Internet Engineering Task Force
Internet-Draft
Intended status: Informational
Expires: 2 September 2023

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1 March 2023

Use Identity as Raw Public Key in EAP-TLS
draft-chen-emu-eap-tls-ibs-05

Abstract

This document specifies the use of identity as a raw public key in EAP-TLS, the procedure of EAP-TIBS is consistent with EAP-TLS's interactive process, identity-based signature is extended to support EAP-TLS's signature algorithms to avoid X.509 certificates, this authentication method can avoid the overhead of receiving and processing certificate chains.

Status of This Memo

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1. Introduction

The Extensible Authentication Protocol(EAP) defined in [RFC3748] can provide support for multiple authentication methods. Transport Layer Security(TLS) provides for mutual authentication, integrity-protected ciphersuite negotiation, and exchange between two endpoints. The EAP-TLS defined in [RFC5216] which combines EAP and TLS that apply EAP method to load TLS procedures.

Traditionally, TLS client and server public keys are obtained in PKIX containers in-band as part of the TLS handshake procedure and are validated using trust anchors based on a PKIX certification authority (CA). But there is another method, Using Raw Public Keys in Transport Layer Security (TLS) and Datagram Transport Layer Security (DTLS) are defined in [RFC7250], the document defines two TLS extensions client_certificate_type and server_certificate_type, which can be used as part of an extended TLS handshake when raw public keys are used. [RFC9190] reads certificates can be of any type supported by TLS including raw public keys. In [RFC7250] it assuming that an out-of-band mechanism is used to bind the public key to the entity presenting the key.

Digital signatures provide the functions of Sender reliability and Message integrity. A chain of trust for such signatures is usually provided by certificates, but in low-bandwidth and resource-constrained environments, the use of certificates might be undesirable. In comparison with the original certificate, the raw public key is fairly small. This document describes a signature algorithm using identity as a raw public key in EAP-TLS, instead of transmitting a full certificate in the EAP-TLS message, only public keys are exchanged between client and server, also known as EAP-TIBS.

With the existing raw public key scheme, a public key and identity mapping table is required at server. This table usually established with offline method and may require additional efforts for establishment and maintenance, especially when the number of devices are huge. On the other hand, with IBS signature algorithm, it not only can take the advantage of raw public key, but also eliminates the efforts for the mapping table establishment and maintenance at the server side. Instead, a small table for CRL is enough for exclude revoked identity from accessing the network. A number of IBE and IBS algorithms have been standardized, such as ECCSI defined in [RFC6507].

IBC was first proposed by Adi Shamir in 1984. For an IBC system, a Key Management System (KMS) is required to generate keys for devices. The KMS choose its KMS Secret Authentication Key(KSAK) as the root of trust. A public parameter, KMS Public Authentication Key (KPAK) is derived from this secrete key and is used by others in verifying the signature. The signatures are generated by an entity with private keys obtained from the KMS. KMS is a trusted third party, users or devices can obtain private key using their identities from KMS. In IBS the private key is also known as Secret Signing Key(SSK). A sender can sign a message using SSK. The receiver can verify the signature with sender’s identity and the KPAK.

This method has great advantages in internal management.

2. Terminology

The following terms are used:

* IBC: Identity-Based Cryptograph, it is an asymmetric public key cryptosystem.

* IBS: Identity-based Signature, such as ECCSI.

* PKI: Public Key Infrastructure, an infrastructure built with a public-key mechanism.

* Authenticator: The entity initiating EAP authentication.

* Peer: The entity that responds to the authenticator.

* Backend authenticator 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.

* 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.

3. EAP TIBS Use Cases

3.1. IoT use case

Used for authentication of Internet of Things devices: due to the limited processing power of IoT devices, resources for secure identity authentication are limited, especially passive, long life cycle devices, however, the traditional certificate authentication based on PKI X509, because of the complexity of certificate processing and certificate chain authentication, not very suitable for the Internet of Things scenario. Internet of Things devices really need a more lightweight authentication method, and EAP-TIBS as one of the candidates.

3.2. Non CA use case

Used for systems that do not support CA certificates: an internal system with network security boundaries that can self-operate the Key Management System(KMS) secret key distribution center, EAP-TIBS can be used between internal subsystems.

4. Structure of the Raw Public Key Extension

To support the negotiation of using raw public key between client and server, a new certificate structure is defined in [RFC7250]. It is used by the client and server in the hello messages to indicate the types of certificates supported by each side. When RawPublicKey type is selected for authentication, SubjectPublicKeyInfo which is a data structure is used to carry the raw public key and its cryptographic algorithm.

The SubjectPublicKeyInfo structure is defined in Section 4.1 of [RFC5280] and not only contains the raw keys, such as the public exponent and the modulus of an RSA public key, but also an algorithm identifier. The algorithm identifier can also include parameters. The structure of SubjectPublicKeyInfo is shown in Figure 1:

```
SubjectPublicKeyInfo  ::=  SEQUENCE  {
          algorithm               AlgorithmIdentifier,
          subjectPublicKey        BIT STRING  }

     AlgorithmIdentifier   ::=  SEQUENCE  {
          algorithm               OBJECT IDENTIFIER,
          parameters              ANY DEFINED BY algorithm OPTIONAL }
```

Figure 1: SubjectPublicKeyInfo ASN.1 Structure

The algorithms identifiers are Object Identifier(OIDs), AlgorithmIdentifier is also data structure with two fields, OID represent the cryptographic algorithm used with raw public key, such as ECCSI, parameters are the necessary parameters associated with the algorithm.

In the case of IBS algorithm, the User's identity is the raw public key which can be represented by "subjectPublicKey", when ECCSI is used as the Identity-based signature algorithm, then "algorithm" is for ECCSI, and "parameters" is the parameters needed in ECCSI.

So far, IBS has the following four algorithms, the following table is the corresponding table of Key type and OID.

Key Type	Document	OID
ISO/IEC 14888-3 IBS-1	ISO/IEC 14888-3: IBS-1 mechanism	1.0.14888.3.0.7
ISO/IEC 14888-3 IBS-2	ISO/IEC 14888-3: IBS-2 mechanism	1.0.14888.3.0.8
ISO/IEC 14888-3 ChineseIBS(SM9)	ISO/IEC 14888-3: ChineseIBS mechanism	1.2.156.10197.1.302.1
Elliptic Curve-Based Signatureless For Identitiy-based Encryption (ECCSI)	Section 5.2 in RFC 6507	1.3.6.1.5.5.7.6.29

Table 1: Algorithm Object Identifiers

In the draft draft-wang-tls-raw-public-key-with-ibc, there extend signature scheme with IBS algorithm which indicated in the client's "signature_algorithms" extension. The SignatureScheme data structure also keep pace with the section 4.

5. EAP-TIBS for TLS1.2

5.1. EAP-TIBS Handshake

This section describes EAP-TIBS in the case of TLS1.2, as described in [RFC7250], the document intrudoces the use of raw public keys in TLS/DTLS, the basic raw public key TLS exchange will appear as follows, Figure 2 shows the client_certificate_type and server_certificate_type extensions added to the client and server hello messages. An extension type MUST NOT appear in the ServerHello unless the same extension type appeared in the corresponding ClientHello, defined in [RFC5246].

The server_certificate_type extension in the client hello indicates the types of certificates the client is able to process when provided by the server in a subsequent certificate payload.

The client_certificate_type and server_certificate_type extensions sent in the client hello each carry a list of supported certificate types, sorted by client preference. When the client supports only one certificate type, it is a list containing a single element. Many types of certificates can be used, such as RawPublicKey, X.509 and OpenPGP.

This section describes EAP-TLS extend using raw public keys, the procedures is as follows, In the discussion, we will use the term "EAP server" to denote the ultimate endpoint conversing with the peer.

Figure 2: EAP-TIBS authentication procedure for TLS1.2

5.2. EAP-TIBS example

In this example, both the TLS client and server use ECCSI for authentication, and they are restricted in that they can only process ECCSI signature algorithm. As a result, the TLS client sets both the server_certificate_type and the client_certificate_type extensions to be raw public key; in addition, the client sets the signature algorithm in the client hello message to be eccsi_sha256.

```
Authenticating Peer                EAP server
   -------------------              -------------
                                     <- EAP-Request/
                                     Identity
   EAP-Response/
   Identity (MyID) ->
                                     <- EAP-Request/
                                     EAP-Type=EAP-TLS
                                     (TLS Start)
   EAP-Response/
   EAP-Type=EAP-TLS
   (TLS client_hello
   signature_algorithm = (eccsi_sha256)
    server_certificate_type = (RawPublicKey,...)
    client_certificate_type = (RawPublicKey,...))->

                                    <- EAP-Request/
                                    EAP-Type=EAP-TLS
                                    (TLS server_hello,
                                    {client_certificate_type = RawPublicKey}
                                    {server_certificate_type = RawPublicKey}
                                    {certificate = (1.3.6.1.5.5.7.6.29, hash
                                    value of ECCSIPublicParameters),
                                    serverID)}
                                    {certificate_request = (eccsi_sha256)}
                                    {server_hello_done}
                             )
   EAP-Response/
   EAP-Type=EAP-TLS
   ({certificate = ((1.3.6.1.5.5.7.6.29,
   hash value of ECCSIPublicParameters),
   ClientID)},
    {certificate_verify = (ECCSI-Sig-Value)},
    {finished}) ->
                                <- EAP-Request/
                                EAP-Type=EAP-TLS
                                (TLS finished)
   EAP-Response/
   EAP-Type=EAP-TLS ->
                                <- EAP-Success
```

Figure 3: EAP-TIBS example

6. EAP-TIBS for TLS1.3

6.1. EAP-TIBS Handshake

TLS1.3 defined in [RFC8446], as TLS 1.3 is not directly compatible with previous versions, all versions of TLS incorporate a versioning mechanism which allows clients and servers to interoperably negotiate a common version if one is supported by both peers. when make the discussion on EAP-TLS using raw public keys we also make a different with TLS1.2, this section is for EAP-TLS1.3 handshake using raw public keys and give example for EAP-TIBS.

This section describes EAP-TLS1.3 extend using raw public keys, the procedures is as follows, both client and server have the extension "key_share", the "key_share" extension contains the endpoint's cryptographic parameters. the "signature_algorithm" extension contains the signature algorithm and hash algorithms the client and server can support for the new signature algorithms specific to the IBS algorithms. When IBS is chosen as signature algorithm, the server need to indicated the required IBS signature algorithms int the signature_algorithm extension within the CertificateRequest.

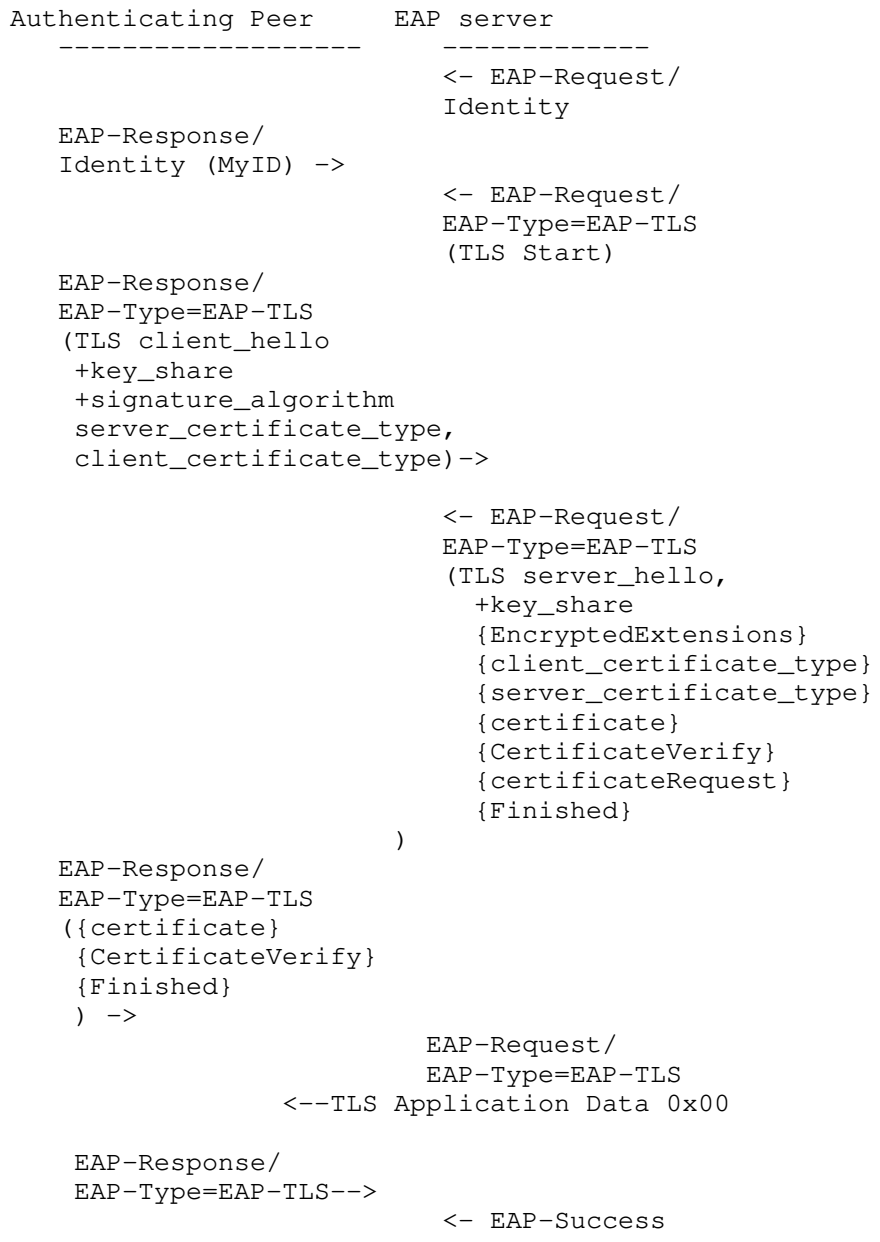

Figure 4: EAP-TIBS authentication procedure for TLS1.3

6.2. EAP-TIBS example

When the EAP server receives the client hello, it processes the message. Since it has an ECCSI raw public key from the KMS, it indicates that it agrees to use ECCSI and provides an ECCSI key by placing the SubjectPublicKeyInfo structure into the Certificate payload back to the client, including the OID, the identity of server, ServerID, which is the public key of server also, and hash value of KMS public parameters. The client_certificate_type indicates that the TLS server accepts raw public key. The TLS server demands client authentication, and therefore includes a certificate_request, which requires the client to use eccsi_sha256 for signature. A signature value based on the eccsi_sha256 algorithm is carried in the CertificateVerify. The client, which has an ECCSI key, returns its ECCSI public key in the Certificate payload to the server, which includes an OID for the ECCSI signature. The example of EAP-TLS1.3-IBS is as follows:

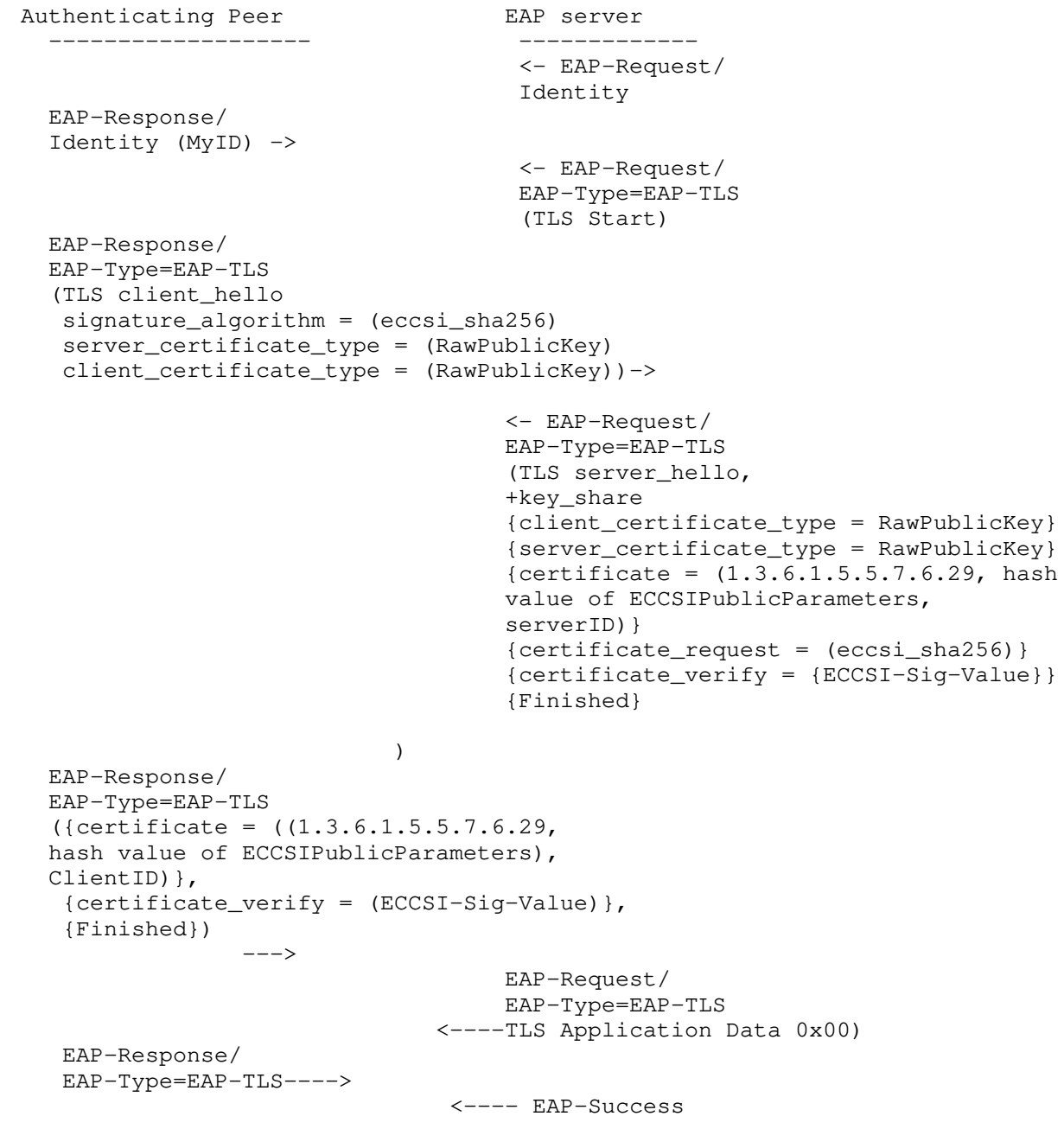

Figure 5: EAP-TLS1.3-IBS example

7. IANA Considerations

This document registers the following item in the "Method Types" registry under the "extensible Authentication Protocol(EAP) Registry" heading.

Value	Description
TBD	EAP-TIBS

8. Security Considerations

Although the identity authentication has been extended, the generation of session key still continues the EAP-TLS method.

9. Informative References

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Network Working Group
Internet-Draft
Intended status: Standards Track
Expires: 24 April 2025

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21 October 2024

Bootstrapped TLS Authentication with Proof of Knowledge (TLS-POK)
draft-ietf-emu-bootstrapped-tls-07

Abstract

This document defines a mechanism that enables a bootstrapping device to establish trust and mutually authenticate against a network. Bootstrapping devices have a public private key pair, and this mechanism enables a network server to prove to the device that it knows the public key, and the device to prove to the server that it knows the private key. The mechanism leverages existing DPP and TLS standards and can be used in an EAP exchange.

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1. Introduction

On-boarding of devices with no, or limited, user interface can be difficult. Typically, a credential is needed to access the network, and network connectivity is needed to obtain a credential. This poses a catch-22.

If a device has a public / private keypair, and trust in the integrity of a device's public key can be obtained in an out-of-band fashion, a device can be authenticated and provisioned with a usable credential for network access. While this authentication can be strong, the device's authentication of the network is somewhat weaker. [duckling] presents a functional security model to address this asymmetry.

Device on-boarding protocols such as the Device Provisioning Profile [DPP], also referred to as Wi-Fi Easy Connect, address this use case but they have drawbacks. [DPP] for instance does not support wired

network access, and does not specify how the device's DPP keypair can be used in a TLS handshake. This document describes an on-boarding protocol that can be used for wired network access, which we refer to as TLS Proof of Knowledge or TLS-POK.

This document does not address the problem of Wi-Fi network discovery, where a bootstrapping device detects multiple different Wi-Fi networks and needs a more robust and scalable mechanism than simple round-robin to determine the correct network to attach to. DPP addresses this issue. Thus, the intention is that DPP is the RECOMMENDED mechanism for bootstrapping against Wi-Fi networks, and TLS-POK is the RECOMMENDED mechanism for bootstrapping against wired networks.

1.1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The following terminology is used throughout this document.

* 802.1X: IEEE Port-Based Network Access Control
* BSK: Bootstrap Key which is an elliptic curve public private key pair from a cryptosystem suitable for doing ECDSA
* DPP: Device Provisioning Protocol [DPP]
* EAP: Extensible Authentication Protocol [RFC3748]
* EC: Elliptic Curve
* ECDSA: Elliptic Curve Digital Signature Algorithm
* EPSK: External Pre-Shared Key
* EST: Enrollment over Secure Transport [RFC7030]
* PSK: Pre-Shared Key
* TEAP: Tunnel Extensible Authentication Protocol [RFC7170]

1.2. Bootstrapping Overview

A bootstrapping device holds a public / private elliptic curve (EC) key pair which we refer to as a Bootstrap Key (BSK). The private key of the BSK is known only by the device. The public key of the BSK is known by the device, is known by the owner or holder of the device, and is provisioned on the network by the network operator. In order to establish trust and mutually authenticate, the network proves to the device that it knows the public part of the BSK, and the device proves to the network that it knows the private part of the BSK. Once this trust has been established during bootstrapping, the network can provision the device with a credential that it uses for subsequent network access. More details on the BSK are given in Section 2.

1.3. EAP Network Access

Enterprise deployments typically require an [IEEE802.1X]/EAP-based authentication to obtain network access. Protocols like Enrollment over Secure Transport (EST) [RFC7030] can be used to enroll devices into a Certification Authority to allow them to authenticate using 802.1X/EAP. This creates a Catch-22 where a certificate is needed for network access and network access is needed to obtain certificate.

Devices whose BSK public key can be obtained in an out-of-band fashion and provisioned on the network can perform a TLS-based EAP exchange, for instance Tunnel Extensible Authentication Protocol (TEAP) [RFC7170], and authenticate the TLS exchange using the bootstrapping mechanisms defined in Section 3. This network connectivity can then be used to perform an enrollment protocol (such as provided by [RFC7170]) to obtain a credential for subsequent network connectivity and certificate lifecycle maintenance.

1.4. Supported EAP Methods

This document defines a boostrapping mechanism that results in a certificate being provisioned on a device that can be used for subsequent network access. Therefore, an EAP method that supports provisioning of a certificate on a device is required. The only EAP method that currently supports provisioning of a certificate on a device is TEAP, therefore this document assumes that TEAP is the only suported EAP method. Section Section 4 describes how TLS-POK is used with TEAP, including defining a suitable NAI.

If future EAP methods are defined that support certificate provisioning, then TLS-POK could potentially be used with those methods. Defining how this would work is out of scope of this document.

2. Bootstrap Key

The mechanism for on-boarding of devices defined in this document relies on an elliptic curve (EC) bootstrap key (BSK). This BSK MUST be from a cryptosystem suitable for doing ECDSA. A bootstrapping client device has an associated EC BSK. The BSK may be static and baked into device firmware at manufacturing time, or may be dynamic and generated at on-boarding time by the device. The BSK public key MUST be encoded as the DER representation of an ASN.1 SEQUENCE SubjectPublicKeyInfo from [RFC5280]. Note that the BSK public key encoding MUST include the ASN.1 AlgorithmIdentifier in addition to the subjectPublicKey. If the BSK public key can be shared in a trustworthy manner with a TLS server, a form of "entity authentication" (the step from which all subsequent authentication proceeds) can be obtained.

The exact mechanism by which the server gains knowledge of the BSK public key is out of scope of this specification, but possible mechanisms include scanning a QR code to obtain a base64 encoding of the DER representation of the ASN.1 SubjectPublicKeyInfo or uploading of a Bill of Materials (BOM) which includes this information. More information on QR encoding is given in {alignment-with-wi-fi-alliance-device-provisioning-profile}. If the QR code is physically attached to the client device, or the BOM is associated with the device, the assumption is that the BSK public key obtained in this bootstrapping method belongs to the client. In this model, physical possession of the device implies legitimate ownership.

The server may have knowledge of multiple BSK public keys corresponding to multiple devices, and existing TLS mechanisms are leveraged that enable the server to identity a specific bootstrap public key corresponding to a specific device.

Using the process defined herein, the client proves to the server that it has possession of the private key of its BSK. Provided that the mechanism in which the server obtained the BSK public key is trustworthy, a commensurate amount of authenticity of the resulting connection can be obtained. The server also proves that it knows the client’s BSK public key which, if the client does not gratuitously expose its public key, can be used to obtain a modicum of correctness, that the client is connecting to the correct network (see [duckling]).

2.1. Alignment with Wi-Fi Alliance Device Provisioning Profile

The definition of the BSK public key aligns with that given in [DPP]. This, for example, enables the QR code format as defined in [DPP] to be reused for TLS-POK. Therefore, a device that supports both wired LAN and Wi-Fi LAN connections can have a single QR code printed on its label, or dynamically display a single QR code on a display, and the bootstrap key can be used for DPP if the device bootstraps against a Wi-Fi network, or TLS-POK if the device bootstraps against a wired network. Similarly, a common bootstrap public key format could be imported into a BOM into a server that handles devices connecting over both wired and Wi-Fi networks.

Any bootstrapping method defined for, or used by, [DPP] is compatible with TLS-POK.

3. Bootstrapping in TLS 1.3

Bootstrapping in TLS 1.3 leverages [RFC8773] Certificate-Based Authentication with an External Pre-Shared Key. The External PSK (EPSK) is derived from the BSK public key as described in Section 3.1, and the EPSK is imported using [RFC9258] Importing External Pre-Shared Keys (PSKs) for TLS 1.3. As the BSK public key is an ASN.1 SEQUENCE SubjectPublicKeyInfo from [RFC5280], and not a full PKI Certificate, the client must use [RFC7250] Using Raw Public Keys in TLS and DTLS in order to present the BSK as raw public key.

The TLS PSK handshake gives the client proof that the server knows the BSK public key. Certificate-based authentication of the client to the server using the BSK gives the server proof that the client knows the BSK private key. This satisfies the proof of ownership requirements outlined in Section 1.

3.1. External PSK Derivation

An [RFC9258] EPSK is made up of the tuple of (Base Key, External Identity, Hash). The Base Key is the DER-encoded ASN.1 subjectPublicKeyInfo representation of the BSK public key. The External Identity is derived from the BSK public key using [RFC5869] with the hash algorithm from the ciphersuite as follows:

```
epskid = HKDF-Expand(HKDF-Extract(<>, Base Key),
                        "tls13-bspsk-identity", L)
where:
  - epskid is the EPSK External Identity
  - Base Key is the DER-encoded ASN.1 subjectPublicKeyInfo
    representation of the BSK public key
  - L is the length of the digest of the underlying hash
    algorithm
  - <> is a NULL salt which is a string of L zeros
```

The [RFC9258] ImportedIdentity structure is defined as:

```
struct {
   opaque external_identity<1...2^16-1>;
   opaque context<0..2^16-1>;
   uint16 target_protocol;
   uint16 target_kdf;
} ImportedIdentity;
```

and is created using the following values:

```
external_identity = epskid
context = "tls13-bsk"
target_protocol = TLS1.3(0x0304)
target_kdf = HKDF_SHA256(0x0001)
```

The ImportedIdentity context value MUST be "tls13-bsk". This informs the server that the mechanisms specified in this document for deriving the EPSK and executing the TLS handshake MUST be used. The EPSK and ImportedIdentity are used in the TLS handshake as specified in [RFC9258].

A performance versus storage tradeoff a server can choose is to precompute the identity of every bootstrapped key with every hash algorithm that it uses in TLS and use that to quickly lookup the bootstrap key and generate the PSK. Servers that choose not to employ this optimization will have to do a runtime check with every bootstrap key it holds against the identity the client provides.

3.2. TLS 1.3 Handshake Details

The client includes the "tls_cert_with_extern_psk" extension in the ClientHello, per [RFC8773]. The client identifies the BSK public key by inserting the serialized content of ImportedIdentity into the PskIdentity.identity in the PSK extension, per [RFC9258]. The client MUST also include the [RFC7250] "client_certificate_type" extension in the ClientHello and MUST specify type of RawPublicKey.

Upon receipt of the ClientHello, the server looks up the client's EPSK key in its database using the mechanisms documented in [RFC9258]. If no match is found, the server MUST terminate the TLS handshake with an alert. If the server found the matching BSK public key, it includes the "tls_cert_with_extern_psk" extension in the ServerHello message, and the corresponding EPSK identity in the "pre_shared_key" extension. When these extensions have been successfully negotiated, the TLS 1.3 key schedule MUST include both the EPSK in the Early Secret derivation and an (EC)DHE shared secret value in the Handshake Secret derivation.

After successful negotiation of these extensions, the full TLS 1.3 handshake is performed with the additional caveat that the server MUST send a CertificateRequest message and client MUST authenticate with a raw public key (its BSK) per [RFC7250]. The BSK is always an elliptic curve key pair, therefore the type of the client's Certificate MUST be ECDSA and MUST contain the client's BSK public key as a DER-encoded ASN.1 subjectPublicKeyInfo SEQUENCE.

Note that the client MUST NOT share its BSK public key with the server until after the client has completed processing of the ServerHello and verified the TLS key schedule. The PSK proof has completed at this stage, and the server has proven to the client that is knows the BSK public key, and it is therefore safe for the client to send the BSK public key to the server in the Certificate message. If the PSK verification step fails when processing the ServerHello, the client terminates the TLS handshake and the BSK public key MUST NOT be shared with the server.

When the server processes the client's Certificate it MUST ensure that it is identical to the BSK public key that it used to generate the EPSK and ImportedIdentity for this handshake.

When clients use the [duckling] form of authentication, they MAY forgo the checking of the server's certificate in the CertificateVerify and rely on the integrity of the bootstrapping method employed to distribute its key in order to validate trust in the authenticated TLS connection.

The handshake is shown in Figure 1.

