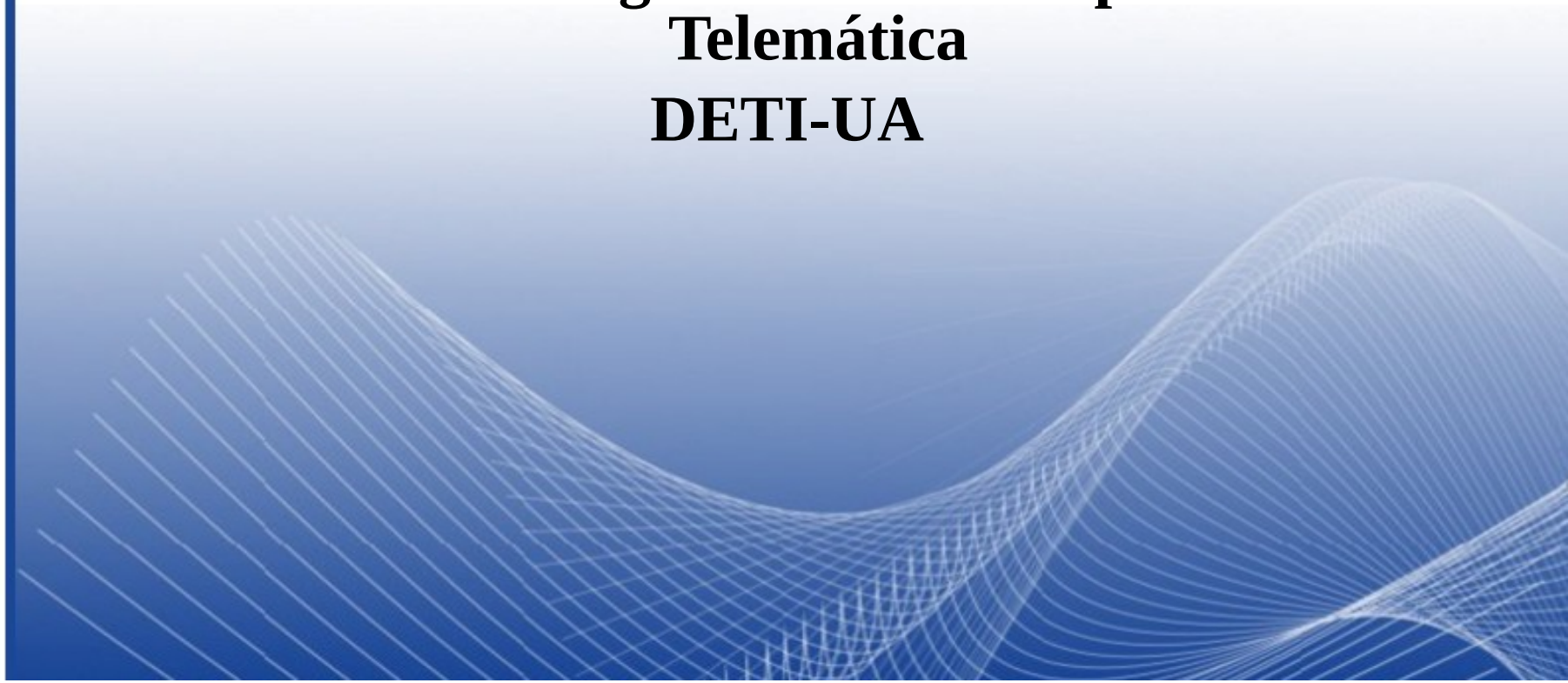
Network Access Control

Segurança em Redes de Comunicações

Mestrado em Cibersegurança

Mestrado em Engenharia de Computadores e Telemática

DETI-UA



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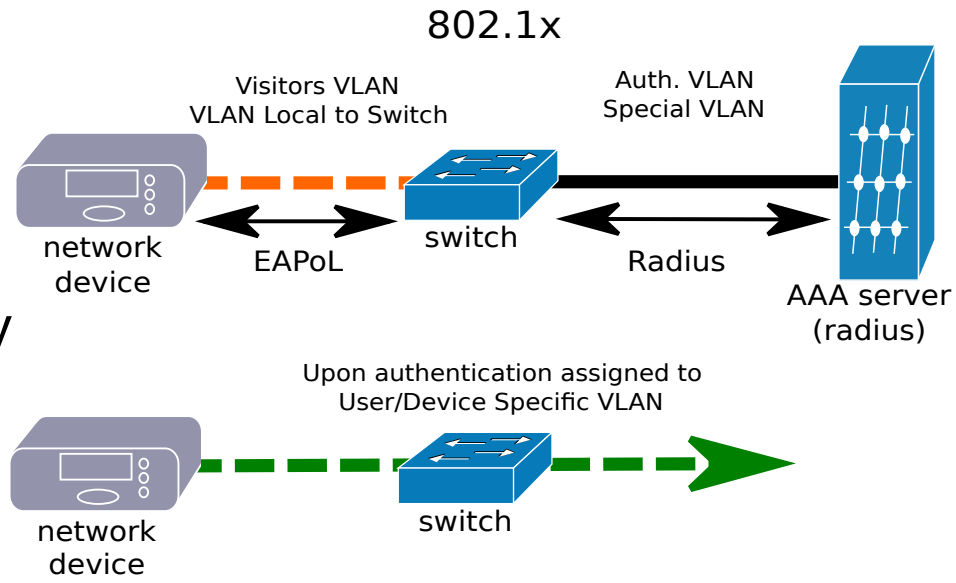
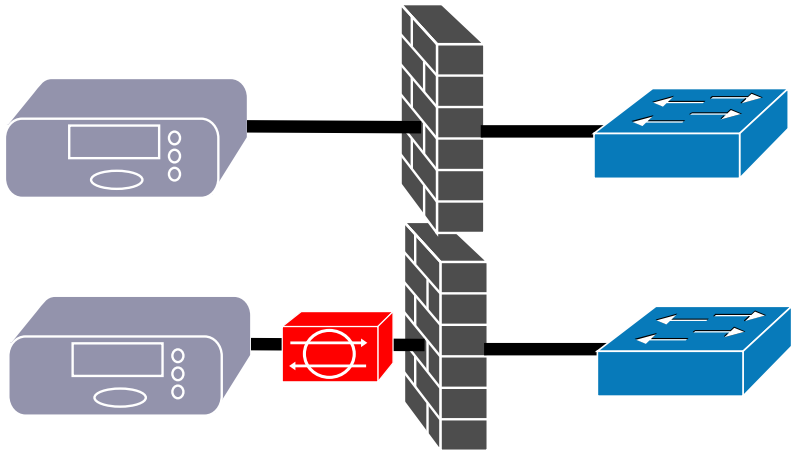
Illicit usage of Ethernet ports

