COM 5335 Network Security Lec 13 - 802.1x, EAP, RADIUS

Scott CH Huang

Wired Equivalent Privacy (WEP)

- Background
  - The only standard for WLAN security till 2000
  - Still used by a large number of legacy implementations
- Objectives behind WEP
  - "Reasonable" strength
    - Intended to make it difficult to break in like a wired network
  - Self synchronizing
    - Each frame is encrypted independently of the others
  - Efficient
    - It must be fast and in software or hardware
  - Exportable
    - There must be no export restriction (1997) – use 40 bit keys
  - Optional

WEP Keys

- Characteristics
  - Keys are either 40 or 104 bits long and symmetric
  - Keys are static – they never change unless manually reconfigured
- Two types – default and key mapping keys
- Default key
  - All MSs and APs use a single set of keys
  - Also called shared key, group key, multicast key or simply key by vendors
  - Possible to have more than one default key (up to 4 values)
    - The default key in use is called the active key
    - Directional usage of keys is also possible
- Key mapping keys – not widely deployed
  - Each MS has a unique key (also called per-station or individual key)
  - AP keeps a table of MSs and keys
  - Need a separate key for multicast/broadcast messages that is shared by all MSs
- Both types of keys can be allowed simultaneously in a WLAN

WEP Authentication

- Open authentication
  - AP accepts connections from all MSs
  - MSs connect to any available AP that is willing to accept a connection

- Shared key authentication
  - Uses a version of the challenge response protocol
  - There is NO key exchange as part of the protocol
  - Easy to hijack sessions after authentication is performed if subsequent encryption is not used
  - Used primarily to eliminate confusion for honest MSs
  - Most systems do not implement any authentication at all

WEP Authentication - Shared Key

- Idea
  - Allow the AP to know that the MS possesses the right secret key
- Process
  - Host requests authentication from access point
  - AP sends 128 bit nonce
  - Host encrypts nonce using shared symmetric key using RC4
  - AP decrypts nonce and authenticates the host
- The authentication is NOT mutual

WEP Confidentiality

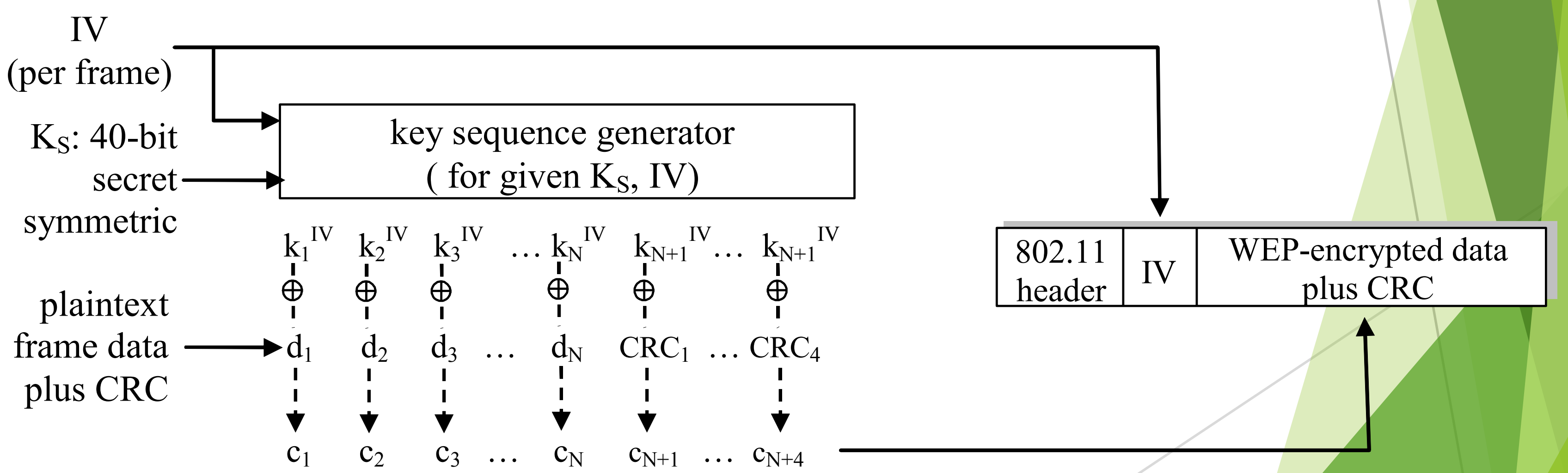
- Data packets are all encrypted using RC4 stream cipher
  - You should NOT use the same key with a stream cipher to encrypt two message (why?)
  - Each packet in IEEE 802.11 is encrypted separately
  - There is only one key shared between the MS and AP
  - How can we avoid the problem with stream ciphers?
- Idea in WEP
  - Combine the secret key with a 24-bit *Initialization Vector (IV)* that changes for every packet
  - This increases the key size from 40 to 64 bits
    - Or from 104 to 128 bits
  - The IV is transmitted in plaintext with each packet making the increase in key size meaningless

WEP Confidentiality (cont.)

- 64 bit key used to generate stream of keys, k_i^{IV}
- k_i^{IV} used to encrypt i^{th} byte, d_i, in frame:

$$c_i = d_i \text{ XOR } k_i^{IV}$$

- IV and encrypted bytes c_i sent in frame
- CRC is used for integrity check



WEP Confidentiality - Weakness

- To be effective, the same IV must not be used twice – ever
  - $2^{24} = 16,777,216$
  - No. of packets/sec at a busy AP = 700
  - Time taken to capture 2^{24} packets = $2^{24}/700$ = 23968 secs. = 399 mins = 6.65 hours
- Many systems
  - Start with the same IV value after shutting down
  - Change IVs in a pseudorandom manner that is predictable
  - Make all MSs start with the same sequence of IVs

Attacks against WEP

- Authentication
  - Useful only if you can prove each time you send a packet that you are a legitimate MS
  - It allows offline key guessing
    - Oscar can authenticate himself ANYTIME
  - No session key is exchanged and subsequent message are not authenticated
  - The AP is not authenticated – easy for Oscar to mount a man-in-the-middle or reflection attack
    - Reflection attack?
      - The attacker initiates a connection to a target.
      - The target attempts to authenticate the attacker by sending it a challenge.
      - The attacker opens another connection to the target, and sends the target this challenge as its own.
      - The target responds to the challenge.
      - The attacker sends that response back to the target on the original connection.

Attacks against WEP (cont.)

- IV Reuse
  - Collisions in IVs are likely to occur sooner than 2^{24} packets
  - If Oscar knows the key stream corresponding to a particular IV, he can also decode all packets with the same IV
  - Attackers can inject packets to speed up the process
- Other weaknesses
  - WEP has no protection against replay
  - WEP encrypted messages can be modified easily because the CRC used is *linear* and encryption is just XOR
    - If you “flip” a bit of the ciphertext, you can predict which bits in the CRC part need to be flipped as well

Attacks against WEP (cont.)

