EMU Working Group
Internet-Draft
Expires: December 28, 2006

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EAP Generalized Pre-Shared Key (EAP-GPSK)
draft-clancy-emu-eap-shared-secret-01.txt

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Abstract

This Internet Draft defines an Extensible Authentication Protocol method called EAP Generalized Pre-Shared Key (EAP-GPSK). This method is a lightweight shared-key authentication protocol supporting mutual authentication and key derivation.

Table of Contents

1. Introduction

EAP Generalized Pre-Shared Key (EAP-GPSK) is an EAP method defining a generalized pre-shared key authentication technique. Mutual authentication is achieved through a nonce-based exchange that is secured by a pre-shared key.

At present, several pre-shared key EAP methods are specified, most notably
- EAP-PAX [I-D.clancy-eap-pax]
- EAP-PSK [I-D.bersani-eap-psk]
- EAP-TLS-PSK [I-D.otto-emu-eap-tls-psk] and
- EAP-SAKE [I-D.vanderveen-eap-sake].

Each proposal has its particular benefits but also its particular deficiencies. EAP-GPSK is a new EAP method that tries to combine the most valuable characteristics of each of these methods and therefore attempts to address a broad range of usage scenarios.

The main design goals of EAP-GPSK are
Simplicity:

EAP-GPSK should be easy to implement and therefore quickly available.

Wide applicability:

EAP-GPSK has been designed in a threat model where the attacker has full control over the communication channel. This is the EAP threat model that is presented in Section 7.1 of [RFC3748]. Thus, it is particularly suited for wireless or battery powered devices.

Efficiency:

EAP-GPSK does not make use of public key cryptography and fully relies of symmetric cryptography. The restriction on symmetric cryptographic computations allows for low computational overhead. Hence, EAP-GPSK is lightweight and well suited for any type of device, especially those with little processing power and memory.

Flexibility:

EAP-GPSK offers cryptographic flexibility. At the beginning, the EAP server selects a set of cryptographic algorithms and key sizes, a so called ciphersuite. The current version of EAP-GPSK comprises two ciphersuites, but additional ones can be easily added.

Extensibility:

The design of EAP-GPSK allows to securely exchange information between the EAP peer and the EAP server using protected data fields. These fields might, for example, be used to exchange channel binding information or to provide support for identity confidentiality.

2. Terminology

In this document, several words are used to signify the requirements of the specification. These words are often capitalized. The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

This section describes the various variables and functions used in the EAP-GPSK method.

Variables:

PD_Payload_X:

Data carried within the X-th protected data payload

CSuite_List:

An octet array listing available ciphersuites (variable length)

CSuite_Sel:

Ciphersuite selected by the client (1 octet or 7 octets)

ID_Client:

Client NAI [RFC2486bis]

ID_Server:

Server identity as an opaque blob.

KS:

Integer representing the key size in octets of the selected ciphersuite CSuite_Sel

RAND_Client:

Random integer generated by the client (256 bits)

RAND_Server:

Random integer generated by the server (256 bits)

KDFData_Client:

Arbitrary data provided by the client to be included in the KDF

KDFData_Server:

Arbitrary data provided by the server to be included in the KDF

Operations:

A || B:

Concatenation of octet strings A and B

ENC_X(Y):

Encryption of message Y with a symmetric key X, using a defined block cipher

KDF_X(Y):

Key Derivation Function that generates an arbitrary number of octets of output using secret X and seed Y

length(X):

Function that returns the length of input X in octets, encoded as a 16-bit integer in network byte order

MAC_X(Y):

Keyed message authentication code computed over Y with symmetric key X

SEC_X(Y):

SEC is a function that provides integrity protection based on the chosen ciphersuite. The function SEC uses the algorithm defined by the selected ciphersuite and applies it to the message content Y with key X. As an output the message returns Y concatenated with

MAC_X(Y).

X[A..B]:

Notation representing octets A through B of octet array X

The following abbreviations are used for the keying material:

PK:

Session key generated from the MK and used during protocol exchange to encrypt protected data (size defined by ciphersuite)

SK:

Session key generated from the MK and used during protocol exchange to prove knowledge of PSK (size defined by ciphersuite)

EMSK:

Extended Master Session Key is exported by the EAP method (512 bits)

MK:

Master Key between the client and EAP server from which all other EAP method session keys are derived (KS octets)

MSK:

Master Session Key exported by to the EAP method (512 bits)

MID:

Method ID exported by the EAP method according to the EAP keying framework [I-D.ietf-eap-keying] (128 bits)