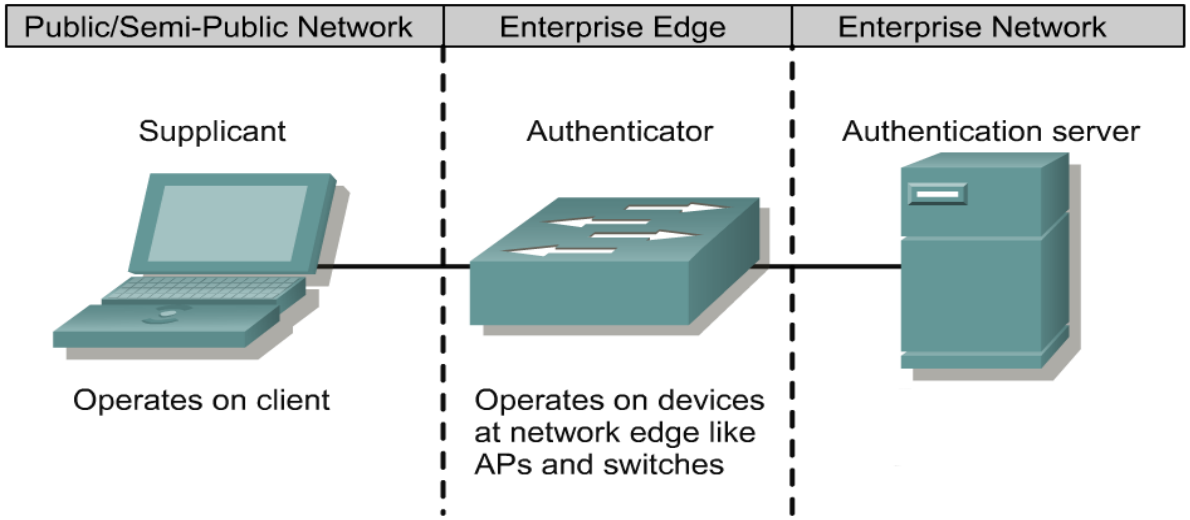
- Common protection:
  - VLAN separation/isolation.
  - 802.1X.
- Unused ports
  - VLAN separation/isolation and/or 802.1x may be enough to mitigate more dangerous attacks (L2 or L3 access to internal machines).
  - Switches MAC flooding attacks and Network overload (Local DoS) are possible.
- In use ports
  - Using an inline device it is possible to break 802.1X using terminal/user authentication.
    - Traffic pass-through.
    - After 802.1X authentication performs inline MAC spoofing.
  - Allows for traffic snooping, injection, and MITM attacks.





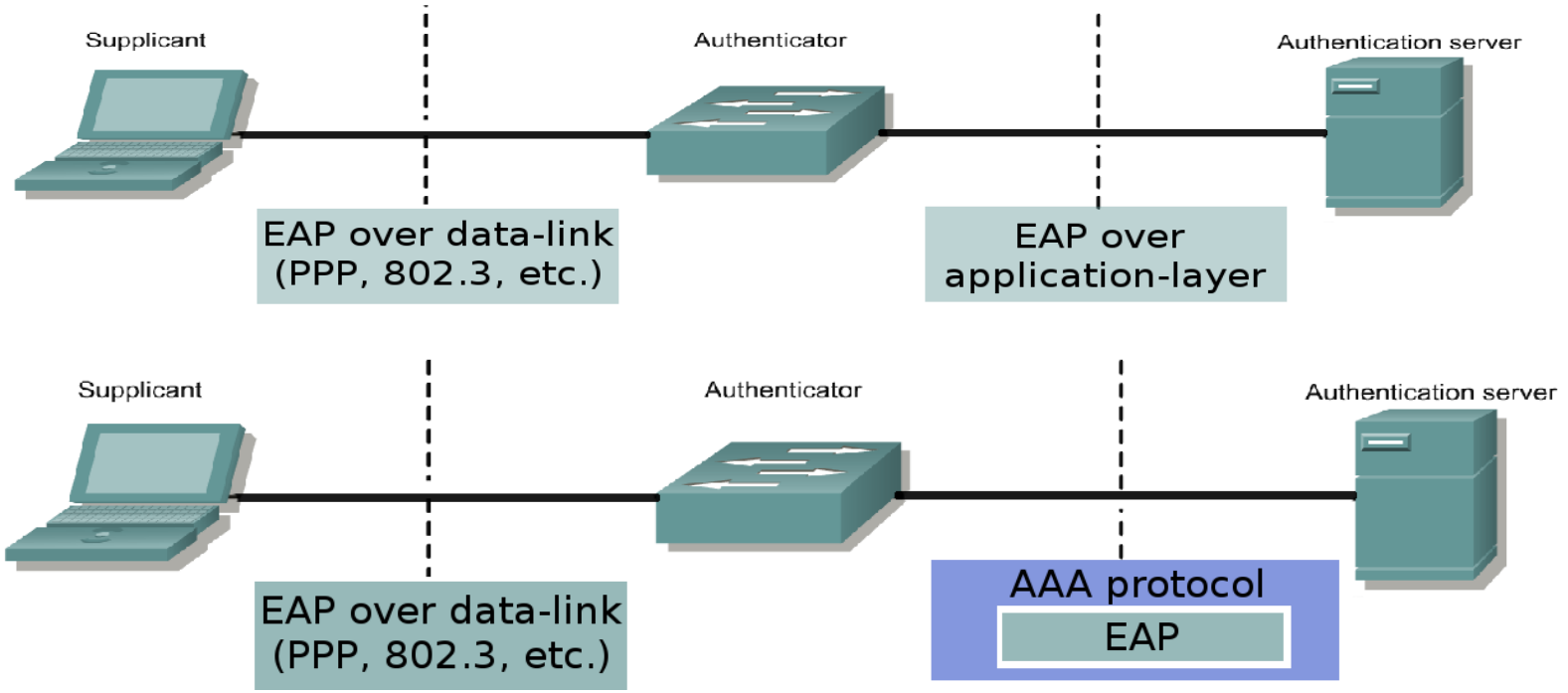
AAA Architecture

- Enables systematic access security
  - Authentication identifies an user
  - Authorization determines what that user can do
  - Accounting monitors the network usage time for billing purposes
- AAA information is typically stored in an external database or remote authentication server
- Traditional AAA Implementation



802.1X

- IEEE 802.1X is an IEEE Standard for Network Access Control (NAC)
  - 802.1X-2001 and 802.1X-2004 only provide authentication.
  - 802.1X-2010 adds optional encryption over the LAN segment.
- It provides an authentication mechanism to devices wishing to attach to a LAN.
- Based on the Extensible Authentication Protocol (EAP).
- AAA protocols/services: TACACS+, RADIUS and DIAMETER.



Extensible Authentication Protocol (EAP)

- EAP defined in [RFC3748] was designed to enable extensible authentication for network access in situations in which the Internet Protocol (IP) protocol is not available.
  - Originally developed for use with Point-to-Point Protocol (PPP) [RFC1661]
  - Subsequently also been applied to IEEE 802 wired networks [IEEE-802.1X], Internet Key Exchange Protocol version 2 (IKEv2)[RFC4306], and wireless networks such as [IEEE-802.11] and [IEEE-802.16e].
- EAP is a two-party protocol spoken between the EAP peer and server.
  - Keying material is generated by EAP authentication algorithms, known as "methods".
  - Part of this keying material can be used by EAP methods themselves, and part of this material can be exported.