- Weak RC4 keys
  - Some keys used in RC4 are weak keys
  - Since the IV is transmitted as a plaintext, it is easy for Oscar to detect a packet that has been encrypted with a weak key
    - To overcome this problem, it is better to drop the first several bits of the key stream (256 bytes is suggested)
  - Fluhrer, Mantin and Shamir showed that Oscar can get the first 8 bits of a key with just 60 messages and subsequent bytes in the same way
    - Attack is linear, not exponential so that longer keys do not help much

WEP Weakness

- IV is too short and not protected from reuse
- The per packet key is constructed from the IV, making it susceptible to weak key attacks
- No effective detection of message tampering (message integrity)
- Master key is used directly and no built-in provision to update the keys
- There is no protection against message replay

Wi-Fi and IEEE 802.11

- Wi-Fi refers to the wireless LAN network
- IEEE 802.11 is a standard, specifying the physical characteristics of the 802.11 LAN
- Wi-Fi Alliance: formed by a group of major manufactures
  - Solve the interoperability problem
  - Ambiguous/undefined areas in 802.11 standard
  - Options of 802.11: some are avoid, some are required in Wi-Fi
  - To obtain the Wi-Fi certification, a manufacturer must submit its product for testing against a set of "gold standard" Wi-Fi products.

IEEE 802.11i and WPA

- IEEE 802.11i is the addendum to the 802.11 standard. 802.11i specifies the new generation of security.
  - 802.11i defines a new type of network called a robust security network (RSN). RSN-enables device is not compatible with Wi-Fi equipment
  - 802.11i task group developed a security solution base on the current capabilities of the Wi-Fi products: TKIP
- Wi-Fi Protected Access (WPA): a subset of RSN specifying TKIP
- RSN and WPA share a single security architecture that covers procedures such as upper-level authentication, key distribution and renewal.
  - More complex and scalable compared to WEP

802.11i – Three pieces, Two Layers

- Lower layer: TKIP and CCMP
  - By the 802.11i working group
  - Temporal Key Integrity Protocol
  - Counter Mode with CBC-MAC protocol
  - Both provides enhanced data integrity over WEP
  - TKIP being targeted at legacy equipment and CCMP being targeted at future WLAN equipment
- Upper Layer: 802.1X
  - 802.1X is a standard for port based access control developed by a different body within the IEEE 802 organization
  - 802.1X provides a framework for robust user authentication and encryption key distribution
    - Original 802.11 has neither of these features.
- The three pieces discussed above work together to form an overall security system

Importance of Access Control

- Separate the world with “good guys” and “bad guys”
- How to do it in WPA and RSN?
  - IEEE 802.1X: Originally designed for authenticating ports on wired LANs
  - EAP: Extensible Authentication Protocol
  - RADIUS: Remote Authentication Dial-In User Service
- IEEE 802.1X with EAP are mandatory for WPA and RSN
- RADIUS is the method of choice by WPA, and is optional in RSN
- EAP and RADIUS were both developed for dial-in access
  - Dial-in access control is organized in a very similar way to IEEE 802.1X

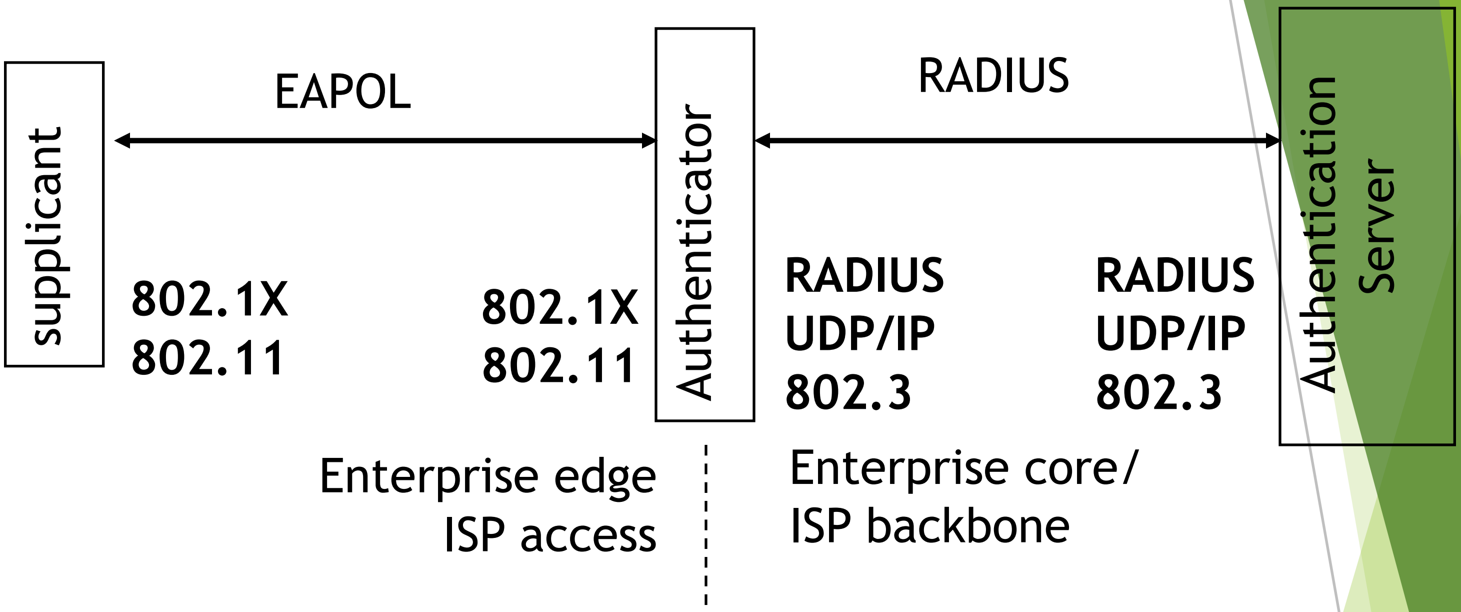
802.1X

- A standard for port based network access control
- It can be applied to both wired and wireless networks and provides a framework for user authentication and encryption key distribution.
  - It can be used to restrict access to a network until the user has been authenticated by the network.
  - In addition, 802.1x is used in conjunction with one of a number of upper layer authentication protocols to perform verification of credentials and generation of encryption keys.

Entities in 802.1X

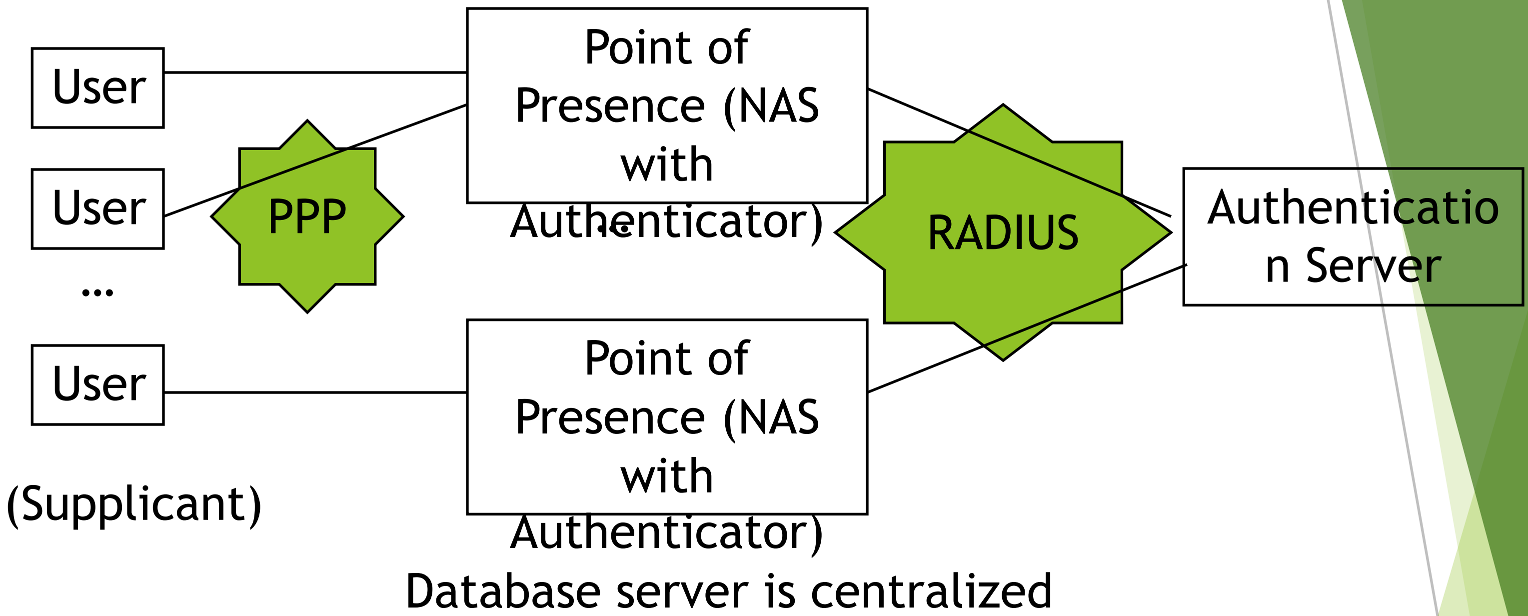
- Three Components
  - Supplicant (client): An entity that wants to have access
  - Authenticator (switch, AP, other NAS, preferably RADIUS capable): An entity that controls the access gate
  - Authentication Server (sometimes part of Authenticator, otherwise RADIUS server, the most common type of authentication server): An entity that decides whether the supplicant is to be admitted – authorizer