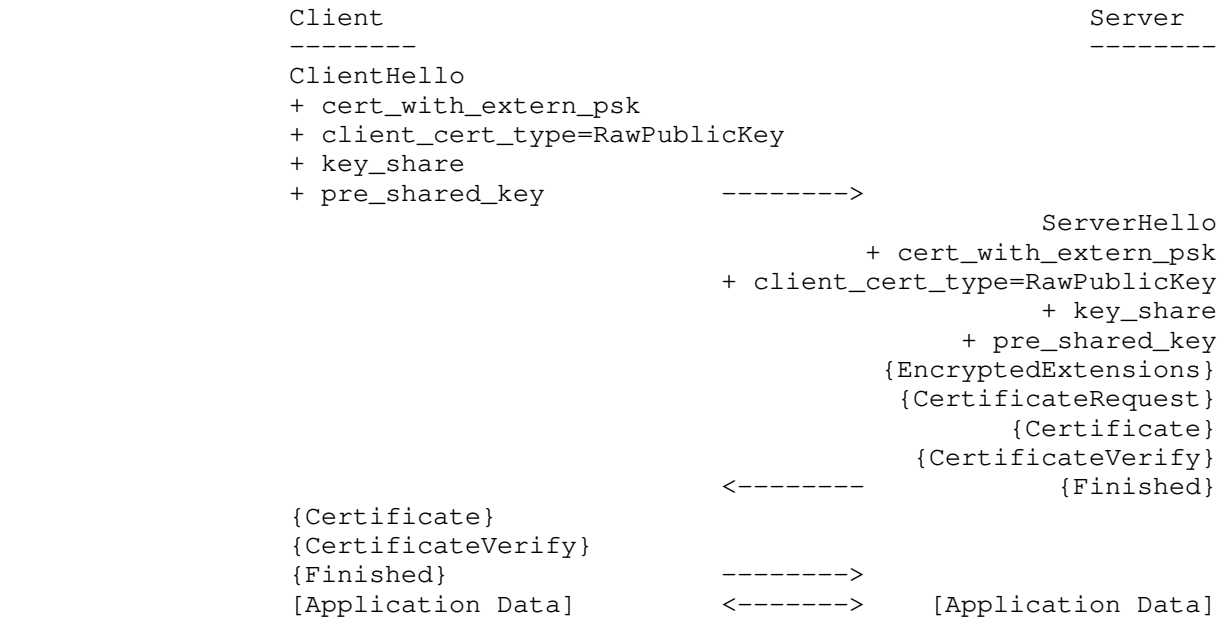
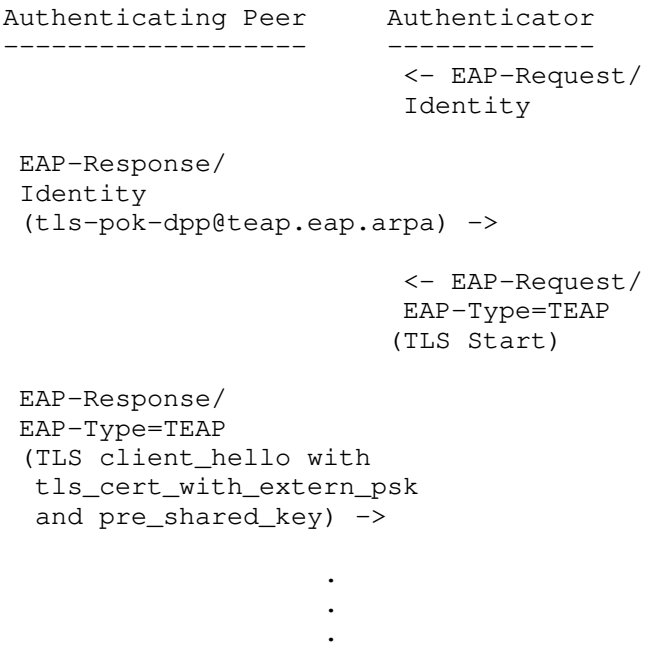


Figure 1: TLS 1.3 TLS-POK Handshake

4. Using TLS Bootstrapping in EAP

Upon "link up", an Authenticator on an 802.1X-protected port will issue an EAP Identity request to the newly connected peer. For unprovisioned devices that desire to take advantage of TLS-POK, there is no initial realm in which to construct an NAI (see [RFC7542]). This document uses the NAI mechanisms defined in [I-D.ietf-emu-eap-arpa] and defines the EAP username "tls-pok-dpp" for use with the TEAP realm "teap.eap.arpa". The username "tls-pok-dpp" MUST be included yielding an initial identity of "tls-pok-dpp@teap.eap.arpa". This identifier MUST be included in the EAP Identity response in order to indicate to the Authenticator that TEAP is the desired EAP method. [I-D.ietf-emu-eap-arpa] recommends how the device should behave if the Authenticator does not support TEAP or TLS-POK.



Both client and server have derived the EPSK and associated [RFC9258] ImportedIdentity from the BSK public key as described in Section 3.1. When the client starts the TLS exchange in the EAP transaction, it includes the ImportedIdentity structure in the pre_shared_key extension in the ClientHello. When the server received the ClientHello, it extracts the ImportedIdentity and looks up the EPSK and BSK public key. As previously mentioned in Section 2, the exact mechanism by which the server has gained knowledge of or been provisioned with the BSK public key is outside the scope of this document.

The server continues with the TLS handshake and uses the EPSK to prove that it knows the BSK public key. When the client replies with its Certificate, CertificateVerify and Finished messages, the server MUST ensure that the public key in the Certificate message matches the BSK public key.

Once the TLS handshake completes, the client and server have established mutual trust. The server can then proceed to provision a credential onto the client using, for example, the mechanisms outlined in [RFC7170].

The client can then use this provisioned credential for subsequent network authentication. The BSK is only used during bootstrap, and is not used for any subsequent network access.

5. IANA Considerations

None.

6. Security Considerations

Bootstrap and trust establishment by the TLS server is based on proof of knowledge of the client's bootstrap public key, a non-public datum. The TLS server obtains proof that the client knows its bootstrap public key and, in addition, also possesses its corresponding private key.

Trust on the part of the client is based on successful completion of the TLS 1.3 handshake using the EPSK derived from the BSK. This proves to the client that the server knows its BSK public key. In addition, the client assumes that knowledge of its BSK public key is not widely disseminated and therefore any server that proves knowledge of its BSK public key is the appropriate server from which to receive provisioning, for instance via [RFC7170]. [duckling] describes a security model for this type of "imprinting".

An attack on the bootstrapping method which substitutes the public key of a corrupted device for the public key of an honest device can result in the TLS sever on-boarding and trusting the corrupted device.

If an adversary has knowledge of the bootstrap public key, the adversary may be able to make the client bootstrap against the adversary's network. For example, if an adversary intercepts and scans QR labels on clients, and the adversary can force the client to connect to its server, then the adversary can complete the TLS-POK handshake with the client and the client will connect to the adversary's server. Since physical possession implies ownership, there is nothing to prevent a stolen device from being on-boarded.

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EMU working group
Internet-Draft
Obsoletes: 7170 (if approved)
Updates: 9427 (if approved)
Intended status: Standards Track
Expires: 11 July 2025

A. DeKok (Ed)

7 January 2025

Tunnel Extensible Authentication Protocol (TEAP) Version 1
draft-ietf-emu-rfc7170bis-20

Abstract

This document defines the Tunnel Extensible Authentication Protocol (TEAP) version 1. TEAP is a tunnel-based EAP method that enables secure communication between a peer and a server by using the Transport Layer Security (TLS) protocol to establish a mutually authenticated tunnel. Within the tunnel, TLV objects are used to convey authentication-related data between the EAP peer and the EAP server. This document obsoletes RFC 7170 and updates RFC 9427 by moving all TEAP specifications from those documents to this one.

About This Document

This note is to be removed before publishing as an RFC.

Status information for this document may be found at https://datatracker.ietf.org/doc/draft-ietf-emu-rfc7170bis/.

Discussion of this document takes place on the EMU Working Group mailing list (mailto:emu@ietf.org), which is archived at https://mailarchive.ietf.org/arch/browse/emu/. Subscribe at https://www.ietf.org/mailman/listinfo/emu/.

Source for this draft and an issue tracker can be found at https://github.com/emu-wg/rfc7170bis.git.

Status of This Memo

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Table of Contents

1. Introduction

A tunnel-based Extensible Authentication Protocol (EAP) method is an EAP method that establishes a secure tunnel and executes other EAP methods under the protection of that secure tunnel. A tunnel-based EAP method can be used in any lower-layer protocol that supports EAP authentication. There are several existing tunnel-based EAP methods that use Transport Layer Security (TLS) [RFC8446] to establish the secure tunnel. EAP methods supporting this include Protected EAP (PEAP) [PEAP], EAP Tunneled Transport Layer Security (EAP-TTLS) [RFC5281], and EAP Flexible Authentication via Secure Tunneling (EAP-FAST) [RFC4851]. However, they all are either vendor-specific or informational, and the industry calls for a Standards Track tunnel-based EAP method. [RFC6678] outlines the list of requirements for a standard tunnel-based EAP method.

This document describes the Tunnel Extensible Authentication Protocol (TEAP) version 1, which is based on EAP-FAST [RFC4851]. The changes from EAP-FAST to TEAP are largely minor, in order to meet the requirements outlined in [RFC6678] for a standard tunnel-based EAP method.

This specification describes TEAPv1, and defines cryptographic derivations for use with TLS 1.2. When TLS 1.3 is used, the definitions of cryptographic derivations in [RFC9427] MUST be used instead of the ones given here.

Note that while it is technically possible to use TEAPv1 with TLS 1.0 and TLS 1.1, those protocols have been deprecated in [RFC8996]. As such, the definitions given here are only applicable for TLS 1.2, and for TLS 1.3.

1.1. Specification Requirements

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

1.2. Terminology

Much of the terminology in this document comes from [RFC3748]. Additional terms are defined below:

Type-Length-Value (TLV)

: The TEAP protocol utilizes objects in TLV format. The TLV format is defined in Section 4.2.

Inner Method

: An authentication method which is sent as application data inside of a TLS exchange which is carried over TEAP. The inner method can be an EAP authentication method, a username / password authentication, or a vendor-specific authentication method. Where the TLS connection is authenticated, the inner method could also be a Public Key Cryptography Standard (PKCS) exchange.

2. Protocol Overview

TEAP authentication occurs in two phases after the initial EAP Identity request/response exchange. In the first phase, TEAP employs the TLS [RFC8446] handshake to provide an authenticated key exchange and to establish a protected tunnel. Once the tunnel is established, the second phase begins with the peer and server engaging in further conversations to establish the required authentication and authorization policies. TEAP makes use of TLV objects to carry out the inner authentication, results, and other information, such as channel-binding information.

As discussed in [RFC9190] Section 2.1.7 and [RFC9427] Section 3.1, the outer EAP Identity SHOULD be an anonymous Network Access Identifier (NAI) as described in [RFC7542], Section 2.4. While [RFC3748] Section 5.1 places no limits on the contents of the Identity field, [RFC7542] Section 2.6 states that Identities which do not follow the NAI format cannot be transported in an Authentication, Authorization, and Accounting (AAA) proxy network. As such, Identities in non-NAI form are likely to not work outside of limited and local networks.

Any inner identities (EAP or otherwise) SHOULD also follow the recommendations of [RFC9427], Section 3.1 about inner identities.

[RFC7170] defined a Protected Access Credential (PAC) to mirror EAP-FAST [RFC4851]. However, implementation experience and analysis determined that the PAC was not necessary. Instead, TEAP performs session resumption using the NewSessionTicket message as defined in [RFC9190] Section 2.1.2 and Section 2.1.3. As such, the PAC has been deprecated.

The TEAP conversation is used to establish or resume an existing session to typically establish network connectivity between a peer and the network. Upon successful execution of TEAP, the EAP peer and EAP server both derive strong session key material (Master Session Key [RFC3748]) that can then be communicated to the network access server (NAS) for use in establishing a link-layer security association.

2.1. Architectural Model

The network architectural model for TEAP usage is shown below:

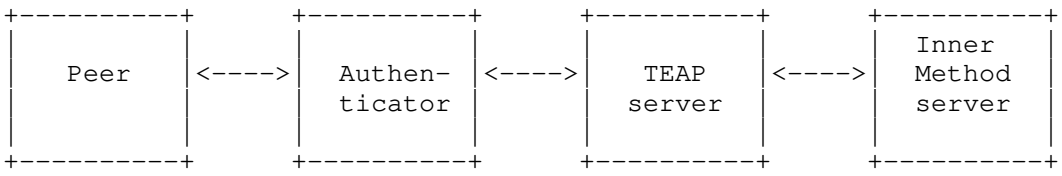


Figure 1: TEAP Architectural Model

The Peer and Authenticator are defined in Section 1.2 of [RFC3748]. The TEAP server is the "backend authentication server" defined in Section 1.2 of [RFC3748]. The "Inner Method server" is usually part of the TEAP server, and handles the application data (inner methods, EAP, passwords, etc.) inside of the TLS tunnel.

The entities depicted above are logical entities and may or may not correspond to separate network components. For example, the TEAP server and Inner Method server might be a single entity; the authenticator and TEAP server might be a single entity; or the functions of the authenticator, TEAP server, and Inner Method server might be combined into a single physical device. For example, typical IEEE 802.11 deployments place the authenticator in an access point (AP) while a RADIUS server may provide the TEAP and inner method server components. The above diagram illustrates the division of labor among entities in a general manner and shows how a distributed system might be constructed; however, actual systems might be realized more simply. The security considerations in Section 7.3 provide an additional discussion of the implications of separating the TEAP server from the Inner Method server.

2.2. Protocol-Layering Model

TEAP packets are encapsulated within EAP; EAP in turn requires a transport protocol. TEAP packets encapsulate TLS, which is then used to encapsulate user authentication information. Thus, TEAP messaging can be described using a layered model, where each layer encapsulates the layer above it. The following diagram clarifies the relationship between protocols:

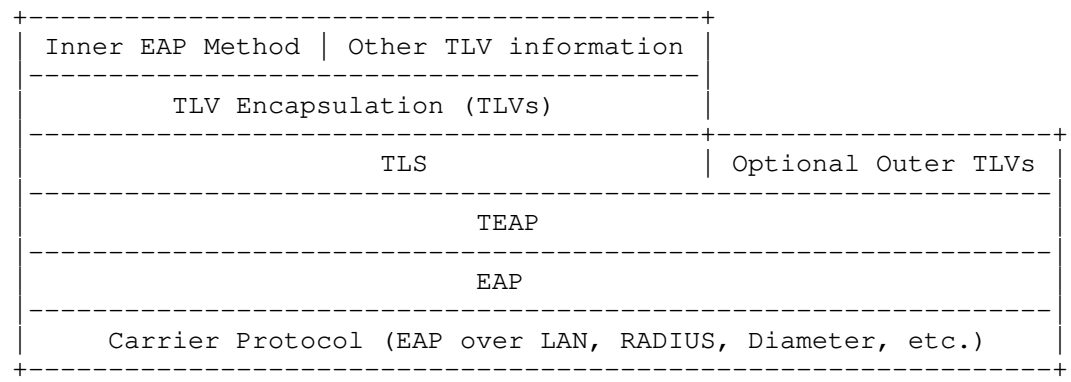


Figure 2: Protocol-Layering Model

The TLV layer is a payload with TLV objects as defined in Section 4.2. The TLV objects are used to carry arbitrary parameters between an EAP peer and an EAP server. All data exchanges in the TEAP protected tunnel are encapsulated in a TLV layer.

Methods for encapsulating EAP within carrier protocols are already defined. For example, IEEE 802.1X [IEEE.802-1X.2020] may be used to transport EAP between the peer and the authenticator; RADIUS [RFC3579] or Diameter [RFC4072] may be used to transport EAP between the authenticator and the EAP server.

2.3. Outer TLVs versus Inner TLVs

TEAP packets may include TLVs both inside and outside the TLS tunnel defined as follows:

Outer TLVs

> This term is used to refer to optional TLVs outside the TLS tunnel, which are only allowed in the first two messages in the TEAP protocol. That is the first EAP-server-to-peer message and first peer-to-EAP-server message. If the message is fragmented, the whole set of fragments is counted as one message.

Inner TLVs

> This term is used to refer to TLVs sent within the TLS tunnel. In TEAP Phase 1, Outer TLVs are used to help establish the TLS tunnel, but no Inner TLVs are used. In Phase 2 of TEAP, TLS records may encapsulate zero or more Inner TLVs, but no Outer TLVs are used.

3. TEAP Protocol

The operation of the protocol, including Phase 1 and Phase 2, is the topic of this section. The format of TEAP messages is given in Section 4, and the cryptographic calculations are given in Section 5.

3.1. Version Negotiation

TEAP packets contain a 3-bit Version field, following the TLS Flags field, which enables future TEAP implementations to be backward compatible with previous versions of the protocol. This specification documents the TEAP version 1 protocol; implementations of this specification MUST use a Version field set to 1.

Version negotiation proceeds as follows:

1. In the first EAP-Request sent with EAP type=TEAP, the EAP server MUST set the Version field to the highest version it supports.

2. If the EAP peer supports this version of the protocol, it responds with an EAP-Response of EAP type=TEAP, including the version number proposed by the TEAP server.

3. If the TEAP peer does not support the proposed version but supports a lower version, it responds with an EAP-Response of EAP type=TEAP and sets the Version field to its highest supported version.

4. If the TEAP peer only supports versions higher than the version proposed by the TEAP server, then use of TEAP will not be possible. In this case, the TEAP peer sends back an EAP-Nak either to negotiate a different EAP type or to indicate no other EAP types are available.

5. If the TEAP server does not support the version number proposed by the TEAP peer, it MUST either terminate the conversation with an EAP Failure or negotiate a new EAP type.

6. If the TEAP server does support the version proposed by the TEAP peer, then the conversation continues using the version proposed by the TEAP peer.

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

The TEAP version is not protected by TLS and hence can be modified in transit. In order to detect a bid-down attack on the TEAP version, the peers MUST exchange the TEAP version number received during version negotiation using the Crypto-Binding TLV described in Section 4.2.13. The receiver of the Crypto-Binding TLV MUST verify that the version received in the Crypto-Binding TLV matches the version sent by the receiver in the TEAP version negotiation.

Intermediate results are signaled via the Intermediate-Result TLV. However, the Crypto-Binding TLV MUST be validated before any Intermediate-Result TLV or Result TLV is examined. If the Crypto-Binding TLV fails to be validated for any reason, then it is a fatal error and is handled as described in Section 3.9.3.

The true success or failure of TEAP is conveyed by the Result TLV, with value Success or Failure. However, as EAP terminates with either a cleartext EAP Success or Failure, a peer will also receive a cleartext EAP Success or Failure. The received cleartext EAP Success or Failure MUST match that received in the Result TLV; the peer SHOULD silently discard those cleartext EAP Success or Failure messages which do not coincide with the status sent in the protected Result TLV.

3.2. TEAP Authentication Phase 1: Tunnel Establishment

TEAP relies on the TLS handshake [RFC8446] to establish an authenticated and protected tunnel. The TLS version offered by the peer and server MUST be TLS version 1.2 [RFC5246] or later. This version of the TEAP implementation MUST support the following TLS cipher suites:

* TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256

* TLS_ECDHE_ECDSA_WITH_AES_128_GCM_SHA256

Other cipher suites MAY be supported. Implementations MUST implement the recommended cipher suites in [RFC9325] Section 4.2 for TLS 1.2, and in [RFC9325] Section 4.3 for TLS 1.3.

It is REQUIRED that anonymous cipher suites such as TLS_DH_anon_WITH_AES_128_CBC_SHA [RFC5246] only be used in the case when the inner method provides mutual authentication, key generation, and resistance to on-path and dictionary attacks. TLS cipher suites that do not provide confidentiality MUST NOT be used. During the TEAP Phase 1, the TEAP endpoints MAY negotiate TLS compression. During TLS tunnel establishment, TLS extensions MAY be used. For instance, the Certificate Status Request extension [RFC6066] and the Multiple Certificate Status Request extension [RFC6961] can be used

to leverage a certificate-status protocol such as Online Certificate Status Protocol (OCSP) [RFC6960] to check the validity of server certificates. TLS renegotiation indications defined in RFC 5746 [RFC5746] MUST be supported.

Use of TLS-PSK is NOT RECOMMENDED. TEAP has not been designed to work with TLS-PSK, and no use-cases, security analyses, or implementations have been done. TLS-PSK may work (or not) with TEAP, depending on the status of a particular implementation, and it is therefore not useful to deploy it.

The EAP server initiates the TEAP conversation with an EAP request containing a TEAP/Start packet. This packet includes a set Start (S) bit, the TEAP version as specified in Section 3.1, and an authority identity TLV. The TLS payload in the initial packet is empty. The authority identity TLV (Authority-ID TLV) is used to provide the peer a hint of the server's identity that may be useful in helping the peer select the appropriate credential to use. Assuming that the peer supports TEAP, the conversation continues with the peer sending an EAP-Response packet with EAP type of TEAP with the Start (S) bit clear and the version as specified in Section 3.1. This message encapsulates one or more TLS handshake messages. If the TEAP version negotiation is successful, then the TEAP conversation continues until the EAP server and EAP peer are ready to enter Phase 2. When the full TLS handshake is performed, then the first payload of TEAP Phase 2 MAY be sent along with a server-finished handshake message to reduce the number of round trips.

TEAP implementations MUST support mutual peer authentication during tunnel establishment using the TLS cipher suites specified in this section. The TEAP peer does not need to authenticate as part of the TLS exchange but can alternatively be authenticated through additional exchanges carried out in Phase 2.

The TEAP tunnel protects peer identity information exchanged during Phase 2 from disclosure outside the tunnel. Implementations that wish to provide identity privacy for the peer identity need to carefully consider what information is disclosed outside the tunnel prior to Phase 2. TEAP implementations SHOULD support the immediate renegotiation of a TLS session to initiate a new handshake message exchange under the protection of the current cipher suite. This allows support for protection of the peer's identity when using TLS client authentication. An example of the exchanges using TLS renegotiation to protect privacy is shown in Appendix C.

3.3. Server Certificate Requirements

Server Certificates MUST include a subjectAltName extension, with the dnsName attribute containing an FQDN string. Server certificates MAY also include a SubjectDN containing a single element, "CN=" containing the FQDN of the server. However, this use of SubjectDN is deprecated for TEAP, and is forbidden in [RFC9525] Section 2.

The KeyUsage extension MAY be included, but are not required.

The ExtendedKeyUsage extensions defined in [RFC5280] MAY also be included, but their use is discouraged. Systems SHOULD use a private Certification Authority (CA) for EAP in preference to public CAs. The most commonly used public CAs are focused on the web, and those certificates are not always suitable for use with EAP. In contrast, private CAs can be designed for any purposes, and can be restricted to an enterprise or an other organization.

3.4. Server Certificate Validation

As part of the TLS negotiation, the server usually presents a certificate to the peer. In most cases the certificate needs to be validated, but there are a number of situations where the EAP peer need not do certificate validation:

* when the peer has the Server’s End Entity (EE) certificate pinned or loaded directly into it’s trusted anchor information [RFC4949];

* when the peer is requesting server unauthenticated provisioning;

* when the peer is certain that it will be using an authenticated inner method.

In some cases such as onboarding (or "bootstrapping"), the certificate validation may be delayed. However, once the onboarding has taken place, the validation steps described below MUST still be performed.

In all other cases, the EAP peer MUST validate the server certificate. This validation is done in the same manner as is done for EAP-TLS, which is discussed in [RFC9190] Section 5.3 and in [RFC5216] Section 5.3. Further guidance on server identity validation can be found in [RFC9525] Section 6..

Where the EAP peer has an NAI, EAP peers MUST use the realm to perform the DNS-ID validation as per [RFC9525] Section 6, The realm is used both to construct the list of reference identifiers as defined in [RFC9525] Section 6.2.1, and as the "source domain" field of that same section.

When performing server certificate validation, implementations MUST also support the rules in [RFC5280] for validating certificates against a known trust anchor. In addition, implementations MUST support matching the realm portion of the peer's NAI against a SubjectAltName of type dnsName within the server certificate. However, in certain deployments, this comparison might not be appropriate or enabled.

In most situations, the EAP peer will have no network access during the authentication process. It will therefore have no way of correlating the server identity given in the certificate presented by the EAP server with a hostname, as is done with other protocols such as HTTPS. Therefore, if the EAP peer has no preconfigured trust anchor, it will have few, if any ways of validating the servers certificate.

3.4.1. Client Certificates sent during Phase 1

Note that since TLS client certificates are sent in the clear with TLS 1.2, if identity protection is required, then it is possible for the TLS authentication to be renegotiated 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 TEAP Phase 2, the server MAY send a TLS hello_request. This allows the peer 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 TEAP Phase 2 instead. Assuming that the peer permits renegotiation by sending a client_hello, then the server will respond with server_hello, certificate, and certificate_request messages. The peer replies with certificate, client_key_exchange, and certificate_verify messages. Since this renegotiation occurs within the encrypted TLS channel, it does not reveal client certificate details. It is possible to perform certificate authentication using EAP (for example, EAP-TLS) within the TLS session in TEAP Phase 2 instead of using TLS handshake renegotiation.

When TLS 1.3 or later is used, it is RECOMMENDED that client certificates are sent in Phase 1, instead of via Phase 2 and EAP-TLS. Doing so will reduce the number of round trips. Further discussion of this issue is given below in Section 3.6.4

3.5. Resumption

For resumption, [RFC9190] Section 5.7 discusses EAP-TLS resumption for all versions of TLS, and is incorporated herein by reference. [RFC9427] Section 4 is also incorporated by reference, as it provides generic discussion of resumption for TLS-based EAP methods when TLS 1.3 is used.

This document only describes TEAP issues when resumption is used for TLS versions of 1.2 and earlier. It also describes resumption issues which are specific to TEAP for TLS 1.3.

If the server agrees to resume the session, Phase 2 is bypassed entirely. If the server does not agree to resume the session, then the server rejects the resumption as per [RFC9190] Section 5.7. It then continues with a full handshake. After the full TLS handshake has completed, both EAP server and peer MUST proceed with Phase 2.

All TEAP implementations MUST support resumption. Using resumption can significantly improve the scalability and stability of authentication systems. For example, some environments such as universities may have users re-authenticating multiple times a day, if not hourly. Failure to implement resumption would increase the load on the user database by orders of magnitude, leading to unnecessary cost.

The following sections describe how a TEAP session can be resumed based on server-side or client-side state.

3.5.1. TLS Session Resumption Using Server State

TEAP session resumption is achieved in the same manner TLS achieves session resumption. To support session resumption, the server and peer cache the Session ID, master secret, and cipher suite. The peer attempts to resume a session by including a valid Session ID from a previous TLS handshake in its ClientHello message. If the server finds a match for the Session ID and is willing to establish a new connection using the specified session state, the server will respond with the same Session ID and proceed with the TEAP Phase 1 tunnel establishment based on a TLS abbreviated handshake.

3.5.2. TLS Session Resumption Using Client State

TEAP supports the resumption of sessions based on state being stored on the client side using the TLS SessionTicket extension techniques described in [RFC5077] and [RFC9190].

3.6. TEAP Authentication Phase 2: Tunneled Authentication

The second portion of the TEAP authentication occurs immediately after successful completion of Phase 1. Phase 2 occurs even if both peer and authenticator are authenticated in the Phase 1 TLS negotiation. Phase 2 MUST NOT occur if the Phase 1 TLS handshake fails, as that will compromise the security as the tunnel has not been established successfully. Phase 2 consists of a series of requests and responses encapsulated in TLV objects defined in Section 4.2. Phase 2 MUST always end with a Crypto-Binding TLV exchange described in Section 4.2.13 and a protected termination exchange described in Section 3.6.5.

If the peer is not authenticated in Phase 1, the TEAP peer SHOULD send one or more Identity-Hint TLVs (Section 4.2.20 as soon as the TLS connection has been established. This information lets the TEAP server choose an authentication type which is appropriate for that identity. When the TEAP peer does not provide an Identity-Hint TLV, the TEAP server does not know which inner method is supported by the peer. It must necessarily choose an inner method, and propose it to the peer, which may reject that inner method. The result will be that the peer fails to authenticate, and fails to obtain network access.

The TLV exchange includes the execution of zero or more inner methods within the protected tunnel as described in Section 3.6.1 and Section 3.6.2. A server MAY proceed directly to the protected termination exchange, without performing any inner authentication if it does not wish to request further authentication from the peer. A server MAY request one or more authentications within the protected tunnel. After completion of each inner method, the server decides whether or not to begin another inner method, or to send a Result TLV.

Implementations MUST support at least two sequential inner methods, which allows both Machine and User authentication to be performed. Implementations SHOULD also limit the number of sequential inner authentications, as there is no reason to perform a large number of inner authentications in one TEAP conversation.

Implementations wishing to use their own proprietary authentication method, may substitute the EAP-Payload or Basic-Password-Auth-Req TLV for the Vendor-Specific TLV which carries another authentication method. Any vendor-specific authentication method MUST support calculation of the Crypto-Binding TLV, and MUST use Intermediate-Result TLV and Result TLV as is done with other authentication methods.

Implementations SHOULD support both EAP and basic password for inner methods. Implementations which support multiple types of inner method MUST support all of those methods in any order or combination. That is, it is explicitly permitted to "mix and match" inner methods.

However, the peer and server MUST NOT assume that either will skip inner methods or other TLV exchanges, as the other peer might have a different security policy. The peer may have roamed to a network that requires conformance with a different authentication policy, or the peer may request the server take additional action (e.g., channel binding) through the use of the Request-Action TLV as defined in Section 4.2.9.

The completion of each inner method is signaled by an Intermediate-Result TLV. Where the Intermediate-Result TLV indicates failure, an Error TLV SHOULD also be included, using the most descriptive error code possible. The Intermediate-Result TLV may be accompanied by another TLV indicating that the server wishes to perform a subsequent authentication. When the authentication sequence completes, the server MUST send a Result TLV indicating success or failure instead of a TLV which carries an inner method.

3.6.1. Inner EAP Authentication

EAP [RFC3748] prohibits use of multiple authentication methods within a single EAP conversation in order to limit vulnerabilities to on-path attacks. TEAP addresses on-path attacks through support for cryptographic protection of the inner EAP exchange and cryptographic binding of the inner EAP method(s) to the protected tunnel. Inner methods are executed serially in a sequence. This version of TEAP does not support initiating multiple inner methods simultaneously in parallel. The inner methods need not be distinct. For example, EAP-TLS ([RFC5216] and [RFC9190]) could be run twice as an inner method, first using machine credentials followed by a second instance using user credentials.

When EAP is used as an inner method, the EAP messages are carried within EAP-Payload TLVs defined in Section 4.2.10. Note that in this use-case, TEAP is simply a carrier for EAP, much as RADIUS is a carrier for EAP. The full EAP state machine is run as normal, and is carried over the EAP-Payload TLV. Each distinct EAP authentication MUST be managed as a separate EAP state machine.

A TEAP server therefore MUST begin an EAP authentication with an EAP-Request/Identity (carried in an EAP-Payload TLV). However, a TEAP server MUST NOT finish the EAP conversation with an EAP Success or EAP Failure packet, the Intermediate-Result TLV is used instead.

Upon completion of each EAP authentication in the tunnel, the server MUST send an Intermediate-Result TLV indicating the result of that authentication. When the result indicates, success it MUST be accompanied by a Crypto-Binding TLV. The peer MUST respond to the Intermediate-Result TLV indicating its own result and similarly on success MUST accompany the TLV with it's own Crypto-Binding TLV. The Crypto-Binding TLV is further discussed in Section 4.2.13 and Section 5.3. The Intermediate-Result TLVs can be included with other TLVs which indicate a subsequent authentication, or with the Result TLV used in the protected termination exchange.

If both peer and server indicate success, then the authentication is considered successful. If either indicates failure, then the authentication is considered failed. The result of failure of an EAP authentication does not always imply a failure of the overall authentication. If one inner method fails, the server may attempt to authenticate the peer with a different method (EAP or password).

If a particular inner method succeeds, the server MUST NOT attempt a subsequent inner method for the same Identity-Type. For example, if a user is authenticated via an inner method of EAP-TLS, there is no benefit to also requesting additional authentication via a different inner method.

3.6.2. Inner Password Authentication

The authentication server initiates password authentication by sending a Basic-Password-Auth-Req TLV defined in Section 4.2.14. If the peer wishes to participate in password authentication, then it responds with a Basic-Password-Auth-Resp TLV as defined in Section 4.2.15 that contains the username and password. If it does not wish to perform password authentication, then it responds with a NAK TLV indicating the rejection of the Basic-Password-Auth-Req TLV.

The basic password authentication defined here is similar in functionality to that used by EAP-TTLS ([RFC5281]) with inner password authentication. It shares a similar security and risk analysis.

Multiple round trips of password authentication requests and responses MAY be used to support some "housekeeping" functions such as a password or pin change before a user is considered to be authenticated. Multiple rounds MAY also be used to communicate a user's password, and separately a one-time password such as Time-Based One-Time Passwords (TOTP) [RFC6238].

Implementations MUST limit the number of rounds trips for password authentication. It is reasonable to use one or two round trips. Further round trips are likely to be problematic, and SHOULD be avoided.

The first Basic-Password-Auth-Req TLV received in a session MUST include a prompt, which the peer displays to the user. Subsequent authentication rounds SHOULD include a prompt, but it is not always necessary.

When the peer first receives a Basic-Password-Auth-Req TLV, it should allow the user to enter both a Username and a Password, which are then placed in the Basic-Password-Auth-Resp TLV. If the peer receives subsequent Basic-Password-Auth-Req TLVs in the same authentication session, it MUST NOT prompt for a Username, and instead allow the user to enter only a password. The peer MUST copy the Username used in the first Basic-Password-Auth-Resp TLV into all subsequent Basic-Password-Auth-Resp TLVs.