EAP Overview (1)

- Where EAP key derivation is supported, the conversation typically takes place in three phases:
- Phase 0: Discovery
- Phase 1: Authentication
  - 1a: EAP authentication
  - 1b: AAA Key Transport (optional)
- Phase 2: Secure Association Protocol
  - 2a: Unicast Secure Association
  - 2b: Multicast Secure Association (optional)

EAP Overview (2)

- EAP lower layers implement phase 0, 2a, and 2b in different ways:
  - IEEE 802.1X
    - IEEE 802.1X-2004 does not support discovery (phase 0), nor does it provide for derivation of unicast or multicast secure associations (phase 2).
  - IEEE 802.11
    - Handles discovery via the Beacon and Probe Request/Response mechanisms.
    - Access Points (APs) periodically announce their Service Set Identifiers (SSIDs) as well as capabilities using Beacon frames.
    - Stations can query for APs by sending a Probe Request.
      - Neither Beacon nor Probe Request/Response frames are secured.
    - A 4-way handshake enables the derivation of unicast (phase 2a) and multicast/broadcast (phase 2b) secure associations.

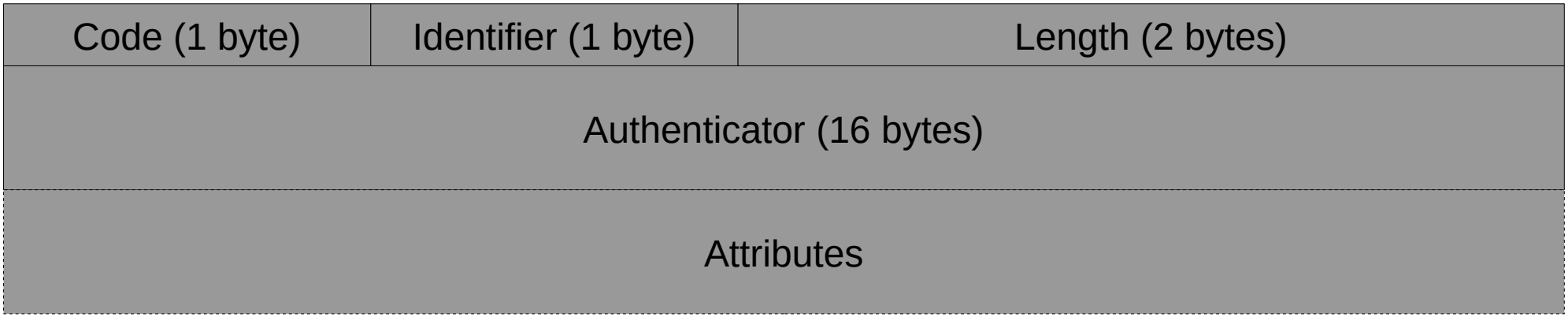
TACACS+

- Terminal Access Controller Access Control System Plus
- Forwards username and password information to a centralized security server
- Centralized server can be either a TACACS database or a database like the UNIX password le with TACACS support
- Features
  - Separates all AAA functionalities
  - Uses TCP
  - Bidirectional authentication
  - All packet is encrypted
  - Limited accounting customization

RADIUS

- Remote Authentication Dial-In User Service
- The network access device operates as a client of RADIUS
- RADIUS servers are responsible for
  - Receiving user connection requests
  - Authenticating the user
  - Return all configuration information necessary for the client to deliver service to the user
- Transactions between the client and RADIUS server are authenticated using a shared secret
- Supports a variety of methods to authenticate a user
  - PAP, CHAP, or MS-CHAP, UNIX login, and other authentication mechanisms
- Combines Authentication and Authorization. Separates Accounting (less flexible than TACACS+)
- Uses UDP (less robust)
- Unidirectional authentication
- Only encrypts the password (less secure)
- RADIUS accounting can hold more information

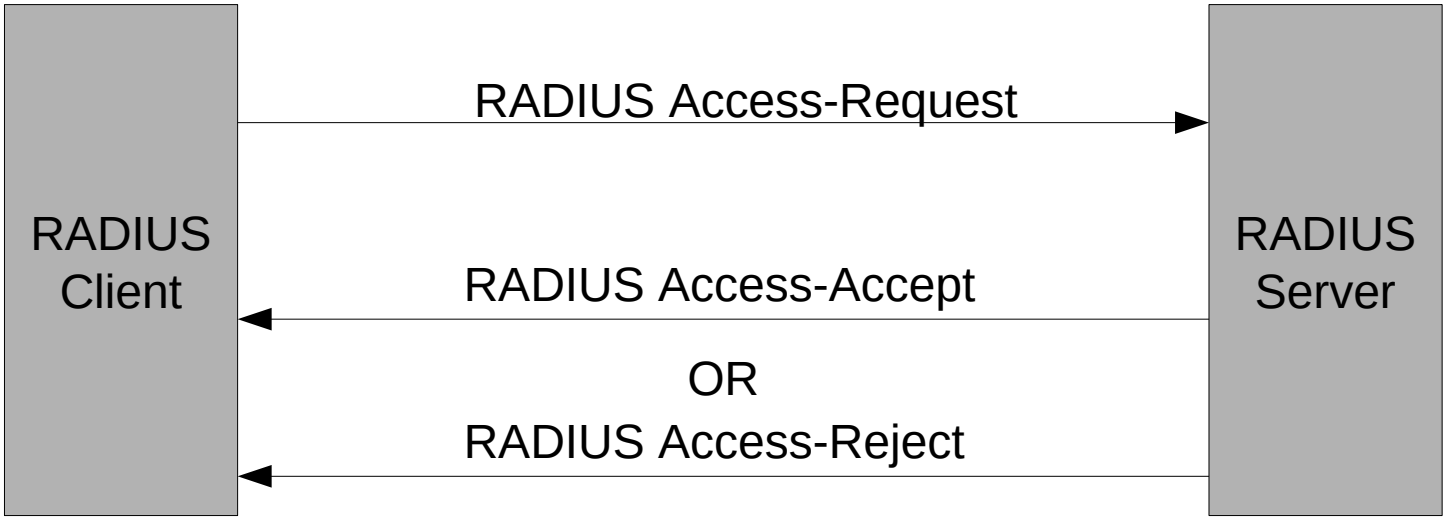
RADIUS Packet



- Code - Identifies the type of RADIUS packet
  - (1) Access-Request, (2) Access-Accept, (3) Access-Reject, (4) Accounting-Request, (5) Accounting-Response and (11) Access-Challenge
- Identifier - Allows the RADIUS client to match a RADIUS response with the correct pending request (usually is implemented as a counter)
- Authenticator
  - In client Requests – Random value
  - In server Responses - MD5 Hash function of (Code,ID,Length,Request Auth,Attributes,Shared Secret)
- Attributes - Section where an arbitrary number of attribute fields can be sent (e.g. User-Name and User-Password attributes)

