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Protected EAP Protocol (PEAP) Version 2

Abstract

The Extensible Authentication Protocol (EAP) provides for support of multiple authentication methods. This document defines the Protected Extensible Authentication Protocol (PEAP) Version 2, which provides an encrypted and authenticated tunnel based on transport layer security (TLS) that encapsulates EAP authentication mechanisms. PEAPv2 uses TLS to protect against rogue authenticators, protect against various attacks on the confidentiality and integrity of the inner EAP method exchange and provide EAP peer identity privacy. PEAPv2 also provides support for chaining multiple EAP mechanisms, cryptographic binding between authentications performed by inner EAP mechanisms and the tunnel, exchange of arbitrary parameters (TLVs), optimized session resumption, and fragmentation and reassembly.

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1. Introduction

The Extensible Authentication Protocol (EAP), defined in [RFC2284bis], provides for support of multiple authentication methods. EAP was developed for use on wired networks, where physical security was presumed. EAP over PPP, defined in [RFC2284bis], is typically deployed with leased lines or modem connections, requiring an attacker to gain access to the telephone network in order to snoop on the conversation or inject packets. [IEEE8021X] defines EAP over IEEE 802 local area networks(EAPOL), presuming the existence of switched media; in order to snoop or inject packets, an attacker would need to gain administrative access to the switch. Due to the presumption of physical security, facilities for protection of the EAP conversation were not provided. Where an attacker can easily gain access to the medium (such as on a wireless network or where EAP is run over IP), the presumption of physical security is no longer valid.

Since its deployment, a number of weaknesses in EAP framework have become apparent. These include lack of:

identity protection
protected method negotiation
protected notification messages
protected termination messages
support for sequences of EAP methods
support for fragmentation and reassembly
support for a generic way to exchange arbitrary
parameters in a secure channel

support for generic optimized re-authentication

In addition many EAP methods lack the following features:

mutual authentication
resistance to dictionary attacks
adequate key generation

By wrapping the EAP protocol within TLS, Protected EAP (PEAP) Version 2 addresses these deficiencies in EAP or EAP methods. TLS provides per-packet encryption, authentication, integrity and replay protection of the EAP conversation. Benefits of PEAP Version 2 include:

Identity protection
: By encrypting the identity exchange, and allowing client certificates to be provided after negotiation of the TLS channel, PEAPv2 provides for identity protection.

Dictionary attack resistance
: By conducting the EAP conversation within a TLS channel, PEAPv2 protects EAP methods that might be subject to an offline dictionary attack were they to be conducted in the clear.

Protected negotiation
: Since within PEAPv2, the EAP conversation is authenticated, integrity and replay protected on a per-packet basis, the EAP method negotiation that occurs within PEAPv2 is protected, as are error messages sent within the TLS channel (TLS alerts or EAP Notification packets). EAP negotiation outside of PEAPv2 is not protected.

Header protection
: Within PEAPv2, the EAP conversation is conducted within a TLS channel. As a result, the Type-Data field within PEAPv2 (including the EAP header of the EAP method within PEAPv2) is protected against modification. However, the EAP header of PEAPv2 itself is not protected against modification, including the Code, Identifier and Type fields.

Protected termination

By sending success/failure indications within the TLS channel, PEAPv2 provides support for protected termination of the EAP conversation. This prevents an attacker from carrying out denial of service attacks by spoofing EAP Failure messages, or fooling the EAP peer into accepting a rogue NAS, by spoofing EAP Success messages.

Fragmentation and Reassembly
: Since EAP does not include support for fragmentation and reassembly, individual methods need to include this capability. By including support for fragmentation and reassembly within PEAPv2, methods leveraging PEAPv2 do not need to support this on their own.

Fast reconnect
: Where EAP is used for authentication in wireless networks, the authentication latency is a concern. As a result, it is valuable to be able to do a quick re-authentication on roaming between access points. PEAPv2 supports this capability by leveraging the TLS session resumption facility, and any EAP method running under PEAPv2 can take advantage of it.

Standard key establishment
: In order to provide keying material for a wide range of link layer ciphersuites, EAP methods need to provide keying material. Key derivation is complex. PEAPv2 provides for key establishment by relying on the widely implemented and well-reviewed TLS [RFC2246]

key derivation mechanism. PEAPv2 provides keying material for any EAP method running within it. If EAP methods will also be deployed without external protection (e.g PEAPv2 or IPSec), then the EAP methods should follow the guidelines in section 6.8 to prevent the man-in-the-middle attacks.

Sequencing of multiple EAP methods
: In order to enhance security, PEAPv2 implementations may choose to provide multi-factor authentication that validates different identities (for example user and machine identities) and/or uses different credentials of the same or different identities of the peer (e.g. user password and machine cert). PEAPv2 provides a standard way to chain different types of authentication mechanisms supporting different types of credentials.

Protected exchange of arbitrary parameters (TLVs)
: Type-Length-Value (TLV) tuples provide a way to exchange arbitrary information between peer and EAP server within a secure channel. This information can include signaling parameters for EAP protocol, provisioning parameters, media specific and environment specific data, and authorization parameters. The advantage of using PEAP TLVs is that every EAP method does not have to be modified.

1.1. Requirements language

In this document, the key words "MAY", "MUST, "MUST NOT", "OPTIONAL", "RECOMMENDED", "SHOULD", and "SHOULD NOT", are to be interpreted as described in [RFC2119].

1.2. Terminology

This document frequently uses the following terms:

Access Point
: A Network Access Server implementing 802.11.

Authenticator
: The end of the link initiating EAP authentication. This term is also used in [IEEE8021X] and has the same meaning in this document.

Backend Authentication Server
: A backend authentication server is an entity that provides an authentication service to an Authenticator. When used, this server typically executes EAP methods for the Authenticator. This terminology is also used in [IEEE8021X].

EAP server
: The entity that terminates the EAP authentication method with the

peer. In the case where no backend authentication server is used, the EAP server is part of the Authenticator. In the case where the authenticator operates in pass-through mode, the EAP server is located on the backend authentication server.

Link layer ciphersuite
: The ciphersuite negotiated for use at the link layer.

NAS Short for "Network Access Server".

Peer The end of the link that responds to the authenticator. In [IEEE8021X], this end is known as the Supplicant.

TLS Ciphersuite
The ciphersuite negotiated for protection of the PEAPv2 Part 2 conversation.

EAP Master key (MK)
A key derived between the PEAPv2 client and server during the authentication conversation, and that is kept local to PEAPv2 and not exported or made available to a third party.

Master Session Key (MSK)
Keying material (64 octets) that is derived between the PEAPv2 client and server and exported by the PEAPv2 implementation.

AAA-Key
Where a backend authentication server is present, acting as an EAP server, keying material known as the AAA-Key is transported from the authentication server to the authenticator. The AAA-Key is used by the EAP peer and authenticator in the derivation of Transient Session Keys (TSKs) for the ciphersuite negotiated between the EAP peer and authenticator. As a result, the AAA-Key is typically known by all parties in the EAP exchange: the peer, authenticator and the authentication server (if present).

Extended Master Session Key (EMSK)
Additional keying material (64 octets) derived between the EAP client and server that is exported by the EAP method. The EMSK is known only to the EAP peer and server and is not provided to a third party.

Initialization Vector (IV)
A 64 octet quantity, suitable for use in an initialization vector field, that is derived between the EAP client and server. Since the IV is a known value in PEAPv2, it cannot be used by itself for computation of any quantity that needs to remain secret. As a result, PEAPv2 implementations are not required to generate it.

Pairwise Master Key (PMK)

The AAA-Key is divided into two halves, the "Peer to Authenticator Encryption Key" (Enc-RECV-Key) and "Authenticator to Peer Encryption Key" (Enc-SEND-Key) (reception is defined from the point of view of the authenticator). Within [IEEE80211i] Octets 0-31 of the AAA-Key (Enc-RECV-Key) are known as the Pairwise Master Key (PMK).

Transient EAP Keys (TEKs)
: Session keys which are used to establish a protected channel between the EAP peer and server during the EAP authentication exchange. The TEKs are appropriate for use with the ciphersuite negotiated between EAP peer and server for use in protecting the EAP conversation. Note that the ciphersuite used to set up the protected channel between the EAP peer and server during EAP authentication is unrelated to the ciphersuite used to subsequently protect data sent between the EAP peer and Authenticator.

TLV
: TLV standards for objects of format Type-Length-Value. The TLV format is defined in Section 4 of this document.

1.3. Operational model

In EAP, the EAP server may be implemented either within a Network Access Server (NAS) or on a backend authentication server. Where the EAP server resides on a NAS, the NAS is required to implement the desired EAP methods, and therefore needs to be upgraded to support each new EAP method.

One of the goals of EAP is to enable development of new authentication methods without requiring deployment of new code on the Network Access Server (NAS). Where a backend authentication server is deployed, the NAS acts as a "passthrough" and need not understand specific EAP methods.

This allows new EAP methods to be deployed on the EAP peer and backend authentication server, without the need to upgrade code residing on the NAS.

Figure 1 describes the relationship between the EAP peer, NAS and EAP server. As described in the figure, the EAP conversation occurs between the EAP peer and EAP server, "passing through" the NAS. In order for the conversation to proceed in the case where the NAS and EAP server reside on separate machines, the NAS and EAP server need to establish trust beforehand.

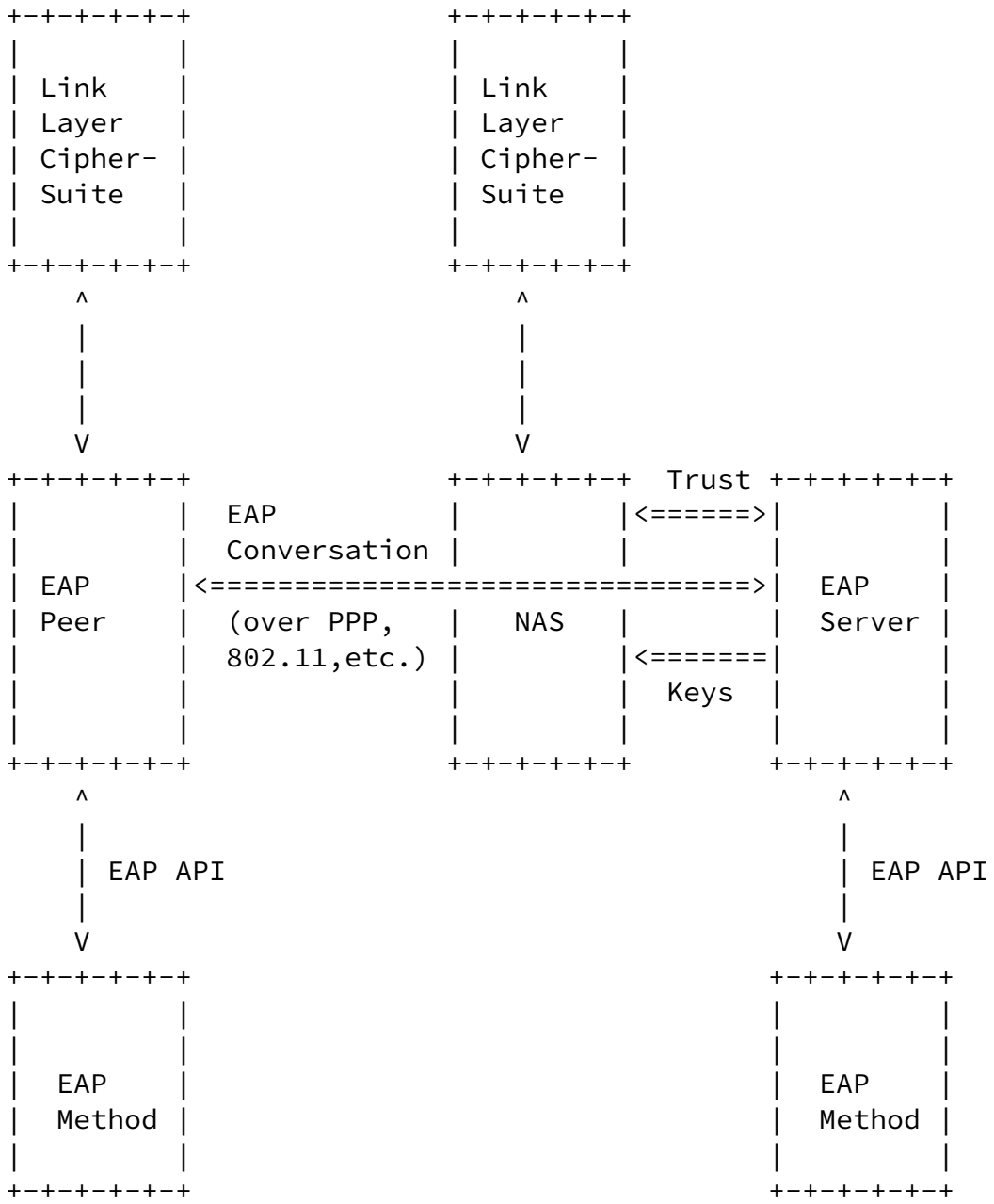


Figure 1 - Relationship between EAP client, backend authentication server and NAS.

In PEAPv2, the conversation between the EAP peer and the EAP server is encrypted, authenticated, integrity and replay protected within a TLS channel.

As a result, where the NAS acts as a "passthrough" it does not have knowledge of the TLS master secret derived between the peer and the EAP server. In order to provide keying material for link-layer ciphersuites, the NAS obtains the master session key, which is derived from a one-way function of the TLS master secret as well as keying material provided by EAP methods protected within a TLS channel. This enables the NAS and EAP peer to subsequently derive transient session keys suitable for encrypting, authenticating and integrity protecting session data. However, the NAS cannot decrypt the PEAPv2 conversation or spoof session resumption, since this requires knowledge of the TLS master secret.

1.3.1. Sequences

EAP [RFC2284bis] prohibits use of multiple authentication methods within a single EAP conversation, except when tunneled methods such as PEAPv2 are used. This restriction was imposed in order to limit vulnerabilities to man-in-the-middle attacks as well as to ensure compatibility with existing EAP implementations.

Within PEAP these concerns are addressed since PEAPv2 includes support for cryptographic binding to address man-in-the-middle attacks, as well as version negotiation so as to enable backward compatibility with prior versions of PEAP.