Servers MUST track the Username across multiple password rounds, and reject authentication if the identity changes from one Basic-Password-Auth-Resp TLV to the next. There is no reason for a user (or machine) to change identities in the middle of authentication.

Upon reception of a Basic-Password-Auth-Resp TLV in the tunnel, the server MUST send an Intermediate-Result TLV indicating the result. The peer MUST respond to the Intermediate-Result TLV indicating its result. If the result indicates success, the Intermediate-Result TLV MUST be accompanied by a Crypto-Binding TLV. The Crypto-Binding TLV is further discussed in Section 4.2.13 and Section 5.3.

The Intermediate-Result TLVs can be included with other TLVs which indicate a subsequent authentication, or with the Result TLV used in the protected termination exchange.

The use of EAP-FAST-GTC as defined in [RFC5421] is NOT RECOMMENDED with TEAPv1 because EAP-FAST-GTC is not compliant with EAP-GTC defined in [RFC3748]. Implementations should instead make use of the password authentication TLVs defined in this specification.

3.6.3. EAP-MSCHAPv2

If using EAP-MSCHAPv2 [KAMATH] as an inner EAP method, the EAP-FAST-MSCHAPv2 variant defined in Section 3.2.3 of [RFC5422] MUST be used, instead of the derivation defined in [MSCHAP].

The difference between EAP-MSCHAPv2 and EAP-FAST-MSCHAPv2 is that the first and the second 16 octets of EAP-MSCHAPv2 MSK are swapped when it is used as the Inner Method Session Keys (IMSK) for TEAP.

3.6.4. Limitations on inner methods

Implementations SHOULD limit the permitted inner EAP methods to a small set such as EAP-TLS and the EAP-FAST-MSCHAPv2 variant of EAP-MSCHAPv2. These EAP methods are the most commonly supported inner methods in TEAP, and are known to be interoperable among multiple implementations.

Other EAP methods such as EAP-pwd, EAP-SIM, EAP-AKA, or EAP-AKA' can be used within a TEAP tunnel. Any EAP method which derives both MSK and ESMK is likely to work as an inner method for TEAP, because EAP-TLS has that behavior, and it works. EAP methods which derive only MSK should work, as EAP-FAST-MSCHAPv2 has that behavior, and it works. Other EAP methods are untested, and may or may not work.

Tunneled EAP methods such as (PEAP) [PEAP], EAP-TTLS [RFC5281], and EAP-FAST [RFC4851] MUST NOT be used for inner EAP authentication. There is no reason to have multiple layers of TLS in order to protect a password exchange.

The EAP methods defined in [RFC3748] Section 5 such as MD5-Challenge, One-Time Password (OTP), and Generic Token Card (GTC) do not derive a Master Session Key (MSK) or an Extended Master Session Key (EMSK), and are vulnerable to on-path attacks. The construction of the OTP and GTC methods makes this attack less relevant, as the information being sent is generally a one-time token. However, EAP-OTP and EAP-GTC offer no benefit over the basic password authentication defined in Section 3.6.2, which also does not perform crypto-binding of the inner method to the TLS session. These EAP methods are therefore not useful as phase 2 methods within TEAP.

Other EAP methods are less widely used, and highly likely to not work as the inner EAP method for TEAP.

In order to protect from on-path attacks, TEAP implementations MUST NOT permit the use of inner EAP methods which fail to perform crypto-binding of the inner method to the TLS session.

Implementations MUST NOT permit resumption for the inner EAP methods such as EAP-TLS. If the user or machine needs to be authenticated, it should use a method which provides full authentication. If the user or machine needs to do resumption, it can perform a full authentication once, and then rely on the outer TLS session for resumption. This restriction applies also to all TLS-based EAP methods which can tunnel other EAP methods. As a result, this document updates [RFC9427].

In general, the reason to use a non-TLS-based EAP method inside of a TLS-based EAP method such as TEAP is for privacy. Many previous EAP methods may leak information about user identity, and those leaks are prevented by running the method inside of a protected TLS tunnel.

EAP-TLS is permitted in Phase 2 for two use-cases. The first is when TLS 1.2 is used, as the client certificate is not protected as with TLS 1.3. It is therefore RECOMMENDED that when TLS 1.3 is used for the outer TEAP exchange, the client certificate is sent in Phase 1, instead of doing EAP-TLS in Phase 2. This behavior will simplify the authentication exchange, and use fewer round trips than doing EAP-TLS inside of TEAP.

The second use-case for EAP-TLS in Phase 2 is where both the user and machine use client certificates for authentication. Since TLS permits only one client certificate to be presented, only one certificate can be used in Phase 1. The second certificate is then presented via EAP-TLS in Phase 2.

For basic password authentication, it is RECOMMENDED that this method be only used for the exchange of one-time passwords. The existence of password-based EAP methods such as EAP-pwd ([RFC5931] and [RFC8146]) makes most clear-text password exchanges unnecessary. The updates to EAP-pwd in [RFC8146] permit it to be used with databases which store passwords in "salted" form, which greatly increases security.

Where the inner method does not provide an MSK or EMSK, the Crypto-Binding TLV offers little protection, as it cannot tie the inner EMSK to the TLS session via the TLS-PRF. As a result, the TEAP session will be vulnerable to on-path active attacks. Implementations and deployments SHOULD adopt various mitigation strategies described in [RFC7029] Section 3.2.

3.6.5. Protected Termination and Acknowledged Result Indication

A successful TEAP Phase 2 conversation MUST always end in a successful Crypto-Binding TLV and Result TLV exchange. A TEAP server may initiate the Crypto-Binding TLV and Result TLV exchange without initiating any inner methods in TEAP Phase 2. After the final Result TLV exchange, the TLS tunnel is terminated, and a cleartext EAP Success or EAP Failure is sent by the server. Peers implementing TEAP MUST NOT accept a cleartext EAP Success or failure packet prior to the peer and server reaching synchronized protected result indication.

The Crypto-Binding TLV exchange is used to prove that both the peer and server participated in the tunnel establishment and sequence of authentications. It also provides verification of the TEAP type, version negotiated, and Outer TLVs exchanged before the TLS tunnel establishment. Except as noted below, the Crypto-Binding TLV MUST be exchanged and verified before the final Result TLV exchange, regardless of whether or not there is an inner method. The Crypto-Binding TLV and Intermediate-Result TLV MUST be included to perform cryptographic binding after each successful authentication in a sequence of one or more inner methods. The server may send the final Result TLV along with an Intermediate-Result TLV and a Crypto-Binding TLV to indicate its intention to end the conversation. If the peer requires nothing more from the server, it will respond with a Result TLV indicating success accompanied by a Crypto-Binding TLV and Intermediate-Result TLV if necessary. The server then tears down the tunnel and sends a cleartext EAP Success or EAP Failure.

If the peer receives a Result TLV indicating success from the server, but its authentication policies are not satisfied (for example, it requires a particular authentication mechanism to be run), it may request further action from the server using the Request-Action TLV. The Request-Action TLV is sent with a Status field indicating what EAP Success/Failure result the peer would expect if the requested action is not granted. The value of the Action field indicates what the peer would like to do next. The format and values for the Request-Action TLV are defined in Section 4.2.9.

Upon receiving the Request-Action TLV, the server may process the request or ignore it, based on its policy. If the server ignores the request, it proceeds with termination of the tunnel and sends the cleartext EAP Success or Failure message based on the Status field of the peer's Request-Action TLV. If the server honors and processes the request, it continues with the requested action. The conversation completes with a Result TLV exchange. The Result TLV may be included with the TLV that completes the requested action.

Error handling for Phase 2 is discussed in Section 3.9.3.

3.7. Determining Peer-Id and Server-Id

The Peer-Id and Server-Id [RFC5247] may be determined based on the types of credentials used during either the TEAP tunnel creation or authentication. In the case of multiple peer authentications, all authenticated peer identities and their corresponding identity types (Section 4.2.3) need to be exported. In the case of multiple server authentications, all authenticated server identities need to be exported.

When X.509 certificates are used for peer authentication, the Peer-Id is determined by the subject and subjectAltName fields in the peer certificate. As noted in [RFC5280]:

The subject field identifies the entity associated with the public key stored in the subject public key field. The subject name MAY be carried in the subject field and/or the subjectAltName extension. . . . If subject naming information is present only in the subjectAltName extension (e.g., a key bound only to an email address or URI), then the subject name MUST be an empty sequence and the subjectAltName extension MUST be critical.

Where it is non-empty, the subject field MUST contain an X.500 distinguished name (DN).

If an inner EAP authentication method is run, then the Peer-Id is obtained from that inner EAP authentication method.

When the server uses an X.509 certificate to establish the TLS tunnel, the Server-Id is determined in a similar fashion as stated above for the Peer-Id, e.g., the subject and subjectAltName fields in the server certificate define the Server-Id.

3.8. TEAP Session Identifier

For TLS 1.2 and earlier, the EAP session identifier [RFC5247] is constructed using the tls-unique from the Phase 1 outer tunnel at the beginning of Phase 2 as defined by Section 3.1 of [RFC5929]. The Session-Id is defined as follows:

Session-Id = teap_type | tls-unique

where | denotes concatenation, and teap_type is the EAP Type assigned to TEAP

tls-unique = tls-unique from the Phase 1 outer tunnel at the beginning of Phase 2 as defined by Section 3.1 of [RFC5929]

The Session-Id derivation for TLS 1.3 is given in [RFC9427] Section 2.1

3.9. Error Handling

TEAP uses the error-handling rules summarized below:

1. Errors in the outer EAP packet layer are handled as defined in Section 3.9.1.

2. Errors in the TLS layer are communicated via TLS alert messages in both phases of TEAP.

3. The Intermediate-Result TLVs carry success or failure indications of the individual inner methods in TEAP Phase 2. Errors within an EAP conversation in Phase 2 are expected to be handled by the individual EAP authentication methods.

4. Violations of the Inner TLV rules are handled using Result TLVs together with Error TLVs.

5. Tunnel-compromised errors (errors caused by a failed or missing Crypto-Binding) are handled using Result TLVs and Error TLVs.

3.9.1. Outer-Layer Errors

Errors on the TEAP outer-packet layer are handled in the following ways:

1. If Outer TLVs are invalid or contain unknown values, they will be ignored.

2. The entire TEAP packet will be ignored if other fields (version, length, flags, etc.) are inconsistent with this specification.

3.9.2. TLS Layer Errors

If the TEAP server detects an error at any point in the TLS handshake or the TLS layer, the server SHOULD send a TEAP request encapsulating a TLS record containing the appropriate TLS alert message rather than immediately terminating the TEAP exchange so as to allow the peer to inform the user of the cause of the failure. The TEAP peer MUST send a TEAP response to an alert message. The EAP-Response packet sent by the peer SHOULD contain a TEAP response with a zero-length message. The server MUST terminate the TEAP exchange with an EAP Failure

packet, no matter what the client says.

If the TEAP peer detects an error at any point in the TLS layer, the TEAP peer SHOULD send a TEAP response encapsulating a TLS record containing the appropriate TLS alert message, and which contains a zero-length message. The server then MUST terminate the conversation with an EAP failure, as discussed in the previous paragraph.

While TLS 1.3 ([RFC8446]) allows for the TLS conversation to be restarted, it is not clear when that would be useful (or used) for TEAP. Fatal TLS errors will cause the TLS conversation to fail. Non-fatal TLS errors can likely be ignored entirely. As a result, TEAP implementations MUST NOT permit TLS restarts.

3.9.3. Phase 2 Errors

There are a large number of situations where errors can occur during Phase 2 processing. This section describes both those errors, and the recommended processing of them.

When the server receives a Result TLV with a fatal Error TLV from the peer, it MUST terminate the TLS tunnel and reply with an EAP Failure.

When the peer receives a Result TLV with a fatal Error TLV from the server, it MUST respond with a Result TLV indicating failure. The server MUST discard any data it receives from the peer, and reply with an EAP Failure. The final message from the peer is required by the EAP state machine, and serves only to allow the server to reply to the peer with the EAP Failure.

The following items describe specific errors and processing in more detail.

Fatal Error processing a TLV

: Any time the peer or the server finds a fatal error outside of the TLS layer during Phase 2 TLV processing, it MUST send a Result TLV of failure and an Error TLV using the most descriptive error code possible.

Fatal Error during TLV Exchanges

: For errors involving the processing of the sequence of exchanges, such as a violation of TLV rules (e.g., multiple EAP-Payload TLVs), the error code is Unexpected TLVs Exchanged.

Fatal Error due to tunnel compromise

For errors involving a tunnel compromise such as when the Crypto-Binding TLV fails validation, the error code is Tunnel Compromise Error.

Non-Fatal Error due to inner method

If there is a non-fatal error while running the inner method, the receiving side SHOULD NOT silently drop the inner method exchange. Instead, it SHOULD reply with an Error TLV containing using the most descriptive error code possible.

If there is no error code which matches the particular issue, then the value Inner Method Error (1001) SHOULD be used. This response is a positive indication that there was an error processing the current inner method. The side receiving a non-fatal Error TLV MAY decide to start a new and different inner method instead or, send back a Result TLV to terminate the TEAP authentication session.

3.10. Fragmentation

Fragmentation of EAP packets is discussed in [RFC5216] Section 2.1.5. There is no special handling of fragments for TEAP.

3.11. Services Requested by the Peer

Several TEAP operations, including server unauthenticated provisioning, certificate provisioning, and channel binding, depend on the peer trusting the TEAP server. If the peer trusts the provided server certificate, then the server is authenticated.

Typically, this authentication process involves the peer validating the certificate to a trust anchor by verifying that the server presenting the certificate holds the private key, and confirming that the entity named by the certificate is the intended server. Server authentication also occurs when the procedures in Section 3.2 are used to resume a session where the peer and server were previously mutually authenticated. Alternatively, the server is deemed to be authenticated if an inner EAP method provides mutual authentication along with a Master Session Key (MSK) and/or Extended Master Session Key (EMSK). The inner method MUST also provide for cryptographic binding via the Compound Message Authentication Code (MAC), as discussed in Section 4.2.13. This issue is further described in Section 3.11.3.

TEAP peers MUST track whether or not server authentication has taken place. When the server cannot be authenticated, the peer MUST NOT request any services such as certificate provisioning ({#cert-provisioning}) from it.

Unless the peer requests server unauthenticated provisioning, it MUST authenticate the server, and fail the current authentication session fails if the server cannot be authenticated.

An additional complication arises when an inner method authenticates multiple parties such as authenticating both the peer machine and the peer user to the EAP server. Depending on how authentication is achieved, only some of these parties may have confidence in it. For example, if a strong shared secret is used to mutually authenticate the user and the EAP server, the machine may not have confidence that the EAP server is the authenticated party if the machine cannot trust the user not to disclose the shared secret to an attacker. In these cases, the parties who participate in the authentication need to be considered when evaluating whether the peer should request these services, or whether the server should provide them.

The server MUST also authenticate the peer before providing these services. The alternative is to send provisioning data to unauthenticated and potentially malicious peers, which can have negative impacts on security.

When a device is provisioned via TEAP, any subsequent authorization MUST be done on the authenticated credentials. That is, there may be no credentials (or anonymous credentials) passed in Phase 1, but there will be credentials passed or provisioned in Phase 2. If later authorizations are done on the Phase 1 identity, then a device could obtain the wrong authorization. If instead authorization is done on the authenticated credentials, then the device will obtain the correct kind of network access.

The correct authorization must also be applied to any resumption, as noted in [RFC9190] Section 5.7. However, as it is possible in TEAP for the credentials to change, the new credentials MUST be associated with the session ticket. If this association cannot be done, then the server MUST invalidate any session tickets for the current session. This invalidation will force a full re-authentication on any subsequent connection, at which point the correct authorization will be associated with any session ticket.

Note that the act of re-provisioning a device is essentially indistinguishable from any initial provisioning. The device authenticates, and obtains new credentials via the standard provisioning mechanisms. The only caveat is that the device SHOULD NOT discard the old credentials unless either they are known to have expired, or the new credentials have been verified to work.

3.11.1. Certificate Provisioning within the Tunnel

Provisioning of a peer's certificate is supported in TEAP by performing the Simple PKI Request/Response from [RFC5272] using PKCS#10 and PKCS#7 TLVs, respectively. A peer sends the Simple PKI Request using a PKCS#10 CertificateRequest [RFC2986] encoded into the body of a PKCS#10 TLV (see Section 4.2.17). The TEAP server issues a Simple PKI Response using a PKCS#7 [RFC2315] unsigned (i.e. degenerate) "Certificates Only" message encoded into the body of a PKCS#7 TLV (see Section 4.2.16), only after an inner method has run and provided an identity proof on the peer prior to a certificate is being issued.

In order to provide linking identity and proof-of-possession by including information specific to the current authenticated TLS session within the signed certification request, the peer generating the request SHOULD obtain the tls-unique value from the TLS subsystem as defined in "Channel Bindings for TLS" [RFC5929]. The TEAP peer operations between obtaining the tls-unique value through generation of the Certification Signing Request (CSR) that contains the current tls-unique value and the subsequent verification of this value by the TEAP server are the "phases of the application protocol during which application-layer authentication occurs" that are protected by the synchronization interoperability mechanism described in the interoperability note in "Channel Bindings for TLS" ([RFC5929], Section 3.1). When performing renegotiation, TLS "secure_renegotiation" [RFC5746] MUST be used.

The tls-unique value is base-64-encoded as specified in Section 4 of [RFC4648], and the resulting string is placed in the certification request challengePassword field ([RFC2985], Section 5.4.1). The challengePassword field is limited to 255 octets (Section 7.4.9 of [RFC5246] indicates that no existing cipher suite would result in an issue with this limitation). If tls-unique information is not embedded within the certification request, the challengePassword field MUST be empty to indicate that the peer did not include the optional channel-binding information (any value submitted is verified by the server as tls-unique information).

The server SHOULD verify the tls-unique information. This ensures that the signed certificate request is being presented by an authenticated TEAP peer which is in possession of the private key.

The Simple PKI Request/Response generation and processing rules of [RFC5272] SHALL apply to TEAP, with the exception of error conditions. In the event of an error, the TEAP server SHOULD respond with an Error TLV using the most descriptive error code possible; it MAY ignore the PKCS#10 request that generated the error.

3.11.2. Certificate Content and Uses

It is not enough to verify that the CSR provided by the peer to the authenticator is from an authenticated user. The CSR itself should also be examined by the authenticator or Certification Authority (CA) before any certificate is issued.

The format of a CSR is complex, and contains a substantial amount of information. That information could be incorrect, such as a user claiming a wrong physical address, email address, etc. It is RECOMMENDED that systems provisioning these certificates validate that the CSR both contains the expected data, and also that is does not contain unexpected data. For example, a CA could refuse to issue the certificate if the CSR contained unknown fields, or if a known field contained an unexpected or invalid value. The CA can modify or refuse a particular CSR to address these deficiencies for any reasons, including local site policy. We note that the "A" in "CA" means for "Authority", while the "R" in "CSR" means "Request". There is no requirement for a CA to sign any and all CSRs which are presented to it.

Once an EAP peer receives the signed certificate, the peer could potentially be (ab) used for in TLS contexts other than TEAP. For example, the certificate could be used with EAP-TLS, or even with HTTPS. It is NOT RECOMMENDED to use certificates provisioned via TEAP for any non-TEAP protocol. One method of enforcing this restriction is to have different CAs (or different intermediate CAs) which issue certificates for different uses. For example, TLS-based EAP methods could share one CA, and even use different intermediary CAs for different TLS-based EAP methods. HTTPS servers could use an entirely different CA. The different protocols could then be configured to validate client certificates only from their preferred CA, which would prevent peers from using certificates outside of the intended use-case.

Another method of limiting the uses of a certificate is to provision it with an appropriate value for the Extended Key Usage field [RFC7299]. For example, the id-kp-eapOverLAN [RFC4334] value could be used to indicate that this certificate is intended for use only with EAP.

It is difficult to give more detailed recommendations than the above. Each CA or organization may have its own local policy as to what is permitted or forbidden in a certificate. All we can do in this document is to highlight the issues, and make the reader aware that they have to be addressed.

3.11.3. Server Unauthenticated Provisioning Mode

In Server Unauthenticated Provisioning Mode, an unauthenticated tunnel is established in Phase 1, and the peer and server negotiate an inner method or methods in Phase 2. This inner method MUST support mutual authentication, provide key derivation, and be resistant to attacks such as on-path and dictionary attacks. In most cases, this inner method will be an EAP authentication method. Example inner methods which satisfy these criteria include EAP-pwd [RFC5931] and EAP-EKE [RFC6124], but not EAP-FAST-MSCHAPv2.

This provisioning mode enables the bootstrapping of peers when the peer lacks the ability to authenticate the server during Phase 1. This includes both cases in which the cipher suite negotiated does not provide authentication and in which the cipher suite negotiated provides the authentication but the peer is unable to validate the identity of the server for some reason.

Upon successful completion of the inner method in Phase 2, the peer and server exchange a Crypto-Binding TLV to bind the inner method with the outer tunnel and ensure that an on-path attack has not been attempted.

Support for the Server Unauthenticated Provisioning Mode is optional. The cipher suite TLS_DH_anon_WITH_AES_128_CBC_SHA is RECOMMENDED when using Server Unauthenticated Provisioning Mode, but other anonymous cipher suites MAY be supported as long as the TLS pre-master secret is generated from contribution from both peers.

When a strong inner method is not used with Server Unauthenticated Provisioning Mode, it is possible for an attacker to perform an on-path attack. In effect, Server Unauthenticated Provisioning Mode has similar security issues as just running the inner method in the open, without the protection of TLS. All of the information in the tunnel should be assumed to be visible to, and modifiable by, an attacker.

Implementations SHOULD exchange minimal data in Server Unauthenticated Provisioning Mode. Instead, they should use that mode to set up a secure / authenticated tunnel, and then use that tunnel to perform any needed data exchange.

It is RECOMMENDED that client implementations and deployments authenticate TEAP servers if at all possible. Authenticating the server means that a client can be provisioned securely with no chance of an attacker eaves-dropping on the connection.

Note that server Unauthenticated Provisioning can only use anonymous cipher suites in TLS 1.2 and earlier. These cipher suites have been deprecated in TLS 1.3 ([RFC8446] Section C.5). For TLS 1.3, the server MUST provide a certificate, and the peer performs server unauthenticated provisioning by not validating the certificate chain or any of its contents.

3.11.4. Channel Binding

[RFC6677] defines channel bindings for EAP which solve the "lying NAS" and the "lying provider" problems, using a process in which the EAP peer gives information about the characteristics of the service provided by the authenticator to the Authentication, Authorization, and Accounting (AAA) server protected within the EAP authentication method. This allows the server to verify the authenticator is providing information to the peer that is consistent with the information received from this authenticator as well as the information stored about this authenticator.

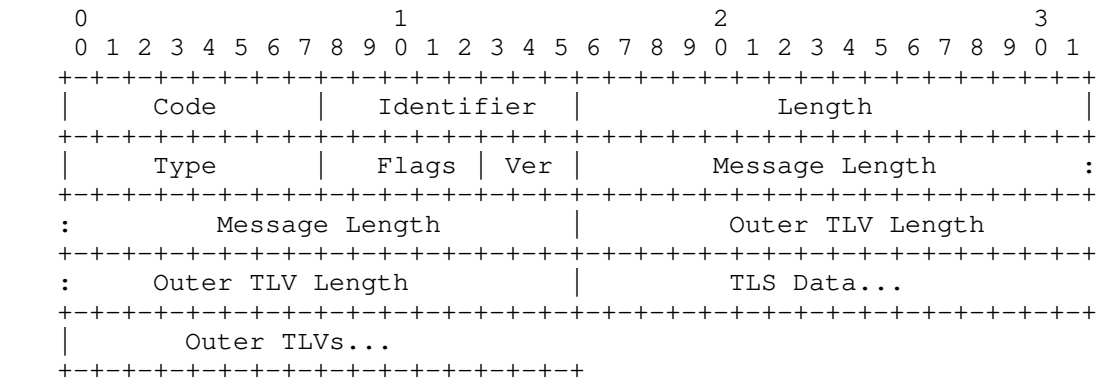
TEAP supports EAP channel binding using the Channel-Binding TLV defined in Section 4.2.7. If the TEAP server wants to request the channel-binding information from the peer, it sends an empty Channel-Binding TLV to indicate the request. The peer responds to the request by sending a Channel-Binding TLV containing a channel-binding message as defined in [RFC6677]. The server validates the channel-binding message and sends back a Channel-Binding TLV with a result code. If the server did not initiate the channel-binding request and the peer still wants to send the channel-binding information to the server, it can do that by using the Request-Action TLV along with the Channel-Binding TLV. The peer MUST only send channel-binding information after it has successfully authenticated the server and established the protected tunnel.

4. Message Formats

The following sections describe the message formats used in TEAP. The fields are transmitted from left to right in network byte order.

4.1. TEAP Message Format

A summary of the TEAP Request/Response packet format is shown below.



Code

The Code field is one octet in length and is defined as follows:

1 Request

2 Response

Identifier

The Identifier field is one octet and aids in matching responses with requests. The Identifier field MUST be changed on each Request packet. The Identifier field in the Response packet MUST match the Identifier field from the corresponding request.

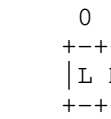
Length

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

Type

55 for TEAP

Flags



L Length included; set to indicate the presence of the four-octet Message Length field. It MUST be present for the first fragment of a fragmented message. It MUST NOT be present for any other message.

M More fragments; set on all but the last fragment.

S TEAP start; set in a TEAP Start message sent from the server to the peer.

O Outer TLV length included; set to indicate the presence of the four-octet Outer TLV Length field. It MUST be present only in the initial request and response messages. If the initial message is fragmented, then it MUST be present only on the first fragment.

R Reserved (MUST be zero and ignored upon receipt)

Ver

This field contains the version of the protocol. This document describes version 1 (001 in binary) of TEAP.

Message Length

The Message Length field is four octets and is present only if the L bit is set. This field provides the total length of the message that may be fragmented over the data fields of multiple packets.

Outer TLV Length

The Outer TLV Length field is four octets and is present only if the O bit is set. This field provides the total length of the Outer TLVs if present.

TLS Data

When the TLS Data field is present, it consists of an encapsulated TLS packet in TLS record format. A TEAP packet with Flags and Version fields, but with zero length TLS Data field, is used to indicate TEAP acknowledgment for either a fragmented message, a TLS Alert message, or a TLS Finished message.

Outer TLVs

The Outer TLVs consist of the optional data used to help establish the TLS tunnel in TLV format. They are only allowed in the first two messages in the TEAP protocol. That is the first EAP-server-to-peer message and first peer-to-EAP-server message. The start of the Outer TLVs can be derived from the EAP Length field and Outer TLV Length field.

4.2. TEAP TLV Format and Support

The TLVs defined here are TLV objects. The TLV objects could be used to carry arbitrary parameters between an EAP peer and EAP server within the protected TLS tunnel.

The EAP peer may not necessarily implement all the TLVs supported by the EAP server. To allow for interoperability, TLVs are designed to allow an EAP server to discover if a TLV is supported by the EAP peer using the NAK TLV. The mandatory bit in a TLV indicates whether support of the TLV is required. If the peer or server does not support a TLV marked mandatory, then it MUST send a NAK TLV in the response, and all the other TLVs in the message MUST be ignored. If an EAP peer or server finds an unsupported TLV that is marked as optional, it can ignore the unsupported TLV. It MUST only send a NAK TLV for a TLV which is marked mandatory but is not understood, and MUST NOT otherwise send a NAK TLV. If all TLVs in a message are marked optional and none are understood by the peer, then a Result TLV SHOULD be sent to the other side in order to continue the conversation. It is also possible to send a NAK TLV when all TLVs in a message are marked optional.

Note that a peer or server may support a TLV with the mandatory bit set but may not understand the contents. The appropriate response to a supported TLV with content that is not understood is defined by the individual TLV specification.

EAP implementations compliant with this specification MUST support TLV exchanges as well as the processing of mandatory/optional settings on the TLV. Implementations conforming to this specification MUST support the following TLVs:

* Authority-ID TLV
* Identity-Type TLV
* Result TLV
* NAK TLV

* Error TLV

* Request-Action TLV

* EAP-Payload TLV

* Intermediate-Result TLV

* Crypto-Binding TLV

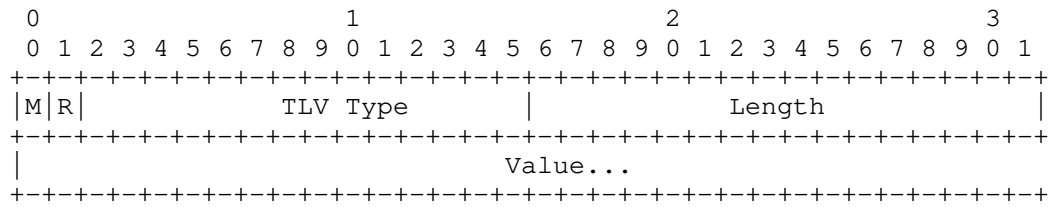
* Basic-Password-Auth-Req TLV

* Basic-Password-Auth-Resp TLV

4.2.1. General TLV Format

TLVs are defined as described below. The fields are transmitted from left to right.

If a peer or server receives a TLV which is not of the correct format, the TLV MUST be discarded. It is generally useful to log an error or debugging message which indicates which TLV had an issue, and what the problem is. However, TLVs which are malformed are invalid, and cannot be used.



M

0 Optional TLV

1 Mandatory TLV

R

Reserved, set to zero (0)

TLV Type

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

0 Unassigned

1 Authority-ID TLV (Section 4.2.2)

2 Identity-Type TLV (Section 4.2.3)

3 Result TLV (Section 4.2.4)

4 NAK TLV (Section 4.2.5)

5 Error TLV (Section 4.2.6)

6 Channel-Binding TLV (Section 4.2.7)

7 Vendor-Specific TLV (Section 4.2.8)

8 Request-Action TLV (Section 4.2.9)

9 EAP-Payload TLV (Section 4.2.10)

10 Intermediate-Result TLV (Section 4.2.11)

11 PAC TLV (DEPRECATED)

12 Crypto-Binding TLV (Section 4.2.13)

13 Basic-Password-Auth-Req TLV (Section 4.2.14)

14 Basic-Password-Auth-Resp TLV (Section 4.2.15)

15 PKCS#7 TLV (Section 4.2.16)

16 PKCS#10 TLV (Section 4.2.17)

17 Trusted-Server-Root TLV (Section 4.2.18)

18 CSR-Attributes TLV (Section 4.2.19)

19 Identity-Hint TLV (Section 4.2.20)

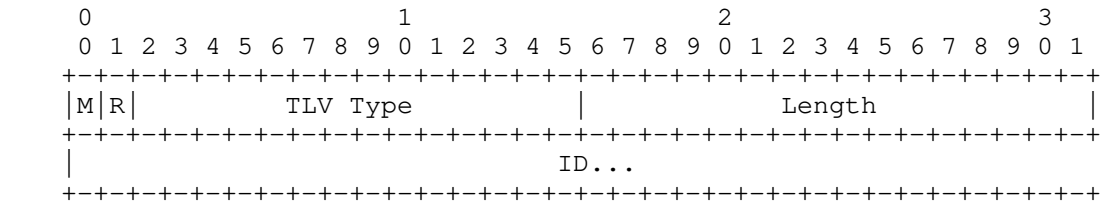
Length

The length of the Value field in octets.

Value

The value of the TLV.

4.2.2. Authority-ID TLV



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

1 - Authority-ID

Length

The Length field is two octets and contains the length of the ID field in octets.

ID

Hint of the identity of the server to help the peer to match the credentials available for the server. It should be unique across the deployment.

4.2.3. Identity-Type TLV

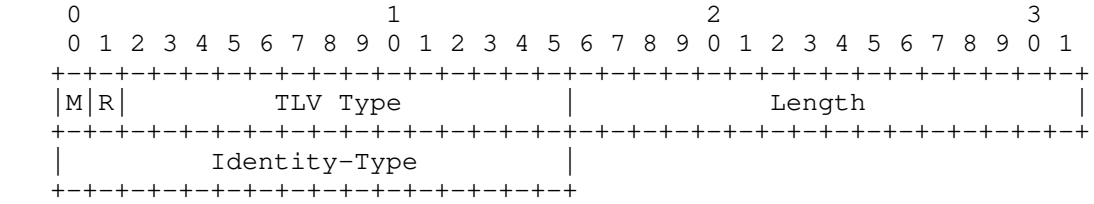
The Identity-Type TLV allows an EAP server to send a hint to help the EAP peer select the right type of identity, for example, user or machine. TEAPv1 implementations MUST support this TLV. Only one Identity-Type TLV SHOULD be present in the TEAP request or response packet.