RADIUS Protocol (1)

Example - RADIUS exchange involving just a username and user password:



- Only password is encrypted
  - The shared secret followed by the Request Authenticator is put through an MD5 hash to create a 16 octet value which is XORed with the password entered by the user
  - If the user password is greater than 16 octets, the password is broken into 16-octet blocks and additional MD5 calculations are performed

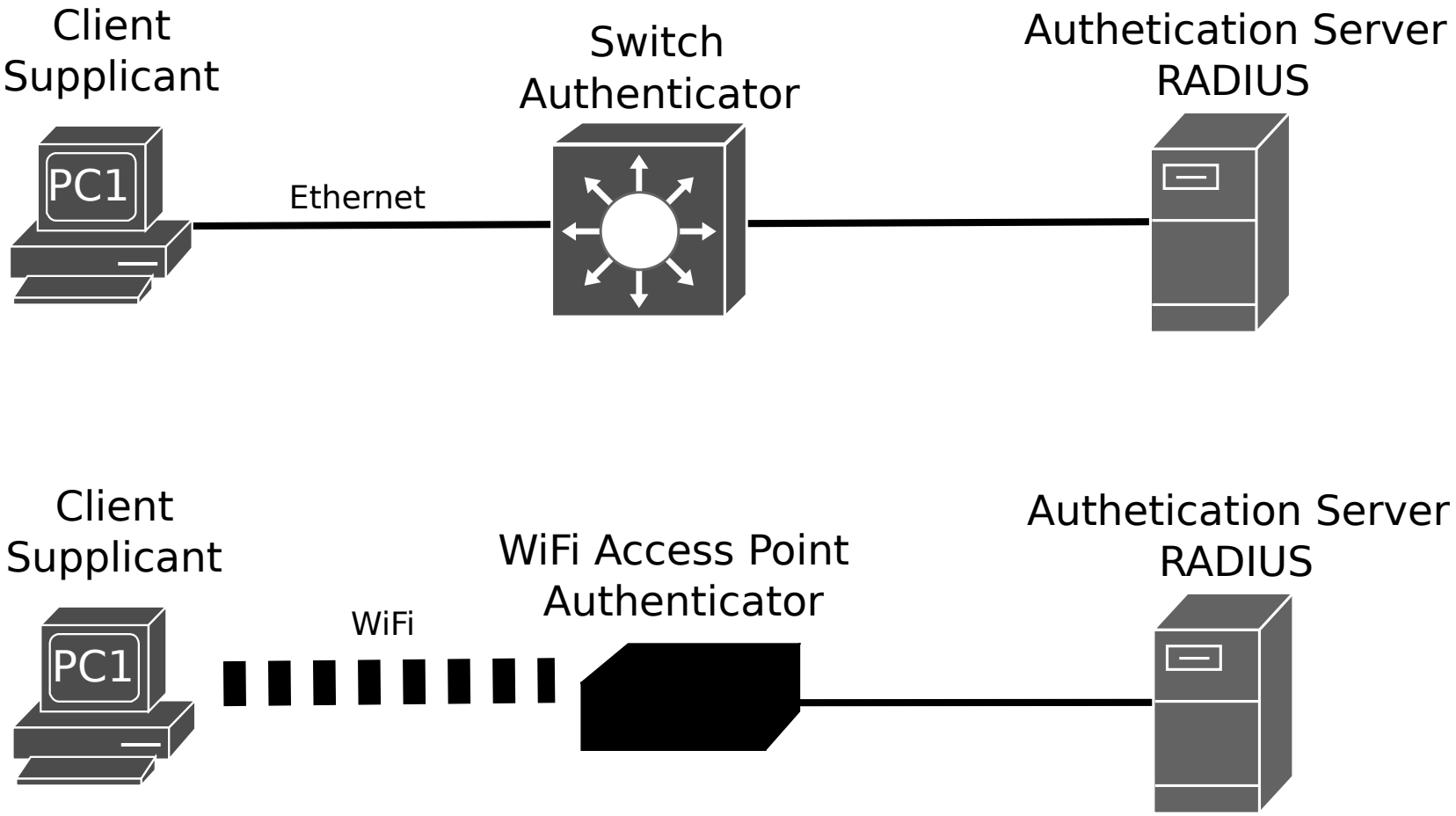
RADIUS Protocol (2)

- The RADIUS protocol has a set of vulnerabilities
  - The Access-Request packet is not authenticated at all.
  - Many client implementations do not create Request Authenticators that are sufficiently random.
  - Many administrators choose RADIUS shared secrets with insufficient information entropy and many implementations limit the shared secret key space.

DIAMETER

- DIAMETER is a newest framework in IETF for the next-generation AAA server
- Provides an AAA framework for Mobile-IP
- Does not use the same RADIUS protocol data unit, but is backward compatible with RADIUS to ease migration
- Bidirectional authentication
- It uses UDP but has a scheme that regulates the flow of packets
- Challenge/response attributes can be secured using end-to-end encryption and authentication
- Supports end-to-end security

802.1X - Ethernet vs. WiFi



Ethernet - EAP and RADIUS

11.564981	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	EAP	60	Request, Identity
11.565227	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	EAP	60	Response, Identity
11.585255	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	EAP	60	Request, MD5-Challenge EAP (EAP-MD5-CHALLENGE)
11.585554	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	EAP	60	Response, Legacy Nak (Response Only)
11.605541	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	EAP	60	Request, Protected EAP (EAP-PEAP)
11.606107	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	TLSv1	221	Client Hello
11.625805	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	EAP	1022	Request, Protected EAP (EAP-PEAP)
11.626628	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	EAP	60	Response, Protected EAP (EAP-PEAP)
11.646176	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	TLSv1	212	Server Hello, Certificate, Server Key Exchange, Server Hello Don
11.649978	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	TLSv1	162	Client Key Exchange, Change Cipher Spec, Encrypted Handshake Mes
11.666300	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	TLSv1	83	Change Cipher Spec, Encrypted Handshake Message
11.666636	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	EAP	60	Response, Protected EAP (EAP-PEAP)
11.686625	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	TLSv1	61	Application Data
11.686915	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	TLSv1	98	Application Data, Application Data
11.706925	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	TLSv1	93	Application Data
11.708108	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	TLSv1	162	Application Data, Application Data
11.727323	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	TLSv1	109	Application Data
11.728248	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	TLSv1	98	Application Data, Application Data
11.747691	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	TLSv1	61	Application Data
11.748540	PcsCompu_64:26:6d	Nearest-non-TPMR-bridge	TLSv1	98	Application Data, Application Data
11.768072	c2:01:d1:5d:f1:00	PcsCompu_64:26:6d	EAP	60	Success