Within this document, the term "sequence" refers to a series of EAP authentication methods run in sequence. The methods need not be distinct - for example, EAP-TLS could be run initially with machine credentials followed by the same protocol authenticating with user credentials.

PEAPv2 supports two types of sequences:

[1] Serial authentication. Initiating additional EAP method(s) after a first successful authentication. In this case the sequence is

successful if each of the EAP authentication methods completes successfully. For example, successful authentication might require a successful machine authentication followed by a successful user authentication.

[2] Parallel authentication. Initiating an alternative EAP method after failure of one or more initial methods. In this case the overall authentication is successful if any of the methods is successful. For example, if machine authentication fails, then user

authentication can be attempted.

2. Protocol overview

Protected EAP (PEAP) Version 2 is comprised of a two-part conversation:

[1] In Part 1, a TLS session is negotiated, with server authenticating to the client and optionally the client to the server. The negotiated key is then used to encrypt the rest of the conversation.

[2] In Part 2, within the TLS session, zero or more EAP methods are carried out. Part 2 completes with a success/failure indication protected by the TLS session or a protected error (TLS alert).

In the next two sections, we provide an overview of each of the parts of the PEAPv2 conversation.

2.1. PEAPv2 Part 1

2.1.1. Initial identity exchange

The PEAP conversation typically begins with an optional identity exchange. The authenticator will typically send an EAP-Request/Identity packet to the peer, and the peer will respond with an EAP-Response/Identity packet to the authenticator.

The initial identity exchange is used primarily to route the EAP conversation to the EAP server. Since the initial identity exchange is in the clear, the peer MAY decide to place a routing realm instead of its real name in the EAP-Response/Identity. The real identity of

the peer can be established later in PEAPv2 part 2.

If the EAP server is known in advance (such as when all users authenticate against the same backend server infrastructure and roaming is not supported), or if the identity is otherwise determined (such as from the dialing phone number or client MAC address), then the EAP-Request/Response-identity exchange MAY be omitted.

Once the optional initial Identity Request/Response exchange is completed, while nominally the EAP conversation occurs between the authenticator and the peer, the authenticator MAY act as a passthrough device, with the EAP packets received from the peer being encapsulated for transmission to a backend authentication server. However, PEAP does not require a backend authentication server; if the authenticator implements PEAP, then it can authenticate local users.

In the discussion that follows, we will use the term "EAP server" to denote the ultimate endpoint conversing with the peer.

2.1.2. TLS Session Establishment

In this section, the protocol is described assuming a certificate based ciphersuite is negotiated in TLS. The conversation may slightly differ if other TLS ciphersuites are used.

Once having received the peer's Identity, and determined that PEAP authentication is to occur, the EAP server MUST respond with a PEAP/Start packet, which is an EAP-Request packet with EAP-Type=PEAP, the Start (S) bit set, the PEAP version as specified in Section 2.1.5, and no data. Assuming that the peer supports PEAP, the PEAP conversation will then begin, with the peer sending an EAP-Response packet with EAP-Type=PEAP.

The data field of the EAP-Response packet will encapsulate one or more TLS records in TLS record layer format, containing a TLS client_hello handshake message. The current cipher spec for the TLS records will be TLS_NULL_WITH_NULL_NULL and null compression. This current cipher spec remains the same until the change_cipher_spec message signals that subsequent records will have the negotiated attributes for the remainder of the handshake.

The client_hello message contains the client's TLS version number, a sessionId, a random number, and a set of TLS ciphersuites supported by the client. The version offered by the client MUST correspond to TLS v1.0 or later.

The EAP server will then respond with an EAP-Request packet with EAP-Type=PEAP. The data field of this packet will encapsulate one or more TLS records. These will contain a TLS server_hello handshake message, possibly followed by TLS certificate, server_key_exchange, certificate_request, server_hello_done and/or finished handshake messages, and/or a TLS change_cipher_spec message.

Since after the TLS session is established, another complete EAP negotiation will occur and the peer will authenticate using a secondary mechanism, with PEAPv2 the client need not authenticate as part of TLS session establishment. As a result, although the EAP-Request packet sent by the EAP Server MAY contain a certificate_request message, this is not required.

The certificate_request message indicates that the server desires the client to authenticate itself via public key. It is valid for the server to request a certificate in the server_hello and for the client refuse to provide one.

Note that since TLS client certificates are sent in the clear, if identity protection is required, then it is possible for the TLS authentication to be re-negotiated after the first server authentication. To accomplish this, the server will typically not request a certificate in the server_hello, then after the server_finished message is sent, and before PEAP part 2, the server MAY send a TLS hello_request. This allows the client to perform client authentication by sending a client_hello if it wants to, or send a no_renegotiation alert to the server indicating that it wants to continue with PEAP part 2 instead. Assuming that the client permits renegotiation by sending a client_hello, then the server will respond with server_hello, a certificate and certificate_request messages. The client replies with certificate, client_key_exchange and certificate_verify messages. Since this re-negotiation occurs within the encrypted TLS channel, it does not reveal client certificate details.

The server_hello handshake message contains a TLS version number,

another random number, a sessionId, and a TLS ciphersuite. The version offered by the server MUST correspond to TLS v1.0 or later.

If the client's sessionId is null or unrecognized by the server, the server MUST choose the sessionId to establish a new session; otherwise, the sessionId will match that offered by the client, indicating a resumption of the previously established session with that sessionId. The server will also choose a TLS ciphersuite from those offered by the client; if the session matches the client's, then the TLS ciphersuite MUST match the one negotiated during the handshake protocol execution that established the session.

PEAP implementations need not necessarily support all TLS ciphersuites listed in [RFC2246]. Not all TLS ciphersuites are supported by available TLS tool kits and licenses may be required to support some TLS ciphersuites (e.g. TLS ciphersuites utilizing the IDEA encryption algorithm).

To ensure interoperability, PEAP peers and EAP servers MUST support and be able to negotiate the following TLS ciphersuites:

    TLS_RSA_WITH_3DES_EDE_CBC_SHA

In addition, PEAP peers and EAP servers SHOULD support and be able to negotiate the following TLS ciphersuites.

    TLS_RSA_WITH_AES_128_CBC_SHA
    TLS_RSA_WITH_RC4_128_MD5
    TLS_RSA_WITH_RC4_128_SHA

TLS as described in [RFC2246] supports compression as well as ciphersuite negotiation. Therefore during the PEAPv2 Part 1 conversation the EAP endpoints MAY request or negotiate TLS compression.

2.1.3. Full handshake

If the EAP server is not resuming a previously established session, and if a ciphersuite based on certificates is used, then it MUST include a TLS server_certificate handshake message, and a server_hello_done handshake message MUST be the last handshake

message encapsulated in this EAP-Request packet.

The certificate message contains a public key certificate chain for either a key exchange public key (such as an RSA or Diffie-Hellman key exchange public key) or a signature public key (such as an RSA or DSS signature public key). In the latter case, a TLS server_key_exchange handshake message MUST also be included to allow the key exchange to take place.

If the preceding server_hello message sent by the EAP server in the preceding EAP-Request packet did not indicate the resumption of a previous session, then the peer MUST respond to the EAP-Request with an EAP-Response packet of EAP-Type=PEAP. The data field of this packet will encapsulate one or more TLS records containing a TLS change_cipher_spec message and finished handshake message, and possibly certificate, certificate_verify and/or client_key_exchange handshake messages.

The EAP server MUST then respond with an EAP-Request packet with EAP-Type=PEAP, which includes, in the case of a new TLS session, one or more TLS records containing TLS change_cipher_spec, finished handshake messages; and the first payload of PEAPv2 part 2. The first payload of PEAPv2 part 2 is sent along with finished handshake message to reduce number of round trips.

2.1.4. Session resumption

The purpose of the sessionId within the TLS protocol is to allow for improved efficiency in the case where a client repeatedly attempts to authenticate to an EAP server within a short period of time. This capability is particularly useful for support of wireless roaming.

It is left up to the peer whether to attempt to continue a previous session, thus shortening the PEAP Part 1 conversation. Typically the peer's decision will be made based on the time elapsed since the previous authentication attempt to that EAP server.

Based on the sessionId chosen by the peer, and the time elapsed since the previous authentication, the EAP server will decide whether to allow the continuation, or whether to choose a new session.

In the case where the EAP server and the authenticator reside on the same device, then the client will only be able to continue sessions when connecting to the same NAS or channel server. Should these devices be set up in a rotary or round-robin then it may not be possible for the peer to know in advance the authenticator it will be connecting to, and therefore which sessionId to attempt to reuse. As a result, it is likely that the continuation attempt will fail.

In the case where the EAP authentication is remoted then continuation is much more likely to be successful, since multiple NAS devices and channel servers will remote their EAP authentications to the same backend authentication server.

If the EAP server is resuming a previously established session, then it MUST include only a TLS change_cipher_spec message and a TLS finished handshake message after the server_hello message. The finished message contains the EAP server's authentication response to the peer.

If the preceding server_hello message sent by the EAP server in the preceding EAP-Request packet indicated the resumption of a previous session, then the peer MUST send only the change_cipher_spec and finished handshake messages. The finished message contains the peer's authentication response to the EAP server. The latter contains the EAP server's authentication response to the peer. The peer will verify the hash in order to authenticate the EAP server.

If authentication fails, then the peer and EAP-server MUST follow the error handling behavior specified in section 2.3.

Even if the session is successfully resumed with the same EAP server, the peer and EAP server MUST not assume that either will skip inner EAP methods. The peer may have roamed to a network which may use the same EAP server, but may require conformance with a different authentication policy.

2.1.5. Version negotiation

PEAP packets contain a three bit version field, which enables PEAP implementations to be backward compatible with previous versions of the protocol. This specification documents the PEAP version 2 protocol; implementations of this specification MUST use a version field set to 2. Version negotiation proceeds as follows:

[1] In the first EAP-Request sent with EAP type=PEAP, the EAP server MUST set the version field to the highest supported version number.

[2] If the EAP peer supports this version of the protocol, it MUST respond with an EAP-Response of EAP type=PEAP, and the version number proposed by the EAP server.

[3] If the EAP peer does not support this version, it responds with an EAP-Response of EAP type=PEAP and the highest supported version number.

[4] If the PEAP server does not support the version number proposed by the PEAP peer, it terminates the conversation, as described in Section 2.2.2.

The version negotiation procedure guarantees that the EAP peer and server will agree to the latest version supported by both parties. If version negotiation fails, then use of PEAP will not be possible, and another mutually acceptable EAP method will need to be negotiated if authentication is to proceed.

The PEAP version field is not protected by TLS and therefore can be modified in transit. In order to detect modification of the PEAP version which could occur as part of a "downgrade" attack, the PEAPv2 peer and server MUST exchange information on the highest supported versions proposed by the peers using the crypto-binding-TLV.

2.2. PEAPv2 Part 2

The second portion of the PEAPv2 conversation typically consists of a complete EAP conversation occurring within the TLS session negotiated in PEAPv2 Part 1; ending with protected termination using the Result-TLV. PEAPv2 part 2 will occur only if establishment of a new TLS session in Part 1 is successful or a TLS session is successfully resumed in Part 1. In cases where a new TLS session is established in PEAPv2 part 1, the first payload of the part 2 conversation is sent by the EAP server along with the finished message to save a round-trip.

Part 2 MUST NOT occur if the EAP Server authenticates unsuccessfully or if an EAP-Failure has been sent by the EAP server to the peer, terminating the conversation. Since all packets sent within the PEAPv2 Part 2 conversation occur after TLS session establishment, they are protected using the negotiated TLS ciphersuite. All EAP packets of the EAP conversation in part 2 including the EAP header of the inner EAP method are protected using the negotiated TLS

ciphersuite.

Part 2 MAY NOT always include a EAP conversation within the TLS session, referred to in this document as inner EAP methods. However, Part 2 MUST always end with either protected termination or protected error termination.

Within Part 2, protected EAP conversation and protected termination packets are always carried within an EAP-TLV packet. The EAP-TLV packet does not include an EAP header. There are TLVs defined for specific purposes such as carrying EAP-authentication messages and carrying cryptographic binding. New TLVs may be developed for other purposes.

2.2.1. Protected conversation

Part 2 of the PEAP conversation typically begins with the EAP server sending an optional EAP-Request/Identity packet to the peer, protected by the TLS ciphersuite negotiated in PEAP Part 1. The peer responds with an EAP-Response/Identity packet to the EAP server, containing the peer's userId. Since this Identity Request/Response exchange is protected by the ciphersuite negotiated in TLS, it is not vulnerable to snooping or packet modification attacks.

After the TLS session-protected Identity exchange, the EAP server will then select authentication method(s) for the peer, and will send an EAP-Request with the Type field set to the initial method. As described in [RFC2284BIS], the peer can NAK the suggested EAP method, suggesting an alternative. Since the NAK will be sent within the TLS channel, it is protected from snooping or packet modification. As a result, an attacker snooping on the exchange will be unable to inject NAKs in order to "negotiate down" the authentication method. An attacker will also not be able to determine which EAP method was negotiated.

The EAP conversation within the TLS protected session may involve a sequence of zero or more EAP authentication methods; it completes with the protected termination described in section 2.2.2. Several EAP-TLVs may be included in each Request and Response. EAP-methods (except if the type is EAP-TLV) are always encapsulated within EAP Payload-TLV.

In a typical EAP conversation, the result of the conversation is communicated by sending EAP Success or EAP Failure packets after the EAP method is complete. The EAP Success or Failure packet is considered the last packet of the EAP conversation; and therefore cannot be used when sequences need to be supported. Hence, instead of using the EAP-success or EAP-failure packet, both peer and EAP server MUST use the Intermediate Result TLV to communicate the result.

In a typical EAP conversation, the EAP Success or EAP Failure is considered the last packet of the EAP conversation. Within PEAP, the EAP server can start another EAP method after success or failure of the previous EAP method inside the protected session.

In a sequence of more than one EAP authentication method, to make sure the same parties are involved in tunnel establishment and successful completion of previous inner EAP methods, before completing negotiation of the next EAP method, both peer and EAP server MUST use crypto binding (Crypto-Binding TLV). If no EAP methods have been negotiated inside the tunnel or no EAP methods have been successfully completed inside the tunnel, the crypto-binding TLV MUST NOT be used.