For a server sending the Identity-Type TLV, the request MUST also include an EAP-Payload TLV or a Basic-Password-Auth-Resp TLV. For a peer sending an Identity-Type TLV, the response MUST also include EAP-Payload TLV or a Basic-Password-Auth-Resp TLV.

If the EAP peer has an identity corresponding to the identity type requested, then the peer SHOULD respond with an Identity-Type TLV with the requested type. If the Identity-Type field does not contain one of the known values or if the EAP peer does not have an identity

corresponding to the identity type requested, then the peer SHOULD respond with an Identity-Type TLV with the one of available identity types. If the server receives an identity type in the response that does not match the requested type, then the peer does not possess the requested credential type, and the server SHOULD proceed with authentication for the credential type proposed by the peer, proceed with requesting another credential type, or simply apply the network policy based on the configured policy, e.g., sending Result TLV with Failure.

The Identity-Type TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

2 - Identity-Type TLV

Length

2

Identity-Type

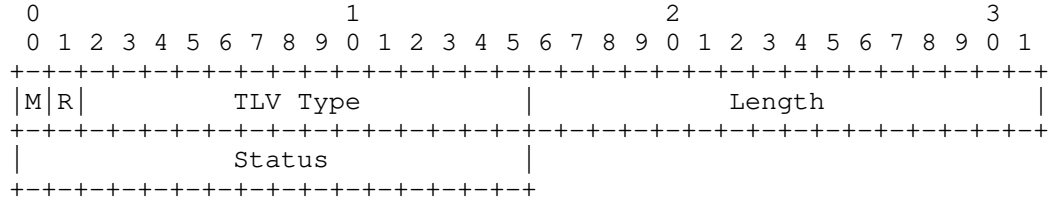
The Identity-Type field is two octets. Values include:

1 User

2 Machine

4.2.4. Result TLV

The Result TLV provides support for acknowledged success and failure messages for protected termination within TEAP. If the Status field does not contain one of the known values, then the peer or EAP server MUST treat this as a fatal error of Unexpected TLVs Exchanged. The behavior of the Result TLV is further discussed in Section 3.6.5 and Section 3.9.3. A Result TLV indicating failure MUST NOT be accompanied by the following TLVs: NAK, EAP-Payload TLV, or Crypto-Binding TLV. The Result TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

3 - Result TLV

Length

2

Status

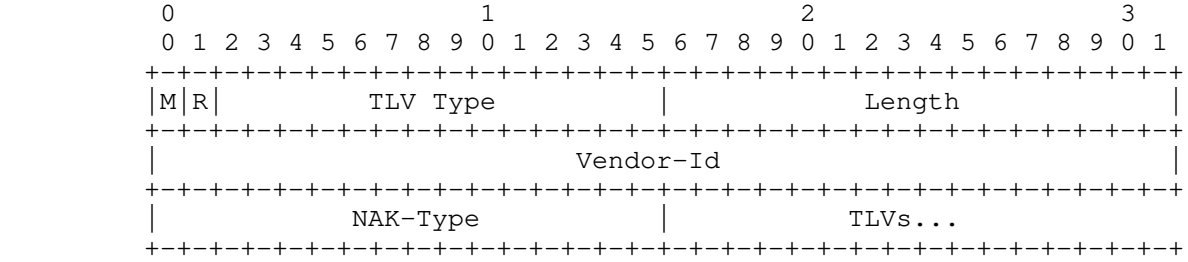
The Status field is two octets. Values include:

1 Success

2 Failure

4.2.5. NAK TLV

The NAK TLV allows a peer to detect TLVs that are not supported by the other peer. A TEAP packet can contain 0 or more NAK TLVs. A NAK TLV should not be accompanied by other TLVs. A NAK TLV MUST NOT be sent in response to a message containing a Result TLV, instead a Result TLV of failure should be sent indicating failure and an Error TLV of Unexpected TLVs Exchanged. The NAK TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

4 - NAK TLV

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 three octets are the Structure of Management Information (SMI) Network Management Private Enterprise Number of the Vendor in network byte order. The Vendor-Id field MUST be zero for TLVs that are not Vendor-Specific TLVs.

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

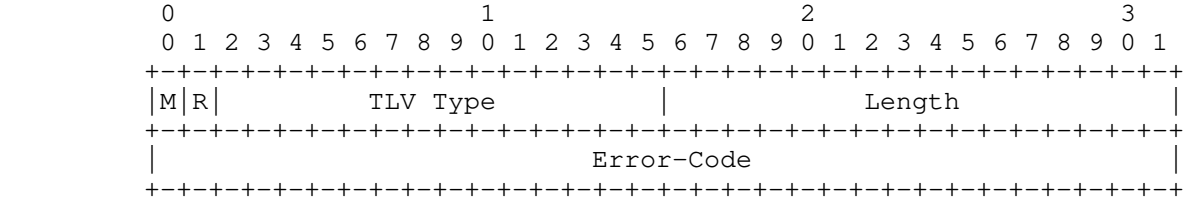
This field contains a list of zero or more TLVs, each of which MUST NOT have the mandatory bit set. These optional TLVs are for future extensibility to communicate why the offending TLV was determined to be unsupported.

4.2.6. Error TLV

The Error TLV allows an EAP peer or server to indicate errors to the other party. A TEAP packet can contain 0 or more Error TLVs. The Error-Code field describes the type of error. Error codes 1-999 represent successful outcomes (informative messages), 1000-1999 represent warnings, and 2000-2999 represent fatal errors. A fatal Error TLV MUST be accompanied by a Result TLV indicating failure, and the conversation is terminated as described in Section 3.9.3.

Many of the error codes below refer to errors in inner method processing that may be retrieved if made available by the inner method. Implementations MUST take care that error messages do not reveal too much information to an attacker. For example, the usage of error message 1031 (User account credentials incorrect) is NOT RECOMMENDED, because it allows an attacker to determine valid usernames by differentiating this response from other responses. It should only be used for troubleshooting purposes.

The Error TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

5 - Error TLV

Length

4

Error-Code

The Error-Code field is four octets. Currently defined values for Error-Code include:

1 User account expires soon

2 User account credential expires soon

3 User account authorizations change soon

4 Clock skew detected

5 Contact administrator

6 User account credentials change required

1001 Inner Method Error

1002 Unspecified authentication infrastructure problem

1003 Unspecified authentication failure

1004 Unspecified authorization failure

1005 User account credentials unavailable

1006 User account expired

1007 User account locked: try again later

1008 User account locked: admin intervention required

1009 Authentication infrastructure unavailable

1010 Authentication infrastructure not trusted

1011 Clock skew too great

1012 Invalid inner realm

1013 Token out of sync: administrator intervention required

1014 Token out of sync: PIN change required

1015 Token revoked

1016 Tokens exhausted

1017 Challenge expired

1018 Challenge algorithm mismatch

1019 Client certificate not supplied

1020 Client certificate rejected

1021 Realm mismatch between inner and outer identity

1022 Unsupported Algorithm In Certificate Signing Request

1023 Unsupported Extension In Certificate Signing Request

1024 Bad Identity In Certificate Signing Request

1025 Bad Certificate Signing Request

1026 Internal CA Error

1027 General PKI Error

1028 Inner method's channel-binding data required but not supplied

1029 Inner method's channel-binding data did not include required information

1030 Inner method's channel binding failed

1031 User account credentials incorrect [USAGE NOT RECOMMENDED]

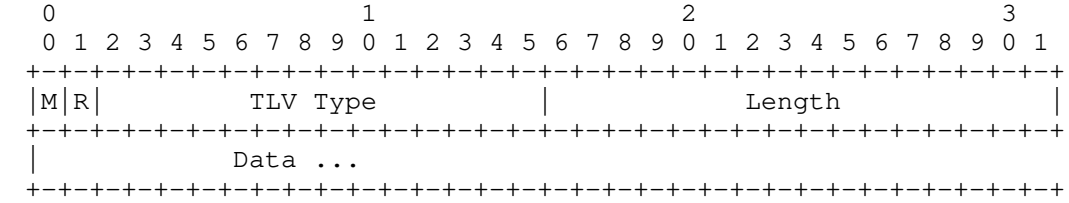
1032 Inner method not supported

2001 Tunnel Compromise Error

2002 Unexpected TLVs Exchanged

4.2.7. Channel-Binding TLV

The Channel-Binding TLV provides a mechanism for carrying channel-binding data from the peer to the EAP server and a channel-binding response from the EAP server to the peer as described in [RFC6677]. TEAPv1 implementations MAY support this TLV, which cannot be responded to with a NAK TLV. If the Channel-Binding data field does not contain one of the known values or if the EAP server does not support this TLV, then the server MUST ignore the value. The Channel-Binding TLV is defined as follows:



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

6 - Channel-Binding TLV

Length

variable

Data

The data field contains a channel-binding message as defined in Section 5.3 of [RFC6677].

4.2.8. Vendor-Specific TLV

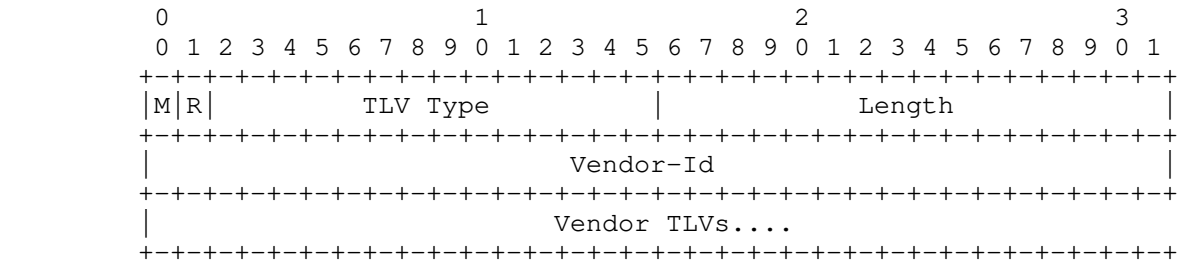
The Vendor-Specific TLV is available to allow vendors to support their own extended attributes not suitable for general usage. A Vendor-Specific TLV attribute can contain one or more TLVs, referred to as Vendor TLVs. The TLV type of a particular Vendor TLV is defined by the vendor. All the Vendor TLVs inside a single Vendor-Specific TLV belong to the same vendor. There can be multiple

Vendor-Specific TLVs from different vendors in the same message. Error handling in the Vendor TLV could use the vendor's own specific error-handling mechanism or use the standard TEAP error codes defined.

Vendor TLVs may be optional or mandatory. Vendor TLVs sent with Result TLVs MUST be marked as optional. If the Vendor-Specific TLV is marked as mandatory, then it is expected that the receiving side needs to recognize the vendor ID, parse all Vendor TLVs within, and deal with error handling within the Vendor-Specific TLV as defined by the vendor.

Where a Vendor-Specific TLV carries an authentication protocol in the inner method, it MUST define values for MSK and EMSK. Where these values cannot be derived from cryptographic primitives, they MUST be set to zero, as happens when Basic-Password-Auth-Req is used.

The Vendor-Specific TLV is defined as follows:



M

0 or 1

R

Reserved, set to zero (0)

TLV Type

7 - Vendor-Specific TLV

Length

4 + cumulative length of all included Vendor TLVs

Vendor-Id

The Vendor-Id field is four octets and contains the Vendor-Id of the TLV. The high-order octet is 0, and the low-order 3 octets are the SMI Network Management Private Enterprise Number of the Vendor in network byte order.

Vendor TLVs

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

4.2.9. Request-Action TLV

The Request-Action TLV MAY be sent at any time. The Request-Action TLV allows the peer or server to request that other side negotiates additional inner methods or process TLVs which are passed inside of the Request-Action TLV.

The receiving side MUST process this TLV. The processing for the TLV is as follows:

The receiving entity MAY choose to process any of the TLVs that are included in the message.

If the receiving entity chooses NOT to process any TLV in the list, then it sends back a Result TLV with the same code in the Status field of the Request-Action TLV.

If multiple Request-Action TLVs are in the request, the session can continue if any of the TLVs in any Request-Action TLV are processed.

If multiple Request-Action TLVs are in the request and none of them is processed, then the most fatal status should be used in the Result TLV returned. If a status code in the Request-Action TLV is not understood by the receiving entity, then it SHOULD be treated as a fatal error. Otherwise, the receiving entity MAY send a Request-Action TLV containing an Error TLV of value 2002 (Unexpected TLVs Exchanged).

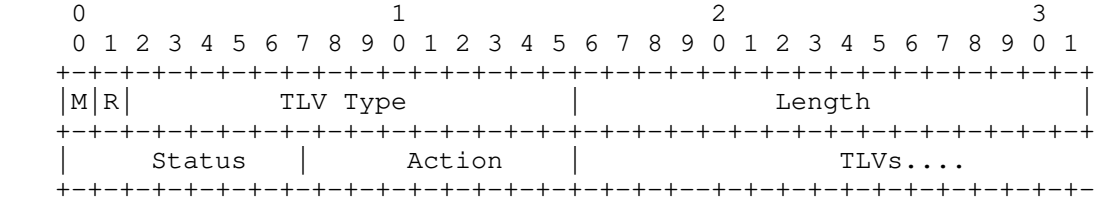
After processing the TLVs or inner method in the request, another round of Result TLV exchange MUST occur to synchronize the final status on both sides.

The peer or the server MAY send multiple Request-Action TLVs to the other side. Two Request-Action TLVs MUST NOT occur in the same TEAP packet if they have the same Status value. The order of processing multiple Request-Action TLVs is implementation dependent. If the receiving side processes the optional (non-fatal) items first, it is

possible that the fatal items will disappear at a later time. If the receiving side processes the fatal items first, the communication time will be shorter.

The peer or the server MAY return a new set of Request-Action TLVs after one or more of the requested items have been processed and the other side has signaled it wants to end the EAP conversation.

The Request-Action TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

8 - Request-Action TLV

Length

2 + cumulative length of all included TLVs

Status

The Status field is one octet. This indicates the result if the party who receives this TLV does not process the action. Values include:

1 Success

2 Failure

Action

The Action field is one octet. Values include:

1 Process-TLV

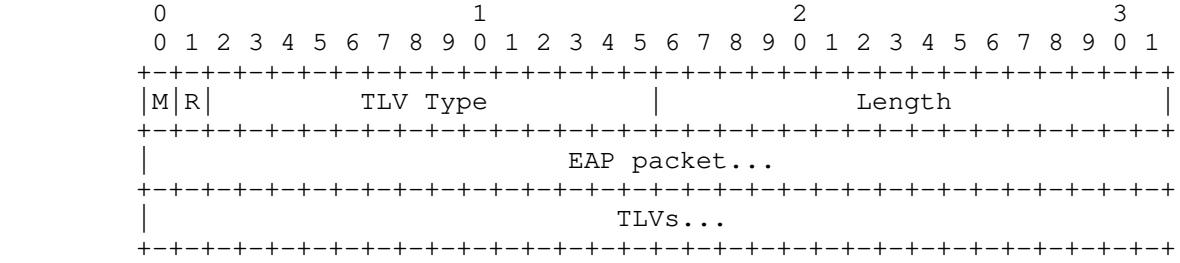
2 Negotiate-EAP

TLVs

This field is of indefinite length. It contains TLVs that the peer wants the server to process.

4.2.10. EAP-Payload TLV

To allow coalescing an EAP request or response with other TLVs, the EAP-Payload TLV is defined, which includes an encapsulated EAP packet and a list of optional TLVs. The optional TLVs are provided for future extensibility to provide hints about the current EAP authentication. Only one EAP-Payload TLV is allowed in a message. The EAP-Payload TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

9 - EAP-Payload TLV

Length

length of embedded EAP packet + cumulative length of additional TLVs

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 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.

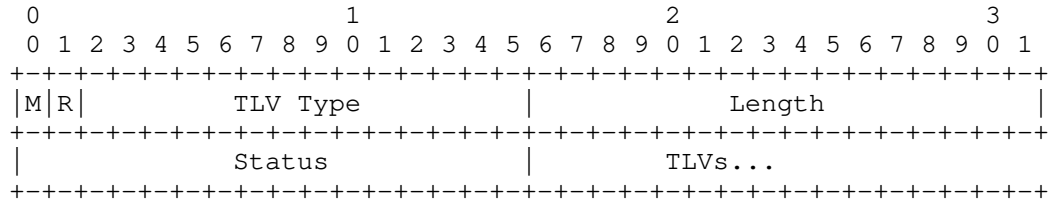
4.2.11. Intermediate-Result TLV

The Intermediate-Result TLV signals intermediate Success and Failure messages for all inner methods. The Intermediate-Result TLV MUST be be used for all inner methods.

An Intermediate-Result TLV indicating Success MUST be accompanied by a Crypto-Binding TLV.

An Intermediate-Result TLV indicating Failure SHOULD be accompanied by an Error TLV which indicates why the authentication failed.

The optional TLVs associated with this TLV are provided for future extensibility to provide hints about the current result. The Intermediate-Result TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

10 - Intermediate-Result TLV

Length

2 + cumulative length of the embedded associated TLVs

Status

The Status field is two octets. Values include:

1 Success

2 Failure

TLVs

This field is of indeterminate length and contains zero or more of the TLVs associated with the Intermediate Result TLV. The TLVs in this field MUST NOT have the mandatory bit set.

4.2.12. PAC TLV

[RFC7170] defined a Protected Access Credential (PAC) to mirror EAP-FAST [RFC4851]. However, implementation experience and analysis determined that the PAC was not necessary. Instead, TEAP performs session resumption using the NewSessionTicket message as defined in [RFC9190] Section 2.1.2 and Section 2.1.3. As such, the PAC TLV has been deprecated.

As the PAC TLV is deprecated, an entity receiving it SHOULD send a Result TLV indicating failure, and an Error TLV of Unexpected TLVs Exchanged.

4.2.13. Crypto-Binding TLV

The Crypto-Binding TLV is used to prove that both the peer and server participated in the tunnel establishment and sequence of authentications. It also provides verification of the TEAP type, version negotiated, and Outer TLVs exchanged before the TLS tunnel establishment.

The Crypto-Binding TLV MUST be exchanged and validated before any Intermediate-Result or Result TLV value is examined, regardless of whether there is an inner method or not. It MUST be included with the Intermediate-Result TLV to perform cryptographic binding after each successful inner method in a sequence of inner methods, before proceeding with another inner method. If no MSK or EMSK has been generated and a Crypto-Binding TLV is required then the MSK Compound MAC field contains the MAC using keys generated according to Section 5.3.

The Crypto-Binding TLV is valid only if the following checks pass:

* The Crypto-Binding TLV version is supported.

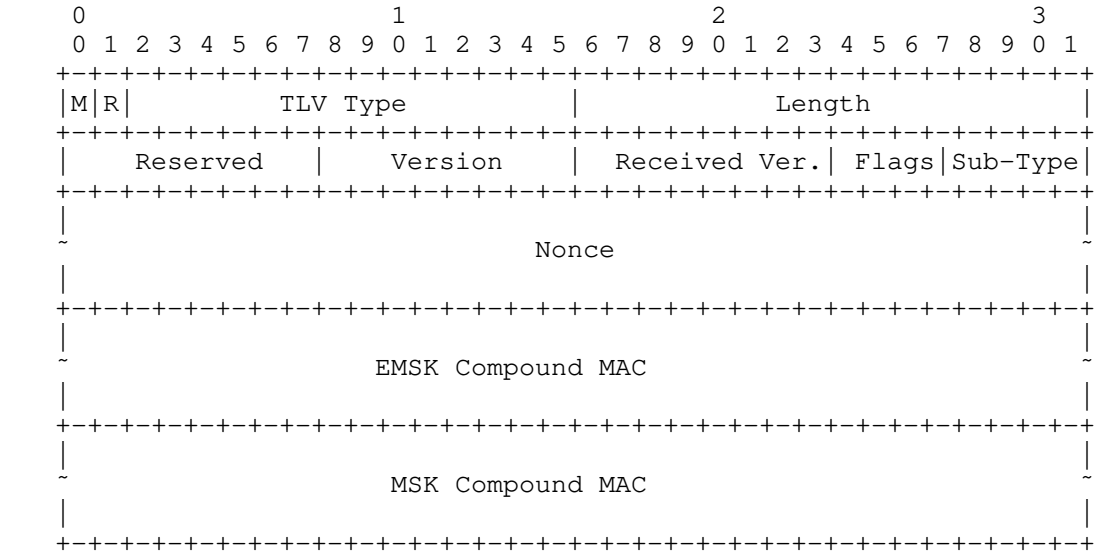
* The MAC verifies correctly.

* The received version in the Crypto-Binding TLV matches the version sent by the receiver during the EAP version negotiation.

* The subtype is set to the correct value.

If any of the above checks fails, then the TLV is invalid. An invalid Crypto-Binding TLV is a fatal error and is handled as described in Section 3.9.3

The Crypto-Binding TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

12 - Crypto-Binding TLV

Length

76

Reserved

Reserved, set to zero (0)

Version

The Version field is a single octet, which is set to the version of Crypto-Binding TLV the TEAP method is using. For an implementation compliant with this version of TEAP, the version number MUST be set to one (1).

Received Ver

The Received Ver field is a single octet and MUST be set to the TEAP version number received during version negotiation. Note that this field only provides protection against downgrade attacks, where a version of EAP requiring support for this TLV is required on both sides.

Flags

The Flags field is four bits. Defined values include

1 EMSK Compound MAC is present

2 MSK Compound MAC is present

3 Both EMSK and MSK Compound MAC are present

Sub-Type

The Sub-Type field is four bits. Defined 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. The nonce in a request MUST have its least significant bit set to zero (0), and the nonce in a response MUST have the same value as the request nonce except the least significant bit MUST be set to one (1).

EMSK Compound MAC

The EMSK Compound MAC field is 20 octets. This can be the Server MAC (B1_MAC) or the Client MAC (B2_MAC). The computation of the MAC is described in Section 5.3.

Note that this field is always 20 octets in length. Any larger MAC is simply truncated. All validations or comparisons MUST be done on the truncated value.

MSK Compound MAC

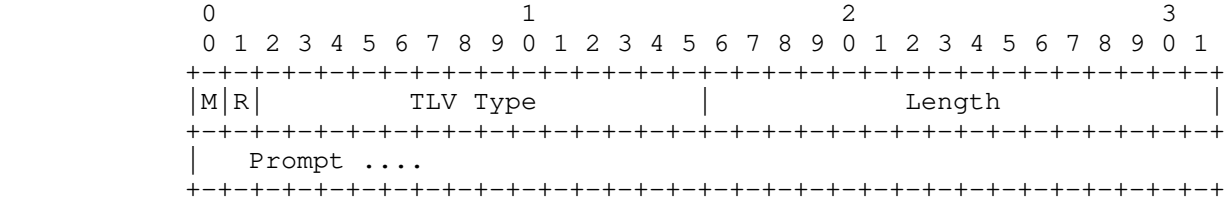
The MSK Compound MAC field is 20 octets. This can be the Server MAC (B1_MAC) or the Client MAC (B2_MAC). The computation of the MAC is described in Section 5.3.

Note that this field is always 20 octets in length. Any larger MAC is simply truncated. All validations or comparisons MUST be done on the truncated value.

4.2.14. Basic-Password-Auth-Req TLV

The Basic-Password-Auth-Req TLV is used by the authentication server to request a username and password from the peer. It contains an optional user prompt message for the request. The peer is expected to obtain the username and password and send them in a Basic-Password-Auth-Resp TLV.

The Basic-Password-Auth-Req TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

13 - Basic-Password-Auth-Req TLV

Length

variable

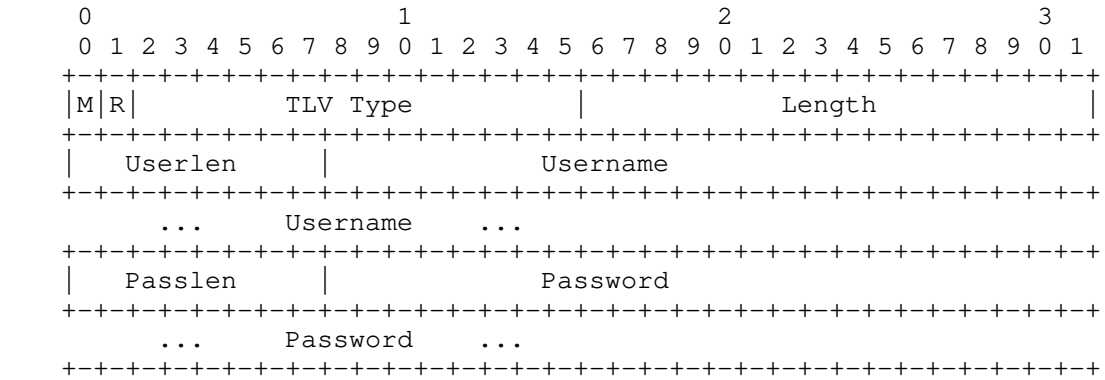
Prompt

optional user prompt message in UTF-8 [RFC3629] format

4.2.15. Basic-Password-Auth-Resp TLV

The Basic-Password-Auth-Resp TLV is used by the peer to respond to a Basic-Password-Auth-Req TLV with a username and password. The TLV contains a username and password. The username and password are in UTF-8 [RFC3629] format.

The Basic-Password-Auth-Resp TLV is defined as follows:



M

Mandatory, set to one (1)

R

Reserved, set to zero (0)

TLV Type

14 - Basic-Password-Auth-Resp TLV

Length

variable

Userlen

Length of Username field in octets

The value of Userlen MUST NOT be zero.

Username

Username in UTF-8 [RFC3629] format

The content of Username SHOULD follow the guidelines set in [RFC9427] Section 3.1.

Passlen

Length of Password field in octets

The value of Passlen MUST NOT be zero.

Password

Password in UTF-8 [RFC3629] format

Note that there is no requirement that passwords be humanly readable. Octets in a passwords may have values less than 0x20, including 0x00.

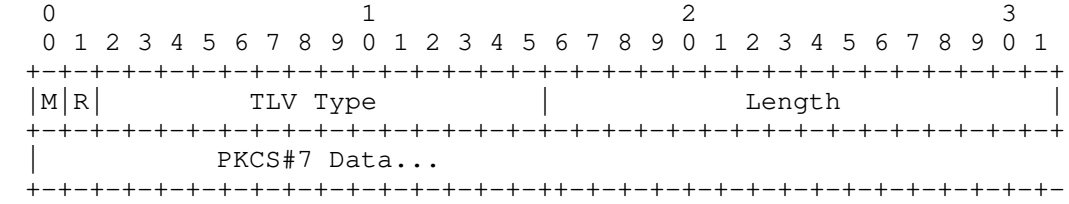
4.2.16. PKCS#7 TLV

The PKCS#7 TLV is used by the EAP server to deliver certificate(s) to the peer. The format consists of a certificate or certificate chain in binary DER encoding [X.690] in a degenerate Certificates Only PKCS#7 SignedData Content as defined in [RFC5652].

When used in response to a Trusted-Server-Root TLV request from the peer, the EAP server MUST send the PKCS#7 TLV inside a Trusted-Server-Root TLV. When used in response to a PKCS#10 certificate enrollment request from the peer, the EAP server MUST send the PKCS#7 TLV without a Trusted-Server-Root TLV. The PKCS#7 TLV is always marked as optional, which cannot be responded to with a NAK TLV. TEAP implementations that support the Trusted-Server-Root TLV or the PKCS#10 TLV MUST support this TLV. Peers MUST NOT assume that the certificates in a PKCS#7 TLV are in any order.

TEAP servers MAY return self-signed certificates. Peers that handle self-signed certificates or trust anchors MUST NOT implicitly trust these certificates merely due to their presence in the certificate bag. Note: Peers are advised to take great care in deciding whether to use a received certificate as a trust anchor. The authenticated nature of the tunnel in which a PKCS#7 bag is received can provide a level of authenticity to the certificates contained therein. Peers are advised to take into account the implied authority of the EAP server and to constrain the trust it can achieve through the trust anchor received in a PKCS#7 TLV.

The PKCS#7 TLV is defined as follows:



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

15 - PKCS#7 TLV

Length

The length of the PKCS#7 Data field.

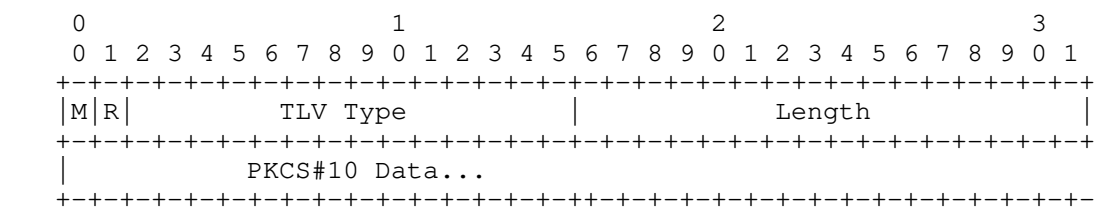
PKCS#7 Data

This field contains the DER-encoded X.509 certificate or certificate chain in a Certificates-Only PKCS#7 SignedData message.

4.2.17. PKCS#10 TLV

The PKCS#10 TLV is used by the peer to initiate the "simple PKI" Request/Response from [RFC5272]. The format of the request is as specified in Section 6.4 of [RFC4945]. The PKCS#10 TLV is always marked as optional, which cannot be responded to with a NAK TLV.

The PKCS#10 TLV is defined as follows:



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

16 - PKCS#10 TLV

Length

The length of the PKCS#10 Data field.

PKCS#10 Data

This field contains the DER-encoded PKCS#10 certificate request.

4.2.18. Trusted-Server-Root TLV

Trusted-Server-Root TLV facilitates the request and delivery of a trusted server root certificate. The Trusted-Server-Root TLV can be exchanged in regular TEAP authentication mode or provisioning mode. The Trusted-Server-Root TLV is always marked as optional and cannot be responded to with a Negative Acknowledgment (NAK) TLV. The Trusted-Server-Root TLV MUST only be sent as an Inner TLV (inside the protection of the tunnel).

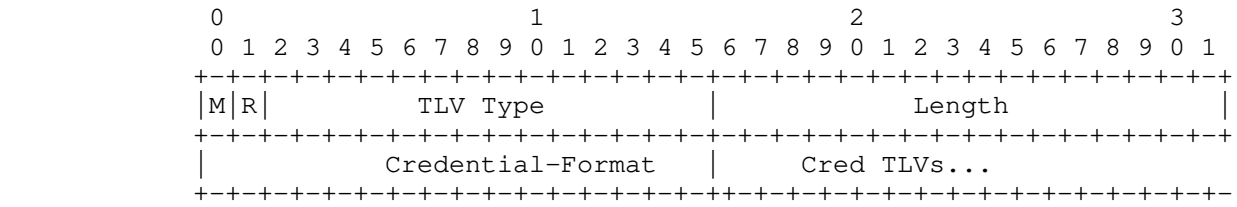
After the peer has determined that it has successfully authenticated the EAP server and validated the Crypto-Binding TLV, it MAY send one or more Trusted-Server-Root TLVs (marked as optional) to request the trusted server root certificates from the EAP server. The EAP server MAY send one or more root certificates with a Public Key Cryptographic System #7 (PKCS#7) TLV inside the Trusted-Server-Root TLV. The EAP server MAY also choose not to honor the request.

The Trusted-Server-Root TLV allows the peer to send a request to the EAP server for a list of trusted roots. The server may respond with one or more root certificates in PKCS#7 [RFC2315] format.

If the EAP server sets the credential format to PKCS#7-Server-Certificate-Root, then the Trusted-Server-Root TLV should contain the root of the certificate chain of the certificate issued to the EAP server packaged in a PKCS#7 TLV. If the server certificate is a self-signed certificate, then the root is the self-signed certificate.

If the Trusted-Server-Root TLV credential format contains a value unknown to the peer, then the EAP peer should ignore the TLV.