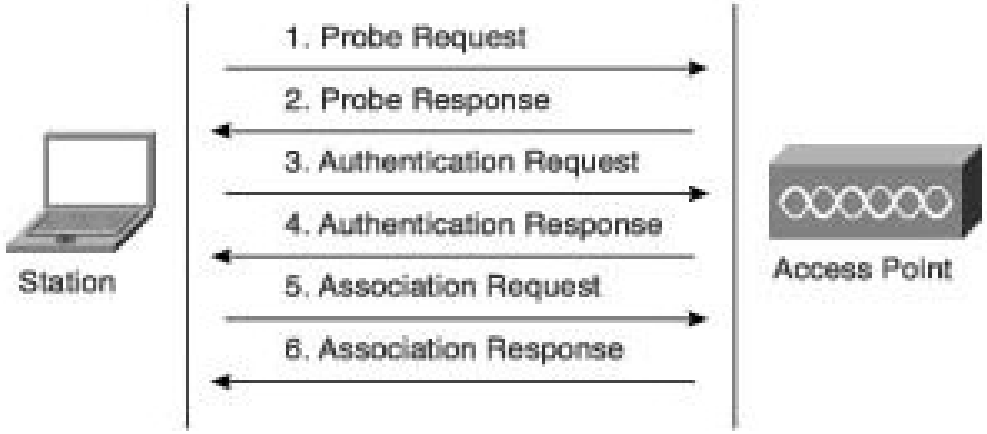
0.000000	10.0.0.1	10.0.0.100	RADIUS	154	Access-Request id=1
0.000594	10.0.0.100	10.0.0.1	RADIUS	122	Access-Challenge id=1
0.020271	10.0.0.1	10.0.0.100	RADIUS	165	Access-Request id=2
0.020944	10.0.0.100	10.0.0.1	RADIUS	106	Access-Challenge id=2
0.040451	10.0.0.1	10.0.0.100	RADIUS	362	Access-Request id=3
0.049097	10.0.0.100	10.0.0.1	RADIUS	1110	Access-Challenge id=3
0.060742	10.0.0.1	10.0.0.100	RADIUS	165	Access-Request id=4
0.062137	10.0.0.100	10.0.0.1	RADIUS	294	Access-Challenge id=4
0.081103	10.0.0.1	10.0.0.100	RADIUS	303	Access-Request id=5
0.081845	10.0.0.100	10.0.0.1	RADIUS	165	Access-Challenge id=5
0.101366	10.0.0.1	10.0.0.100	RADIUS	165	Access-Request id=6
0.101883	10.0.0.100	10.0.0.1	RADIUS	143	Access-Challenge id=6
0.121651	10.0.0.1	10.0.0.100	RADIUS	239	Access-Request id=7
0.122255	10.0.0.100	10.0.0.1	RADIUS	175	Access-Challenge id=7
0.141930	10.0.0.1	10.0.0.100	RADIUS	303	Access-Request id=8
0.143019	10.0.0.100	10.0.0.1	RADIUS	191	Access-Challenge id=8
0.162277	10.0.0.1	10.0.0.100	RADIUS	239	Access-Request id=9
0.163695	10.0.0.100	10.0.0.1	RADIUS	143	Access-Challenge id=9
0.182642	10.0.0.1	10.0.0.100	RADIUS	239	Access-Request id=10
0.184255	10.0.0.100	10.0.0.1	RADIUS	212	Access-Accept id=10

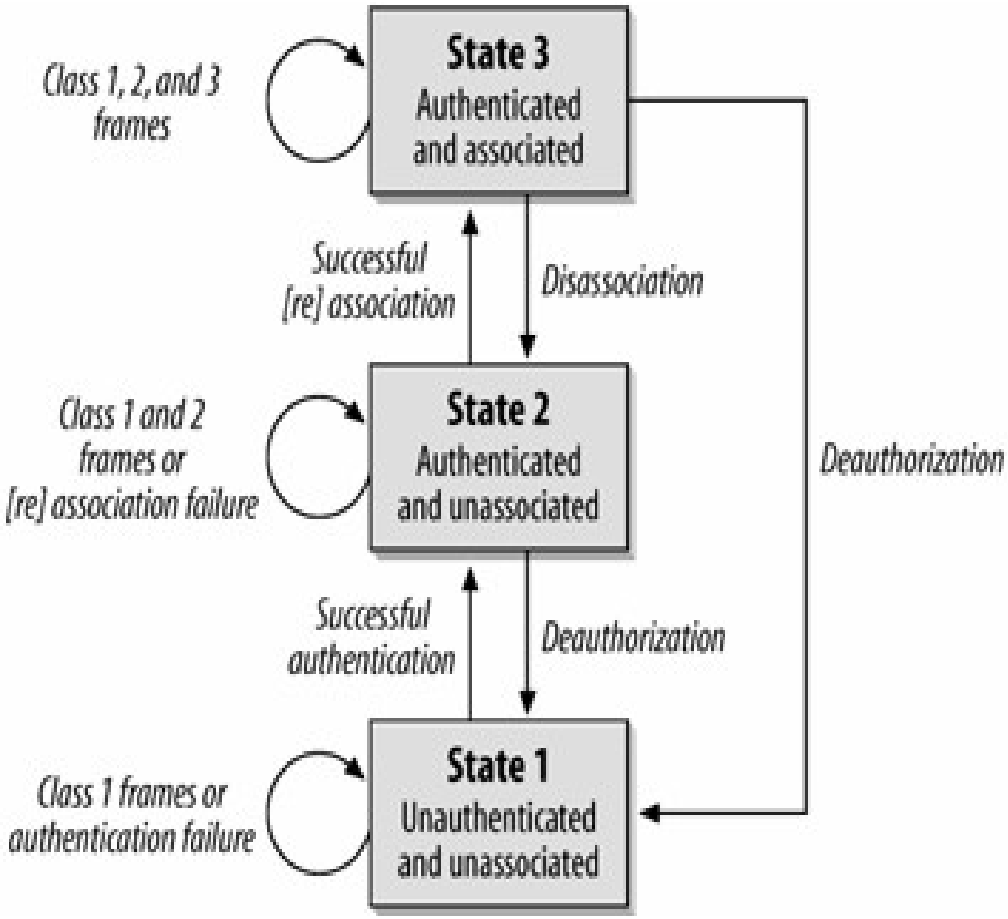
IEEE 802.11 services

- Station services (similar to wired network)
  - Authentication (login)
  - De-authentication (logout)
  - Privacy
  - Data delivery
- Distribution services
  - Association
    - Make logical connection between the AP and the station – the AP will not receive any data from a station before association
  - Re-association (similar to association)
    - Send repeatedly to the AP.
    - Help the AP to know if the station has moved from/to another BSS.
    - After Power Save
  - Disassociation
    - Manually disconnect (PC is shutdown or adapter is ejected)