802.1X Architecture



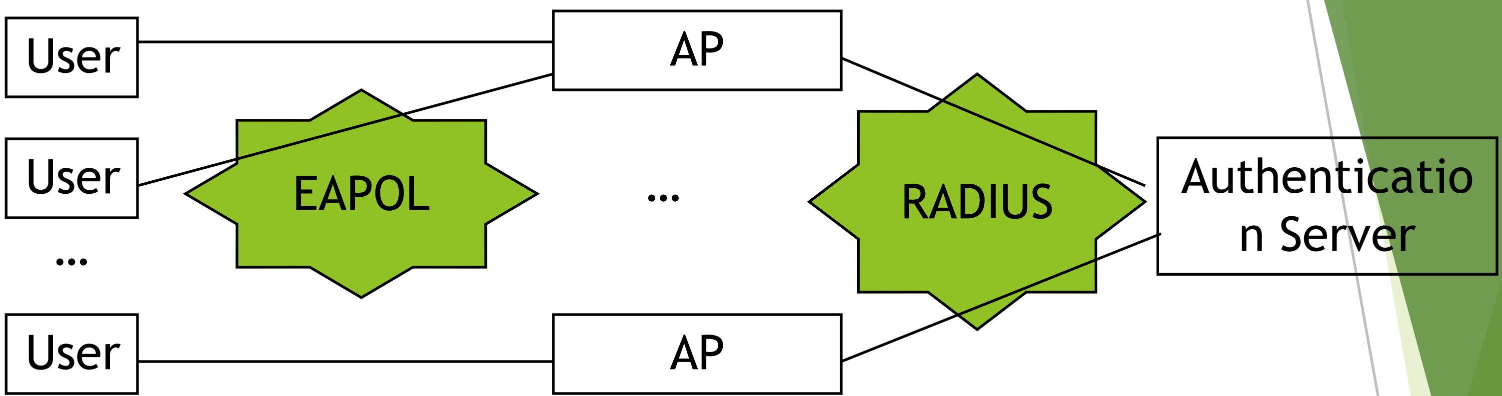
- Authenticator acts as a bridge
- 802.1X is a framework, not a complete specification in and of itself. The actual authentication mechanism is implemented by the authentication server

Authentication for Dial-In Users



PPP protocol defines two weak authentication methods:
PAP and CHAP -- Users provide UNANE and PWD
PAP: UNAME and PWD are transmitted in clear text
CHAP: a challenge-response scheme is exploited
EAP is proposed for stronger authentication in PPP

Authentication for Wireless LAN Users



Database server is centralized

- Similar to the dial-in network organization
- IEEE 802.1X Utilizes EAP for access control
  - 802.1X implement access control at the point at which a user joins the network
  - In Wireless LAN, an AP needs to create a logical port in software with an authenticator for each wireless user -- no physical port is available!
  - The number of 802.1X entities in operation is the same as the number of associated mobile devices
  - Port traffic, except for 802.1X, blocked until successful authentication

More on 802.1X

- 802.1X authenticates users, rather than machines
  - WEP relies on the shared key, stored each machine
- 802.1X is a framework based on EAP; it is an IEEE adaptation of the IETF's EAP
  - EAP is originally specified in RFC 2284 and updated by RFC 3748
- EAP is a framework protocol too.
  - Rather than specifying how to authenticate users, EAP allows protocol designers to build their own EAP methods, subprotocols, that perform the authentication transaction
  - EAP methods can have different goals, and therefore, often use many different methods for authenticating users depending on the requirements of a particular situation

EAP

- Motivation of EAP
  - When PPP is first introduced in the early 1990s, there were two protocols available for user authentication: PAP and CHAP
  - Both PAP and CHAP require the use of a PPP protocol number
    - Assigning a PPP protocol number to each authentication method that might be obsolete soon is not favorable
  - EAP uses a single PPP protocol number while supporting a wide variety of authentication mechanisms
    - EAP is a single encapsulation that can run over link layer such as PPP, 802.3, 802l.11
    - It is most widely deployed on PPP links
- Generic EAP packet format (EAP over PPP & EAP over LAN

