Network Working Group
Internet-Draft
Obsoletes: 4880, 5581, 6637 (if approved)
Intended status: Standards Track
Expires: 18 September 2025

W. Koch
g10 Code GmbH
R. H. Tse
Ribose

17 March 2025

LibrePGP Message Format
draft-koch-librepgp-03

Abstract

This document specifies the message formats used in LibrePGP. LibrePGP is an extension of the OpenPGP format which provides encryption with public-key or symmetric cryptographic algorithms, digital signatures, compression and key management.

This document is maintained in order to publish all necessary information needed to develop interoperable applications based on the LibrePGP format. It is not a step-by-step cookbook for writing an application. It describes only the format and methods needed to read, check, generate, and write conforming packets crossing any network. It does not deal with storage and implementation questions. It does, however, discuss implementation issues necessary to avoid security flaws.

This document is based on: RFC 4880 (OpenPGP), RFC 5581 (Camellia in OpenPGP), and RFC 6637 (Elliptic Curves in OpenPGP).

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on 18 September 2025.

Table of Contents

1. Introduction

This document provides information on the message-exchange packet formats used by LibrePGP to provide encryption, decryption, signing, and key management functions. It is a revision of RFC 4880, "OpenPGP Message Format", which is a revision of RFC 2440, which itself replaces RFC 1991, "PGP Message Exchange Formats" [RFC1991] [RFC2440] [RFC4880].

LibrePGP is fully compatible to the OpenPGP specification as specified by: RFC 4880 (OpenPGP), RFC 5581 (Camellia cipher), and RFC 6637 (ECC for OpenPGP).

1.1. Terms

* LibrePGP - This is a term for security software that is based on OpenPGP with updates for newer algorithms and an advertency to long-term stability and critical deployments. It is formalized in this document.

* OpenPGP - This is a term for security software that uses PGP 5 as a basis.

* PGP - Pretty Good Privacy. PGP is a family of software systems developed by Philip R. Zimmermann from which OpenPGP is based.

* PGP 2 - This version of PGP has many variants; where necessary a more detailed version number is used here. PGP 2 uses only RSA, MD5, and IDEA for its cryptographic transforms. An informational RFC, RFC 1991, was written describing this version of PGP.

* PGP 5 - This version of PGP is formerly known as "PGP 3" in the community. It has new formats and corrects a number of problems in the PGP 2 design. It is referred to here as PGP 5 because that software was the first release of the "PGP 3" code base.

* GnuPG - GNU Privacy Guard, also called GPG, is the leading Open Source implementation of LibrePGP and OpenPGP and has been developed along with the OpenPGP standard since 1997.

* RNP - LibrePGP and OpenPGP implementation by Ribose. Relied upon by the mail client Thunderbird for secure email.

"PGP" is a trademark of CA, INC. The use of this, or any other, marks is solely for identification purposes. The terms "OpenPGP" and "LibrePGP" refer to the protocol described in this and related documents.

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].

The key words "PRIVATE USE", "EXPERT REVIEW", "SPECIFICATION REQUIRED", "RFC REQUIRED", and "IETF REVIEW" that appear in this document when used to describe namespace allocation are to be interpreted as described in [RFC8126].

2. General functions

LibrePGP provides data integrity services for messages and data files by using these core technologies:

* digital signatures

* encryption

* compression

* Radix-64 conversion

In addition, LibrePGP provides key management and certificate services, but many of these are beyond the scope of this document.

2.1. Confidentiality via Encryption

LibrePGP combines symmetric-key encryption and public-key encryption to provide confidentiality. When made confidential, first the object is encrypted using a symmetric encryption algorithm. Each symmetric key is used only once, for a single object. A new "session key" is generated as a random number for each object (sometimes referred to as a session). Since it is used only once, the session key is bound to the message and transmitted with it. To protect the key, it is encrypted with the receiver’s public key. The sequence is as follows:

1. The sender creates a message.

2. The sending LibrePGP generates a random number to be used as a session key for this message only.

3. The session key is encrypted using each recipient’s public key. These "encrypted session keys" start the message.

4. The sending LibrePGP encrypts the message using the session key, which forms the remainder of the message. Note that the message is also usually compressed.

5. The receiving LibrePGP decrypts the session key using the recipient’s private key.

6. The receiving LibrePGP decrypts the message using the session key. If the message was compressed, it will be decompressed.

With symmetric-key encryption, an object may be encrypted with a symmetric key derived from a passphrase (or other shared secret), or a two-stage mechanism similar to the public-key method described above in which a session key is itself encrypted with a symmetric algorithm keyed from a shared secret.

Both digital signature and confidentiality services may be applied to the same message. First, a signature is generated for the message and attached to the message. Then the message plus signature is encrypted using a symmetric session key. Finally, the session key is encrypted using public-key encryption and prefixed to the encrypted block.

2.2. Authentication via Digital Signature

The digital signature uses a hash code or message digest algorithm, and a public-key signature algorithm. The sequence is as follows:

1. The sender creates a message.
2. The sending software generates a hash code of the message.
3. The sending software generates a signature from the hash code using the sender's private key.
4. The binary signature is attached to the message.
5. The receiving software keeps a copy of the message signature.
6. The receiving software generates a new hash code for the received message and verifies it using the message's signature. If the verification is successful, the message is accepted as authentic.

2.3. Compression

LibrePGP implementations SHOULD compress the message after applying the signature but before encryption.

If an implementation does not implement compression, its authors should be aware that most OpenPGP and LibrePGP messages in the world are compressed. Thus, it may even be wise for a space-constrained implementation to implement decompression, but not compression.

Furthermore, compression has the added side effect that some types of attacks can be thwarted by the fact that slightly altered, compressed data rarely uncompresses without severe errors. This is hardly rigorous, but it is operationally useful. These attacks can be rigorously prevented by implementing and using Modification Detection Codes as described in sections following.

2.4. Conversion to Radix-64

LibrePGP's underlying native representation for encrypted messages, signature certificates, and keys is a stream of arbitrary octets. Some systems only permit the use of blocks consisting of seven-bit, printable text. For transporting LibrePGP's native raw binary octets through channels that are not safe to raw binary data, a printable encoding of these binary octets is needed. LibrePGP provides the service of converting the raw 8-bit binary octet stream to a stream of printable ASCII characters, called Radix-64 encoding or ASCII Armor.

Implementations SHOULD provide Radix-64 conversions.

2.5. Signature-Only Applications

LibrePGP is designed for applications that use both encryption and signatures, but there are a number of problems that are solved by a signature-only implementation. Although this specification requires both encryption and signatures, it is reasonable for there to be subset implementations that are non-conformant only in that they omit encryption.

3. Data Element Formats

This section describes the data elements used by LibrePGP.

3.1. Scalar Numbers

Scalar numbers are unsigned and are always stored in big-endian format. Using n[k] to refer to the kth octet being interpreted, the value of a two-octet scalar is ((n[0] << 8) + n[1]). The value of a four-octet scalar is ((n[0] << 24) + (n[1] << 16) + (n[2] << 8) + n[3]).

3.2. Multiprecision Integers

Multiprecision integers (also called MPIs) are unsigned integers used to hold large integers such as the ones used in cryptographic calculations.

An MPI consists of two pieces: a two-octet scalar that is the length of the MPI in bits followed by a string of octets that contain the actual integer.

These octets form a big-endian number; a big-endian number can be made into an MPI by prefixing it with the appropriate length.

Examples:

(all numbers are in hexadecimal)

The string of octets [00 01 01] forms an MPI with the value 1. The string [00 09 01 FF] forms an MPI with the value of 511.

Additional rules:

The size of an MPI is ((MPI.length + 7) / 8) + 2 octets.

The length field of an MPI describes the length starting from its most significant non-zero bit. Thus, the MPI [00 02 01] is not formed correctly. It should be [00 01 01].

Unused bits of an MPI MUST be zero.

Also note that when an MPI is encrypted, the length refers to the plaintext MPI. It may be ill-formed in its ciphertext.

3.3. Simple Octet Strings

Simple Octet Strings (also called SOSs) are used to convey arbitrary octet strings with a length of up to 8191 octets.

An SOS consists of two pieces: a two-octet scalar that is the length of the octet string measured in bits followed by an opaque string of octets of this length. An SOS is compatible to the format of a well-formed MPI. However if the value of an SOS starts with a zero byte it does not represent a well-format MPI and in this case the length is measured as 8-times the number of octets.

The entire size of an SOS is always ((SOS.length + 7) / 8) + 2 octets.

3.4. Key IDs

A Key ID is an eight-octet scalar that identifies a key. Implementations SHOULD NOT assume that Key IDs are unique. The section "Enhanced Key Formats" below describes how Key IDs are formed.

3.5. Text

Unless otherwise specified, the character set for text is the UTF-8 [RFC3629] encoding of Unicode [ISO10646].

3.6. Time Fields

A time field is an unsigned four-octet number containing the number of seconds elapsed since midnight, 1 January 1970 UTC.

3.7. Keyrings

A keyring is a collection of one or more keys in a file or database. Traditionally, a keyring is simply a sequential list of keys, but may be any suitable database. It is beyond the scope of this standard to discuss the details of keyrings or other databases.

3.8. String-to-Key (S2K) Specifiers

String-to-key (S2K) specifiers are used to convert passphrase strings into symmetric-key encryption/decryption keys. They are used in two places, currently: to encrypt the secret part of private keys in the private keyring, and to convert passphrases to encryption keys for symmetrically encrypted messages.

3.8.1. String-to-Key (S2K) Specifier Types

There are three types of S2K specifiers currently supported, and some reserved values:

ID	S2K Type
0	Simple S2K
1	Salted S2K
2	Reserved value
3	Iterated and Salted S2K
100 to 110	Private/Experimental S2K

Table 1

These are described in the following Sections.

3.8.1.1. Simple S2K

This directly hashes the string to produce the key data. See below for how this hashing is done.

Octet 0: 0x00
Octet 1: hash algorithm

Simple S2K hashes the passphrase to produce the session key. The manner in which this is done depends on the size of the session key (which will depend on the cipher used) and the size of the hash algorithm’s output. If the hash size is greater than the session key size, the high-order (leftmost) octets of the hash are used as the key.

If the hash size is less than the key size, multiple instances of the hash context are created --- enough to produce the required key data. These instances are preloaded with 0, 1, 2, ... octets of zeros (that is to say, the first instance has no preloading, the second gets preloaded with 1 octet of zero, the third is preloaded with two octets of zeros, and so forth).

As the data is hashed, it is given independently to each hash context. Since the contexts have been initialized differently, they will each produce different hash output. Once the passphrase is hashed, the output data from the multiple hashes is concatenated, first hash leftmost, to produce the key data, with any excess octets on the right discarded.

3.8.1.2. Salted S2K

This includes a "salt" value in the S2K specifier --- some arbitrary data --- that gets hashed along with the passphrase string, to help prevent dictionary attacks.

```
Octet 0:        0x01
Octet 1:        hash algorithm
Octets 2-9:     8-octet salt value
```

Salted S2K is exactly like Simple S2K, except that the input to the hash function(s) consists of the 8 octets of salt from the S2K specifier, followed by the passphrase.

3.8.1.3. Iterated and Salted S2K

This includes both a salt and an octet count. The salt is combined with the passphrase and the resulting value is hashed repeatedly. This further increases the amount of work an attacker must do to try dictionary attacks.

```
Octet  0:        0x03
Octet  1:        hash algorithm
Octets 2-9:      8-octet salt value
Octet  10:       count, a one-octet, coded value
```

The count is coded into a one-octet number using the following formula:

```
#define EXPBIAS 6
    count = ((Int32)16 + (c & 15)) << ((c >> 4) + EXPBIAS);
```

The above formula is in C, where "Int32" is a type for a 32-bit integer, and the variable "c" is the coded count, Octet 10.

Iterated-Salted S2K hashes the passphrase and salt data multiple times. The total number of octets to be hashed is specified in the encoded count in the S2K specifier. Note that the resulting count value is an octet count of how many octets will be hashed, not an iteration count.

Initially, one or more hash contexts are set up as with the other S2K algorithms, depending on how many octets of key data are needed. Then the salt, followed by the passphrase data, is repeatedly hashed until the number of octets specified by the octet count has been hashed. The one exception is that if the octet count is less than the size of the salt plus passphrase, the full salt plus passphrase will be hashed even though that is greater than the octet count. After the hashing is done, the data is unloaded from the hash context(s) as with the other S2K algorithms.

3.8.2. String-to-Key Usage

Implementations SHOULD use salted or iterated-and-salted S2K specifiers, as simple S2K specifiers are more vulnerable to dictionary attacks.

3.8.2.1. Secret-Key Encryption

An S2K specifier can be stored in the secret keyring to specify how to convert the passphrase to a key that unlocks the secret data. Older versions of PGP just stored a cipher algorithm octet preceding the secret data or a zero to indicate that the secret data was unencrypted. The MD5 hash function was always used to convert the passphrase to a key for the specified cipher algorithm.

For compatibility, when an S2K specifier is used, the special value 253, 254, or 255 is stored in the position where the hash algorithm octet would have been in the old data structure. This is then followed immediately by a one-octet algorithm identifier, and then by the S2K specifier as encoded above.

Therefore, preceding the secret data there will be one of these possibilities:

0:	secret data is unencrypted (no passphrase)
255, 254, or 253:	followed by algorithm octet and S2K specifier
Cipher alg:	use Simple S2K algorithm using MD5 hash

This last possibility, the cipher algorithm number with an implicit use of MD5 and IDEA, is provided for backward compatibility; it MAY be understood, but SHOULD NOT be generated, and is deprecated.

These are followed by an Initial Vector of the same length as the block size of the cipher for the decryption of the secret values, if they are encrypted, and then the secret-key values themselves.

3.8.2.2. Symmetric-Key Message Encryption

LibrePGP can create a Symmetric-key Encrypted Session Key (ESK) packet at the front of a message. This is used to allow S2K specifiers to be used for the passphrase conversion or to create messages with a mix of symmetric-key ESKs and public-key ESKs. This allows a message to be decrypted either with a passphrase or a public-key pair.

PGP 2 always used IDEA with Simple string-to-key conversion when encrypting a message with a symmetric algorithm. This is deprecated, but MAY be used for backward-compatibility.

4. Packet Syntax

This section describes the packets used by LibrePGP.

4.1. Overview

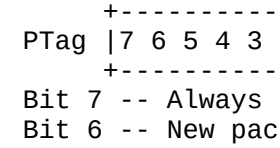
An LibrePGP message is constructed from a number of records that are traditionally called packets. A packet is a chunk of data that has a tag specifying its meaning. An LibrePGP message, keyring, certificate, and so forth consists of a number of packets. Some of those packets may contain other LibrePGP packets (for example, a compressed data packet, when uncompressed, contains LibrePGP packets).

Each packet consists of a packet header, followed by the packet body. The packet header is of variable length.

4.2. Packet Headers

The first octet of the packet header is called the "Packet Tag". It determines the format of the header and denotes the packet contents. The remainder of the packet header is the length of the packet.

Note that the most significant bit is the leftmost bit, called bit 7. A mask for this bit is 0x80 in hexadecimal.



PGP 2.6.x only uses old format packets. Thus, software that interoperates with those versions of PGP must only use old format packets. If interoperability is not an issue, the new packet format is RECOMMENDED. Note that old format packets have four bits of packet tags, and new format packets have six; some features cannot be used and still be backward-compatible.

Also note that packets with a tag greater than or equal to 16 MUST use new format packets. The old format packets can only express tags less than or equal to 15.

Old format packets contain:

Bits 5-2 -- packet tag
Bits 1-0 -- length-type

New format packets contain:

Bits 5-0 -- packet tag

4.2.1. Old Format Packet Lengths

The meaning of the length-type in old format packets is:

0 The packet has a one-octet length. The header is 2 octets long.

1 The packet has a two-octet length. The header is 3 octets long.

2 The packet has a four-octet length. The header is 5 octets long.

3 The packet is of indeterminate length. The header is 1 octet long, and the implementation must determine how long the packet is. If the packet is in a file, this means that the packet extends until the end of the file. In general, an implementation SHOULD NOT use indeterminate-length packets except where the end of the data will be clear from the context, and even then it is better to use a definite length, or a new format header. The new format headers described below have a mechanism for precisely encoding data of indeterminate length.

4.2.2. New Format Packet Lengths

New format packets have four possible ways of encoding length:

1. A one-octet Body Length header encodes packet lengths of up to 191 octets.

2. A two-octet Body Length header encodes packet lengths of 192 to 8383 octets.

3. A five-octet Body Length header encodes packet lengths of up to 4,294,967,295 (0xFFFFFFFF) octets in length. (This actually encodes a four-octet scalar number.)

4. When the length of the packet body is not known in advance by the issuer, Partial Body Length headers encode a packet of indeterminate length, effectively making it a stream.

4.2.2.1. One-Octet Lengths

A one-octet Body Length header encodes a length of 0 to 191 octets. This type of length header is recognized because the one octet value is less than 192. The body length is equal to:

```
bodyLen = 1st_octet;
```

4.2.2.2. Two-Octet Lengths

A two-octet Body Length header encodes a length of 192 to 8383 octets. It is recognized because its first octet is in the range 192 to 223. The body length is equal to:

```
bodyLen = ((1st_octet - 192) << 8) + (2nd_octet) + 192
```

4.2.2.3. Five-Octet Lengths

A five-octet Body Length header consists of a single octet holding the value 255, followed by a four-octet scalar. The body length is equal to:

```
bodyLen = (2nd_octet << 24) | (3rd_octet << 16) |
          (4th_octet << 8)  | 5th_octet
```

This basic set of one, two, and five-octet lengths is also used internally to some packets.

4.2.2.4. Partial Body Lengths

A Partial Body Length header is one octet long and encodes the length of only part of the data packet. This length is a power of 2, from 1 to 1,073,741,824 (2 to the 30th power). It is recognized by its one octet value that is greater than or equal to 224, and less than 255. The Partial Body Length is equal to:

```
partialBodyLen = 1 << (1st_octet & 0x1F);
```

Each Partial Body Length header is followed by a portion of the packet body data. The Partial Body Length header specifies this portion's length. Another length header (one octet, two-octet, five-octet, or partial) follows that portion. The last length header in the packet MUST NOT be a Partial Body Length header. Partial Body Length headers may only be used for the non-final parts of the packet.

Note also that the last Body Length header can be a zero-length header.

An implementation MAY use Partial Body Lengths for data packets, be they literal, compressed, or encrypted. The first partial length MUST be at least 512 octets long. Partial Body Lengths MUST NOT be used for any other packet types.

4.2.3. Packet Length Examples

These examples show ways that new format packets might encode the packet lengths.

A packet with length 100 may have its length encoded in one octet: 0x64. This is followed by 100 octets of data.

A packet with length 1723 may have its length encoded in two octets: 0xC5, 0xFB. This header is followed by the 1723 octets of data.

A packet with length 100000 may have its length encoded in five octets: 0xFF, 0x00, 0x01, 0x86, 0xA0.

It might also be encoded in the following octet stream: 0xEF, first 32768 octets of data; 0xE1, next two octets of data; 0xE0, next one octet of data; 0xF0, next 65536 octets of data; 0xC5, 0xDD, last 1693 octets of data. This is just one possible encoding, and many variations are possible on the size of the Partial Body Length headers, as long as a regular Body Length header encodes the last portion of the data.

Please note that in all of these explanations, the total length of the packet is the length of the header(s) plus the length of the body.

4.3. Packet Tags

The packet tag denotes what type of packet the body holds. Note that old format headers can only have tags less than 16, whereas new format headers can have tags as great as 63. The defined tags (in decimal) are as follows:

Tag	Packet Type
0	Reserved - a packet tag MUST NOT have this value
1	Public-Key Encrypted Session Key Packet
2	Signature Packet
3	Symmetric-Key Encrypted Session Key Packet
4	One-Pass Signature Packet
5	Secret-Key Packet
6	Public-Key Packet
7	Secret-Subkey Packet
8	Compressed Data Packet
9	Symmetrically Encrypted Data Packet
10	Marker Packet
11	Literal Data Packet
12	Trust Packet
13	User ID Packet
14	Public-Subkey Packet
17	User Attribute Packet
18	Sym. Encrypted and Integrity Protected Data Packet
19	Modification Detection Code Packet
20	OCB Encrypted Data Packet
21	Reserved
26	Reserved (CMS Encrypted Session Key Packet)
60 to 63	Private or Experimental Values

Table 2

5. Packet Types

5.1. Public-Key Encrypted Session Key Packets (Tag 1)

A Public-Key Encrypted Session Key (PKESK) packet holds the session key used to encrypt a message. Zero or more Public-Key Encrypted Session Key packets and/or Symmetric-Key Encrypted Session Key packets may precede a Symmetrically Encrypted Data Packet, which holds an encrypted message. The message is encrypted with the session key, and the session key is itself encrypted and stored in the Encrypted Session Key packet(s). The Symmetrically Encrypted Data Packet is preceded by one Public-Key Encrypted Session Key packet for each LibrePGP key to which the message is encrypted. The recipient of the message finds a session key that is encrypted to their public key, decrypts the session key, and then uses the session key to decrypt the message.

The body of this packet consists of:

* A one-octet number giving the version number of the packet type. The currently defined value for packet version is 3.

* An eight-octet number that gives the Key ID of the public key to which the session key is encrypted. If the session key is encrypted to a subkey, then the Key ID of this subkey is used here instead of the Key ID of the primary key.

* A one-octet number giving the public-key algorithm used.

* A string of octets that is the encrypted session key. This string takes up the remainder of the packet, and its contents are dependent on the public-key algorithm used.

  Algorithm Specific Fields for RSA encryption:

  - Multiprecision integer (MPI) of RSA encrypted value m^e mod n.

  Algorithm Specific Fields for Elgamal encryption:

  - MPI of Elgamal (Diffie-Hellman) value g^k mod p.

  - MPI of Elgamal (Diffie-Hellman) value m * y^k mod p.

  Algorithm-Specific Fields for ECDH encryption:

  - SOS of an EC point representing an ephemeral public key.

- a one-octet scalar octet count of the following symmetric key encoded using the method described in Section 13.5.

Algorithm-Specific Fields for ML-KEM (Kyber) encryption:

- SOS of an EC point representing an ephemeral public key.

- A four-octet scalar octet count of the following ML-KEM ciphertext. The value for the count is 1088 for ML-KEM-768 and 1568 for ML-KEM-1024.

- A one-octet algorithm identifier which must indicate one of the AES algorithms (7, 8, or 9) to be used for the session key.

- a one-octet scalar octet count of the following symmetric key wrapped using the method described in Section 14.1.

The value "m" in the above formulas is derived from the session key as follows. First, the session key is prefixed with a one-octet algorithm identifier that specifies the symmetric encryption algorithm used to encrypt the following Symmetrically Encrypted Data Packet. Then a two-octet checksum is appended, which is equal to the sum of the preceding session key octets, not including the algorithm identifier, modulo 65536. This value is then encoded as described in PKCS#1 block encoding EME-PKCS1-v1_5 in Section 7.2.1 of [RFC3447] to form the "m" value used in the formulas above. See Section 15.1 of this document for notes on LibrePGP's use of PKCS#1.

Note that when an implementation forms several PKESKs with one session key, forming a message that can be decrypted by several keys, the implementation MUST make a new PKCS#1 encoding for each key.

An implementation MAY accept or use a Key ID of zero as a "wild card" or "speculative" Key ID. In this case, the receiving implementation would try all available private keys, checking for a valid decrypted session key. This format helps reduce traffic analysis of messages.

Note that the confidentiality of a message is only post-quantum secure when encrypting to multiple recipients iff only ML-KEM algorithms are used for all recipients.

5.2. Signature Packet (Tag 2)

A Signature packet describes a binding between some public key and some data. The most common signatures are a signature of a file or a block of text, and a signature that is a certification of a User ID.

Three versions of Signature packets are defined. Version 3 provides basic signature information, while versions 4 and 5 provide an expandable format with subpackets that can specify more information about the signature. PGP 2.6.x only accepts version 3 signatures.

Implementations MUST generate version 5 signatures when using a version 5 key. Implementations SHOULD generate V4 signatures with version 4 keys. Implementations MUST NOT create version 3 signatures; they MAY accept version 3 signatures.

5.2.1. Signature Types

There are a number of possible meanings for a signature, which are indicated in a signature type octet in any given signature. Please note that the vagueness of these meanings is not a flaw, but a feature of the system. Because LibrePGP places final authority for validity upon the receiver of a signature, it may be that one signer's casual act might be more rigorous than some other authority's positive act. See Section 5.2.4, "Computing Signatures", for detailed information on how to compute and verify signatures of each type.

These meanings are as follows:

0x00 Signature of a binary document. This means the signer owns it, created it, or certifies that it has not been modified.

0x01 Signature of a canonical text document. This means the signer owns it, created it, or certifies that it has not been modified. The signature is calculated over the text data with its line endings converted to <CR><LF>.

0x02 Standalone signature. This signature is a signature of only its own subpacket contents. It is calculated identically to a signature over a zero-length binary document. Note that it doesn't make sense to have a V3 standalone signature.

0x10 Generic certification of a User ID and Public-Key packet. The issuer of this certification does not make any particular assertion as to how well the certifier has checked that the owner of the key is in fact the person described by the User ID.

0x11 Persona certification of a User ID and Public-Key packet. The issuer of this certification has not done any verification of the claim that the owner of this key is the User ID specified.

0x12 Casual certification of a User ID and Public-Key packet. The

issuer of this certification has done some casual verification of the claim of identity.