Joining a BSS

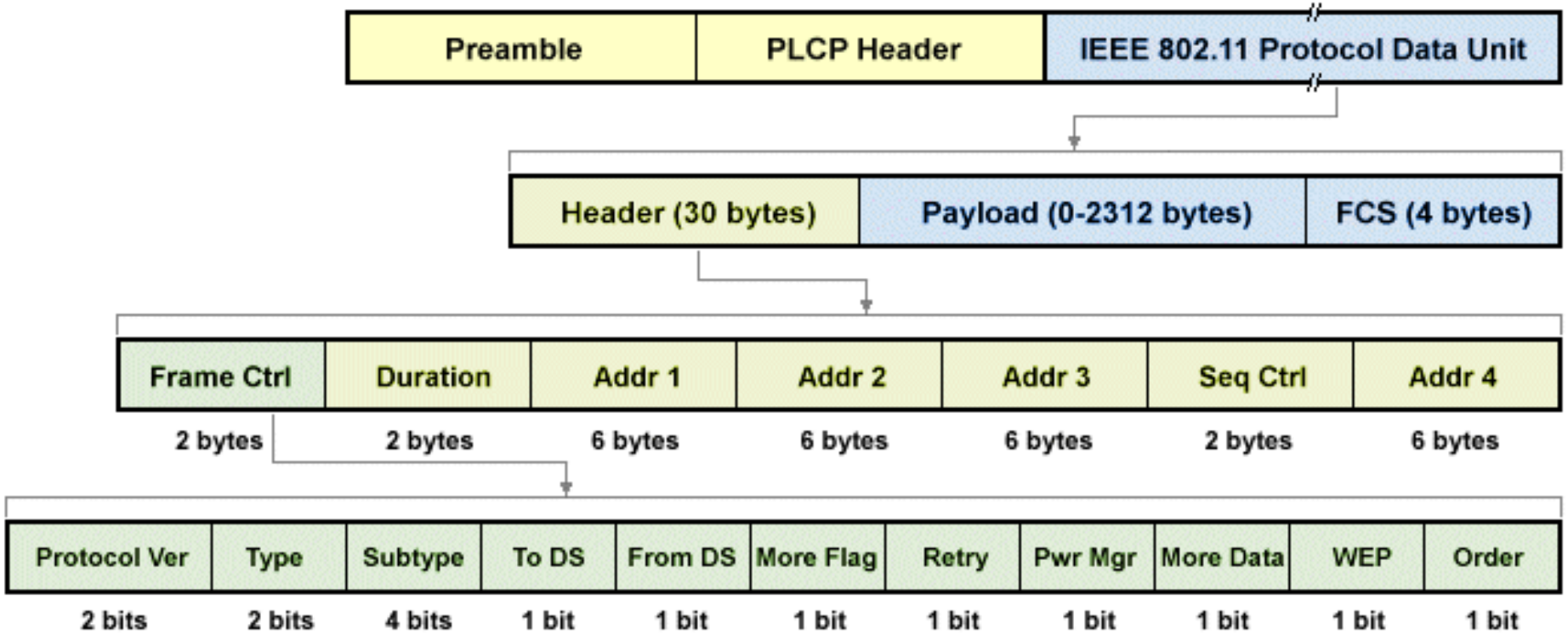
- Station finds BSS/AP by **Scanning/Probing**.
- BSS with AP: both **Authentication** and **Association** are necessary for joining a BSS.





WLAN Frames

- Three types of frames
  - Control: RTS, CTS, ACK
  - Management
  - Data
- Header is different for the different types of frames.



Joining BSS with AP: Scanning

- A station willing to join a BSS must get in contact with the AP. This can happen through:
- 1. Passive scanning
  - The station scans the channels for a Beacon frame that is sent periodically from an AP to announce its presence and provide the SSID, and other parameters for WNICs within range
- 2. Active scanning (the station tries to find an AP)
  - The station sends a Probe Request frame - Sent from a station when it requires information from another station
  - All AP's within reach reply with a Probe Response frame - Sent from an AP containing capability information, supported data rates, etc., after receiving a probe request frame

Beacon Frame

```
▾ IEEE 802.11 Beacon frame, Flags: ........C
    Type/Subtype: Beacon frame (0x0008)
  ▸ Frame Control Field: 0x8000
    .000 0000 0000 0000 = Duration: 0 microseconds
    Receiver address: Broadcast (ff:ff:ff:ff:ff:ff)
    Destination address: Broadcast (ff:ff:ff:ff:ff:ff)
    Transmitter address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
    Source address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
    BSS Id: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
    .... .... .... 0000 = Fragment number: 0
    1001 1000 1010 .... = Sequence number: 2442
    Frame check sequence: 0x6f0b825c [unverified]
    [FCS Status: Unverified]
▾ IEEE 802.11 wireless LAN
  ▾ Fixed parameters (12 bytes)
      Timestamp: 660070796
      Beacon Interval: 0.102400 [Seconds]
    ▸ Capabilities Information: 0x0421
  ▾ Tagged parameters (123 bytes)
    ▸ Tag: SSID parameter set: LABCOM
    ▸ Tag: Supported Rates 1(B), 2(B), 5.5(B), 6, 9, 11(B), 12, 18, [Mbit/sec]
    ▸ Tag: DS Parameter set: Current Channel: 13
    ▸ Tag: Traffic Indication Map (TIM): DTIM 0 of 0 bitmap
    ▸ Tag: ERP Information
    ▸ Tag: Extended Supported Rates 24, 36, 48, 54, [Mbit/sec]
    ▸ Tag: Cisco CCX1 CKIP + Device Name
    ▸ Tag: Vendor Specific: Microsoft Corp.: WMM/WME: Parameter Element
    ▸ Tag: Vendor Specific: Cisco Systems, Inc.: Aironet Unknown (1) (1)
    ▸ Tag: Vendor Specific: Cisco Systems, Inc.: Aironet CCX version = 5
    ▸ Tag: Vendor Specific: Cisco Systems, Inc.: Aironet Unknown (11) (11)
    ▸ Tag: Vendor Specific: Cisco Systems, Inc.: Aironet Client MFP Disabled
```