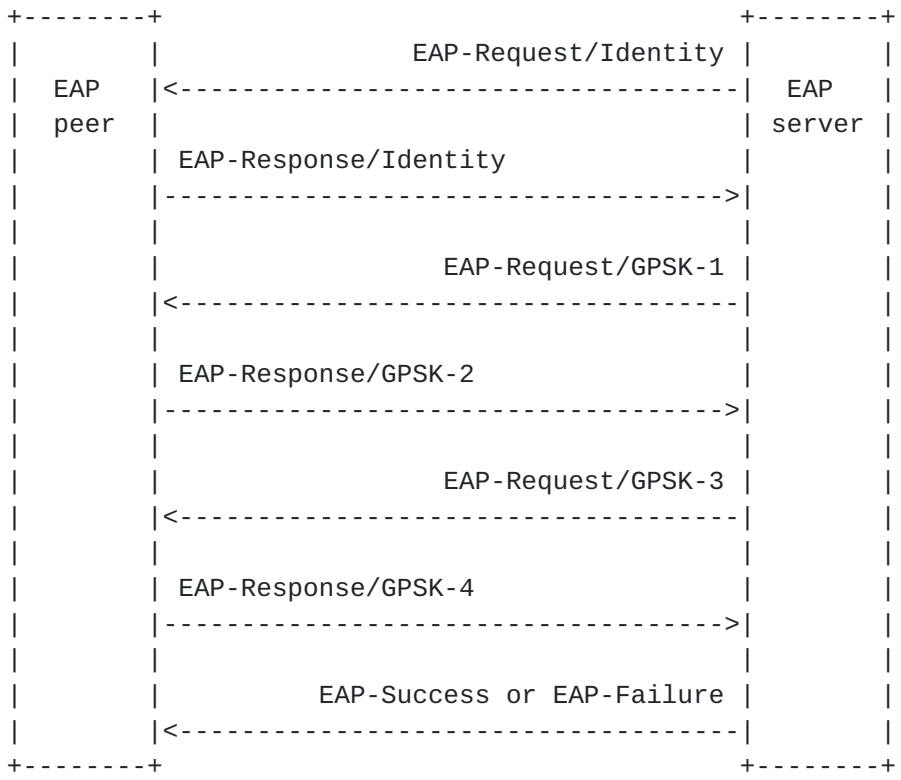
PSK:

Long-term key shared between the client and the server (PL octets)

3. Overview

The EAP framework [RFC3748] defines four basic steps that occur during the execution of an EAP conversation between client and

server. The first phase, discovery, is handled by the underlying protocol. The authentication phase is defined here. The key distribution and secure association phases are handled differently depending on the underlying protocol, and are not discussed in this document.



EAP-GPSK performs mutual authentication between EAP peer ("Client") and EAP server ("Server") based on a pre-shared key (PSK). The protocol consists of two EAP message exchanges, in which both sides

- exchange nonces and their identities and
- compute and exchange a Message Authentication Code (MAC) over the previously exchanged values, keyed with the pre-shared key. This MAC is considered as proof of possession of the pre-shared key.

The full EAP-GPSK protocol is as follows:
GPSK-1:

ID_Server, RAND_Server, CSuite_List

GPSK-2:

SEC_SK(ID_Client, ID_Server, RAND_Client, RAND_Server,
CSuite_List, CSuite_Sel [, ENC_PK(PD_Payload_1), ...])

GPSK-3

SEC_SK(RAND_Client, RAND_Server, CSuite_Sel [,
ENC_PK(PD_Payload_2)])

GPSK-4:

[SEC_SK(ENC_PK(PD_Payload_3))]

The EAP server begins EAP-GPSK creating a random number RAND_Server and by encoding the supported ciphersuites into CSuite_List. A ciphersuite consists of an encryption algorithm, a key derivation function and a message authentication code.

In GPSK-1, the EAP server sends its identity ID_Server, a random number RAND_Server and the identifier of the chosen ciphersuite. The decision which ciphersuite to use is policy-dependent and therefore outside the scope of this document.

In GPSK-2, the peer sends its identity ID_Client, a random number RAND_Client. Furthermore, it repeats the received parameters of the GPSK-1 message and computes a Message Authentication Code over all these parameters.

The EAP server verifies the received Message Authentication Code. In case of successful verification, the EAP server computes a Message Authentication Code over the session parameter and returns it to the client (within GPSK-3). Within GPSK-2 and GPSK-3, peer and EAP server have the possibility to exchange encrypted protected data parameters.

The peer verifies the received Message Authentication Code. If the verification is successful, GPSK-4 is prepared. This message can optionally contain the client's protected data parameters.

Upon receipt of GPSK-4, the server assures that the peer has derived session keys SK and PK properly. Then, the EAP server sends an EAP Success message to indicate the successful outcome of the authentication.

4. Key Derivation

EAP-GPSK provides key derivation in compliance to the requirements of [RFC3748] and [I-D.ietf-eap-keying].

The long-term credential shared between EAP peer and EAP server SHOULD be a strong pre-shared key PSK of at least 16 bytes, though its length and entropy is variable. while it is possible to use a password or passphrase, doing so is NOT RECOMMENDED as it would make EAP-GPSK vulnerable to dictionary attack.

During an EAP-GPSK authentication, a Master Key MK, a Session Key SK and a Protected Data Encryption Key PK are derived using the ciphersuite-specified KDF and the entropy exchanged during the execution of the protocol.

In case of successful completion, EAP-GPSK derives and exports an MSK and EMSK both in length of 64 byte. This keying material is derived using the ciphersuite-specified KDF as follows:

- Entropy = RAND_Client || RAND_Server || ID_Client || ID_Server
- MK = KDF_Zero-String (PL || PSK || CSuite_Sel || Entropy)[0..KS-1]
- SK = KDF_MK (Entropy)[128..127+KS]
- PK = KDF_MK (Entropy)[128+KS..127+2*KS]
- MSK = KDF_MK (Entropy || KDFData_Client || KDFData_Server)[0..63]
- EMSK = KDF_MK (Entropy || KDFData_Client || KDFData_Server)[64..127]
- MID = KDF_Zero-String ("Method ID" || EAP_Method_Type || CSuite_Sel || Entropy)[0..15]

Note that the term 'Zero-String' refers to a sequence of 0x00 values, KS octets in length. EAP_Method_Type refers to the integer value of the IANA allocated EAP Type code.

Figure 2 depicts the key derivation procedure of EAP-GPSK.