The Trusted-Server-Root TLV is defined as follows:



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

17 - Trusted-Server-Root TLV

Length

>=2 octets

Credential-Format

The Credential-Format field is two octets. Values include:

1 - PKCS#7-Server-Certificate-Root

Cred TLVs

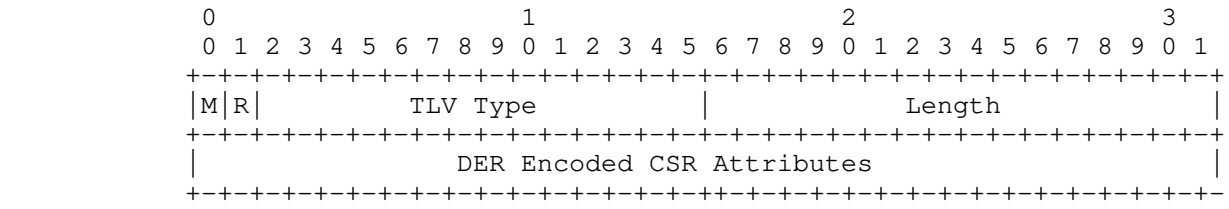
This field is of indefinite length. It contains TLVs associated with the credential format. The peer may leave this field empty when using this TLV to request server trust roots.

4.2.19. CSR-Attributes TLV

The CSR-Attributes TLV provides information from the server to the peer on how certificate signing requests should be formed. The purpose of CSR attributes is described in Section 4.5 of [RFC7030]. Servers MAY send the CSR-Attributes TLV directly after the TLS session has been established. A server MAY also send in the same message a Request Action frame for a PKCS#10 TLV. This is an indication to the peer that the server would like the peer to renew its certificate using the parameters provided in this TLV. Servers shall construct the contents of the CSR-Attributes TLV as specified in [RFC7030] Section 4.5.2 with the exception that the DER encoding MUST NOT be encoded in base64. The base64 encoding is used in [RFC7030] because the transport protocol used there requires textual encoding. In contrast, TEAP attributes can transport arbitrary binary data.

Servers and peers MUST follow the guidance provided in [I-D.ietf-lamps-rfc7030-csrattrs] when creating the CSR-Attributes TLV. Peers MAY ignore the contents of the TLV if they are unable to do so, but then servers may not process PKCS#10 certificate requests for this or any other reason.

The CSR-Attributes TLV is defined as follows:



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

18 - CSR-Attributes

Length

>=2 octets

4.2.20. Identity-Hint TLV

The Identity-Hint TLV is an optional TLV which can be sent by the peer to the server at the beginning of the Phase 2 TEAP conversation. The purpose of the TLV is to provide a "hint" as to the identity or identities which the peer will be using by subsequent inner methods.

The purpose of this TLV is to solve the "bootstrapping" problem for the server. In order to perform authentication, the server must choose an inner method. However, the server has no knowledge of what methods are supported by the peer. Without an identity hint, the server needs to propose a method, and then have the peer return a response indicating that the requested method is not available. This negotiation increases the number of round trips required for TEAP to conclude, with no additional benefit.

When the Identity-Hint is used, the peer can signal which identities it has available, which enables the server to choose an inner method which is appropriate for that identity.

The peer SHOULD send an Identity-Hint TLV for each Identity-Type which is available to it. For example, if the peer can do both Machine and User authentication, it can send two Identity-Hint TLVs, with values "host/name.example.com" (for a machine with hostname "name.example.com"), and "user@example.com" (for a person with identity "user@example.com").

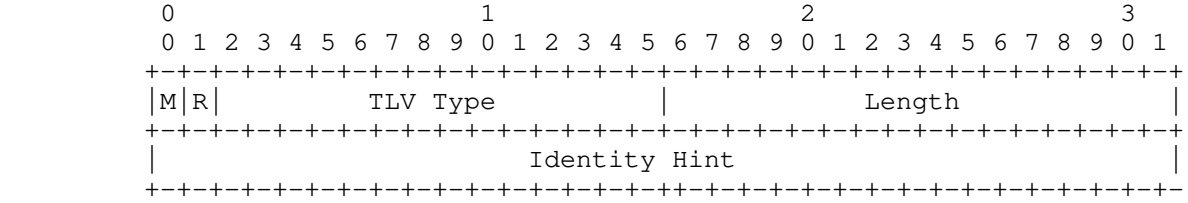
The contents of the Identity-Hint TLV SHOULD be in the format of an NAI [RFC7542], but we note that as given in the example above, Machine identities might not follow that format. As these identities are never used for AAA routing as discussed in [RFC7542] Section 3, the format and definition of these identities are entirely site local. Robust implementations MUST support arbitrary data in the content of this TLV, including binary octets.

As the Identity-Hint TLV is a "hint", server implementations are free to ignore the hints given, and do whatever is required by site-local policies.

The Identity-Hint TLV is used only as a guide when selecting which inner methods to use. This TLV has no other meaning, and it MUST NOT be used for any other purpose. Specifically. server implementations MUST NOT compare the identities given this TLV to later identities given as part of the inner methods. There is no issue with the hint(s) failing to match any subsequent identity which is used.

The Identity-Hint TLV MUST NOT be used for Server Unauthenticated Provisioning. This TLV is only used as a hint for normal authentication.

The Identity-Hint TLV is defined as follows:



M

0 - Optional TLV

R

Reserved, set to zero (0)

TLV Type

19 - Identity-Hint

Length

>=2 octets

4.3. TLV Rules

To save round trips, multiple TLVs can be sent in a single TEAP packet. However, multiple EAP Payload TLVs, multiple Basic Password Authentication TLVs, or an EAP Payload TLV with a Basic Password Authentication TLV within one single TEAP 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 terminate the connection with the Result TLV. The order in which TLVs are encoded in a TEAP packet does not matter, however there is an order in which TLVs in a packet must be processed:

1. Crypto-Binding TLV

2. Intermediate-Result TLV

3. Result TLV or Request-Action TLV

4. Identity-Type TLV

5. EAP-Payload TLV[Identity-Request] or Basic-Password-Auth-Req TLV

6. Other TLVs

That is, cryptographic binding is checked before any result is used, and identities are checked before proposing an inner method, as the identity may influence the chosen inner method.

The following define the meaning of the table entries in the sections below:

0 This TLV MUST NOT be present in the message.

0+ Zero or more instances of this TLV MAY be present in the message.

0-1 Zero or one instance of this TLV MAY be present in the message.

1 Exactly one instance of this TLV MUST be present in the message.

4.3.1. Outer TLVs

The following table provides a guide to which TLVs may be included in the TEAP packet outside the TLS channel, which kind of packets, and in what quantity:

Request	Response	Success	Failure	TLVs
0-1	0	0	0	Authority-ID
0-1	0-1	0	0	Identity-Type
0+	0+	0	0	Vendor-Specific

Outer TLVs MUST be marked as optional. Vendor TLVs inside of a Vendor-Specific TLV MUST be marked as optional when included in Outer TLVs. Outer TLVs MUST NOT be included in messages after the first two TEAP messages sent by peer and EAP-server respectively. That is the first EAP-server-to-peer message and first peer-to-EAP-server message. If the message is fragmented, the whole set of messages is counted as one message. If Outer TLVs are included in messages after the first two TEAP messages, they MUST be ignored.

4.3.2. Inner TLVs

The following table provides a guide to which Inner TLVs may be encapsulated in TLS in TEAP Phase 2, in which kind of packets, and in what quantity. The messages are as follows: Request is a TEAP Request, Response is a TEAP Response, Success is a message containing a successful Result TLV, and Failure is a message containing a failed Result TLV.

Request	Response	Success	Failure	TLVs
0-1	0-1	0	0	Identity-Type
0-1	0-1	1	1	Result
0+	0+	0	0	NAK
0+	0+	0+	0+	Error
0-1	0-1	0	0	Channel-Binding
0+	0+	0+	0+	Vendor-Specific
0+	0+	0+	0+	Request-Action
0-1	0-1	0	0	EAP-Payload
0-1	0-1	0-1	0-1	Intermediate-Result
0-1	0-1	0-1	0-1	Crypto-Binding
0-1	0	0	0	Basic-Password-Auth-Req
0	0-1	0	0	Basic-Password-Auth-Resp
0-1	0	0-1	0	PKCS#7
0	0-1	0	0	PKCS#10
0-1	0-1	0-1	0	Trusted-Server-Root
0-1	0	0	0	CSR-Attributes TLV
0	0+	0	0	Identity-Hint TLV

NOTE: Vendor TLVs (included in Vendor-Specific TLVs) sent with a Result TLV MUST be marked as optional. Also, the CSR-Attributes TLV is never transmitted by the peer, and so is treated as a request in this table.

5. Cryptographic Calculations

For key derivation and crypto-binding, TEAP uses the Pseudorandom Function (PRF) and MAC algorithms negotiated in the underlying TLS session. Since these algorithms depend on the TLS version and cipher suite, TEAP implementations need a mechanism to determine the version and cipher suite in use for a particular session. The implementation can then use this information to determine which PRF and MAC algorithm to use.

5.1. TEAP Authentication Phase 1: Key Derivations

With TEAPv1, the TLS master secret is generated as specified in TLS. If session resumption is used, then the master secret is obtained as described in [RFC5077].

TEAPv1 makes use of the TLS Keying Material Exporters defined in [RFC5705] to derive the session_key_seed as follows:

```
session_key_seed = TLS-Exporter(
                   "EXPORTER: teap session key seed",, 40)
```

No context data is used in the export process.

The session_key_seed is used by the TEAP authentication Phase 2 conversation to both cryptographically bind the inner method(s) to the tunnel as well as generate the resulting TEAP session keys. The other TLS keying materials are derived and used as defined in [RFC5246].

5.2. Intermediate Compound Key Derivations

The session_key_seed derived as part of TEAP Phase 2 is used in TEAP Phase 2 to generate an Intermediate Compound Key (IMCK) used to verify the integrity of the TLS tunnel after each successful inner authentication and in the generation of Master Session Key (MSK) and Extended Master Session Key (EMSK) defined in [RFC3748]. Note that the IMCK MUST be recalculated after each successful inner method.

The first step in these calculations is the generation of the base compound key, IMCK[j] from the session_key_seed, and any session keys derived from the successful execution of j’th inner methods. The inner method(s) MUST provide Inner Method Session Keys (IMSKs),

IMSK[1]..IMSK[n], corresponding to inner method 1 through n. When a particular inner method does not provide key material (such as with password exchange) then a special "all zero" IMSK is used as described below.

If an inner method supports export of an Extended Master Session Key (EMSK), then the IMSK SHOULD be derived from the EMSK as defined in [RFC5295]. The optional data parameter is not used in the derivation.

```
IMSK[j] = First 32 octets of TLS-PRF(
       EMSK[j],
       "TEAPbindkey@ietf.org",
       0x00 | 0x00 | 0x40)
```

where "|" denotes concatenation and the TLS-PRF is defined in [RFC5246] as:

```
PRF(secret, label, seed) = P_<hash>(secret, label | seed)
```

The secret is the EMSK from the j'th inner method, the usage label used is "TEAPbindkey@ietf.org" consisting of the ASCII value for the label "TEAPbindkey@ietf.org" (without quotes), the seed consists of the "\0" null delimiter (0x00) and 2-octet unsigned integer length of 64 octets in network byte order (0x00 | 0x40) specified in [RFC5295].

If an inner method does not support export of an Extended Master Session Key (EMSK), then the IMSK is derived from the MSK of the inner method. The MSK is truncated at 32 octets if it is longer than 32 octets or padded to a length of 32 octets with zeros if it is less than 32 octets. In this case, IMSK[j] is the adjusted MSK.

An inner method may not provide either EMSK or MSK, such as when basic password authentication is used or when no inner method has been run and the crypto-binding TLV for the Result TLV needs to be generated. In this case, IMSK[j] is set to all zeroes (i.e., IMSK[j] = MSK = 32 octets of 0x00s).

Note that using an MSK of all zeroes opens up TEAP to on-path attacks, as discussed below in {#separation-p1-p2}. It is therefore NOT RECOMMENDED to use inner methods which fail to generate an EMSK or MSK. These methods should only be used in conjunction with another inner method which does provide for EMSK or MSK generation. It is also RECOMMENDED that TEAP peers order authentication such that methods which generate EMSKs are performed before methods which do not generate EMSKs.

For example, Phase 2 could perform both Machine authentication using EAP-TLS, followed by User authentication via the Basic Password Authentication TLVs. In that case, the use of EAP-TLS would allow an attacker to be detected before the User password was sent.

However, it is possible that the peer and server sides might not have the same capability to export EMSK. In order to maintain maximum flexibility while prevent downgrading attack, the following mechanism is in place.

On the sender of the Crypto-Binding TLV side:

If the EMSK is not available, then the sender computes the Compound MAC using the MSK of the inner method.

If the EMSK is available and the sender's policy accepts MSK-based MAC, then the sender computes two Compound MAC values. The first is computed with the EMSK. The second one is computed using the MSK. Both MACs are then sent to the other side.

If the EMSK is available but the sender's policy does not allow downgrading to MSK-generated MAC, then the sender SHOULD only send EMSK-based MAC.

On the receiver of the Crypto-Binding TLV side:

If the EMSK is not available and an MSK-based Compound MAC was sent, then the receiver validates the Compound MAC and sends back an MSK-based Compound MAC response.

If the EMSK is not available and no MSK-based Compound MAC was sent, then the receiver handles like an invalid Crypto-Binding TLV with a fatal error.

If the EMSK is available and an EMSK-based Compound MAC was sent, then the receiver validates it and creates a response Compound MAC using the EMSK.

If the EMSK is available but no EMSK-based Compound MAC was sent and its policy accepts MSK-based MAC, then the receiver validates it using the MSK and, if successful, generates and returns an MSK-based Compound MAC.

If the EMSK is available but no EMSK Compound MAC was sent and its policy does not accept MSK-based MAC, then the receiver handles like an invalid Crypto-Binding TLV with a fatal error.

If an inner method results in failure, then it is not included in this calculation.

The derivation of S-IMCK is as follows:

```
S-IMCK[0] = session_key_seed
For j = 1 to n-1 do
     IMCK[j] = the first 60 octets of TLS-PRF(S-IMCK[j-1],
          "Inner Methods Compound Keys",
          IMSK[j])
     S-IMCK[j] = first 40 octets of IMCK[j]
     CMK[j] = last 20 octets of IMCK[j]
```

where TLS-PRF is the PRF described above negotiated as part of TLS handshake [RFC5246]. The value j refers to a corresponding inner method 1 through n. The special value of S-IMCK[0] is used to bootstrap the calculations, and can be done as soon as the TLS connection is established, and before any inner methods are run.

In practice, the requirement to use either MSK or EMSK means that an implement MUST track two independent derivations of IMCK[j], one which depends on the MSK, and another which depends on EMSK. That is, we have both values derived from MSK:

```
IMSK_MSK[j]
S-IMCK_MSK[j]
CMK_MSK[j]
```

and then also values derived from EMSK:

```
IMSK_EMSK[j]
S-IMCK_EMSK[j]
CMK_EMSK[j]
```

At the conclusion of a successfully exchange of Crypto-Binding TLVs, a single S-IMCK[j] is selected based on which Compound MAC value was included in the Crypto-Binding TLV from the client. If EMSK Compound MAC was included, S-IMCK[j] is taken from S-IMCK_EMSK[j]. Otherwise, S-IMCK[j] is taken from S-IMCK_MSK[j].

5.2.1. Unintended Side Effects

The above description has issues which were only discovered after TEAP had been widely implemented, following draft publications of this document. These issues need to be documented in order to enable interoparable implementations.

As noted above, some inner EAP methods derive MSK, but do not derive EMSK. When there is no EMSK, it is therefore not possible to derive IMCK_EMSK[j] from it. The choice of multiple implementations was then to simply define:

IMCK_EMSK[j] = IMCK_EMSK[j - 1]

This definition can be trivially implementation by simply keeping a cached copy of IMCK_EMSK in a data structure. If EMSK is available, IMCK_EMCK is updated from it via the TLS-PRF function as defined above. If EMSK is not available, then the IMCK_EMSK value is unmodified.

This behavior was not explicitly anticipated by earlier drafts of this document. It instead appears to be an accidental outcome of implementing the derivations above, with the limitiation of a missing EMSK. This behavior is explicitly called out here in the interest of fully documenting TEAP.

Another unintended consequence is in the calculation of the Crypto-Binding TLV. That TLV includes compound MACs which depend on the MSK and EMSK of the current authentication method. Where the current method does not provide an EMSK, the Crypto-Binding TLV does not include a compound MAC which depends on the EMSK. Where the current method does not provide an MSK, the Crypto-Binding TLV includes a compound MAC which depends on a special "all zero" IMSK as discussed earlier.

The result of this definition is that the final Crypto-Binding TLV in an inner TEAP exchange may not include a compond MAC which depends on EMSK, even if earlier EAP methods in the phase 2 exchange provided an ESMK. This result likely has negative affects on security, though the full impact is unknown at the time of writing this document.

These design flaws have nonetheless resulted in multiple interoperable implementations. We note that these implementations seem to support only EAP-TLS and the EAP-FAST-MSCHAPv2 variant of EAP-MSCHAPv2. Other inner EAP methods may work by accident, but are not likely to work by design. For this document, we can only ensure that the behavior of TEAPv1 is fully documented, even if that behavior was an unintended consequence of unclear text in earlier versions of this document.

We expect that these issues will be addressed in a future revision of TEAP.

5.3. Computing the Compound MAC

For inner methods that generate keying material, further protection against on-path attacks is provided through cryptographically binding keying material established by both TEAP Phase 1 and TEAP Phase 2 conversations. After each successful inner EAP authentication, EAP EMSK and/or MSKs are cryptographically combined with key material from TEAP Phase 1 to generate a Compound Session Key (CMK). The CMK is used to calculate the Compound MAC as part of the Crypto-Binding TLV described in Section 4.2.13, which helps provide assurance that the same entities are involved in all communications in TEAP. During the calculation of the Compound MAC, the MAC field is filled with zeros.

The Compound MAC computation is as follows:

```
Compound-MAC = the first 20 octets of MAC( CMK[n], BUFFER )
```

where n is the number of the last successfully executed inner method, MAC is the MAC function negotiated in TLS (e.g. TLS 1.2 in [RFC5246]), and BUFFER is created after concatenating these fields in the following order:

1. The entire Crypto-Binding TLV attribute with both the EMSK and MSK Compound MAC fields zeroed out.

2. The EAP Type sent by the other party in the first TEAP message, which MUST be TEAP, encoded as one octet of 0x37.

3. All the Outer TLVs from the first TEAP message sent by EAP server to peer. If a single TEAP message is fragmented into multiple TEAP packets, then the Outer TLVs in all the fragments of that message MUST be included.

4. All the Outer TLVs from the first TEAP message sent by the peer to the EAP server. If a single TEAP message is fragmented into multiple TEAP packets, then the Outer TLVs in all the fragments of that message MUST be included.

If no inner method is run, then no EMSK or MSK will be generated. If an IMSK needs to be generated then the MSK and therefore the IMSK is set to all zeroes (i.e., IMSK = MSK = 32 octets of 0x00s).

Note that there is no boundary marker between the fields in steps (3) and (4). However, the server calculates the compound MAC using the outer TLVs it sent, and the outer TLVs it received from the peer. On the other side, the peer calculates the compound MAC using the outer TLVs it sent, and the outer TLVs it received from the server. As a

result, and modification in transit of the outer TLVs will be detected because the two sides will calculate different values for the compound MAC.

If no key generating inner method is run then no EMSK or MSK will be generated. If an IMSK needs to be generated then the MSK and therefore the IMSK is set to all zeroes (i.e., IMSK = MSK = 32 octets of 0x00s)

5.4. EAP Master Session Key Generation

TEAP authentication assures the Master Session Key (MSK) and Extended Master Session Key (EMSK) output from running TEAP are the combined result of all inner methods by generating an Intermediate Compound Key (IMCK). The IMCK is mutually derived by the peer and the server as described in Section 5.2 by combining the MSKs from inner methods with key material from TEAP Phase 1. The resulting MSK and EMSK are generated from the final ("n"th) inner method, as part of the IMCK[n] key hierarchy via the following derivation:

```
MSK  = the first 64 octets of TLS-PRF(S-IMCK[n],
       "Session Key Generating Function")
EMSK = the first 64 octets of TLS-PRF(S-IMCK[n],
       "Extended Session Key Generating Function")
```

The secret is S-IMCK[n] where n is the number of the last generated S-IMCK[j] from Section 5.2. The label is the ASCII value for the string without quotes. The seed is empty (0 length) and is omitted from the derivation.

The EMSK is typically only known to the TEAP peer and server and is not provided to a third party. The derivation of additional keys and transportation of these keys to a third party are outside the scope of this document.

If no inner method has created an EMSK or MSK, the MSK and EMSK will be generated directly from the session_key_seed meaning S-IMCK[0] = session_key_seed.

As we noted above, not all inner methods generate both MSK and EMSK, so we have to maintain two independent derivations of S-IMCK[j], one for each of MSK[j] and EMSK[j]. The final derivation using S-IMCK[n] must choose only one of these keys.

If the Crypto-Binding TLV contains an EMSK compound MAC, then the derivation is taken from the S-IMCK_EMSK[n]. Otherwise it is taken from the S-IMCK_MSK[n].

6. IANA Considerations

This section provides guidance to the Internet Assigned Numbers Authority (IANA) regarding registration of values related to the TEAP protocol, in accordance with BCP 26 [RFC8126].

Except as noted below, IANA is instructed to update the "Tunnel Extensible Authentication Protocol (TEAP) Parameters" registry to change the Reference field in all tables from [RFC7170] to [THIS-DOCUMENT].

6.1. TEAP TLV Types

IANA is instructed to update the references in the "TEAP TLV Types" registry to from [RFC7170] to [THIS-DOCUMENT], and add TLV 18 and TLV 19 to to the registry. The Unassigned values then begin at 20 instead of at 18.

Value,Description,Reference
18,CSR-Attributes TLV,[THIS-DOCUMENT]
19,Identity-Hint TLV,[THIS-DOCUMENT]
20-16383,Unassigned,

IANA is instructed to close the "TEAP PAC TLV (value 11) PAC Attribute Type Codes" and "TEAP PAC TLV (value 11) PAC-Type Type Codes" to new registrations, and update update those registries with with a NOTE:

This registry has been closed. See [THIS-DOCUMENT].

6.2. TEAP Error TLV (value 5) Error Codes

IANA is instructed to update the "TEAP Error TLV (value 5) Error Codes" registry to add the following entry:

Value,Description,Reference
1032,Inner method not supported,[THIS-DOCUMENT]

6.3. TLS Exporter Labels

IANA is instructed to update the "TLS Exporter Labels" registry to change the Reference field for Value "EXPORTER: teap session key seed" as follows:

Value,DTLS-OK,Recommended,Reference
EXPORTER: teap session key seed,N,Y,[THIS-DOCUMENT]

6.4. Extended Master Session Key (EMSK) Parameters

IANA is instructed to update the "User Specific Root Keys (USRK) Key Labels" registry to change the Reference field for Value "TEAPbindkey@ietf.org" as follows:

Value,Description,Reference
TEAPbindkey@ietf.org,TEAP binding usage label,[THIS-DOCUMENT]

6.5. Extensible Authentication Protocol (EAP) Registry

IANA is instructed to update the "Method Types" registry to change the Reference field for Value "55" as follows:

Value,Description,Reference
55,TEAP,[THIS-DOCUMENT]

7. Security Considerations

TEAP is designed with a focus on wireless media, where the medium itself is inherent to eavesdropping. Whereas in wired media an attacker would have to gain physical access to the wired medium, wireless media enables anyone to capture information as it is transmitted over the air, enabling passive attacks. Thus, physical security can not be assumed, and security vulnerabilities are far greater. The threat model used for the security evaluation of TEAP is defined in EAP [RFC3748].

7.1. Mutual Authentication and Integrity Protection

As a whole, TEAP provides message and integrity protection by establishing a secure tunnel for protecting the inner method(s). The confidentiality and integrity protection is defined by TLS and provides the same security strengths afforded by TLS employing a strong entropy shared master secret. The integrity of the key generating inner methods executed within the TEAP tunnel is verified through the calculation of the Crypto-Binding TLV. This ensures that the tunnel endpoints are the same as the inner method endpoints.

Where Server Unauthenticated Provisioning is performed, TEAP requires that the inner provisioning method provide for both peer and server authentication.

7.2. Method Negotiation

As is true for any negotiated EAP protocol, EAP NAK message used to suggest an alternate EAP authentication method are sent unprotected and, as such, are subject to spoofing. During unprotected EAP method negotiation, NAK packets may be interjected as active attacks to bid-down to a weaker form of authentication, such as EAP-MD5 (which only provides one-way authentication and does not derive a key). Both the peer and server should have a method selection policy that prevents them from negotiating down to weaker methods. Inner method negotiation resists attacks because it is protected by the mutually authenticated TLS tunnel established. Selection of TEAP as an authentication method does not limit the potential inner methods, so TEAP should be selected when available.

An attacker cannot readily determine the inner method used, except perhaps by traffic analysis. It is also important that peer implementations limit the use of credentials with an unauthenticated or unauthorized server.

7.3. Separation of Phase 1 and Phase 2 Servers

Separation of the TEAP Phase 1 from the Phase 2 conversation is NOT RECOMMENDED. Allowing the Phase 1 conversation to be terminated at a different server than the Phase 2 conversation can introduce vulnerabilities if there is not a proper trust relationship and protection for the protocol between the two servers. Some vulnerabilities include:

* Loss of identity protection

* Offline dictionary attacks

* Lack of policy enforcement

* on-path active attacks (as described in [RFC7029])

There may be cases where a trust relationship exists between the Phase 1 and Phase 2 servers, such as on a campus or between two offices within the same company, where there is no danger in revealing the inner identity and credentials of the peer to entities between the two servers. In these cases, using a proxy solution without end-to-end protection of TEAP MAY be used. The TEAP encrypting/decrypting gateway MUST, at a minimum, provide support for IPsec, TLS, or similar protection in order to provide confidentiality for the portion of the conversation between the gateway and the EAP server. In addition, separation of the TEAP server and Inner servers allows for crypto-binding based on the inner method MSK to be

thwarted as described in [RFC7029]. If the inner method derives an EMSK, then this threat is mitigated as TEAP uses the Crypto-Binding TLV tie the inner EMSK to the TLS session via the TLS-PRF, as described above in Section 5.

On the other hand, if the inner method is not deriving EMSK as with password authentication or unauthenticated provisioning, then this threat still exists. Implementations therefore need to limit the use of inner methods as discussed above in Section 3.6.4

7.4. Mitigation of Known Vulnerabilities and Protocol Deficiencies

TEAP addresses the known deficiencies and weaknesses in some EAP authentication methods. By employing a shared secret between the peer and server to establish a secured tunnel, TEAP enables:

* Per-packet confidentiality and integrity protection
* User identity protection
* Better support for notification messages
* Protected inner method negotiation, including EAP method
* Sequencing of inner methods, including EAP methods
* Strong mutually derived MSKs
* Acknowledged success/failure indication
* Faster re-authentications through session resumption
* Mitigation of offline dictionary attacks
* Mitigation of on-path attacks
* Mitigation of some denial-of-service attacks

It should be noted that in TEAP, as in many other authentication protocols, a denial-of-service attack can be mounted by adversaries sending erroneous traffic to disrupt the protocol. This is a problem in many authentication or key agreement protocols and is therefore noted for TEAP as well.

TEAP was designed with a focus on protected inner methods that typically rely on weak credentials, such as password-based secrets. To that extent, the TEAP authentication mitigates several vulnerabilities, such as offline dictionary attacks, by protecting

the weak credential-based inner method. The protection is based on strong cryptographic algorithms in TLS to provide message confidentiality and integrity. The keys derived for the protection relies on strong random challenges provided by both peer and server as well as an established key with strong entropy. Implementations should follow the recommendation in [RFC4086] when generating random numbers.

7.4.1. User Identity Protection and Verification

The initial identity request response exchange is sent in cleartext outside the protection of TEAP. Typically, the Network Access Identifier (NAI) [RFC7542] in the identity response is useful only for the realm of information that is used to route the authentication requests to the right EAP server. This means that the identity response may contain an anonymous identity and just contain realm information. In other cases, the identity exchange may be eliminated altogether if there are other means for establishing the destination realm of the request. In no case should an intermediary place any trust in the identity information in the identity response since it is unauthenticated and may not have any relevance to the authenticated identity. TEAP implementations should not attempt to compare any identity disclosed in the initial cleartext EAP Identity response packet with those Identities authenticated in Phase 2.

When the server is authenticated, identity request/response exchanges sent after the TEAP tunnel is established are protected from modification and eavesdropping by attackers. For server unauthenticated provisioning, the outer TLS session provides little security, and the provisioning method must necessarily provide this protection instead.

When a client certificate is sent outside of the TLS tunnel in Phase 1, the peer MUST include Identity-Type as an outer TLV, in order to signal the type of identity which that client certificate is for. Further, when a client certificate is sent outside of the TLS tunnel, the server MUST proceed with Phase 2. If there is no Phase 2 data, then the EAP server MUST reject the session.

Issues related to confidentiality of a client certificate are discussed above in Section 3.4.1

Note that the Phase 2 data could simply be a Result TLV with value Success, along with a Crypto-Binding TLV. This Phase 2 data serves as a protected success indication as discussed in [RFC9190] Section 2.1.1

7.5. Dictionary Attack Resistance

TEAP was designed with a focus on protected inner methods that typically rely on weak credentials, such as password-based secrets. TEAP mitigates offline dictionary attacks by allowing the establishment of a mutually authenticated encrypted TLS tunnel providing confidentiality and integrity to protect the weak credential-based inner method.

TEAP mitigates dictionary attacks by permitting inner methods such as EAP-pwd which are not vulnerable to dictionary attacks.

TEAP implementations can mitigate online "brute force" dictionary attempts by limiting the number of failed authentication attempts for a particular identity.

7.5.1. Protection against On-Path Attacks

TEAP provides protection from on-path attacks in a few ways:

1. By using a certificates or a session ticket to mutually authenticate the peer and server during TEAP authentication Phase 1 establishment of a secure TLS tunnel.

2. When the TLS tunnel is not secured, by using the keys generated by the inner method (if the inner methods are key generating) in the crypto-binding exchange and in the generation of the key material exported by the inner method described in Section 5.

TEAP crypto binding does not guarantee protection from on-path attacks if the client allows a connection to an untrusted server, such as in the case where the client does not properly validate the server's certificate. If the TLS cipher suite derives the master secret solely from the contribution of secret data from one side of the conversation (such as cipher suites based on RSA key transport), then an attacker who can convince the client to connect and engage in authentication can impersonate the client to another server even if a strong inner method is executed within the tunnel. If the TLS cipher suite derives the master secret from the contribution of secrets from both sides of the conversation (such as in cipher suites based on Diffie-Hellman), then crypto binding can detect an attacker in the conversation if a strong inner method is used.

7.6. Protecting against Forged Cleartext EAP Packets

EAP Success and EAP Failure packets are, in general, sent in cleartext and may be forged by an attacker without detection. Forged EAP Failure packets can be used to attempt to convince an EAP peer to disconnect. Forged EAP Success packets may be used to attempt to convince a peer that authentication has succeeded, even though the authenticator has not authenticated itself to the peer.

By providing message confidentiality and integrity, TEAP provides protection against these attacks. Once the peer and authentication server (AS) initiate the TEAP authentication Phase 2, compliant TEAP implementations MUST silently discard all cleartext EAP messages, unless both the TEAP peer and server have indicated success or failure using a protected mechanism. Protected mechanisms include the TLS alert mechanism and the protected termination mechanism described in Section 3.6.5.

The success/failure decisions within the TEAP tunnel indicate the final decision of the TEAP authentication conversation. After a success/failure result has been indicated by a protected mechanism, the TEAP peer can process unprotected EAP Success and EAP Failure messages; however, the peer MUST ignore any unprotected EAP Success or Failure messages where the result does not match the result of the protected mechanism.