The Crypto-Binding TLV and the Intermediate-Result TLV MUST be sent after each successful EAP method (except for type EAP-TLV). If these TLVs are not sent, it should be considered as tunnel compromise error by peer and EAP server.

Both TLVs can be sent in an EAP-TLV packet. Alternatively, if a subsequent EAP conversation is being attempted, then in order to reduce round trips, both TLVs SHOULD be sent in the EAP-Payload of the first EAP packet of the next EAP conversation (for example, EAP-Identity or EAP-packet of the EAP method). Alternatively, if the next packet is the PEAP termination packet, then in order to reduce round trips, both TLVs SHOULD be sent with the termination packet.

If the EAP server sends a valid Crypto-Binding-TLV to the peer, the peer MUST respond with a Crypto-Binding TLV. If the Crypto-Binding-TLV is invalid, it should be considered a tunnel compromise error by the peer. If the peer does not respond with a EAP-TLV packet containing the crypto-binding TLV, it should be considered a tunnel compromise error by the EAP server.

2.2.2. Protected Termination

The PEAPv2 part 2 conversation is completed by an exchange of success/failure indications (Result-TLV) within a EAP-TLV packet protected by the TLS session.

If the Crypto-Binding TLV and the Intermediate-Result TLV have NOT been exchanged in the previous conversation, then they MUST be present in the protected indication packet. Otherwise, it should be considered a tunnel compromise error by the peer and EAP server.

The Result TLV is sent within the TLS channel. The PEAP client then replies with a Result-TLV. The conversation concludes with the PEAP server sending a cleartext success/failure indication.

The only outcome which should be considered as successful authentication is when an EAP Request of Type=EAP-TLVs with Result TLV of Status=Success, is answered by an EAP Response of Type=EAP-TLVs with Result TLV of Status=Success.

All other combinations (EAP-TLVs Failure, EAP-TLVs Success), (EAP-TLVs Failure, EAP-TLVs Failure), (no EAP-TLVs exchange or no protected EAP Success or Failure) should be considered failed authentications, both by the PEAP peer and EAP server. Once the PEAPv2 peer and PEAPv2 server considers them as failed authentications, they are the last packets inside the protected tunnel. These are considered failed authentications regardless of whether a cleartext EAP Success or EAP Failure packet is subsequently sent.

After the PEAPv2 server has sent the success indication, the peer is allowed to refuse to accept a Success message from the PEAPv2 server since the client's policy may require completion of certain EAP methods. If the peer wants the server to negotiate EAP methods, it MUST send the EAP-TLV packet with Result-TLV with Status=Failure. If the success indication from the EAP server contains the crypto-binding TLV, then the peer MUST include a crypto-binding TLV in the EAP-TLV response. If the peer does not respond with a EAP-TLV packet containing the crypto-binding TLV or if the crypto-binding TLV is invalid, it should be considered as a tunnel compromise error by the EAP server.

If the EAP server has set Result-TLV with Status=Success; and the response from the peer is Status=Failure, then the EAP server MUST either start another EAP conversation inside the protected channel or return Result=TLV with Status=Failure without a crypto-binding TLV and Intermediate Result TLV.

A PEAPv2 tunnel may be nested inside another tunnel, for example, PEAPv2 may be negotiated as a EAP method inside a PEAPv2 tunnel. In this case, each tunnel MUST use protected termination.

2.3. Error handling

Once the peer responds with the first PEAP packet and the EAP server receives the first PEAP packet from the peer, both MUST silently discard all clear text EAP messages unless both the PEAP peer and server have indicated success or failure or an error using a protected error or protected termination mechanism. If the PEAPv2 tunnel is nested inside another tunnel, then the clear text EAP messages should be accepted after protected termination of all the tunnels. After a Fatal alert is received or after protected termination is complete, the peer or EAP server should accept clear

text EAP messages.

Other than supporting TLS alert messages, PEAPv2 does not have its own error message capabilities. This is unnecessary since errors in the PEAPv2 Part 1 conversation are communicated via TLS alert messages, and errors in the PEAPv2 Part 2 conversation are expected to be handled by individual EAP methods.

If an error occurs at any point in the TLS layer, the EAP server SHOULD send a TLS alert message instead of the next EAP-request packet to the peer. The EAP server SHOULD send an EAP-Request packet with EAP-Type=PEAP, encapsulating a TLS record containing the appropriate TLS alert message. The EAP server SHOULD send a TLS alert message rather than immediately terminating the conversation so as to allow the peer to inform the user of the cause of the failure and possibly allow for a restart of the conversation. To ensure that the peer receives the TLS alert message, the EAP server MUST wait for the peer to reply with an EAP-Response packet.

The EAP-Response packet sent by the peer MAY encapsulate a TLS client_hello handshake message, in which case the EAP server MAY allow the PEAPv2 conversation to be restarted, or it MAY contain an EAP-Response packet with EAP-Type=PEAP and no data, in which case the PEAPv2 server MUST send an EAP-Failure packet, and terminate the conversation.

It is up to the EAP server whether to allow restarts, and if so, how many times the conversation can be restarted. An EAP server implementing restart capability SHOULD impose a limit on the number of restarts, so as to protect against denial of service attacks.

If an error occurs at any point in the TLS layer, the peer SHOULD send a TLS alert message instead of the next EAP-response packet to the EAP server. The peer SHOULD send an EAP-Response packet with EAP-Type=PEAP, encapsulating a TLS record containing the appropriate TLS alert message. The EAP server may restart the conversation by sending a EAP-Request packet encapsulating the TLS hello_request_handshake message, in which case the peer MAY allow the PEAPv2 conversation to be restarted; or the EAP server can response with EAP Failure.

Any time the peer or the EAP server finds an error when processing the sequence of exchanges, such a violation of TLV rules, it should send a Result TLV of failure and terminate the tunnel. This is usually due to an implementation problem and is considered an fatal error.

If a tunnel compromise error (see Section 2.2) is detected by the

peer, the peer SHOULD send a TLS Internal Error alert (a Fatal error) message instead of the next EAP-response packet to the EAP server. Similarly, if a tunnel compromise error is detected by the EAP server, the EAP server SHOULD send a TLS Internal error alert (a Fatal error) message instead of the next EAP-response packet to the peer.

2.4. Fragmentation

A single TLS record may be up to 16384 octets in length, but a TLS message may span multiple TLS records, and a TLS certificate message may in principle be as long as 16MB. The group of PEAP messages sent

in a single round may thus be larger than the PPP MTU size, the maximum RADIUS packet size of 4096 octets, or even the Multilink Maximum Received Reconstructed Unit (MRRU). As described in [RFC1990], the multilink MRRU is negotiated via the Multilink MRRU LCP option, which includes an MRRU length field of two octets, and thus can support MRRUs as large as 64 KB.

However, note that in order to protect against reassembly lockup and denial of service attacks, it may be desirable for an implementation to set a maximum size for one such group of TLS messages. Since a typical certificate chain is rarely longer than a few thousand octets, and no other field is likely to be anywhere near as long, a reasonable choice of maximum acceptable message length might be 64 KB.

If this value is chosen, then fragmentation can be handled via the multilink PPP fragmentation mechanisms described in [RFC1990]. While this is desirable, EAP methods are used in other applications such as [IEEE80211] and there may be cases in which multilink or the MRRU LCP option cannot be negotiated. As a result, a PEAPv2 implementation MUST provide its own support for fragmentation and reassembly.

Since EAP is an ACK-NAK protocol, fragmentation support can be added in a simple manner. In EAP, fragments that are lost or damaged in transit will be retransmitted, and since sequencing information is provided by the Identifier field in EAP, there is no need for a fragment offset field as is provided in IPv4.

PEAPv2 fragmentation support is provided through addition of flag bits within the EAP-Response and EAP-Request packets, as well as a TLS Message Length field of four octets. Flags include the Length included (L), More fragments (M), and PEAP Start (S) bits. The L flag is set to indicate the presence of the four octet TLS Message Length field, and MUST be set only for the first fragment of a fragmented TLS message or set of messages.

The TLS Message Length field in the PEAPv2 header is not protected; and hence can be modified by a attacker. The TLS record length in the TLS data is protected. Hence, if TLS Message length received in the first packet (with L bit set) is greater or less than the total size of TLS data received including multiple fragments, then the TLS

message length should be ignored.

A single TLS record may be up to 16384 octets in length, but a TLS message may span multiple TLS records, and a TLS certificate message may in principle be as long as 16MB. However, note that in order to protect against reassembly lockup and denial of service attacks, it may be desirable for an implementation to set a maximum size for one such group of TLS messages. Since a typical certificate chain is rarely longer than a few thousand octets, and no other field is likely to be anywhere near as long, a reasonable choice of maximum acceptable message length might be 64 KB.

The M flag is set on all but the last fragment. The S flag is set only within the PEAP start message sent from the EAP server to the peer. The TLS Message Length field is four octets, and provides the total length of the TLS message or set of messages that is being fragmented; this simplifies buffer allocation.

When a PEAPv2 peer receives an EAP-Request packet with the M bit set, it MUST respond with an EAP-Response with EAP-Type=PEAP and no data. This serves as a fragment ACK. The EAP server MUST wait until it receives the EAP-Response before sending another fragment. In order to prevent errors in processing of fragments, the EAP server MUST increment the Identifier field for each fragment contained within an EAP-Request, and the peer MUST include this Identifier value in the fragment ACK contained within the EAP-Response. Retransmitted fragments will contain the same Identifier value.

Similarly, when the EAP server receives an EAP-Response with the M bit set, it MUST respond with an EAP-Request with EAP-Type=PEAP and no data. This serves as a fragment ACK. The EAP peer MUST wait until it receives the EAP-Request before sending another fragment. In order to prevent errors in the processing of fragments, the EAP server MUST increment the Identifier value for each fragment ACK contained within an EAP-Request, and the peer MUST include this Identifier value in the subsequent fragment contained within an EAP-Response.

2.5. Key derivation

Since the normal TLS keys are used in the handshake, and therefore should not be used in a different context, new keys must be derived from the TLS master secret for use with the selected link layer

ciphersuites.

Instead of deriving keys specific to link layer ciphersuites EAP methods provides a Master Session Key (MSK) used to derive keys in a link layer specific manner. The method used to extract ciphering keys from the MSK is beyond the scope of this document.

PEAPv2 also derives an Extended Master Session Key (EMSK) which is reserved for use in deriving keys in other ciphering applications. This draft also does not discuss the format of the attributes used to communicate the master session keys from the backend authentication server to the NAS; examples of such attributes are provided in [RFC2548].

PEAPv2 combines key material from the TLS exchange with key material from inner key generating EAP methods to provide stronger keys and to bind inner authentication mechanisms to the TLS tunnel. Both the peer and EAP server MUST derive compound MAC and compound session keys using the procedure described below.

The input for the cryptographic binding includes the following:

[a] The PEAPv2 tunnel key (TK) is calculated using the first 64 octets of the (secret) key material generated as described in the EAP-TLS algorithm (RFC2716 section 3.5)

[b] The MSK provided by each successful inner EAP method (should not include the 64 octets of EMSK); for each successful EAP method completed within the tunnel.

ISK1..ISKn are the MSK portion of the EAP keying material obtained from methods 1 to n. In some cases (except in the case of the EAP-TLV method), where the inner EAP method does not provide keys: ISKi, for some i, may be the null string ("").

The algorithm uses P_SHA-1 PRF specified in the TLS specification [RFC2246] ("|" denotes concatenation).

The intermediate combined key is generated after each successful EAP method inside the tunnel.

Generating the intermediate combined key:

Take the second 32 octets of TK

IPMK0 = TK

for j = 1 to k do

IPMKj = P_SHA1(IPMK(j-1),"Intermediate PEAP MAC key" | ISKj);

k = the last successful EAP method inside the tunnel at the point where the combined MAC key is derived.

Each IPMKj output is 32 octets. IPMKn is the intermediate combined key used to derive combined session and combined MAC keys.

Compound MAC Key derivation:

The Compound MAC Key for the server (the B1_MAC) is derived CMK_B1

CMK_B1 = P_SHA1(IPMKn,"PEAP Server B1 MAC key" | S_NONCE)

The Compound MAC Key for the client (the B2_MAC) is derived from MAC key called CMK B2.

CMK_B2 = P_SHA1(IPMKn,"PEAP Client B2 MAC key" | C_NONCE | S_NONCE)

The compound MAC keys (CMK_B1 and CMK_B2) are each 20 octets long.

Compound Session Key derivation:

The compound session key (CSK) is derived on both the peer and EAP server after successful completion of protected termination.

CSK = P_SHA1 (IPMKn, "PEAP compound session key" | C_NONCE | S_NONCE | OutputLength)

The output length of the CSK must be at least 128 bytes. The first 64 octets are taken and the MSK and the second 64 octets are taken as the EMSK. The MSK and EMSK are described in [RFC2284bis].

2.6. Ciphersuite negotiation

Since TLS supports TLS ciphersuite negotiation, peers completing the TLS negotiation will also have selected a TLS ciphersuite, which includes key strength, encryption and hashing methods. However, unlike in [RFC2716], within PEAPv2, the negotiated TLS ciphersuite relates only to the mechanism by which the PEAPv2 Part 2 conversation will be protected, and has no relationship to link layer security mechanisms negotiated within the PPP Encryption Control Protocol

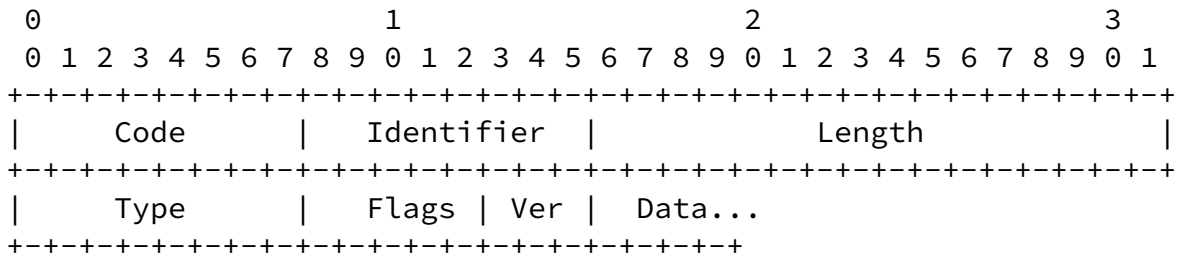
(ECP) [RFC1968] or within IEEE 802.11 [IEEE80211].

