. A wireless mesh network can be considered an example of such an architecture.

Access Controller (AC): The network entity in the Centralized WLAN Architecture that provides WTPs access to the centralized hierarchical network infrastructure in the data plane, control plane, management plane, or a combination therein.

Standalone WTP: Refers to the WTP in Autonomous WLAN Architecture.

Controlled WTP: Refers to the WTP in Centralized WLAN Architecture.

Split MAC Architecture: A subgroup of the Centralized WLAN Architecture whereby WTPs in such WLAN access networks only implement the delay sensitive MAC services (including all control frames and some management frames) for IEEE 802.11, while all the remaining management and data frames are tunnelled to the AC for centralized processing. The IEEE 802.11 MAC, as defined by IEEE 802.11 Standards in [1], is effectively split between the WTP and AC.

Remote MAC Architecture: A subgroup of the Centralized WLAN Architecture, where the entire set of 802.11 MAC functions (including delay-sensitive functions) is implemented at the AC. The WTP terminates the 802.11 PHY functions.

Local MAC Architecture: A subgroup of the Centralized WLAN Architecture, where the majority or entire set of 802.11 MAC functions (including most of the 802.11 management frame processing) are implemented at the WTP. Therefore, the 802.11 MAC stays intact and local in the WTP, along with PHY.

3.3. Terminology Used Historically but Not Recommended

While some terminology has been used by vendors historically to describe "Access Points", we recommend deferring its use, in order to avoid further confusion. A list of such terms and the recommended new terminology is provided below:

Split WLAN Architecture: Use Centralized WLAN Architecture.

Hierarchical WLAN Architecture: Use Centralized WLAN Architecture.

Standalone Access Point: Use Standalone WTP.

Fat Access Point: Use Standalone WTP.

Thin Access Point: Use Controlled WTP.

Light weight Access Point: Use Controlled WTP.

Split AP Architecture: Use Local MAC Architecture.

Antenna AP Architecture: Use Remote MAC Architecture.

4. Autonomous Architecture

4.1. Overview

Figure 1 shows an example network of the Autonomous WLAN Architecture. This architecture implements all the 802.11 functionality in a single physical device, the Wireless Termination Point (WTP). An embodiment of this architecture is a WTP that translates between 802.11 frames to/from its radio interface and 802.3 frames to/from an Ethernet interface. An 802.3 infrastructure that interconnects the Ethernet interfaces of different WTPs provides the distribution system. It can also provide portals for integrated 802.3 LAN segments.

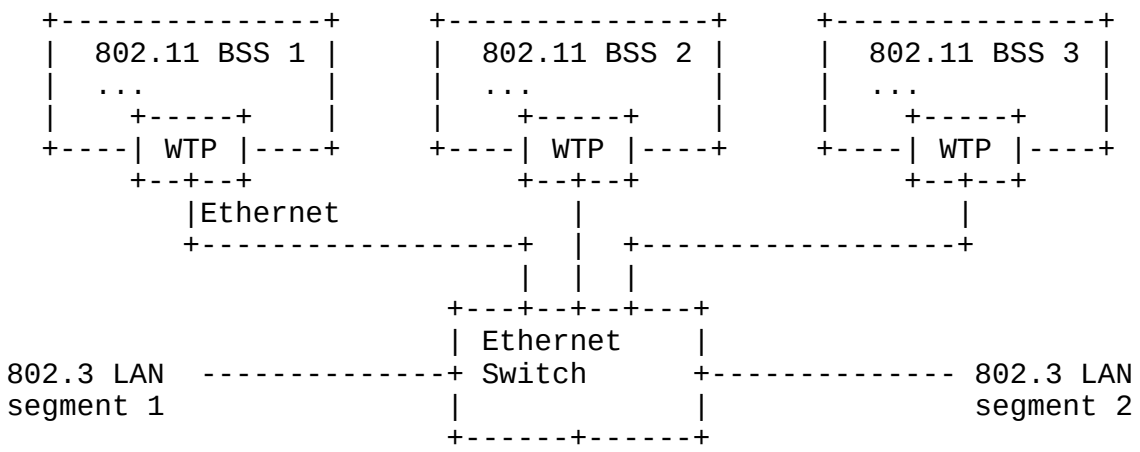


Figure 1: Example of Autonomous WLAN Architecture

A single physical WTP can optionally be provisioned as multiple virtual WTPs by supporting multiple SSIDs to which 802.11 clients may associate. In some cases, this will involve putting a corresponding 802.1Q VLAN tag on each packet forwarded to the Ethernet infrastructure and removing 802.1Q tags prior to forwarding the packets to the wireless medium.

The scope of the ESS(s) created by interconnecting the WTPs will be confined by the constraints imposed by the Ethernet infrastructure.

Authentication of 802.11 clients may be performed locally by the WTP or by using a centralized authentication server.

4.2. Security

Since both the 802.11 and CAPWAP functions are tightly integrated into a single physical device, security issues with this architecture are confined to the WTP. There are no extra implications from the client authentication and encryption/decryption perspective, as the AAA interface and the key generation mechanisms required for 802.11i encryption/decryption are integrated into the WTP.

One of the security needs in this architecture is for mutual authentication between the WTP and the Ethernet infrastructure. This can be ensured by existing mechanisms such as 802.1X between the WTP and the Ethernet switch to which it connects. Another critical security issue is the fact that the WTP is most likely not under lock and key, but contains secret information to communicate with back-end systems, such as AAA and SNMP. Because IT personnel uses the common management method of pushing a "template" to all devices, theft of such a device would potentially compromise the wired network.

5. Centralized WLAN Architecture

Centralized WLAN Architecture is an emerging architecture family in the WLAN market. Contrary to the Autonomous WLAN Architecture, where the 802.11 functions and network control functions are all implemented within each Wireless Termination Point (WTP), the Centralized WLAN Architecture employs one or more centralized controllers, called Access Controller(s), to enable network-wide monitoring, improve management scalability, and facilitate dynamic configurability.

The following figure schematically shows the Centralized WLAN Architecture network diagram, where the Access Controller (AC) connects to multiple Wireless Termination Points (WTPs) via an interconnection medium. This can be a direct connection, an L2-switched, or an L3-routed network as described in Section 5.1. The AC exchanges configuration and control information with the WTP devices, allowing the management of the network from a centralized point. Designs of the Centralized WLAN Architecture family do not presume (as the diagram might suggest) that the AC necessarily intercedes in the data plane to/from the WTP(s). More details are provided later in this section.