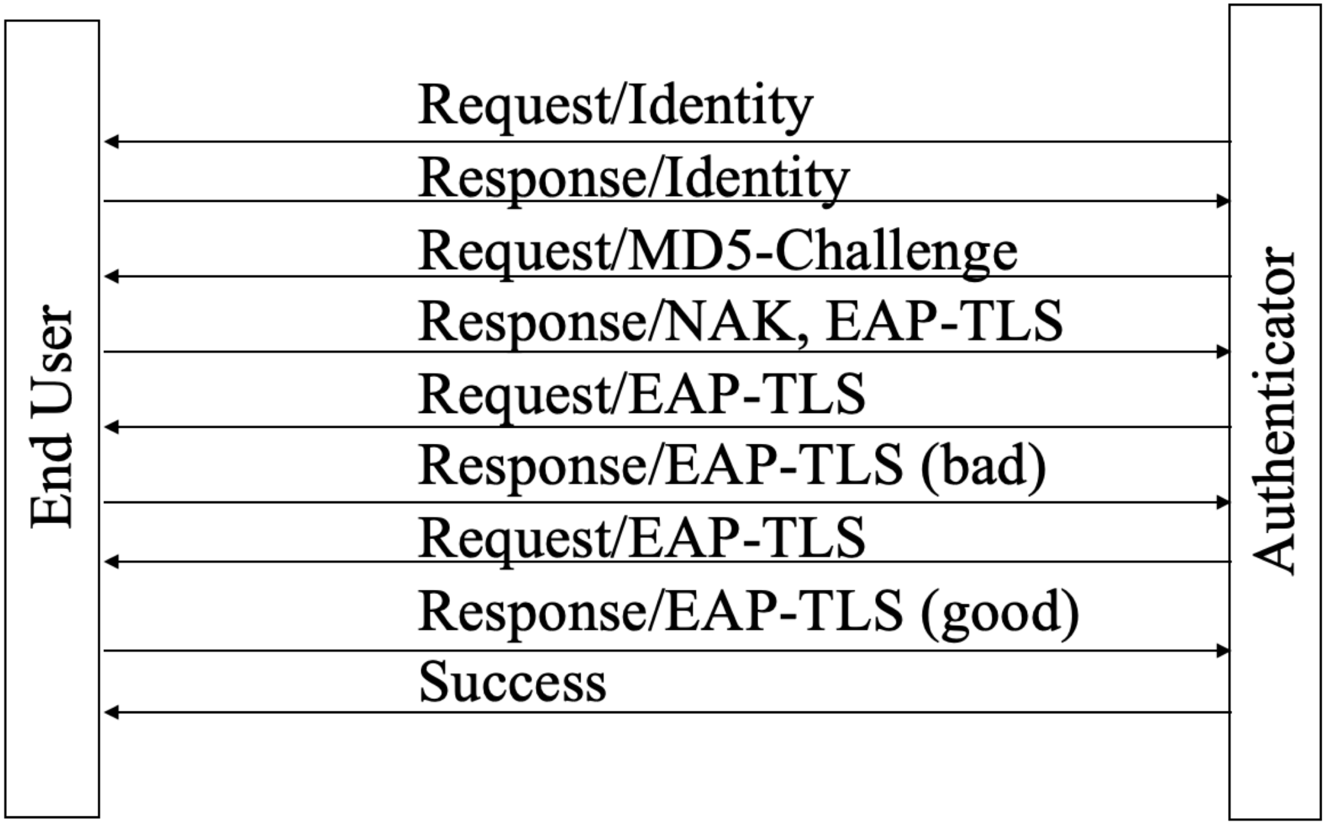
PPP Header	Code	Identifier	Length	Data
	1	1	2	Variable length

LAN Header	Code	Identifier	Length	Data

EAP Packet Format (Four Types)

- EAP Requests and Responses
  - Code = 1 for request and 2 for response
  - Extra field called Type-Code in EAP Request/Response message before the Data field
    - Type Code: 1 for identity, 2 for notification, 3 for NAK
    - Notification: for notification message (eg. Pwd is going to expire…), rarely used for 802.1X
    - NAK: Null ACK, used to suggest a new authentication method
  - Type-Code >3 specifying authentication method
    - Type-code = 4: MD5 Challenge
    - Type-code = 13: EAP-TLS
  - Identifier: a number incremented for each message send, data field may contain a prompt (Req/Res) message; used for pairing the request/response – same number for the pair
- EAP Success and Failure
  - Code = 3 for success, =4 for failure
  - Short data package containing no data

A Simple EAP Message Exchange



Request/Identity: starting the exchange, telling the end users That the network is likely to drop data traffic before the authentication procedure is complete

EAP Demystified

- Authentication framework
  - EAP utilizes authentication-specific messages
  - Authenticators only need to recognize a few well defined messages
    - Request/Response
    - Success/Failure
  - EAP subtypes allow for new types of authentication methods to be added without requiring upgrades to the Authenticators
  - You can write MyMethod over EAP

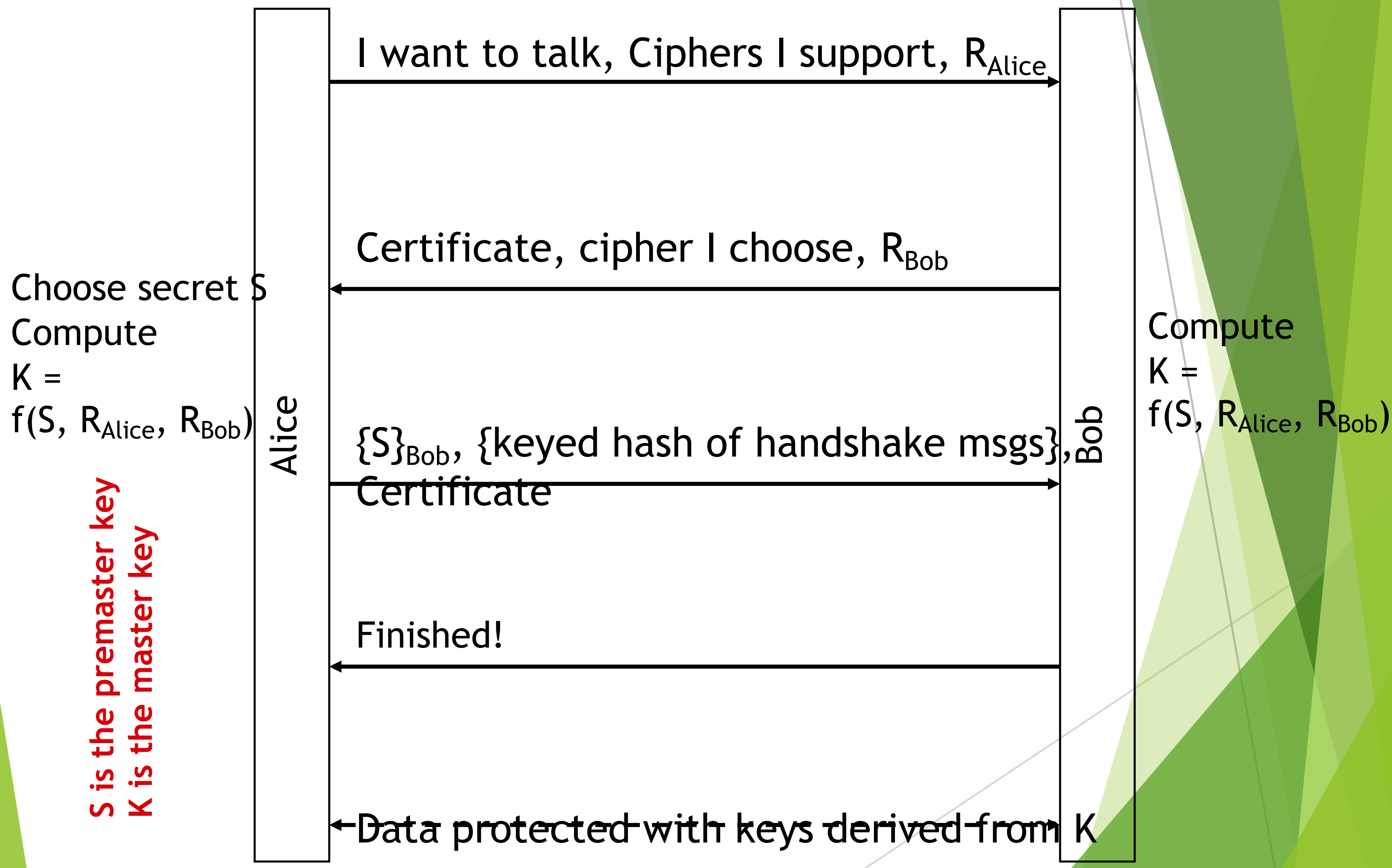
How to Choose an EAP Method?