To abide by [RFC3748], the server sends a cleartext EAP Success or EAP Failure packet to terminate the EAP conversation. However, since EAP Success and EAP Failure packets are not retransmitted, the final packet may be lost. While a TEAP-protected EAP Success or EAP Failure packet should not be a final packet in a TEAP conversation, it may occur based on the conditions stated above, so an EAP peer should not rely upon the unprotected EAP Success and Failure messages.

7.7. Use of Clear-text Passwords

TEAP can carry clear-text passwords in the Basic-Password-Auth-Resp TLV. Implementations should take care to protect this data. For example, passwords should not normally be logged, and password data should be securely scrubbed from memory when it is no longer needed.

7.8. Accidental or Unintended Behavior

Due to the complexity of TEAP, and the long time between [RFC7170] and any substantial implementation, there are many accidental or unintended behaviors in the protocol.

The first one is that EAP-FAST-MSCHAPv2 is used instead of EAP-MSCHAPv2. While [RFC7170] defined TEAP to use EAP-MSCHAPv2, an early implementor or implementors instead used EAP-FAST-MSCHAPv2. The choice for this document was either to define a new version of TEAP which used EAP-MSCHAPv2, or instead to document implemented behavior. The choice taken here was to document running code.

The issues discussed in Section 5.2.1 could have security impacts, but no analysis has been performed. The choice of using a special "all zero" IMSK in Section 5.2 was made for simplicity, but could also have negative security impacts.

The definition of the Crypto-Binding TLV means that it the final Crypto-Binding TLV values might not depend on all previous values of MSK and EMSK. This limitation could have negative security impacts, but again no analysis has been performed.

We suggest that the TEAP protocol be revised to TEAP version 2, which could address these issues. There are proposals at this time to better derive the various keying materials and cryptographic binding derivations. However, in the interest of documenting running code, we are publishing this document with the acknowledgement that there are improvements to be made.

7.9. Security Claims

This section provides the needed security claim requirement for EAP [RFC3748].

Auth. mechanism:	Certificate-based, shared-secret-based, and various tunneled authentication mechanisms.
Cipher Suite negotiation:	Yes
Mutual authentication:	Yes
Integrity protection:	Yes. Any method executed within the TEAP tunnel is integrity protected. The cleartext EAP headers outside the tunnel are not integrity protected. Server unauthenticated provisioning provides its own protection mechanisms.
Replay protection:	Yes
Confidentiality:	Yes
Key derivation:	Yes
Key strength:	See Note 1 below.
Dictionary attack prot.:	See Note 2 below.
Fast reconnect:	Yes
Cryptographic binding:	Yes
Session independence:	Yes
Fragmentation:	Yes
Key Hierarchy:	Yes
Channel binding:	Yes

Notes

Note 1. BCP 86 [RFC3766] offers advice on appropriate key sizes. The National Institute for Standards and Technology (NIST) also offers advice on appropriate key sizes in [NIST-SP-800-57]. [RFC3766], Section 5 advises use of the following required RSA or DH (Diffie-Hellman) module and DSA (Digital Signature Algorithm) subgroup size in bits for a given level of attack resistance in bits. Based on the table below, a 2048-bit RSA key is required to provide 112-bit equivalent key strength:

Attack Resistance (bits)	RSA or DH Modulus size (bits)	DSA subgroup size (bits)
70	947	129
80	1228	148
90	1553	167
100	1926	186
150	4575	284
200	8719	383
250	14596	482

Note 2. TEAP protects against offline dictionary attacks when secure inner methods are used. TEAP protects against online dictionary attacks by limiting the number of failed authentications for a particular identity.

8. Acknowledgments

Nearly all of the text in this document was taken directly from [RFC7170]. We are grateful to the original authors and reviewers for that document. The acknowledgments given here are only for the changes which resulted in this document.

Alexander Clouter provided substantial and detailed technical feedback on nearly every aspect of the specification. The corrections in this document are based on his work.

We wish to thank the many reviewers and commenters in the EMU WG, including Eliot Lear, Joe Salowey, Heikki Vatiainen, Bruno Pereria Vidal, and Michael Richardson. Many corner cases and edge conditions were caught and corrected as a result of their feedback.

Jouni Malinin initially pointed out the issues with RFC 7170. Those comments resulted in substantial discussion on the EMU WG mailing list, and eventually this document. Jouni also made substantial contributions in analyzing corner cases, which resulted in the text in Section 5.2.1.

9. Changes from RFC 7170

Alan DeKok was added as editor.

The document was converted to Markdown, from the [RFC7170] text output.

Any formatting changes mostly result from differences between using Markdown versus XML for source.

The IANA considerations section was replaced with a note to change the IANA registry references to this document.

A new section was added to explain that the inner EAP-MSCHAPv2 derivation follows EAP-FAST. This is the largest technical change from the previous revision of this document, and follows existing implementations.

Many small changes have been made throughout the document to correct inconsistencies, and to address mistakes. At a high level:

* All open errata have been addressed.

* A new term "inner method" has been defined.

* The definitions and derivation of IMSK, S-IMCK, etc. have been corrected and clarified.

* The diagrams in Appendix C have been updated to match the TEAP state machine

All uses of the PAC were removed. It had not been implemented, and there were no plans by implementors to use it.

Text was added on recommendations for inner and outer identities.

Section 5.2.1 was added late in the document life cycle, in order to document accidental behavior which could result in interability issues.

Appendix A Evaluation against Tunnel-Based EAP Method Requirements

This section evaluates all tunnel-based EAP method requirements described in [RFC6678] against TEAP version 1.

A.1. Requirement 4.1.1: RFC Compliance

TEAPv1 meets this requirement by being compliant with RFC 3748 [RFC3748], RFC 4017 [RFC4017], RFC 5247 [RFC5247], and RFC 4962 [RFC4962]. It is also compliant with the "cryptographic algorithm agility" requirement by leveraging TLS 1.2 for all cryptographic algorithm negotiation.

A.2. Requirement 4.2.1: TLS Requirements

TEAPv1 meets this requirement by mandating TLS version 1.2 support as defined in Section 3.2.

A.3. Requirement 4.2.1.1.1: Cipher Suite Negotiation

TEAPv1 meets this requirement by using TLS to provide protected cipher suite negotiation.

A.4. Requirement 4.2.1.1.2: Tunnel Data Protection Algorithms

TEAPv1 meets this requirement by mandating cipher suites as defined in Section 3.2.

A.5. Requirement 4.2.1.1.3: Tunnel Authentication and Key Establishment

TEAPv1 meets this requirement by mandating cipher suites which only include cipher suites that use strong cryptographic algorithms. They do not include cipher suites providing mutually anonymous authentication or static Diffie-Hellman cipher suites as defined in Section 3.2.

A.6. Requirement 4.2.1.2: Tunnel Replay Protection

TEAPv1 meets this requirement by using TLS to provide sufficient replay protection.

A.7. Requirement 4.2.1.3: TLS Extensions

TEAPv1 meets this requirement by allowing TLS extensions, such as TLS Certificate Status Request extension [RFC6066] and SessionTicket extension [RFC5077], to be used during TLS tunnel establishment.

A.8. Requirement 4.2.1.4: Peer Identity Privacy

TEAPv1 meets this requirement by establishment of the TLS tunnel and protection identities specific to the inner method. In addition, the peer certificate can be sent confidentially (i.e., encrypted).

A.9. Requirement 4.2.1.5: Session Resumption

TEAPv1 meets this requirement by mandating support of TLS session resumption as defined in Section 3.5.1 and TLS session resumption using the methods defined in [RFC9190]

A.10. Requirement 4.2.2: Fragmentation

TEAPv1 meets this requirement by leveraging fragmentation support provided by TLS as defined in Section 3.10.

A.11. Requirement 4.2.3: Protection of Data External to Tunnel

TEAPv1 meets this requirement by including the TEAP version number received in the computation of the Crypto-Binding TLV as defined in Section 4.2.13.

A.12. Requirement 4.3.1: Extensible Attribute Types

TEAPv1 meets this requirement by using an extensible TLV data layer inside the tunnel as defined in Section 4.2.

A.13. Requirement 4.3.2: Request/Challenge Response Operation

TEAPv1 meets this requirement by allowing multiple TLVs to be sent in a single EAP request or response packet, while maintaining the half-duplex operation typical of EAP.

A.14. Requirement 4.3.3: Indicating Criticality of Attributes

TEAPv1 meets this requirement by having a mandatory bit in each TLV to indicate whether it is mandatory to support or not as defined in Section 4.2.

A.15. Requirement 4.3.4: Vendor-Specific Support

TEAPv1 meets this requirement by having a Vendor-Specific TLV to allow vendors to define their own attributes as defined in Section 4.2.8.

A.16. Requirement 4.3.5: Result Indication

TEAPv1 meets this requirement by having a Result TLV to exchange the final result of the TEAP authentication so both the peer and server have a synchronized state as defined in Section 4.2.4.

A.17. Requirement 4.3.6: Internationalization of Display Strings

TEAPv1 meets this requirement by supporting UTF-8 format in the Basic-Password-Auth-Req TLV as defined in Section 4.2.14 and the Basic-Password-Auth-Resp TLV as defined in Section 4.2.15.

A.18. Requirement 4.4: EAP Channel-Binding Requirements

TEAPv1 meets this requirement by having a Channel-Binding TLV to exchange the EAP channel-binding data as defined in Section 4.2.7.

A.19. Requirement 4.5.1.1: Confidentiality and Integrity

TEAPv1 meets this requirement by running the password authentication inside a protected TLS tunnel.

A.20. Requirement 4.5.1.2: Authentication of Server

TEAPv1 meets this requirement by mandating authentication of the server before establishment of the protected TLS and then running inner password authentication as defined in Section 3.2.

A.21. Requirement 4.5.1.3: Server Certificate Revocation Checking

TEAPv1 meets this requirement by supporting TLS Certificate Status Request extension [RFC6066] during tunnel establishment.

A.22. Requirement 4.5.2: Internationalization

TEAPv1 meets this requirement by supporting UTF-8 format in Basic-Password-Auth-Req TLV as defined in Section 4.2.14 and Basic-Password-Auth-Resp TLV as defined in Section 4.2.15.

A.23. Requirement 4.5.3: Metadata

TEAPv1 meets this requirement by supporting Identity-Type TLV as defined in Section 4.2.3 to indicate whether the authentication is for a user or a machine.

A.24. Requirement 4.5.4: Password Change

TEAPv1 meets this requirement by supporting multiple Basic-Password-Auth-Req TLV and Basic-Password-Auth-Resp TLV exchanges within a single EAP authentication, which allows "housekeeping"" functions such as password change.

A.25. Requirement 4.6.1: Method Negotiation

TEAPv1 meets this requirement by supporting inner EAP method negotiation within the protected TLS tunnel.

A.26. Requirement 4.6.2: Chained Methods

TEAPv1 meets this requirement by supporting inner EAP method chaining within protected TLS tunnels as defined in Section 3.6.1.

A.27. Requirement 4.6.3: Cryptographic Binding with the TLS Tunnel

TEAPv1 meets this requirement by supporting cryptographic binding of the inner EAP method keys with the keys derived from the TLS tunnel as defined in Section 4.2.13.

A.28. Requirement 4.6.4: Peer-Initiated EAP Authentication

TEAPv1 meets this requirement by supporting the Request-Action TLV as defined in Section 4.2.9 to allow a peer to initiate another inner EAP method.

A.29. Requirement 4.6.5: Method Metadata

TEAPv1 meets this requirement by supporting the Identity-Type TLV as defined in Section 4.2.3 to indicate whether the authentication is for a user or a machine.

Appendix B. Major Differences from EAP-FAST

This document is a new standard tunnel EAP method based on revision of EAP-FAST version 1 [RFC4851] that contains improved flexibility, particularly for negotiation of cryptographic algorithms. The major changes are:

1. The EAP method name has been changed from EAP-FAST to TEAP; this change thus requires that a new EAP Type be assigned.

2. This version of TEAP MUST support TLS 1.2 [RFC5246]. TLS 1.1 and earlier MUST NOT be used with TEAP.

3. The key derivation now makes use of TLS keying material exporters [RFC5705] and the PRF and hash function negotiated in TLS. This is to simplify implementation and better support cryptographic algorithm agility.

4. TEAP is in full conformance with TLS ticket extension [RFC5077].

5. Support is provided for passing optional Outer TLVs in the first two message exchanges, in addition to the Authority-ID TLV data in EAP-FAST.

6. Basic password authentication on the TLV level has been added in addition to the existing inner EAP method.

7. Additional TLV types have been defined to support EAP channel binding and metadata. They are the Identity-Type TLV and Channel-Binding TLVs, defined in Section 4.2.

Appendix C. Examples

C.1. Successful Authentication

The following exchanges show a successful TEAP authentication with basic password authentication. The conversation will appear as follows:

```
   Authenticating Peer     Authenticator
   -------------------     -------------
                           <- EAP-Request/
                           Identity
   EAP-Response/
   Identity (MyID1) ->
                           <- EAP-Request/
                           EAP-Type=TEAP, V=1
                           (TEAP Start, S bit set, Authority-ID)

   EAP-Response/
   EAP-Type=TEAP, V=1
   (TLS client_hello) ->

                           <- EAP-Request/
                           EAP-Type=TEAP, V=1
                           (TLS server_hello,
                           (TLS change_cipher_spec,
                            TLS finished)

   EAP-Response/
   EAP-Type=TEAP, V=1 ->
   (TLS change_cipher_spec,
    TLS finished)

   TLS channel established
   (messages sent within the TLS channel)

                        <- Basic-Password-Auth-Req TLV, Challenge

   Basic-Password-Auth-Resp TLV, Response with both
   username and password) ->

   optional additional exchanges (new pin mode,
   password change, etc.) ...

                       <- Intermediate-Result TLV (Success),
                           Crypto-Binding TLV (Request),
                           Result TLV (Success)
```

```
      Intermediate-Result TLV (Success),
      Crypto-Binding TLV(Response),
      Result TLV (Success) ->

      TLS channel torn down
      (messages sent in cleartext)

                              <- EAP-Success
```

C.2. Failed Authentication

The following exchanges show a failed TEAP authentication due to wrong user credentials. The conversation will appear as follows:

```
      Authenticating Peer     Authenticator
      -------------------     -------------
                              <- EAP-Request/Identity

      EAP-Response/
      Identity (MyID1) ->


                              <- EAP-Request/
                              EAP-Type=TEAP, V=1
                              (TEAP Start, S bit set, Authority-ID)

      EAP-Response/
      EAP-Type=TEAP, V=1
      (TLS client_hello) ->

                              <- EAP-Request/
                              EAP-Type=TEAP, V=1
                              (TLS server_hello,
                              (TLS change_cipher_spec,
                               TLS finished)

      EAP-Response/
      EAP-Type=TEAP, V=1 ->
      (TLS change_cipher_spec,
       TLS finished)

      TLS channel established
      (messages sent within the TLS channel)

                             <- Basic-Password-Auth-Req TLV, Challenge

      Basic-Password-Auth-Resp TLV, Response with both
      username and password) ->

                              <- Intermediate-Result TLV (Failure),
                                 Result TLV (Failure)

      Intermediate-Result TLV (Failure),
      Result TLV (Failure) ->

      TLS channel torn down
      (messages sent in cleartext)

                              <- EAP-Failure
```

C.3. Full TLS Handshake Using Certificate-Based Cipher Suite

In the case within TEAP Phase 1 where an abbreviated TLS handshake is tried, fails, and falls back to the certificate-based full TLS handshake, 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=TEAP, V=1
                          (TEAP Start, S bit set, Authority-ID)
  EAP-Response/
  EAP-Type=TEAP, V=1
  (TLS client_hello with
  SessionTicket extension)->

  // If the server rejects the session resumption,
     it falls through to the full TLS handshake.

                          <- EAP-Request/
                          EAP-Type=TEAP, V=1
                          (TLS server_hello,
                           TLS certificate,
                          [TLS server_key_exchange,]
                          [TLS certificate_request,]
                           TLS server_hello_done)

  EAP-Response/
  EAP-Type=TEAP, V=1
  ([TLS certificate,]
   TLS client_key_exchange,
  [TLS certificate_verify,]
   TLS change_cipher_spec,
   TLS finished) ->
                          <- EAP-Request/
                          EAP-Type=TEAP, V=1
                          (TLS change_cipher_spec,
                           TLS finished,
                           EAP-Payload TLV[EAP-Request/
                           Identity])
```

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

     // First EAP Payload TLV is coalesced with the TLS Finished as
        Application Data and protected by the TLS tunnel.

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

     // identity protected by TLS.

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

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

     // Method X exchanges followed by Protected Termination

                           <- Intermediate-Result TLV (Success),
                               Crypto-Binding TLV (Request),
                               Result TLV (Success)

     Intermediate-Result TLV (Success),
     Crypto-Binding TLV (Response),
     Result TLV (Success) ->

     // TLS channel torn down
     (messages sent in cleartext)

                              <- EAP-Success
```

C.4. Client Authentication during Phase 1 with Identity Privacy

In the case where a certificate-based TLS handshake occurs within TEAP Phase 1 and client certificate authentication and identity privacy is desired (and therefore TLS renegotiation is being used to transmit the peer credentials in the protected TLS tunnel), the conversation will appear as follows for TLS 1.2:

```
  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=TEAP, V=1
                            (TEAP Start, S bit set, Authority-ID)
     EAP-Response/
     EAP-Type=TEAP, V=1
     (TLS client_hello)->
                            <- EAP-Request/
                            EAP-Type=TEAP, V=1
                            (TLS server_hello,
                             TLS certificate,
                            [TLS server_key_exchange,]
                            [TLS certificate_request,]
                             TLS server_hello_done)
     EAP-Response/
     EAP-Type=TEAP, V=1
     (TLS client_key_exchange,
      TLS change_cipher_spec,
      TLS finished) ->
                            <- EAP-Request/
                            EAP-Type=TEAP, V=1
                            (TLS change_cipher_spec,
                             TLS finished,
                             EAP-Payload TLV[EAP-Request/
                             Identity])

     // TLS channel established
        (EAP Payload messages sent within the TLS channel)

     // peer sends TLS client_hello to request TLS renegotiation
     TLS client_hello ->

                            <- TLS server_hello,
                             TLS certificate,
                             [TLS server_key_exchange,]
                             [TLS certificate_request,]
                             TLS server_hello_done
     [TLS certificate,]
      TLS client_key_exchange,
     [TLS certificate_verify,]
      TLS change_cipher_spec,
      TLS finished ->

                            <- TLS change_cipher_spec,
                               TLS finished,
                               Crypto-Binding TLV (Request),
                               Result TLV (Success)
```

```
     Crypto-Binding TLV (Response),
     Result TLV (Success)) ->

     //TLS channel torn down
     (messages sent in cleartext)

                              <- EAP-Success
```

C.5. Fragmentation and Reassembly

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

```
     Authenticating Peer     Authenticator
     -------------------     -------------
                             <- EAP-Request/
                             Identity
     EAP-Response/
     Identity (MyID) ->
                             <- EAP-Request/
                             EAP-Type=TEAP, V=1
                             (TEAP Start, S bit set, Authority-ID)

     EAP-Response/
     EAP-Type=TEAP, V=1
     (TLS client_hello)->

                             <- EAP-Request/
                             EAP-Type=TEAP, V=1
                             (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=TEAP, V=1 ->

                             <- EAP-Request/
                                EAP-Type=TEAP, V=1
                             (Fragment 2: M bit set)
     EAP-Response/
     EAP-Type=TEAP, V=1 ->
                             <- EAP-Request/
                             EAP-Type=TEAP, V=1
                             (Fragment 3)
     EAP-Response/
```

```
     EAP-Type=TEAP, V=1
     ([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=TEAP, V=1
     EAP-Response/
     EAP-Type=TEAP, V=1
     (Fragment 2)->
                             <- EAP-Request/
                              EAP-Type=TEAP, V=1
                              (TLS change_cipher_spec,
                               TLS finished,
                              [EAP-Payload TLV[
                              EAP-Request/Identity]])

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

     // First EAP Payload TLV is coalesced with the TLS Finished as
        Application Data and protected by the TLS tunnel.

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

     // identity protected by TLS.

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

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

     // Method X exchanges followed by Protected Termination

                           <- Intermediate-Result TLV (Success),
                               Crypto-Binding TLV (Request),
                               Result TLV (Success)

     Intermediate-Result TLV (Success),
     Crypto-Binding TLV (Response),
     Result TLV (Success) ->

     // TLS channel torn down
```

```
     (messages sent in cleartext)

                              <- EAP-Success
```

C.6. Sequence of EAP Methods

When TEAP 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=TEAP, V=1
                          (TEAP Start, S bit set, Authority-ID)

  EAP-Response/
  EAP-Type=TEAP, V=1
  (TLS client_hello)->

                          <- EAP-Request/
                          EAP-Type=TEAP, V=1
                          (TLS server_hello,
                           TLS certificate,
                          [TLS server_key_exchange,]
                          [TLS certificate_request,]
                           TLS server_hello_done)
  EAP-Response/
  EAP-Type=TEAP, V=1
  ([TLS certificate,]
   TLS client_key_exchange,
  [TLS certificate_verify,]
   TLS change_cipher_spec,
   TLS finished) ->
                         <- EAP-Request/
                          EAP-Type=TEAP, V=1
                          (TLS change_cipher_spec,
                           TLS finished,
                           Identity-Type TLV,
                          EAP-Payload TLV[
                          EAP-Request/Identity])

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

```
     // First EAP Payload TLV is coalesced with the TLS Finished as
        Application Data and protected by the TLS tunnel

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

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

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

            // Optional additional X Method exchanges...

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

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

                              <- Intermediate Result TLV (Success),
                               Crypto-Binding TLV (Request),
                               Identity-Type TLV,
                              EAP-Payload TLV[
                              EAP-Request/Identity])

     // Compound MAC calculated using keys generated from
        EAP method X and the TLS tunnel.

     // Next EAP conversation started (with EAP-Request/Identity)
        after successful completion of previous method X.  The
        Intermediate-Result and Crypto-Binding TLVs are sent in
        the next packet to minimize round trips.

     Intermediate Result TLV (Success),
     Crypto-Binding TLV (Response),
     EAP-Payload TLV [EAP-Response/Identity (MyID2)] ->

            // Optional additional EAP method Y exchanges...

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

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

                             <- Intermediate-Result TLV (Success),
```

```
                              Crypto-Binding TLV (Request),
                              Result TLV (Success)

     Intermediate-Result TLV (Success),
     Crypto-Binding TLV (Response),
     Result TLV (Success) ->

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

     // TLS channel torn down (messages sent in cleartext)

                              <- EAP-Success
```

C.7. Failed Crypto-Binding

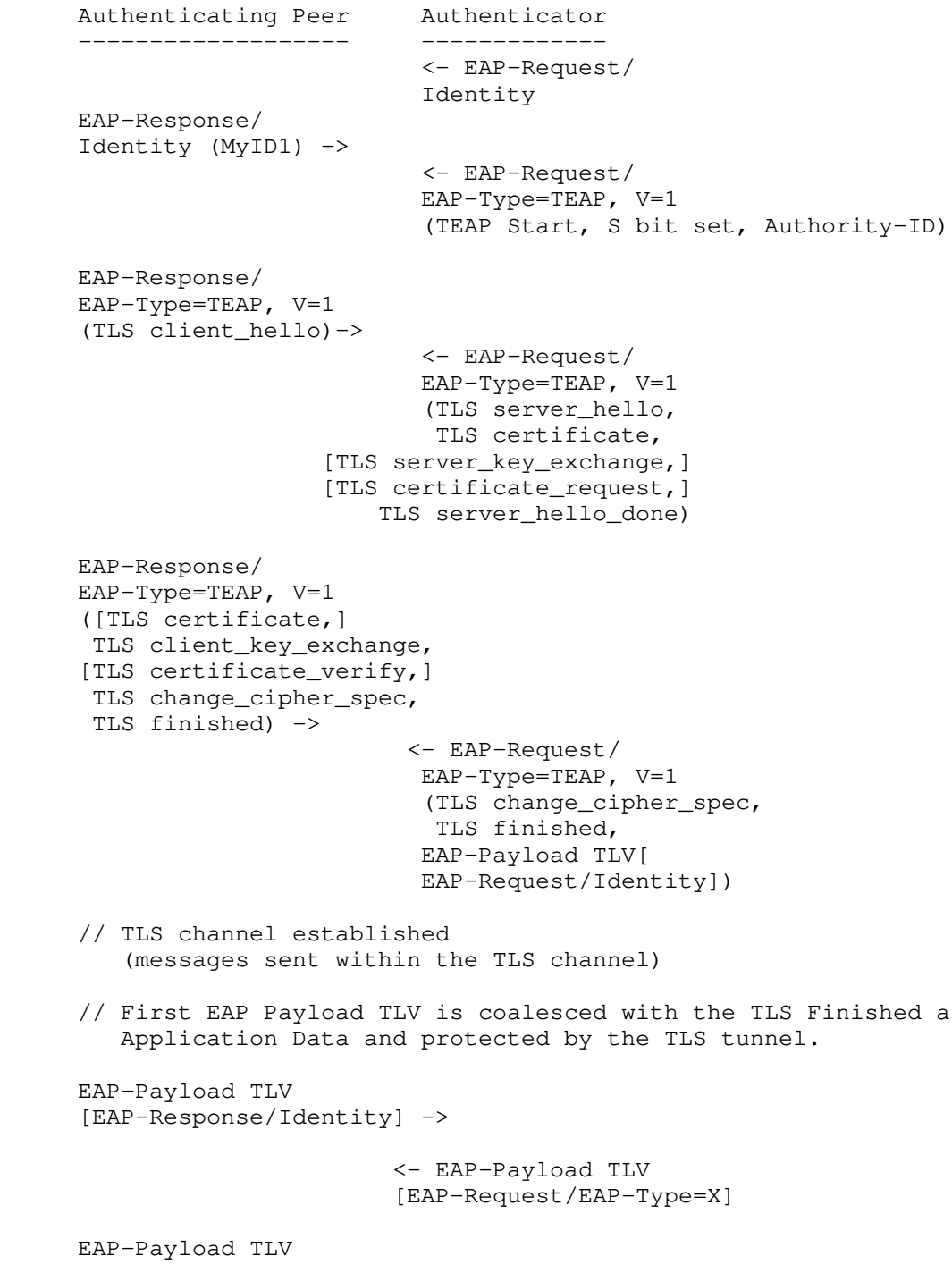
The following exchanges show a failed crypto-binding validation. The conversation will appear as follows:

```
  Authenticating Peer     Authenticator
  -------------------     -------------
                          <- EAP-Request/
                          Identity
  EAP-Response/
  Identity (MyID1) ->
                          <- EAP-Request/
                          EAP-Type=TEAP, V=1
                          (TEAP Start, S bit set, Authority-ID)

  EAP-Response/
  EAP-Type=TEAP, V=1
  (TLS client_hello) ->
                          <- EAP-Request/
                          EAP-Type=TEAP, V=1
                          (TLS Server Key Exchange
                           TLS Server Hello Done)
  EAP-Response/
  EAP-Type=TEAP, V=1 ->
  (TLS Client Key Exchange
   TLS change_cipher_spec,
   TLS finished)

                          <- EAP-Request/
                          EAP-Type=TEAP, V=1
                          (TLS change_cipher_spec
                           TLS finished)
```

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

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

        // First EAP Payload TLV is coalesced with the TLS Finished as
           Application Data and protected by the TLS tunnel.

     EAP-Payload TLV/
     EAP Identity Response ->

                           <-  EAP Payload TLV, EAP-Request,
                               (EAP-FAST-MSCHAPV2, Challenge)

     EAP Payload TLV, EAP-Response,
     (EAP-FAST-MSCHAPV2, Response) ->

                           <-  EAP Payload TLV, EAP-Request,
                               (EAP-FAST-MSCHAPV2, Success Request)

     EAP Payload TLV, EAP-Response,
     (EAP-FAST-MSCHAPV2, Success Response) ->

                         <- Intermediate-Result TLV (Success),
                             Crypto-Binding TLV (Request),
                                Result TLV (Success)

        Intermediate-Result TLV (Success),
        Result TLV (Failure)
        Error TLV with
        (Error Code = 2001) ->

     // TLS channel torn down
        (messages sent in cleartext)

                           <- EAP-Failure
```

C.8. Sequence of EAP Method with Vendor-Specific TLV Exchange

When TEAP is negotiated with a sequence of EAP methods followed by a Vendor-Specific TLV exchange, the conversation will occur as follows:


Authenticating Peer
Authenticator
<- EAP-Request/
Identity
EAP-Response/
Identity (MyID1) ->
<- EAP-Request/
EAP-Type=TEAP, V=1
(TEAP Start, S bit set, Authority-ID)
EAP-Response/
EAP-Type=TEAP, V=1
(TLS client_hello)->
<- EAP-Request/
EAP-Type=TEAP, V=1
(TLS server_hello,
TLS certificate,
[TLS server_key_exchange,]
[TLS certificate_request,]
TLS server_hello_done)
EAP-Response/
EAP-Type=TEAP, V=1
([TLS certificate,]
TLS client_key_exchange,
[TLS certificate_verify,]
TLS change_cipher_spec,
TLS finished) ->
<- EAP-Request/
EAP-Type=TEAP, V=1
(TLS change_cipher_spec,
TLS finished,
EAP-Payload TLV[
EAP-Request/Identity])
// TLS channel established
(messages sent within the TLS channel)
// First EAP Payload TLV is coalesced with the TLS Finished as
Application Data and protected by the TLS tunnel.
EAP-Payload TLV
[EAP-Response/Identity] ->
<- EAP-Payload TLV
[EAP-Request/EAP-Type=X]
EAP-Payload TLV

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

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

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

                              <- Intermediate Result TLV (Success),
                               Crypto-Binding TLV (Request),
                               Vendor-Specific TLV,

     // Vendor-Specific TLV exchange started after successful
        completion of previous method X.  The Intermediate-Result
        and Crypto-Binding TLVs are sent with Vendor-Specific TLV
        in next packet to minimize round trips.

     // Compound MAC calculated using keys generated from
        EAP method X and the TLS tunnel.

     Intermediate Result TLV (Success),
     Crypto-Binding TLV (Response),
     Vendor-Specific TLV ->

         // Optional additional Vendor-Specific TLV exchanges...

                             <- Vendor-Specific TLV

     Vendor-Specific TLV ->
                             <- Result TLV (Success)

     Result TLV (Success) ->

     // TLS channel torn down (messages sent in cleartext)

                              <- EAP-Success
```

C.9. Peer Requests Inner Method after Server Sends Result TLV

In the case where the peer is authenticated during Phase 1 and the server sends back a Result TLV but the peer wants to request another inner method, 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. TLS client certificate is also sent.