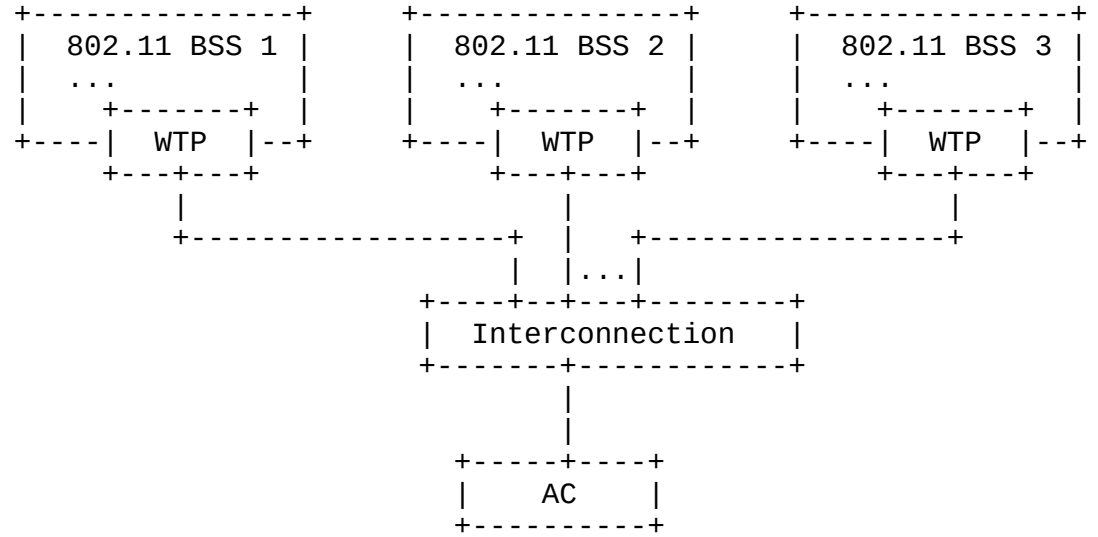


Figure 2: Centralized WLAN Architecture Diagram

In the diagram above, the AC is shown as a single physical entity that provides all of the CAPWAP functions listed in Section 1.2. However, this may not always be the case. Closer examination of the functions reveals that their different resource requirements (e.g., CPU, memory, storage) may be distributed across different devices. For instance, complex radio control algorithms can be CPU intensive. Storing and downloading images and configurations can be storage intensive. Therefore, different CAPWAP functions might be implemented on different physical devices due to the different nature of their resource requirements. The network entity marked 'AC' in the diagram above should be thought of as a multiplicity of logical functions, and not necessarily as a single physical device. The ACs may also choose to implement some control functions locally, and provide interfaces to access other global network management functions, which are typically implemented on separate boxes, such as a SNMP Network Management Station and an AAA back-end server (e.g., Radius Authentication Server).

5.1. Interconnection between WTPs and ACs

There are several connectivity options to consider between the AC(s) and the WTPs, including direct connection, L2 switched connection, and L3 routed connection, as shown in Figures 3, 4, and 5.