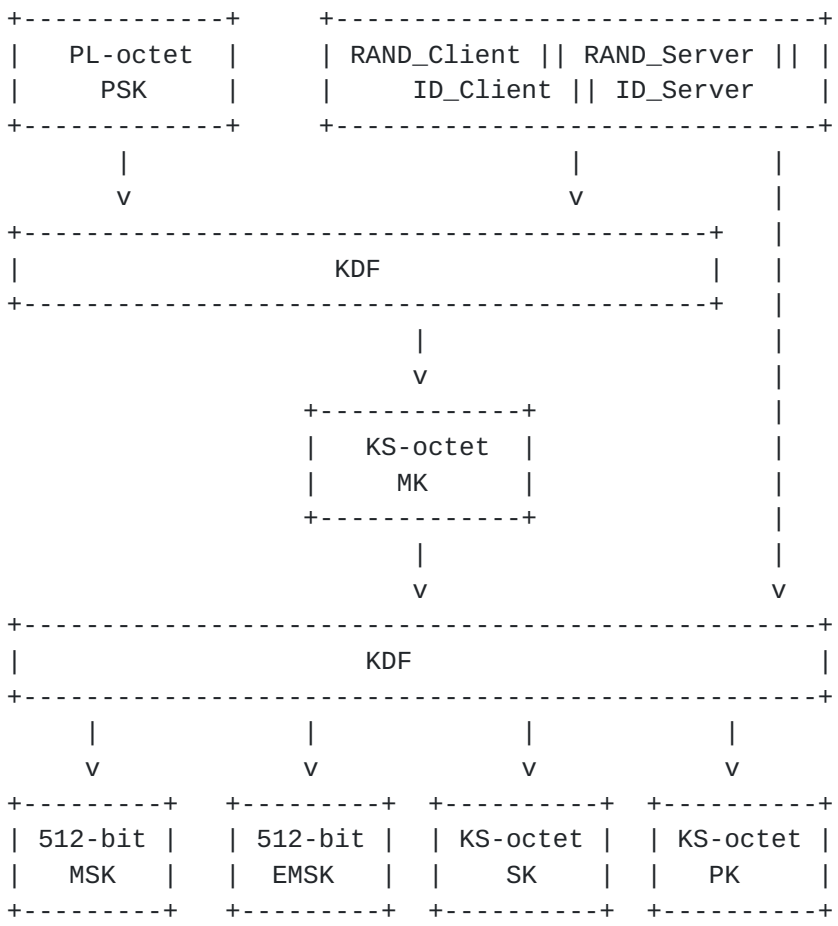


Figure 2: EAP-GPSK Key Derivation

5. Ciphersuites

The design of EAP-GPSK allows cryptographic algorithms and key sizes, called ciphersuite, to be negotiated during the protocol run. The ability to specify block-based and hash-based ciphersuites is offered. Extensibility is provided with the introduction of new ciphersuites; this document specifies an initial set. The CSuite/ Specifier column in Figure 3 uniquely identifies a ciphersuite.

For a vendor-specific ciphersuite the first three octets are the vendor-specific OID, and the last three octets are vendor assigned for the specific ciphersuite.

The following ciphersuites are specified in this document:

CSuite/ Specifier	KS	Encryption	Integrity	Key Derivation Function
0x000001	16	AES-EAX-128	AES-CMAC-128	GKDF-128
0x000002	32	NULL	HMAC-SHA256	GKDF-256

Figure 3: Ciphersuites

Ciphersuite 1, which is based on AES as a cryptographic primitive, is mandatory to implement.

Each ciphersuite needs to specify a key derivation function. The ciphersuites defined in this document make use of the Generalized Key Distribution Function (GKDF). Future ciphersuites can use any other formally specified KDF that takes as arguments a key and a seed or entropy value, and produces at least 1024+2*KS bits of output.

If GKDF is invoked by a MAC-based ciphersuite, then the variable "size" contains the MAC output size in octets. In case of a block cipher-based ciphersuite, "size" contains the block size in octets.

GKDF has the following structure:

GKDF-X(Y, Z)

X length, in octets, of the desired output
Y secret key used to protect the computation
Z data specific for the protocol run

```
GKDF-X (Y, Z)
{
    n = int( X / size - 1 ) + 1; /* determine number of
                                    output blocks */
    M_0 = "";
    result = "";

    for i=1 to n {
        M_i = MAC_Y (M_{i-1} || Z || i || X);
        result = result || M_i;
    }

    return truncate (result; X)
}
```

Note that the variables 'i' and 'X' in M_i are represented as 16-bit values in network byte order.

6. Ciphersuites Processing Rules

6.1. Ciphersuite #1

6.1.1. Encryption

With this ciphersuite all cryptography is built around a single cryptographic primitive, AES-128. Within the protected data frames, AES-128 is used in EAX mode of operation. Ciphersuite 1 makes use of the EAX mode of encryption. EAX is an Authenticated-Encryption-With-Associated-Data (AEAD) scheme. It has as input a plaintext M, a header H and a nonce N and is keyed with a key K. The idea is that both M and H are integrity protected, but only M is encrypted. Therefore, EAX encryption returns the ciphertext, which consists of H and encrypted M, and a cryptographic checksum Tag T.

H || C || T = EAX.Encrypt (K; N, H, M)

H || M = EAX.Decrypt (K; N, H, C, T)

EAX strongly relies on CMAC and is therefore suited to be used in combination with this.

The following instantiation is used:

E = C || T = EAX.Encrypt (SK; Input), where Input refers to the following content:

- Value of PD_Payload_1 in message GPSK-2
- Value of PD_Payload_2 in message GPSK-3
- Value of PD_Payload_3 in message GPSK-4

6.1.2. Integrity

Ciphersuite 1 uses CMAC as Message Authentication Code. CMAC is recommended by NIST. Among its advantages, CMAC is capable to work with messages of arbitrary length. A detailed description of CMAC can be found in [CMAC].