As a result, this specification currently does not support secure negotiation of link layer ciphersuites, although this capability may be added in future by addition of TLVs to the EAP TLV method defined in Section 4.

3. Detailed description of the PEAPv2 protocol

3.1. PEAPv2 Packet Format

A summary of the PEAPv2 Request/Response packet format is shown below. The fields are transmitted from left to right.



Code

1 - Request
2 - Response

Identifier

The Identifier field is one octet and aids in matching responses with requests.

Length

The Length field is two octets and indicates the length of the EAP packet including the Code, Identifier, Length, Type, and Data fields. Octets outside the range of the Length field should be treated as Data Link Layer padding and should be ignored on reception.

Type

25 - PEAP

Flags

```
 0 1 2 3 4
+-+-+-+-+-+
|L M S R R|
+-+-+-+-+-+
```

L = Length included
M = More fragments
S = PEAP start
R = Reserved (must be zero)

The L bit (length included) is set to indicate the presence of the four octet TLS Message Length field, and MUST be set for the first fragment of a fragmented TLS message or set of messages. The L bit MUST NOT be set for other fragments of the same set of messages. The M bit(more fragments) is set on all but the last fragment. The S bit (PEAP start) is set in a PEAP Start message. This differentiates the PEAP Start message from a fragment acknowledgment.

Version

```
 0 1 2
+-+-+-+
|R|1|0|
+-+-+-+
```

R = Reserved (must be zero)

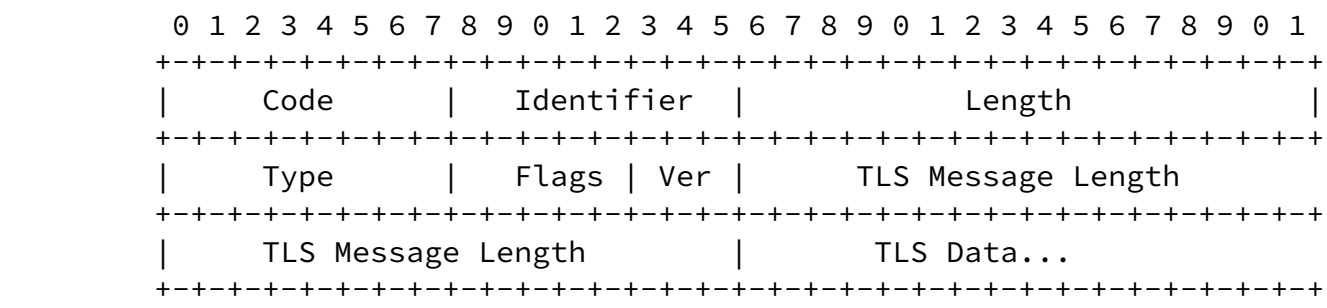
Data

The format of the Data field is determined by the Code field.

3.2. PEAPv2 Request Packet

A summary of the PEAPv2 Request packet format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
```



Code

1

Identifier

The Identifier field is one octet and aids in matching responses with requests. The Identifier field MUST be changed on each Request packet.

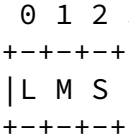
Length

The Length field is two octets and indicates the length of the EAP packet including the Code, Identifier, Length, Type, Flags, TLS message length and TLS data fields.

Type

25 - PEAP

Flags



L = Length included
M = More fragments
S = PEAP start
R = Reserved (must be zero)

The L bit (length included) is set to indicate the presence of the

four octet TLS Message Length field, and MUST be set for the first fragment of a fragmented TLS message or set of messages. The M bit(more fragments) is set on all but the last fragment. The S bit (PEAP start) is set in a PEAP Start message. This differentiates the PEAP Start message from a fragment acknowledgment.

Version

```
 0 1 2
+-+-+-+
|R|1|0|
+-+-+-+
```

R = Reserved (must be zero)

TLS Message Length

The TLS Message Length field is four octets, and is present only if the L bit is set. This field provides the total length of the TLS message or set of messages that is being fragmented.

TLS data

The TLS data consists of the encapsulated packet in TLS record format.

3.3. PEAPv2 Response Packet

A summary of the PEAPv2 Response packet format is shown below. The fields are transmitted from left to right.

Code

2

Identifier

The Identifier field is one octet and MUST match the Identifier field from the corresponding request.

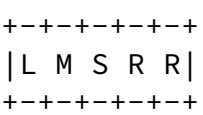
Length

The Length field is two octets and indicates the length of the EAP packet including the Code, Identifier, Length, Type, Flags, Ver, TLS message length, and TLS data fields.

Type

25 - PEAP

Flags



L = Length included
M = More fragments
S = PEAP start
R = Reserved (must be zero)

The L bit (length included) is set to indicate the presence of the four octet TLS Message Length field, and MUST be set for the first

fragment of a fragmented TLS message or set of messages. The M bit (more fragments) is set on all but the last fragment. The S bit (PEAP start) is set in a PEAP Start message. This differentiates the PEAP Start message from a fragment acknowledgment.

Version