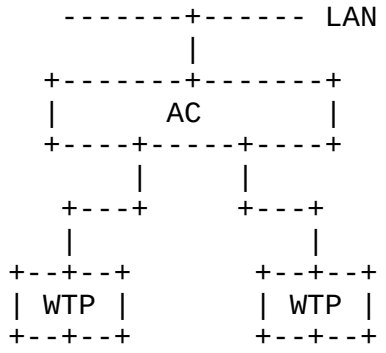


Figure 3: Directly Connected

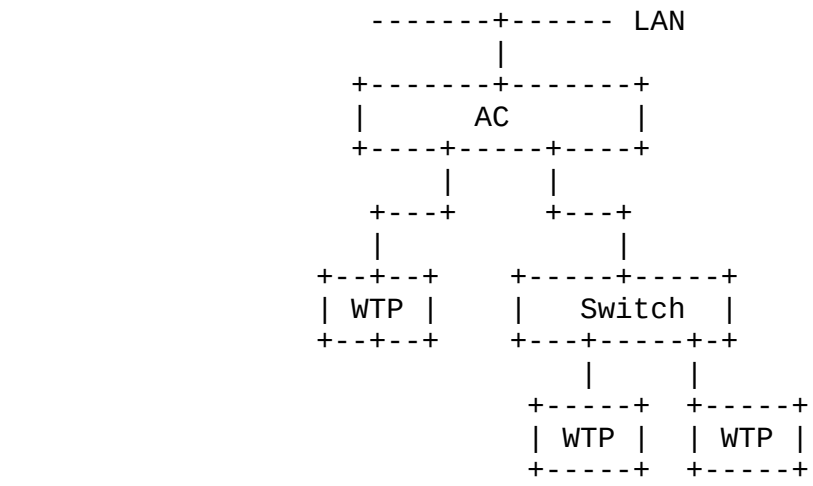


Figure 4: Switched Connections

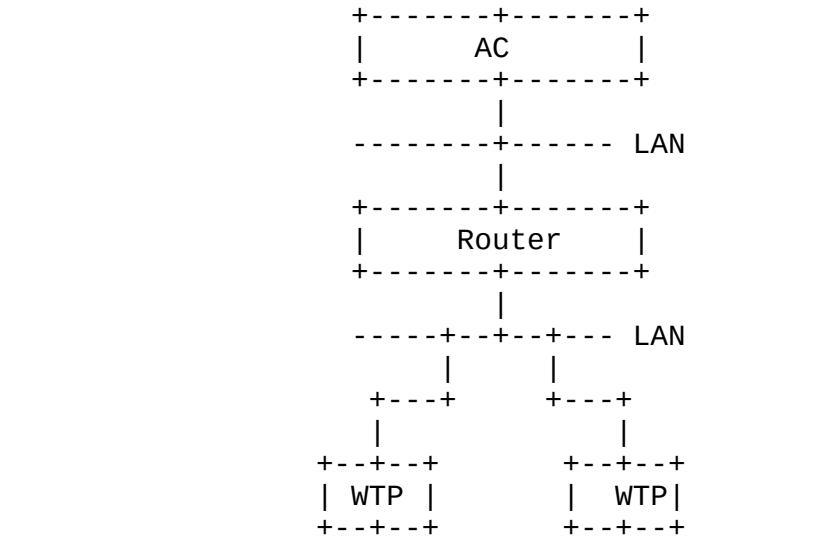


Figure 5: Routed Connections

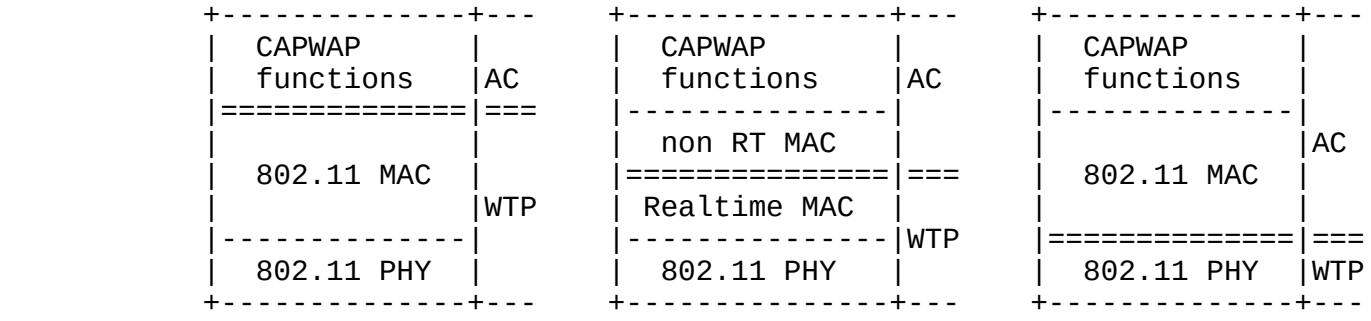
5.2. Overview of Three Centralized WLAN Architecture Variants

Dynamic and consistent network management is one of the primary motivations for the Centralized Architecture. The survey data from vendors also shows that different varieties of this architecture family have emerged to meet a complex set of different requirements for various possible deployment scenarios. This is also a direct result of the inherent flexibility in the 802.11 standard [1] regarding the implementation of the logical functions that are

broadly described under the term "Access Point (AP)". Because there is no standard mapping of these AP functions to physical network entities, several design choices have been made by vendors that offer related products. Moreover, the increased demand for monitoring and consistent configuration of large wireless networks has resulted in a set of 'value-added' services provided by the various vendors, most of which share common design properties and service goals.

In the following, we describe the three main variants observed from the survey data within the family of Centralized WLAN Architecture, namely the Local MAC, Split MAC, and Remote MAC approaches. For each approach, we provide the mapping characteristics of the various functions into the network entities from each vendor. The naming of Local MAC, Split MAC, and Remote MAC reflects how the functions, and especially the 802.11 MAC functions, are mapped onto the network entities. Local MAC indicates that the MAC functions stay intact and local to WTPs, while Remote MAC denotes that the MAC has moved away from the WTP to a remote AC in the network. Split MAC shows the MAC being split between the WTPs and ACs, largely along the line of realtime sensitivity. Typically, Split MAC vendors choose to put realtime functions on the WTPs while leaving non-realtime functions to the ACs. 802.11 does not clearly specify what constitutes realtime functions versus non-realtime functions, and so a clear and definitive line does not exist. As shown in Section 5.4, each vendor has its own interpretation on this, and there are some discrepancies about where to draw the line between realtime and non-realtime functions. However, vendors agree on the characterization of the majority of MAC functions. For example, every vendor classifies the DCF as a realtime function.

The differences among Local MAC, Split MAC and Remote MAC architectures are shown graphically in the following figure:



(a) "Local MAC" (b) "Split MAC" (c) "Remote MAC"

Figure 6: Three Architectural Variants within the Centralized WLAN Architecture Family

5.3. Local MAC

The main motivation of the Local MAC architecture model, as shown in Figure 6 (a), is to offload network access policies and management functions (CAPWAP functions described in Section 1.2) to the AC without splitting the 802.11 MAC functionality between WTPs and AC. The whole 802.11 MAC resides on the WTPs locally, including all the 802.11 management and control frame processing for the STAs. On the other hand, information related to management and configuration of the WTP devices is communicated with a centralized AC to facilitate management of the network and maintain a consistent network-wide configuration for the WTP devices.

Figure 7 shows a tabular representation of the design choices made by the six vendors in the survey that follow the Local MAC approach, with respect to the above mentioned architecture considerations. "WTP-AC connectivity" shows the type connectivity between the WTPs and AC that every vendor’s architecture can support. Clearly, all the vendors can support L3 routed network connectivity between WTPs and the AC, which implies that direct connections and L2 switched networks are also supported by all vendors. By ’802.11 mgmt termination’, and ’802.11 control termination’, we denote the physical network device on which processing of the 802.11 management and control frames is done respectively. All the vendors here choose to terminate 802.11 management and control frames at the WTPs. The last row of the table, ’802.11 data aggregation’, refers to the device on which aggregation and delivery of 802.11 data frames from one STA to another (possibly through a DS) is performed. As shown by the table, vendors make different choices as to whether all the 802.11 data traffic is aggregated and routed through the AC. The survey data shows that some vendors choose to tunnel or encapsulate all the station traffic to or from the ACs, implying that the AC also acts as the access router for this WLAN access network. Other vendors choose to separate the control and data plane by letting the station traffic be bridged or routed locally, while keeping the centralized control at the AC.

	Arch7	Arch8	Arch9	Arch10	Arch11
WTP-AC connectivity	L3	L3	L3	L3	L3
802.11 mgmt termination	WTP	WTP	WTP	WTP	WTP
802.11 control termination	WTP	WTP	WTP	WTP	WTP
802.11 data aggregation	AC	AC	WTP	AC	WTP

Figure 7: Architecture Considerations for Local MAC Architecture

Figure 8 reveals that most of the CAPWAP functions, as described in Section 1.2, are implemented at the AC with help from WTPs to monitor RF channels, and collect statistics and state information from the STAs, as the AC offers the advantages of network-wide visibility, which is essential for many of the control, configuration, and value-added services.

	Arch7	Arch8	Arch9	Arch10	Arch11
RF Monitoring	WTP	WTP	AC/WTP	WTP	WTP
RF Config.	AC	AC	AC	AC	AC
WTP config.	AC	AC	AC	AC	AC
WTP Firmware	AC	AC	AC	AC	AC
STA state info database	AC	AC/WTP	AC/WTP	AC/WTP	AC
AC/WTP mutual authent.	AC/WTP	AC/WTP	AC/WTP	AC/WTP	AC/WTP

Figure 8: Mapping of CAPWAP Functions for Local MAC Architecture

The matrix in Figure 9 shows that most of the 802.11 functions are implemented at the WTPs for Local MAC Architecture, with some minor differences among the vendors regarding distribution service, 802.11e scheduling, and 802.1X/EAP authentication. The difference in distribution service is consistent with that described earlier regarding "802.11 data aggregation" in Figure 7.