Probe Request/Response Frames

```
IEEE 802.11 Probe Request, Flags: ........C
  Type/Subtype: Probe Request (0x0004)
  Frame Control Field: 0x4000
  .000 0000 0000 0000 = Duration: 0 microseconds
  Receiver address: Broadcast (ff:ff:ff:ff:ff:ff)
  Destination address: Broadcast (ff:ff:ff:ff:ff:ff)
  Transmitter address: Microsof_0a:43:e3 (c0:33:5e:0a:43:e3)
  Source address: Microsof_0a:43:e3 (c0:33:5e:0a:43:e3)
  BSS Id: Broadcast (ff:ff:ff:ff:ff:ff)
  .... .... .... 0000 = Fragment number: 0
  1100 1011 0001 .... = Sequence number: 3249
  Frame check sequence: 0xc7056d0a [unverified]
  [FCS Status: Unverified]
IEEE 802.11 wireless LAN
  Tagged parameters (62 bytes)
    Tag: SSID parameter set: TD_WIFI_GUEST
    Tag: Supported Rates 1, 2, 5.5, 6, 9, 11, 12, 18, [Mbit/sec]
    Tag: DS Parameter set: Current Channel: 13
    Tag: HT Capabilities (802.11n D1.10)
    Tag: Extended Supported Rates 24, 36, 48, 54, [Mbit/sec]
```

```
IEEE 802.11 Probe Response, Flags: ........C
  Type/Subtype: Probe Response (0x0005)
  Frame Control Field: 0x5000
  .000 0001 0011 1010 = Duration: 314 microseconds
  Receiver address: IntelCor_d2:98:58 (28:b2:bd:d2:98:58)
  Destination address: IntelCor_d2:98:58 (28:b2:bd:d2:98:58)
  Transmitter address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  Source address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  BSS Id: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  .... .... .... 0000 = Fragment number: 0
  1010 0010 1001 .... = Sequence number: 2601
  Frame check sequence: 0x80831320 [unverified]
  [FCS Status: Unverified]
IEEE 802.11 wireless LAN
  Fixed parameters (12 bytes)
    Timestamp: 664064263
    Beacon Interval: 0.102400 [Seconds]
    Capabilities Information: 0x0421
  Tagged parameters (117 bytes)
    Tag: SSID parameter set: LABCOM
    Tag: Supported Rates 1(B), 2(B), 5.5(B), 6, 9, 11(B), 12, 18, [Mbit/sec]
    Tag: DS Parameter set: Current Channel: 13
    Tag: ERP Information
    Tag: Extended Supported Rates 24, 36, 48, 54, [Mbit/sec]
    Tag: Cisco CCX1 CKIP + Device Name
    Tag: Vendor Specific: Microsoft Corp.: WMM/WME: Parameter Element
    Tag: Vendor Specific: Cisco Systems, Inc.: Aironet Unknown (1) (1)
    Tag: Vendor Specific: Cisco Systems, Inc.: Aironet CCX version = 5
    Tag: Vendor Specific: Cisco Systems, Inc.: Aironet Unknown (11) (11)
    Tag: Vendor Specific: Cisco Systems, Inc.: Aironet Client MFP Disabled
```

Joining BSS with AP: Authentication

- Once an AP is found/selected, a station goes through authentication
- Open system authentication (default, 2-step process)
  - Station sends authentication frame with its identity
  - AP sends frame as an Ack / NAck
- Shared key authentication
  - Stations receive shared secret key through secure channel independent of 802.11
  - After the WNIC sends its initial authentication request, it will receive an authentication frame from the AP containing a challenge text
  - The WNIC sends an authentication frame containing the encrypted version of the challenge text to the AP.
  - The AP ensures the text was encrypted with the correct key by decrypting it with its own key.
  - The result of this process determines the WNIC's authentication status.

Authentication Frames

- Nowadays, WPA* sedcure networks use “Open System”.
- Non-”Open System” authentication was used for WEP protected networks (unsecured and functionally deprecated).

```
IEEE 802.11 Authentication, Flags: ........
  Type/Subtype: Authentication (0x000b)
  Frame Control Field: 0xb000
  .000 0001 0011 1010 = Duration: 314 microseconds
  Receiver address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  Destination address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  Transmitter address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
  Source address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
  BSS Id: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  .... .... .... 0000 = Fragment number: 0
  0001 0100 1011 .... = Sequence number: 331
IEEE 802.11 wireless LAN
  Fixed parameters (6 bytes)
    Authentication Algorithm: Open System (0)
    Authentication SEQ: 0x0001
    Status code: Successful (0x0000)
```

← From Station

From AP →

```
IEEE 802.11 Authentication, Flags: ........C
  Type/Subtype: Authentication (0x000b)
  Frame Control Field: 0xb000
  .000 0001 0011 1010 = Duration: 314 microseconds
  Receiver address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
  Destination address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
  Transmitter address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  Source address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  BSS Id: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  .... .... .... 0000 = Fragment number: 0
  1010 1001 0000 .... = Sequence number: 2704
  Frame check sequence: 0x9f8350e1 [unverified]
  [FCS Status: Unverified]
IEEE 802.11 wireless LAN
  Fixed parameters (6 bytes)
    Authentication Algorithm: Open System (0)
    Authentication SEQ: 0x0002
    Status code: Successful (0x0000)
```

Joining BSS with AP: Association

- Once a station is authenticated, it starts the association process, i.e., information exchange about the AP/station capabilities and roaming
  - STA → AP: Associate Request frame
    - Enables the AP to allocate resources and synchronize. The frame carries information about the WNIC, including supported data rates and the SSID of the network the station wishes to associate with.
  - AP → STA: Association Response frame
    - Acceptance or rejection to an association request. If it is an acceptance, the frame will contain information such as association ID and supported data rates.
  - New AP informs old AP (if it is a handover).
- Only after association is completed, a station can transmit and receive data frames.

Association Request/Response Frames

← From Station

```
IEEE 802.11 Association Request, Flags: ........
  Type/Subtype: Association Request (0x0000)
  Frame Control Field: 0x0000
  .000 0001 0011 1010 = Duration: 314 microseconds
  Receiver address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  Destination address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  Transmitter address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
  Source address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
  BSS Id: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  .... .... .... 0000 = Fragment number: 0
  0001 0100 1100 .... = Sequence number: 332
IEEE 802.11 wireless LAN
  Fixed parameters (4 bytes)
    Capabilities Information: 0x0421
    Listen Interval: 0x000a
  Tagged parameters (43 bytes)
    Tag: SSID parameter set: LABCOM
    Tag: Supported Rates 1, 2, 5.5, 11, 6, 9, 12, 18, [Mbit/sec]
    Tag: Extended Supported Rates 24, 36, 48, 54, [Mbit/sec]
    Tag: Extended Capabilities (8 octets)
    Tag: Vendor Specific: Microsoft Corp.: WMM/WME: Information E
```

From AP →

```
IEEE 802.11 Association Response, Flags: ........C
  Type/Subtype: Association Response (0x0001)
  Frame Control Field: 0x1000
  .000 0001 0011 1010 = Duration: 314 microseconds
  Receiver address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
  Destination address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
  Transmitter address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  Source address: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  BSS Id: Cisco_61:ee:d0 (00:1c:f6:61:ee:d0)
  .... .... .... 0000 = Fragment number: 0
  1010 1001 0001 .... = Sequence number: 2705
  Frame check sequence: 0xe7103b15 [unverified]
  [FCS Status: Unverified]
IEEE 802.11 wireless LAN
  Fixed parameters (6 bytes)
    Capabilities Information: 0x0421
    Status code: Successful (0x0000)
    ..00 0000 0000 0001 = Association ID: 0x0001
  Tagged parameters (42 bytes)
    Tag: Supported Rates 1(B), 2(B), 5.5(B), 6, 9, 11(B), 12, 18, [Mbit/sec]
    Tag: Extended Supported Rates 24, 36, 48, 54, [Mbit/sec]
    Tag: Vendor Specific: Microsoft Corp.: WMM/WME: Parameter Element
```