```
 0 1 2
+-+-+-+
|R|1|0|
+-+-+-+
```

R = Reserved (must be zero)

TLS Message Length

The TLS Message Length field is four octets, and is present only if the L bit is set. This field provides the total length of the TLS message or set of messages that is being fragmented.

TLS data

The TLS data consists of the encapsulated TLS packet in TLS record format.

3.4. PEAPv2 Part 2 Packet Format

The PEAPv2 Part 2 packet format is the same as the PEAPv2 Request and Response packet formats described in Sections 3.1 and 3.2, except that the TLS Data field encapsulates TLS packets in TLS record format, representing encrypted EAP-TLVs.

Although the EAP-TLV method has been allocated an EAP Type, use of this method is prohibited outside of a tunnel by [RFC2284bis]. Since EAP-TLVs are self-describing, when transmitted within PEAPv2, the EAP header portion of the EAP-TLV packet is absent (including the Code, Identifier, Length and Type fields), leaving only a list of TLVs as the payload.

Within PEAPv2, all inner EAP method packets are encapsulated in EAP-TLV format. The EAP-Payload is an (optional) TLV which encapsulates EAP packets (including all EAP header fields) and in addition carries TLVs associated with them.

PEAP Part 2 packet format = EAP-TLV [EAP-Payload TLV [[EAP packet], TLVs, ...], TLVs, ...] OR TLS Alert

The EAP-TLV packet is included without the EAP header fields (Code, Identifier, Length, Type)

4. EAP-TLV method

The EAP-TLV method is a payload with standard Type-Length-Value (TLV) objects. The TLV objects could be used to carry arbitrary parameters between EAP peer and EAP server. Possible uses for TLV objects include: language and character set for Notification messages; cryptographic binding; MIPv6 Binding Update.

The EAP peer may not necessarily implement all the TLVs supported by the EAP server; and hence to allow for interoperability, the TLV method allows a EAP server to discover if a TLV is supported by the EAP peer, using the NAK TLV.

The mandatory bit in a TLV indicates that if the peer does not support the TLV, it MUST send a NAK TLV in response; and all the other TLVs in the message MUST be ignored. If an EAP peer finds an unsupported TLV which is marked as optional, it MUST NOT send an NAK TLV.

The mandatory bit does not imply that the peer is required to understand the contents of the TLV. The appropriate response to a supported TLV with content that is not understood is defined by the TLV specification.

If the EAP peer finds that the packet has no TLVs, then it MUST send a response with EAP-TLV Response Packet.

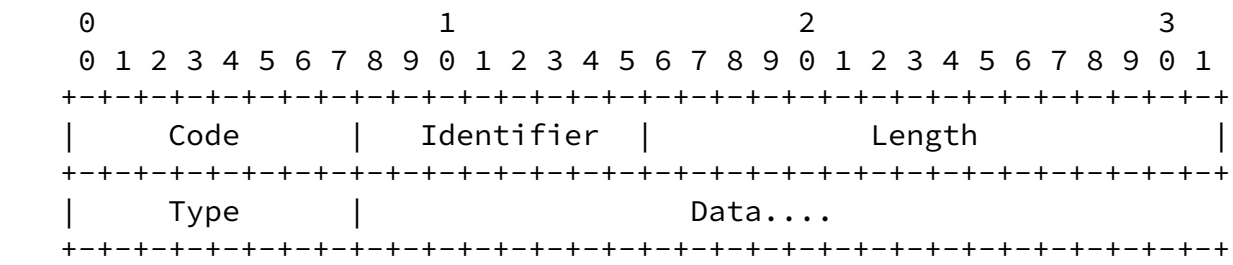
The mandatory bit in a TLV indicates that if the EAP server does not support the TLV, it MUST send a NAK TLV in response; otherwise it MUST send a protected termination message. If an EAP server finds an unsupported TLV which is marked as mandatory; the other TLVs in the message MUST be ignored.

An EAP-TLV packet is a EAP method and within a PEAPv2 tunnel, it can be sequenced before or after any other EAP method. An EAP-TLV packet does not have to contain any TLVs nor need it contain any mandatory TLVs.

PEAPv2 implementations MUST support the EAP TLV method, as well as processing of mandatory/optional settings on the TLV.

4.1. EAP-TLV Request Packet

A summary of the EAP-TLV Request packet format is shown below. The fields are transmitted from left to right.



Code

1

Identifier

The Identifier field is one octet and aids in matching responses with requests. The Identifier field MUST be changed on each Request packet.

Length

The Length field is two octets and indicates the length of the EAP packet including the Code, Identifier, Length, Type, and Data fields.

Type

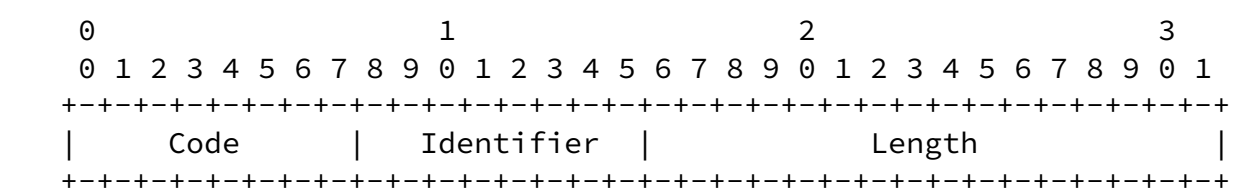
33 - EAP-TLV

Data

The Data field is of variable length, and contains Type-Length-Value tuples (TLVs).

4.2. EAP-TLV Response Packet

A summary of the Extension Response packet format is shown below. The fields are transmitted from left to right.



Code

2

Identifier

The Identifier field is one octet and aids in matching responses with requests. The Identifier field MUST be changed on each Request packet.

Length

The Length field is two octets and indicates the length of the EAP packet including the Code, Identifier, Length, Type, and Data fields.

Type

33 - EAP-TLV

Data

The Data field is of variable length, and contains Type-Length-Value tuples (TLVs).

4.3. TLV format

EAP-TLV TLVs are defined as follows:

M

0 - Non-mandatory TLV
1 - Mandatory TLV

R

Reserved, set to zero (0)

TLV Type

A 14-bit field, denoting the TLV type. Allocated Types include:

0 - Reserved
1 - Reserved
2 - Reserved
3 - RESULT_TLV - Acknowledged Result
4 - NAK_TLV
5 - Crypto-Binding TLV
6 - Connection-Binding TLV
7 - Vendor-Specific TLV
8 - URI TLV
9 - EAP Payload TLV
10 - Intermediate Result TLV

Length

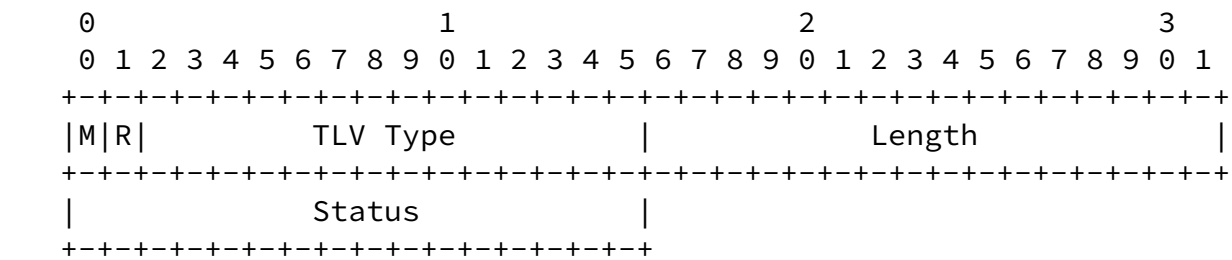
The length of the Value field in octets.

Value

The value of the TLV.

4.4. Result TLV

The Result TLV provides support for acknowledged success and failure messages within PEAPv2. PEAPv2 implementations MUST support this TLV, which cannot be responded to with a NAK TLV. If the Status field does not contain one of the known values, then the peer or EAP server MUST drop the connection. The Result TLV is defined as follows:



M

1 - Mandatory TLV

R

Reserved, set to zero (0)

TLV Type

3

Length

2

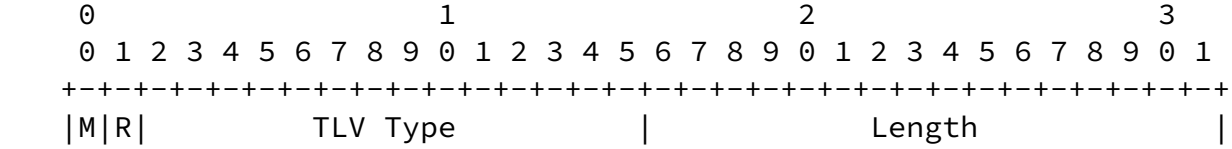
Status

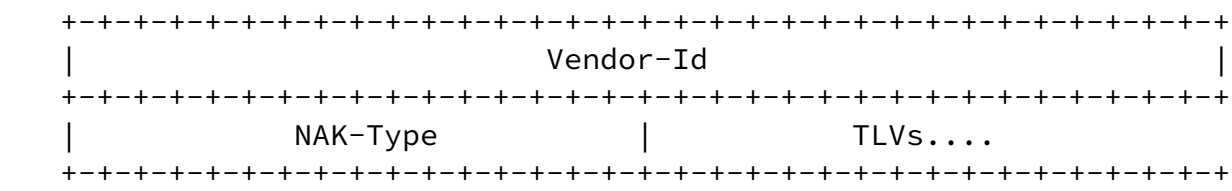
The Status field is two octets. Values include:

1 - Success
2 - Failure

4.5. NAK TLV

The NAK TLV allows a peer to detect TLVs that are not supported by the other peer. An EAP-TLV packet can contain 0 or more NAK TLVs. PEAPv2 implementations MUST support this TLV and this TLV cannot be responded to with a NAK TLV. The NAK TLV is defined as follows:





M

1 - Mandatory TLV

R

Reserved, set to zero (0)

TLV Type

4

Length

>=6

Vendor-Id

The Vendor-Id field is four octets, and contains the Vendor-Id of the TLV that was not supported. The high-order octet is 0 and the

low-order 3 octets are the SMI Network Management Private Enterprise Code of the Vendor in network byte order. The Vendor-Id field MUST be zero for TLVs that are not Vendor-Specific TLVs. For Vendor-Specific TLVs, the Vendor-ID MUST be set to the SMI code.

NAK-Type

The NAK-Type field is two octets. The field contains the Type of the TLV that was not supported. A TLV of this Type MUST have been included in the previous packet.

TLVs

This field contains a list of TLVs, each of which MUST NOT have

the mandatory bit set. These optional TLVs can be used in the future to communicate why the offending TLV was determined to be unsupported.

4.6. Crypto-binding TLV

The Crypto-Binding TLV is used prove that both peers participated in the sequence of authentications (specifically the TLS session and inner EAP methods that generate keys).

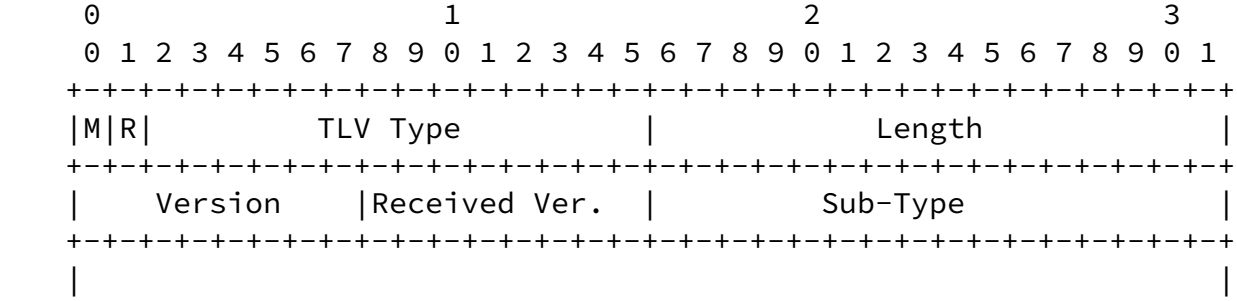
Both the Binding Request (B1) and Binding Response (B2) use the same packet format. However the Sub-Type indicates whether it is B1 or B2.

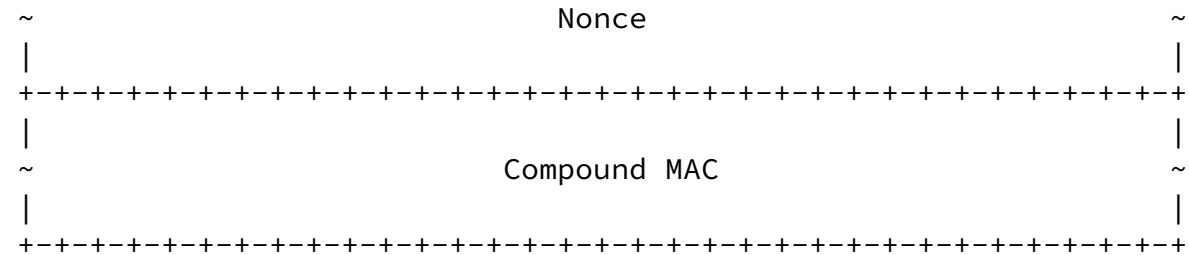
The Crypto-Binding TLV MUST be used to perform Cryptographic Binding after each successful EAP method (except EAP-TLV) in a sequence of EAP methods is complete in PEAPv2 part 2. The Crypto-Binding TLV can also be used during Protected Termination.

The crypto-binding TLV must have the version number received during the PEAP version negotiation. The receiver of the crypto binding TLV must verify that the version in the crypto binding TLV matches the version it sent during the PEAP version negotiation. If this check fails then the TLV is invalid.

The receiver of the crypto binding TLV must verify that the subtype is not set to any value other than the ones allowed. If this check fails then the TLV is invalid.

This message format is used for the Binding Request (B1) and also the Binding Response. This uses TLV type CRYPTO_BINDING_TLV. PEAPv2 implementations MUST support this TLV and this TLV cannot be responded to with a NAK TLV. The format is as given below.





M

1 - Mandatory TLV

R

Reserved, set to zero (0)

TLV Type

5

Length

52

Version

The Version field is a single octet, which is set to the version of crypto binding TLV. For the crypto-binding TLV defined in this specification, It is set to zero (0).

Received Version

The Received Version field is a single octet and MUST be set to the PEAP version number received during version negotiation. Note that this field only provides protection against downgrade attacks where a version of PEAP requiring support for this TLV is required on both sides (such as PEAPv2 or a more recent version).

Sub-Type

The Sub-Type field is two octets. Possible values include:

0 - Binding Request
1 - Binding Response

Nonce

The Nonce field is 32 octets. It contains a 256 bit nonce that is temporally unique, used for compound MAC key derivation at each end. This is the S_NONCE for the B1 message and a C_NONCE for the B2 message.

Compound MAC

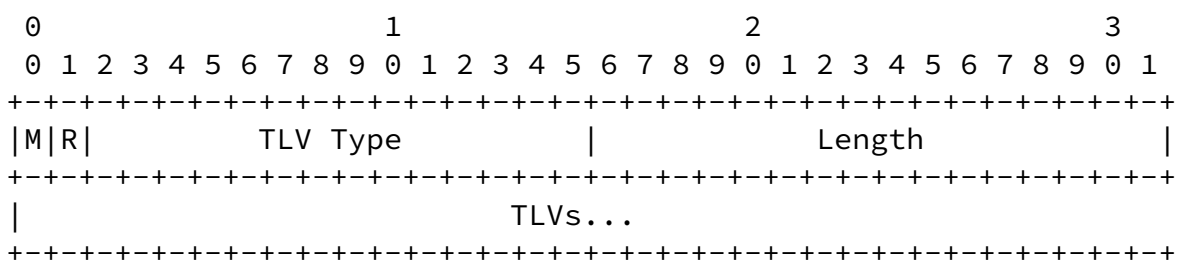
The Compound MAC field is 16 octets. This can be the Server MAC (B1_MAC) or the Client MAC (B2_MAC). It is computed over the entire Crypto-Binding TLV attribute using the HMAC-SHA1-128 that provides 128 bits of output using the CMK_B1 or CMK_B2 with the MAC field zeroed out.

4.7. Connection-Binding TLV

The Connection-Binding TLV allows for connection specific information to be sent by the peer to the AAA server. This TLV should be logged by the EAP or AAA server. The AAA or EAP server should not deny access if there i s a mismatch between the value sent through the AAA protocol and this TLV.

The format of this TLV is defined for the layer that defines the parameters. The format of the value sent by the peer to the EAP server may be different from the format of the corresponding value sent through the AAA protocol. For example, the connection binding TLV may contain 802.11 MAC Address and SSID.

PEAP implementations MAY support this TLV and this TLV MUST NOT be responded to with a NAK TLV. It is defined as follows:



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

6

Length

>=0

TLVs...

The field contains a list of TLVs, each in the same format defined in Section 4.3, with the optional bit set. These TLVs contain information on the identity of the peer and authenticator (layer 2 or IP addresses); the media used to connect the peer and authenticator (NAS-Port-Type); and/or the service the client is trying to access on the gateway (SSID). The format of these TLVs will be defined in a separate draft.

4.8. Vendor-Specific TLV

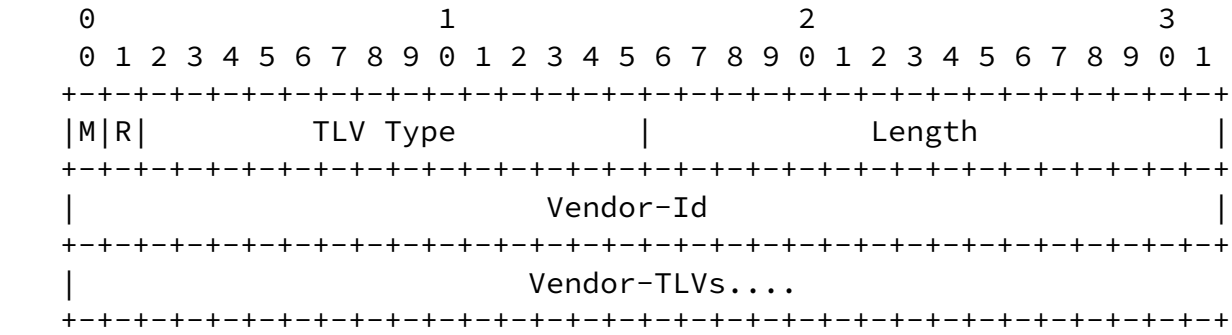
The Vendor-Specific TLV is available to allow vendors to support their own extended attributes not suitable for general usage.

A Vendor-Specific-TLV attribute can contain one or more TLVs, referred to as Vendor-TLVs. The TLV-type of the Vendor-TLV will be defined by the vendor. All the Vendor-TLVs inside a single Vendor-Specific TLV belong to the same vendor.

PEAPv2 implementations MUST support the Vendor-Specific TLV; and this TLV cannot be responded to with a NAK TLV. PEAPv2 implementations MAY NOT support the Vendor-TLVs included in the Vendor-Specific TLV and can respond with a NAK TLV.

Vendor-TLVs may be optional or mandatory. Vendor-TLVs sent in the protected success and failure packets MUST be marked as optional. If Vendor-TLVs sent in protected success/failure packets are marked as Mandatory, then the peer or EAP server MUST drop the connection.

A summary of the Vendor-Specific Attribute format is shown below. The fields are transmitted from left to right.



M

1 - Mandatory TLV

R

Reserved, set to zero (0)

TLV Type

7

Length

>=4

Vendor-Id

The Vendor-Id field is four octets. The high-order octet is 0 and the low-order 3 octets are the SMI Network Management Private Enterprise Code of the Vendor in network byte order. The Vendor-Id MUST be zero for TLVs that are not Vendor-Specific TLVs. For Vendor-Specific TLVs, the Vendor-ID MUST be set to the SMI code.

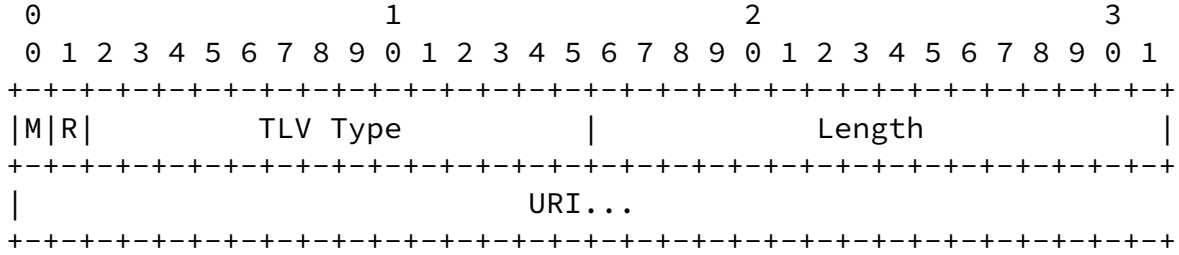
Vendor-TLVs

This field is of indefinite length. It contains vendor-specific TLVs, in a format defined by the vendor.

4.9. URI TLV

The URI TLV allows a server to send a URI to the client to refer it to a resource. The TLV contains a URI in the format specified in RFC2396 with UTF-8 encoding. If a packet contains multiple URI TLVs, then the client SHOULD select the first TLV it can implement, and ignore the others. If the client is unable to implement any of the URI TLVs, then it MAY ignore the error. PEAP implementations MAY support this TLV; and this TLV cannot be responded to with a NAK TLV.

A summary of this field is shown below:



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

8

Length

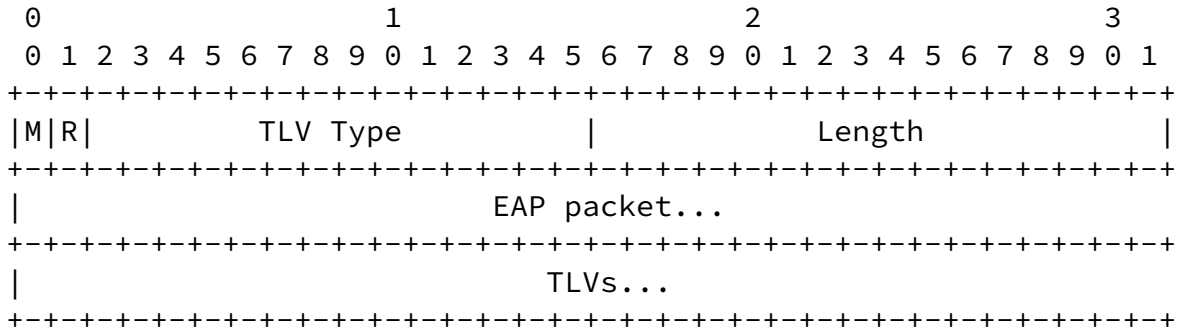
>=0

URI

This field is of indefinite length, and conforms to the format specified in [RFC2396].

4.10. EAP-Payload TLV

To allow piggybacking EAP request and response with other TLVs, the EAP Payload TLV is defined, which includes an encapsulated EAP packet and 0 or more TLVs. PEAPv2 implementations MUST support this TLV, which cannot be responded to with a NAK TLV. The EAP-Payload TLV is defined as follows:



M

1 - Mandatory TLV

R

Reserved, set to zero (0)

TLV Type

8

Length

>=0

EAP packet

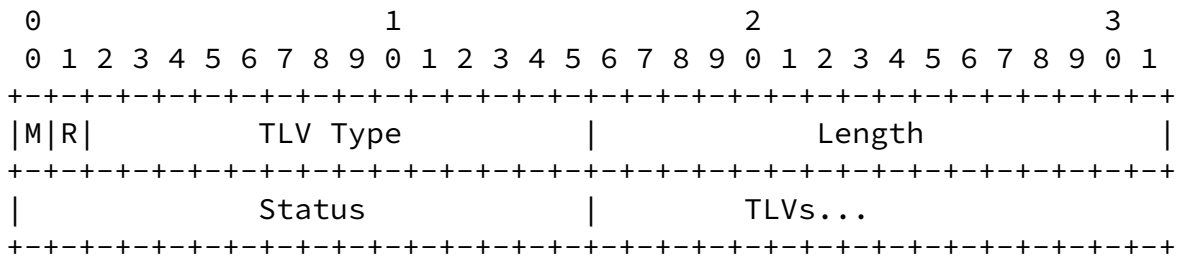
This field contains a complete EAP packet, including the EAP header (Code, Identifier, Length, Type) fields. The length of this field is determined by the Length field of the encapsulated EAP packet.

TLVs...

This (optional) field contains a list of TLVs associated with the EAP packet field. The TLVs utilize the same format described Section 4.3, and MUST NOT have the mandatory bit set. The total length of this field is equal to the Length field of the EAP-Payload-TLV, minus the Length field in the EAP header of the EAP packet field.

4.11. Intermediate Result TLV

The Intermediate Result TLV provides support for acknowledged intermediate Success and Failure messages within EAP. PEAPv2 implementations MUST support this TLV, which cannot be responded to with a NAK TLV. This TLV is defined as follows:



M

1 - Mandatory TLV

R

Reserved, set to zero (0)

TLV Type

10

Length

>=2

Status

The Status field is two octets. Values include:

1 - Success
2 - Failure

TLVs

This (optional) field is of indeterminate length, and contains the TLVs associated with the Intermediate Result TLV, in the same format as described in Section 4.3. The TLVs in this field MUST NOT have the mandatory bit set.

4.12. TLV Rules

To save round trips, multiple TLVs can be sent in the single PEAPv2 packet. However, multiple EAP Payload TLVs within one single PEAPv2 packet is not supported in this version and MUST NOT be sent. If the peer or EAP server receives multiple EAP Payload TLVs, then it MUST drop the connection.

The following table provides a guide to which TLVs may be found in which kind of packets, and in which quantity:

Request	Response	Success	Failure	TLV
0-1	0-1	0-1	0-1	Intermediate Result TLV
0-1	0-1	0	0	EAP Payload TLV
0-1	0-1	1	1	Result TLV
0-1	0-1	0-1	0-1	Crypto-Binding TLV
0+	0+	0	0	NAK TLV
0-1	0-1	0-1	0-1	Connection-Binding TLV
0+	0+	0+	0+	Vendor-Specific TLV
0+	0	0+	0-1	URI TLV

The following table defines the meaning of the above table entries.

0	This TLV MUST NOT be present in the packet.
0+	Zero or more instances of this TLV MAY be present in packet.
0-1	Zero or one instance of this TLV MAY be present in packet.
1	Exactly one instance of this TLV MUST be present in packet.

Packet type	Description
Request	- EAP-TLV request packet sent by EAP server to peer.
Response	- EAP-TLV response packet sent by peer to EAP server.

Success - EAP-TLV packet sent by Peer or EAP server as protected success
Failure - EAP-TLV packet sent by Peer or EAP server as protected failure.

The EAP-Payload TLV can contain other TLVs. The table below defines which TLVs can be contained inside the EAP-Payload TLV and how many such TLVs can be included.

EAP-Payload-TLV	TLV
0	Intermediate Result TLV
0	EAP Payload TLV
0	Result TLV
0	Crypto-Binding TLV
0+	NAK TLV
0	Connection-Binding TLV
0+	Vendor-Specific TLV
0	URI TLV

5. Security Considerations

5.1. Authentication and integrity protection

PEAPv2 provides a server authenticated, encrypted and integrity protected tunnel. All data within the tunnel has these properties. Data outside the tunnel such as EAP Success and Failure, authentication methods negotiated outside of PEAPv2 and the PEAPv2 headers themselves are not protected by this tunnel.

In addition, the crypto-binding TLV can reveal man-in-the-middle attack described in section 6.8. Hence, the server should not reveal any sensitive data to the client until after the Crypto-Binding TLV has been properly verified.

5.2. Method negotiation

If the peer does not support PEAPv2, or does not wish to utilize PEAPv2 authentication, it MUST respond to the initial EAP-

Request/PEAP-Start with a NAK, suggesting an alternate authentication method. Since the NAK is sent in cleartext with no integrity protection or authentication, it is subject to spoofing. Inauthentic NAK packets can be used to trick the peer and authenticator into "negotiating down" to a weaker form of authentication, such as EAP-MD5 (which only provides one way authentication and does not derive a key).

Since a subsequent protected EAP conversation can take place within the TLS session, selection of PEAPv2 as an authentication method does not limit the potential secondary authentication methods. As a result, the only legitimate reason for a peer to NAK PEAPv2 as an authentication method is that it does not support it. Where the additional security of PEAPv2 is required, server implementations SHOULD respond to a NAK with an EAP-Failure, terminating the authentication conversation.

Since method negotiation outside of PEAP is not protected, if the peer is configured to allow PEAP and other EAP methods at the same time, the negotiation is subject to downgrade attacks. Since method negotiation outside of PEAP is not protected, if the peer is configured to allow PEAP version 2; and previous PEAP versions at the same time, the negotiation is subject to negotiation downgrade attacks. However, peers configured to allow PEAPv2 and later PEAP versions may not be subject to downgrade negotiation attack since the highest version supported by both peers is checked within the protected tunnel.

If peer implementations select incorrect methods or credentials with EAP servers, then attacks are possible on the credentials. Hence, a PEAPv2 peer implementation should preferably be configured with a set of credentials and methods that may be used with a specific PEAPv2 Server. The peer implementation may be configured to use different methods and/or credentials based on the PEAPv2 server.

5.3. TLS session cache handling

In cases where a TLS session has been successfully resumed, in some circumstances, it is possible for the EAP server to skip the PEAPv2 Part 2 conversation, and successfully conclude the conversation with a protected termination.

PEAPv2 "fast reconnect" is desirable in applications such as wireless roaming, since it minimizes interruptions in connectivity. It is

also desirable when the "inner" EAP mechanism used is such that it requires user interaction. The user should not be required to re-authenticate herself, using biometrics, token cards or similar, every time the radio connectivity is handed over between access points in wireless environments.

However, there are issues that need to be understood in order to avoid introducing security vulnerabilities.

Since PEAPv2 Part 1 may not provide client authentication, establishment of a TLS session (and an entry in the TLS session cache) does not by itself provide an indication of the peer's authenticity.