	Arch7	Arch8	Arch9	Arch10	Arch11
Distribution Service	AC	AC	WTP	AC	WTP
Integration Service	WTP	WTP	WTP	WTP	WTP
Beacon Generation	WTP	WTP	WTP	WTP	WTP
Probe Response	WTP	WTP	WTP	WTP	WTP
Power mgmt Packet Buffering	WTP	WTP	WTP	WTP	WTP
Fragmentation/ Defragment.	WTP	WTP	WTP	WTP	WTP
Association Disassoc. Reassociation	AC	WTP	WTP	WTP	WTP
WME/11e					
classifying	AC				WTP
scheduling	WTP	AC/WTP	WTP	WTP	WTP
queuing	WTP		WTP	WTP	WTP

Authentication and Privacy					
802.1X/EAP	AC	AC	AC/WTP	AC	AC/WTP
Keys Management	AC	AC	WTP	AC	AC
802.11 Encryption/ Decryption	WTP	WTP	WTP	WTP	WTP

Figure 9: Mapping of 802.11 Functions for Local MAC Architecture

From Figures 7, 8, and 9, it is clear that differences among vendors in the Local MAC Architecture are relatively minor, and most of the functional mapping appears to be common across vendors.

5.4. Split MAC

As depicted in Figure 6 (b), the main idea behind the Split MAC architecture is to implement part of the 802.11 MAC functionality on a centralized AC instead of the WTPs, in addition to providing the required services for managing and monitoring the WTP devices. Usually, the decision of which functions of the 802.11 MAC need to be provided by the AC is based on the time-criticality of the services considered.

In the Split MAC architecture, the WTP terminates the infrastructure side of the wireless physical link, provides radio-related management, and also implements time-critical functionality of the 802.11 MAC. In addition, the non-realtime management functions are handled by a centralized AC, along with higher level services, such as configuration, QoS, policies for load balancing, and access control lists. The key distinction between Local MAC and Split MAC relates to non-realtime functions: in Split MAC architecture, the AC terminates 802.11 non realtime functions, whereas in Local MAC architecture, the WTP terminates the 802.11 non-realtime functions and consequently sends appropriate messages to the AC.

There are several motivations for taking the Split MAC approach. The first is to offload functionality that is specific and relevant only to the locality of each BSS to the WTP, in order to allow the AC to scale to a large number of 'light weight' WTP devices. Moreover, realtime functionality is subject to latency constraints and cannot tolerate delays due to transmission of 802.11 control frames (or other realtime information) over multiple-hops. The latter would limit the available choices for connectivity between the AC and the

WTP. Therefore, the realtime criterion is usually employed to separate MAC services between the devices. Another consideration is cost reduction of the WTP to make it as cheap and simple as possible. Finally, moving functions like encryption and decryption to the AC reduces vulnerabilities from a compromised WTP, since user encryption keys no longer reside on the WTP. As a result, any advancements in security protocol and algorithm designs do not necessarily obsolete the WTPs; the ACs implement the new security schemes instead, which simplifies the management and update task. Additionally, the network is protected against LAN-side eavesdropping.

Since there is no clear definition in the 802.11 specification as to which 802.11 MAC functions are considered "realtime", each vendor interprets this in their own way. Most vendors agree that the following services of 802.11 MAC are examples of realtime services, and are chosen to be implemented on the WTPs.

- Beacon Generation
- Probe Response/Transmission
- Processing of Control Frames: RTS/CTS/ACK/PS-Poll/CF-End/CF-ACK
- Synchronization
- Retransmissions
- Transmission Rate Adaptation

The following list includes examples of non-realtime MAC functions as interpreted by most vendors:

- Authentication/De-authentication
- Association/Disassociation/Reassociation/Distribution
- Integration Services: Bridging between 802.11 and 802.3
- Privacy: 802.11 Encryption/Decryption
- Fragmentation/Defragmentation

However, some vendors may choose to classify some of the above "non-realtime" functions as realtime functions in order to support specific applications with strict QoS requirements. For example, Reassociation is sometimes implemented as a "realtime" function to support VoIP applications.

The non-realtime aspects of the 802.11 MAC are handled by the AC through the processing of raw 802.11 management frames (Split MAC). The following matrix in Figure 10 offers a tabular representation of the design choices made by the six vendors that follow the Split MAC design regarding the architecture considerations. While most vendors support L3 connectivity between WTPs and ACs, some can only support L2 switched connections due to the tighter delay constraint resulting from splitting MAC between two physical entities across a network. In Figure 7, it is clear that the WTP processes the 802.11 control frames in both the Split MAC and Local MAC. The difference between the two lies in the termination point for 802.11 management frames. Local MAC terminates 802.11 management frames at WTP, while at least some of the 802.11 management frames are terminated at the AC for the Split MAC Architecture. Since in most cases WTP devices are IP-addressable, any of the direct connection, L2-switched, or L3-routed connections of Section 1.2 can be used. If only Ethernet-encapsulation is performed (e.g., as in Architecture 4), then only direct connection and L2-switched connections are supported.

	Arch1	Arch2	Arch3	Arch4	Arch5	Arch6
WTP-AC connectivity	L3	L3	L3	L2	L3	L3
802.11 mgmt termination	AC	AC	AC	AC	AC/WTP	AC
802.11 control termination	WTP	WTP	WTP	WTP	WTP	WTP
802.11 data aggregation	AC	AC	AC	AC	AC	AC

Figure 10: Architecture Considerations for Split MAC Architecture

Similar to the Local MAC Architecture, the matrix in Figure 11 shows that most of the CAPWAP control functions are implemented at the AC. The exception is RF monitoring, and in some cases RF configuration, which are performed locally at the WTPs.