0x13 Positive certification of a User ID and Public-Key packet. The issuer of this certification has done substantial verification of the claim of identity.

Most LibrePGP implementations make their "key signatures" as 0x10 certifications. Some implementations can issue 0x11-0x13 certifications, but few differentiate between the types.

0x16 Attested Key Signature. This signature is issued by the primary key over itself and its User ID (or User Attribute). It MUST contain an "Attested Certifications" subpacket and a "Signature Creation Time" subpacket. This type of key signature does not replace or override any standard certification (0x10-0x13). Only the most recent Attestation Key Signature is valid for any given <key,userid> pair. If more than one Certification Attestation Key Signature is present with the same Signature Creation Time, the set of attestations should be treated as the union of all "Attested Certifications" subpackets from all such signatures with the same timestamp.

Note that this class is deprecated due to the deprecation of the "Attested Certifications" subpacket.

0x18 Subkey Binding Signature. This signature is a statement by the top-level signing key that indicates that it owns the subkey. This signature is calculated directly on the primary key and subkey, and not on any User ID or other packets. A signature that binds a signing subkey MUST have an Embedded Signature subpacket in this binding signature that contains a 0x19 signature made by the signing subkey on the primary key and subkey.

0x19 Primary Key Binding Signature. This signature is a statement by a signing subkey, indicating that it is owned by the primary key and subkey. This signature is calculated the same way as a 0x18 signature: directly on the primary key and subkey, and not on any User ID or other packets.

0x1F Signature directly on a key. This signature is calculated directly on a key. It binds the information in the Signature subpackets to the key, and is appropriate to be used for subpackets that provide information about the key, such as the Revocation Key subpacket. It is also appropriate for statements that non-self certifiers want to make about the key itself, rather than the binding between a key and a name.

0x20 Key revocation signature. The signature is calculated directly on the key being revoked. A revoked key is not to be used. Only revocation signatures by the key being revoked, or by an authorized revocation key, should be considered valid revocation signatures.

0x28 Subkey revocation signature. The signature is calculated directly on the subkey being revoked. A revoked subkey is not to be used. Only revocation signatures by the top-level signature key that is bound to this subkey, or by an authorized revocation key, should be considered valid revocation signatures.

0x30 Certification revocation signature. This signature revokes an earlier User ID certification signature (signature class 0x10 through 0x13) or direct-key signature (0x1F). It should be issued by the same key that issued the revoked signature or an authorized revocation key. The signature is computed over the same data as the certificate that it revokes, and should have a later creation date than that certificate.

0x40 Timestamp signature. This signature is only meaningful for the timestamp contained in it.

0x50 Third-Party Confirmation signature. This signature is a signature over some other LibrePGP Signature packet(s). It is analogous to a notary seal on the signed data. A third-party signature SHOULD include Signature Target subpacket(s) to give easy identification. Note that we really do mean SHOULD. There are plausible uses for this (such as a blind party that only sees the signature, not the key or source document) that cannot include a target subpacket.

5.2.2. Version 3 Signature Packet Format

The body of a version 3 Signature Packet contains:

* One-octet version number (3).
* One-octet length of following hashed material. MUST be 5.
* One-octet signature type.
* Four-octet creation time.
* Eight-octet Key ID of signer.
* One-octet public-key algorithm.

* One-octet hash algorithm.

* Two-octet field holding left 16 bits of signed hash value.

* One or more multiprecision integers comprising the signature. This portion is algorithm specific, as described below.

  The concatenation of the data to be signed, the signature type, and creation time from the Signature packet (5 additional octets) is hashed. The resulting hash value is used in the signature algorithm. The high 16 bits (first two octets) of the hash are included in the Signature packet to provide a way to reject some invalid signatures without performing a signature verification.

  Algorithm-Specific Fields for RSA signatures:

  - Multiprecision integer (MPI) of RSA signature value m^d mod n.

  Algorithm-Specific Fields for DSA and ECDSA signatures:

  - MPI of DSA or ECDSA value r.

  - MPI of DSA or ECDSA value s.

The signature calculation is based on a hash of the signed data, as described above. The details of the calculation are different for DSA signatures than for RSA signatures.

With RSA signatures, the hash value is encoded using PKCS#1 encoding type EMSA-PKCS1-v1_5 as described in Section 9.2 of RFC 3447. This requires inserting the hash value as an octet string into an ASN.1 structure. The object identifier for the type of hash being used is included in the structure. The hexadecimal representations for the currently defined hash algorithms are as follows:

- MD5: 0x2A, 0x86, 0x48, 0x86, 0xF7, 0x0D, 0x02, 0x05

- RIPEMD-160: 0x2B, 0x24, 0x03, 0x02, 0x01

- SHA-1: 0x2B, 0x0E, 0x03, 0x02, 0x1A

- SHA2-224: 0x60, 0x86, 0x48, 0x01, 0x65, 0x03, 0x04, 0x02, 0x04

- SHA2-256: 0x60, 0x86, 0x48, 0x01, 0x65, 0x03, 0x04, 0x02, 0x01

- SHA2-384: 0x60, 0x86, 0x48, 0x01, 0x65, 0x03, 0x04, 0x02, 0x02

- SHA2-512: 0x60, 0x86, 0x48, 0x01, 0x65, 0x03, 0x04, 0x02, 0x03

The ASN.1 Object Identifiers (OIDs) are as follows:

- MD5: 1.2.840.113549.2.5

- RIPEMD-160: 1.3.36.3.2.1

- SHA-1: 1.3.14.3.2.26

- SHA2-224: 2.16.840.1.101.3.4.2.4

- SHA2-256: 2.16.840.1.101.3.4.2.1

- SHA2-384: 2.16.840.1.101.3.4.2.2

- SHA2-512: 2.16.840.1.101.3.4.2.3

The full hash prefixes for these are as follows:

- MD5: 0x30, 0x20, 0x30, 0x0C, 0x06, 0x08, 0x2A, 0x86,
  0x48, 0x86, 0xF7, 0x0D, 0x02, 0x05, 0x05, 0x00,
  0x04, 0x10

- RIPEMD-160: 0x30, 0x21, 0x30, 0x09, 0x06, 0x05, 0x2B, 0x24,
  0x03, 0x02, 0x01, 0x05, 0x00, 0x04, 0x14

- SHA-1: 0x30, 0x21, 0x30, 0x09, 0x06, 0x05, 0x2b, 0x0E,
  0x03, 0x02, 0x1A, 0x05, 0x00, 0x04, 0x14

- SHA2-224: 0x30, 0x2D, 0x30, 0x0d, 0x06, 0x09, 0x60, 0x86,
  0x48, 0x01, 0x65, 0x03, 0x04, 0x02, 0x04, 0x05,
  0x00, 0x04, 0x1C

- SHA2-256: 0x30, 0x31, 0x30, 0x0d, 0x06, 0x09, 0x60, 0x86,
  0x48, 0x01, 0x65, 0x03, 0x04, 0x02, 0x01, 0x05,
  0x00, 0x04, 0x20

- SHA2-384: 0x30, 0x41, 0x30, 0x0d, 0x06, 0x09, 0x60, 0x86,
  0x48, 0x01, 0x65, 0x03, 0x04, 0x02, 0x02, 0x05,
  0x00, 0x04, 0x30

- SHA2-512: 0x30, 0x51, 0x30, 0x0d, 0x06, 0x09, 0x60, 0x86,
  0x48, 0x01, 0x65, 0x03, 0x04, 0x02, 0x03, 0x05,
  0x00, 0x04, 0x40

DSA signatures MUST use hashes that are equal in size to the number of bits of q, the group generated by the DSA key’s generator value.

If the output size of the chosen hash is larger than the number of bits of q, the hash result is truncated to fit by taking the number of leftmost bits equal to the number of bits of q. This (possibly truncated) hash function result is treated as a number and used directly in the DSA signature algorithm.

5.2.3. Version 4 and 5 Signature Packet Formats

The body of a V4 and V5 Signature packet contains:

* One-octet version number. This is 4 for V4 signatures and 5 for V5 signatures.

* One-octet signature type.

* One-octet public-key algorithm.

* One-octet hash algorithm.

* Two-octet scalar octet count for following hashed subpacket data. Note that this is the length in octets of all of the hashed subpackets; a pointer incremented by this number will skip over the hashed subpackets.

* Hashed subpacket data set (zero or more subpackets).

* Two-octet scalar octet count for the following unhashed subpacket data. Note that this is the length in octets of all of the unhashed subpackets; a pointer incremented by this number will skip over the unhashed subpackets.

* Unhashed subpacket data set (zero or more subpackets).

* Two-octet field holding the left 16 bits of the signed hash value.

* One or more multiprecision integers comprising the signature. This portion is algorithm specific:

  Algorithm-Specific Fields for RSA signatures:

  - Multiprecision integer (MPI) of RSA signature value m^d mod n.

  Algorithm-Specific Fields for DSA or ECDSA signatures:

  - MPI of DSA or ECDSA value r.

  - MPI of DSA or ECDSA value s.

Algorithm-Specific Fields for EdDSA signatures:

- MPI of an EC point r.

- EdDSA value s, in MPI, in the little endian representation.

The format of R and S for use with EdDSA is described in [RFC8032]. A version 3 signature MUST NOT be created and MUST NOT be used with EdDSA.

The concatenation of the data being signed and the signature data from the version number through the hashed subpacket data (inclusive) is hashed. The resulting hash value is what is signed. The high 16 bits (first two octets) of the hash are included in the Signature packet to provide a way to reject some invalid signatures without performing a signature verification.

There are two fields consisting of Signature subpackets. The first field is hashed with the rest of the signature data, while the second is unhashed. The second set of subpackets is not cryptographically protected by the signature and should include only advisory information.

The difference between a V4 and V5 signature is that the latter includes additional meta data.

The algorithms for converting the hash function result to a signature are described in a section below.

5.2.3.1. Signature Subpacket Specification

A subpacket data set consists of zero or more Signature subpackets. In Signature packets, the subpacket data set is preceded by a two-octet scalar count of the length in octets of all the subpackets. A pointer incremented by this number will skip over the subpacket data set.

Each subpacket consists of a subpacket header and a body. The header consists of:

* the subpacket length (1, 2, or 5 octets),

* the subpacket type (1 octet),

and is followed by the subpacket-specific data.

The length includes the type octet but not this length. Its format is similar to the "new" format packet header lengths, but cannot have Partial Body Lengths. That is:

```
if the 1st octet <  192, then
    lengthOfLength = 1
    subpacketLen = 1st_octet

if the 1st octet >= 192 and < 255, then
    lengthOfLength = 2
    subpacketLen = ((1st_octet - 192) << 8) + (2nd_octet) + 192

if the 1st octet = 255, then
    lengthOfLength = 5
    subpacket length = [four-octet scalar starting at 2nd_octet]
```

The value of the subpacket type octet may be:

Type	Description
0	Reserved
1	Reserved
2	Signature Creation Time
3	Signature Expiration Time
4	Exportable Certification
5	Trust Signature
6	Regular Expression
7	Revocable
8	Reserved
9	Key Expiration Time
10	Placeholder for backward compatibility
11	Preferred Symmetric Algorithms
12	Revocation Key
13 to 15	Reserved

16	Issuer
17 to 19	Reserved
20	Notation Data
21	Preferred Hash Algorithms
22	Preferred Compression Algorithms
23	Key Server Preferences
24	Preferred Key Server
25	Primary User ID
26	Policy URI
27	Key Flags
28	Signer’s User ID
29	Reason for Revocation
30	Features
31	Signature Target
32	Embedded Signature
33	Issuer Fingerprint
34	Preferred Encryption Modes
35	Intended Recipient Fingerprint
37	Attested Certifications (deprecated)
38	Key Block
39	Reserved
40	Literal Data Meta Hash
41	Trust Alias
100 to 110	Private or experimental

+------------+--+

Table 3

An implementation SHOULD ignore any subpacket of a type that it does not recognize.

Bit 7 of the subpacket type is the "critical" bit. If set, it denotes that the subpacket is one that is critical for the evaluator of the signature to recognize. If a subpacket is encountered that is marked critical but is unknown to the evaluating software, the evaluator SHOULD consider the signature to be in error.

An evaluator may "recognize" a subpacket, but not implement it. The purpose of the critical bit is to allow the signer to tell an evaluator that it would prefer a new, unknown feature to generate an error than be ignored.

Implementations SHOULD implement the four preferred algorithm subpackets (11, 21, 22, and 34), as well as the "Reason for Revocation" subpacket. Note, however, that if an implementation chooses not to implement some of the preferences, it is required to behave in a polite manner to respect the wishes of those users who do implement these preferences.

5.2.3.2. Signature Subpacket Types

A number of subpackets are currently defined. Some subpackets apply to the signature itself and some are attributes of the key. Subpackets that are found on a self-signature are placed on a certification made by the key itself. Note that a key may have more than one User ID, and thus may have more than one self-signature, and differing subpackets.

A subpacket may be found either in the hashed or unhashed subpacket sections of a signature. If a subpacket is not hashed, then the information in it cannot be considered definitive because it is not part of the signature proper.

5.2.3.3. Notes on Self-Signatures

A self-signature is a binding signature made by the key to which the signature refers. There are three types of self-signatures, the certification signatures (types 0x10-0x13), the direct-key signature (type 0x1F), and the subkey binding signature (type 0x18). For certification self-signatures, each User ID may have a self-signature, and thus different subpackets in those self-signatures. For subkey binding signatures, each subkey in fact has a self-

signature. Subpackets that appear in a certification self-signature apply to the user name, and subpackets that appear in the subkey self-signature apply to the subkey. Lastly, subpackets on the direct-key signature apply to the entire key.

Implementing software should interpret a self-signature's preference subpackets as narrowly as possible. For example, suppose a key has two user names, Alice and Bob. Suppose that Alice prefers the symmetric algorithm AES-256, and Bob prefers Camellia-256 or AES-128. If the software locates this key via Alice's name, then the preferred algorithm is AES-256; if software locates the key via Bob's name, then the preferred algorithm is Camellia-256. If the key is located by Key ID, the algorithm of the primary User ID of the key provides the preferred symmetric algorithm.

Revoking a self-signature or allowing it to expire has a semantic meaning that varies with the signature type. Revoking the self-signature on a User ID effectively retires that user name. The self-signature is a statement, "My name X is tied to my signing key K" and is corroborated by other users' certifications. If another user revokes their certification, they are effectively saying that they no longer believe that name and that key are tied together. Similarly, if the users themselves revoke their self-signature, then the users no longer go by that name, no longer have that email address, etc. Revoking a binding signature effectively retires that subkey. Revoking a direct-key signature cancels that signature. Please see the "Reason for Revocation" subpacket (Section 5.2.3.25) for more relevant detail.

Since a self-signature contains important information about the key's use, an implementation SHOULD allow the user to rewrite the self-signature, and important information in it, such as preferences and key expiration.

It is good practice to verify that a self-signature imported into an implementation doesn't advertise features that the implementation doesn't support, rewriting the signature as appropriate.

An implementation that encounters multiple self-signatures on the same object may resolve the ambiguity in any way it sees fit, but it is RECOMMENDED that priority be given to the most recent self-signature.

5.2.3.4. Signature Creation Time

(4-octet time field)

The time the signature was made.

MUST be present in the hashed area.

5.2.3.5. Issuer

(8-octet Key ID)

The LibrePGP Key ID of the key issuing the signature. If the version of that key is greater than 4, this subpacket MUST NOT be included in the signature.

5.2.3.6. Key Expiration Time

(4-octet time field)

The validity period of the key. This is the number of seconds after the key creation time that the key expires. If this is not present or has a value of zero, the key never expires. This is found only on a self-signature.

5.2.3.7. Preferred Symmetric Algorithms

(array of one-octet values)

Symmetric algorithm numbers that indicate which algorithms the key holder prefers to use. The subpacket body is an ordered list of octets with the most preferred listed first. It is assumed that only algorithms listed are supported by the recipient's software. Algorithm numbers are in Section 9. This is only found on a self-signature.

5.2.3.8. Preferred Encryption Modes

(array of one-octet values)

This is a deprecated subpacket with encryption mode numbers to indicate which modes the key holder prefers to use with OCB Encrypted Data Pakets. Implementations SHOULD ignore this subpacket and assume OCB. The subpacket body is an ordered list of octets with the most preferred listed first. It is assumed that only modes listed are supported by the recipient's software. Mode numbers are in Section 9.6. This is only found on a self-signature. Note that support for the OCB Encrypted Data packet in the general is indicated by a Feature Flag.

5.2.3.9. Preferred Hash Algorithms

(array of one-octet values)

Message digest algorithm numbers that indicate which algorithms the key holder prefers to receive. Like the preferred symmetric algorithms, the list is ordered. Algorithm numbers are in Section 9.5. This is only found on a self-signature.

5.2.3.10. Preferred Compression Algorithms

(array of one-octet values)

Compression algorithm numbers that indicate which algorithms the key holder prefers to use. Like the preferred symmetric algorithms, the list is ordered. Algorithm numbers are in Section 9.4. If this subpacket is not included, ZIP is preferred. A zero denotes that uncompressed data is preferred; the key holder's software might have no compression software in that implementation. This is only found on a self-signature.

5.2.3.11. Signature Expiration Time

(4-octet time field)

The validity period of the signature. This is the number of seconds after the signature creation time that the signature expires. If this is not present or has a value of zero, it never expires.

5.2.3.12. Exportable Certification

(1 octet of exportability, 0 for not, 1 for exportable)

This subpacket denotes whether a certification signature is "exportable", to be used by other users than the signature's issuer. The packet body contains a Boolean flag indicating whether the signature is exportable. If this packet is not present, the certification is exportable; it is equivalent to a flag containing a 1.

Non-exportable, or "local", certifications are signatures made by a user to mark a key as valid within that user's implementation only.

Thus, when an implementation prepares a user's copy of a key for transport to another user (this is the process of "exporting" the key), any local certification signatures are deleted from the key.

The receiver of a transported key "imports" it, and likewise trims any local certifications. In normal operation, there won't be any, assuming the import is performed on an exported key. However, there are instances where this can reasonably happen. For example, if an implementation allows keys to be imported from a key database in addition to an exported key, then this situation can arise.

Some implementations do not represent the interest of a single user (for example, a key server). Such implementations always trim local certifications from any key they handle.

5.2.3.13. Revocable

(1 octet of revocability, 0 for not, 1 for revocable)

Signature's revocability status. The packet body contains a Boolean flag indicating whether the signature is revocable. Signatures that are not revocable have any later revocation signatures ignored. They represent a commitment by the signer that he cannot revoke his signature for the life of his key. If this packet is not present, the signature is revocable.

5.2.3.14. Trust Signature

(1 octet "level" (depth), 1 octet of trust amount)

Signer asserts that the key is not only valid but also trustworthy at the specified level. Level 0 has the same meaning as an ordinary validity signature. Level 1 means that the signed key is asserted to be a valid trusted introducer, with the 2nd octet of the body specifying the degree of trust. Level 2 means that the signed key is asserted to be trusted to issue level 1 trust signatures, i.e., that it is a "meta introducer". Generally, a level n trust signature asserts that a key is trusted to issue level n-1 trust signatures. The trust amount is in a range from 0-255, interpreted such that values less than 120 indicate partial trust and values of 120 or greater indicate complete trust. Implementations SHOULD emit values of 60 for partial trust and 120 for complete trust.

5.2.3.15. Regular Expression

(null-terminated regular expression)

Used in conjunction with Trust Signature packets (of level > 0) to limit the scope of trust that is extended. Only signatures by the target key on User IDs that match the regular expression in the body of this packet have trust extended by the trust Signature subpacket. The regular expression uses the same syntax as the Henry Spencer's "almost public domain" regular expression [REGEX] package. A description of the syntax is found in Section 8 below.

5.2.3.16. Trust Alias

(String)

This subpacket allows a keyholder to state an alias for a mail address in the User ID. The value is expected to be the UTF-8 encoded addr-spec part of a mail address.

If used in conjunction with a Trust Signature subpacket of level > 0 and a Regular Expression subpacket the User ID is not considered and the trust is only extended if at least one Trust Alias matches the regular expression.

If this subpacket is found on a self-signature, a signature done with a Trust Signature subpacket of level > 0 and a Regular Expression subpacket is computed over the User ID, an octet 0x00, and the value of the Trust Alias subpacket. If more than one Trust Alias subpacket exists all those subpackets are first sorted using binary ordering and then concatenated using an octet 0x00 as separator.

This subpacket is useful to handle the common case that mails with and without subdomains are used. For example alice@example.org is her canonical address but she receives mail also under the address alice@lab.example.org. All other properties are identical for the second address and thus a second User ID packet is not useful here.

5.2.3.17. Revocation Key

(1 octet of class, 1 octet of public-key algorithm ID, 20 or 32 octets of fingerprint)

V4 keys SHOULD use the full 20 octet fingerprint; V5 keys use the full 32 octet fingerprint.

Authorizes the specified key to issue revocation signatures for this key. Class octet must have bit 0x80 set. If the bit 0x40 is set, then this means that the revocation information is sensitive. Other bits are for future expansion to other kinds of authorizations. This is only found on a direct-key self-signature (type 0x1f). The use on other types of self-signatures is unspecified.

If the "sensitive" flag is set, the keyholder feels this subpacket contains private trust information that describes a real-world sensitive relationship. If this flag is set, implementations SHOULD NOT export this signature to other users except in cases where the data needs to be available: when the signature is being sent to the designated revoker, or when it is accompanied by a revocation signature from that revoker. Note that it may be appropriate to isolate this subpacket within a separate signature so that it is not combined with other subpackets that need to be exported.

5.2.3.18. Notation Data

```
(4 octets of flags, 2 octets of name length (M),
                    2 octets of value length (N),
                    M octets of name data,
                    N octets of value data)
```

This subpacket describes a "notation" on the signature that the issuer wishes to make. The notation has a name and a value, each of which are strings of octets. There may be more than one notation in a signature. Notations can be used for any extension the issuer of the signature cares to make. The "flags" field holds four octets of flags.

All undefined flags MUST be zero. Defined flags are as follows:

First octet: 0x80 = human-readable. This note value is text.
Other octets: none.

Notation names are arbitrary strings encoded in UTF-8. They reside in two namespaces: The IETF namespace and the user namespace.

The IETF namespace is registered with IANA. These names MUST NOT contain the "@" character (0x40). This is a tag for the user namespace.

Names in the user namespace consist of a UTF-8 string tag followed by "@" followed by a DNS domain name. Note that the tag MUST NOT contain an "@" character. For example, the "sample" tag used by Example Corporation could be "sample@example.com".

Names in a user space are owned and controlled by the owners of that domain. Obviously, it’s bad form to create a new name in a DNS space that you don’t own.

Since the user namespace is in the form of an email address, implementers MAY wish to arrange for that address to reach a person who can be consulted about the use of the named tag. Note that due to UTF-8 encoding, not all valid user space name tags are valid email addresses.

If there is a critical notation, the criticality applies to that specific notation and not to notations in general.

The following subsections define a set of standard notations.

5.2.3.18.1. The ’charset’ Notation

The "charset" notation is a description of the character set used to encode the signed plaintext. The default value is "UTF-8". If used, the value MUST be encoded as human readable and MUST be present in the hashed subpacket section of the signature. This notation is useful for cleartext signatures in cases where it is not possible to encode the text in UTF-8. By having the used character set a part of the signed data, attacks exploiting different representation of code points will be mitigated.

5.2.3.18.2. The ’manu’ Notation

The "manu" notation is a string that declares the device manufacturer’s name. The certifier key is asserting this string (which may or may not be related to the User ID of the certifier’s key).

5.2.3.18.3. The ’make’ Notation

This notation defines the product make. It is a free form string.

5.2.3.18.4. The ’model’ Notation

This notation defines the product model name/number. It is a free form string.

5.2.3.18.5. The ’prodid’ Notation

This notation contains the product identifier. It is a free form string.

5.2.3.18.6. The ’pvers’ Notation

This notation defines the product version number (which could be a release number, year, or some other identifier to differentiate different versions of the same make/model). It is a free form string.

5.2.3.18.7. The ’lot’ Notation

This notation defines the product lot number (which is an indicator of the batch of product). It is a free form string.

5.2.3.18.8. The ’qty’ Notation

This notation defines the quantity of items in this package. It is a decimal integer representation with no punctuation, e.g. "10", "1000", "10000", etc.

5.2.3.18.9. The ’loc’ and ’dest’ Notations

The "loc" and ’dest’ notations declare a GeoLocation as defined by RFC 5870 [RFC5870] but without the leading "geo:" header. For example, if you had a GeoLocation URI of "geo:13.4125,103.8667" you would encode that in these notations as "13.4125,103.8667".

The ’loc’ notation is meant to encode the geo location where the signature was made. The ’dest’ notation is meant to encode the geo location where the device is "destined" (i.e., a "destination" for the device).

5.2.3.18.10. The ’hash’ Notation

A ’hash’ notation is a means to include external data in the contents of a signature without including the data itself. This is done by hashing the external data separately and then including the data’s name and hash in the signature via this notation. This is useful, for example, to have an external "manifest," "image," or other data that might not be vital to the signature itself but still needs to be protected and authenticated without requiring a second signature.

The ’hash’ notation has the following structure:

* A single byte specifying the length of the name of the hashed data.

* A UTF-8 string of the name of the hashed data.

* A single byte specifying the hash algorithm (see section 9.4).

* The binary hash output of the hashed data using the specified algorithm. (The length of this data is implicit based on the algorithm specified).

Due to its nature a 'hash' notation is not human readable and MUST NOT be marked as such when used.