Some PEAPv2 implementations may not be capable of removing TLS session cache entries established in PEAPv2 Part 1 after an unsuccessful PEAPv2 Part 2 authentication. In such implementations, the existence of a TLS session cache entry provides no indication that the peer has previously been authenticated. As a result, implementations that do not remove TLS session cache entries after a failed PEAPv2 Part 2 authentication or failed protected termination MUST use other means than successful TLS resumption as the indicator of whether the client is authenticated or not. The implementation MUST determine that the client is authenticated only after the completion of protected termination. Failing to do this would enable a peer to gain access by completing PEAPv2 Part 1, tearing down the connection, re-connecting and resuming PEAPv2 Part 1, thereby proving herself authenticated. Thus, TLS resumption MUST only be enabled if the implementation supports TLS session cache removal. If an EAP server implementing PEAPv2 removes TLS session cache entries of peers failing PEAPv2 Part 2 authentication, then it MAY skip the PEAPv2 Part 2 conversation entirely after a successful session resumption, successfully terminating the PEAPv2 conversation as described in Section 2.4.

5.4. Certificate revocation

Since the EAP server is on the Internet during the EAP conversation, the server is capable of following a certificate chain or verifying whether the peer's certificate has been revoked. In contrast, the peer may or may not have Internet connectivity, and thus while it can validate the EAP server's certificate based on a pre-configured set of CAs, it may not be able to follow a certificate chain or verify whether the EAP server's certificate has been revoked.

In the case where the peer is initiating a voluntary Layer 2 channel using PPTP or L2TP, the peer will typically already have Internet

connectivity established at the time of channel initiation. As a

result, during the EAP conversation it is capable of checking for certificate revocation.

As part of the TLS negotiation, the server presents a certificate to the peer. The peer SHOULD verify the validity of the EAP server certificate, and SHOULD also examine the EAP server name presented in the certificate, in order to determine whether the EAP server can be trusted. Please note that in the case where the EAP authentication is remoted, the EAP server will not reside on the same machine as the authenticator, and therefore the name in the EAP server's certificate cannot be expected to match that of the intended destination. In this case, a more appropriate test might be whether the EAP server's certificate is signed by a CA controlling the intended destination and whether the EAP server exists within a target sub-domain.

In the case where the peer is attempting to obtain network access, it will not have Internet connectivity. The TLS Extensions [RFC3546] support piggybacking of an Online Certificate Status Protocol (OCSP) response within TLS, therefore can be utilized by the peer in order to verify the validity of server certificate. However, since not all TLS implementations implement the TLS extensions, it may be necessary for the peer to wait to check for certificate revocation until after Internet access has been obtained. In this case, the peer SHOULD conduct the certificate status check immediately upon going online and SHOULD NOT send data until it has received a positive response to the status request. If the server certificate is found to be invalid as per client policy, then the peer SHOULD disconnect.

If the client has a policy to require checking certificate revocation and it cannot obtain revocation information then it may need to disallow the use of all or some of the inner methods since some methods may reveal some sensitive information.

5.5. Separation of the EAP server and the authenticator

As a result of a complete PEAPv2 Part 1 and Part 2 conversation, the EAP endpoints will mutually authenticate, and derive a session key for subsequent use in link layer security. Since the peer and EAP client reside on the same machine, it is necessary for the EAP client module to pass the session key to the link layer encryption module.

The situation may be more complex on the Authenticator, which may or may not reside on the same machine as the EAP server. In the case where the EAP server and the Authenticator reside on different machines, there are several implications for security. Firstly, the mutual authentication defined in PEAP will occur between the peer and the EAP server, not between the peer and the authenticator. This means that as a result of the PEAP conversation, it is not possible

for the peer to validate the identity of the NAS or channel server that it is speaking to.

The second issue is that the session key negotiated between the peer and EAP server will need to be transmitted to the authenticator. Therefore a secure mechanism needs to be provided to transmit the session key from the EAP server to the authenticator or channel server that needs to use the key. The specification of this transit mechanism is outside the scope of this document.

5.6. Separation of PEAPv2 Part 1 and Part 2 Servers

The EAP server involved in PEAPv2 Part 2 need not necessarily be the same as the EAP server involved in PEAPv2 Part 1. For example, a local authentication server or proxy might serve as the endpoint for the Part 1 conversation, establishing the TLS channel. Subsequently, once the EAP-Response/Identity has been received within the TLS channel, it can be decrypted and forwarded in cleartext to the destination realm EAP server. The rest of the conversation will therefore occur between the destination realm EAP server and the peer, with the local authentication server or proxy acting as an encrypting/decrypting gateway. This permits a non-TLS capable EAP server to participate in the PEAPv2 conversation.

Note however that such an approach introduces security vulnerabilities. Since the EAP Response/Identity is sent in the clear between the proxy and the EAP server, this enables an attacker to snoop the user's identity. It also enables a remote environments, which may be public hot spots or Internet coffee shops, to gain knowledge of the identity of their users. Since one of the potential benefits of PEAP is identity protection, this is undesirable.

If the EAP method negotiated during PEAPv2 Part 2 does not support

mutual authentication, then if the Part 2 conversation is proxied to another destination, the PEAP peer will not have the opportunity to verify the secondary EAP server's identity. Only the initial EAP server's identity will have been verified as part of TLS session establishment.

Similarly, if the EAP method negotiated during PEAPv2 Part 2 is vulnerable to dictionary attack, then an attacker capturing the cleartext exchange will be able to mount an offline dictionary attack on the password.

Finally, when a Part 2 conversation is terminated at a different location than the Part 1 conversation, the Part 2 destination is unaware that the EAP client has negotiated PEAPv2. As a result, it is unable to enforce policies requiring PEAP. Since some EAP methods

require PEAPv2 in order to generate keys or lessen security vulnerabilities, where such methods are in use, such a configuration may be unacceptable.

In summary, PEAPv2 encrypting/decrypting gateway configurations are vulnerable to attack and SHOULD NOT be used. Instead, the entire PEAPv2 connection SHOULD be proxied to the final destination, and the subsequently derived master session keys need to be transmitted back. T his provides end to end protection of PEAPv2. The specification of this transit mechanism is outside the scope of this document, but mechanisms similar to [RFC2548] can be used. These steps protect the client from revealing her identity to the remote environment.

In order to find the proper PEAP destination, the EAP client SHOULD place a Network Access Identifier (NAI) conforming to [RFC2486] in the Identity Response.

There may be cases where a natural trust relationship exists between the (foreign) authentication server and final EAP server, such as on a campus or between two offices within the same company, where there is no danger in revealing the identity of the station to the authentication server. In these cases, a proxy solution without end to end protection of PEAPv2 MAY be used. If RADIUS is used to communicate between gateway and EAP server, then the PEAPv2 encrypting/decrypting gateway SHOULD provide support for IPsec protection of RADIUS in order to provide confidentiality for the

portion of the conversation between the gateway and the EAP server, as described in [RFC3579].

5.7. Identity verification

Since the TLS session has not yet been negotiated, the initial Identity request/response occurs in the clear without integrity protection or authentication. It is therefore subject to snooping and packet modification.

In configurations where all users are required to authenticate with PEAPv2 and the first portion of the PEAPv2 conversation is terminated at a local backend authentication server, without routing by proxies, the initial cleartext Identity Request/Response exchange is not needed in order to determine the required authentication method(s) or route the authentication conversation to its destination. As a result, the initial Identity and Request/Response exchange MAY NOT be present, and a subsequent Identity Request/Response exchange MAY occur after the TLS session is established.

If the initial cleartext Identity Request/Response has been tampered with, after the TLS session is established, it is conceivable that

the EAP Server will discover that it cannot verify the peer's claim of identity. For example, the peer's userID may not be valid or may not be within a realm handled by the EAP server. Rather than attempting to proxy the authentication to the server within the correct realm, the EAP server SHOULD terminate the conversation.

The PEAPv2 peer can present the server with multiple identities. This includes the claim of identity within the initial EAP-Response/Identity (MyID) packet, which is typically used to route the EAP conversation to the appropriate home backend authentication server. There may also be subsequent EAP-Response/Identity packets sent by the peer once the TLS channel has been established.

Note that since the PEAPv2 peer may not present a certificate, it is not always possible to check the initial EAP-Response/Identity against the identity presented in the certificate, as is done in [RFC2716].

Moreover, it cannot be assumed that the peer identities presented

within multiple EAP-Response/Identity packets will be the same. For example, the initial EAP-Response/Identity might correspond to a machine identity, while subsequent identities might be those of the user. Thus, PEAPv2 implementations SHOULD NOT abort the authentication just because the identities do not match. However, since the initial EAP-Response/Identity will determine the EAP server handling the authentication, if this or any other identity is inappropriate for use with the destination EAP server, there is no alternative but to terminate the PEAPv2 conversation.

The protected identity or identities presented by the peer within PEAPv2 Part 2 may not be identical to the cleartext identity presented in PEAPv2 Part 1, for legitimate reasons. In order to shield the userID from snooping, the cleartext Identity may only provide enough information to enable routing of the authentication request to the correct realm. For example, the peer may initially claim the identity of "nouser@bigco.com" in order to route the authentication request to the bigco.com EAP server. Subsequently, once the TLS session has been negotiated, in PEAPv2 Part 2, the peer may claim the identity of "fred@bigco.com". Thus, PEAPv2 can provide protection for the user's identity, though not necessarily the destination realm, unless the PEAPv2 Part 1 conversation terminates at the local authentication server.

As a result, PEAPv2 implementations SHOULD NOT attempt to compare the Identities claimed with Parts 1 and 2 of the PEAPv2 conversation. Similarly, if multiple Identities are claimed within PEAPv2 Part 2, these SHOULD NOT be compared. An EAP conversation may involve more than one EAP authentication method, and the identities claimed for

each of these authentications could be different (e.g. a machine authentication, followed by a user authentication).

5.8. Man-in-the-middle attack protection

TLS protection can address a number of weaknesses in the EAP method; as well as EAP protocol weaknesses listed in the abstract and introduction sections in this document.

Hence, the recommended solution is to always deploy authentication methods with protection of PEAPv2.

if a deployment chooses to allow a EAP method protected by PEAP without protection of PEAP or IPsec at the same time, then this opens up a possibility of a man-in-the-middle attack.

A man-in-the-middle can spoof the client to authenticate to it instead of the real EAP server; and forward the authentication to the real server over a protected tunnel. Since the attacker has access to the keys derived from the tunnel, it can gain access to the network.

PEAP version 2 prevents this attack by using the keys generated by the inner EAP method in the crypto-binding exchange described in protected termination section. This attack is not prevented if the inner EAP method does not generate keys or if the keys generated by the inner EAP method can be compromised.

Alternatively, the attack can also be thwarted if the inner EAP method can signal to the peer that the packets are being sent within the tunnel. In most cases this may require modification to the inner EAP method. In order to allow for these implementations, PEAPv2 implementations should inform inner EAP methods that the EAP method is being protected by a PEAPv2 tunnel.

Since all sequence negotiations and exchanges are protected by TLS channel, they are immune to snooping and MITM attacks with the use of Crypto-Binding TLV. To make sure the same parties are involved tunnel establishment and previous inner method, before engaging the next method to sent more sensitive information, both peer and server MUST use the Crypto-Binding TLV between methods to check the tunnel integrity. If the Crypto-Binding TLV failed validation, they SHOULD stop the sequence and terminate the tunnel connection, to prevent more sensitive information being sent in subsequent methods.

5.9. Cleartext forgeries

As described in [RFC2284bis], EAP Success and Failure packets are not authenticated, so that they may be forged by an attacker without fear

of detection. Forged EAP Failure packets can be used to convince an EAP peer to disconnect. Forged EAP Success and Failure packets may be used to convince a peer to disconnect; or convince a peer to access the network even before authentication is complete, resulting in denial of service for the peer.

By supporting encrypted, authenticated and integrity protected success/failure indications, PEAPv2 provides protection against these attacks.

When the peer responds with the first PEAP packet; and the EAP server receives the first PEAPv2 packet from the peer, both MUST silently discard all clear text EAP messages unless both the PEAPv2 peer and server have indicated success or failure or error using a protected error or protected termination mechanism. The success/failure decisions sent by a protected mechanism indicate the final decision of the EAP authentication conversation. After success/failure has been indicated by a protected mechanism, the PEAPv2 client can process unprotected EAP success and EAP failure message; however MUST ignore any unprotected EAP success or failure messages where the decision does not match the decision of the protected mechanism.

[RFC2284bis] states that an EAP Success or EAP Failure packet terminates the EAP conversation, so that no response is possible. Since EAP Success and EAP Failure packets are not retransmitted, if the final packet is lost, then authentication will fail. As a result, where packet loss is expected to be non-negligible, unacknowledged success/failure indications lack robustness.

As a result, a EAP server SHOULD send a clear text EAP success or EAP-failure packet after the protected success or failure packet or TLS alert. The peer MUST NOT require the clear text EAP Success or EAP Failure if it has received the protected success or failure or TLS alert. For more details, refer to [RFC228bis], Section 4.2.

5.10. TLS Ciphersuites

Anonymous ciphersuites are vulnerable to man-in-the-middle attacks, and SHOULD NOT be used with PEAPv2, unless the EAP methods inside PEAPv2 can address the man-in-the-middle attack or unless the man-in-the-middle attack can be addressed by mechanisms external to PEAPv2.

5.11. Denial of service attacks

Denial of service attacks are possible if the attacker can insert or modify packets in the authentication channel. The attacker can modify unprotected fields in the PEAP packet such as the EAP protocol or PEAP version number. This can result in a denial of service

attack. It is also possible for the attacker to modify protected fields in a packet to cause decode errors resulting in a denial of service. In these ways the attacker can prevent access for peers connecting to the network.

Denial of service attacks with multiplier impacts are more interesting than the ones above. It is possible to multiply the impact by creating a large number of TLS sessions with the EAP server.

5.12. Security Claims

Intended use:	Wireless or Wired networks, and over the Internet, where physical security cannot be assumed.
Auth. mechanism:	Use arbitrary EAP and TLS authentication mechanisms for authentication of the client and server.
Ciphersuite negotiation:	Yes.
Mutual authentication:	Yes. Depends on the type of EAP method used within the tunnel and the type of authentication used within TLS.
Integrity protection:	Yes
Replay protection:	Yes
Confidentiality:	Yes
Key derivation:	Yes
Key strength:	Variable
Dictionary attack prot:	Not susceptible.
Fast reconnect:	Yes
Crypt. binding:	Yes.
Acknowledged S/F:	Yes
Session independence:	Yes.
Fragmentation:	Yes

PEAPv2 derives keys by combining keys from TLS and the inner EAP methods. It should be noted that the use of TLS ciphersuites with a particular key lengths does not guarantee that the key strength of the keys will be equivalent to the length. The key exchange mechanisms (eg. RSA or Diffie-Hellman) used must provide sufficient security or they will be the weakest link. For example RSA key sizes with a modulus of 1024 bits provides less than 128 bits of security, this may provide sufficient key strength for some applications and not for others. See [PKLENGTH] for a detailed analysis of determining the public key strengths used to exchange symmetric keys.

6. IANA Considerations

This section provides guidance to the Internet Assigned Numbers Authority (IANA) regarding registration of values related to the EAP protocol, in accordance with BCP 26, [RFC2434].

There is one name space in EAP-TLV that requires registration: PEAPv2 TLV-Types.

6.1. Definition of Terms

The following terms are used here with the meanings defined in BCP 26: "name space", "assigned value", "registration".

The following policies are used here with the meanings defined in BCP 26: "Private Use", "First Come First Served", "Expert Review", "Specification Required", "IETF Consensus", "Standards Action".

6.2. Recommended Registration Policies

For "Designated Expert with Specification Required", the request is posted to the EAP WG mailing list (or, if it has been disbanded, a successor designated by the Area Director) for comment and review, and MUST include a pointer to a public specification. Before a period of 30 days has passed, the Designated Expert will either approve or deny the registration request and publish a notice of the decision to the EAP WG mailing list or its successor. A denial notice must be justified by an explanation and, in the cases where it is possible, concrete suggestions on how the request can be modified so as to become acceptable.

EAP-TLVs have a 14-bit field, of which 0-10 have been allocated.

Additional EAP-TLV type codes may be allocated following Designated Expert with Specification Required [RFC2434].

7. References

7.1. Normative references

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Appendix A - Examples

A.1 Cleartext Identity Exchange

In the case where an identity exchange occurs within PEAPv2 Part 1, the conversation will appear as follows:

```
Authenticating Peer     Authenticator
-------------------     -------------
                        <- EAP-Request/
                        Identity
EAP-Response/
Identity (MyID1) ->
```

// Identity sent in the clear. May be a hint to help route the authentication request to EAP server, instead of the full user identity.

```
                        <- EAP-Request/
                        EAP-Type=PEAP, V=2
                        (PEAP Start, S bit set)
```

```
   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS client_hello)->
                            <- EAP-Request/
                            EAP-Type=PEAP, V=2
                            (TLS server_hello,
                             TLS certificate,
                        [TLS server_key_exchange,]
                        [TLS certificate_request,]
                            TLS server_hello_done)
   EAP-Response/
   EAP-Type=PEAP, V=2
   ([TLS certificate,]
    TLS client_key_exchange,
   [TLS certificate_verify,]
    TLS change_cipher_spec,
    TLS finished) ->
                            <- EAP-Request/
                            EAP-Type=PEAP, V=2
                            (TLS change_cipher_spec,
                             TLS finished,
                             EAP-Request/EAP-Type=EAP-TLV
                            [EAP-Payload-TLV[EAP-Request/
                             Identity]])

   // identity protected by TLS. EAP-TLV packet does not include an EAP-
```



```
   header.

   TLS channel established (EAP messages sent within TLS channel
   encapsulated in EAP-TLV packets without EAP header)

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/Identity (MyID2)]]]->

                            <- EAP-TLV [EAP-Payload-TLV
                            [EAP-Request/EAP-Type=X]]

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/EAP-Type=X]] ->
```

```
   // Protected termination

                              <- EAP-TLV [Result TLV (Success),
                              Crypto-Binding-TLV (Version=0,
                              received-version=2, Nonce, B1_MAC),
                              Intermediate-Result-TLV (Success)]

   EAP-TLV [Result-TLV (Success),
   Intermediate-Result-TLV (Success),
   Crypto-Binding-TLV (Version=0,
   received-version=2,Nonce, B2_MAC)]->

   TLS channel torn down
   (messages sent in cleartext)

                              <- EAP-Success
```

A.2 No cleartext Identity Exchange

Where all peers are known to support PEAPv2, a non-certificate authentication is desired for the client and the PEAP Part 1 conversation is carried out between the peer and a local EAP server, the cleartext identity exchange may be omitted and the conversation appears as follows:

```
   Authenticating Peer     Authenticator
   -------------------     -------------
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (PEAP Start, S bit set)

   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS client_hello)->
```



```
                              <- EAP-Request/
                              EAP-Type=PEAP, V=2
                              (TLS server_hello,
                               TLS certificate,
                          [TLS server_key_exchange,]
                          [TLS certificate_request,]
                              TLS server_hello_done)
```

```
   EAP-Response/
   EAP-Type=PEAP, V=2
   ([TLS certificate,]
    TLS client_key_exchange,
   [TLS certificate_verify,]
    TLS change_cipher_spec,
    TLS finished) ->
                            <- EAP-Request/
                            EAP-Type=PEAP, V=2
                            (TLS change_cipher_spec,
                             TLS finished,
                            EAP-TLV [EAP-Payload-TLV
                            (EAP-Request/Identity)])

   TLS channel established
   (messages sent within the TLS channel)

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/Identity (MyID)]] ->

                           <- EAP-TLV [EAP-Payload-TLV
                           [EAP-Type=EAP-Request/
                           EAP-Type=X]]

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/EAP-Type=X
   or NAK] ->
                           <- EAP-TLV [EAP-Payload-TLV
                           [EAP-Request/EAP-Type=X]]

   EAP-TLV [EAP-Payload-TLV [EAP-Response/
   EAP-Type=X]] ->

   // Protected success
                            <- EAP-TLV [Crypto-Binding-TLV=
                            (Version=0, Received-version=2,
                            Nonce, B1_MAC),
                            Intermediate-Result-TLV(Success),
                            Result TLV (Success)]

   EAP-TLV [Crypto-Binding-TLV=
```

```
(Version=0,Received-version=2,
Nonce, B2_MAC),
Intermediate-Result-TLV (Success),
Result TLV (Success)]->

TLS channel torn down
(messages sent in cleartext)

                          <- EAP-Success
```

A.3 Client certificate authentication with identity privacy

Where all peers are known to support PEAPv2, where client certificate authentication is desired and the PEAPv2 Part 1 conversation is carried out between the peer and a local EAP server, the cleartext identity exchange may be omitted and the conversation appears as follows:

```
Authenticating Peer     Authenticator
-------------------     -------------
                        <- EAP-Request/
                        EAP-Type=PEAP, V=2
                        (PEAP Start, S bit set)

EAP-Response/
EAP-Type=PEAP, V=2
(TLS client_hello)->
                        <- EAP-Request/
                        EAP-Type=PEAP, V=2
                        (TLS server_hello,
                         TLS certificate,
                         [TLS server_key_exchange,]
                         TLS server_hello_done)
EAP-Response/
EAP-Type=PEAP, V=2
(TLS client_key_exchange,
 TLS change_cipher_spec,
 TLS finished) ->
                        <- EAP-Request/
                        EAP-Type=PEAP, V=2
                        (TLS change_cipher_spec,
                         TLS finished,TLS Hello-Request)
EAP-Response/
EAP-Type=PEAP, V=2
(TLS client_hello)->