	Arch1	Arch2	Arch3	Arch4	Arch5	Arch6
RF Monitoring	WTP	WTP	WTP	WTP	WTP	WTP
RF Config.	AC/WTP		AC/WTP	AC	AC	AC
WTP config.	AC		AC	AC	AC	AC
WTP Firmware	AC		AC	AC	AC	AC
STA state info database	AC		AC	AC	AC	AC
AC/WTP mutual authent.	AC/WTP	AC/WTP	AC/WTP	AC/WTP		

Figure 11: Mapping of CAPWAP Functions for Split MAC Architecture

The most interesting matrix for Split MAC Architecture is the Functional Distribution Matrix for 802.11 functions, as shown below in Figure 12. Vendors map the functions onto the WTPs and AC with a certain regularity. For example, all vendors choose to implement Distribution, Integration Service at the AC, along with 802.1X/EAP authentication and keys management. All vendors also choose to implement beacon generation at WTPs. On the other hand, vendors sometimes choose to map many of the other functions differently. Therefore, Split MAC Architectures are not consistent regarding the exact way the MAC is split.

	Arch1	Arch2	Arch3	Arch4	Arch5	Arch6
Distribution Service	AC	AC	AC	AC	AC	AC
Integration Service	AC	AC	AC	AC	AC	AC
Beacon Generation	WTP	WTP	WTP	WTP	WTP	WTP
Probe Response	WTP	AC/WTP	WTP	WTP	WTP	WTP
Power mgmt Packet Buffering	WTP	WTP	WTP	AC	AC/WTP	WTP
Fragmentation Defragment.	WTP		WTP	AC	AC	AC
Association Disassoc. Reassociation	AC	AC	AC	AC	WTP	AC
WME/11e						
classifying			AC	AC	AC	AC
scheduling	WTP/AC	AC	WTP	AC	AC	WTP/AC
queuing	WTP/AC	WTP	WTP	AC	WTP	WTP

Authentication and Privacy						
802.1X/EAP	AC	AC	AC	AC	AC	AC
Keys Management	AC	AC	AC	AC	AC	AC
802.11 Encryption/ Decryption	WTP	AC	WTP	AC	AC	AC

Figure 12: Mapping of 802.11 Functions for Split MAC Architecture

5.5. Remote MAC

One of the main motivations for the Remote MAC Architecture is to keep the WTPs as light weight as possible, by having only the radio interfaces on the WTPs and offloading the entire set of 802.11 MAC functions (including delay-sensitive ones) to the Access Controller. This leaves all the complexities of the MAC and other CAPWAP control functions to the centralized controller.

The WTP acts only as a pass-through between the Wireless LAN clients (STA) and the AC, though they may have an additional feature to convert the frames from one format (802.11) to the other (i.e., Ethernet, TR, Fiber). The centralized controller provides network monitoring, management and control, an entire set of 802.11 AP services, security features, resource management, channel selection features, and guarantees Quality of Service to the users. Because the MAC is separated from the PHY, we call this the "Remote MAC Architecture". Typically, such architecture is deployed with special attention to the connectivity between the WTPs and AC so that the delay is minimized. The Radio over Fiber (RoF) from Architecture 5 is an example of Remote MAC Architecture.

5.6. Comparisons of Local MAC, Split MAC, and Remote MAC

Two commonalities across all three Centralized Architectures (Local MAC, Split MAC, and Remote MAC) are:

- Most of the CAPWAP functions related to network control and configuration reside on the AC.
- IEEE 802.11 PHY resides on the WTP.

There is a clear difference between Remote MAC and the other two Centralized Architectures (namely, Local MAC and Split MAC), as the 802.11 MAC is completely separated from the PHY in the former, while the other two keep some portion of the MAC functions together with PHY at the WTPs. The implication of PHY and MAC separation is that it severely limits the kind of interconnection between WTPs and ACs, so that the 802.11 timing constraints are satisfied. As pointed out earlier, this usually results in tighter constraint over the interconnection between WTP and AC for the Remote MAC Architecture. The advantage of Remote MAC Architecture is that it offers the lightest possible WTPs for certain deployment scenarios.

The commonalities and differences between Local MAC and Split MAC are most clearly seen by comparing Figure 7 to Figure 10. The commonality is that 802.11 control frames are terminated at WTPs in both cases. The main difference between Local MAC and Split MAC is that the WTP terminates only the 802.11 control frames in the Split MAC, while the WTP may terminate all 802.11 frames in the Local MAC. An interesting consequence of this difference is that the Integration Service, which essentially refers to bridging between 802.11 and 802.3 frames, is implemented by the AC in the Split MAC and by the WTP in the Local MAC, as shown in Figures 9 and 12, respectively.

As a second note, the Distribution Service, although usually provided by the AC, can also be implemented at the WTP in some Local MAC architectures. This approach is meant to increase performance in delivering STAs data traffic by avoiding tunneling it to the AC, and relaxing the dependency of the WTP from the AC. Therefore, it is possible for the data and control planes to be separated in the Local MAC Architecture.

Even though all the 802.11 traffic is aggregated at ACs in the case of Split MAC Architecture, the data and control planes can still be separated by employing multiple ACs. For example, one AC can implement most of the CAPWAP functions (control plane), while other ACs can be used for 802.11 frames bridging (data plane).

Each of the three architectural variants may be advantageous for certain deployment scenarios. While the Local MAC retains most of the STA’s state information at the local WTPs, Remote MAC centralizes most of the state into the back-end AC. Split MAC sits somewhat in the middle of this spectrum, keeping some state information locally at the WTPs, and the rest centrally at the AC. Many factors should be taken into account to determine the exact balance desired between the centralized and decentralized state. The impact of such balance on network manageability is currently a matter of dispute within the technical community.

5.7. Communication Interface between WTPs and ACs

Before any messages can be exchanged between an AC and WTP, the WTP needs to discover, authenticate, and register with the AC first, then download the firmware and establish a control channel with the AC. Message exchanges between the WTP and AC for control and configuration can happen after that. The following list outlines the basic operations that are typically performed between the WTP and the AC in their typical order:

1. Discovery: The WTPs discover the AC with which they will be bound to and controlled by. The discovery procedure can employ either static or dynamic configuration. In the latter case, a protocol is used in order for the WTP to discover candidate AC(s).

2. Authentication: After discovery, the WTP device authenticates itself with the AC. However, mutual authentication, in which the WTP also authenticates the AC, is not always supported since some vendors strive for zero-configuration on the WTP side. This is not necessarily secure as it leaves the possible vulnerability of the WTP being attached to a rogue AC.

3. WTP Association: After successful authentication, a WTP registers with the AC in order to start receiving management and configuration messages.

4. Firmware Download: After successful association, the WTP may pull, or the AC may push, the WTPs firmware, which may be protected in some manner, such as digital signatures.