5.2.3.19. Key Server Preferences

(N octets of flags)

This is a list of one-bit flags that indicate preferences that the key holder has about how the key is handled on a key server. All undefined flags MUST be zero.

First octet: 0x80 = No-modify

The key holder requests that this key only be modified or updated by the key holder or an administrator of the key server.

If No-modify is set on the most recent self-sig over a User ID, then a keyserver should only redistribute those third-party certifications over that User ID that have been attested to in the most recent Attestation Key Signature packet (see "Attested Certifications" below).

This is found only on a self-signature.

5.2.3.20. Preferred Key Server

(String)

This is a URI of a key server that the key holder prefers be used for updates. Note that keys with multiple User IDs can have a preferred key server for each User ID. Note also that since this is a URI, the key server can actually be a copy of the key retrieved by ftp, http, finger, etc.

5.2.3.21. Primary User ID

(1 octet, Boolean)

This is a flag in a User ID's self-signature that states whether this User ID is the main User ID for this key. It is reasonable for an implementation to resolve ambiguities in preferences, etc. by referring to the primary User ID. If this flag is absent, its value is zero. If more than one User ID in a key is marked as primary, the implementation may resolve the ambiguity in any way it sees fit, but it is RECOMMENDED that priority be given to the User ID with the most recent self-signature.

When appearing on a self-signature on a User ID packet, this subpacket applies only to User ID packets. When appearing on a self-signature on a User Attribute packet, this subpacket applies only to User Attribute packets. That is to say, there are two different and independent "primaries" --- one for User IDs, and one for User Attributes.

5.2.3.22. Policy URI

(String)

This subpacket contains a URI of a document that describes the policy under which the signature was issued.

5.2.3.23. Key Flags

(N octets of flags)

This subpacket contains a list of binary flags that hold information about a key. It is a string of octets, and an implementation MUST NOT assume a fixed size. This is so it can grow over time. If a list is shorter than an implementation expects, the unstated flags are considered to be zero. The defined flags are as follows:

First octet:

0x01 - This key may be used to certify other keys.

0x02 - This key may be used to sign data.

0x04 - This key may be used to encrypt communications.

0x08 - This key may be used to encrypt storage.

0x10 - The private component of this key may have been split by a secret-sharing mechanism.

0x20 - This key may be used for authentication.

0x80 - The private component of this key may be in the possession of more than one person.

Second octet:

0x04 - This key may be used to encrypt communications or storage.

0x08 - This key may be used for timestamping.

Usage notes:

The flags in this packet may appear in self-signatures or in certification signatures. They mean different things depending on who is making the statement --- for example, a certification signature that has the "sign data" flag is stating that the certification is for that use. On the other hand, the "communications encryption" flag in a self-signature is stating a preference that a given key be used for communications. Note however, that it is a thorny issue to determine what is "communications" and what is "storage". This decision is left wholly up to the implementation; the authors of this document do not claim any special wisdom on the issue and realize that accepted opinion may change.

The "split key" (1st,0x10) and "group key" (1st,0x80) flags are placed on a self-signature only; they are meaningless on a certification signature. They SHOULD be placed only on a direct-key signature (type 0x1F) or a subkey signature (type 0x18), one that refers to the key the flag applies to.

The "restricted encryption key" (2nd,0x04) does not take part in any automatic selection of encryption keys. It is only found on a subkey signature (type 0x18), one that refers to the key the flag applies to.

5.2.3.24. Signer's User ID

(String)

This subpacket allows a keyholder to state which User ID is responsible for the signing. Many keyholders use a single key for different purposes, such as business communications as well as personal communications. This subpacket allows such a keyholder to state which of their roles is making a signature.

This subpacket is not appropriate to use to refer to a User Attribute packet.

5.2.3.25. Reason for Revocation

(1 octet of revocation code, N octets of reason string)

This subpacket is used only in key revocation and certification revocation signatures. It describes the reason why the key or certificate was revoked.

The first octet contains a machine-readable code that denotes the reason for the revocation:

Code	Reason
0	No reason specified (key revocations or cert revocations)
1	Key is superseded (key revocations)
2	Key material has been compromised (key revocations)
3	Key is retired and no longer used (key revocations)
32	User ID information is no longer valid (cert revocations)
100-110	Private Use

Table 4

Following the revocation code is a string of octets that gives information about the Reason for Revocation in human-readable form (UTF-8). The string may be null, that is, of zero length. The length of the subpacket is the length of the reason string plus one. An implementation SHOULD implement this subpacket, include it in all revocation signatures, and interpret revocations appropriately. There are important semantic differences between the reasons, and there are thus important reasons for revoking signatures.

If a key has been revoked because of a compromise, all signatures created by that key are suspect. However, if it was merely superseded or retired, old signatures are still valid. If the revoked signature is the self-signature for certifying a User ID, a revocation denotes that that user name is no longer in use. Such a revocation SHOULD include a 0x20 code.

Note that any signature may be revoked, including a certification on some other person’s key. There are many good reasons for revoking a certification signature, such as the case where the keyholder leaves the employ of a business with an email address. A revoked certification is no longer a part of validity calculations.

5.2.3.26. Features

(N octets of flags)

The Features subpacket denotes which advanced LibrePGP features a user’s implementation supports. This is so that as features are added to LibrePGP that cannot be backwards-compatible, a user can state that they can use that feature. The flags are single bits that indicate that a given feature is supported.

This subpacket is similar to a preferences subpacket, and only appears in a self-signature.

An implementation SHOULD NOT use a feature listed when sending to a user who does not state that they can use it.

Defined features are as follows:

First octet:

0x01 - Modification Detection (packets 18 and 19)

0x02 - OCB Encrypted Data Packet (packet 20) and version 5 Symmetric-Key Encrypted Session Key Packets (packet 3)

0x04 - Version 5 Public-Key Packet format and corresponding new fingerprint format

If an implementation implements any of the defined features, it SHOULD implement the Features subpacket, too.

An implementation may freely infer features from other suitable implementation-dependent mechanisms.

5.2.3.27. Signature Target

(1 octet public-key algorithm, 1 octet hash algorithm, N octets hash)

This subpacket identifies a specific target signature to which a signature refers. For revocation signatures, this subpacket provides explicit designation of which signature is being revoked. For a third-party or timestamp signature, this designates what signature is signed. All arguments are an identifier of that target signature.

The N octets of hash data MUST be the size of the hash of the signature. For example, a target signature with a SHA-1 hash MUST have 20 octets of hash data.

5.2.3.28. Embedded Signature

(1 signature packet body)

This subpacket contains a complete Signature packet body as specified in Section 5.2 above. It is useful when one signature needs to refer to, or be incorporated in, another signature.

5.2.3.29. Issuer Fingerprint

(1 octet key version number, N octets of fingerprint)

The LibrePGP Key fingerprint of the key issuing the signature. This subpacket SHOULD be included in all signatures. If the version of the issuing key is 4 and an Issuer subpacket is also included in the signature, the key ID of the Issuer subpacket MUST match the low 64 bits of the fingerprint.

Note that the length N of the fingerprint for a version 4 key is 20 octets; for a version 5 key N is 32.

5.2.3.30. Intended Recipient Fingerprint

(1 octet key version number, N octets of fingerprint)

The LibrePGP Key fingerprint of the intended recipient primary key. If one or more subpackets of this type are included in a signature, it SHOULD be considered valid only in an encrypted context, where the key it was encrypted to is one of the indicated primary keys, or one of their subkeys. This can be used to prevent forwarding a signature outside of its intended, encrypted context.

Note that the length N of the fingerprint for a version 4 key is 20 octets; for a version 5 key N is 32.

5.2.3.31. Attested Certifications

(N octets of certification digests)

Due to general problems with the concept of public keyservers, implementations SHOULD NOT implement or consider this subpacket. This subpacket was specified for experimental purposes to mitigate problems with the keyserver but it merely increases the complexity for no good benefit.

This subpacket MUST only appear as a hashed subpacket of an Attestation Key Signature. It has no meaning in any other signature type. It is used by the primary key to attest to a set of third-party certifications over the associated User ID or User Attribute. This enables the holder of an LibrePGP primary key to mark specific third-party certifications as re-distributable with the rest of the Transferable Public Key (see the "No-modify" flag in "Key Server Preferences", above). Implementations MUST include exactly one Attested Certification subpacket in any generated Attestation Key Signature.

The contents of the subpacket consists of a series of digests using the same hash algorithm used by the signature itself. Each digest is made over one third-party signature (any Certification, i.e., signature type 0x10-0x13) that covers the same Primary Key and User ID (or User Attribute). For example, an Attestation Key Signature made by key X over User ID U using hash algorithm SHA256 might contain an Attested Certifications subpacket of 192 octets (6*32 octets) covering six third-party certification Signatures over <X,U>. They SHOULD be ordered by binary hash value from low to high (e.g., a hash with hexadecimal value 037a... precedes a hash with value 0392..., etc). The length of this subpacket MUST be an integer multiple of the length of the hash algorithm used for the enclosing Attestation Key Signature.

The listed digests MUST be calculated over the third-party certification's Signature packet as described in the "Computing Signatures" section, but without a trailer: the hash data starts with the octet 0x88, followed by the four-octet length of the Signature, and then the body of the Signature packet. (Note that this is an old-style packet header for a Signature packet with the length-of-length field set to zero.) The unhashed subpacket data of the Signature packet being hashed is not included in the hash, and the unhashed subpacket data length value is set to zero.

If an implementation encounters more than one such subpacket in an Attestation Key Signature, it MUST treat it as a single Attested Certifications subpacket containing the union of all hashes.

The Attested Certifications subpacket in the most recent Attestation Key Signature over a given User ID supersedes all Attested Certifications subpackets from any previous Attestation Key Signature. However, note that if more than one Attestation Key Signatures has the same (most recent) Signature Creation Time subpacket, implementations MUST consider the union of the attestations of all Attestation Key Signatures (this allows the keyholder to attest to more third-party certifications than could fit in a single Attestation Key Signature).

If a keyholder Alice has already attested to third-party certifications from Bob and Carol and she wants to add an attestation to a certification from David, she should issue a new Attestation Key Signature (with a more recent Signature Creation timestamp) that contains an Attested Certifications subpacket covering all three third-party certifications.

If she later decides that she does not want Carol's certification to be redistributed with her certificate, she can issue a new Attestation Key Signature (again, with a more recent Signature Creation timestamp) that contains an Attested Certifications subpacket covering only the certifications from Bob and David.

Note that Certification Revocation Signatures are not relevant for Attestation Key Signatures. To rescind all attestations, the primary key holder needs only to publish a more recent Attestation Key Signature with an empty Attested Certifications subpacket.

5.2.3.32. Key Block

(1 octet with value 0, N octets of key data)

This subpacket MAY be used to convey key data along with a signature of class 0x00, 0x01, or 0x02. It MUST contain the key used to create the signature; either as the primary key or as a subkey. The key SHOULD contain a primary or subkey capable of encryption and the entire key must be a valid LibrePGP key including at least one User ID packet and the corresponding self-signatures.

Implementations MUST ignore this subpacket if the first octet does not have a value of zero or if the key data does not represent a valid transferable public key.

5.2.3.33. Literal Data Meta Hash

(1 octet with value 0, 32 octets hash value)

This subpacket MAY be used to protect the meta data from the Literal Data Packet with V4 signatures. The hash is computed using SHA2-256 from this data:

* the one-octet content format,
* the file name as a string (one octet length, followed by the file name),
* a four-octet number that indicates a date.

These three data items need to mirror the corresponding values of the Literal Data packet. Implementations encountering this subpacket must re-create the hash from the received Literal Data packet and compare them. If the hash values do not match or if this packet is used in a V5 signature the signature MUST be deemed as invalid.

5.2.4. Computing Signatures

All signatures are formed by producing a hash over the signature data, and then using the resulting hash in the signature algorithm.

For binary document signatures (type 0x00), the document data is hashed directly. For text document signatures (type 0x01), the document is canonicalized by converting line endings to <CR><LF>, and the resulting data is hashed.

When a V4 signature is made over a key, the hash data starts with the octet 0x99, followed by a two-octet length of the key, and then body of the key packet; when a V5 signature is made over a key, the hash data starts with the octet 0x9a for V5, followed by a four-octet length of the key, and then body of the key packet. A subkey binding signature (type 0x18) or primary key binding signature (type 0x19)

then hashes the subkey using the same format as the main key (also using 0x99 or 0x9a as the first octet). Primary key revocation signatures (type 0x20) hash only the key being revoked. Subkey revocation signature (type 0x28) hash first the primary key and then the subkey being revoked.

A certification signature (type 0x10 through 0x13) hashes the User ID being bound to the key into the hash context after the above data. A V3 certification hashes the contents of the User ID or attribute packet packet, without any header. A V4 or V5 certification hashes the constant 0xB4 for User ID certifications or the constant 0xD1 for User Attribute certifications, followed by a four-octet number giving the length of the User ID or User Attribute data, and then the User ID or User Attribute data.

An Attestation Key Signature (0x16) hashes the same data body that a standard certification signature does: primary key, followed by User ID or User Attribute.

When a signature is made over a Signature packet (type 0x50, "Third-Party Confirmation signature"), the hash data starts with the octet 0x88, followed by the four-octet length of the signature, and then the body of the Signature packet. (Note that this is an old-style packet header for a Signature packet with the length-of-length field set to zero.) The unhashed subpacket data of the Signature packet being hashed is not included in the hash, and the unhashed subpacket data length value is set to zero.

Once the data body is hashed, then a trailer is hashed. This trailer depends on the version of the signature.

* A V3 signature hashes five octets of the packet body, starting from the signature type field. This data is the signature type, followed by the four-octet signature time.

* A V4 signature hashes the packet body starting from its first field, the version number, through the end of the hashed subpacket data and a final extra trailer. Thus, the hashed fields are:

  - the signature version (0x04),

  - the signature type,

  - the public-key algorithm,

  - the hash algorithm,

  - the hashed subpacket length,

- the hashed subpacket body,

- the two octets 0x04 and 0xFF,

- a four-octet big-endian number that is the length of the hashed data from the Signature packet stopping right before the 0x04, 0XFF octets.

  The four-octet big-endian number is considered to be an unsigned integer modulo 2^32.

* A V5 signature hashes the packet body starting from its first field, the version number, through the end of the hashed subpacket data and a final extra trailer. Thus, the hashed fields are:

  - the signature version (0x05),

  - the signature type,

  - the public-key algorithm,

  - the hash algorithm,

  - the hashed subpacket length,

  - the hashed subpacket body,

  - Only for document signatures (type 0x00 or 0x01) the following three data items are hashed here:

    o the one-octet content format,

    o the file name as a string (one octet length, followed by the file name),

    o a four-octet number that indicates a date,

  - the two octets 0x05 and 0xFF,

  - a eight-octet big-endian number that is the length of the hashed data from the Signature packet stopping right before the 0x05, 0XFF octets.

  The three data items hashed for document signatures need to mirror the values of the Literal Data packet. Note that for a detached signatures this means to hash 6 0x00 octets and for a cleartext signature this means to hash a ’t’ followed by 5 0x00 octets.

After all this has been hashed in a single hash context, the resulting hash field is used in the signature algorithm and placed at the end of the Signature packet.

5.2.4.1. Subpacket Hints

It is certainly possible for a signature to contain conflicting information in subpackets. For example, a signature may contain multiple copies of a preference or multiple expiration times. In most cases, an implementation SHOULD use the last subpacket in the signature, but MAY use any conflict resolution scheme that makes more sense. Please note that we are intentionally leaving conflict resolution to the implementer; most conflicts are simply syntax errors, and the wishy-washy language here allows a receiver to be generous in what they accept, while putting pressure on a creator to be stingy in what they generate.

Some apparent conflicts may actually make sense --- for example, suppose a keyholder has a V3 key and a V4 key that share the same RSA key material. Either of these keys can verify a signature created by the other, and it may be reasonable for a signature to contain an issuer subpacket for each key, as a way of explicitly tying those keys to the signature.

5.3. Symmetric-Key Encrypted Session Key Packets (Tag 3)

The Symmetric-Key Encrypted Session Key packet holds the symmetric-key encryption of a session key used to encrypt a message. Zero or more Public-Key Encrypted Session Key packets and/or Symmetric-Key Encrypted Session Key packets may precede a Symmetrically Encrypted Data packet that holds an encrypted message. The message is encrypted with a session key, and the session key is itself encrypted and stored in the Encrypted Session Key packet or the Symmetric-Key Encrypted Session Key packet.

If the Symmetrically Encrypted Data packet is preceded by one or more Symmetric-Key Encrypted Session Key packets, each specifies a passphrase that may be used to decrypt the message. This allows a message to be encrypted to a number of public keys, and also to one or more passphrases. This packet type is new and is not generated by PGP 2 or PGP version 5.0.

A version 4 Symmetric-Key Encrypted Session Key packet consists of:

* A one-octet version number with value 4.

* A one-octet number describing the symmetric algorithm used.

* A string-to-key (S2K) specifier, length as defined above.

* Optionally, the encrypted session key itself, which is decrypted with the string-to-key object.

If the encrypted session key is not present (which can be detected on the basis of packet length and S2K specifier size), then the S2K algorithm applied to the passphrase produces the session key for decrypting the message, using the symmetric cipher algorithm from the Symmetric-Key Encrypted Session Key packet.

If the encrypted session key is present, the result of applying the S2K algorithm to the passphrase is used to decrypt just that encrypted session key field, using CFB mode with an IV of all zeros. The decryption result consists of a one-octet algorithm identifier that specifies the symmetric-key encryption algorithm used to encrypt the following Symmetrically Encrypted Data packet, followed by the session key octets themselves.

Note: because an all-zero IV is used for this decryption, the S2K specifier MUST use a salt value, either a Salted S2K or an Iterated-Salted S2K. The salt value will ensure that the decryption key is not repeated even if the passphrase is reused.

A version 5 Symmetric-Key Encrypted Session Key packet consists of:

* A one-octet version number with value 5.

* A one-octet cipher algorithm.

* A one-octet encryption mode number which MUST be 2 to indicate OCB.

* A string-to-key (S2K) specifier, length as defined above.

* A starting initialization vector of size specified by the mode.

* The encrypted session key itself, which is decrypted with the string-to-key object using the given cipher and encryption mode.

* An authentication tag for the encryption mode.

The encrypted session key is encrypted using the encryption mode specified for the OCB Encrypted Packet. Note that no chunks are used and that there is only one authentication tag. The Packet Tag in new format encoding (bits 7 and 6 set, bits 5-0 carry the packet tag), the packet version number, the cipher algorithm octet, and the mode octet are given as additional data. For example, the additional data used with OCB and AES-128 consists of the octets 0xC3, 0x05, 0x07, and 0x02.

5.4. One-Pass Signature Packets (Tag 4)

The One-Pass Signature packet precedes the signed data and contains enough information to allow the receiver to begin calculating any hashes needed to verify the signature. It allows the Signature packet to be placed at the end of the message, so that the signer can compute the entire signed message in one pass.

A One-Pass Signature does not interoperate with PGP 2.6.x or earlier.

The body of this packet consists of:

* A one-octet version number. The currently specified version is 3.

* A one-octet signature type. Signature types are described in Section 5.2.1.

* A one-octet number describing the hash algorithm used.

* A one-octet number describing the public-key algorithm used.

* An eight-octet number holding the Key ID of the signing key.

* A one-octet number holding a flag showing whether the signature is nested. A zero value indicates that the next packet is another One-Pass Signature packet that describes another signature to be applied to the same message data.

Note that if a message contains more than one one-pass signature, then the Signature packets bracket the message; that is, the first Signature packet after the message corresponds to the last one-pass packet and the final Signature packet corresponds to the first one-pass packet.

5.5. Key Material Packet

A key material packet contains all the information about a public or private key. There are four variants of this packet type, and two major versions. Consequently, this section is complex.

5.5.1. Key Packet Variants

5.5.1.1. Public-Key Packet (Tag 6)

A Public-Key packet starts a series of packets that forms an LibrePGP key (sometimes called an LibrePGP certificate).

5.5.1.2. Public-Subkey Packet (Tag 14)

A Public-Subkey packet (tag 14) has exactly the same format as a Public-Key packet, but denotes a subkey. One or more subkeys may be associated with a top-level key. By convention, the top-level key provides signature services, and the subkeys provide encryption services.

Note: in PGP version 2.6, tag 14 was intended to indicate a comment packet. This tag was selected for reuse because no previous version of PGP ever emitted comment packets but they did properly ignore them. Public-Subkey packets are ignored by PGP version 2.6 and do not cause it to fail, providing a limited degree of backward compatibility.

5.5.1.3. Secret-Key Packet (Tag 5)

A Secret-Key packet contains all the information that is found in a Public-Key packet, including the public-key material, but also includes the secret-key material after all the public-key fields.

5.5.1.4. Secret-Subkey Packet (Tag 7)

A Secret-Subkey packet (tag 7) is the subkey analog of the Secret Key packet and has exactly the same format.

5.5.2. Public-Key Packet Formats

There are three versions of key-material packets. Version 3 packets were first generated by PGP version 2.6. Version 4 keys first appeared in PGP 5 and are the preferred key version for LibrePGP.

LibrePGP implementations MUST create keys with version 4 format. V3 keys are deprecated; an implementation MUST NOT generate a V3 key, but MAY accept it.

A version 3 public key or public-subkey packet contains:

* A one-octet version number (3).

* A four-octet number denoting the time that the key was created.

* A two-octet number denoting the time in days that this key is valid. If this number is zero, then it does not expire.

* A one-octet number denoting the public-key algorithm of this key.

* A series of multiprecision integers comprising the key material:

  - a multiprecision integer (MPI) of RSA public modulus n;

  - an MPI of RSA public encryption exponent e.

V3 keys are deprecated. They contain three weaknesses. First, it is relatively easy to construct a V3 key that has the same Key ID as any other key because the Key ID is simply the low 64 bits of the public modulus. Secondly, because the fingerprint of a V3 key hashes the key material, but not its length, there is an increased opportunity for fingerprint collisions. Third, there are weaknesses in the MD5 hash algorithm that make developers prefer other algorithms. See below for a fuller discussion of Key IDs and fingerprints.

V2 keys are identical to the deprecated V3 keys except for the version number. An implementation MUST NOT generate them and MAY accept or reject them as it sees fit.

The version 4 format is similar to the version 3 format except for the absence of a validity period. This has been moved to the Signature packet. In addition, fingerprints of version 4 keys are calculated differently from version 3 keys, as described in the section "Enhanced Key Formats".

A version 4 packet contains:

* A one-octet version number (4).

* A four-octet number denoting the time that the key was created.

* A one-octet number denoting the public-key algorithm of this key.

* A series of values comprising the key material. This is algorithm-specific and described in Section 5.6.

The version 5 format is similar to the version 4 format except for the addition of a count for the key material. This count helps parsing secret key packets (which are an extension of the public key packet format) in the case of an unknown algoritm. In addition, fingerprints of version 5 keys are calculated differently from version 4 keys, as described in the section "Enhanced Key Formats".

A version 5 packet contains:

* A one-octet version number (5).

* A four-octet number denoting the time that the key was created.

* A one-octet number denoting the public-key algorithm of this key.

* A four-octet scalar octet count for the following public key material.

* A series of values comprising the public key material. This is algorithm-specific and described in Section 5.6.

5.5.3. Secret-Key Packet Formats

The Secret-Key and Secret-Subkey packets contain all the data of the Public-Key and Public-Subkey packets, with additional algorithm-specific secret-key data appended, usually in encrypted form.

The packet contains:

* A Public-Key or Public-Subkey packet, as described above.

* One octet indicating string-to-key usage conventions. Zero indicates that the secret-key data is not encrypted. 255 or 254 indicates that a string-to-key specifier is being given. Any other value is a symmetric-key encryption algorithm identifier. A version 5 packet MUST NOT use the value 255.

* Only for a version 5 packet, a one-octet scalar octet count of the next 4 optional fields.

* [Optional] If string-to-key usage octet was 255, 254, or 253, a one-octet symmetric encryption algorithm.

* [Optional] If string-to-key usage octet was 253, an octet with the values 0x02 to indicate the OCB encryption mode.

* [Optional] If string-to-key usage octet was 255, 254, or 253, a string-to-key specifier. The length of the string-to-key specifier is implied by its type, as described above.

* [Optional] If secret data is encrypted (string-to-key usage octet not zero), an Initial Vector (IV) of the same length as the cipher's block size. If string-to-key usage octet was 253 the IV is used as the nonce for the OCB mode. If the OCB mode requires a shorter nonce, the high-order bits of the IV are used and the remaining bits MUST be zero.

* Only for a version 5 packet, a four-octet scalar octet count for the following secret key material. This includes the encrypted SHA-1 hash or OCB tag if the string-to-key usage octet is 254 or 253.

* Plain or encrypted series of values comprising the secret key material. This is algorithm-specific and described in section Section 5.6. Note that if the string-to-key usage octet is 254, a 20-octet SHA-1 hash of the plaintext of the algorithm-specific portion is appended to plaintext and encrypted with it. If the string-to-key usage octet is 253, then the OCB authentication tag is part of that data.

* If the string-to-key usage octet is zero or 255, then a two-octet checksum of the plaintext of the algorithm-specific portion (sum of all octets, mod 65536).

Note that the version 5 packet format adds two count values to help parsing packets with unknown S2K or public key algorithms.

Secret MPI values can be encrypted using a passphrase. If a string-to-key specifier is given, that describes the algorithm for converting the passphrase to a key, else a simple MD5 hash of the passphrase is used. Implementations MUST use a string-to-key specifier; the simple hash is for backward compatibility and is deprecated, though implementations MAY continue to use existing private keys in the old format. The cipher for encrypting the MPIs is specified in the Secret-Key packet.