- Driven by the back-end authentication system
- An EAP method for Wireless LAN should meet the three major goals
  - Strong cryptographic protection of user credentials
  - Mutual authentication
  - Key derivation

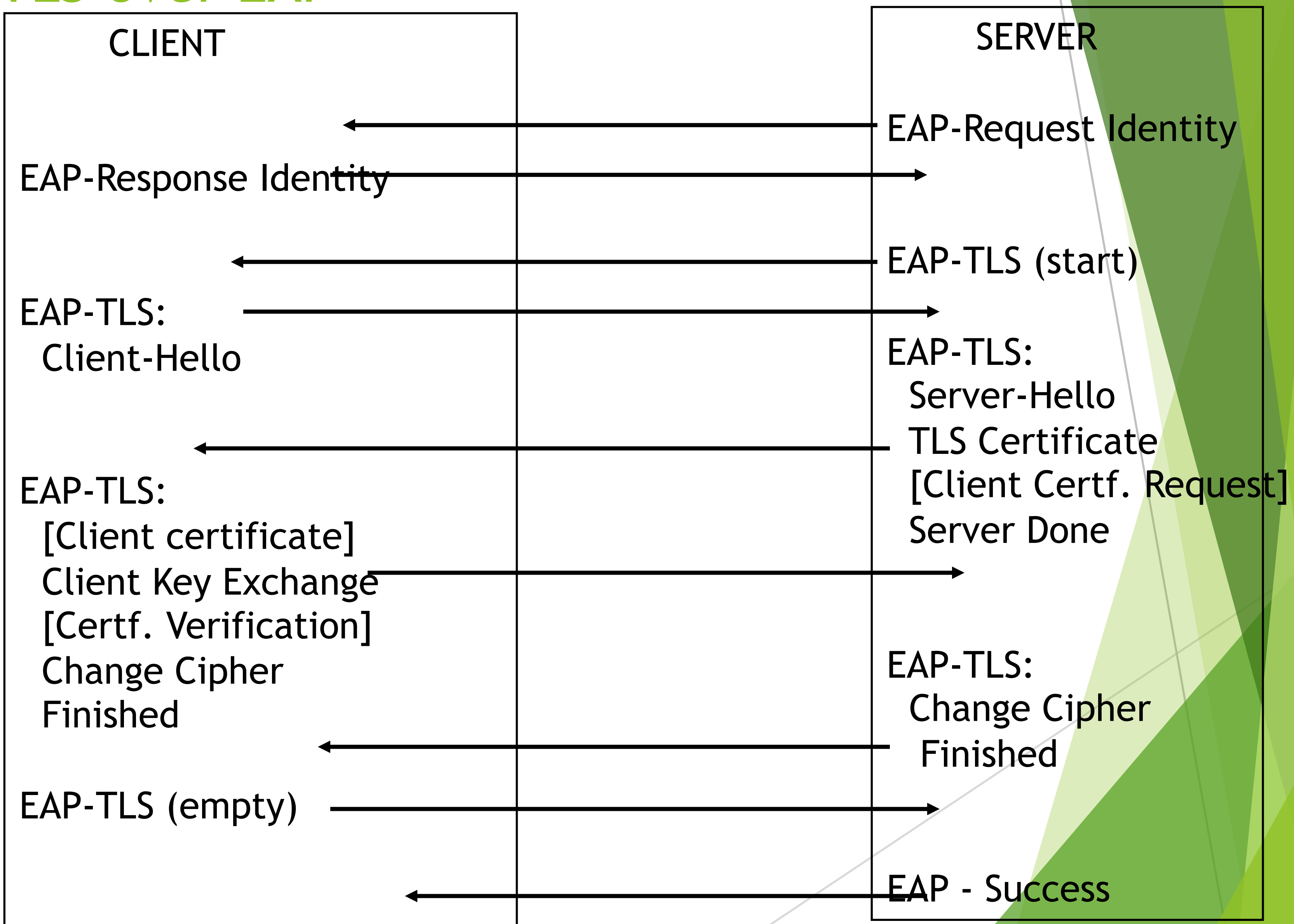
EAP Authentication Methods

- EAP-MD5
  - Does NOT provide for dynamic encryption – encryption key can't be generated dynamically
  - User authenticated by password
  - Network NOT authenticated to user (no mutual authentication)
- EAP-TLS
  - Provides for dynamic encryption
  - User and network mutually authenticated using certificates
  - Meet the three goals
  - Has limited use due to the requirement of the PKI (digital certificate)
- EAP-TTLS and PEAP
  - Provides for dynamic encryption
  - Network authenticated using certificate (outer authentication), the protocol is similar to EAP-TLS
  - Client authentication tunneled inside of EAP-TLS (inner authentication)
    - Significantly decrease the number of digital certificates
    - Non-cryptographic or older EAP methods such as PAP and CHAP can be applied for inner authentication because a secure tunnel has been created
  - Inner and outer authentication can use different user name, even anonymous usernames

TLS Basic Protocol



TLS over EAP


CLIENT
SERVER
EAP-Request Identity
EAP-Response Identity
EAP-TLS (start)
EAP-TLS:
Client-Hello
EAP-TLS:
Server-Hello
TLS Certificate
[Client Certf. Request]
Server Done
EAP-TLS:
[Client certificate]
Client Key Exchange
[Certf. Verification]
Change Cipher
Finished
EAP-TLS:
Change Cipher
Finished
EAP-TLS (empty)
EAP - Success