The following instantiation is used: AES-128-CMAC(SK, Input) denotes the MAC of Input under the key SK.

where Input refers to the following content:

- Value of SEC_SK in message GPSK-2
- Value of SEC_SK in message GPSK-3
- Value of SEC_SK in message GPSK-4

6.1.3. Key Derivation

This ciphersuite instantiates the KDF in the following way:

MK = GKDF-16 (PSK[0..15], RAND_Client || RAND_Server || ID_Server || ID_Client)

KDF_out = GKDF-160 (MK, RAND_Client || RAND_Server || ID_Server || ID_Client)

MSK = KDF_out[0..63]

EMSK = KDF_out[64..127]

SK = KDF_out[128..143]

PK = KDF_out[144..159]

MID = GKDF-16 (Zero-String, "Method ID" || EAP_Method_Type || RAND_Client || RAND_Server || ID_Server || ID_Client)

6.2. Ciphersuite #2

6.2.1. Encryption

Ciphersuite 2 does not include an algorithm for encryption. With a NULL encryption algorithm, encryption is defined as:

E_X(Y) = Y

When using this ciphersuite, the data exchanged inside the protected data blocks is not encrypted. Therefore this mode MUST NOT be used if confidential information appears inside the protected data blocks.

6.2.2. Integrity

Ciphersuite 2 uses the keyed MAC function HMAC, with the SHA256 hash algorithm.

For integrity protection the following instantiation is used:

HMAC-SHA256(SK, Input) denotes the MAC of Input under the key SK where Input refers to the following content:

- Value of SEC_SK in message GPSK-2
- Value of SEC_SK in message GPSK-3
- Value of SEC_SK in message GPSK-4

6.2.3. Key Derivation

This ciphersuite instantiates the KDF in the following way:

MK = GKDF-32 (PSK, RAND_Client || RAND_Server || ID_Server || ID_Client || CSuite_Sel)

KDF_out = GKDF-192 (MK, RAND_Client || RAND_Server || ID_Server || ID_Client)

MSK = KDF_out[0..63]

EMSK = KDF_out[64..127]

SK = KDF_out[128..159]

PK = KDF_out[160..191]

MID = GKDF-16 (Zero-String, "Method ID" || EAP_Method_Type || RAND_Client || RAND_Server || ID_Server || ID_Client)

7. Packet Formats

This section defines the packet format of the EAP-GPSK messages.

7.1. Header Format

The EAP-GPSK header has the following structure:

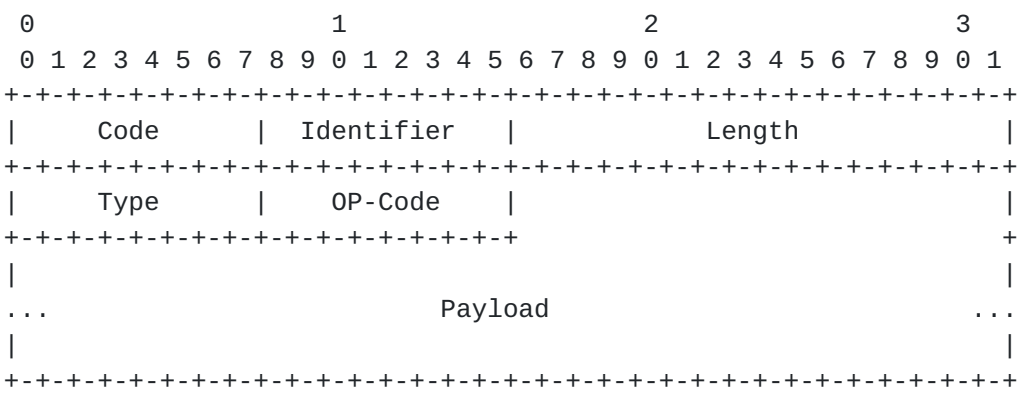


Figure 5

The Code, Identifier, Length, and Type fields are all part of the EAP header, and defined in [RFC3748]. IANA has allocated EAP Method Type XX for EAP-GPSK, thus the Type field in the EAP header MUST be XX.

The OP-Code field is one of four values:

- 0x01 : GPSK-1
- 0x02 : GPSK-2
- 0x03 : GPSK-3
- 0x04 : GPSK-4

7.2. Ciphersuite Formatting

Ciphersuites are encoded as 6-octet arrays. The first three octets indicate the CSuite/Vendor field. For vendor-specific ciphersuites, this represents the vendor OID. The last three octets indicate the CSuite/Specifier field, which identifies the particular ciphersuite. The 3-byte CSuite/Vendor value 0x000000 indicates ciphersuites allocated by the IETF.

Graphically, they are represented as

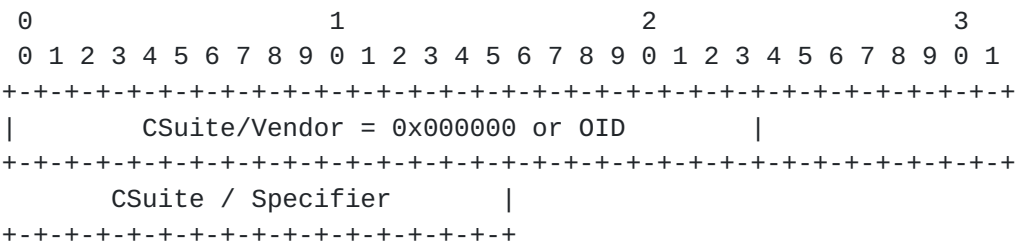


Figure 6

CSuite_Sel is encoded as a 6-octet ciphersuite CSuite/Vendor and CSuite/Specifier pair.