                        <- EAP-Request/
                        EAP-Type=TEAP, V=1
                        (TEAP Start, S bit set, Authority-ID)
EAP-Response/
EAP-Type=TEAP, V=1
(TLS client_hello)->
                        <- EAP-Request/
                        EAP-Type=TEAP, V=1
                        (TLS server_hello,
                         TLS certificate,
                        [TLS server_key_exchange,]
                        [TLS certificate_request,]
                         TLS server_hello_done)

EAP-Response/
EAP-Type=TEAP, V=1
[TLS certificate,]
 TLS client_key_exchange,
[TLS certificate_verify,]
 TLS change_cipher_spec,
 TLS finished ->
                        <- EAP-Request/
                        EAP-Type=TEAP, V=1
                        (TLS change_cipher_spec,
                         TLS finished,
                         Crypto-Binding TLV (Request),
                          Result TLV (Success))

// TLS channel established
   (TLV Payload messages sent within the TLS channel)

 Crypto-Binding TLV(Response),
 Request-Action TLV
 (Status=Failure, Action=Negotiate-EAP)->

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

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

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

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

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

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

                             <- Intermediate Result TLV (Success),
                                Crypto-Binding TLV (Request),
                                Result TLV (Success)

     Intermediate Result TLV (Success),
     Crypto-Binding TLV (Response),
     Result TLV (Success)) ->

     // TLS channel torn down
     (messages sent in cleartext)

                             <- EAP-Success
```

C.10. Channel Binding

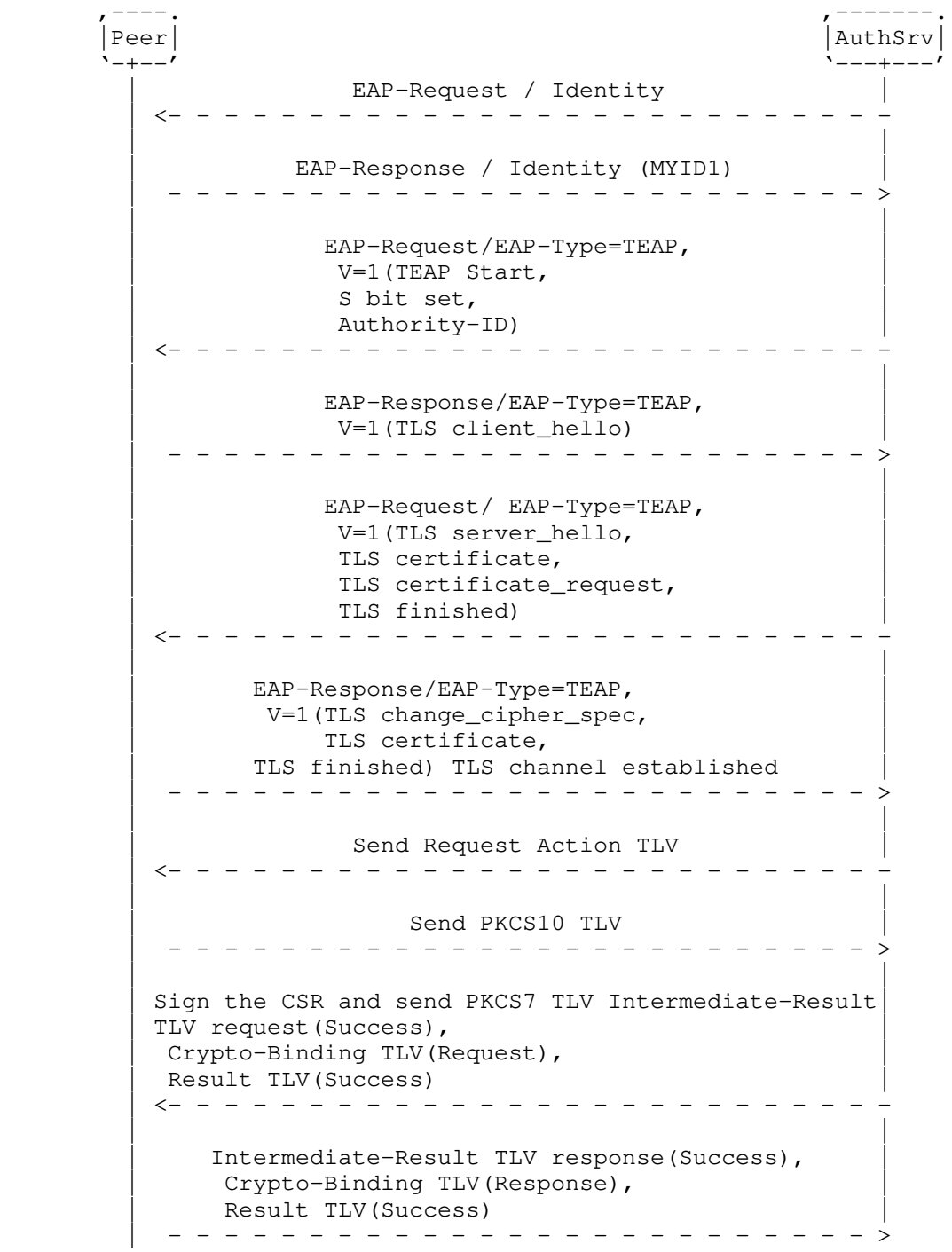
The following exchanges show a successful TEAP authentication with basic password authentication and channel binding using a Request-Action TLV. The conversation will appear as follows:

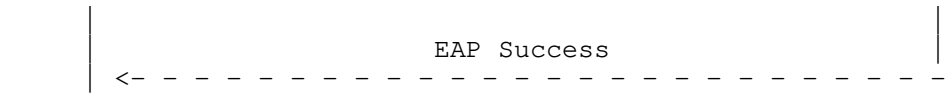
```
   Authenticating Peer     Authenticator
   -------------------     -------------
                           <- EAP-Request/
                           Identity
   EAP-Response/
   Identity (MyID1) ->

                           <- EAP-Request/
                           EAP-Type=TEAP, V=1
                           (TEAP Start, S bit set, Authority-ID)

   EAP-Response/
   EAP-Type=TEAP, V=1
   (TLS client_hello) ->
```

```
                              <- EAP-Request/
                              EAP-Type=TEAP, V=1
                              (TLS server_hello,
                              (TLS change_cipher_spec,
                               TLS finished)

      EAP-Response/
      EAP-Type=TEAP, V=1 ->
      (TLS change_cipher_spec,
       TLS finished)

      TLS channel established
      (messages sent within the TLS channel)

                            <- Basic-Password-Auth-Req TLV, Challenge

      Basic-Password-Auth-Resp TLV, Response with both
      username and password) ->

      optional additional exchanges (new pin mode,
      password change, etc.) ...

                           <- Crypto-Binding TLV (Request),
                               Result TLV (Success),

      Crypto-Binding TLV(Response),
      Request-Action TLV
      (Status=Failure, Action=Process TLV,
      TLV=Channel-Binding TLV)->

                              <- Channel-Binding TLV (Response),
                              Result TLV (Success),

      Result TLV (Success) ->

      TLS channel torn down
      (messages sent in cleartext)

                              <- EAP-Success
```

C.11. PKCS Exchange

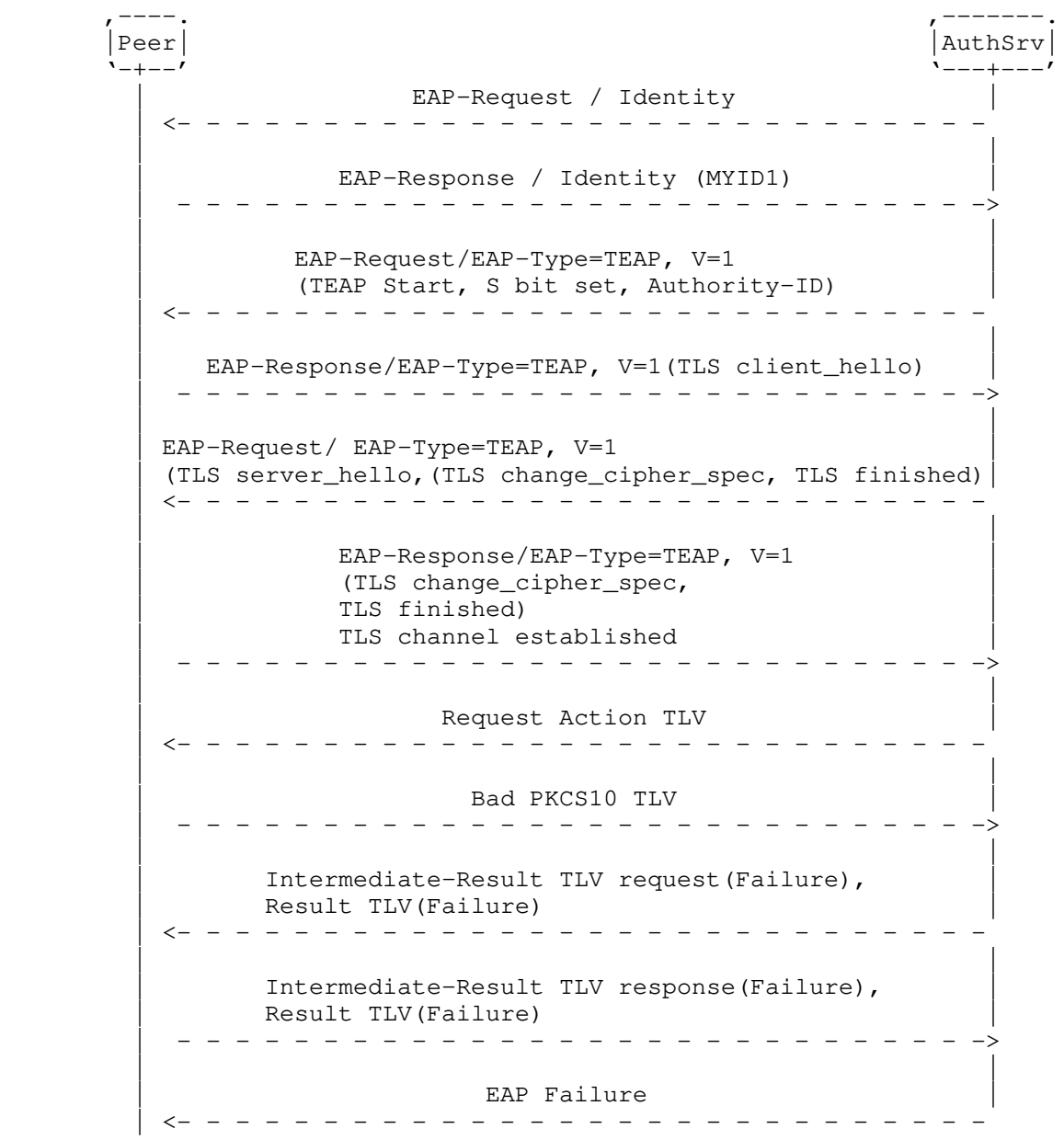
The following exchanges show the peer sending a PKCS#10 TLV, and server replying with a PKCS7 TLV. The exchange below assumes that the EAP peer is authenticated in Phase 1, either via bi-directional certificate exchange, or some other TLS method such as a proof of knowledge (TLS-POK). The conversation will appear as follows:


Peer
AuthSrv
EAP-Request / Identity
EAP-Response / Identity (MYID1)
EAP-Request/EAP-Type=TEAP,
V=1(TEAP Start,
S bit set,
Authority-ID)
EAP-Response/EAP-Type=TEAP,
V=1(TLS client_hello)
EAP-Request/ EAP-Type=TEAP,
V=1(TLS server_hello,
TLS certificate,
TLS certificate_request,
TLS finished)
EAP-Response/EAP-Type=TEAP,
V=1(TLS change_cipher_spec,
TLS certificate,
TLS finished) TLS channel established
Send Request Action TLV
Send PKCS10 TLV
Sign the CSR and send PKCS7 TLV Intermediate-Result
TLV request(Success),
Crypto-Binding TLV(Request),
Result TLV(Success)
Intermediate-Result TLV response(Success),
Crypto-Binding TLV(Response),
Result TLV(Success)



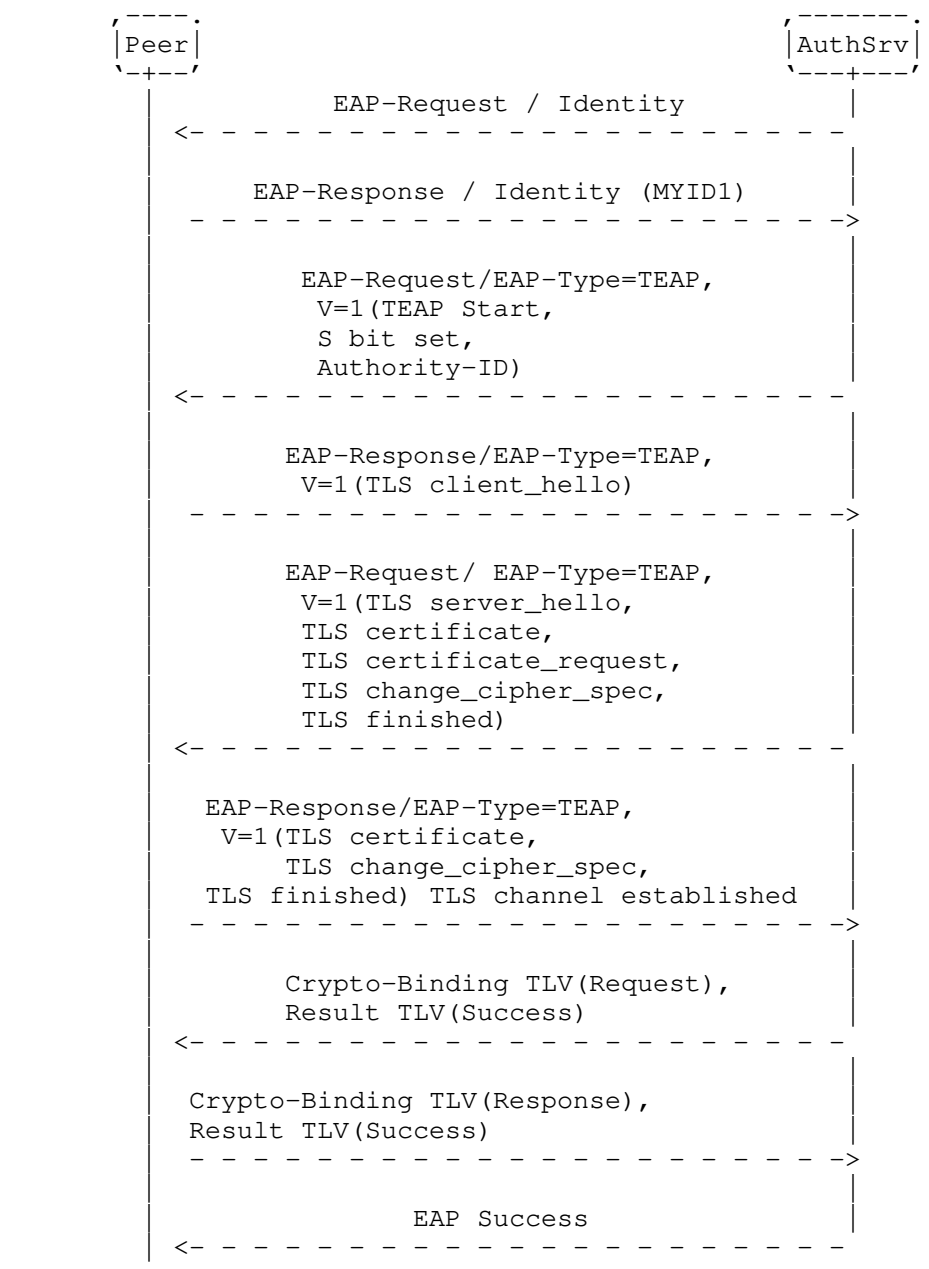
C.12. Failure Scenario

The following exchanges shows a failure scenario. The conversation will appear as follows:



C.13. Client certificate in Phase 1

The following exchanges shows a scenario where the client certificate is sent in Phase 1, and no additional authentication or provisioning is performed in Phase 2. The conversation will appear as follows:



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EMU Working Group
Internet-Draft
Intended status: Standards Track
Expires: 15 March 2024

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Using the Extensible Authentication Protocol with Ephemeral Diffie-Hellman over COSE (EDHOC) draft-ingles-eap-edhoc-05

Abstract

The Extensible Authentication Protocol (EAP), defined in RFC 3748, provides a standard mechanism for support of multiple authentication methods. This document specifies the use of EAP-EDHOC with Ephemeral Diffie-Hellman Over COSE (EDHOC). EDHOC provides a lightweight authenticated Diffie-Hellman key exchange with ephemeral keys, using COSE (RFC 8152) to provide security services efficiently encoded in CBOR (RFC 8949). This document also provides guidance on authentication and authorization for EAP-EDHOC.

Table of Contents

1. Introduction

The Extensible Authentication Protocol (EAP), defined in [RFC3748], provides a standard mechanism for support of multiple authentication methods. This document specifies the EAP authentication method EAP-EDHOC which uses COSE defined credential-based mutual authentication, utilizing the EDHOC protocol cipher suite negotiation and establishment of shared secret keying material. Ephemeral Diffie-Hellman Over COSE (EDHOC, [I-D.ietf-lake-edhoc]) is a very compact

and lightweight authenticated key exchange protocol designed for highly constrained settings. The main objective for EDHOC is to be a matching security handshake protocol to OSCORE [RFC8613], i.e., to provide authentication and session key establishment for IoT use cases such as those built on CoAP [RFC7252] involving 'things' with embedded microcontrollers, sensors, and actuators. EDHOC reuses the same lightweight primitives as OSCORE, CBOR [RFC8949] and COSE [RFC8152], and specifies the use of CoAP but is not bound to a particular transport. The EAP-EDHOC method will enable the integration of EDHOC in different applications and use cases making use of the EAP framework.

2. Conventions and Definitions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. Protocol Overview

3.1. Overview of the EAP-EDHOC Conversation

The EDHOC protocol running between an Initiator and a Responder consists of three mandatory messages (message_1, message_2, message_3), an optional message_4, and an error message. EAP-EDHOC uses all messages in the exchange, and message_4 is mandatory, as an alternate success indication.

After receiving an EAP-Request packet with EAP-Type=EAP-EDHOC as described in this document, the conversation will continue with the EDHOC protocol encapsulated in the data fields of EAP-Response and EAP-Request packets. When EAP-EDHOC is used, the formatting and processing of the EDHOC message SHALL be done as specified in [I-D.ietf-lake-edhoc]. This document only lists additional and different requirements, restrictions, and processing compared to [I-D.ietf-lake-edhoc].

3.1.1. Authentication

EAP-EDHOC authentication credentials can be of any type supported by COSE and be transported or referenced by EDHOC.

EAP-EDHOC provides forward secrecy by exchange of ephemeral Diffie-Hellman public keys in message_1 and message_2.

The optimization combining the execution of EDHOC with the first subsequent OSCORE transaction specified in [I-D.ietf-core-oscore-edhoc] is not supported in this EAP method.

Figure 1 shows an example message flow for a successful EAP-EDHOC.

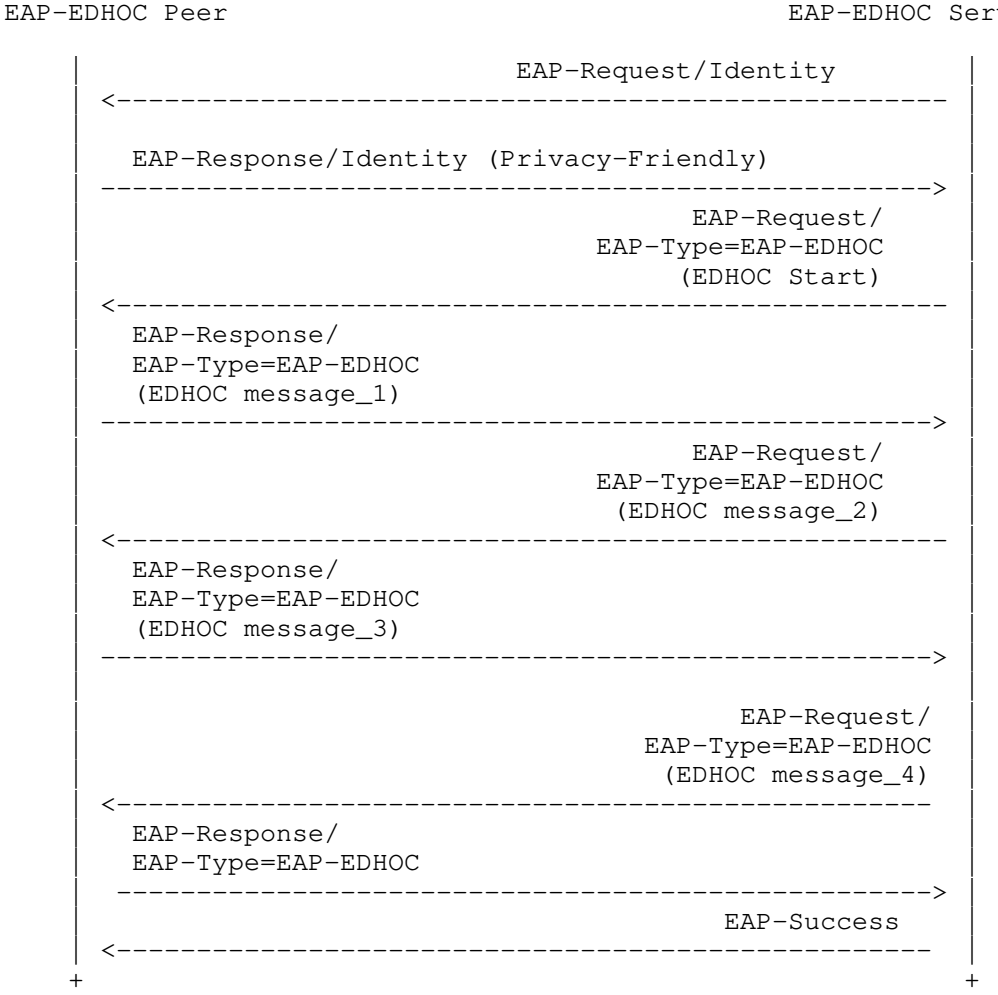


Figure 1: EAP-EDHOC Mutual Authentication

3.1.2. Transport and Message Correlation

EDHOC is not bound to a particular transport layer and can even be used in environments without IP. Nonetheless, EDHOC specification has a set of requirements for its transport protocol [I-D.ietf-lake-edhoc]. These include handling message loss, reordering, duplication, fragmentation, demultiplex EDHOC messages from other types of messages, denial-of-service protection, and message correlation. All these requirements are fulfilled either by the EAP protocol, EAP method or EAP lower layer, as specified in [RFC3748].

For message loss, this can be either fulfilled by the EAP protocol or the EAP lower layer, as retransmissions can occur both in the lower layer and the EAP layer when EAP is run over a reliable lower layer. In other words, the EAP layer will do the retransmissions if the EAP lower layer cannot do it.

For reordering, EAP is reliant on the EAP lower layer ordering guarantees for correct operation.

For duplication and message correlation, EAP has the Identifier field, which provides both the peer and authenticator with the ability to detect duplicates and match a request with a response.

Fragmentation is defined by this EAP method, see Section 3.1.6. The EAP framework [RFC3748] specifies that EAP methods need to provide fragmentation and reassembly if EAP packets can exceed the minimum MTU of 1020 octets.

To demultiplex EDHOC messages from other types of messages, EAP provides the Code field.

This method does not provide other mitigation against denial-of-service than EAP [RFC3748].

3.1.3. Termination

If the EAP-EDHOC peer authenticates successfully, the EAP-EDHOC server MUST send an EAP-Request packet with EAP-Type=EAP-EDHOC containing message_4 as a protected success indication.

If the EAP-EDHOC server authenticates successfully, the EAP-EDHOC peer MUST send an EAP-Response message with EAP-Type=EAP-EDHOC containing no data. Finally, the EAP-EDHOC server sends an EAP-Success.

Figure 2, Figure 3 and Figure 4 illustrate message flows in several cases where the EAP-EDHOC peer or EAP-EDHOC server sends an EDHOC error message.

Figure 2 shows an example message flow where the EAP-EDHOC server rejects message_1 with an EDHOC error message.

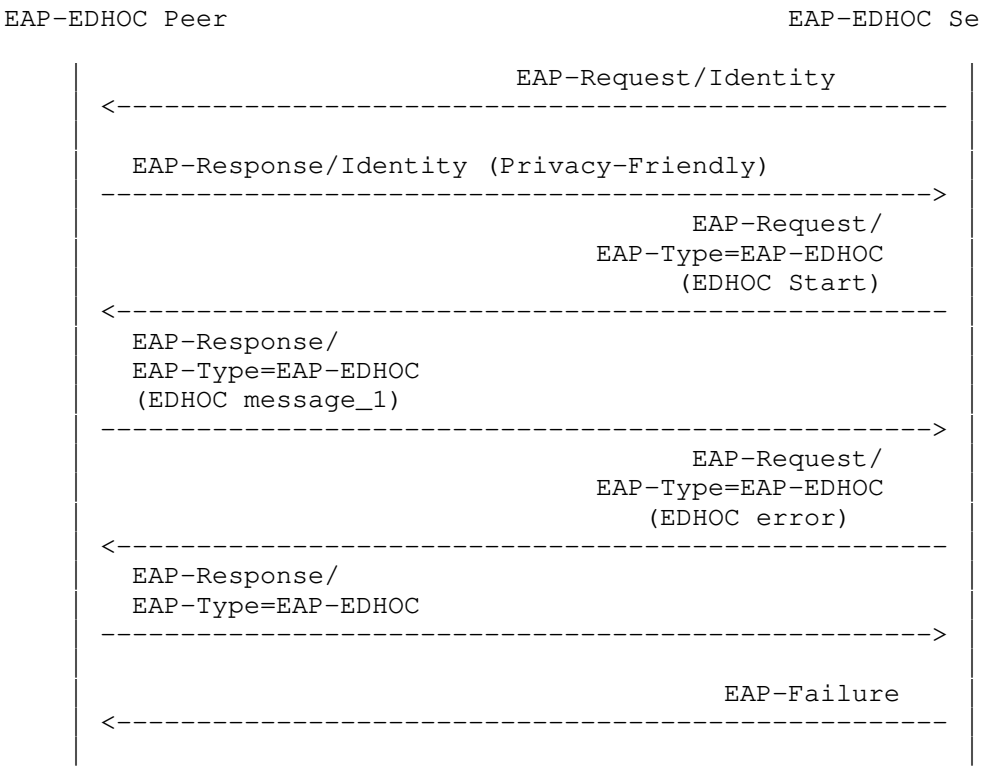


Figure 2: EAP-EDHOC Server rejection of message_1

Figure 3 shows an example message flow where the EAP-EDHOC server authentication is unsuccessful and the EAP-EDHOC peer sends an EDHOC error message.

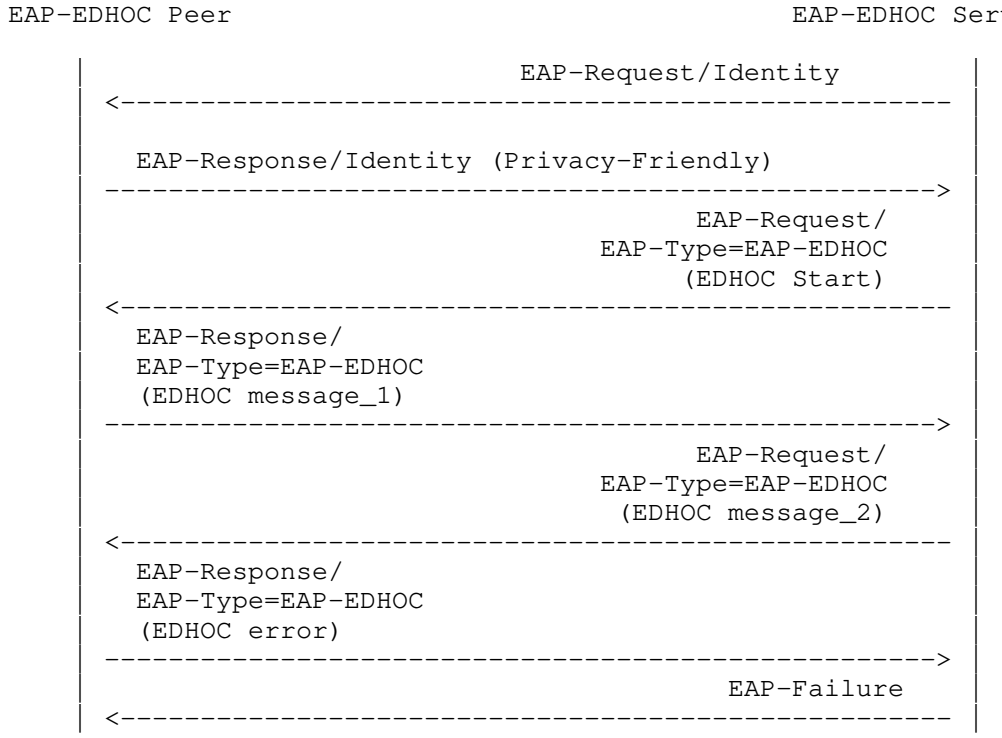


Figure 3: EAP-EDHOC Peer rejection of message_2

Figure 4 shows an example message flow where the EAP-EDHOC server authenticates to the EAP-EDHOC peer successfully, but the EAP-EDHOC peer fails to authenticate to the EAP-EDHOC server and the server sends an EDHOC error message.

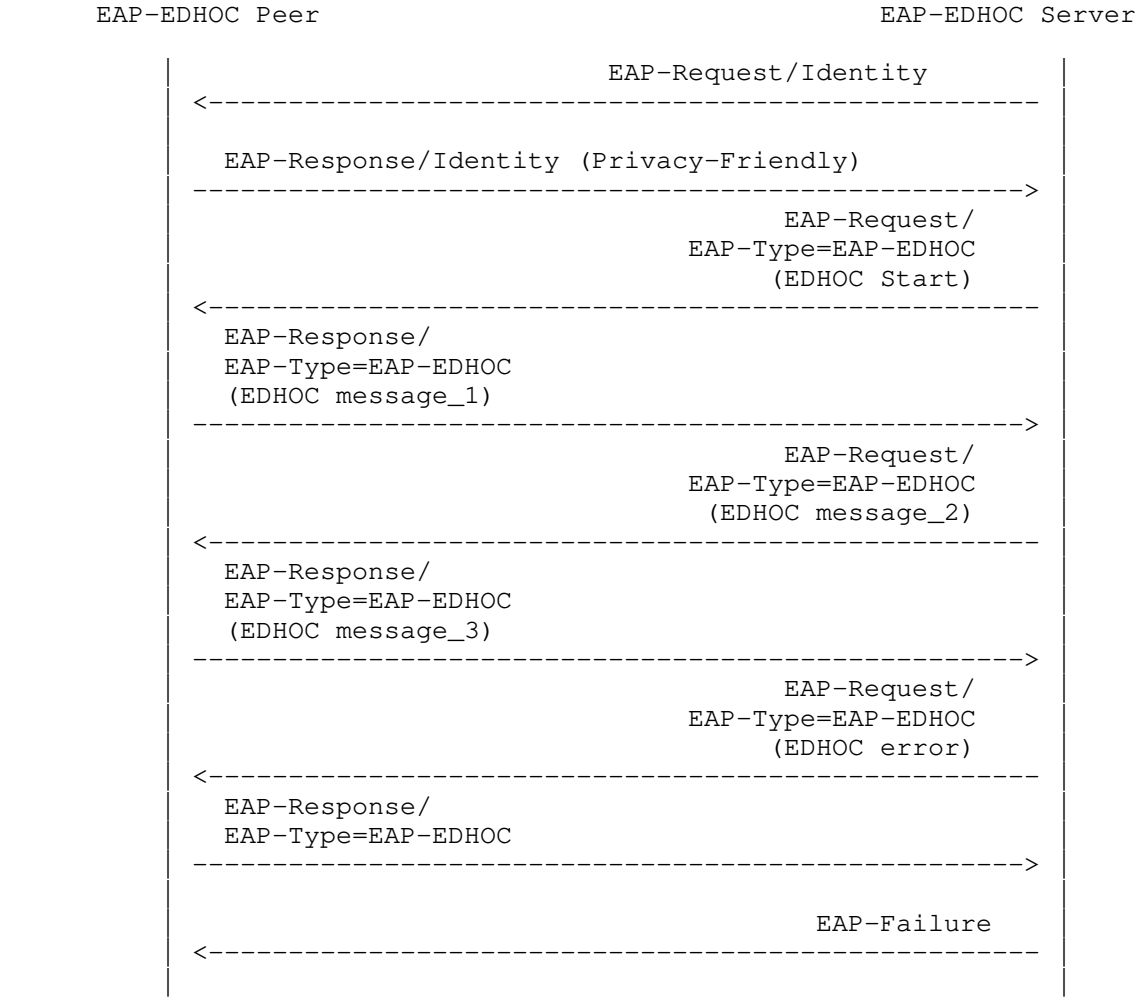


Figure 4: EAP-EDHOC Server rejection of message_3

Figure 4 shows an example message flow where the EAP-EDHOC server sends the EDHOC message_4 to the EAP peer, but the success indication fails, and the peer sends an EDHOC error message.

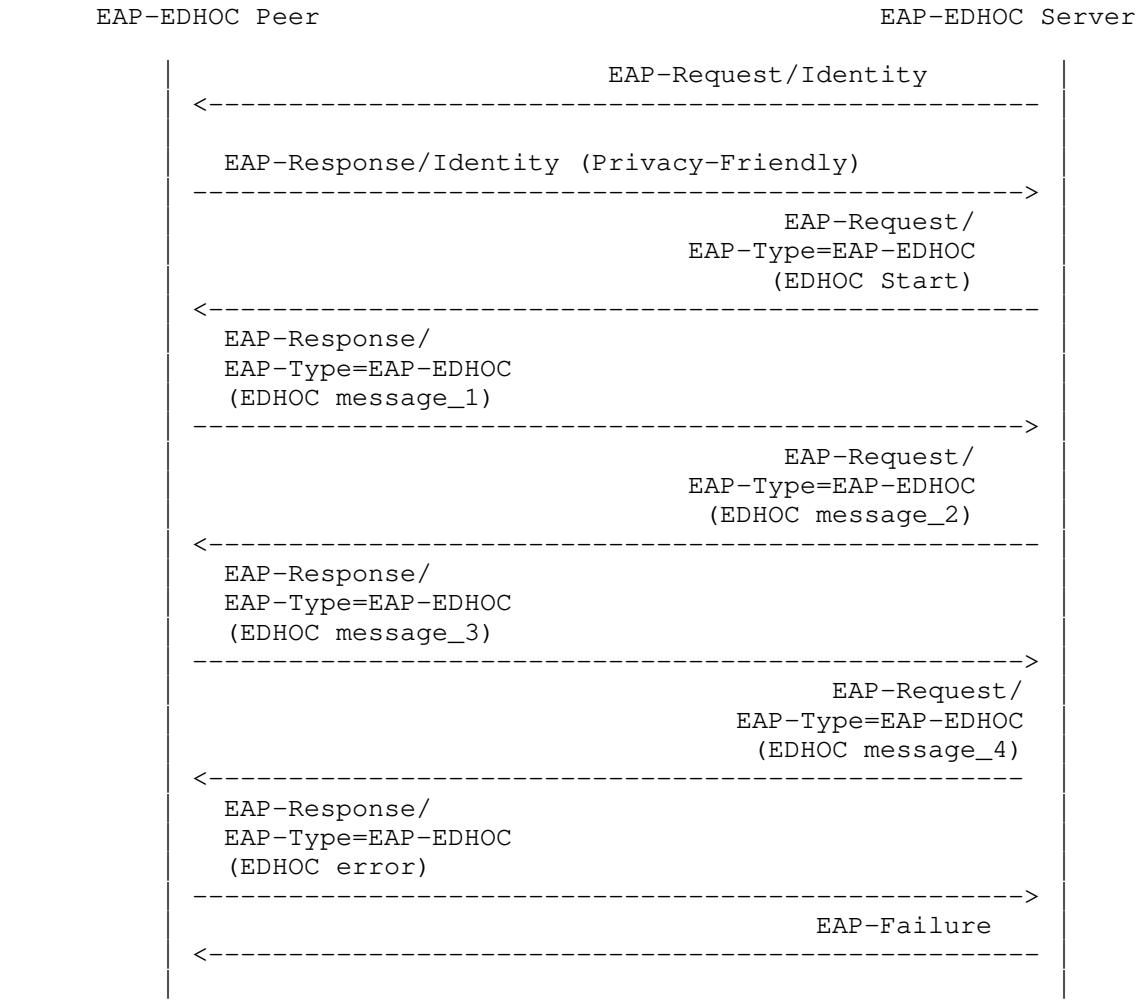


Figure 5: EAP-EDHOC Peer rejection of message_4

3.1.4. Identity

It is RECOMMENDED to use anonymous NAIs [RFC7542] in the Identity Response as such identities are routable and privacy-friendly.

While opaque blobs are allowed by [RFC3748], such identities are NOT RECOMMENDED as they are not routable and should only be considered in local deployments where the EAP-EDHOC peer, EAP authenticator, and EAP-EDHOC server all belong to the same network.

Many client certificates contain an identity such as an email address, which is already in NAI format. When the client certificate contains an NAI as subject name or alternative subject name, an anonymous NAI SHOULD be derived from the NAI in the certificate; See Section 3.1.5.

3.1.5. Privacy

EAP-EDHOC peer and server implementations supporting EAP-EDHOC MUST support anonymous Network Access Identifiers (NAIs) (Section 2.4 of [RFC7542]). A client supporting EAP-EDHOC MUST NOT send its username (or any other permanent identifiers) in cleartext in the Identity Response (or any message used instead of the Identity Response). Following [RFC7542], it is RECOMMENDED to omit the username (i.e., the NAI is @realm), but other constructions such as a fixed username (e.g., anonymous@realm) or an encrypted username (e.g., xCZINCPTK5+7y81CrSYbPg+RKPE3OTrYLn4AQc4AC2U=@realm) are allowed. Note that the NAI MUST be a UTF-8 string as defined by the grammar in Section 2.2 of [RFC7542].

EAP-EDHOC is always used with privacy. This does not add any extra round trips and the message flow with privacy is just the normal message flow as shown in Figure 1.

3.1.6. Fragmentation

EAP-EDHOC fragmentation support is provided through the addition of a flags octet within the EAP-Response and EAP-Request packets, as well as a (conditional) EAP-EDHOC Message Length field of four octets. To do so, the EAP request and response messages of EAP-EDHOC have a set of information fields that allow for the specification of the fragmentation process (See Section 4 for the detailed description). Of these fields, we will highlight the one that contains the flag octet, which is used to steer the fragmentation process. If the L bit is set, we are specifying that the next message will be fragmented and that in such a message we can also find the length of the message.

Implementations MUST NOT set the L bit in unfragmented messages, but they MUST accept unfragmented messages with and without the L bit set. Some EAP implementations and access networks may limit the number of EAP packet exchanges that can be handled. To avoid fragmentation, it is RECOMMENDED to keep the sizes of EAP-EDHOC peer, EAP-EDHOC server, and trust anchor authentication credentials small and the length of the certificate chains short. In addition, it is RECOMMENDED to use mechanisms that reduce the sizes of Certificate messages.

EDHOC is designed to perform well in constrained networks where message sizes are restricted for performance reasons. In the basic message construction, the size of plaintext in message_2 is limited to the length of the output of the key derivation function which in turn is decided by the EDHOC hash function. For example, with SHA-256 as EDHOC hash algorithm the maximum size of plaintext in message_2 is 8160 bytes. However, EDHOC also defines an optional backwards compatible method for handling arbitrarily long message_2 plaintext sizes, see Appendix G in [I-D.ietf-lake-edhoc]. The other three EAP-EDHOC messages do not have an upper bound.

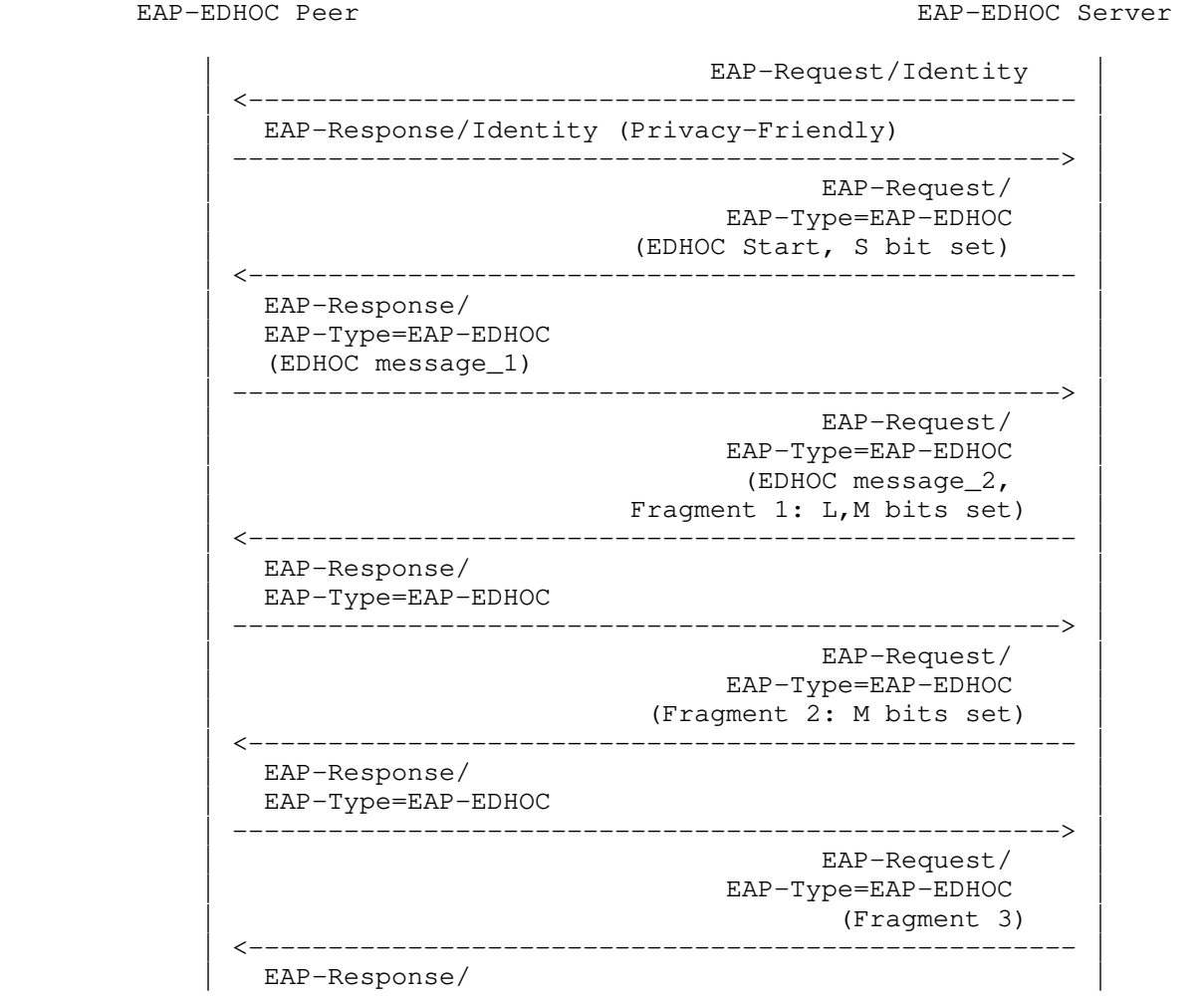
Furthermore, in the case of sending a certificate in a message instead of a reference, a certificate may in principle be as long as 16 MB. Hence, the EAP-EDHOC messages sent in a single round may thus be larger than the MTU size or the maximum Remote Authentication Dial-In User Service (RADIUS) packet size of 4096 octets. As a result, an EAP-EDHOC implementation MUST provide its own support for fragmentation and reassembly.

Since EAP is a simple 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 EAP-EDHOC fragmentation support is provided through the addition of a flags octet within the EAP-Response and EAP-Request packets, as well as a EDHOC Message Length field of four octets. Flags include the Length included (L), More fragments (M), and EAP-EDHOC Start (S) bits. The L flag is set to indicate the presence of the four-octet EDHOC Message Length field, and MUST be set for the first fragment of a fragmented EDHOC message or set of messages. The M flag is set on all but the last fragment. The S flag is set only within the EAP-EDHOC start message sent from the EAP server to the peer. The EDHOC Message Length field is four octets, and provides the total length of the EDHOC message or set of messages that is being fragmented; this simplifies buffer allocation.

When an EAP-EDHOC peer receives an EAP-Request packet with the M bit set, it MUST respond with an EAP-Response with EAP-Type=EAP-EDHOC 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 the 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=EAP-EDHOC 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.

In the case where the EAP-EDHOC mutual authentication is successful, and fragmentation is required, the conversation will appear as follows:



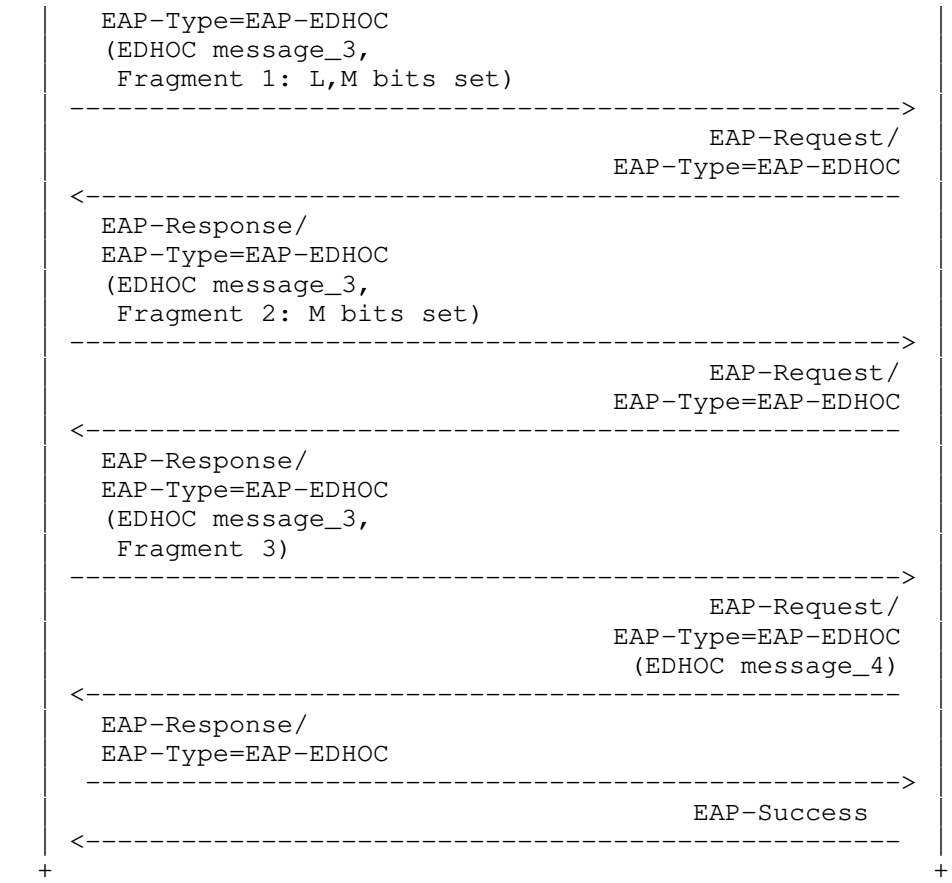


Figure 6: Fragmentation example of EAP-EDHOC Authentication

3.2. Identity Verification

The EAP peer identity provided in the EAP-Response/Identity is not authenticated by EAP-EDHOC. Unauthenticated information MUST NOT be used for accounting purposes or to give authorization. The authenticator and the EAP-EDHOC server MAY examine the identity presented in EAP-Response/Identity for purposes such as routing and EAP method selection. EAP-EDHOC servers MAY reject conversations if the identity does not match their policy.

The EAP server identity in the EDHOC server certificate is typically a fully qualified domain name (FQDN) in the SubjectAltName (SAN) extension. Since EAP-EDHOC deployments may use more than one EAP server, each with a different certificate, EAP peer implementations SHOULD allow for the configuration of one or more trusted root

certificates (CA certificate) to authenticate the server certificate and one or more server names to match against the SubjectAltName (SAN) extension in the server certificate. If any of the configured names match any of the names in the SAN extension, then the name check passes. To simplify name matching, an EAP-EDHOC deployment can assign a name to represent an authorized EAP server and EAP Server certificates can include this name in the list of SANs for each certificate that represents an EAP-EDHOC server. If server name matching is not used, then it degrades the confidence that the EAP server with which it is interacting is authoritative for the given network. If name matching is not used with a public root CA, then effectively any server can obtain a certificate that will be trusted for EAP authentication by the peer.

The process of configuring a root CA certificate and a server name is non-trivial; therefore, automated methods of provisioning are RECOMMENDED. For example, the eduroam federation [RFC7593] provides a Configuration Assistant Tool (CAT) to automate the configuration process. In the absence of a trusted root CA certificate (user-configured or system-wide), EAP peers MAY implement a trust on first use (TOFU) mechanism where the peer trusts and stores the server certificate during the first connection attempt. The EAP peer ensures that the server presents the same stored certificate on subsequent interactions. The use of a TOFU mechanism does not allow for the server certificate to change without out-of-band validation of the certificate and is therefore not suitable for many deployments including ones where multiple EAP servers are deployed for high availability. TOFU mechanisms increase the susceptibility to traffic interception attacks and should only be used if there are adequate controls in place to mitigate this risk.

3.3. Key Hierarchy

The key schedule for EDHOC is described in Section 4 of [I-D.ietf-lake-edhoc]. The Key_Material and Method-Id SHALL be derived from the PRK_exporter using the EDHOC-Exporter interface, see Section 4.2.1 of [I-D.ietf-lake-edhoc].

Type is the value of the EAP Type field defined in Section 2 of [RFC3748]. For EAP-EDHOC, the Type field has the value TBD1.