Encryption/decryption of the secret data is done in CFB mode using the key created from the passphrase and the Initial Vector from the packet. A different mode is used with V3 keys (which are only RSA) than with other key formats. With V3 keys, the MPI bit count prefix (i.e., the first two octets) is not encrypted. Only the MPI non-prefix data is encrypted. Furthermore, the CFB state is resynchronized at the beginning of each new MPI value, so that the CFB block boundary is aligned with the start of the MPI data.

With V4 and V5 keys, a simpler method is used. All secret MPI values are encrypted, including the MPI bitcount prefix.

If the string-to-key usage octet is 253, the encrypted MPI values are encrypted as one combined plaintext using OCB mode. Note that no chunks are used and that there is only one authentication tag. The Packet Tag in new format encoding (bits 7 and 6 set, bits 5-0 carry the packet tag), the cipher algorithm octet, an octet with value 0x02 (to indicate OCB mode), followed by the public-key packet fields, starting with its packet version number are given as additional data. For example, the additional data used with AES-128 in a Secret-Key Packet of version 4 consists of the octets 0xC5, 0x07, 0x02, 0x04, followed by the creation time field up to the last value of the public-key material; in a Secret-Subkey Packet the first octet would be 0xC7.

The two-octet checksum that follows the algorithm-specific portion is the algebraic sum, mod 65536, of the plaintext of all the algorithm-specific octets (including MPI prefix and data). With V3 keys, the checksum is stored in the clear. With V4 keys, the checksum is encrypted like the algorithm-specific data. This value is used to check that the passphrase was correct. However, this checksum is deprecated; an implementation SHOULD NOT use it, but should rather use the SHA-1 hash denoted with a usage octet of 254. The reason for this is that there are some attacks that involve undetectably modifying the secret key. If the string-to-key usage octet is 253 no checksum or SHA-1 hash is used but the authentication tag of the OCB mode follows.

5.6. Algorithm-specific Parts of Keys

The public and secret key format specifies algorithm-specific parts of a key. The following sections describe them in detail.

5.6.1. Algorithm-Specific Part for RSA Keys

The public key is this series of multiprecision integers:

* MPI of RSA public modulus n;

* MPI of RSA public encryption exponent e.

The secret key is this series of multiprecision integers:

* MPI of RSA secret exponent d;

* MPI of RSA secret prime value p;

* MPI of RSA secret prime value q (p < q);

* MPI of u, the multiplicative inverse of p, mod q.

5.6.2. Algorithm-Specific Part for DSA Keys

The public key is this series of multiprecision integers:

* MPI of DSA prime p;
* MPI of DSA group order q (q is a prime divisor of p-1);
* MPI of DSA group generator g;
* MPI of DSA public-key value y (= g^x mod p where x is secret).

The secret key is this single multiprecision integer:

* MPI of DSA secret exponent x.

5.6.3. Algorithm-Specific Part for Elgamal Keys

The public key is this series of multiprecision integers:

* MPI of Elgamal prime p;
* MPI of Elgamal group generator g;
* MPI of Elgamal public key value y (= g^x mod p where x is secret).

The secret key is this single multiprecision integer:

* MPI of Elgamal secret exponent x.

5.6.4. Algorithm-Specific Part for ECDSA Keys

The public key is this series of values:

* a variable-length field containing a curve OID, formatted as: a one-octet size of the following field with values 0 and 0xFF reserved for future extensions and the octets representing a curve OID, defined in Section 9.2;
* a SOS of an EC point representing a public key.

The secret key is this single multiprecision integer:

* a SOS of the secret key, which is a scalar of the public EC point.

5.6.5. Algorithm-Specific Part for EdDSA Keys

The public key is this series of values:

* a variable-length field containing a curve OID, formatted as: a one-octet size of the following field with values 0 and 0xFF reserved for future extensions and the octets representing a curve OID, defined in Section 9.2;

* a SOS with an EC point representing a public key Q as described under EdDSA Point Format below.

The secret key is this single multiprecision integer:

* a SOS representing the secret key, which is a scalar of the public EC point.

5.6.6. Algorithm-Specific Part for ECDH Keys

The public key is this series of values:

* a variable-length field containing a curve OID, formatted as: a one-octet size of the following field with values 0 and 0xFF reserved for future extensions and the octets representing a curve OID, defined in Section 9.2;

* a SOS with an EC point representing a public key;

* a variable-length field containing KDF parameters, formatted as follows:

  - a one-octet size of the following fields; values 0 and 0xff are reserved for future extensions;

  - a one-octet value 1, reserved for future extensions;

  - a one-octet hash function ID used with a KDF;

  - a one-octet algorithm ID for the symmetric algorithm used to wrap the symmetric key used for the message encryption; see Section 13.5 for details.

Observe that an ECDH public key is composed of the same sequence of fields that define an ECDSA key, plus the KDF parameters field.

The secret key is this single multiprecision integer:

* a SOS representing the secret key, which is a scalar of the public EC point.

5.6.7. Algorithm-Specific Part for ML-KEM Keys

The public key is this series of values:

* a variable-length field containing a curve OID, formatted as: a one-octet size of the following field with values 0 and 0xFF reserved for future extensions and the octets representing a curve OID, defined in Section 9.2. For Curve25519 the alternative OID (1.3.102.110) MUST be used;

* a SOS with an EC point representing a public key;

* A four-octet scalar octet count of the following octet string containing the ML-KEM public key. Valid octet counts are 1184 for ML-KEM-768 and 1568 for ML-KEM-1024.

The secret key is this series of values:

* a SOS representing the secret key, which is a scalar of the public EC point;

* A four-octet scalar octet count of the follwoing octet string containing the ML-KEM secret key. Valid octet counts are 2400 for ML-KEM-768 and 3168 for ML-KEM-1024.

5.7. Compressed Data Packet (Tag 8)

The Compressed Data packet contains compressed data. Typically, this packet is found as the contents of an encrypted packet, or following a Signature or One-Pass Signature packet, and contains a literal data packet.

The body of this packet consists of:

* One octet that gives the algorithm used to compress the packet.

* Compressed data, which makes up the remainder of the packet.

A Compressed Data Packet’s body contains an block that compresses some set of packets. See section "Packet Composition" for details on how messages are formed.

ZIP-compressed packets are compressed with raw RFC 1951 [RFC1951] DEFLATE blocks. Note that PGP V2.6 uses 13 bits of compression. If an implementation uses more bits of compression, PGP V2.6 cannot decompress it.

ZLIB-compressed packets are compressed with RFC 1950 [RFC1950] ZLIB-style blocks.

BZip2-compressed packets are compressed using the BZip2 [BZ2] algorithm.

5.8. Symmetrically Encrypted Data Packet (Tag 9)

The Symmetrically Encrypted Data packet contains data encrypted with a symmetric-key algorithm. When it has been decrypted, it contains other packets (usually a literal data packet or compressed data packet, but in theory other Symmetrically Encrypted Data packets or sequences of packets that form whole LibrePGP messages).

This packet is obsolete. An implementation MUST NOT create this packet. An implementation MAY process such a packet but it MUST return a clear diagnostic that a non-integrity protected packet has been processed. The implementation SHOULD also return an error in this case and stop processing.

The body of this packet consists of:

* Encrypted data, the output of the selected symmetric-key cipher operating in LibrePGP’s variant of Cipher Feedback (CFB) mode.

The symmetric cipher used may be specified in a Public-Key or Symmetric-Key Encrypted Session Key packet that precedes the Symmetrically Encrypted Data packet. In that case, the cipher algorithm octet is prefixed to the session key before it is encrypted. If no packets of these types precede the encrypted data, the IDEA algorithm is used with the session key calculated as the MD5 hash of the passphrase, though this use is deprecated.

The data is encrypted in CFB mode, with a CFB shift size equal to the cipher's block size. The Initial Vector (IV) is specified as all zeros. Instead of using an IV, LibrePGP prefixes a string of length equal to the block size of the cipher plus two to the data before it is encrypted. The first block-size octets (for example, 8 octets for a 64-bit block length) are random, and the following two octets are copies of the last two octets of the IV. For example, in an 8-octet block, octet 9 is a repeat of octet 7, and octet 10 is a repeat of octet 8. In a cipher of length 16, octet 17 is a repeat of octet 15 and octet 18 is a repeat of octet 16. As a pedantic clarification, in both these examples, we consider the first octet to be numbered 1.

After encrypting the first block-size-plus-two octets, the CFB state is resynchronized. The last block-size octets of ciphertext are passed through the cipher and the block boundary is reset.

The repetition of 16 bits in the random data prefixed to the message allows the receiver to immediately check whether the session key is incorrect. See the "Security Considerations" section for hints on the proper use of this "quick check".

5.9. Marker Packet (Obsolete Literal Packet) (Tag 10)

An experimental version of PGP used this packet as the Literal packet, but no released version of PGP generated Literal packets with this tag. With PGP 5, this packet has been reassigned and is reserved for use as the Marker packet.

The body of this packet consists of:

* The three octets 0x50, 0x47, 0x50 (which spell "PGP" in UTF-8).

Such a packet MUST be ignored when received. It may be placed at the beginning of a message that uses features not available in PGP version 2.6 in order to cause that version to report that newer software is necessary to process the message.

5.10. Literal Data Packet (Tag 11)

A Literal Data packet contains the body of a message; data that is not to be further interpreted.

The body of this packet consists of:

* A one-octet field that describes how the data is formatted.

If it is a b (0x62), then the Literal packet contains binary data. If it is a t (0x74), then it contains text data, and thus may need line ends converted to local form, or other text-mode changes. The tag u (0x75) means the same as t, but also indicates that implementation believes that the literal data contains UTF-8 text. If it is a m (0x6d), then it contains a MIME message body part [RFC2045].

Early versions of PGP also defined a value of l as a 'local' mode for machine-local conversions. RFC 1991 [RFC1991] incorrectly stated this local mode flag as 1 (ASCII numeral one). Both of these local modes are deprecated.

* File name as a string (one-octet length, followed by a file name). This may be a zero-length string. Commonly, if the source of the encrypted data is a file, this will be the name of the encrypted file. An implementation MAY consider the file name in the Literal packet to be a more authoritative name than the actual file name.

  If the special name "_CONSOLE" is used, the message is considered to be "for your eyes only". This advises that the message data is unusually sensitive, and the receiving program should process it more carefully, perhaps avoiding storing the received data to disk, for example.

* A four-octet number that indicates a date associated with the literal data. Commonly, the date might be the modification date of a file, or the time the packet was created, or a zero that indicates no specific time.

* The remainder of the packet is literal data.

  Text data is stored with <CR><LF> text endings (i.e., network-normal line endings). These should be converted to native line endings by the receiving software.

Note that V3 and V4 signatures do not include the formatting octet, the file name, and the date field of the literal packet in a signature hash and thus are not protected against tampering in a signed document. In contrast V5 signatures include them.

5.11. Trust Packet (Tag 12)

The Trust packet is used only within keyrings and is not normally exported. Trust packets contain data that record the user's specifications of which key holders are trustworthy introducers, along with other information that implementing software uses for trust information. The format of Trust packets is defined by a given implementation.

Trust packets SHOULD NOT be emitted to output streams that are transferred to other users, and they SHOULD be ignored on any input other than local keyring files.

5.12. User ID Packet (Tag 13)

A User ID packet consists of UTF-8 text that is intended to represent the name and email address of the key holder. By convention, it includes an RFC 2822 [RFC2822] mail name-addr, but there are no restrictions on its content. The packet length in the header specifies the length of the User ID.

5.13. User Attribute Packet (Tag 17)

The User Attribute packet is a variation of the User ID packet. It is capable of storing more types of data than the User ID packet, which is limited to text. Like the User ID packet, a User Attribute packet may be certified by the key owner ("self-signed") or any other key owner who cares to certify it. Except as noted, a User Attribute packet may be used anywhere that a User ID packet may be used.

While User Attribute packets are not a required part of the LibrePGP standard, implementations SHOULD provide at least enough compatibility to properly handle a certification signature on the User Attribute packet. A simple way to do this is by treating the User Attribute packet as a User ID packet with opaque contents, but an implementation may use any method desired.

The User Attribute packet is made up of one or more attribute subpackets. Each subpacket consists of a subpacket header and a body. The header consists of:

* the subpacket length (1, 2, or 5 octets)

* the subpacket type (1 octet)

and is followed by the subpacket specific data.

The following table lists the currently known subpackets:

Type	Attribute Subpacket
1	Image Attribute Subpacket
[TBD1]	User ID Attribute Subpacket
100-110	Private/Experimental Use

Table 5

An implementation SHOULD ignore any subpacket of a type that it does not recognize.

5.13.1. The Image Attribute Subpacket

The Image Attribute subpacket is used to encode an image, presumably (but not required to be) that of the key owner.

The Image Attribute subpacket begins with an image header. The first two octets of the image header contain the length of the image header. Note that unlike other multi-octet numerical values in this document, due to a historical accident this value is encoded as a little-endian number. The image header length is followed by a single octet for the image header version. The only currently defined version of the image header is 1, which is a 16-octet image header. The first three octets of a version 1 image header are thus 0x10, 0x00, 0x01.

The fourth octet of a version 1 image header designates the encoding format of the image. The only currently defined encoding format is the value 1 to indicate JPEG. Image format types 100 through 110 are reserved for private or experimental use. The rest of the version 1 image header is made up of 12 reserved octets, all of which MUST be set to 0.

The rest of the image subpacket contains the image itself. As the only currently defined image type is JPEG, the image is encoded in the JPEG File Interchange Format (JFIF), a standard file format for JPEG images [JFIF].

An implementation MAY try to determine the type of an image by examination of the image data if it is unable to handle a particular version of the image header or if a specified encoding format value is not recognized.

5.13.2. User ID Attribute Subpacket

A User ID Attribute subpacket has type [IANA --- assignment TBD1].

A User ID Attribute subpacket, just like a User ID packet, consists of UTF-8 text that is intended to represent the name and email address of the key holder. By convention, it includes an RFC 2822 [RFC2822] mail name-addr, but there are no restrictions on its content. For devices using LibrePGP for device certificates, it may just be the device identifier. The packet length in the header specifies the length of the User ID.

Because User Attribute subpackets can be used anywhere a User ID packet can be used, implementations MAY choose to trust a signed User Attribute subpacket that includes a User ID Attribute subpacket.

5.14. Sym. Encrypted Integrity Protected Data Packet (Tag 18)

The Symmetrically Encrypted Integrity Protected Data packet is a variant of the Symmetrically Encrypted Data packet. It is a new feature created for LibrePGP that addresses the problem of detecting a modification to encrypted data. It is used in combination with a Modification Detection Code packet.

There is a corresponding feature in the features Signature subpacket that denotes that an implementation can properly use this packet type. An implementation MUST support decrypting these packets and SHOULD prefer generating them to the older Symmetrically Encrypted Data packet when possible. Since this data packet protects against modification attacks, this standard encourages its proliferation. While blanket adoption of this data packet would create interoperability problems, rapid adoption is nevertheless important. An implementation SHOULD specifically denote support for this packet, but it MAY infer it from other mechanisms.

For example, an implementation might infer from the use of a cipher such as Advanced Encryption Standard (AES) or Twofish that a user supports this feature. It might place in the unhashed portion of another user's key signature a Features subpacket. It might also present a user with an opportunity to regenerate their own self-signature with a Features subpacket.

This packet contains data encrypted with a symmetric-key algorithm and protected against modification by the SHA-1 hash algorithm. When it has been decrypted, it will typically contain other packets (often a Literal Data packet or Compressed Data packet). The last decrypted packet in this packet's payload MUST be a Modification Detection Code packet.

The body of this packet consists of:

* A one-octet version number. The only defined value is 1. There won't be any future versions of this packet because the MDC system has been superseded by the OCB Encrypted Data packet.

* Encrypted data, the output of the selected symmetric-key cipher operating in Cipher Feedback mode with shift amount equal to the block size of the cipher (CFB-n where n is the block size).

The symmetric cipher used MUST be specified in a Public-Key or Symmetric-Key Encrypted Session Key packet that precedes the Symmetrically Encrypted Data packet. In either case, the cipher algorithm octet is prefixed to the session key before it is encrypted.

The data is encrypted in CFB mode, with a CFB shift size equal to the cipher's block size. The Initial Vector (IV) is specified as all zeros. Instead of using an IV, LibrePGP prefixes an octet string to the data before it is encrypted. The length of the octet string equals the block size of the cipher in octets, plus two. The first octets in the group, of length equal to the block size of the cipher, are random; the last two octets are each copies of their 2nd preceding octet. For example, with a cipher whose block size is 128 bits or 16 octets, the prefix data will contain 16 random octets, then two more octets, which are copies of the 15th and 16th octets, respectively. Unlike the Symmetrically Encrypted Data Packet, no special CFB resynchronization is done after encrypting this prefix data. See "LibrePGP CFB Mode" below for more details.

The repetition of 16 bits in the random data prefixed to the message allows the receiver to immediately check whether the session key is incorrect.

The plaintext of the data to be encrypted is passed through the SHA-1 hash function, and the result of the hash is appended to the plaintext in a Modification Detection Code packet. The input to the hash function includes the prefix data described above; it includes all of the plaintext, and then also includes two octets of values 0xD3, 0x14. These represent the encoding of a Modification Detection Code packet tag and length field of 20 octets.

The resulting hash value is stored in a Modification Detection Code (MDC) packet, which MUST use the two octet encoding just given to represent its tag and length field. The body of the MDC packet is the 20-octet output of the SHA-1 hash.

The Modification Detection Code packet is appended to the plaintext and encrypted along with the plaintext using the same CFB context.

During decryption, the plaintext data should be hashed with SHA-1, including the prefix data as well as the packet tag and length field of the Modification Detection Code packet. The body of the MDC packet, upon decryption, is compared with the result of the SHA-1 hash.

Any failure of the MDC indicates that the message has been modified and MUST be treated as a security problem. Failures include a difference in the hash values, but also the absence of an MDC packet, or an MDC packet in any position other than the end of the plaintext. Any failure SHOULD be reported to the user.

NON-NORMATIVE EXPLANATION

The MDC system, as packets 18 and 19 are called, were created to provide an integrity mechanism that is less strong than a signature, yet stronger than bare CFB encryption.

It is a limitation of CFB encryption that damage to the ciphertext will corrupt the affected cipher blocks and the block following. Additionally, if data is removed from the end of a CFB-encrypted block, that removal is undetectable. (Note also that CBC mode has a similar limitation, but data removed from the front of the block is undetectable.)

The obvious way to protect or authenticate an encrypted block is to digitally sign it. However, many people do not wish to habitually sign data, for a large number of reasons beyond the scope of this document. Suffice it to say that many people consider properties such as deniability to be as valuable as integrity.

LibrePGP addresses this desire to have more security than raw encryption and yet preserve deniability with the MDC system. An MDC is intentionally not a MAC. Its name was not selected by accident. It is analogous to a checksum.

Despite the fact that it is a relatively modest system, it has proved itself in the real world. It is an effective defense to several attacks that have surfaced since it has been created. It has met its modest goals admirably.

Consequently, because it is a modest security system, it has modest requirements on the hash function(s) it employs. It does not rely on a hash function being collision-free, it relies on a

hash function being one-way. If a forger, Frank, wishes to send Alice a (digitally) unsigned message that says, "I've always secretly loved you, signed Bob", it is far easier for him to construct a new message than it is to modify anything intercepted from Bob. (Note also that if Bob wishes to communicate secretly with Alice, but without authentication or identification and with a threat model that includes forgers, he has a problem that transcends mere cryptography.)

Note also that unlike nearly every other LibrePGP subsystem, there are no parameters in the MDC system. It hard-defines SHA-1 as its hash function. This is not an accident. It is an intentional choice to avoid downgrade and cross-grade attacks while making a simple, fast system. (A downgrade attack would be an attack that replaced SHA2-256 with SHA-1, for example. A cross-grade attack would replace SHA-1 with another 160-bit hash, such as RIPE-MD/160, for example.)

However, no update will be needed because the MDC will be replaced by the OCB encryption described in this document.

5.15. Modification Detection Code Packet (Tag 19)

The Modification Detection Code packet contains a SHA-1 hash of plaintext data, which is used to detect message modification. It is only used with a Symmetrically Encrypted Integrity Protected Data packet. The Modification Detection Code packet MUST be the last packet in the plaintext data that is encrypted in the Symmetrically Encrypted Integrity Protected Data packet, and MUST appear in no other place.

A Modification Detection Code packet MUST have a length of 20 octets.

The body of this packet consists of:

* A 20-octet SHA-1 hash of the preceding plaintext data of the Symmetrically Encrypted Integrity Protected Data packet, including prefix data, the tag octet, and length octet of the Modification Detection Code packet.

Note that the Modification Detection Code packet MUST always use a new format encoding of the packet tag, and a one-octet encoding of the packet length. The reason for this is that the hashing rules for modification detection include a one-octet tag and one-octet length in the data hash. While this is a bit restrictive, it reduces complexity.

5.16. OCB Encrypted Data Packet (Tag 20)

The OCBED packet contains data encrypted with an authenticated encryption and additional data (AEAD) construction. When it has been decrypted, it will typically contain other packets (often a Literal Data packet or Compressed Data packet).

The body of this packet consists of:

* A one-octet version number. The only currently defined value is 1.

* A one-octet cipher algorithm.

* A one-octet encryption mode octet with the fixed value 0x02. If decryption using the EAX mode is supported this octet may have the value 0x01.

* A one-octet chunk size.

* A starting initialization vector of size specified by the encryption mode (15 octets for OCB).

* Encrypted data, the output of the selected symmetric-key cipher operating in the given encryption mode.

* A final, summary authentication tag for the encryption mode (16 octets for OCB).

An OCB Encrypted Data packet consists of one or more chunks of data. The plaintext of each chunk is of a size specified using the chunk size octet using the method specified below.

The encrypted data consists of the encryption of each chunk of plaintext, followed immediately by the relevant authentication tag. If the last chunk of plaintext is smaller than the chunk size, the ciphertext for that data may be shorter; it is nevertheless followed by a full authentication tag.

For each chunk, the AEAD construction is given the Packet Tag in new format encoding (bits 7 and 6 set, bits 5-0 carry the packet tag), version number, cipher algorithm octet, encryption mode octet, chunk size octet, and an eight-octet, big-endian chunk index as additional data. The index of the first chunk is zero. For example, the additional data of the first chunk using OCB and AES-128 with a chunk size of 64 kiByte consists of the octets 0xD4, 0x01, 0x07, 0x02, 0x10, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, and 0x00.

After the final chunk, the encryption mode is used to produce a final authentication tag encrypting the empty string. This AEAD instance is given the additional data specified above, plus an eight-octet, big-endian value specifying the total number of plaintext octets encrypted. This allows detection of a truncated ciphertext. Please note that the big-endian number representing the chunk index in the additional data is increased accordingly, although it's not really a chunk.

The chunk size octet specifies the size of chunks using the following formula (in C), where c is the chunk size octet:

```
chunk_size = ((uint64_t)1 << (c + 6))
```

To facilitate interoperability between a wide variety of implementations, from constrained to large compute environments, a chunk size maximum is specified: An implementation MUST accept chunk size octets with values from 0 to 16. An implementation MUST NOT create data with a chunk size octet value larger than 16 (4 MiB chunks).

A new random initialization vector MUST be used for each message. Failure to do so for each message will lead to a catastrophic failure depending on the used encryption mode.

5.16.1. EAX Mode

The EAX algorithm can only use block ciphers with 16-octet blocks. The starting initialization vector and authentication tag are both 16 octets long.

The starting initialization vector for this mode MUST be unique and unpredictable.

The nonce for EAX mode is computed by treating the starting initialization vector as a 16-octet, big-endian value and exclusive-oring the low eight octets of it with the chunk index.

The security of EAX requires that the nonce is never reused, hence the requirement that the starting initialization vector be unique.

EAX mode is deprecated due to the far better properties of the OCB mode. Implementations may use EAX mode only for decryption of existing data.

5.16.2. OCB Mode

The OCB Authenticated-Encryption Algorithm used in this document is defined in [RFC7253].

OCB usage requires specification of the following parameters:

* a blockcipher that operate on 128-bit (16-octet) blocks
* an authentication tag length of 16 octets
* a nonce of 15 octets long (which is the longest nonce allowed specified by [RFC7253])
* an initialization vector of at least 15 octets long

In the case that the initialization vector is longer than 15 octets (such as in Section 5.5.1.3, only the 15 leftmost octets are used in calculations; the remaining octets MUST be considered as zero.

The nonce for OCB mode is computed by the exclusive-oring of the initialization vector as a 15-octet, big endian value, against the chunk index.

Security of OCB mode depends on the non-repeated nature of nonces used for the same key on distinct plaintext [RFC7253]. Therefore the initialization vector per message MUST be distinct, and OCB mode SHOULD only be used in environments when there is certainty to fulfilling this requirement.

6. Radix-64 Conversions

As stated in the introduction, LibrePGP's underlying native representation for objects is a stream of arbitrary octets, and some systems desire these objects to be immune to damage caused by character set translation, data conversions, etc.

In principle, any printable encoding scheme that met the requirements of the unsafe channel would suffice, since it would not change the underlying binary bit streams of the native LibrePGP data structures. The LibrePGP standard specifies one such printable encoding scheme to ensure interoperability.