5. Control Channel Establishment: The WTP establishes either an IP-tunnel or performs Ethernet encapsulation with the AC in order to transfer data traffic and management frames.

6. Configuration Download: Following the control channel establishment process, the AC may push configuration parameters to the WTPs.

5.8. Security

Given the varied distribution of functionalities for the Centralized Architecture, as surveyed in Section 4.3, it is obvious that an extra network binding is created between the WTP and the AC. This brings new and unique security issues and subsequent requirements.

5.8.1. Client Data Security

The survey shows clearly that the termination point for "over the air" 802.11 encryption [4] can be implemented either in the WTP or in the AC. Furthermore, the 802.1X/EAP [6] functionality is distributed between the WTP and the AC where, in most cases, the AC performs the necessary functions as the authenticator in the 802.1X exchange.

If the STA and AC are the parties in the 4-way handshake (defined in [4]), and 802.11i traffic encryption terminates at the WTP, then the Pairwise Transient Key (PTK) has to be transferred from the AC to the WTP. Since the keying material is part of the control and provisioning of the WTPs, a secure encrypted tunnel for control frames is employed to transport the keying material.

The centralized model encourages AC implementations to use one PMK for many different WTPs. This practice facilitates speedy transition by an STA from one WTP to another that is connected to the same AC without establishing a separate PMK. However, this leaves the STA in a difficult position, as the STA cannot distinguish between a compromised PMK and one that is intentionally being shared. This issue must be resolved, but the resolution is beyond the scope of the CAPWAP working group. The venue for this resolution is to be determined by the IEEE 802 and IETF liaisons.

When the 802.11i encryption/decryption is performed in the AC, the key exchange and state transitions occur between the AC and the STA. Therefore, there is no need to transfer any crypto material between the AC and the WTP.

Regardless of where the 802.11i termination point occurs, the Centralized WLAN Architecture records two practices for "over the wire" client data security. In some cases there is an encrypted tunnel (IPsec or SSL) between the WTP and AC, which assumes that the security boundary is in the AC. In other cases, an end-to-end mutually authenticated secure VPN tunnel is assumed between the client and AC, other security gateway, or end host entity.

5.8.2. Security of Control Channel between the WTP and AC

In order for the CAPWAP functions to be implemented in the Centralized WLAN Architecture, a control channel is necessary between the WTP and AC.

To address potential security threats against the control channel, existing implementations feature one or more of the following security mechanisms:

1. Secure discovery of WTP and AC.

2. Authentication of the WTPs to the ACs (and possibly mutual authentication).

3. Confidentiality, integrity, and replay protection of control channel frames.

4. Secure management of WTPs and ACs, including mechanisms for securely setting and resetting secrets and state.

Discovery and authentication of WTPs are addressed in the submissions by implementing authentication mechanisms that range from X.509 certificates, AAA authentication to pre-shared credential authentication. In all cases, confidentiality, integrity, and protection against man-in-the-middle attacks of the control frames are addressed by a secure encrypted tunnel between the WTP and AC(s), utilizing keys derived from the authentication methods mentioned previously. Finally, one of the motivations for the Centralized WLAN Architecture is to minimize the storage of cryptographic and security sensitive information, in addition to operational configuration parameters within the WTPs. It is for that reason that the majority of the submissions under the Centralized Architecture category have employed a post WTP authenticated discovery phase of configuration provisioning, which in turn protects against the theft of WTPs.

5.8.3. Physical Security of WTPs and ACs

To provide comprehensive radio coverage, WTPs are often installed in locations that are difficult to secure physically; it is relatively easier to secure the AC physically. If high-value secrets, such as a RADIUS shared secret, are stored in the AC instead of WTPs, then the physical loss of an WTP does not compromise these secrets. Hence, the Centralized Architecture may reduce the security consequences of a stolen WTP. On the other hand, concentrating all the high-value secrets in one place makes the AC an attractive target that requires strict physical, procedural, and technical controls to protect the secrets.

6. Distributed Mesh Architecture

Out of the sixteen architecture survey submissions, three belong to the Distributed Mesh Architecture family. An example of the Distributed Mesh Architecture is shown in Figure 13, and reflects some of the common characteristics found in these three submissions.

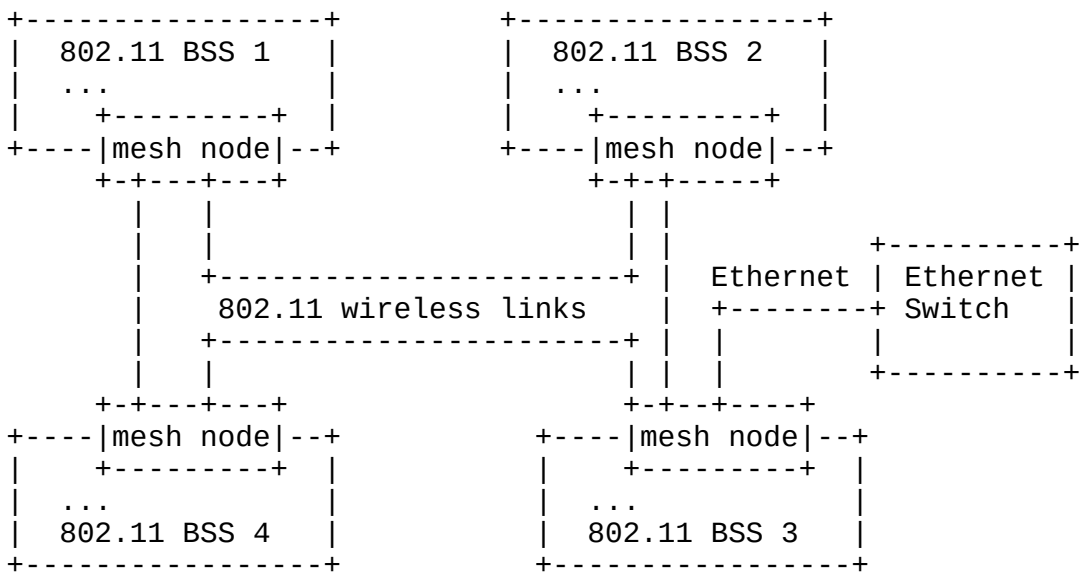


Figure 13: Example of Distributed Mesh Architecture

6.1. Common Characteristics

To provide wider wireless coverage, mesh nodes in the network may act as APs to client stations in their respective BSS, as well as traffic relays to neighboring mesh nodes via 802.11 wireless links. It is also possible that some mesh nodes in the network may serve only as wireless traffic relays for other mesh nodes, but not as APs for any client stations. Instead of pulling Ethernet cable connections to every AP, wireless mesh networks provide an attractive alternative to relaying backhaul traffic.