```
Type        =  TBD1
MSK         =  EDHOC-Exporter(TBD2 ,<< Type >>, 64)
EMSK        =  EDHOC-Exporter(TBD3 ,<< Type >>, 64)
Method-Id   =  EDHOC-Exporter(TBD4, << Type >>, 64)
Session-Id  =  Type || Method-Id
```

EAP-EDHOC exports the MSK and the EMSK and does not specify how it is used by lower layers.

3.4. Parameter Negotiation and Compliance Requirements

The EAP-EDHOC peers and EAP-EDHOC servers MUST comply with the compliance requirements (mandatory-to-implement cipher suites, signature algorithms, key exchange algorithms, extensions, etc.) defined in Section 7 of [I-D.ietf-lake-edhoc].

3.5. EAP State Machines

The EAP-EDHOC server sends message_4 in an EAP-Request as a protected success result indication.

EDHOC error messages SHOULD be considered failure result indication, as defined in [RFC3748]. After sending or receiving an EDHOC error message, the EAP-EDHOC server may only send an EAP-Failure. EDHOC error messages are unprotected.

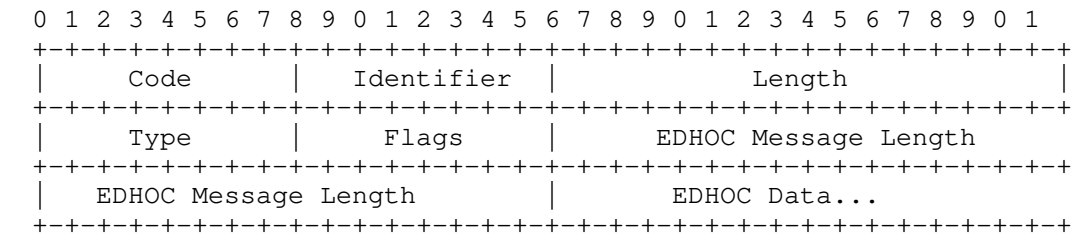
The keying material can be derived after the EDHOC message_2 has been sent or received. Implementations following [RFC4137] can then set the eapKeyData and aaaEapKeyData variables.

The keying material can be made available to lower layers and the authenticator after the authenticated success result indication has been sent or received (message_4). Implementations following [RFC4137] can set the eapKeyAvailable and aaaEapKeyAvailable variables.

4. Detailed Description of the EAP-EDHOC Protocol

4.1. EAP-EDHOC Request Packet

A summary of the EAP-EDHOC 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.

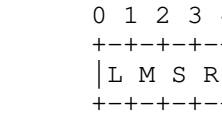
Length

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

Type

TBD1 -- EAP-EDHOC

Flags



L = Length included
M = More fragments
S = EAP-EDHOC start
R = Reserved

The L bit (length included) is set to indicate the presence of the four-octet EDHOC Message Length field and MUST be set for the first fragment of a fragmented EDHOC message or set of messages. The M bit (more fragments) is set on all but the last fragment. The S bit (EAP-EDHOC start) is set in an EAP-EDHOC Start message. This differentiates the EAP-EDHOC Start message from a fragment acknowledgement. Implementations of this specification MUST set the reserved bits to zero and MUST ignore them on reception.

EDHOC Message Length

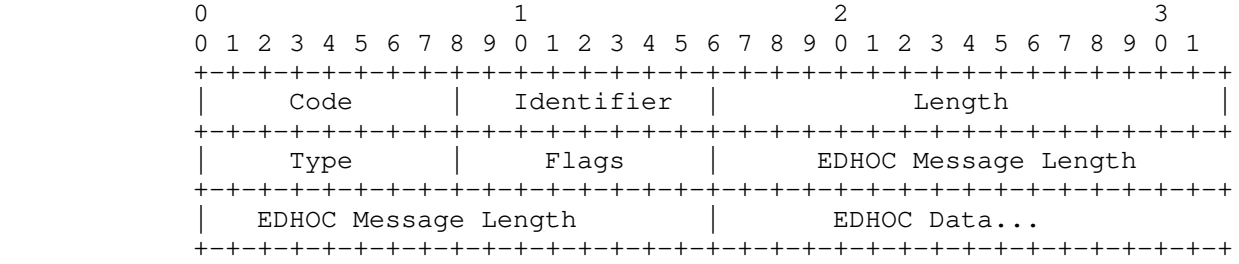
The EDHOC Message Length field is four octets and is present only if the L bit is set. This field provides the total length of the EDHOC message or set of messages that is being fragmented.

EDHOC data

The EDHOC data consists of the encapsulated EDHOC packet in EDHOC message format.

4.2. EAP-EDHOC Response Packet

A summary of the EAP-EDHOC 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.

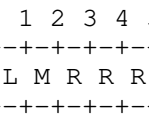
Length

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

Type

TBD1 -- EAP-EDHOC

Flags



L = Length included
M = More fragments
R = Reserved

The L bit (length included) is set to indicate the presence of the four-octet EDHOC Message Length field, and MUST be set for the first fragment of a fragmented EDHOC message or set of messages. The M bit (more fragments) is set on all but the last fragment. Implementations of this specification MUST set the reserved bits to zero and MUST ignore them on reception.

EDHOC Message Length

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

EDHOC data

The EDHOC data consists of the encapsulated EDHOC message.

5. IANA Considerations

5.1. EAP Type

IANA has allocated EAP Type TBD1 for method EAP-EDHOC. The allocation has been updated to reference this document.

5.2. EDHOC Exporter Label Registry

IANA has registered the following new labels in the "EDHOC Exporter Label" registry under the group name "Ephemeral Diffie-Hellman Over COSE (EDHOC)":

Label: TBD2
Description: MSK of EAP method EAP-EDHOC

Label: TBD3
Description: EMSK of EAP method EAP-EDHOC

Label: TBD4
Description: Method-Id of EAP method EAP-EDHOC

The allocations have been updated to reference this document.

6. Security Considerations

TBD.

[Editor's note: More security considerations to be added.]

6.1. Security Claims

Using EAP-EDHOC provides the security claims of EDHOC, which are described next.

[1] Mutual authentication: The initiator and responder authenticate each other through the EDHOC exchange.

[2] Forward secrecy: Only ephemeral Diffie-Hellman methods are supported by EDHOC, which ensures that the compromise of one session key does not also compromise earlier sessions' keys.

[3] Identity protection: EDHOC secures the Responder's credential identifier against passive attacks and the Initiator's credential identifier against active attacks. An active attacker can get the credential identifier of the Responder by eavesdropping on the destination address used for transporting message_1 and then sending its own message_1 to the same address.

[4] Cipher suite negotiation: The Initiator's list of supported cipher suites and order of preference is fixed and the selected cipher suite is the first cipher suite that the Responder supports.

[5] Integrity protection: EDHOC integrity protects all message content using transcript hashes for key derivation and as additional authenticated data, including, e.g., method type, ciphersuites, and external authorization data.

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Acknowledgments

Work on this document has in part been supported by the H2020 Projects IoTCrawler (grant agreement no. 779852) and INSPIRE-5Gplus (grant agreement no. 871808).

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anima Working Group
Internet-Draft
Intended status: Standards Track
Expires: 4 October 2023

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EAP defaults for devices that need to onboard
draft-richardson-emu-eap-onboarding-03

Abstract

This document describes a method by which an unconfigured device can use EAP to join a network on which further device onboarding, network attestation or other remediation can be done. While RFC 5216 supports EAP-TLS without a client certificate, that document defines no method by which unauthenticated EAP-TLS can be used. This draft addresses that issue. First, by defining the @eap.arpa domain, and second by showing how it can be used to provide quarantined network access for onboarding unauthenticated devices.

About This Document

This note is to be removed before publishing as an RFC.

Status information for this document may be found at https://datatracker.ietf.org/doc/draft-richardson-emu-eap-onboarding/.

Discussion of this document takes place on the anima Working Group mailing list (mailto:anima@ietf.org), which is archived at https://mailarchive.ietf.org/arch/browse/anima/.

Source for this draft and an issue tracker can be found at https://github.com/mcr/eap-onboarding.git.

Status of This Memo

Copyright Notice

Table of Contents

1. Introduction

There are a multitude of situations where a network device needs to join a new (wireless) network but where the device does not yet have the right credentials for that network. As the device does not have credentials, it cannot access networks which typically require authentication. However, since the device does not have network access, it cannot download a new configuration which contains updated credentials.

The process by which a device acquires these credentials has become known as onboarding [I-D.irtf-t2trg-secure-bootstrapping]. There are many onboarding protocols, including [RFC8995], [RFC9140], [dpp], CSA MATTER, and OPC UA Part 21. Some of these protocols use WiFi Public frames, or provide for provisioning as part of EAP, such as [RFC7170]. Other systems require pre-existing IP connectivity in order to configure credentials for a device, which causes a circular dependancy.

This document defines a method where devices can use unauthenticated EAP in order to obtain network access, albeit in a captive portal [RFC8952]. Once the device is in a captive portal, it has access to the full suite of Internet Protocol (IP) technologies, and can proceed with onboarding. We believe that the method defined here is clearer, safer, and easier to implement and deploy than alternatives. This method also allows for multiple onboarding technologies to co-exist, and for the technologies to evolve without requiring invasive upgrades to layer-2 infrastructure.

The method detailed in this document uses the unauthenticated client mode of EAP-TLS. While [RFC5216] defines EAP-TLS without a client certificate, that document defines no method by which unauthenticated EAP-TLS can be used.

This draft addresses that issue. First, by defining the @eap.arpa domain, and second by showing how it can be used to provid network access for onboarding unauthenticated devices.

Note that this specification does not specify the exact method used for onboarding devices! There are many possibilities, with some methods yet to be defined. Not all of them are enumerated here.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The term _supplicant_ is used to refer to the network device which is attempting to do EAP-TLS.

The term _pledge_ (from [RFC8995]) is used to refer to the network device which has successfully performed unauthenticated client mode EAP-TLS, and now has access to a network on which is may perform onboarding.

3. Protocol Details

The onboarding is divided into the following phases:

* Discovery - the supplicant determines that a network can do onboarding,

* Authentication - the supplicant connects to the network as an unauthenticated device,

* Authorization - the network provides limited connectivity to the device/pledge,

* Onboarding - the device/pledge uses standard IP protocols to perform onboarding,

* Full network access - the device has provisioned credentials, and can proceed with normal network access.

3.1. Discovery

The network should use 802.11u to signal that it can potentially perform onboarding, by using 802.11u and indicating that it supports the realm "eap.arpa".

When a supplicant which requires onboarding sees this realm, it knows that the network may be suitable for onboarding.

Note that not all such networks are suitable for onboarding using the technologies that a supplicant has. Some networks might have only a captive portal, intended for human use. This is the "coffee shop" case.

There may be multiple such networks available, and only one (or none) may be willing to onboard this particular device. Further, the device does not necessarily trust any such network.

There are situations where there may be many hundreds of networks which offer onboarding, and a supplicant device may need to try all of them until it finds a network to which it can successfully onboard. An example of such a situation is in a large (dozens to hundreds of floors) apartment building in a downtown core, where radio signals may leak from adjacent units, reflect off glass windows, come from other floors, and even cross the street from adjacent buildings. This document does not address this issue, but anticipates future work in 802.11u, perhaps involving some filtering mechanism using Bloom Filters.

Supplicants MUST limit their actions in the onboarding network to the action of onboarding. If this process cannot be completed, the device MUST disconnect from the onboarding network, and try again, usually by selecting a different network.

As soon as the device has been onboarded, the device MUST disconnect from the onboarding network, and use the provided configuration to authenticate and connect to a fully-capable network.

3.2. Authentication

The supplicant presents itself as an unauthenticated peer, which is allowed by EAP-TLS [RFC5216] Section 2.1.1. TLS 1.2 or TLS 1.3 [RFC9190] may be used, but TLS 1.3 or higher is RECOMMENDED.

The supplicant uses an identity of onboarding@eap.arpa, and provides no TLS client certificate. The use of the "eap.arpa" domain signals to the network that the device wishes to use unauthenticated EAP-TLS.

3.3. Authorization

Upon receipt of a supplicant without any authentication, the AAA server returns instructions to the authenticator to place the new client into the quarantined or captive portal network. The exact method is network-dependent, but it is usually done with a dedicated VLAN which has limited network access.

3.4. Characteristics of the Quarantine Network

The quarantine network SHOULD be segregated at layer-two (ethernet), and should not permit ethernet frames to any destination other than a small set of specified routers.

Specifically, the layer infrastructure should prevent one pledge from attempting to connect to another pledge.

For some onboarding protocols such as [RFC8995], only IPv6 Link-Local frames are needed. Such a network MUST provide a Join Proxy as specified in [RFC8995], Section 4.

For other onboarding protocols more capabilities may be needed, in particular there need for a DHCPv4 server may be critical for the device to believe it has connected correctly. This is particularly the case where a normal "smartphone" or laptop system will onboard via a captive portal.

Once on the quarantine network, device uses other protocols [RFC6876] to perform the onboarding action.

4. Captive Portal

While this document imposes no requirements on the rest of the network, captive portals [RFC8952] have been used for almost two decades. The administration and operation of captive portals is typically within the authority of administrators who are responsible for network access. As such, this document defines additional behavior on, and requirements for, captive portals, so long as those changes materially benefit the network access administrator.

5. Privacy Considerations

Devices should take care to hide all identifying information from the onboarding network. Any identifying information MUST be sent encrypted via a method such as TLS.

6. Security Considerations

Devices using an onboarding network MUST assume that the network is untrusted. All network traffic SHOULD be encrypted in order to prevent attackers from both eavesdropping, and from modifying any provisioning information.

Similarly onboarding networks MUST assume that devices are untrusted, and could be malicious. Networks MUST make provisions to prevent Denial of Service (DoS) attacks, such as when many devices attempt to connect at the same time.

Networks MUST limit network access to onboarding protocols only.

Networks SHOULD also limit the bandwidth used by any device which is being onboarded.

The configuration information is likely to be small (megabytes at most), and it is reasonable to require a second or two for this process to take place.

Any device which cannot be onboarded within approximately 30 seconds SHOULD be disconnected. Such a delay signals either a malicious device / network, or a misconfigured device / network. If onboarding cannot be finished within a short timer, the device should choose another network.

6.1. Use of eap.arpa

Supplicants MUST use the "eap.arpa" domain only for onboarding and related activities. Supplicant MUST use unauthenticated EAP-TLS.

Networks which support onboarding via the "eap.arpa" domain MUST require that supplicants use unauthenticated EAP-TLS. The use of other EAP types MUST result in rejection, and a denial of all network access.

The "eap.arpa" domain MUST NOT be used in any other context, such as in an NAI [RFC7542], etc. in any other protocol.

7. IANA Considerations

The special-use domain "eap.arpa" should be registered in the .arpa registry (https://www.iana.org/domains/arpa (https://www.iana.org/domains/arpa)). No A, AAAA, or PTR records are requested.

7.1. Domain Name Reservation Considerations

This template is filled in, complying with [RFC6761] section 5.

Users: Human users are not expected to recognize this name as special.

Application Software: Only writers of network connectivity sub-systems (WiFi) are expected to see this new domain. No other software (such browsers) should care about this name.

Name Resolution APIs and Libraries: Name Resolution APIs and Libraries do not need to mark this name as special.

Caching DNS Servers: DNS Caches do not need to do any special processing for this name.

Authoritative DNS Servers: Authoritative DNS servers do not need any

special processing.

DNS Server Operators: ; DNS Server Opreators do not need to do anything special.

DNS Registries/Registrars: DNS Registrars presently do not registar any names in .arpa, and this name reservation will be no different.

8. Acknowledgements

TBD.

9. Changelog

01 to 02: minor edits.

10. References

10.1. Normative References

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