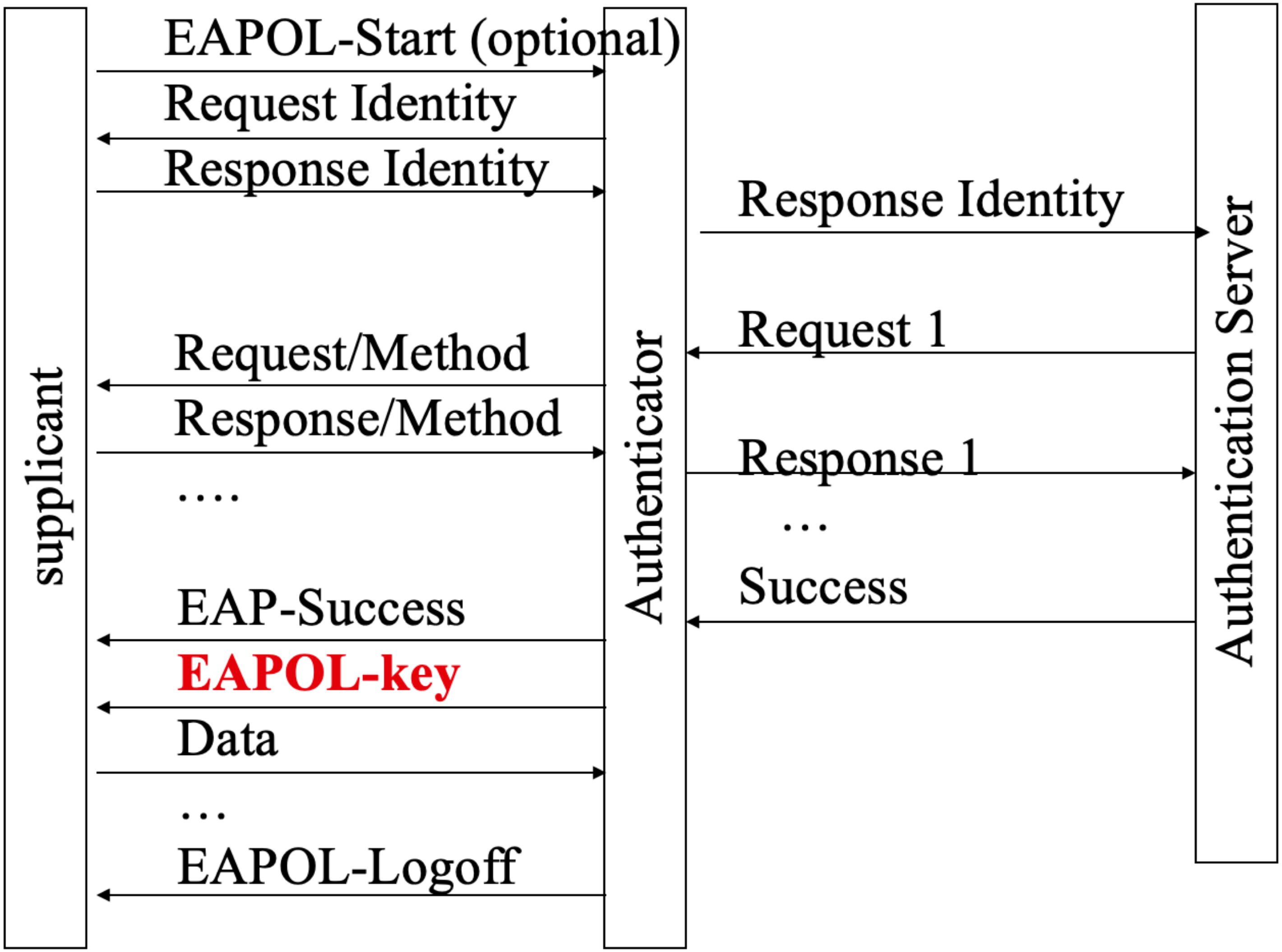
TLS and WPA/RSN

- TLS handshake process accomplishes three things:
  - Server authentication (optionally for client)
  - A master key for the session
  - Cipher suites to protect the communication (multiple keys are derived)
- In WPA
  - Encryption and integrity protection is provided by WEP or TKIP
- In RSN
  - Encryption and integrity protection is provided by TKIP or AES-CCMP
- For WPA and RSN,
  - All we need from TLS is the authentication function and the master key generation function

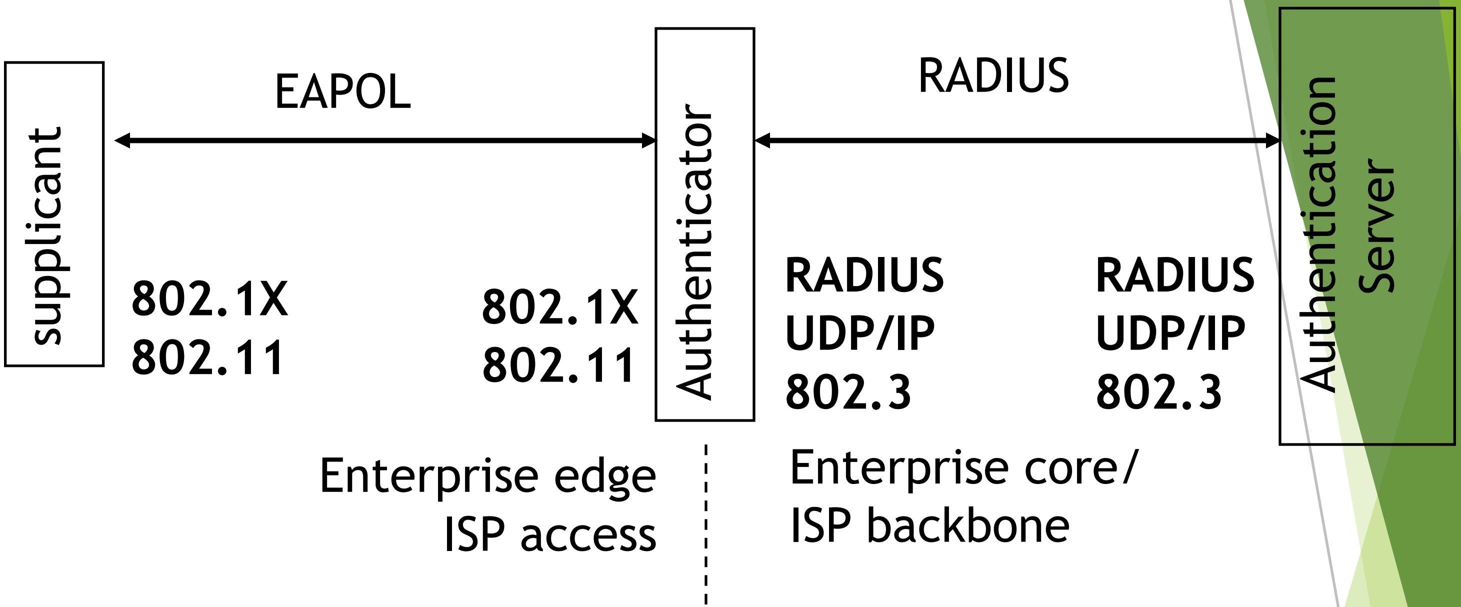
EAP Over LAN

- EAP RFC does not specify how messages should be passed around
  - It was originally designed for use with dial-up authentication via a modem
- EAP messages have to be encapsulated in order to be transmitted in a Wi-Fi network
  - Prepend the MAC address? – most simple way
- IEEE 802.1X defines EAPOL: EAP Over LAN
  - Not just prepend the MAC header. Defines more messages and fields
  - EAPOL-Start message to a special group-multicast address (reserved for 802.1X authenticators) to announce the existence of a supplicant
  - EAPOL-Key from the authenticator to send encryption keys to the suppliant
    - How to encrypt the key? – no definition
  - EAPOL-Packet, for transmitting the original EAP messages
  - EAPOL-Logoff
  - EAPOL-Encapsulated-ASF-Alert (not used by WPA and RSN)