LibrePGP's Radix-64 encoding is composed of two parts: a base64 encoding of the binary data and a checksum. The base64 encoding is identical to the MIME base64 content-transfer-encoding [RFC2045].

The checksum is a 24-bit Cyclic Redundancy Check (CRC) converted to four characters of radix-64 encoding by the same MIME base64 transformation, preceded by an equal sign (=). The CRC is computed by using the generator 0x864CFB and an initialization of 0xB704CE. The accumulation is done on the data before it is converted to radix-64, rather than on the converted data. A sample implementation of this algorithm is in the next section.

The checksum with its leading equal sign MAY appear on the first line after the base64 encoded data.

Rationale for CRC-24: The size of 24 bits fits evenly into printable base64. The nonzero initialization can detect more errors than a zero initialization.

6.1. An Implementation of the CRC-24 in "C"

```
<CODE BEGINS>
  #define CRC24_INIT 0xB704CEL
  #define CRC24_POLY 0x864CFBL

  typedef long crc24;
  crc24 crc_octets(unsigned char *octets, size_t len)
  {
      crc24 crc = CRC24_INIT;
      int i;
      while (len--) {
          crc ^= (*octets++) << 16;
          for (i = 0; i < 8; i++) {
              crc <<= 1;
              if (crc & 0x1000000)
                  crc ^= CRC24_POLY;
          }
      }
      return crc & 0xFFFFFFL;
  }
<CODE ENDS>
```

6.2. Forming ASCII Armor

When LibrePGP encodes data into ASCII Armor, it puts specific headers around the Radix-64 encoded data, so LibrePGP can reconstruct the data later. An LibrePGP implementation MAY use ASCII armor to protect raw binary data. LibrePGP informs the user what kind of data is encoded in the ASCII armor through the use of the headers.

Concatenating the following data creates ASCII Armor:

* An Armor Header Line, appropriate for the type of data
* Armor Headers
* A blank line
* The ASCII-Armored data
* An Armor Checksum
* The Armor Tail, which depends on the Armor Header Line

An Armor Header Line consists of the appropriate header line text surrounded by five (5) dashes (-, 0x2D) on either side of the header line text. The header line text is chosen based upon the type of data that is being encoded in Armor, and how it is being encoded. Header line texts include the following strings:

BEGIN PGP MESSAGE Used for signed, encrypted, or compressed files.

BEGIN PGP PUBLIC KEY BLOCK Used for armoring public keys.

BEGIN PGP PRIVATE KEY BLOCK Used for armoring private keys.

BEGIN PGP MESSAGE, PART X/Y Used for multi-part messages, where the armor is split amongst Y parts, and this is the Xth part out of Y.

BEGIN PGP MESSAGE, PART X Used for multi-part messages, where this is the Xth part of an unspecified number of parts. Requires the MESSAGE-ID Armor Header to be used.

BEGIN PGP SIGNATURE Used for detached signatures, LibrePGP/MIME signatures, and cleartext signatures. Note that PGP 2 uses BEGIN PGP MESSAGE for detached signatures.

Note that all these Armor Header Lines are to consist of a complete line. That is to say, there is always a line ending preceding the starting five dashes, and following the ending five dashes. The header lines, therefore, MUST start at the beginning of a line, and MUST NOT have text other than whitespace --- space (0x20), tab (0x09) or carriage return (0x0d) --- following them on the same line. These line endings are considered a part of the Armor Header Line for the purposes of determining the content they delimit. This is particularly important when computing a cleartext signature (see below).

The Armor Headers are pairs of strings that can give the user or the receiving LibrePGP implementation some information about how to decode or use the message. The Armor Headers are a part of the armor, not a part of the message, and hence are not protected by any signatures applied to the message.

The format of an Armor Header is that of a key-value pair. A colon (: 0x38) and a single space (0x20) separate the key and value. LibrePGP should consider improperly formatted Armor Headers to be corruption of the ASCII Armor. Unknown keys should be reported to the user, but LibrePGP should continue to process the message.

Note that some transport methods are sensitive to line length. While there is a limit of 76 characters for the Radix-64 data (Section 6.3), there is no limit to the length of Armor Headers. Care should be taken that the Armor Headers are short enough to survive transport. One way to do this is to repeat an Armor Header Key multiple times with different values for each so that no one line is overly long.

Currently defined Armor Header Keys are as follows:

* "Version", which states the LibrePGP implementation and version used to encode the message.

* "Comment", a user-defined comment. LibrePGP defines all text to be in UTF-8. A comment may be any UTF-8 string. However, the whole point of armoring is to provide seven-bit-clean data. Consequently, if a comment has characters that are outside the US-ASCII range of UTF, they may very well not survive transport.

* "Hash", a comma-separated list of hash algorithms used in this message. This is used only in cleartext signed messages.

* "MessageID", a 32-character string of printable characters. The string must be the same for all parts of a multi-part message that uses the "PART X" Armor Header. MessageID strings should be unique enough that the recipient of the mail can associate all the parts of a message with each other. A good checksum or cryptographic hash function is sufficient.

  The MessageID SHOULD NOT appear unless it is in a multi-part message. If it appears at all, it MUST be computed from the finished (encrypted, signed, etc.) message in a deterministic fashion, rather than contain a purely random value. This is to allow the legitimate recipient to determine that the MessageID cannot serve as a covert means of leaking cryptographic key information.

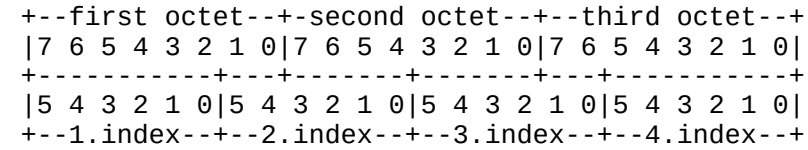
* "Charset", a description of the character set that the plaintext is in. Please note that LibrePGP defines text to be in UTF-8. An implementation will get best results by translating into and out of UTF-8. However, there are many instances where this is easier said than done. Also, there are communities of users who have no need for UTF-8 because they are all happy with a character set like ISO Latin-5 or a Japanese character set. In such instances, an implementation MAY override the UTF-8 default by using this header key. An implementation MAY implement this key and any translations it cares to; an implementation MAY ignore it and assume all text is UTF-8.

The blank line can either be zero-length or contain only whitespace, that is spaces (0x20), tabs (0x09) or carriage returns (0x0d).

The Armor Tail Line is composed in the same manner as the Armor Header Line, except the string "BEGIN" is replaced by the string "END".

6.3. Encoding Binary in Radix-64

The encoding process represents 24-bit groups of input bits as output strings of 4 encoded characters. Proceeding from left to right, a 24-bit input group is formed by concatenating three 8-bit input groups. These 24 bits are then treated as four concatenated 6-bit groups, each of which is translated into a single digit in the Radix-64 alphabet. When encoding a bit stream with the Radix-64 encoding, the bit stream must be presumed to be ordered with the most significant bit first. That is, the first bit in the stream will be the high-order bit in the first 8-bit octet, and the eighth bit will be the low-order bit in the first 8-bit octet, and so on.



Each 6-bit group is used as an index into an array of 64 printable characters from the table below. The character referenced by the index is placed in the output string.

Value	Encoding	Value	Encoding	Value	Encoding	Value	Encoding
0	A	17	R	34	i	51	z
1	B	18	S	35	j	52	0
2	C	19	T	36	k	53	1
3	D	20	U	37	l	54	2
4	E	21	V	38	m	55	3
5	F	22	W	39	n	56	4
6	G	23	X	40	o	57	5
7	H	24	Y	41	p	58	6
8	I	25	Z	42	q	59	7
9	J	26	a	43	r	60	8
10	K	27	b	44	s	61	9
11	L	28	c	45	t	62	+
12	M	29	d	46	u	63	/
13	N	30	e	47	v		
14	O	31	f	48	w	(pad)	=
15	P	32	g	49	x		
16	Q	33	h	50	y		

The encoded output stream must be represented in lines of no more than 76 characters each.

Special processing is performed if fewer than 24 bits are available at the end of the data being encoded. There are three possibilities:

1. The last data group has 24 bits (3 octets). No special processing is needed.

2. The last data group has 16 bits (2 octets). The first two 6-bit groups are processed as above. The third (incomplete) data group has two zero-value bits added to it, and is processed as above. A pad character (=) is added to the output.

3. The last data group has 8 bits (1 octet). The first 6-bit group is processed as above. The second (incomplete) data group has four zero-value bits added to it, and is processed as above. Two pad characters (=) are added to the output.

6.4. Decoding Radix-64

In Radix-64 data, characters other than those in the table, line breaks, and other white space probably indicate a transmission error, about which a warning message or even a message rejection might be appropriate under some circumstances. Decoding software must ignore all white space.

Because it is used only for padding at the end of the data, the occurrence of any "=" characters may be taken as evidence that the end of the data has been reached (without truncation in transit). No such assurance is possible, however, when the number of octets transmitted was a multiple of three and no "=" characters are present.

6.5. Examples of Radix-64

```
Input data:  0x14FB9C03D97E
Hex:     1   4    F   B    9   C     | 0   3    D   9    7   E
8-bit:   00010100 11111011 10011100  | 00000011 11011001 01111110
6-bit:   000101 001111 101110 011100 | 000000 111101 100101 111110
Decimal: 5      15     46     28       0      61     37     62
Output:  F      P      u      c        A      9      l      +
Input data:  0x14FB9C03D9
Hex:     1   4    F   B    9   C     | 0   3    D   9
8-bit:   00010100 11111011 10011100  | 00000011 11011001
                                                pad with 00
6-bit:   000101 001111 101110 011100 | 000000 111101 100100
Decimal: 5      15     46     28       0      61     36
                                                   pad with =
Output:  F      P      u      c        A      9      k      =
Input data:  0x14FB9C03
Hex:     1   4    F   B    9   C     | 0   3
8-bit:   00010100 11111011 10011100  | 00000011
                                       pad with 0000
6-bit:   000101 001111 101110 011100 | 000000 110000
Decimal: 5      15     46     28       0      48
                                            pad with =      =
Output:  F      P      u      c        A      w      =      =
```

6.6. Example of an ASCII Armored Message

```
-----BEGIN PGP MESSAGE-----
Version: OpenPrivacy 0.99

yDgBO22WxBHv7O8X7O/jygAEzol56iUKiXmV+XmpCtmpqQUKiQrFqclFqUDBovzS
vBSFjNSiVHsuAA==
=njUN
-----END PGP MESSAGE-----
```

Note that this example has extra indenting; an actual armored message would have no leading whitespace.

7. Cleartext Signature Framework

It is desirable to be able to sign a textual octet stream without ASCII armoring the stream itself, so the signed text is still readable without special software. In order to bind a signature to such a cleartext, this framework is used, which follows the same basic format and restrictions as the ASCII armoring described above in "Forming ASCII Armor" (Section 6.2). (Note that this framework is not intended to be reversible. RFC 3156 [RFC3156] defines another way to sign cleartext messages for environments that support MIME.)

The cleartext signed message consists of:

* The cleartext header -----BEGIN PGP SIGNED MESSAGE----- on a single line,

* One or more "Hash" Armor Headers,

* Exactly one blank line not included into the message digest,

* The dash-escaped cleartext that is included into the message digest,

* The ASCII armored signature(s) including the -----BEGIN PGP SIGNATURE----- Armor Header and Armor Tail Lines.

If the "Hash" Armor Header is given, the specified message digest algorithm(s) are used for the signature. If there are no such headers, MD5 is used. If MD5 is the only hash used, then an implementation MAY omit this header for improved V2.x compatibility. If more than one message digest is used in the signature, the "Hash" armor header contains a comma-delimited list of used message digests.

Current message digest names are described below with the algorithm IDs.

An implementation SHOULD add a line break after the cleartext, but MAY omit it if the cleartext ends with a line break. This is for visual clarity.

7.1. Dash-Escaped Text

The cleartext content of the message must also be dash-escaped.

Dash-escaped cleartext is the ordinary cleartext where every line starting with a dash - (0x2D) is prefixed by the sequence dash - (0x2D) and space ‘ ‘ (0x20). This prevents the parser from recognizing armor headers of the cleartext itself. An implementation

MAY dash-escape any line, SHOULD dash-escape lines commencing "From" followed by a space, and MUST dash-escape any line commencing in a dash. The message digest is computed using the cleartext itself, not the dash-escaped form.

As with binary signatures on text documents, a cleartext signature is calculated on the text using canonical <CR><LF> line endings. The line ending (i.e., the <CR><LF>) before the -----BEGIN PGP SIGNATURE----- line that terminates the signed text is not considered part of the signed text.

When reversing dash-escaping, an implementation MUST strip the string "- " if it occurs at the beginning of a line, and SHOULD warn on "-" and any character other than a space at the beginning of a line.

Also, any trailing whitespace --- spaces (0x20), tabs (0x09) or carriage returns (0x0d) --- at the end of any line is removed when the cleartext signature is generated and verified.

8. Regular Expressions

A regular expression is zero or more branches, separated by |. It matches anything that matches one of the branches.

A branch is zero or more pieces, concatenated. It matches a match for the first, followed by a match for the second, etc.

A piece is an atom possibly followed by *, +, or ?. An atom followed by * matches a sequence of 0 or more matches of the atom. An atom followed by + matches a sequence of 1 or more matches of the atom. An atom followed by ? matches a match of the atom, or the null string.

An atom is a regular expression in parentheses (matching a match for the regular expression), a range (see below), . (matching any single character), ^ (matching the null string at the beginning of the input string), $ (matching the null string at the end of the input string), a \ followed by a single character (matching that character), or a single character with no other significance (matching that character).

A range is a sequence of characters enclosed in []. It normally matches any single character from the sequence. If the sequence begins with ^, it matches any single character not from the rest of the sequence. If two characters in the sequence are separated by -, this is shorthand for the full list of ASCII characters between them (e.g., [0-9] matches any decimal digit). To include a literal] in the sequence, make it the first character (following a possible ^). To include a literal -, make it the first or last character.

9. Constants

This section describes the constants used in LibrePGP.

Note that these tables are not exhaustive lists; an implementation MAY implement an algorithm not on these lists, so long as the algorithm numbers are chosen from the private or experimental algorithm range.

See the section "Notes on Algorithms" below for more discussion of the algorithms.

9.1. Public-Key Algorithms

ID	Algorithm
1	RSA (Encrypt or Sign) [HAC]
2	RSA Encrypt-Only [HAC]
3	RSA Sign-Only [HAC]
8	Kyber [FIPS203]
16	Elgamal (Encrypt-Only) [ELGAMAL] [HAC]
17	DSA (Digital Signature Algorithm) [FIPS186] [HAC]
18	ECDH public key algorithm
19	ECDSA public key algorithm [FIPS186]
20	Reserved (formerly Elgamal Encrypt or Sign)
21	Reserved for Diffie-Hellman (X9.42, as defined for IETF-S/MIME)
22	EdDSA [RFC8032]

23	Reserved for AEDH
24	Reserved for AEDSA
29	Experimental use as described by FIPS.203.ipd
100--110	Private/Experimental algorithm

Table 6

Implementations MUST implement RSA (1) and ECDSA (19) for signatures, and RSA (1) and ECDH (18) for encryption. Implementations SHOULD implement EdDSA (22) keys.

RSA Encrypt-Only (2) and RSA Sign-Only (3) are deprecated and SHOULD NOT be generated, but may be interpreted. See Section 15.5. See Section 15.9 for notes on Elgamal Encrypt or Sign (20), and X9.42 (21). Implementations MAY implement any other algorithm.

Note that implementations conforming to previous versions of this standard (RFC-4880) have DSA (17) and Elgamal (16) as its only MUST-implement algorithm.

A compatible specification of ECDSA is given in [RFC6090] as "KT-I Signatures" and in [SEC1]; ECDH is defined in Section 13.5 this document.

9.2. ECC Curve OID

The parameter curve OID is an array of octets that define a named curve. The table below specifies the exact sequence of bytes for each named curve referenced in this document:

ASN.1 Object Identifier	OID len	Curve OID bytes in hexadecimal representation	Curve name
1.2.840.10045.3.1.7	8	2A 86 48 CE 3D 03 01 07	NIST P-256
1.3.132.0.34	5	2B 81 04 00 22	NIST P-384
1.3.132.0.35	5	2B 81 04 00 23	NIST P-521
1.3.36.3.3.2.8.1.1.7	9	2B 24 03 03 02 08 01 01 07	brainpoolP256r1
1.3.36.3.3.2.8.1.1.11	9	2B 24 03 03 02 08 01 01 0B	brainpoolP384r1
1.3.36.3.3.2.8.1.1.13	9	2B 24 03 03 02 08 01 01 0D	brainpoolP512r1
1.3.6.1.4.1.11591.15.1	9	2B 06 01 04 01 DA 47 0F 01	Ed25519
1.3.6.1.4.1.3029.1.5.1	10	2B 06 01 04 01 97 55 01 05 01	Curve25519
1.3.101.112	3	2B 65 70	Ed25519(1)
1.3.101.110	3	2B 65 6E	Curve25519(1)
1.3.101.113	3	2B 65 71	Ed448
1.3.101.111	3	2B 65 6F	X448

Table 7

The sequence of octets in the third column is the result of applying the Distinguished Encoding Rules (DER) to the ASN.1 Object Identifier with subsequent truncation. The truncation removes the two fields of encoded Object Identifier. The first omitted field is one octet representing the Object Identifier tag, and the second omitted field is the length of the Object Identifier body. For example, the complete ASN.1 DER encoding for the NIST P-256 curve OID is "06 08 2A 86 48 CE 3D 03 01 07", from which the first entry in the table above is constructed by omitting the first two octets. Only the truncated sequence of octets is the valid representation of a curve OID.

The alternative OIDs for Ed25519 and Curve25519 marked with (1) SHOULD only be used with v5 keys.

9.3. Symmetric-Key Algorithms

ID	Algorithm
0	Plaintext or unencrypted data
1	IDEA [IDEA]
2	TripleDES (DES-EDE, [SCHNEIER] [HAC] - 168 bit key derived from 192)
3	CAST5 (128 bit key, as per [RFC2144])
4	Blowfish (128 bit key, 16 rounds) [BLOWFISH]
5	Reserved
6	Reserved
7	AES with 128-bit key [AES]
8	AES with 192-bit key
9	AES with 256-bit key
10	Twofish with 256-bit key [TWOFISH]
11	Camellia with 128-bit key [RFC3713]
12	Camellia with 192-bit key
13	Camellia with 256-bit key
100--110	Private/Experimental algorithm

Table 8

Implementations MUST implement AES-128. Implementations SHOULD implement AES-256. Implementations that interoperate with RFC-4880 implementations need to support TripleDES and CAST5. Implementations

that interoperate with PGP 2.6 or earlier need to support IDEA, as that is the only symmetric cipher those versions use. Implementations MAY implement any other algorithm.

9.4. Compression Algorithms

ID	Algorithm
0	Uncompressed
1	ZIP [RFC1951]
2	ZLIB [RFC1950]
3	BZip2 [BZ2]
100--110	Private/Experimental algorithm

Table 9

Implementations MUST implement uncompressed data. Implementations SHOULD implement ZLIB. For interoperability reasons implementations SHOULD be able to decompress using ZIP. Implementations MAY implement any other algorithm.

9.5. Hash Algorithms

ID	Algorithm	Text Name
1	MD5 [HAC]	"MD5"
2	SHA-1 [FIPS180]	"SHA1"
3	RIPE-MD/160 [HAC]	"RIPEMD160"
4	Reserved	
5	Reserved	
6	Reserved	
7	Reserved	
8	SHA2-256 [FIPS180]	"SHA256"

9	SHA2-384 [FIPS180]	"SHA384"
10	SHA2-512 [FIPS180]	"SHA512"
11	SHA2-224 [FIPS180]	"SHA224"
12	SHA3-256 [FIPS202]	"SHA3-256"
13	Reserved	
14	SHA3-512 [FIPS202]	"SHA3-512"
100--110	Private/Experimental algorithm	

Table 10

Implementations MUST implement SHA2-256. Implementations MAY implement other algorithms. Implementations SHOULD NOT create messages which require the use of SHA-1 with the exception of computing version 4 key fingerprints and for purposes of the MDC packet. Implementations SHOULD NOT use MD5 or RIPE-MD/160.

9.6. Encryption Modes

ID	Mode
1	EAX [EAX]
2	OCB [RFC7253]

Table 11

Implementations MUST implement OCB if they support the packet 20 (OCB Encrypted Data Packet). Implementations MAY implement EAX only for decryption and only for backward compatibility with former drafts of this specification.

10. IANA Considerations

LibrePGP is highly parameterized, and consequently there are a number of considerations for allocating parameters for extensions. This section describes how IANA should look at extensions to the protocol as described in this document.

10.1. New String-to-Key Specifier Types

LibrePGP S2K specifiers contain a mechanism for new algorithms to turn a string into a key. This specification creates a registry of S2K specifier types. The registry includes the S2K type, the name of the S2K, and a reference to the defining specification. The initial values for this registry can be found in Section 3.8.1. Adding a new S2K specifier MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

10.2. New Packets

Major new features of LibrePGP are defined through new packet types. This specification creates a registry of packet types. The registry includes the packet type, the name of the packet, and a reference to the defining specification. The initial values for this registry can be found in Section 4.3. Adding a new packet type MUST be done through the RFC REQUIRED method, as described in [RFC8126].

10.2.1. User Attribute Types

The User Attribute packet permits an extensible mechanism for other types of certificate identification. This specification creates a registry of User Attribute types. The registry includes the User Attribute type, the name of the User Attribute, and a reference to the defining specification. The initial values for this registry can be found in Section 5.13. Adding a new User Attribute type MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

This document requests that IANA register the User ID Attribute Type found in Section 5.13.2:

Value	Attribute	Reference
1	Image	This Document

Table 12

10.2.2. Image Format Subpacket Types

Within User Attribute packets, there is an extensible mechanism for other types of image-based User Attributes. This specification creates a registry of Image Attribute subpacket types. The registry includes the Image Attribute subpacket type, the name of the Image Attribute subpacket, and a reference to the defining specification. The initial values for this registry can be found in Section 5.13.1. Adding a new Image Attribute subpacket type MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

10.2.3. New Signature Subpackets

LibrePGP signatures contain a mechanism for signed (or unsigned) data to be added to them for a variety of purposes in the Signature subpackets as discussed in Section 5.2.3.1. This specification creates a registry of Signature subpacket types. The registry includes the Signature subpacket type, the name of the subpacket, and a reference to the defining specification. The initial values for this registry can be found in Section 5.2.3.1. Adding a new Signature subpacket MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

10.2.3.1. Signature Notation Data Subpackets

LibrePGP signatures further contain a mechanism for extensions in signatures. These are the Notation Data subpackets, which contain a key/value pair. Notations contain a user space that is completely unmanaged and an IETF space.

This specification creates a registry of Signature Notation Data types. The registry includes the Signature Notation Data type, the name of the Signature Notation Data, its allowed values, and a reference to the defining specification. The initial values for this registry can be found in Section 5.2.3.18. Adding a new Signature Notation Data subpacket MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

This document requests IANA register the following Signature Notation Data types:

Allowed Values	Name	Type	Reference
A String	charset	Character Set	This Doc Section 5.2.3.18.1
Any String	manu	Manufacturer Name	This Doc Section 5.2.3.18.2
Any String	make	Product Make	This Doc Section 5.2.3.18.3
Any String	model	Product Model	This Doc Section 5.2.3.18.4
Any String	prodid	Product ID	This Doc Section 5.2.3.18.5
Any String	pvers	Product Version	This Doc Section 5.2.3.18.6
Any String	lot	Product Lot Number	This Doc Section 5.2.3.18.7
Decimal Integer String	qty	Package Quantity	This Doc Section 5.2.3.18.8
A geo: URI without the "geo:"	loc	Current Geolocation Latitude/Longitude	This Doc Section 5.2.3.18.9
A geo: URI without the "geo:"	dest	Destination Geolocation Latitude/Longitude	This Doc Section 5.2.3.18.9
Hash Notation data	hash	The Hash of external data	This Doc Section 5.2.3.18.10

Table 13

10.2.3.2. Signature Notation Data Subpacket Notation Flags

This specification creates a new registry of Signature Notation Data Subpacket Notation Flags. The registry includes the columns "Flag", "Description", "Security Recommended", "Interoperability Recommended", and "Reference". The initial values for this registry can be found in Section 5.2.3.18. Adding a new item MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

10.2.3.3. Key Server Preference Extensions

LibrePGP signatures contain a mechanism for preferences to be specified about key servers. This specification creates a registry of key server preferences. The registry includes the key server preference, the name of the preference, and a reference to the defining specification. The initial values for this registry can be found in Section 5.2.3.19. Adding a new key server preference MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

10.2.3.4. Key Flags Extensions

LibrePGP signatures contain a mechanism for flags to be specified about key usage. This specification creates a registry of key usage flags. The registry includes the key flags value, the name of the flag, and a reference to the defining specification. The initial values for this registry can be found in Section 5.2.3.23. Adding a new key usage flag MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

10.2.3.5. Reason for Revocation Extensions

LibrePGP signatures contain a mechanism for flags to be specified about why a key was revoked. This specification creates a registry of "Reason for Revocation" flags. The registry includes the "Reason for Revocation" flags value, the name of the flag, and a reference to the defining specification. The initial values for this registry can be found in Section 5.2.3.25. Adding a new feature flag MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

10.2.3.6. Implementation Features

LibrePGP signatures contain a mechanism for flags to be specified stating which optional features an implementation supports. This specification creates a registry of feature-implementation flags. The registry includes the feature-implementation flags value, the name of the flag, and a reference to the defining specification. The initial values for this registry can be found in Section 5.2.3.26.