Mesh nodes can also keep track of the state of their neighboring nodes, or even nodes beyond their immediate neighborhood by exchanging information periodically amongst them; this way, mesh nodes can be fully aware of the dynamic network topology and RF conditions around them. Such peer-to-peer communication model allows mesh nodes to actively coordinate among themselves to achieve self-configuration and self-healing. This is the major distinction between this Distributed Architecture family and the Centralized Architecture -- much of the CAPWAP functions can be implemented

across the mesh nodes in a distributed fashion, without a centralized entity making all the control decisions.

It is worthwhile to point out that mesh networks do not necessarily preclude the use of centralized control. It is possible that a combination of centralized and distributed control co-exists in mesh networks. Some global configuration or policy change may be better served in a coordinated fashion if some form of Access Controller (AC) exists in the mesh network (even if not the full blown version of the AC, as defined in the Centralized WLAN Architecture). For example, a centralized management entity can be used to update every mesh node's default configuration. It may also be more desirable to leave certain functions, such as user authentication to a single centralized end point (such as a RADIUS server), but mesh networks allow each mesh AP to directly talk to the RADIUS server. This eliminates the single point of failure and takes advantage of the client distribution in the network.

The backhaul transport network of the mesh network can be either an L2 or L3 networking technology. Currently, vendors are using proprietary mesh technologies on top of standard 802.11 wireless links to enable peer-to-peer communication between the mesh nodes. Hence, there is no interoperability among mesh nodes from different vendors. The IEEE 802.11 WG has recently started a new Task Group (TGs) to define the mesh standard for 802.11.

6.2. Security

Similar security concerns for client data security, as described in Section 5.8.1, also apply to the Distributed Mesh Architecture. Additionally, one important security consideration for the mesh networks is that the mesh nodes must authenticate each other within the same administrative domain. To protect user and management data that may not be secured at layer 3, data transmission among neighboring nodes should be secured by a layer 2 mechanism of confidentiality, integrity, and replay protection.

7. Summary and Conclusions

We requested existing WLAN vendors and other interested parties to submit a short description of existing or desired WLAN access network architectures to define a taxonomy of possible WLAN access network architectures. The information from the 16 submissions was condensed and summarized in this document.

New terminology has been defined wherever existing terminology was found to be either insufficient or ambiguous in describing the WLAN architectures and supporting functions listed in the document. For

example, the broad set of Access Point functions has been divided into two categories: 802.11 functions, which include those that are required by the IEEE 802.11 standards, and CAPWAP functions, which include those that are not required by the IEEE 802.11, but are deemed essential for control, configuration, and management of 802.11 WLAN access networks. Another term that has caused considerable ambiguity is "Access Point", which usually reflected a physical box that has the antennas, but did not have a uniform set of externally consistent behavior across submissions. To remove this ambiguity, we have redefined the AP as the set of 802.11 and CAPWAP functions, while the physical box that terminates the 802.11 PHY is called the Wireless Termination Point.

Based on the submissions during the architecture survey phase, we have classified the existing WLAN architectures into three broad classes:

1. Autonomous WLAN Architecture: Indicates a family of architectures in which all the 802.11 functions and, where applicable, CAPWAP functions are implemented in the WTPs.

2. Centralized WLAN Architecture: Indicates a family of architectures in which the AP functions are split between the WTPs and the AC, with the AC acting as a centralized control point for multiple WTPs.

3. Distributed WLAN Architecture: Indicates a family of architectures in which part of the control functions is implemented across a distributed network of peer entities.

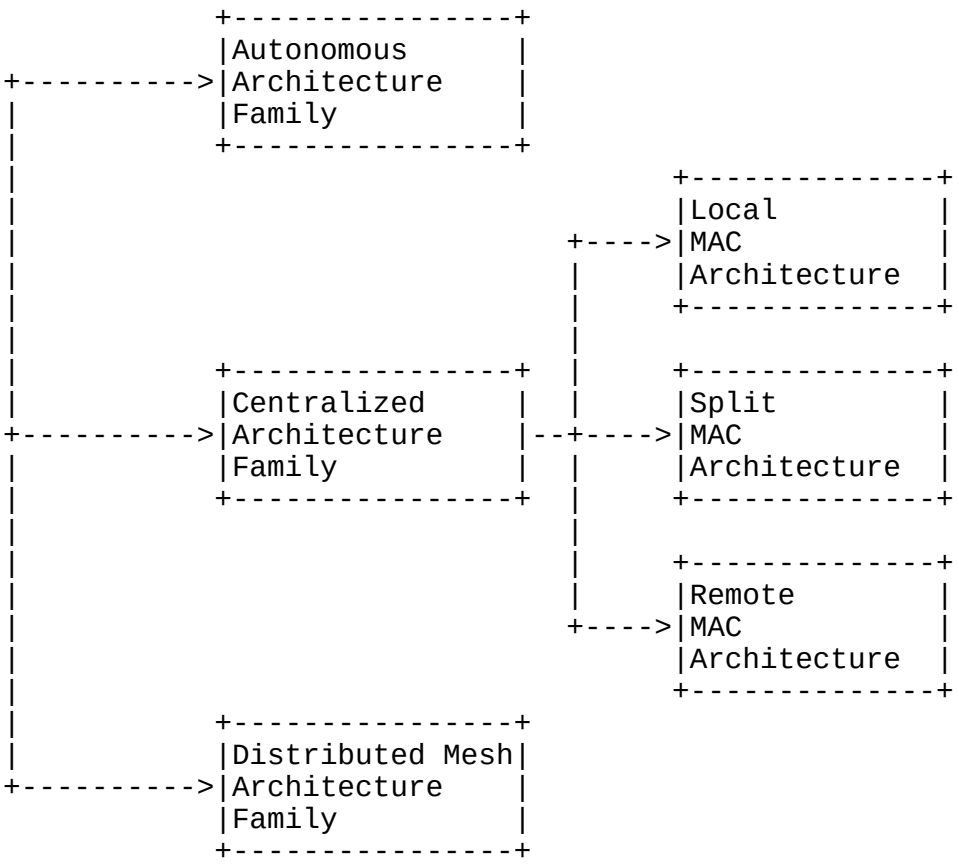
Within the Centralized WLAN Architecture, there are a few visible sub-categories that depend on how one maps the MAC functions (at a high-level), between the WTP and the AC. Three prominent sub-categories emerged from the information in the submissions:

1. Split MAC Architecture: The 802.11 MAC functions are split between the WTP and the AC. This subgroup includes all architectures that split the 802.11 MAC functions even though individual submissions differed on the specifics of the split.