EAPOL Message Flow



802.1X Architecture – Revisited



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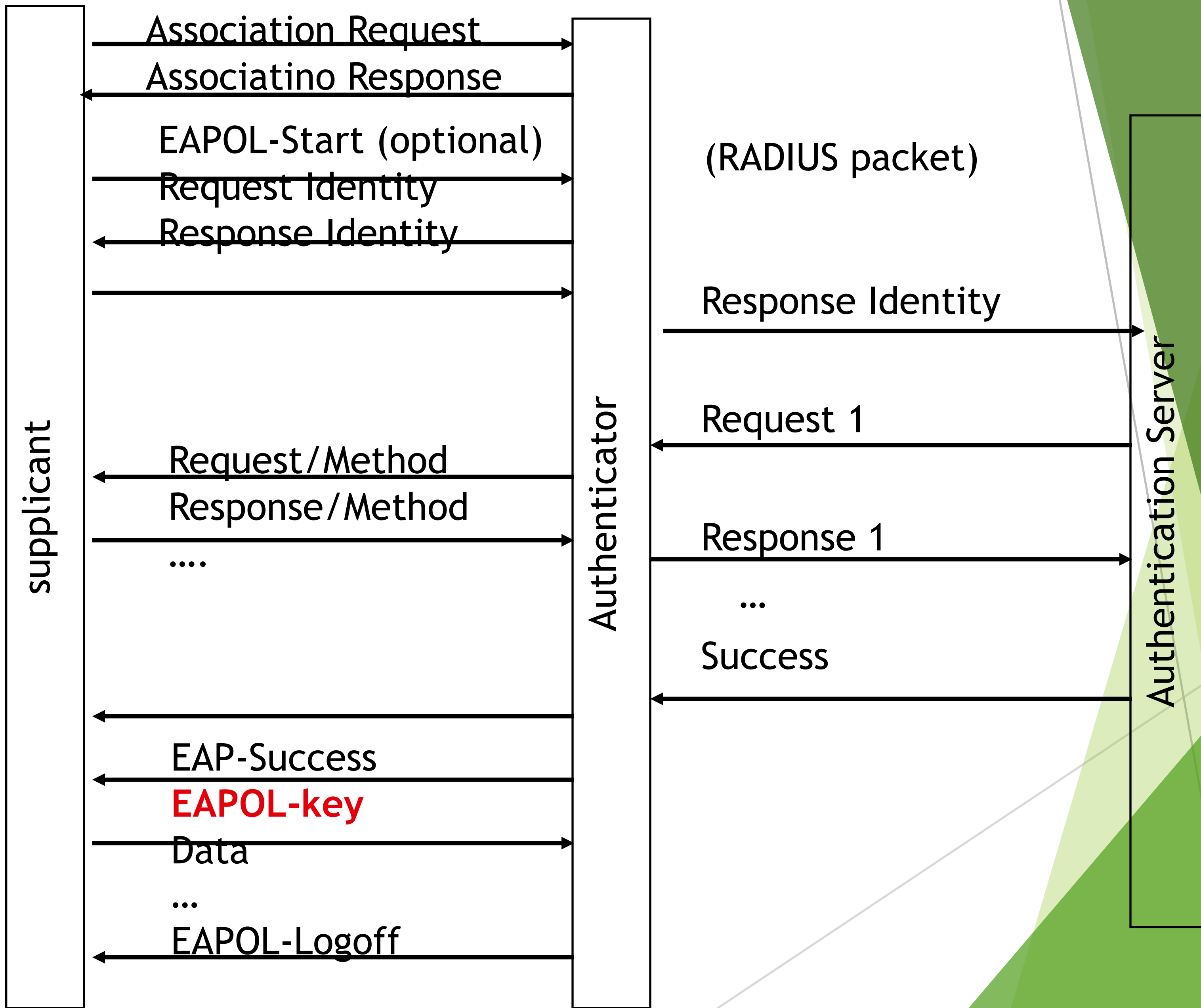
802.1X in AP

- Wireless devices act as supplicants, applying for access by sending messages to the authenticator.
- All done in software
- For SOHO, authentication server could be a simple process inside the AP
  - Eg. Just a list of user names and passwords
  - No need for RADIUS since the authenticator and the authentication server do not need to communicate
  - The number of supported authentication methods would be limited

802.1X over 802.11

- In Wireless LAN, an AP needs to create a logical port with an authenticator for each supplicant (wireless user)
  - The number of 802.1X entities in operation is the same as the number of associated mobile devices
- If authentication server and authenticator both reside in the AP, no RADIUS protocol is needed
- In wireless LAN, EAPOL can proceed only after the association is complete since no port exists; Association process allows supplicant and AP to exchange MAC address