TLS channel established
(messages sent within the TLS channel)
```

```
                              <- EAP-Request/
                              EAP-Type=PEAP, V=2
                              (TLS server_hello,
                               TLS certificate,
                          [TLS server_key_exchange,]
                          [TLS certificate_request,]
                              TLS server_hello_done)
   EAP-Response/
   EAP-Type=PEAP, V=2
   ([TLS certificate,]
    TLS client_key_exchange,
   [TLS certificate_verify,]
    TLS change_cipher_spec,
    TLS finished) ->

                              <- EAP-Request/
                              EAP-Type=PEAP, V=2
                              (TLS change_cipher_spec,
                               TLS finished, EAP-TLV
                              [Crypto-binding-TLV (version=0,
                              Received-version=2, Nonce,
                              B1_MAC),
                              Result-TLV (Success)])

   // packet format within the TLS channel

   EAP-TLV [
   Crypto-Binding-TLV=(Version=0,
   Received-version=2,
   Nonce, B2_MAC),
   Result TLV (Success)]

   TLS channel torn down
   (messages sent in cleartext)

                              <- EAP-Success
```

A.4 Fragmentation and Reassembly

In the case where the PEAP fragmentation is required, the conversation will appear as follows:

```
Authenticating Peer     Authenticator
```

```
   -------------------     -------------
                           <- EAP-Request/
                           Identity
   EAP-Response/
   Identity (MyID) ->
```



```
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (PEAP Start, S bit set)

   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS client_hello)->
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (TLS server_hello,
                            TLS certificate,
                     [TLS server_key_exchange,]
                     [TLS certificate_request,]
                         TLS server_hello_done)
                     (Fragment 1: L, M bits set)

   EAP-Response/
   EAP-Type=PEAP, V=2 ->

                           <- EAP-Request/
                              EAP-Type=PEAP, V=2
                           (Fragment 2: M bit set)
   EAP-Response/
   EAP-Type=PEAP, V=2 ->
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (Fragment 3)
   EAP-Response/
   EAP-Type=PEAP, V=2
   ([TLS certificate,]
    TLS client_key_exchange,
   [TLS certificate_verify,]
    TLS change_cipher_spec,
    TLS finished)
    (Fragment 1: L, M bits set)->
```

```
                            <- EAP-Request/
                           EAP-Type=PEAP, V=2
   EAP-Response/
   EAP-Type=PEAP, V=2
   (Fragment 2)->
                          <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (TLS change_cipher_spec,
                            TLS finished, EAP-TLV
                           [EAP-Payload-TLV[
                           EAP-Request/Identity]])
```



```
   TLS channel established
   (messages sent within the TLS channel)

   EAP-TLV
   [EAP-Payload-TLV
   [EAP-Response/Identity(myID)]] ->

                           <- EAP-TLV [ EAP-Payload-TLV
                          [EAP-Request/EAP-Type=X]]

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/EAP-Type=X or NAK]]->

                           <- EAP-TLV [ EAP-Payload-TLV
                          [EAP-Request/EAP-Type=X]]

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/EAP-Type=X] ->

                           <- EAP-TLV [Crypto-Binding-TLV
                           =(Version=0, Received-Version=2,
                           Nonce, B1_MAC),
                           Intermediate-Result-TLV(Success),
                           Result TLV (Success)]

   EAP-TLV [
   Crypto-Binding-TLV=(Version=0,
   Received-Version=2,Nonce, B2_MAC),
   Result TLV (Success),
```

```
   Intermediate-Result-TLV (Success)] ->

   TLS channel torn down
   (messages sent in cleartext)

                            <- EAP-Success
```

A.5 Server authentication fails in Part 2

In the case where the server authenticates to the client successfully in PEAPv2 Part 1, but the client fails to authenticate to the server in PEAPv2 Part 2, the conversation will appear as follows:

```
   Authenticating Peer     Authenticator
   -------------------     -------------
                           <- EAP-Request/
                           Identity
   EAP-Response/
   Identity (MyID) ->
```



```
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (PEAP Start, S bit set)
   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS client_hello)->
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (TLS server_hello,
                            TLS certificate,
                      [TLS server_key_exchange,]
                      [TLS certificate_request,]
                          TLS server_hello_done)
   EAP-Response/
   EAP-Type=PEAP, V=2
   ([TLS certificate,]
    TLS client_key_exchange,
   [TLS certificate_verify,]
    TLS change_cipher_spec,
    TLS finished) ->
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
```

```
                            (TLS change_cipher_spec,
                             TLS finished, EAP-TLV
                            [EAP-Payload-TLV
                            [EAP-Request/Identity]])


   TLS channel established
   (messages sent within the TLS channel)

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/Identity (MyID)]] ->

                             <- EAP-TLV [EAP-Payload-TLV
                            [EAP-Request/EAP-Type=X]]

   EAP-TLV [EAP-Payload
   [EAP-Response/EAP-Type=X
   or NAK]] ->
                            <- EAP-TLV [EAP-Payload
                            [EAP-Request/EAP-Type=X]]

   EAP-TLV [EAP-Payload
   [EAP-Response/
   EAP-Type=X]] ->
                             <- EAP-TLV [Crypto-Binding-TLV
                             (Version=0, Received-Version=2,
```



```
                            Nonce, B1_MAC),
                            Intermediate-Result-TLV (Failure),
                            Result TLV (Failure)]

   EAP-TLV [Crypto-Binding-TLV
   (Version=0, Received-version=2,
   Nonce, B2_MAC),
   Result TLV (Failure),
   Intermediate-Result-TLV (Failure)]

   (TLS session cache entry flushed)
   TLS channel torn down
   (messages sent in cleartext)

                            <- EAP-Failure
```

A.6 Server authentication fails in Part 1

In the case where server authentication is unsuccessful in PEAP Part 1, the conversation will appear as follows:

```
Authenticating Peer     Authenticator
-------------------     -------------
                        <- EAP-Request/
                        Identity
EAP-Response/
Identity (MyID) ->
                        <- EAP-Request/
                        EAP-Type=PEAP, V=2
                        (PEAP Start)
EAP-Response/
EAP-Type=PEAP, V=2
(TLS client_hello)->
                        <- EAP-Request/
                        EAP-Type=PEAP, V=2
                        (TLS server_hello,
                         TLS certificate,
                    [TLS server_key_exchange,]
                        TLS server_hello_done)
EAP-Response/
EAP-Type=PEAP, V=2
(TLS client_key_exchange,
[TLS certificate_verify,]
 TLS change_cipher_spec,
 TLS finished) ->
                        <- EAP-Request/
                        EAP-Type=PEAP, V=2
                        (TLS change_cipher_spec,
```



```
                         TLS finished, EAP-TLV
                        [EAP-Payload-TLV [
                        EAP-Request/Identity]])
EAP-Response/
EAP-Type=PEAP, V=2
(TLS Alert message) ->
                        <- EAP-Failure
                        (TLS session cache entry flushed)
```

A.7 Session resume success

In the case where a previously established session is being resumed, the EAP server supports TLS session cache flushing for unsuccessful PEAPv2 Part 2 authentications and both sides authenticate successfully, the conversation will appear as follows:

```
Authenticating Peer     Authenticator
-------------------     -------------
                        <- EAP-Request/
                        Identity
EAP-Response/
Identity (MyID) ->
                        <- EAP-Request/
                        EAP-Type=PEAP,V=2
                        (PEAP Start)
EAP-Response/
EAP-Type=PEAP, V=2
(TLS client_hello)->
                        <- EAP-Request/
                        EAP-Type=PEAP, V=2
                        (TLS server_hello,
                        TLS change_cipher_spec
                        TLS finished)
EAP-Response/
EAP-Type=PEAP, V=2
(TLS change_cipher_spec,
 TLS finished) ->
                        <- EAP-Request/
                           EAP-Type=EAP-TLV
                           Result TLV (Success)

// Compound MAC calculated using TLS keys since there were no inner
EAP methods.

EAP-Response/
EAP-Type=EAP-TLV
Crypto-Binding-TLV=(Version=0, Nonce, B2_MAC),
Result TLV (Success)->
```


TLS channel torn down

```
   (messages sent in cleartext)

                           <- EAP-Success
```

A.8 Session resume failure

In the case where a previously established session is being resumed, and the server authenticates to the client successfully but the client fails to authenticate to the server, the conversation will appear as follows:

```
   Authenticating Peer     Authenticator
   -------------------     -------------
                           <- EAP-Request/
                           Identity
   EAP-Response/
   Identity (MyID) ->
                           <- EAP-Request/
                           EAP-Request/
                           EAP-Type=PEAP, V=2
                           (PEAP Start)
   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS client_hello) ->
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (TLS server_hello,
                            TLS change_cipher_spec,
                            TLS finished)
   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS change_cipher_spec,
    TLS finished) ->
                           <- EAP-Request
                           EAP-Type=PEAP, V=2
                           (TLS Alert message)
   EAP-Response
   EAP-Type=PEAP, V=2 ->
                            <- EAP-Failure
                            (TLS session cache entry flushed)
```

A.9 Session resume failure

In the case where a previously established session is being resumed, and the server authentication is unsuccessful, the conversation will appear as follows:

```
   Authenticating Peer     Authenticator
   -------------------     -------------
                          <- EAP-Request/
                           Identity
   EAP-Response/
   Identity (MyID) ->
                           <- EAP-Request/
                           EAP-Request/
                           EAP-Type=PEAP, V=2
                           (PEAP Start)
   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS client_hello)->
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (TLS server_hello,
                            TLS change_cipher_spec,
                            TLS finished)
   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS change_cipher_spec,
   TLS finished)
                           <- EAP-Request/
                           EAP-Type=PEAP, V=2
   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS Alert message) ->

              (TLS session cache entry flushed)
                           <- EAP-Failure
```

A.10 PEAP version negotiation

In the case where the peer and authenticator have mismatched PEAP versions (e.g. the peer has a pre-standard implementation with version 0, and the authenticator has an implementation compliant with this specification), the conversation will occur as follows:

```
   Authenticating Peer     Authenticator
   -------------------     -------------
                          <- EAP-Request/
                           Identity
   EAP-Response/
   Identity (MyID) ->
                           <- EAP-Request/
                           EAP-Request/
```

```
                          EAP-Type=PEAP, V=2
                          (PEAP Start)
```



```
   EAP-Response/
   EAP-Type=PEAP, V=0
   (TLS client_hello)->
                          <- EAP-Request/
                          EAP-Type=PEAP, V=0
                          (TLS server_hello,
                           TLS change_cipher_spec,
                           TLS finished)

   //conversation continued using pre-standard PEAP version 0
```

A.11 Sequences of EAP methods

Where PEAPv2 is negotiated, with a sequence of EAP method X followed by method Y, the conversation will occur as follows:

```
   Authenticating Peer     Authenticator
   -------------------     -------------
                          <- EAP-Request/
                          Identity
   EAP-Response/
   Identity (MyID1) ->
                          <- EAP-Request/
                          EAP-Type=PEAP, V=2
                          (PEAP Start, S bit set)

   EAP-Response/
   EAP-Type=PEAP, V=2
   (TLS client_hello)->
                          <- EAP-Request/
                          EAP-Type=PEAP, V=2
                          (TLS server_hello,
                           TLS certificate,
                     [TLS server_key_exchange,]
                     [TLS certificate_request,]
                         TLS server_hello_done)
   EAP-Response/
   EAP-Type=PEAP, V=2
```

```
([TLS certificate,]
 TLS client_key_exchange,
[TLS certificate_verify,]
 TLS change_cipher_spec,
 TLS finished) ->
                          <- EAP-Request/
                           EAP-Type=PEAP, V=2
                           (TLS change_cipher_spec,
                            TLS finished, EAP-TLV
```



```
                           [EAP-Payload-TLV[
                           EAP-Request/Identity]])

   TLS channel established
   (messages sent within the TLS channel)

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/Identity]] ->

                          <- EAP-TLV [EAP-Payload-TLV
                          [EAP-Request/EAP-Type=X]]]

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/EAP-Type=X]] ->

                           <- EAP-TLV [ EAP-Payload-TLV
                          [EAP-Request/EAP-Type=X]]

   EAP-TLV [EAP-Payload-TLV
   [EAP-Response/EAP-Type=X]]->

                           <- EAP-TLV [EAP Payload TLV [EAP-Type=Y],
                           (Intermediate Result TLV (Success),
                           Crypto-Binding-TLV
                           (Version=0, Received-version=2,
                           Nonce, B1_MAC))]

   // Next EAP conversation started after successful completion of
   previous method X. The intermediate-status and crypto-binding TLVs
   are sent in next packet to minimize round-trips.  In this example,
   identity request is not sent before negotiating EAP-Type=Y.
```

```
   EAP-TLV [EAP-Payload-TLV [EAP-Type=Y],
   (Intermediate Result TLV (Success),
   Crypto-Binding-TLV (Version=0,
   Received-version=2, Nonce, B2_MAC))]->

   // Compound MAC calculated using Keys generated from
   EAP methods X and the TLS tunnel.

                           <- EAP-TLV [EAP Payload TLV [
                           EAP-Type=Y]]

   EAP-TLV[EAP Payload TLV
   [EAP-Type=Y]] ->
                            <- EAP-TLV [Result-TLV (Success),
                            Intermediate Result TLV (Success),
                            Crypto-Binding-TLV
```



```
                            (Version=0, Received-version=2,
                            Nonce, B1_MAC))]

   EAP-TLV [(Result-TLV (Success),
   Intermediate Result TLV (Success),
   Crypto-Binding-TLV (Version=0,
   Received-version=2, Nonce, B2_MAC))]->

   // Compound MAC calculated using Keys generated from EAP methods X
   and Y and the TLS tunnel.  // Compound Keys generated using Keys
   generated from EAP methods X and Y; and the TLS tunnel.

   TLS channel torn down (messages sent in cleartext)

                            <- EAP-Success
```

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The compound binding exchange to address man-in-the-middle attack is based on the draft "The Compound Authentication Binding

Problem"[CompoundBinding].

The vast majority of the work by Simon Josefsson and Hakan Andersson was done while they were employed at RSA Laboratories.

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