Data Frame

```
▾ IEEE 802.11 QoS Data, Flags: .p.....TC
    Type/Subtype: QoS Data (0x0028)
  ▸ Frame Control Field: 0x8841
    .000 0001 0011 1010 = Duration: 314 microseconds
    Receiver address: Cisco_61:ee:d1 (00:1c:f6:61:ee:d1)
    Transmitter address: IntelCor_e8:14:53 (b8:8a:60:e8:14:53)
    Destination address: D-LinkIn_6a:cc:6e (84:c9:b2:6a:cc:6e)
    Source address: IntelCor_e8:14:53 (b8:8a:60:e8:14:53)
    BSS Id: Cisco_61:ee:d1 (00:1c:f6:61:ee:d1)
    STA address: IntelCor_e8:14:53 (b8:8a:60:e8:14:53)
    .... .... .... 0000 = Fragment number: 0
    0000 0000 0011 .... = Sequence number: 3
    Frame check sequence: 0xc72771e8 [unverified]
    [FCS Status: Unverified]
  ▸ Qos Control: 0x0000
  ▸ CCMP parameters
▾ Data (1244 bytes)
    Data: f8002648417037bc923106ead1717d4821fde0989beb08b1…
    [Length: 1244]
```

← Node that will receive frame (AP)
← Node that send frame
← Station to receive data
← Station who sent data

- Station “IntelCor*” sending data to station “D-LinkIn*” (via AP).
- Frame captured between station “IntelCor*” and AP (“Cisco*”).

WPA and 802.11i (WPA2)

- **IEEE 802.11i - IEEE 802.11 task group “MAC enhancement for wireless security”.**
- **Wi-Fi Protected Access (WiFi Alliance), WPA, is a subset internal in 802.11i.**
  - Compatible with work developed in 802.11i.
  - Only supports BSS.
  - Defined to work in actual equipment.
    - Firmware update only.
  - Pass-phrase constant and shared, but keys are generated per session.
  - Used in the AP and station.
- WPA has two distinct components.
  - Authentication, based on 802.1X.
  - Ciphering based on TKIP (Temporal Key Integrity Protocol).

WPA

- Authentication
  - 802.1X (≠ 802.11x) – defined for wired and wireless sessions, as a transport protocol
    - EAP (Extensible Authentication Protocol) – like a wrapper for the specific authentication traffic
    - Impact of EAP
      - Authentication does not traverse the AP (STA - server)
      - It is possible to use different authentication methods without changing APs
  - Defines also a Pre-Shared Key (PSK)
    - For local networks
- Temporal Key Integrity Protocol (TKIP) – internal solution with better protection, for actual equipments
  - Greater privacy
    - Uses the same cipher, but now associated to the MAC and a larger IV
    - “Key rollover” with temporal validity
  - Greater integrity
    - Integrity separated key

802.11i (WPA2)

- Better than WPA
  - Also includes TKIP
  - Authentication IBSS (ad-hoc mode)?
  - RSN (Robust Security Network) protocol
    - Authentication and ciphering between APs and stations
    - Supports new ciphering protocols, resorting to 802.1x and EAP
    - Supports AES (Advanced Encryption Standard) ciphering
- Problems
  - It does not cipher control and management frames
    - (Disassociate, output power, etc).
  - Requires new hardware

WPA* Key Exchange (EAP phase 2)

- Done during the Association process.
  - After Association Request/response frames.
  - Uses (QoS) Data Frames

```
  205 595.669409767  IntelCor_e8:14:53    Cisco_61:ee:d1         802.11   110 Association Request, SN=38, FN=0, Flags=........, SSID=LABCOM_SEC
  206 595.671214291  Cisco_61:ee:d1       IntelCor_e8:14:53      802.11   128 Association Response, SN=14, FN=0, Flags=........
  207 595.673042781  Cisco_61:ee:d1       IntelCor_e8:14:53      EAPOL    211 Key (Message 1 of 4)
  208 595.678333124  IntelCor_e8:14:53    Cisco_61:ee:d1         EAPOL    168 Key (Message 2 of 4)
  209 595.681795313  Cisco_61:ee:d1       IntelCor_e8:14:53      EAPOL    269 Key (Message 3 of 4)
  210 595.683690439  IntelCor_e8:14:53    Cisco_61:ee:d1         EAPOL    146 Key (Message 4 of 4)
```

```
▸ Frame 207: 211 bytes on wire (1688 bits), 211 bytes captured (1688 bits) on interface 0
▸ Radiotap Header v0, Length 56
▸ 802.11 radio information
▾ IEEE 802.11 QoS Data, Flags: ......F.
    Type/Subtype: QoS Data (0x0028)
  ▸ Frame Control Field: 0x8802
    .000 0001 0011 1010 = Duration: 314 microseconds
    Receiver address: IntelCor_e8:14:53 (b8:8a:60:e8:14:53)
    Transmitter address: Cisco_61:ee:d1 (00:1c:f6:61:ee:d1)
    Destination address: IntelCor_e8:14:53 (b8:8a:60:e8:14:53)
    Source address: Cisco_61:ee:d1 (00:1c:f6:61:ee:d1)
    BSS Id: Cisco_61:ee:d1 (00:1c:f6:61:ee:d1)
    STA address: IntelCor_e8:14:53 (b8:8a:60:e8:14:53)
    .... .... .... 0000 = Fragment number: 0
    0000 0001 1100 .... = Sequence number: 28
  ▸ Qos Control: 0x0007
▸ Logical-Link Control
▾ 802.1X Authentication
    Version: 802.1X-2004 (2)
    Type: Key (3)
    Length: 117
    Key Descriptor Type: EAPOL RSN Key (2)
    [Message number: 1]
  ▸ Key Information: 0x008a
    Key Length: 16
    Replay Counter: 1
    WPA Key Nonce: 4f65d0b4e9e77b88f2cbb135749eeb105a3aa1ef65de66a8…
    Key IV: 00000000000000000000000000000000
    WPA Key RSC: 0000000000000000
    WPA Key ID: 0000000000000000
    WPA Key MIC: 00000000000000000000000000000000
    WPA Key Data Length: 22
  ▸ WPA Key Data: dd14000fac046616ebb59b83e8cc1816ced0e542a935
```

Extra References

- Cisco, Wired 802.1X Deployment Guide
- H. N. Thakur, A. Al Hayajneh, K. Thakur, A. Kamruzzaman and M. L. Ali, " A Comprehensive Review of Wireless Security Protocols and Encryption Applications," 2023 IEEE World AI IoT Congress (AIIoT), Seattle, WA, USA, 2023, pp. 0373-0379, doi: 10.1109/AIIoT58121.2023.10174571.
- M. Alhamry and A. Alomary, "Exploring Wi-Fi WPA2-PSK protocol weaknesses," 2022 International Conference on Data Analytics for Business and Industry (ICDABI), Sakhir, Bahrain, 2022, pp. 190-195, doi:10.1109/ICDABI56818.2022.10041465.