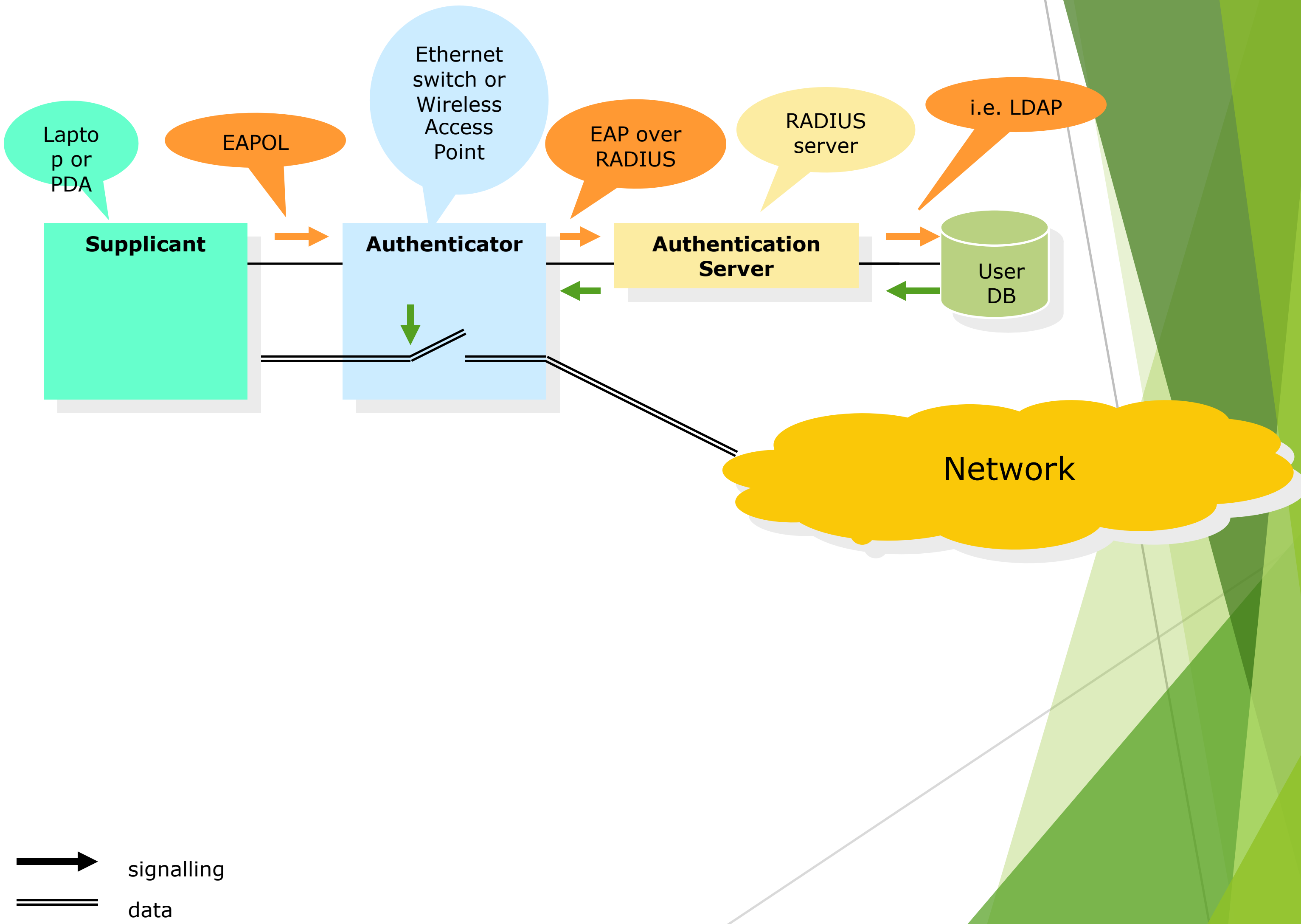
Typical 802.1X Exchange on 802.11



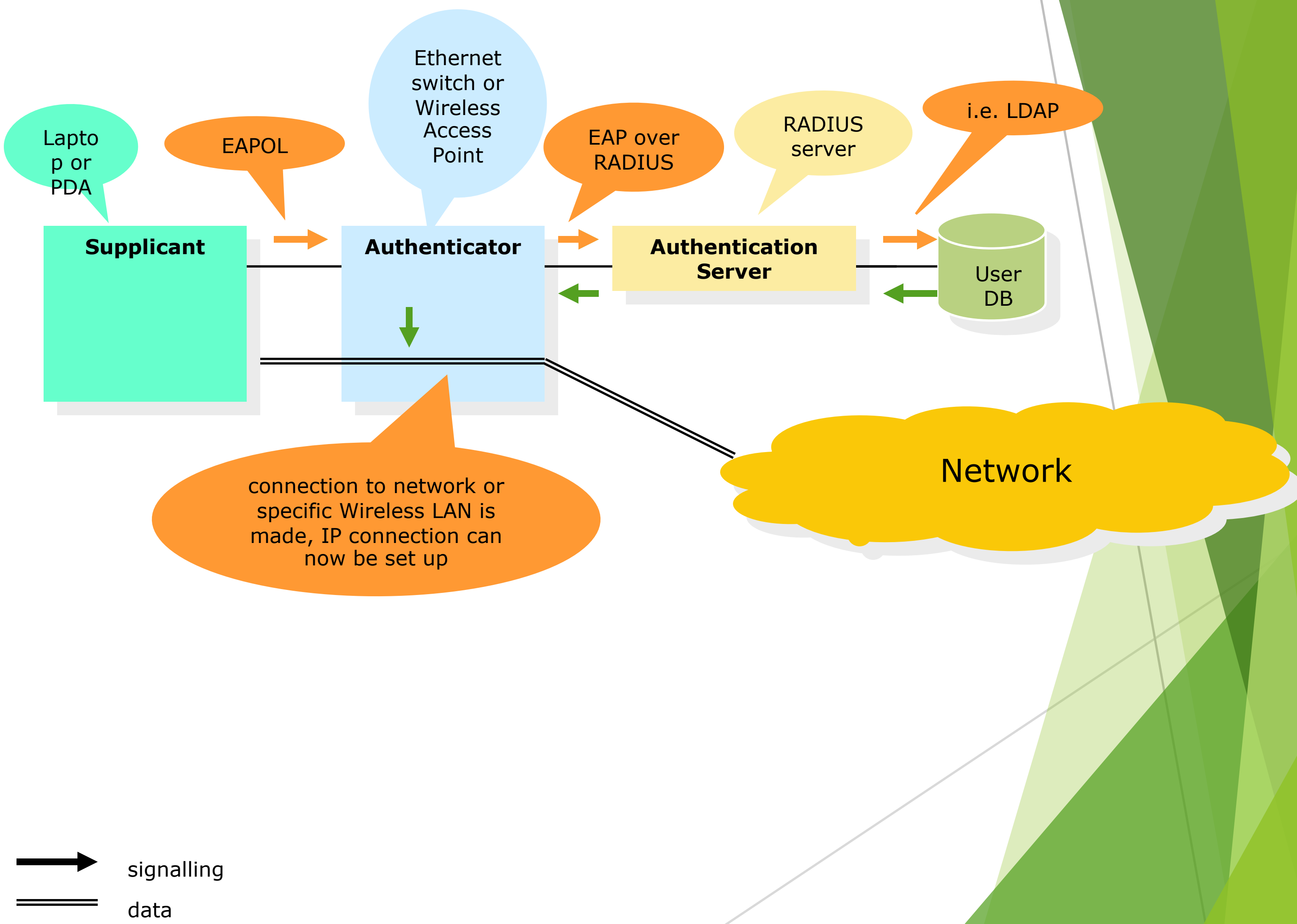
802.1X Message Exchange on 802.11

- Keys are exchanged only after successful authentication
  - EAPOL-Key can be used periodically to dynamically update keys
  - Will be further explained latter when discussing TKIP
- EAPOL starts after the association process is complete
  - Association process exchanges MAC address first

How 802.1X works



How 802.1X works

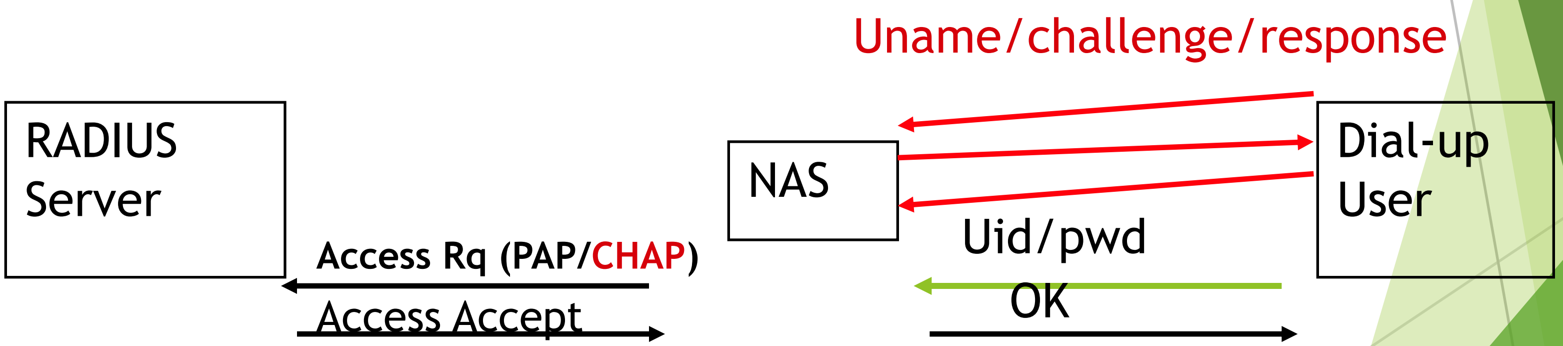


RADIUS – Remote Access Dial-In User Service

- Optional in RSN, originally designed for TCP/IP type of networks
- A protocol for the communication between the NAS (network access server) and the AS (authentication server)
  - Dial-up modem pool server (NAS) at Point-of-Presence
  - RADIUS server (AS)
- In Wi-Fi networks
  - NAS is AP
  - AS is the server with the authentication database

How RADIUS Works

- The core protocol contains four messages:
  - Access-Request (NAS→AS)
  - Access-Challenge (NAS←AS)
  - Access-Accept (AS→NAS)
  - Access-Reject (AS→NAS)
- RADIUS is used for dial-in system authentication, with two options:



  - PAP Operation: username/password sent as plaintexts
  - CHAP Operation: based on challenge response

Basic Format of RADIUS Message

Code	Identifier	Length	Authenticator	Attributes…

- Code identifies the four types of RADIUS messages
  - Access-Request: 1
  - Access-Accept: 2
  - Access-Reject: 3
  - Access-Challenge: 11

  Response messages
- Identifier: a number incremented for each message; used to match up requests and replies
- Authenticator:
  - For Access-Request, a 16B nonce is included.
  - This nonce together with the shared key (between AS and NAS) is used for encrypting the password (together with the shared key) if password value is sent as an attribute
  - For response messages, the nonce with the key will be used for integrity check to counter replay attacks. The integrity check value will be inserted to the Authenticator field. – How to compute?
- Attributes
  - Information carried in RADIUS message is contained within attributes
  - Each attribute contains the fields of Type, Length and Data

EAP over RADIUS

- Defined in RFC 2869
- The EAP message is sent inside one or more special attributes that have a type value of 79

Improvement of 802.1X over WEP

- 802.1x provides support for a centralized security management model for user authentication.
- The primary encryption keys are unique to each station so the traffic on any single key is significantly reduced.
  - Either pre-shared (eg. A password for SOHO) or generated through an upper layer authentication protocol (eg. TLS)
  - When used with an AS, the encryption keys are generated dynamically and don't require a network administrator for configuration or intervention by the user
- It provides support for strong upper layer authentication.