CSuite_List is a variable-length octet array of ciphersuites. It is encoded by concatenating encoded ciphersuite values. Its length in octets MUST be a multiple of 6.

7.3. Payload Formatting

Payload formatting is based on the protocol exchange description in Section 3.

The GPSK-1 payload format is defined as follows:

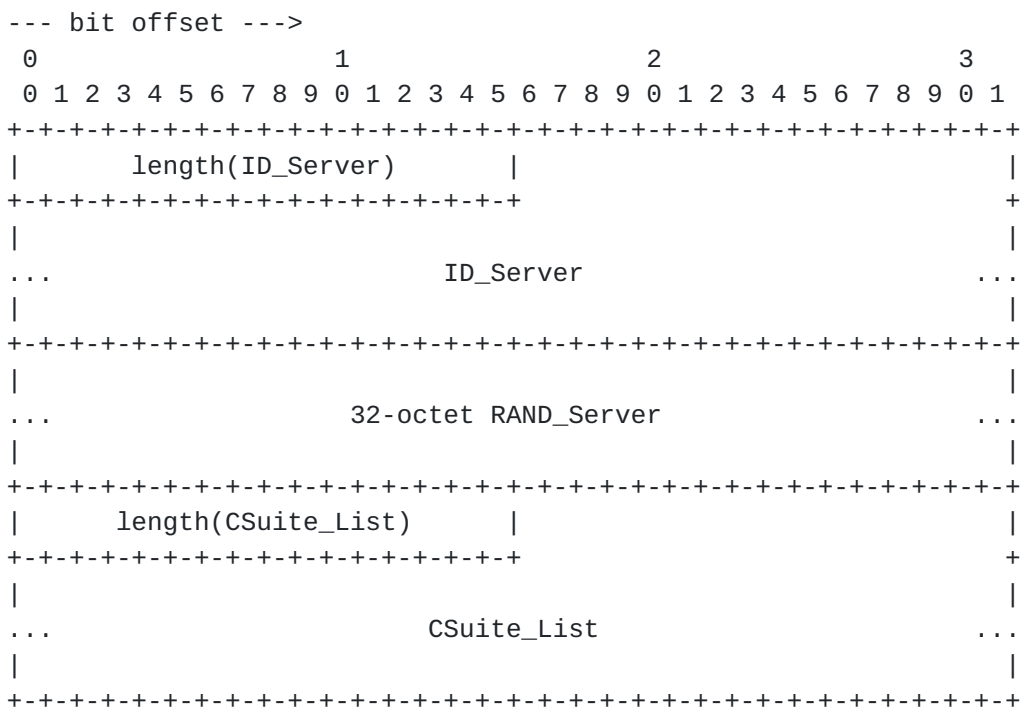


Figure 7: GPSK-1 Payload

The GPSK-2 payload format is defined as follows:

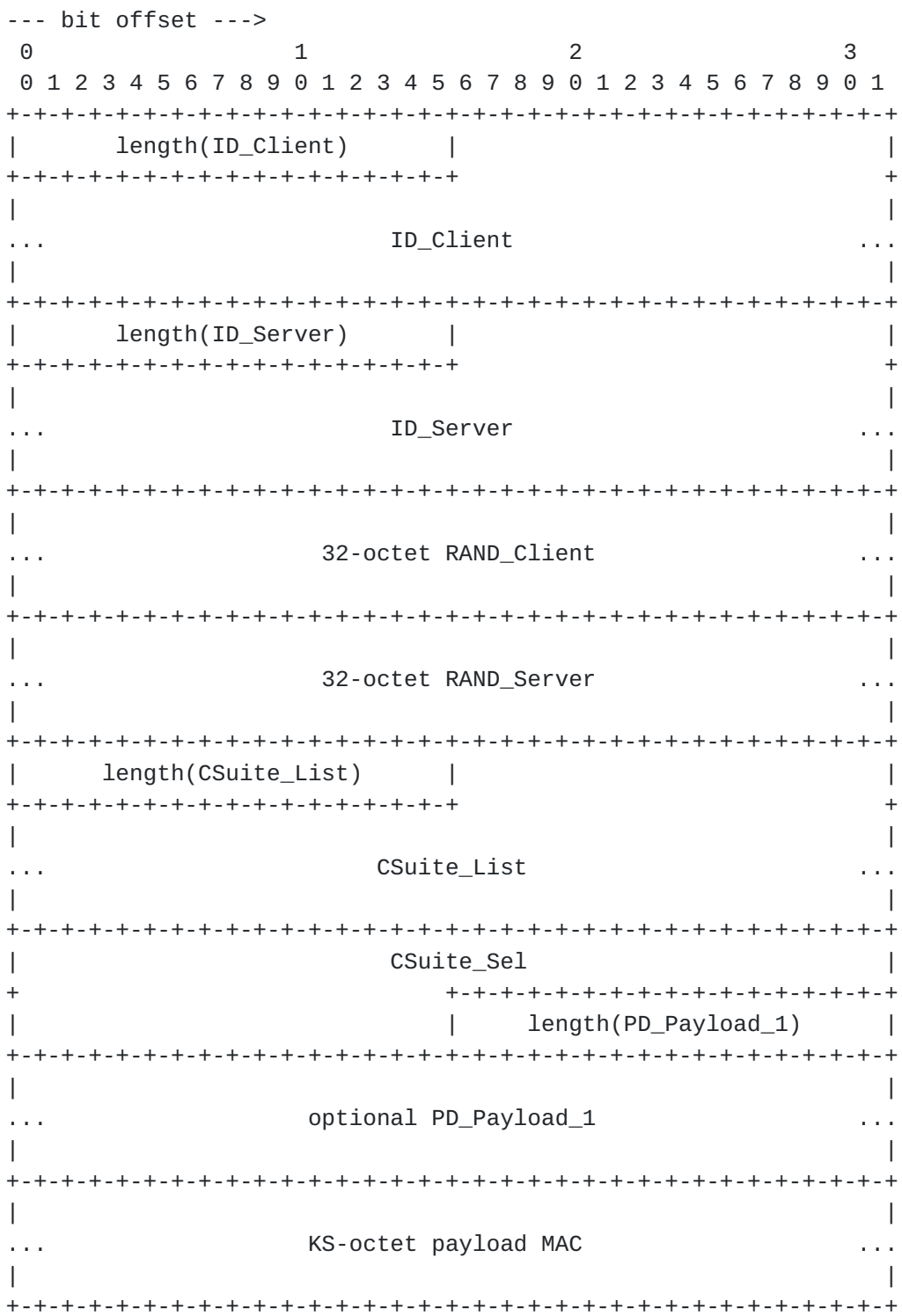


Figure 8: GPSK-2 Payload

If the optional protected data payload is not included, then length(PD_Payload)=0 and the PD payload is excluded.

The GPSK-3 payload is defined as follows:

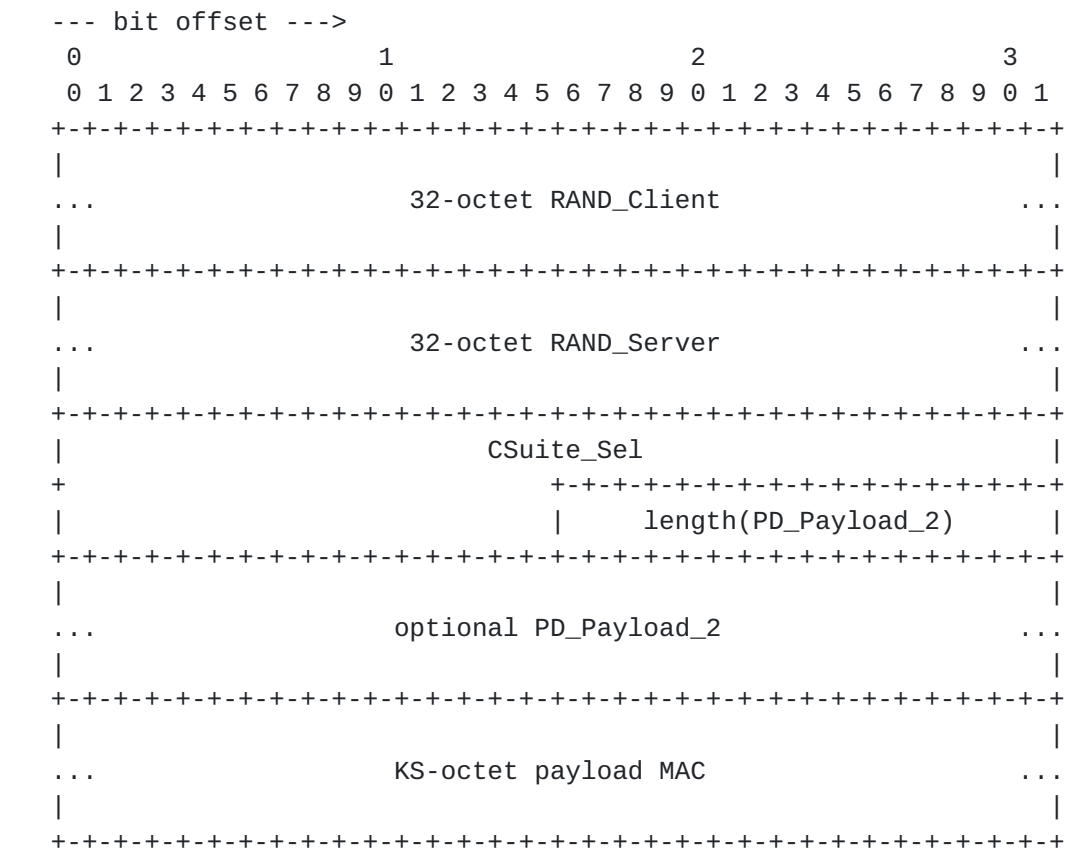


Figure 9: GPSK-3 Payload

If the optional protected data payload is not included, then length(PD_Payload)=0 and the PD payload is excluded.

The GPSK-4 payload format is defined as follows:

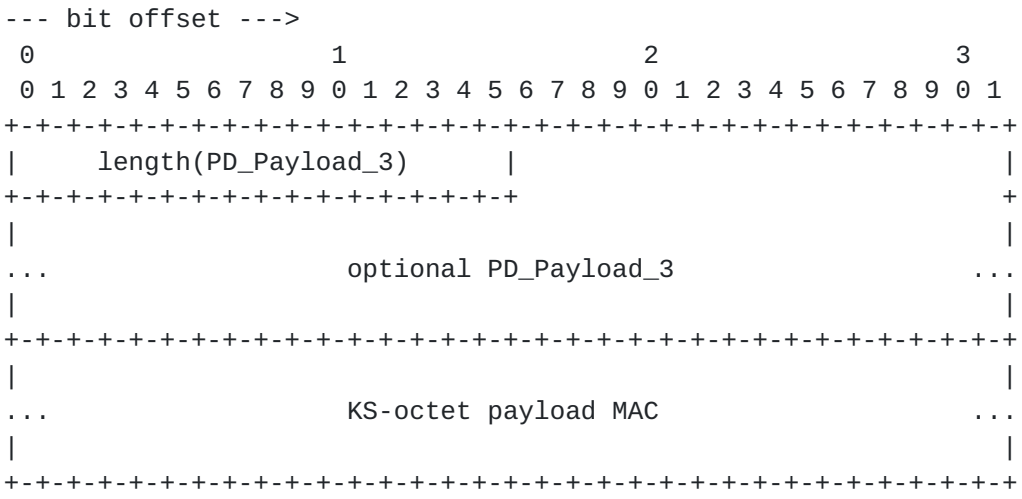


Figure 10: GPSK-4 Payload

If the optional protected data payload is not included, then length(PD_Payload)=0 and the PD payload is excluded. The MAC MUST always be included, regardless of the presence of PD_Payload_3.