Adding a new feature-implementation flag MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

Also see Section 15.12 for more information about when feature flags are needed.

10.2.4. New Packet Versions

The core LibrePGP packets all have version numbers, and can be revised by introducing a new version of an existing packet. This specification creates a registry of packet types. The registry includes the packet type, the number of the version, and a reference to the defining specification. The initial values for this registry can be found in Section 5. Adding a new packet version MUST be done through the RFC REQUIRED method, as described in [RFC8126].

10.3. New Algorithms

Section 9 lists the core algorithms that LibrePGP uses. Adding in a new algorithm is usually simple. For example, adding in a new symmetric cipher usually would not need anything more than allocating a constant for that cipher. If that cipher had other than a 64-bit or 128-bit block size, there might need to be additional documentation describing how LibrePGP-CFB mode would be adjusted. Similarly, when DSA was expanded from a maximum of 1024-bit public keys to 3072-bit public keys, the revision of FIPS 186 contained enough information itself to allow implementation. Changes to this document were made mainly for emphasis.

10.3.1. Public-Key Algorithms

LibrePGP specifies a number of public-key algorithms. This specification creates a registry of public-key algorithm identifiers. The registry includes the algorithm name, its key sizes and parameters, and a reference to the defining specification. The initial values for this registry can be found in Section 9.1. Adding a new public-key algorithm MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

This document requests IANA register the following new public-key algorithm:

ID	Algorithm	Reference
22	EdDSA public key algorithm	This doc, Section 15.8
23	Reserved for AEDH	This doc
24	Reserved for AEDSA	This doc

Table 14

[Notes to RFC-Editor: Please remove the table above on publication. It is desirable not to reuse old or reserved algorithms because some existing tools might print a wrong description. A higher number is also an indication for a newer algorithm. As of now 22 is the next free number.]

10.3.2. Symmetric-Key Algorithms

LibrePGP specifies a number of symmetric-key algorithms. This specification creates a registry of symmetric-key algorithm identifiers. The registry includes the algorithm name, its key sizes and block size, and a reference to the defining specification. The initial values for this registry can be found in Section 9.3. Adding a new symmetric-key algorithm MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

10.3.3. Hash Algorithms

LibrePGP specifies a number of hash algorithms. This specification creates a registry of hash algorithm identifiers. The registry includes the algorithm name, a text representation of that name, its block size, an OID hash prefix, and a reference to the defining specification. The initial values for this registry can be found in Section 9.5 for the algorithm identifiers and text names, and Section 9.2 for the OIDs and expanded signature prefixes. Adding a new hash algorithm MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

This document requests IANA register the following hash algorithms:

ID	Algorithm	Reference
12	SHA3-256	This doc
13	Reserved	
14	SHA3-512	This doc

Table 15

[Notes to RFC-Editor: Please remove the table above on publication. It is desirable not to reuse old or reserved algorithms because some existing tools might print a wrong description. The ID 13 has been reserved so that the SHA3 algorithm IDs align nicely with their SHA2 counterparts.]

10.3.4. Compression Algorithms

LibrePGP specifies a number of compression algorithms. This specification creates a registry of compression algorithm identifiers. The registry includes the algorithm name and a reference to the defining specification. The initial values for this registry can be found in Section 9.4. Adding a new compression key algorithm MUST be done through the SPECIFICATION REQUIRED method, as described in [RFC8126].

11. Packet Composition

LibrePGP packets are assembled into sequences in order to create messages and to transfer keys. Not all possible packet sequences are meaningful and correct. This section describes the rules for how packets should be placed into sequences.

11.1. Transferable Public Keys

LibrePGP users may transfer public keys. The essential elements of a transferable public key are as follows:

* One Public-Key packet
* Zero or more revocation signatures
* One or more User ID packets
* After each User ID packet, one or more Signature packets (certifications and attestation key signatures)

* Zero or more User Attribute packets

* After each User Attribute packet, one or more Signature packets (certifications and attestation key signatures)

* Zero or more Subkey packets

* After each Subkey packet, one Signature packet, plus optionally a revocation

The Public-Key packet occurs first. Each of the following User ID packets provides the identity of the owner of this public key. If there are multiple User ID packets, this corresponds to multiple means of identifying the same unique individual user; for example, a user may have more than one email address, and construct a User ID for each one.

Immediately following each User ID packet, there are one or more Signature packets. Each Signature packet is calculated on the immediately preceding User ID packet and the initial Public-Key packet. The signature serves to certify the corresponding public key and User ID. In effect, the signer is testifying to his or her belief that this public key belongs to the user identified by this User ID. Intermixed with these certifications may be Attestation Key Signature packets issued by the primary key over the same User ID and Public Key packet. The most recent of these is used to attest to third-party certifications over the associated User ID.

Within the same section as the User ID packets, there are zero or more User Attribute packets. Like the User ID packets, a User Attribute packet is followed by one or more Signature packets calculated on the immediately preceding User Attribute packet and the initial Public-Key packet.

User Attribute packets and User ID packets may be freely intermixed in this section, so long as the signatures that follow them are maintained on the proper User Attribute or User ID packet.

After the User ID packet or Attribute packet, there may be zero or more Subkey packets. In general, subkeys are provided in cases where the top-level public key is a signature-only key. However, any V4 or V5 key may have subkeys, and the subkeys may be encryption-only keys, signature-only keys, or general-purpose keys. V3 keys MUST NOT have subkeys.

Each Subkey packet MUST be followed by one Signature packet, which should be a subkey binding signature issued by the top-level key. For subkeys that can issue signatures, the subkey binding signature MUST contain an Embedded Signature subpacket with a primary key binding signature (0x19) issued by the subkey on the top-level key.

Subkey and Key packets may each be followed by a revocation Signature packet to indicate that the key is revoked. Revocation signatures are only accepted if they are issued by the key itself, or by a key that is authorized to issue revocations via a Revocation Key subpacket in a self-signature by the top-level key.

Transferable public-key packet sequences may be concatenated to allow transferring multiple public keys in one operation.

11.2. Transferable Secret Keys

LibrePGP users may transfer secret keys. The format of a transferable secret key is the same as a transferable public key except that secret-key and secret-subkey packets are used instead of the public key and public-subkey packets. Implementations SHOULD include self- signatures on any User IDs and subkeys, as this allows for a complete public key to be automatically extracted from the transferable secret key. Implementations MAY choose to omit the self-signatures, especially if a transferable public key accompanies the transferable secret key.

11.3. LibrePGP Messages

An LibrePGP message is a packet or sequence of packets that corresponds to the following grammatical rules (comma represents sequential composition, and vertical bar separates alternatives):

```
LibrePGP Message :- Encrypted Message | Signed Message |
                    Compressed Message | Literal Message.

Compressed Message :- Compressed Data Packet.

Literal Message :- Literal Data Packet.

ESK :- Public-Key Encrypted Session Key Packet |
       Symmetric-Key Encrypted Session Key Packet.

ESK Sequence :- ESK | ESK Sequence, ESK.

Encrypted Data :- OCB Encrypted Data Packet |
    Symmetrically Encrypted Data Packet |
    Symmetrically Encrypted Integrity Protected Data Packet

Encrypted Message :- Encrypted Data | ESK Sequence, Encrypted Data.

One-Pass Signed Message :- One-Pass Signature Packet,
            LibrePGP Message, Corresponding Signature Packet.

Signed Message :- Signature Packet, LibrePGP Message |
                  One-Pass Signed Message.
```

In addition, decrypting a Symmetrically Encrypted Data packet or a Symmetrically Encrypted Integrity Protected Data packet as well as decompressing a Compressed Data packet must yield a valid LibrePGP Message.

11.4. Detached Signatures

Some LibrePGP applications use so-called "detached signatures". For example, a program bundle may contain a file, and with it a second file that is a detached signature of the first file. These detached signatures are simply a Signature packet stored separately from the data for which they are a signature.

12. Enhanced Key Formats

12.1. Key Structures

The format of a deprecated V3 key is as follows. Entries in square brackets are optional and ellipses indicate repetition.

```
RSA Public Key
   [Revocation Self Signature]
    User ID [Signature ...]
   [User ID [Signature ...] ...]
```

Each signature certifies the RSA public key and the preceding User ID. The RSA public key can have many User IDs and each User ID can have many signatures. Implementations MUST NOT generate new V3 keys, but MAY continue to use existing ones.

The format of an LibrePGP V4 key that uses multiple public keys is similar except that the other keys are added to the end as "subkeys" of the primary key.

```
Primary-Key
   [Revocation Self Signature]
   [Direct Key Signature...]
   User ID [Signature ...]
   [User ID [Signature ...] ...]
   [User Attribute [Signature ...] ...]
   [[Subkey [Binding-Signature-Revocation]
           Primary-Key-Binding-Signature] ...]
```

Note that User Attributes may preceed or be intermixed with User IDs.

A subkey always has a single signature after it that is issued using the primary key to tie the two keys together. This binding signature may be in either V3 or V4 format, but SHOULD be V4. Subkeys that can issue signatures MUST have a V4 binding signature due to the REQUIRED embedded primary key binding signature.

In the above diagram, if the binding signature of a subkey has been revoked, the revoked key may be removed, leaving only one key.

In a V4 key, the primary key SHOULD be a key capable of certification. There are cases, such as device certificates, where the primary key may not be capable of certification. A primary key capable of making signatures SHOULD be accompanied by either a certification signature (on a User ID or User Attribute) or a signature directly on the key.

Implementations SHOULD accept encryption-only primary keys without a signature. It also SHOULD allow importing any key accompanied either by a certification signature or a signature on itself. It MAY accept signature-capable primary keys without an accompanying signature.

The subkeys may be keys of any other type. There may be other constructions of V4 keys, too. For example, there may be a single-key RSA key in V4 format, a DSA primary key with an RSA encryption key, or RSA primary key with an Elgamal subkey, etc.

It is also possible to have a signature-only subkey. This permits a primary key that collects certifications (key signatures), but is used only for certifying subkeys that are used for encryption and signatures.

Implementations with no need for a user ID MAY create a key without any User ID or User Attribute but must be aware that other LibrePGP implementations may not accept such a key.

12.2. Key IDs and Fingerprints

For a V3 key, the eight-octet Key ID consists of the low 64 bits of the public modulus of the RSA key.

The fingerprint of a V3 key is formed by hashing the body (but not the two-octet length) of the MPIs that form the key material (public modulus n, followed by exponent e) with MD5. Note that both V3 keys and MD5 are deprecated.

A V4 fingerprint is the 160-bit SHA-1 hash of the octet 0x99, followed by the two-octet packet length, followed by the entire Public-Key packet starting with the version field. The Key ID is the low-order 64 bits of the fingerprint. Here are the fields of the hash material, with the example of a DSA key:

a.1) 0x99 (1 octet)

a.2) two-octet scalar octet count of (b)-(e)

b) version number = 4 (1 octet);

c) timestamp of key creation (4 octets);

d) algorithm (1 octet): 17 = DSA (example);

e) Algorithm-specific fields.

Algorithm-Specific Fields for DSA keys (example):

e.1) MPI of DSA prime p;

e.2) MPI of DSA group order q (q is a prime divisor of p-1);

e.3) MPI of DSA group generator g;

e.4) MPI of DSA public-key value y (= g^x mod p where x is secret).

A V5 fingerprint is the 256-bit SHA2-256 hash of the octet 0x9A, followed by the four-octet packet length, followed by the entire Public-Key packet starting with the version field. The Key ID is the high-order 64 bits of the fingerprint. Here are the fields of the hash material, with the example of a DSA key:

a.1) 0x9A (1 octet)

a.2) four-octet scalar octet count of (b)-(f)

b) version number = 5 (1 octet);

c) timestamp of key creation (4 octets);

d) algorithm (1 octet): 17 = DSA (example);

e) four-octet scalar octet count for the following key material;

f) algorithm-specific fields.

Algorithm-Specific Fields for DSA keys (example):

f.1) MPI of DSA prime p;

f.2) MPI of DSA group order q (q is a prime divisor of p-1);

f.3) MPI of DSA group generator g;

f.4) MPI of DSA public-key value y (= g^x mod p where x is secret).

Note that it is possible for there to be collisions of Key IDs --- two different keys with the same Key ID. Note that there is a much smaller, but still non-zero, probability that two different keys have the same fingerprint.

Also note that if V3, V4, and V5 format keys share the same RSA key material, they will have different Key IDs as well as different fingerprints.

Finally, the Key ID and fingerprint of a subkey are calculated in the same way as for a primary key, including the 0x99 (V3 and V4 key) or 0x9A (V5 key) as the first octet (even though this is not a valid packet ID for a public subkey).

13. Elliptic Curve Cryptography

This section descripes algorithms and parameters used with Elliptic Curve Cryptography (ECC) keys. A thorough introduction to ECC can be found in [KOBLITZ].

13.1. Supported ECC Curves

This document references six named prime field curves, defined in [FIPS186] as "Curve P-256", "Curve P-384", and "Curve P-521"; and defined in [RFC5639] as "brainpoolP256r1" "brainpoolP384r1", and "brainpoolP512r1". Further curves "Curve25519" and "Curve448", defined in [RFC7748] are referenced for use with Ed25519/Ed448 (EdDSA signing) and X25519/X448 (ECDH encryption).

The named curves are referenced as a sequence of bytes in this document, called throughout, curve OID. Section 9.2 describes in detail how this sequence of bytes is formed.

13.2. ECDSA and ECDH Conversion Primitives

This document defines the uncompressed point format for ECDSA and ECDH and a custom compression format for certain curves. The point is encoded in the Simple Octet String (SOS) format.

For an uncompressed point the content of the SOS is:

B = 04 || x || y

where x and y are coordinates of the point P = (x, y), each encoded in the big-endian format and zero-padded to the adjusted underlying field size. The adjusted underlying field size is the underlying field size that is rounded up to the nearest 8-bit boundary. This encoding is compatible with the definition given in [SEC1].

For a custom compressed point the content of the MPI is:

B = 40 || x

where x is the x coordinate of the point P encoded to the rules defined for the specified curve. This format is used for ECDH keys based on curves expressed in Montgomery form.

Therefore, the exact size of the SOS payload is 515 bits for "Curve P-256", 771 for "Curve P-384", 1059 for "Curve P-521", and 263 for Curve25519.

Even though the zero point, also called the point at infinity, may occur as a result of arithmetic operations on points of an elliptic curve, it SHALL NOT appear in data structures defined in this document.

If other conversion methods are defined in the future, a compliant application MUST NOT use a new format when in doubt that any recipient can support it. Consider, for example, that while both the public key and the per-recipient ECDH data structure, respectively defined in Section 5.6.6 and Section 5.1, contain an encoded point field, the format changes to the field in Section 5.1 only affect a given recipient of a given message.

13.3. EdDSA Point Format

The EdDSA algorithm defines a specific point compression format. To indicate the use of this compression format and to make sure that the key can be represented in the Multiprecision Integer (MPI) format the octet string specifying the point is prefixed with the octet 0x40. This encoding is an extension of the encoding given in [SEC1] which uses 0x04 to indicate an uncompressed point.

For example, the length of a public key for the curve Ed25519 is 263 bit: 7 bit to represent the 0x40 prefix octet and 32 octets for the native value of the public key.

13.4. Key Derivation Function

A key derivation function (KDF) is necessary to implement the EC encryption. The Concatenation Key Derivation Function (Approved Alternative 1) [SP800-56A] with the KDF hash function that is SHA2-256 [FIPS180] or stronger is REQUIRED. See Section 17 for the details regarding the choice of the hash function.

For convenience, the synopsis of the encoding method is given below with significant simplifications attributable to the restricted choice of hash functions in this document. However, [SP800-56A] is the normative source of the definition.

```
//   Implements KDF( X, oBits, Param );
//   Input: point X = (x,y)
//   oBits - the desired size of output
//   hBits - the size of output of hash function Hash
//   Param - octets representing the parameters
//   Assumes that oBits <= hBits
// Convert the point X to the octet string:
//   ZB' = 04 || x || y
// and extract the x portion from ZB'
ZB = x;
MB = Hash ( 00 || 00 || 00 || 01 || ZB || Param );
return oBits leftmost bits of MB.
```

Note that ZB in the KDF description above is the compact representation of X, defined in Section 4.2 of [RFC6090].

13.5. ECDH Algorithm

The method is a combination of an ECC Diffie-Hellman method to establish a shared secret, a key derivation method to process the shared secret into a derived key, and a key wrapping method that uses the derived key to protect a session key used to encrypt a message.

The One-Pass Diffie-Hellman method C(1, 1, ECC CDH) [SP800-56A] MUST be implemented with the following restrictions: the ECC CDH primitive employed by this method is modified to always assume the cofactor as 1, the KDF specified in Section 13.4 is used, and the KDF parameters specified below are used.

The KDF parameters are encoded as a concatenation of the following 5 variable-length and fixed-length fields, compatible with the definition of the OtherInfo bitstring [SP800-56A]:

* a variable-length field containing a curve OID, formatted as follows:
  - a one-octet size of the following field
  - the octets representing a curve OID, defined in Section 9.2
* a one-octet public key algorithm ID defined in Section 9.1
* a variable-length field containing KDF parameters, identical to the corresponding field in the ECDH public key, formatted as follows:
  - a one-octet size of the following fields; values 0 and 0xff are reserved for future extensions

- a one-octet value 01, reserved for future extensions

- a one-octet hash function ID used with the KDF

- a one-octet algorithm ID for the symmetric algorithm used to wrap the symmetric key for message encryption; see Section 13.5 for details

* 20 octets representing the UTF-8 encoding of the string "Anonymous Sender ", which is the octet sequence 41 6E 6F 6E 79 6D 6F 75 73 20 53 65 6E 64 65 72 20 20 20 20

* 20 octets representing a recipient encryption subkey or a master key fingerprint, identifying the key material that is needed for the decryption. For version 5 keys the 20 leftmost octets of the fingerprint are used.

The size of the KDF parameters sequence, defined above, is either 54 for the NIST curve P-256, 51 for the curves P-384 and P-521, or 56 for Curve25519.

The key wrapping method is described in [RFC3394]. KDF produces a symmetric key that is used as a key-encryption key (KEK) as specified in [RFC3394]. Refer to Section 16 for the details regarding the choice of the KEK algorithm, which SHOULD be one of three AES algorithms. Key wrapping and unwrapping is performed with the default initial value of [RFC3394].

The input to the key wrapping method is the value "m" derived from the session key, as described in Section 5.1, "Public-Key Encrypted Session Key Packets (Tag 1)", except that the PKCS #1.5 padding step is omitted. The result is padded using the method described in [PKCS5] to the 8-byte granularity. For example, the following AES-256 session key, in which 32 octets are denoted from k0 to k31, is composed to form the following 40 octet sequence:

09 k0 k1 ... k31 c0 c1 05 05 05 05 05

The octets c0 and c1 above denote the checksum. This encoding allows the sender to obfuscate the size of the symmetric encryption key used to encrypt the data. For example, assuming that an AES algorithm is used for the session key, the sender MAY use 21, 13, and 5 bytes of padding for AES-128, AES-192, and AES-256, respectively, to provide the same number of octets, 40 total, as an input to the key wrapping method.

The output of the method consists of two fields. The first field is the MPI containing the ephemeral key used to establish the shared secret. The second field is composed of the following two fields:

* a one-octet encoding the size in octets of the result of the key wrapping method; the value 255 is reserved for future extensions;

* up to 254 octets representing the result of the key wrapping method, applied to the 8-byte padded session key, as described above.

Note that for session key sizes 128, 192, and 256 bits, the size of the result of the key wrapping method is, respectively, 32, 40, and 48 octets, unless the size obfuscation is used.

For convenience, the synopsis of the encoding method is given below; however, this section, [SP800-56A], and [RFC3394] are the normative sources of the definition.

```
Obtain the authenticated recipient public key R
Generate an ephemeral key pair {v, V=vG}
Compute the shared point S = vR;
m = symm_alg_ID || session key || checksum || pkcs5_padding;
curve_OID_len = (byte)len(curve_OID);
Param = curve_OID_len || curve_OID || public_key_alg_ID || 03
|| 01 || KDF_hash_ID || KEK_alg_ID for AESKeyWrap || "Anonymous
Sender    " || recipient_fingerprint;
Z_len = the key size for the KEK_alg_ID used with AESKeyWrap
Compute Z = KDF( S, Z_len, Param );
Compute C = AESKeyWrap( Z, m ) as per [RFC3394]
VB = convert point V to the octet string
Output (MPI(VB) || len(C) || C).
```

The decryption is the inverse of the method given. Note that the recipient obtains the shared secret by calculating

S = rV = rvG, where (r,R) is the recipient’s key pair.

Consistent with Section 5.16, "OCB Encrypted Data Packet (Tag 20)" and Section 5.14, "Sym. Encrypted Integrity Protected Data Packet (Tag 18)", OCB encryption or a Modification Detection Code (MDC) MUST be used anytime the symmetric key is protected by ECDH.

13.5.1. ECDH Parameters

ECDH keys have a hash algorithm parameter for key derivation and a symmetric algorithm for key encapsulation.

For v4 keys, the following algorithms SHOULD be used depending on the curve. An implementation SHOULD only use an AES algorithm as a KEK algorithm.

For v5 keys, the following algorithms MUST be used depending on the curve. An implementation MUST NOT generate a v5 ECDH key over any listed curve that uses different KDF or KEK parameters. An implementation MUST NOT encrypt any message to a v5 ECDH key over a listed curve that announces a different KDF or KEK parameter.

Curve	Hash algorithm	Symmetric algorithm
NIST P-256	SHA2-256	AES-128
NIST P-384	SHA2-384	AES-192
NIST P-521	SHA2-512	AES-256
brainpoolP256r1	SHA2-256	AES-128
brainpoolP384r1	SHA2-384	AES-192
brainpoolP512r1	SHA2-512	AES-256
Curve25519	SHA2-256	AES-128
X448	SHA2-512	AES-256

Table 16

14. Post-Quantum Cryptography

This section descripes algorithms and parameters used with post-quantum cryptography. Specifically, it defines composite public-key encryption based on ECC-KEM and ML-KEM.

14.1. Kyber Algorithm

ML-KEM [FIPS203], which is also known as CRYSTALS-Kyber, is based on the hardness of solving the learning-with-errors problem in module lattices (MLWE). The scheme is believed to provide security against cryptanalytic attacks by classical as well as quantum computers. This specification defines ML-KEM only in composite combination with ECC-based encryption schemes in order to provide a pre-quantum security fallback. This scheme is built according to the following principal design:

* The encapsulation algorithm of an ECC-based KEM, is invoked to create an ECC ciphertext together with an ECC symmetric key share.

* The ML-KEM encapsulation algorithm is invoked to create a ML-KEM ciphertext together with a ML-KEM symmetric key share.

* A Key-Encryption-Key (KEK) is computed as the output of a Key-Combiner that receives as input both of the above created symmetric key shares and the protocol binding information.

* The session key for content encryption is then wrapped as described in [RFC3394] using AES-256 as algorithm and the KEK as key.

* The PKESK package’s algorithm-specific parts are made up of the ML-KEM ciphertext, the ECC ciphertext, the session key algorithm id, and the wrapped session key.

Valid combinations of ECC curve and ML-KEM version along with the to be used functions are:

Curve	ML-KEM	ECC-KEM	SHAFunc	Requirement
X25519	768	XKem	SHA3-256	SHOULD
X448	768	XKem	SHA3-512	MAY
X25519	1024	XKem	SHA3-256	MAY
X448	1024	XKem	SHA3-512	SHOULD
brainpoolP256r1	768	ecdhKem	SHA3-256	SHOULD
brainpoolP384r1	768	ecdhKem	SHA3-512	MAY
brainpoolP512r1	768	ecdhKem	SHA3-512	MAY
brainpoolP256r1	1024	ecdhKem	SHA3-256	MAY
brainpoolP384r1	1024	ecdhKem	SHA3-512	SHOULD
brainpoolP512r1	1024	ecdhKem	SHA3-512	MAY
NIST P-256	768	ecdhKem	SHA3-256	MAY
NIST P-384	768	ecdhKem	SHA3-512	MAY
NIST P-521	768	ecdhKem	SHA3-512	MAY
NIST P-256	1024	ecdhKem	SHA3-256	MAY
NIST P-384	1024	ecdhKem	SHA3-512	MAY
NIST P-521	1024	ecdhKem	SHA3-512	MAY

Table 17

14.1.1. ECC-KEM for curves X25519 and KEM-X448

The encapsulation and decapsulation operations of XKem are described using the functions and encodings defined in [RFC7748]. With the defintions:

```
XFunc         = X25519() for curve X25519 or X448() for curve X448.
SHAFunc       = See table above.
U(P)          = u-coordinate of the base point of the curve.
r             = eccSecretKey.
R             = eccPublicKey = XFunc (r, U(P))
v             = ephemeral secret key
eccCipherText = ephemeral public key = XFunc(v,U(P)),
X             = shared coordinate
eccKeyShare   = SHAFunc(X || eccCipherText || R).
```

The operation XKem.Encaps() is defined as follows:

* Create a random scalar v as ephemeral secret key,

* Generate the ephemeral public key: eccCipherText = XFunc(v,U(P)),

* Compute the shared coordinate: X = XFunc(v, R),

* Compute the key share:
  eccKeyShare = SHAFunc(X || eccCipherText || R).

* Output eccKeyShare and eccCipherText.