2. Local MAC Architecture: The entire set of 802.11 MAC functions is implemented on the WTP.

3. Remote MAC Architecture: The entire set of 802.11 MAC functions is implemented on the AC.

The following tree diagram summarizes the architectures documented in this taxonomy.



A majority of the submitted WLAN access network architectures (twelve out of sixteen) followed the Centralized WLAN Architecture. All but one of the Centralized WLAN Architecture submissions were grouped into either a Split MAC Architecture or a Local MAC Architecture. One submission followed the Autonomous WLAN Architecture, and three followed the Distributed WLAN Architecture.

The WLAN access network architectures in the submissions indicated that the connectivity assumptions were:

- Direct connection between the WTP and the AC.
- L2 switched connection between the WTP and the AC.
- L3 routed connection between the WTP and the AC.

- o Wireless connection between the mesh nodes in the distributed mesh architecture.

Interoperability between equipment from different vendors is one of the fundamental problems in the WLAN market today. To achieve interoperability via open standard development, the following steps are suggested for IETF and IEEE 802.11.

Using this taxonomy, a functional model of an Access Point should be defined by the new study group recently formed within the IEEE 802.11. The functional model will consist of defining functional elements of an 802.11 Access Point that are considered atomic, i.e., not subject to further splitting across multiple network elements. Such a functional model should serve as a common foundation to support the existing WLAN architectures as outlined in this taxonomy, and any further architecture development within or outside the IEEE 802.11 group. It is possible, and even recommended, that work on the functional model definition may also include impact analysis of implementing each functional element on either the WTP or the AC.

As part of the functional model definition, interfaces must be defined as primitives between these functional elements. If a pair of functional elements that have an interface defined between them is being implemented on two different network entities, then a protocol specification definition between such a pair of network elements is required, and should be developed by the IETF.

8. Security Considerations

This document does not intend to provide a comprehensive threat analysis of all of the security issues with the different WLAN architectures. Nevertheless, in addition to documenting the architectures employed in the existing IEEE 802.11 products in the market, this taxonomy document also catalogues the security issues that arise and the manner in which vendors address these security threats. The WLAN architectures are broadly categorized into three families: Autonomous Architecture, Centralized Architecture, and Distributed Architecture. While Sections 4, 5, and 6 are devoted to each of these three architecture families, respectively, each section also contains a subsection to address the security issues within each architecture family.

In summary, the main security concern in the Autonomous Architecture is the mutual authentication between the WTP and the wired (Ethernet) infrastructure equipment. Physical security of the WTPs is also a network security concern because the WTPs contain secret information and theft of these devices could potentially compromise even the wired network.

In the Centralized Architecture there are a few new security concerns due to the new network binding between the WTP and AC. The following security concerns are raised for this architecture family: keying material for mobile client traffic may need to be securely transported from the AC to WTP; secure discovery of the WTP and AC is required, as well as mutual authentication between the WTPs and AC; man-in-the-middle attacks to the control channel between WTP and AC, confidentiality, integrity and replay protection of control channel frames, and theft of WTPs for extraction of embedded secrets within. Each of the survey results for this broad architecture category has presented mechanisms to address these security issues.

The new security issue in the Distributed Mesh Architecture is the need for mesh nodes to authenticate each other before forming a secure mesh network. Encrypted communication between mesh nodes is recommended to protect both control and user data.

9. Acknowledgements

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- Peyush Agarwal
  STMicroelectronics
  Plot# 18, Sector 16A
  Noida, U.P 201301
  India
  Phone: +91-120-2512021
  EMail: peyush.agarwal@st.com

- Dave Hetherington
  Roving Planet
  4750 Walnut St., Suite 106
  Boulder, CO 80027
  United States
  Phone: +1-303-996-7560
  EMail: Dave.Hetherington@RovingPlanet.com

- Matt Holdrege
  Strix Systems
  26610 Agoura Road
  Calabasas, CA 91302
  Phone: +1 818-251-1058
  EMail: matt@strixsystems.com

- Victor Lin
  Extreme Networks
  3585 Monroe Street
  Santa Clara, CA 95051
  Phone: +1 408-579-3383
  EMail: vlin@extremenetworks.com

- James M. Murphy
  Trapeze Networks
  5753 W. Las Positas Blvd.
  Pleasanton, CA 94588
  Phone: +1 925-474-2233
  EMail: jmurphy@trapezenetworks.com

- Partha Narasimhan
  Aruba Wireless Networks
  180 Great Oaks Blvd
  San Jose, CA 95119
  Phone: +1 408-754-3018
  EMail: partha@arubanetworks.com

- Bob O'Hara
  Airespace
  110 Nortech Parkway
  San Jose, CA 95134
  Phone: +1 408-635-2025
  EMail: bob@airespace.com

- Emek Sadot (see Authors' Addresses)

- Ajit Sanzgiri
  Cisco Systems
  170 W Tasman Drive
  San Jose, CA 95134
  Phone: +1 408-527-4252
  EMail: sanzgiri@cisco.com

- Singh
  Chantry Networks
  1900 Minnesota Court
  Mississauga, Ontario L5N 3C9
  Canada
  Phone: +1 905-567-6900
  EMail: isingh@chantrynetworks.com

- L. Lily Yang (Editor, see Authors' Addresses)

- Petros Zerfos (see Authors' Addresses)

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10. Normative References

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Authors' Addresses

L. Lily Yang
Intel Corp.
MS JF3 206, 2111 NE 25th Avenue
Hillsboro, OR 97124

Phone: +1 503-264-8813
EMail: lily.l.yang@intel.com

Petros Zerfos
UCLA - Computer Science Department
4403 Boelter Hall
Los Angeles, CA 90095

Phone: +1 310-206-3091
EMail: pzerfos@cs.ucla.edu

Emek Sadot
Avaya
Atidim Technology Park, Building #3
Tel-Aviv 61131
Israel

Phone: +972-3-645-7591
EMail: esadot@avaya.com

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