7.4. Protected Data

The protected data blocks are a generic mechanism for the client and server to securely exchange data. If the specified ciphersuite has a NULL encryption primitive, then this channel only offers authenticity, and not confidentiality.

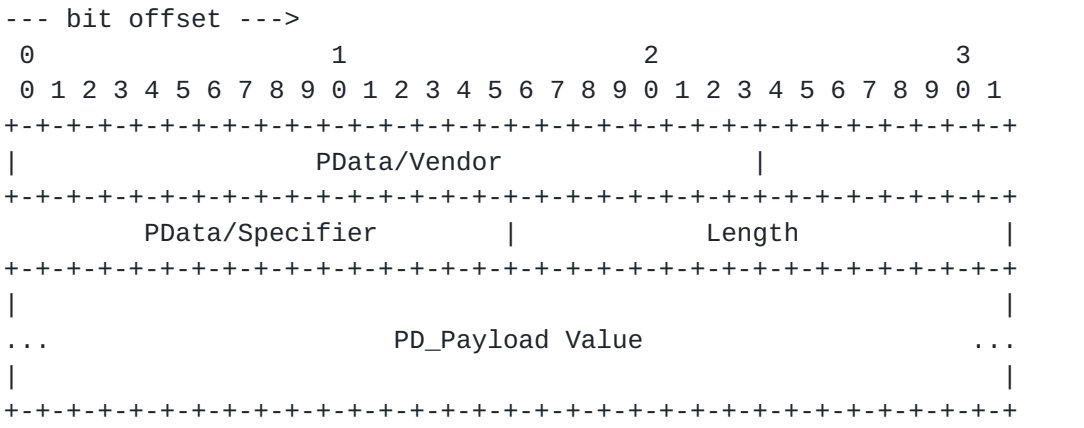
These payloads are encoded as the concatenation of type-length-value (TLV) tripples.

Type values are encoded as a 6-octet string and represented by a 3-octet vendor and 3-octet specifier field. The vendor field indicates the type as either standards-specified or vendor-specific. If these three octets are 0x000000, then the value is standards-specified, and any other value represents a vendor-specific OID.

The specifier field indicates the actual type. For vendor field 0x000000, the specifier field is maintained by IANA. For any other vendor field, the specifier field is maintained by the vendor.

Length fields are specified as 2-octet integers in network byte order, and reflect only the length of the value, and do not include the length of the type and length fields.

Graphically, this can be depicted as follows:



For PData/Vendor field 0x000000, the following PData/Specifier fields are defined:

- 0x000000 : Reserved
- 0x000001 : Channel Binding Data
- 0x000002 : Protected Results Indication
- 0x000003 : Extra KDF Data
- 0x000004 through 0xFFFFFF : Unallocated

Definition of channel binding data is outside the scope of this document. These protected payloads can be used to carry such data once it has been formally specified.

Definition of the protected results indication field is outside the scope of this document. It could be used to indicate the success or failure of both authentication and authorization in a secure way.

The Extra KDF Data field specifies an arbitrary amount of additional data, represented as KDFData_Client and KDFData_Server, and is used in the derivation of the MSK and EMSK exported by GPSK to EAP. It can be used to extensibly bind data into the key derivation process.

KDFData_Server can ONLY be specified in PD_Payload_2. KDFData_Client can only be bound to data specified in PD_Payload_3. If multiple entries are specified in a single PD_Payload with PData/Specifier 3, then the first field must be used. These fields MUST NOT contain plaintext, sensitive data if a ciphersuite is used that specifies a NULL encryption primitive.

If the Extra KDF Data field is not used, then KDFData_Server and KDFData_Client MUST both be zero-length octet arrays, and therefore not included in the KDF.

8. Security Considerations

[RFC3748] highlights several attacks that are possible against EAP since EAP itself does not provide any security.

This section discusses the claimed security properties of EAP-GPSK as well as vulnerabilities and security recommendations in the threat model of [RFC3748].

8.1. Mutual Authentication

EAP-GPSK provides mutual authentication.

The server believes that the peer is authentic because it can calculate a valid MAC and the peer believes that the server is authentic because it can calculate another valid MAC.

The key used for mutual authentication is computed again based on the long-term secret PSK that has to provide sufficient entropy and therefore sufficient strength. In this way EAP-GPSK is no different than other authentication protocols based on pre-shared keys.

8.2. Protected Result Indications

EAP-GPSK provides protected result indications based on information exchanged inside the protected data payloads.

8.3. Integrity Protection

EAP-GPSK provides integrity protection based on the ciphersuites suggested in this document.

8.4. Replay Protection

EAP-GPSK provides replay protection of its mutual authentication part thanks to the use of random numbers RAND_S and RAND_P. Since RAND_S is 128 bit long, one expects to have to record 2**64 (i.e., approximately 1.84*10**19) EAP-GPSK successful authentication before an protocol run can be replayed. Hence, EAP-GPSK provides replay protection of its mutual authentication part as long as RAND_S and RAND_P are chosen at random, randomness is critical for security.