The operation XKem.Decaps() is defined as follows:

* Compute the shared coordinate: X = XFunc(r, eccCipherText),

* Output the key share:
  eccKeyShare = SHAFunc(X || eccCipherText || R).

14.1.2. ECC-KEM for Weierstrass curves

The encapsulation and decapsulation operations of ecdhKEM are described using the functions and encodings defined in [SP800-186] and [RFC5639]. With the defintions:

```
SHAFunc       = See table above.
G             = base point of the curve.
r             = eccSecretKey.
R             = eccPublicKey R = rG.
v             = ephemeral secret key.
V             = ephemeral public key V = vG.
S             = shared point S = vR or S = rV
S_x           = x-coordinate of S
eccPublicKey  = SEC1_encoding(R)
eccCipherText = SEC1_encoding(V)
eccKeyShare   = SHAFunc(S_x || eccCipherText || eccPublicKey).
```

The operation ecdhKem.Encaps() is defined as follows:

* Create a random scalar v as ephemeral secret key,

* Generate an ephemeral public key: V = vG,

* Compute the shared point: S = vR,

* Output the eccCipherText as the [SEC1] encoding of V,

* Output the key share:
  eccKeyShare = SHAFunc(S_x || eccCipherText || eccPublicKey)

The operation ecdhKem.Decaps() is defined as follows:

* Compute the shared point: S = rV

* Output the key share:
  eccKeyShare = SHAFunc(S_x || eccCipherText || eccPublicKey)

14.1.3. ML-KEM

The ML-KEM operations ML-KEM.Encaps and ML-KEM.Decaps as well as the encodings are defined in [FIPS203]. The artifact lengths in octets are given by this table:

ML-KEM	Public Key	Secret Key	Ciphertext
ML-KEM-768	1184	2400	1088
ML-KEM-1024	1568	3168	1568

Table 18

The operation ML-KEM.Encaps() is defined as follows:

* Invoke (mlkemCipherText, mlkemKeyShare) =
  ML-KEM.Encaps(mlkemPublicKey),

* Output mlkemCipherText as the ML-KEM ciphertext,

* Output mlkemKeyShare as the ML-KEM symmetric key share.

The operation ML-KEM.Decaps() is defined as follows:

* Invoke mlkemKeyShare = ML-KEM.Decaps(mlkemCipherText, mlkemSecretKey),

* Output mlkemKeyShare as the ML-KEM symmetric key share

14.1.4. KEM Key Combiner

For the composite KEM schemes the following procedure MUST be used to compute the KEK that wraps a session key. The construction is a one-step key derivation function compliant to [SP800-56C] Section 4, based on KMAC256 [SP800-185]. It is given by the following algorithm:

```
multiKeyCombine (eccKeyShare, eccCipherText,
                 mlkemKeyShare, mlkemCipherText,
                 fixedInfo, oBits)

Input:
eccKeyShare     - the ECC key share encoded as an octet string
eccCipherText   - the ECC ciphertext encoded as an octet string
mlkemKeyShare   - the ML-KEM key share encoded as an octet string
mlkemCipherText - the ML-KEM ciphertext encoded as an octet string
fixedInfo       - the fixed information octet string (see below)
oBits           - the size of the output keying material in bits

Constants:
domSeparation       - the UTF-8 encoding of the string
                      "OpenPGPCompositeKeyDerivationFunction"
counter             - the four-octet big-endian value 0x00000001
customizationString - the UTF-8 encoding of the string "KDF"

eccData = eccKeyShare || eccCipherText
mlkemData = mlkemKeyShare || mlkemCipherText
encData = counter || eccData || mlkemData || fixedInfo

result = KMAC256 (domSeparation, encData, oBits, customizationString)
```

The fixedinfo is used to provide a binding between the KEK and the communication parties. It is the concatenation of

* A one octet algorithm ID describing the symmetric algorithm used for the bulk data in the in the SEIPD (packet 18) or the OCBED (packet 20).

* The 32 octet version 5 fingerprint of the public key. Note that the fingerprint covers the packet format and all other parameters of the public key.

14.1.5. KEM Encryption Procedure

The procedure to perform public-key encryption with a ML-KEM + ECC composite scheme is as follows:

* Extract the eccPublicKey and mlkemPublicKey component from the algorithm specific data of the public key packet.

* Compute (eccCipherText, eccKeyShare) := ECC-Kem.Encaps(eccPublicKey)

* Compute (mlkemCipherText, mlkemKeyShare) := ML-KEM.Encaps(mlkemPublicKey)

* Prepare fixedInfo as specified above

* Compute KEK := multiKeyCombine(eccKeyShare, eccCipherText, mlkemKeyShare, mlkemCipherText, fixedInfo, 256) as defined in Section Section 14.1.4.

* Compute C := AESKeyWrap(KEK, sessionKey) with AES-256 as per [RFC3394] that includes a 64 bit integrity check

* Output eccCipherText, mlkemCipherText, sessionKeyAlgo, and C as specified in the Kyber specific part of the PKESK (packet 1).

Depending on the curve either XKem.Encaps() or ecdhKem.Encaps() is used for ECC-Kem.Encaps().

14.1.6. KEM Decryption Procedure

The decryption procedure is the inverse of the method given above for encryption. Implementations MAY check that the session key algorithm is the same as actually used but there is no security related need for it because the algorithm ID is covered by the key combining process.

Depending on the curve either XKem.Decaps() or ecdhKem.Decaps() is used for ECC-Kem.Decaps().

15. Notes on Algorithms

15.1. PKCS#1 Encoding in LibrePGP

This standard makes use of the PKCS#1 functions EME-PKCS1-v1_5 and EMSA-PKCS1-v1_5. However, the calling conventions of these functions has changed in the past. To avoid potential confusion and interoperability problems, we are including local copies in this document, adapted from those in PKCS#1 v2.1 [RFC3447]. RFC 3447 should be treated as the ultimate authority on PKCS#1 for LibrePGP. Nonetheless, we believe that there is value in having a self-contained document that avoids problems in the future with needed changes in the conventions.

15.1.1. EME-PKCS1-v1_5-ENCODE

Input:

k = the length in octets of the key modulus.

M = message to be encoded, an octet string of length mLen, where mLen <= k - 11.

Output:

EM = encoded message, an octet string of length k.

Error: "message too long".

1. Length checking: If mLen > k - 11, output "message too long" and stop.

2. Generate an octet string PS of length k - mLen - 3 consisting of pseudo-randomly generated nonzero octets. The length of PS will be at least eight octets.

3. Concatenate PS, the message M, and other padding to form an encoded message EM of length k octets as

   EM = 0x00 || 0x02 || PS || 0x00 || M.

4. Output EM.

15.1.2. EME-PKCS1-v1_5-DECODE

Input:

EM = encoded message, an octet string

Output:

M = message, an octet string,

Error: "decryption error",

To decode an EME-PKCS1_v1_5 message, separate the encoded message EM into an octet string PS consisting of nonzero octets and a message M as follows

EM = 0x00 || 0x02 || PS || 0x00 || M.

If the first octet of EM does not have hexadecimal value 0x00, if the second octet of EM does not have hexadecimal value 0x02, if there is no octet with hexadecimal value 0x00 to separate PS from M, or if the length of PS is less than 8 octets, output "decryption error" and stop. See also the security note in Section 16 regarding differences in reporting between a decryption error and a padding error.

15.1.3. EMSA-PKCS1-v1_5

This encoding method is deterministic and only has an encoding operation.

Option:

Hash - a hash function in which hLen denotes the length in octets of the hash function output.

Input:

M = message to be encoded.

emLen = intended length in octets of the encoded message, at least tLen + 11, where tLen is the octet length of the DER encoding T of a certain value computed during the encoding operation.

Output:

EM = encoded message, an octet string of length emLen.

Errors: "message too long";
"intended encoded message length too short".

Steps:

1. Apply the hash function to the message M to produce a hash value H:

   H = Hash(M).

   If the hash function outputs "message too long," output "message too long" and stop.

2. Using the list in Section [](#version-3-signature-packet-format), "Version 3 Signature Packet Format", produce an ASN.1 DER value for the hash function used. Let T be the full hash prefix from the list, and let tLen be the length in octets of T.

3. If emLen < tLen + 11, output "intended encoded message length too short" and stop.

4. Generate an octet string PS consisting of emLen - tLen - 3 octets with hexadecimal value 0xFF. The length of PS will be at least 8 octets.

5. Concatenate PS, the hash prefix T, and other padding to form the encoded message EM as

   EM = 0x00 || 0x01 || PS || 0x00 || T.

6. Output EM.

15.2. Symmetric Algorithm Preferences

The symmetric algorithm preference is an ordered list of algorithms that the keyholder accepts. Since it is found on a self-signature, it is possible that a keyholder may have multiple, different preferences. For example, Alice may have AES-128 only specified for "alice@work.com" but Camellia-256, Twofish, and AES-128 specified for "alice@home.org". Note that it is also possible for preferences to be in a subkey’s binding signature.

Since AES-128 is the MUST-implement algorithm, if it is not explicitly in the list, it is tacitly at the end. However, it is good form to place it there explicitly. Note also that if an implementation does not implement the preference, then it is implicitly an AES-128-only implementation. Note further that implementations conforming to previous versions of this standard (RFC-4880) have TripleDES as its only MUST-implement algorithm.

An implementation MUST NOT use a symmetric algorithm that is not in the recipient's preference list. When encrypting to more than one recipient, the implementation finds a suitable algorithm by taking the intersection of the preferences of the recipients. Note that the MUST-implement algorithm, AES-128, ensures that the intersection is not null. The implementation may use any mechanism to pick an algorithm in the intersection.

If an implementation can decrypt a message that a keyholder doesn't have in their preferences, the implementation SHOULD decrypt the message anyway, but MUST warn the keyholder that the protocol has been violated. For example, suppose that Alice, above, has software that implements all algorithms in this specification. Nonetheless, she prefers subsets for work or home. If she is sent a message encrypted with IDEA, which is not in her preferences, the software warns her that someone sent her an IDEA-encrypted message, but it would ideally decrypt it anyway.

15.3. Other Algorithm Preferences

Other algorithm preferences work similarly to the symmetric algorithm preference, in that they specify which algorithms the keyholder accepts. There are two interesting cases that other comments need to be made about, though, the compression preferences and the hash preferences.

15.3.1. Compression Preferences

Compression has been an integral part of PGP since its first days. LibrePGP and all previous versions of PGP have offered compression. In this specification, the default is for messages to be compressed, although an implementation is not required to do so. Consequently, the compression preference gives a way for a keyholder to request that messages not be compressed, presumably because they are using a minimal implementation that does not include compression. Additionally, this gives a keyholder a way to state that it can support alternate algorithms.

Like the algorithm preferences, an implementation MUST NOT use an algorithm that is not in the preference vector. If the preferences are not present, then they are assumed to be [ZIP(1), Uncompressed(0)].

Additionally, an implementation MUST implement this preference to the degree of recognizing when to send an uncompressed message. A robust implementation would satisfy this requirement by looking at the recipient's preference and acting accordingly. A minimal implementation can satisfy this requirement by never generating a compressed message, since all implementations can handle messages that have not been compressed.

15.3.2. Hash Algorithm Preferences

Typically, the choice of a hash algorithm is something the signer does, rather than the verifier, because a signer rarely knows who is going to be verifying the signature. This preference, though, allows a protocol based upon digital signatures ease in negotiation.

Thus, if Alice is authenticating herself to Bob with a signature, it makes sense for her to use a hash algorithm that Bob's software uses. This preference allows Bob to state in his key which algorithms Alice may use.

Since SHA2-256 is the MUST-implement hash algorithm, if it is not explicitly in the list, it is tacitly at the end. However, it is good form to place it there explicitly.

15.4. Plaintext

Algorithm 0, "plaintext", may only be used to denote secret keys that are stored in the clear. Implementations MUST NOT use plaintext in Symmetrically Encrypted Data packets; they must use Literal Data packets to encode unencrypted or literal data.

15.5. RSA

There are algorithm types for RSA Sign-Only, and RSA Encrypt-Only keys. These types are deprecated. The "key flags" subpacket in a signature is a much better way to express the same idea, and generalizes it to all algorithms. An implementation SHOULD NOT create such a key, but MAY interpret it.

An implementation SHOULD NOT implement RSA keys of size less than 1024 bits.

15.6. DSA

An implementation SHOULD NOT implement DSA keys of size less than 1024 bits. It MUST NOT implement a DSA key with a q size of less than 160 bits. DSA keys MUST also be a multiple of 64 bits, and the q size MUST be a multiple of 8 bits. The Digital Signature Standard (DSS) [FIPS186] specifies that DSA be used in one of the following ways:

* 1024-bit key, 160-bit q, SHA-1, SHA2-224, SHA2-256, SHA2-384, or SHA2-512 hash

* 2048-bit key, 224-bit q, SHA2-224, SHA2-256, SHA2-384, or SHA2-512 hash

* 2048-bit key, 256-bit q, SHA2-256, SHA2-384, or SHA2-512 hash

* 3072-bit key, 256-bit q, SHA2-256, SHA2-384, or SHA2-512 hash

The above key and q size pairs were chosen to best balance the strength of the key with the strength of the hash. Implementations SHOULD use one of the above key and q size pairs when generating DSA keys. If DSS compliance is desired, one of the specified SHA hashes must be used as well. [FIPS186] is the ultimate authority on DSS, and should be consulted for all questions of DSS compliance.

Note that earlier versions of this standard only allowed a 160-bit q with no truncation allowed, so earlier implementations may not be able to handle signatures with a different q size or a truncated hash.

15.7. Elgamal

An implementation SHOULD NOT implement Elgamal keys of size less than 1024 bits.

15.8. EdDSA

Although the EdDSA algorithm allows arbitrary data as input, its use with LibrePGP requires that a digest of the message is used as input (pre-hashed). See section Section 5.2.4, "Computing Signatures" for details. Truncation of the resulting digest is never applied; the resulting digest value is used verbatim as input to the EdDSA algorithm.

15.9. Reserved Algorithm Numbers

A number of algorithm IDs have been reserved for algorithms that would be useful to use in an LibrePGP implementation, yet there are issues that prevent an implementer from actually implementing the algorithm. These are marked in Section 9.1, "Public-Key Algorithms", as "reserved for".

The reserved public-key algorithm X9.42 (21) does not have the necessary parameters, parameter order, or semantics defined. The same is currently true for reserved public-key algorithms AEDH (23) and AEDSA (24).

Previous versions of LibrePGP permitted Elgamal [ELGAMAL] signatures with a public-key identifier of 20. These are no longer permitted. An implementation MUST NOT generate such keys. An implementation MUST NOT generate Elgamal signatures. See [BLEICHENBACHER].

15.10. LibrePGP CFB Mode

LibrePGP does symmetric encryption using a variant of Cipher Feedback mode (CFB mode). This section describes the procedure it uses in detail. This mode is what is used for Symmetrically Encrypted Data Packets; the mechanism used for encrypting secret-key material is similar, and is described in the sections above.

In the description below, the value BS is the block size in octets of the cipher. Most ciphers have a block size of 8 octets. The AES and Twofish have a block size of 16 octets. Also note that the description below assumes that the IV and CFB arrays start with an index of 1 (unlike the C language, which assumes arrays start with a zero index).

LibrePGP CFB mode uses an initialization vector (IV) of all zeros, and prefixes the plaintext with BS+2 octets of random data, such that octets BS+1 and BS+2 match octets BS-1 and BS. It does a CFB resynchronization after encrypting those BS+2 octets.

Thus, for an algorithm that has a block size of 8 octets (64 bits), the IV is 10 octets long and octets 7 and 8 of the IV are the same as octets 9 and 10. For an algorithm with a block size of 16 octets (128 bits), the IV is 18 octets long, and octets 17 and 18 replicate octets 15 and 16. Those extra two octets are an easy check for a correct key.

Step by step, here is the procedure:

1. The feedback register (FR) is set to the IV, which is all zeros.

2. FR is encrypted to produce FRE (FR Encrypted). This is the encryption of an all-zero value.

3. FRE is xored with the first BS octets of random data prefixed to the plaintext to produce C[1] through C[BS], the first BS octets of ciphertext.

4. FR is loaded with C[1] through C[BS].

5. FR is encrypted to produce FRE, the encryption of the first BS octets of ciphertext.

6. The left two octets of FRE get xored with the next two octets of data that were prefixed to the plaintext. This produces C[BS+1] and C[BS+2], the next two octets of ciphertext.

7. (The resynchronization step) FR is loaded with C[3] through C[BS+2].

8. FRE is xored with the first BS octets of the given plaintext, now that we have finished encrypting the BS+2 octets of prefixed data. This produces C[BS+3] through C[BS+(BS+2)], the next BS octets of ciphertext.

9. FR is encrypted to produce FRE.

10. FR is loaded with C[BS+3] to C[BS + (BS+2)] (which is C11-C18 for an 8-octet block).

11. FR is encrypted to produce FRE.

12. FRE is xored with the next BS octets of plaintext, to produce the next BS octets of ciphertext. These are loaded into FR, and the process is repeated until the plaintext is used up.

15.11. Private or Experimental Parameters

S2K specifiers, Signature subpacket types, User Attribute types, image format types, and algorithms described in Section 9 all reserve the range 100 to 110 for private and experimental use. Packet types reserve the range 60 to 63 for private and experimental use. These are intentionally managed with the PRIVATE USE method, as described in [RFC8126].

However, implementations need to be careful with these and promote them to full IANA-managed parameters when they grow beyond the original, limited system.

15.12. Meta-Considerations for Expansion

If LibrePGP is extended in a way that is not backwards-compatible, meaning that old implementations will not gracefully handle their absence of a new feature, the extension proposal can be declared in the key holder's self-signature as part of the Features signature subpacket.

We cannot state definitively what extensions will not be upwards-compatible, but typically new algorithms are upwards-compatible, whereas new packets are not.

If an extension proposal does not update the Features system, it SHOULD include an explanation of why this is unnecessary. If the proposal contains neither an extension to the Features system nor an explanation of why such an extension is unnecessary, the proposal SHOULD be rejected.

16. Security Considerations

* As with any technology involving cryptography, you should check the current literature to determine if any algorithms used here have been found to be vulnerable to attack or have been found to be too weak.

* This specification uses Public-Key Cryptography technologies. It is assumed that the private key portion of a public-private key pair is controlled and secured by the proper party or parties.

* Certain operations in this specification involve the use of random numbers. An appropriate entropy source should be used to generate these numbers (see [RFC4086]).

* The MD5 hash algorithm has been found to have weaknesses, with collisions found in a number of cases. MD5 is deprecated for use in LibrePGP. Implementations MUST NOT generate new signatures using MD5 as a hash function. They MAY continue to consider old signatures that used MD5 as valid.

* SHA2-224 and SHA2-384 require the same work as SHA2-256 and SHA2-512, respectively. In general, there are few reasons to use them outside of DSS compatibility. You need a situation where one needs more security than smaller hashes, but does not want to have the full 256-bit or 512-bit data length.

* Many security protocol designers think that it is a bad idea to use a single key for both privacy (encryption) and integrity (signatures). In fact, this was one of the motivating forces

behind the V4 key format with separate signature and encryption keys. If you as an implementer promote dual-use keys, you should at least be aware of this controversy.

* The DSA algorithm will work with any hash, but is sensitive to the quality of the hash algorithm. Verifiers should be aware that even if the signer used a strong hash, an attacker could have modified the signature to use a weak one. Only signatures using acceptably strong hash algorithms should be accepted as valid.

* If you are building an authentication system, the recipient may specify a preferred signing algorithm. However, the signer would be foolish to use a weak algorithm simply because the recipient requests it.

* In late summer 2002, Jallad, Katz, and Schneier published an interesting attack on the LibrePGP protocol and some of its implementations [JKS02]. In this attack, the attacker modifies a message and sends it to a user who then returns the erroneously decrypted message to the attacker. The attacker is thus using the user as a random oracle, and can often decrypt the message.

  Compressing data can ameliorate this attack. The incorrectly decrypted data nearly always decompresses in ways that defeat the attack. However, this is not a rigorous fix, and leaves open some small vulnerabilities. For example, if an implementation does not compress a message before encryption (perhaps because it knows it was already compressed), then that message is vulnerable. Because of this happenstance --- that modification attacks can be thwarted by decompression errors --- an implementation SHOULD treat a decompression error as a security problem, not merely a data problem.

  This attack can be defeated by the use of modification detection, provided that the implementation does not let the user naively return the data to the attacker. The modification detection is prefereabble implemented by using the OCB Encrypted Data Packet and only if the recipients don’t supports this by use of the Symmmetric Encrypted and Integrity Protected Data Packet. An implementation MUST treat an authentication or MDC failure as a security problem, not merely a data problem.

  In either case, the implementation SHOULD NOT allow the user access to the erroneous data, and MUST warn the user as to potential security problems should that data be returned to the sender.

While this attack is somewhat obscure, requiring a special set of circumstances to create it, it is nonetheless quite serious as it permits someone to trick a user to decrypt a message. Consequently, it is important that:

1. Implementers treat authentication errors, MDC errors, decompression failures or no use of MDC or AEAD as security problems.

2. Implementers implement OCB with all due speed and encourage its spread.

3. Users migrate to implementations that support OCB encryption with all due speed.

* PKCS#1 has been found to be vulnerable to attacks in which a system that reports errors in padding differently from errors in decryption becomes a random oracle that can leak the private key in mere millions of queries. Implementations must be aware of this attack and prevent it from happening. The simplest solution is to report a single error code for all variants of decryption errors so as not to leak information to an attacker.

* Some technologies mentioned here may be subject to government control in some countries.

* In winter 2005, Serge Mister and Robert Zuccherato from Entrust released a paper describing a way that the "quick check" in LibrePGP CFB mode can be used with a random oracle to decrypt two octets of every cipher block [MZ05]. They recommend as prevention not using the quick check at all.

  Many implementers have taken this advice to heart for any data that is symmetrically encrypted and for which the session key is public-key encrypted. In this case, the quick check is not needed as the public-key encryption of the session key should guarantee that it is the right session key. In other cases, the implementation should use the quick check with care.

  On the one hand, there is a danger to using it if there is a random oracle that can leak information to an attacker. In plainer language, there is a danger to using the quick check if timing information about the check can be exposed to an attacker, particularly via an automated service that allows rapidly repeated queries.

On the other hand, it is inconvenient to the user to be informed that they typed in the wrong passphrase only after a petabyte of data is decrypted. There are many cases in cryptographic engineering where the implementer must use care and wisdom, and this is one.

* Refer to [FIPS186], B.4.1, for the method to generate a uniformly distributed ECC private key.

* This document explicitly discourages the use of algorithms other than AES as a KEK algorithm because backward compatibility of the ECDH format is not a concern. The KEK algorithm is only used within the scope of a Public-Key Encrypted Session Key Packet, which represents an ECDH key recipient of a message. Compare this with the algorithm used for the session key of the message, which MAY be different from a KEK algorithm.

  Compliant applications SHOULD implement, advertise through key preferences, and use the strongest algorithms specified in this document.

  Note that the symmetric algorithm preference list may make it impossible to use the balanced strength of symmetric key algorithms for a corresponding public key. For example, the presence of the symmetric key algorithm IDs and their order in the key preference list affects the algorithm choices available to the encoding side, which in turn may make the adherence to the table above infeasible. Therefore, compliance with this specification is a concern throughout the life of the key, starting immediately after the key generation when the key preferences are first added to a key. It is generally advisable to position a symmetric algorithm ID of strength matching the public key at the head of the key preference list.

  Encryption to multiple recipients often results in an unordered intersection subset. For example, if the first recipient’s set is {A, B} and the second’s is {B, A}, the intersection is an unordered set of two algorithms, A and B. In this case, a compliant application SHOULD choose the stronger encryption algorithm.

  Resource constraints, such as limited computational power, is a likely reason why an application might prefer to use the weakest algorithm. On the other side of the spectrum are applications that can implement every algorithm defined in this document. Most applications are expected to fall into either of two categories. A compliant application in the second, or strongest, category SHOULD prefer AES-256 to AES-192.

SHA-1 MUST NOT be used with the ECDSA or the KDF in the ECDH method.

MDC MUST be used when a symmetric encryption key is protected by ECDH. None of the ECC methods described in this document are allowed with deprecated V3 keys. A compliant application MUST only use iterated and salted S2K to protect private keys, as defined in Section 3.8.1.3, "Iterated and Salted S2K".

Side channel attacks are a concern when a compliant application's use of the LibrePGP format can be modeled by a decryption or signing oracle model, for example, when an application is a network service performing decryption to unauthenticated remote users. ECC scalar multiplication operations used in ECDSA and ECDH are vulnerable to side channel attacks. Countermeasures can often be taken at the higher protocol level, such as limiting the number of allowed failures or time-blinding of the operations associated with each network interface. Mitigations at the scalar multiplication level seek to eliminate any measurable distinction between the ECC point addition and doubling operations.

* Although technically possible, the EdDSA algorithm MUST NOT be used with a digest algorithms weaker than SHA2-256.

LibrePGP was designed with security in mind, with many smart, intelligent people spending a lot of time thinking about the ramifications of their decisions. Removing the requirement for self-certifying User ID (and User Attribute) packets on a key means that someone could surreptitiously add an unwanted ID to a key and sign it. If enough "trusted" people sign that surreptitious identity then other people might believe it. The attack could wind up sending encrypted mail destined for alice to some other target, bob, because someone added "alice" to bob's key without bob's consent.

In the case of device certificates the device itself does not have any consent. It is given an identity by the device manufacturer and the manufacturer can insert that ID on the device certificate, signing it with the manufacturer's key. If another people wants to label the device by another name, they can do so. There is no harm in multiple IDs, because the verification is all done based on who has signed those IDs.