8.5. Reflection attacks

EAP-GPSK provides protection against reflection attacks in case of an extended authentication because of the messages are constructed in a different fashion.

8.6. Dictionary Attacks

EAP-GPSK relies on a long-term shared secret (PSK) that MUST be based on at least 128 bits of entropy to guarantee security against dictionary attacks. Users who use passwords or weak keys are not guaranteed security against dictionary attacks. Derivation of the long-term shared secret from a password is highly discouraged.

8.7. Key Derivation

EAP-GPSK supports key derivation as shown in Section 4.

8.8. Denial of Service Resistance

Denial of Service resistance (DoS) has not been a design goal for EAP-GPSK.

It is however believed that EAP-GPSK does not provide any obvious and avoidable venue for such attacks.

It is worth noting that the server has to maintain some state when it engages in an EAP-GPSK conversation, namely to generate and to remember the 16-byte RAND_S. This should however not lead to resource exhaustion as this state and the associated computation are fairly lightweight.

It is recommended that EAP-GPSK does not allow EAP notifications to be interleaved in its dialog to prevent potential DoS attacks. Indeed, since EAP Notifications are not integrity protected, they can easily be spoofed by an attacker. Such an attacker could force a peer that allows EAP Notifications to engage in a discussion which would delay his authentication or result in the peer taking unexpected actions (e.g., in case a notification is used to prompt the peer to do some "bad" action).

It is up to the implementation of EAP-GPSK or to the peer and the server to specify the maximum number of failed cryptographic checks that are allowed.

8.9. Session Independence

Thanks to its key derivation mechanisms, EAP-GPSK provides session independence: passive attacks (such as capture of the EAP conversation) or active attacks (including compromise of the MSK or EMSK) do not enable compromise of subsequent or prior MSKs or EMSKs. The assumption that RAND_P and RAND_S are random is central for the security of EAP-GPSK in general and session independance in particular.

8.10. Exposition of the PSK

EAP-GPSK does not provide perfect forward secrecy. Compromise of the PSK leads to compromise of recorded past sessions.

Compromise of the PSK enables the attacker to impersonate the peer and the server and it allows the adversary to compromise future sessions.

EAP-GPSK provides no protection against a legitimate peer sharing its PSK with a third party. Such protection may be provided by appropriate repositories for the PSK, which choice is outside the scope of this document. The PSK used by EAP-GPSK must only be shared between two parties: the peer and the server. In particular, this PSK must not be shared by a group of peers communicating with the same server.

The PSK used by EAP-GPSK must be cryptographically separated from keys used by other protocols, otherwise the security of EAP-GPSK may be compromised.

8.11. Fragmentation

EAP-GPSK does not support fragmentation and reassembly since the message size is kept small.

8.12. Channel Binding

This document enables the ability to exchange channel binding information. It does not, however, define the encoding of channel binding information in the document.

8.13. Fast Reconnect

EAP-GPSK does not provide the fast reconnect capability since this method is already at the lower limit of the number of roundtrips and the cryptographic operations.

8.14. Identity Protection

Identity protection is not specified in this document. Extensions can be defined that enhanced this protocol to provide this feature.

8.15. Protected Ciphersuite Negotiation

EAP-GPSK provides protected ciphersuite negotiation via the indication of available ciphersuites by the server in the first message and a confirmation by the client in the subsequent message.

8.16. Confidentiality

Although EAP-GPSK provides confidentiality in its protected data payloads, it cannot claim to do so as per Section 7.2.1 of [RFC3748].

8.17. Cryptographic Binding

Since EAP-GPSK does not tunnel another EAP method, it does not implement cryptographic binding.

9. IANA Considerations

This document requires IANA to allocate a new EAP Type for EAP-GPSK.

This document requires IANA to create a new registry for ciphersuites and protected data types. IANA is furthermore instructed to add the specified ciphersuites and protected data types to this registry as defined in this document. Values can be added or modified with informational RFCs defining either block-based or hash-based ciphersuites. Each ciphersuite needs to provide processing rules and needs to specify how the following algorithms are instantiated: Encryption, Integrity and Key Derivation. Additionally, the preferred key size needs to be specified.

The following layout represents the initial ciphersuite CSuite/ Specifier registry setup:

- 0x000000 : Reserved
- 0x000001 : AES-EAX-128, AES-CMAC-128, GKDF-128
- 0x000002 : NULL, HMAC-SHA256, GKDF-256
- 0x000003 through 0xFFFFFF : Unallocated

The following is the initial protected data PData/Specifier registry setup:

- 0x000000 : Reserved
- 0x000001 : Channel Binding Data
- 0x000002 : Protected Results Indication
- 0x000003 : Extra KDF Data
- 0x000004 through 0xFFFFFF : Unallocated

10. Contributors

This work is a joint effort of the EAP Method Update (EMU) design team of the EMU Working Group that was created to develop a mechanism based on strong shared secrets that meets RFC 3748 [RFC3748] and RFC

4017 [RFC4017] requirements. The contributors (in alphabetical order) include:

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Finally, we would like to thank Thomas Otto for this review, feedback and text input.

11. Acknowledgment

We would like to thank Jouni Malinen and Bernard Aboba for their comments in June 2006.

12. Open Issues

The list of open issues can be found at:
http://www.tschofenig.com:8080/eap-gpsk/

A first prototype implementation by Jouni Malinen can be found at:
http://hostap.epitest.fi/releases/snapshots/

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Acknowledgment

Funding for the RFC Editor function is currently provided by the Internet Society.