When a key can self-sign, it is still suggested to self-certify IDs, even if it no longer required by this modification to LibrePGP. This at least signals to recipients of keys that yes, the owner of this key asserts that this identity belongs to herself. Note, however, that mallet could still assert that he is 'alice' and could even self-certify that. So the attack is not truly different. Moreover,

in the case of device certificates, it’s more the manufacturer than the device that wants to assert an identity (even if the device could self-certify).

There is no signaling whether a key is using this looser-requirement key format. An attacker could therefore just remove the self-signature off a published key. However one would hope that wide publication would result in another copy still having that signature and it being returned quickly. However, the lack of signaling also means that a user with an application following RFC 4880 directly would see a key following this specification as "broken" and may not accept it.

On a different note, including the "geo" notation could leak information about where a signer is located. However it is just an assertion (albeit a signed assertion) so there is no verifiable truth to the location information released. Similarly, all the rest of the signature notations are pure assertions, so they should be taken with the trustworthiness of the signer.

Combining the User ID with the User Attribute means that an ID and image would not be separable. For a person this is probably not good, but for a device it’s unlikely the image will change so it makes sense to combine the ID and image into a single signed packet with a single signature.

17. Compatibility Profiles

17.1. LibrePGP ECC Profile

A compliant application MUST implement NIST curve P-256, SHOULD implement NIST curve P-521, SHOULD implement brainpoolP256r1 and brainpoolP512r1, SHOULD implement Ed25519, SHOULD implement Curve25519, MAY implement NIST curve P-384, and MAY implement brainpoolP384r1, as defined in Section 9.2.

A compliant application MUST implement SHA2-256 and SHOULD implement SHA2-384 and SHA2-512. A compliant application MUST implement AES-128 and SHOULD implement AES-256.

A compliant application SHOULD follow Section 16 regarding the choice of the following algorithms for each curve:

* the KDF hash algorithm,

* the KEK algorithm,

* the message digest algorithm and the hash algorithm used in the key certifications,

* the symmetric algorithm used for message encryption.

It is recommended that the chosen symmetric algorithm for message encryption be no less secure than the KEK algorithm.

18. Implementation Nits

This section is a collection of comments to help an implementer, particularly with an eye to backward compatibility. Previous implementations of PGP are not LibrePGP compliant. Often the differences are small, but small differences are frequently more vexing than large differences. Thus, this is a non-comprehensive list of potential problems and gotchas for a developer who is trying to be backward-compatible.

* When exporting a private key, PGP 2 generates the header "BEGIN PGP SECRET KEY BLOCK" instead of "BEGIN PGP PRIVATE KEY BLOCK". All previous versions ignore the implied data type, and look directly at the packet data type.

* PGP versions 2.0 through 2.5 generated V2 Public-Key packets. These are identical to the deprecated V3 keys except for the version number. An implementation MUST NOT generate them and may accept or reject them as it sees fit. Some older PGP versions generated V2 PKESK packets (Tag 1) as well. An implementation may accept or reject V2 PKESK packets as it sees fit, and MUST NOT generate them.

* PGP version 2.6 will not accept key-material packets with versions greater than 3.

* There are many ways possible for two keys to have the same key material, but different fingerprints (and thus Key IDs). Perhaps the most interesting is an RSA key that has been "upgraded" to V4 format, but since a V4 fingerprint is constructed by hashing the key creation time along with other things, two V4 keys created at different times, yet with the same key material will have different fingerprints.

* If an implementation is using zlib to interoperate with PGP 2, then the "windowBits" parameter should be set to -13.

* The 0x19 back signatures were not required for signing subkeys until relatively recently. Consequently, there may be keys in the wild that do not have these back signatures. Implementing software may handle these keys as it sees fit.

* LibrePGP does not put limits on the size of public keys. However, larger keys are not necessarily better keys. Larger keys take more computation time to use, and this can quickly become impractical. Different LibrePGP implementations may also use different upper bounds for public key sizes, and so care should be taken when choosing sizes to maintain interoperability. As of 2007 most implementations have an upper bound of 4096 bits for RSA, DSA, and Elgamal

* ASCII armor is an optional feature of LibrePGP. The LibrePGP working group strives for a minimal set of mandatory-to-implement features, and since there could be useful implementations that only use binary object formats, this is not a "MUST" feature for an implementation. For example, an implementation that is using LibrePGP as a mechanism for file signatures may find ASCII armor unnecessary. LibrePGP permits an implementation to declare what features it does and does not support, but ASCII armor is not one of these. Since most implementations allow binary and armored objects to be used indiscriminately, an implementation that does not implement ASCII armor may find itself with compatibility issues with general-purpose implementations. Moreover, implementations of OpenPGP-MIME [RFC3156] already have a requirement for ASCII armor so those implementations will necessarily have support.

19. References

19.1. Normative References

[AES] NIST, "FIPS PUB 197, Advanced Encryption Standard (AES)", November 2001, <http://csrc.nist.gov/publications/fips/fips197/fips-197.{ps,pdf}>.

[BLOWFISH] Schneier, B., "Description of a New Variable-Length Key, 64-Bit Block Cipher (Blowfish)", Fast Software Encryption, Cambridge Security Workshop Proceedings Springer-Verlag, 1994, pp191-204, December 1993, <http://www.counterpane.com/bfsverlag.html>.

[BZ2] Seward, J., "The Bzip2 and libbzip2 home page", 2010, <http://www.bzip.org/>.

[EAX] Bellare, M., Rogaway, P., and D. Wagner, "A Conventional Authenticated-Encryption Mode", April 2003.

[ELGAMAL] Elgamal, T., "A Public-Key Cryptosystem and a Signature Scheme Based on Discrete Logarithms", IEEE Transactions on Information Theory v. IT-31, n. 4, 1985, pp. 469-472, 1985.

[FIPS180] National Institute of Standards and Technology, U.S. Department of Commerce, "Secure Hash Standard (SHS), FIPS 180-4", August 2015, <http://dx.doi.org/10.6028/NIST.FIPS.180-4>.

[FIPS186] National Institute of Standards and Technology, U.S. Department of Commerce, "Digital Signature Standard (DSS), FIPS 186-4", July 2013, <http://dx.doi.org/10.6028/NIST.FIPS.186-4>.

[FIPS202] National Institute of Standards and Technology, U.S. Department of Commerce, "SHA-3 Standard: Permutation-Based Hash and Extendable-Output Functions, FIPS 202", August 2015, <http://dx.doi.org/10.6028/NIST.FIPS.202>.

[FIPS203] National Institute of Standards and Technology, U.S. Department of Commerce, "Module-Lattice-Based Key-Encapsulation Mechanism Standard", August 2024, <https://doi.org/10.6028/NIST.FIPS.203>.

[HAC] Menezes, A. J., v Oorschot, P., and S. Vanstone, "Handbook of Applied Cryptography", 1996.

[IDEA] Lai, X., "On the design and security of block ciphers", ETH Series in Information Processing, J.L. Massey (editor) Vol. 1, Hartung-Gorre Verlag Konstanz, Technische Hochschule (Zurich), 1992.

[ISO10646] International Organization for Standardization, "Information Technology - Universal Multiple-octet coded Character Set (UCS) - Part 1: Architecture and Basic Multilingual Plane", ISO Standard 10646-1, May 1993.

[JFIF] CA, E. H. M., "JPEG File Interchange Format (Version 1.02).", September 1996.

[PKCS5] RSA Laboratories, "PKCS #5 v2.0: Password-Based Cryptography Standard", 25 March 1999.

[RFC1950] Deutsch, P. and J. Gailly, "ZLIB Compressed Data Format Specification version 3.3", RFC 1950, DOI 10.17487/RFC1950, May 1996, <https://www.rfc-editor.org/rfc/rfc1950>.

[RFC1951] Deutsch, P., "DEFLATE Compressed Data Format Specification version 1.3", RFC 1951, DOI 10.17487/RFC1951, May 1996, <https://www.rfc-editor.org/rfc/rfc1951>.

[RFC2045] Freed, N. and N. Borenstein, "Multipurpose Internet Mail Extensions (MIME) Part One: Format of Internet Message Bodies", RFC 2045, DOI 10.17487/RFC2045, November 1996, <https://www.rfc-editor.org/rfc/rfc2045>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/rfc/rfc2119>.

[RFC2144] Adams, C., "The CAST-128 Encryption Algorithm", RFC 2144, DOI 10.17487/RFC2144, May 1997, <https://www.rfc-editor.org/rfc/rfc2144>.

[RFC2822] Resnick, P., Ed., "Internet Message Format", RFC 2822, DOI 10.17487/RFC2822, April 2001, <https://www.rfc-editor.org/rfc/rfc2822>.

[RFC3156] Elkins, M., Del Torto, D., Levien, R., and T. Roessler, "MIME Security with OpenPGP", RFC 3156, DOI 10.17487/RFC3156, August 2001, <https://www.rfc-editor.org/rfc/rfc3156>.

[RFC3394] Schaad, J. and R. Housley, "Advanced Encryption Standard (AES) Key Wrap Algorithm", RFC 3394, DOI 10.17487/RFC3394, September 2002, <https://www.rfc-editor.org/rfc/rfc3394>.

[RFC3447] Jonsson, J. and B. Kaliski, "Public-Key Cryptography Standards (PKCS) #1: RSA Cryptography Specifications Version 2.1", RFC 3447, DOI 10.17487/RFC3447, February 2003, <https://www.rfc-editor.org/rfc/rfc3447>.

[RFC3629] Yergeau, F., "UTF-8, a transformation format of ISO 10646", STD 63, RFC 3629, DOI 10.17487/RFC3629, November 2003, <https://www.rfc-editor.org/rfc/rfc3629>.

[RFC3713] Matsui, M., Nakajima, J., and S. Moriai, "A Description of the Camellia Encryption Algorithm", RFC 3713, DOI 10.17487/RFC3713, April 2004, <https://www.rfc-editor.org/rfc/rfc3713>.

[RFC4086] Eastlake 3rd, D., Schiller, J., and S. Crocker, "Randomness Requirements for Security", BCP 106, RFC 4086, DOI 10.17487/RFC4086, June 2005, <https://www.rfc-editor.org/rfc/rfc4086>.

[RFC5639] Lochter, M. and J. Merkle, "Elliptic Curve Cryptography (ECC) Brainpool Standard Curves and Curve Generation", RFC 5639, DOI 10.17487/RFC5639, March 2010, <https://www.rfc-editor.org/rfc/rfc5639>.

[RFC5870] Mayrhofer, A. and C. Spanring, "A Uniform Resource Identifier for Geographic Locations (’geo’ URI)", RFC 5870, DOI 10.17487/RFC5870, June 2010, <https://www.rfc-editor.org/rfc/rfc5870>.

[RFC7253] Krovetz, T. and P. Rogaway, "The OCB Authenticated-Encryption Algorithm", RFC 7253, DOI 10.17487/RFC7253, May 2014, <https://www.rfc-editor.org/rfc/rfc7253>.

[RFC7748] Langley, A., Hamburg, M., and S. Turner, "Elliptic Curves for Security", RFC 7748, DOI 10.17487/RFC7748, January 2016, <https://www.rfc-editor.org/rfc/rfc7748>.

[RFC8032] Josefsson, S. and I. Liusvaara, "Edwards-Curve Digital Signature Algorithm (EdDSA)", RFC 8032, DOI 10.17487/RFC8032, January 2017, <https://www.rfc-editor.org/rfc/rfc8032>.

[RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 8126, DOI 10.17487/RFC8126, June 2017, <https://www.rfc-editor.org/rfc/rfc8126>.

[SCHNEIER] Schneier, B., "Applied Cryptography Second Edition: protocols, algorithms, and source code in C", 1996.

[SP800-185] Kelsey, J., Chang, S., and R. Perlner, "SHA-3 Derived Functions: cSHAKE, KMAC, TupleHash, and ParallelHash", NIST Special Publication 800-185, December 2016, <https://doi.org/10.6028/NIST.SP.800-185>.

[SP800-186]
Chen, L., Moody, D., Regenscheid, A., and K. Randal, "Recommendations for Discrete Logarithm-Based Cryptography: Elliptic Curve Domain Parameters", NIST Special Publication 800-186, February 2023, <https://doi.org/10.6028/NIST.SP.800-186>.

[SP800-56A]
Barker, E., Johnson, D., and M. Smid, "Recommendation for Pair-Wise Key Establishment Schemes Using Discrete Logarithm Cryptography", NIST Special Publication 800-56A Revision 1, March 2007, <https://doi.org/10.6028/NIST.SP.800-56Ar3>.

[SP800-56C]
Barker, E., Chen, L., and R. Davis, "Recommendation for Key-Derivation Methods in Key-Establishment Schemes", NIST Special Publication 800-56C Revision 2, August 2020, <https\://doi.org/10.6028/NIST.SP.800-56Cr2>.

[TWOFISH] Schneier, B., Kelsey, J., Whiting, D., Wagner, D., Hall, C., and N. Ferguson, "The Twofish Encryption Algorithm", 1999.

19.2. Informative References

[BLEICHENBACHER]
Bleichenbacher, D., "Generating ElGamal Signatures Without Knowing the Secret Key", Lecture Notes in Computer Science Volume 1070, pp. 10-18, 1996.

[JKS02] Jallad, K., Katz, J., and B. Schneier, "Implementation of Chosen-Ciphertext Attacks against PGP and GnuPG", 2002, <http://www.counterpane.com/pgp-attack.html>.

[KOBLITZ] Koblitz, N., "A course in number theory and cryptography, Chapter VI. Elliptic Curves", ISBN 0-387-96576-9, 1997.

[MZ05] Mister, S. and R. Zuccherato, "An Attack on CFB Mode Encryption As Used By OpenPGP", IACR ePrint Archive Report 2005/033, 8 February 2005, <http://eprint.iacr.org/2005/033>.

[REGEX] Friedl, J., "Mastering Regular Expressions", ISBN 0-596-00289-0, August 2002.

[RFC1991] Atkins, D., Stallings, W., and P. Zimmermann, "PGP Message Exchange Formats", RFC 1991, DOI 10.17487/RFC1991, August 1996, <https://www.rfc-editor.org/rfc/rfc1991>.

[RFC2440] Callas, J., Donnerhacke, L., Finney, H., and R. Thayer, "OpenPGP Message Format", RFC 2440, DOI 10.17487/RFC2440, November 1998, <https://www.rfc-editor.org/rfc/rfc2440>.

[RFC4880] Callas, J., Donnerhacke, L., Finney, H., Shaw, D., and R. Thayer, "OpenPGP Message Format", RFC 4880, DOI 10.17487/RFC4880, November 2007, <https://www.rfc-editor.org/rfc/rfc4880>.

[RFC6090] McGrew, D., Igoe, K., and M. Salter, "Fundamental Elliptic Curve Cryptography Algorithms", RFC 6090, DOI 10.17487/RFC6090, February 2011, <https://www.rfc-editor.org/rfc/rfc6090>.

[SEC1] Standards for Efficient Cryptography Group, "SEC 1: Elliptic Curve Cryptography", September 2000.

Appendix A. Test vectors

To help implementing this specification a non-normative example for the EdDSA algorithm is given.

A.1. Sample EdDSA key

The secret key used for this example is:

D: 1a8b1ff05ded48e18bf50166c664ab023ea70003d78d9e41f5758a91d850f8d2

Note that this is the raw secret key used as input to the EdDSA signing operation. The key was created on 2014-08-19 14:28:27 and thus the fingerprint of the LibrePGP key is:

C959 BDBA FA32 A2F8 9A15 3B67 8CFD E121 9796 5A9A

The algorithm specific input parameters without the MPI length headers are:

oid: 2b06010401da470f01

q: 403f098994bdd916ed4053197934e4a87c80733a1280d62f8010992e43ee3b2406

The entire public key packet is thus:

```
98 33 04 53 f3 5f 0b 16  09 2b 06 01 04 01 da 47
0f 01 01 07 40 3f 09 89  94 bd d9 16 ed 40 53 19
79 34 e4 a8 7c 80 73 3a  12 80 d6 2f 80 10 99 2e
43 ee 3b 24 06
```

A.2. Sample EdDSA signature

The signature is created using the sample key over the input data "LibrePGP" on 2015-09-16 12:24:53 and thus the input to the hash function is:

m: 4f70656e50475004001608000605025 5f95f9504ff0000000c

Using the SHA2-256 hash algorithm yields the digest:

d: f6220a3f757814f4c2176ffbb68b00249cd4ccdc059c4b34ad871f30b1740280

Which is fed into the EdDSA signature function and yields this signature:

r: 56f90cca98e2102637bd983fdb16c131dfd27ed82bf4dde5606e0d756aed3366

s: d09c4fa11527f038e0f57f2201d82f2ea2c9033265fa6ceb489e854bae61b404

The entire signature packet is thus:

```
88 5e 04 00 16 08 00 06  05 02 55 f9 5f 95 00 0a
09 10 8c fd e1 21 97 96  5a 9a f6 22 01 00 56 f9
0c ca 98 e2 10 26 37 bd  98 3f db 16 c1 31 df d2
7e d8 2b f4 dd e5 60 6e  0d 75 6a ed 33 66 01 00
d0 9c 4f a1 15 27 f0 38  e0 f5 7f 22 01 d8 2f 2e
a2 c9 03 32 65 fa 6c eb  48 9e 85 4b ae 61 b4 04
```

A.3. Sample OCB encryption and decryption

Encryption is performed with the string ’Hello, world!’,LF and password ’password’, using AES-128 with OCB encryption.

A.3.1. Sample Parameters

S2K:

type 3

Iterations:

524288 (144), SHA2-256

Salt:

9f0b7da3e5ea6477

A.3.2. Sample symmetric-key encrypted session key packet (v5)

Packet header:

c3 3d

Version, algorithms, S2K fields:

05 07 02 03 08 9f 0b 7d a3 e5 ea 64 77 90

OCB IV:

99 e3 26 e5 40 0a 90 93 6c ef b4 e8 eb a0 8c

OCB encrypted CEK:

67 73 71 6d 1f 27 14 54 0a 38 fc ac 52 99 49 da

Authentication tag:

c5 29 d3 de 31 e1 5b 4a eb 72 9e 33 00 33 db ed

A.3.3. Starting OCB decryption of CEK

The derived key is:

eb 9d a7 8a 9d 5d f8 0e c7 02 05 96 39 9b 65 08

Authenticated Data:

c3 05 07 02

Nonce:

99 e3 26 e5 40 0a 90 93 6c ef b4 e8 eb a0 8c

Decrypted CEK:

d1 f0 1b a3 0e 13 0a a7 d2 58 2c 16 e0 50 ae 44

A.3.4. Sample OCB Encrypted Data packet

Packet header:

```
  d4 49
```

Version, AES-128, OCB, Chunk bits (14):

```
  01 07 02 0e
```

IV:

```
  5e d2 bc 1e 47 0a be 8f 1d 64 4c 7a 6c 8a 56
```

OCB Encrypted data chunk #0:

```
  7b 0f 77 01 19 66 11 a1  54 ba 9c 25 74 cd 05 62
  84 a8 ef 68 03 5c
```

Chunk #0 authentication tag:

```
  62 3d 93 cc 70 8a 43 21 1b b6 ea f2 b2 7f 7c 18
```

Final (zero-size chunk #1) authentication tag:

```
  d5 71 bc d8 3b 20 ad d3 a0 8b 73 af 15 b9 a0 98
```

A.3.5. Decryption of data

Starting OCB decryption of data, using the CEK.

Chunk #0:

Authenticated data:

```
  d4 01 07 02 0e 00 00 00 00 00 00 00 00
```

Nonce:

```
  5e d2 bc 1e 47 0a be 8f 1d 64 4c 7a 6c 8a 56
```

Decrypted chunk #0.

Literal data packet with the string contents ’Hello, world!\n’.

```
  cb 14 62 00 00 00 00 00  48 65 6c 6c 6f 2c 20 77
  6f 72 6c 64 21 0a
```

Authenticating final tag:

Authenticated data:

```
d4 01 07 02 0e 00 00 00 00 00 00 00 01 00 00 00
00 00 00 00 16
```

Nonce:

```
5e d2 bc 1e 47 0a be 8f 1d 64 4c 7a 6c 8a 57
```

A.3.6. Complete OCB encrypted packet sequence

Symmetric-key encrypted session key packet (v5):

```
c3 3d 05 07 02 03 08 9f  0b 7d a3 e5 ea 64 77 90
99 e3 26 e5 40 0a 90 93  6c ef b4 e8 eb a0 8c 67
73 71 6d 1f 27 14 54 0a  38 fc ac 52 99 49 da c5
29 d3 de 31 e1 5b 4a eb  72 9e 33 00 33 db ed
```

OCB Encrypted Data packet:

```
d4 49 01 07 02 0e 5e d2  bc 1e 47 0a be 8f 1d 64
4c 7a 6c 8a 56 7b 0f 77  01 19 66 11 a1 54 ba 9c
25 74 cd 05 62 84 a8 ef  68 03 5c 62 3d 93 cc 70
8a 43 21 1b b6 ea f2 b2  7f 7c 18 d5 71 bc d8 3b
20 ad d3 a0 8b 73 af 15  b9 a0 98
```

Appendix B. ECC Point compression flag bytes

This specification introduces the new flag byte 0x40 to indicate the point compression format. The value has been chosen so that the high bit is not cleared and thus to avoid accidental sign extension. Two other values might also be interesting for other ECC specifications:

Flag	Description
0x04	Standard flag for uncompressed format
0x40	Native point format of the curve follows
0x41	Only X coordinate follows.
0x42	Only Y coordinate follows.

Appendix C. Changes since RFC-4880

* Applied errata 2270, 2271, 2242, 3298.

* Added Camellia cipher from RFC 5581.

* Incorporated RFC 6637 (ECC for OpenPGP)

* Added draft-atkins-openpgp-device-certificates

* Added draft-koch-eddsa-for-openpgp-04
* Added Issuer Fingerprint signature subpacket.
* Added a v5 key and fingerprint format.
* Added OIDs for brainpool curves and Curve25519.
* Marked SHA2-256 as MUST implement.
* Marked Curve25519 and Ed25519 as SHOULD implement.
* Marked SHA-1 as SHOULD NOT be used to create messages.
* Marked MD5 as SHOULD NOT implement.
* Changed v5 key fingerprint format to full 32 octets.
* Added Literal Data Packet format octet m.
* Added Feature Flag for v5 key support.
* Added OCB Encrypted Data Packet.
* Removed notes on extending the MDC packet.
* Added v5 Symmetric-Key Encrypted Session Key packet.
* Added OCB encryption of secret keys.
* Added test vectors for OCB.
* Added the Restricted Encryption key flag.
* Deprecated the Symmetrically Encrypted Data Packet.
* Suggest limitation of the OCB chunksize to 128 MiB.
* Specified the V5 signature format.
* Deprectated the creation of V3 signatures.
* Adapted terms from RFC 8126.
* Removed editorial marks and updated cross-references.
* Added the timestamping usage key flag.

* Added Intended Recipient signature subpacket.

* Added Attested Certifications signature subpacket and signature class.

* Added Key Block signature subpacket.

* Added Literal Data Meta Hash subpacket.

Changes since draft-koch-openpgp-2015-rfc4880bis-01:

* Changed Secret-Key Packet Format for OCB mode to include the entire public key has additional data.

* Added Trust Alias subpacket.

* Added alternative OIDs for Ed25519 and Curve25519.

Changes since draft-koch-openpgp-2015-rfc4880bis-02:

* Added ML-KEM parts from draft-wussler-openpgp-pqc-03.txt

* Changed name of the specification to LibrePGP.

Changes since draft-koch-librepgp-00:

* Introduced the SOS data type as compatible specification for MPIs.

* Rework the ML-KEM key and PKESK algorithm specific parts to be aligned with other algorithms

* Descriped the ML-KEM encryption process. Compatible to draft-wussler-openpgp-pqc-03.txt but with a changed fixed-info.

Changes since draft-koch-librepgp-01:

* Switched to the final algorithm ID for Kyber.

* Drop the remains of support for V6 signatures. (see commit b1193e2216)

* Add a note on user and attribute ID requirements.

Changes since draft-koch-librepgp-02:

* Drop the optional extended V4 fingerprint for a revocation key.

* Deprecate the experimental Attested Certifications subpacket.

Appendix D. Acknowledgments

There have been a number of authors involved with the development of the OpenPGP specification as described by RFC-4880, RFC-5581, and RFC-6637:

Jon Callas
EMail: jon@callas.org

Lutz Donnerhacke
EMail: lutz@iks-jena.de

Hal Finney

David Shaw
EMail: dshaw@jabberwocky.com

Rodney Thayer
EMail: rodney@canola-jones.com

Andrey Jivsov
EMail: Andrey_Jivsov@symantec.com

The work to update RFC-4880 was mainly conducted by the authors of this document and the following authors:

brian m. carlson
Email: sandals@crustytoothpaste.net

Derek Atkins
Email: derek@ihtfp.com

Daniel Kahn Gillmor
Email: dkg@fifthhorseman.net

The PQC algorithm extension was conducted by the following authors:

Stavros Kousidis
Email: stavros.kousidis@bsi.bund.de

Falko Strenzke
Email: falko.strenzke@mtg.de

Aron Wussler
Email: aron@wussler.it

Authors' Addresses

Werner Koch
g10 Code GmbH
Germany
Email: wk@gnupg.org

Ronald Henry Tse
Ribose
Hong Kong
Email: ronald.tse@ribose.com