Federal Office
for Information Security

Technical Guideline TR-02102-2 Cryptographic Mechanisms: Recommendations and Key Lengths

Part 2 – Use of Transport Layer Security (TLS)

Document history

Table 1: Document history

Version	***Date***	***Description***
2019-01	2019-02-22	Adjustment of the periods of use, recommendation of TLS 1.3, recommendation of PSK cipher suites of RFC 8442, recommendation of CCM mode
2020-01	2020-02-28	Adjustment of the periods of use, discontinuation of HMAC-SHA-1
2021-01	2021-03-12	Adjustment of the periods of use
2022-01	2022-01-24	Adjustment of the periods of use, recommendation of elliptic curve secp521r1
2023-01	2023-01-17	Increase of the security level to 120 bits, adjustment of the periods of use
2024-01	2024-02-29	Adjustment of the periods of use, discontinuation of DSA and of DHE cipher suite recommendations from 2029

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1 Introduction

This Technical Guideline contains recommendations for the use of the cryptographic protocol *Transport Layer Security (TLS)*. It is used for the secure transmission of information in data networks, where in particular the *confidentiality*, *integrity* and *authenticity* of the transmitted information are important.

The Technical Guideline at hand contains recommendations for the protocol version to be used as well as the cryptographic algorithms and key lengths as a concretisation of the general recommendations in Part 1 of this Technical Guideline [TR-02102-1]. As mentioned in Part 1 of [TR-02102-1], mechanisms which are not listed are not necessarily considered by the BSI to be insecure.

This Technical Guideline does not contain recommendations for concrete applications, risk assessments or attack vectors that result from errors in the implementation of the protocol.

Note: Even if all recommendations for the use of TLS are being considered, data can leak from a cryptographic system to a considerable amount, e.g. by exploiting side channels (measurement of timing behaviour, power consumption, data rates etc.). Therefore, the developer of a cryptographic system should identify possible side channels by involving experts in this field and implement appropriate countermeasures. Depending on the application, this also applies to fault attacks.

Note: For the definitions of the cryptographic terms used in this document, please see the glossary in [TR-02102-1].

2 Basic information

Transport Layer Security (TLS), formerly known as Secure Socket Layer (SSL), allows the secure transmission of information from the application layer (e.g. HTTPS, FTPS or IMAPS) via TCP/IP-based connections (the Internet in particular).

Before data can be transmitted, a secure connection between the two connection partners (client and server) must be established. This process is called *handshake* and is an important part of the TLS protocol. Client and the server agree upon:

1. Cryptographic algorithms for *data encryption*, *protection of the integrity*, *key agreement* and, if necessary, (one-sided or two-sided) *authentication*. These algorithms are defined by the cipher suite and further cryptographic parameters (see Sections 3.3and 3.3.4).
2. A shared secret, the *master secret*, from which the session keys for the protection of the integrity and for encryption will be derived.

Note: The TLS protocol also allows for connections that are not authenticated or authenticated only on one side (example: HTTPS connections are usually authenticated only on the server side). For this reason, system developers of cryptographic systems should take into consideration whether further authentication in the application layer is required (example: authentication of a home banking user by requiring a password). For particularly critical operations, authentication by means of knowledge and ownership (two-factor authentication) should be carried out in general. Such authentication should also cover the transmitted data by using cryptographic mechanisms.

3 Recommendations

3.1 General remarks

3.1.1 Periods of use

The recommendations in this Technical Guideline have a maximum period of use. The indication of the year means that the respective mechanism can be used until the end of the year stated. If the year is marked with a “+” sign, it is possible to extend the period of use.

3.1.2 Security level

The security level for all cryptographic mechanisms in this Technical Guideline depends on the security level stated in Section 1.1 in [TR-02102-1] and is 120 bits.

3.2 SSL/TLS versions

The SSL protocol is available in the versions 1.0, 2.0 and 3.0, whereby version 1.0 was not published. TLS 1.0 is a direct further development of SSL 3.0 and is specified in [RFC 2246]. Furthermore, the TLS protocol is available in the versions 1.1, 1.2, and 1.3 which are specified in [RFC 4346], [RFC 5246], and [RFC 8446].

Recommendations for the choice of the TLS version:

- In general, TLS 1.2 or TLS 1.3 should be used.
- TLS 1.0 and TLS 1.1 are **not recommended** (see also [RFC 8996]).
- SSL v2 ([SSLv2]) and SSL v3 ([SSLv3]) are **not recommended** (see also [RFC 6176] and [RFC 7568]).

3.3 Recommendations for TLS 1.2

In TLS 1.2, cryptographic mechanisms of a connection are defined by a cipher suite. A cipher suite specifies a key agreement mechanism (with authentication) for the handshake protocol, an authenticated encryption algorithm for the record protocol, and a hash function for key derivation. Depending on the cipher suite, a Diffie-Hellman group (in a finite field or over an elliptic curve) and a signature algorithm for key agreement must be specified as well.

A complete list of all defined cipher suites with references to the respective specifications is available at [IANA].

3.3.1 Cipher suites

For cipher suites in TLS 1.2, the naming convention `TLS_`*`AKE`*`_WITH_`*`Enc`*`_`*`Hash`* is usually used, where *`AKE`* denotes a key agreement mechanism (with authentication), *`Enc`* denotes an encryption algorithm with mode of operation, and *`Hash`* denotes a hash function. The function *`Hash`* is used for an HMAC (*Keyed-Hash Message Authentication Code*) which is employed by the PRF (*Pseudo-Random Function*) used for key derivation.[1] If *`Enc`* is not an AEAD algorithm (*Authenticated Encryption with Associated Data*), then HMAC is also utilized for integrity protection in the record protocol.

In general, it is recommended to only use cipher suites which meet the requirements for algorithms and key lengths as given in [TR-02102-1].

[1] For cipher suites using the CCM mode of operation, no hash function is indicated. These cipher suites use SHA-256 for the PRF.

3.3.1.1 (EC)DHE cipher suites

The use of the following cipher suites with Perfect Forward Secrecy[2] is recommended:

Table 2: Recommended cipher suites for TLS 1.2 with Perfect Forward Secrecy

Cipher suite	*IANA no.*	*Specification*	*Use up to*
TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA256	0xC0,0x23	[RFC 5289]	2030+
TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA384	0xC0,0x24	[RFC 5289]	2030+
TLS_ECDHE_ECDSA_WITH_AES_128_GCM_SHA256	0xC0,0x2B	[RFC 5289]	2030+
TLS_ECDHE_ECDSA_WITH_AES_256_GCM_SHA384	0xC0,0x2C	[RFC 5289]	2030+
TLS_ECDHE_ECDSA_WITH_AES_128_CCM	0xC0,0xAC	[RFC 7251]	2030+
TLS_ECDHE_ECDSA_WITH_AES_256_CCM	0xC0,0xAD	[RFC 7251]	2030+
TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA256	0xC0,0x27	[RFC 5289]	2030+
TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA384	0xC0,0x28	[RFC 5289]	2030+
TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256	0xC0,0x2F	[RFC 5289]	2030+
TLS_ECDHE_RSA_WITH_AES_256_GCM_SHA384	0xC0,0x30	[RFC 5289]	2030+
TLS_DHE_DSS_WITH_AES_128_CBC_SHA256	0x00,0x40	[RFC 5246]	2029
TLS_DHE_DSS_WITH_AES_256_CBC_SHA256	0x00,0x6A	[RFC 5246]	2029
TLS_DHE_DSS_WITH_AES_128_GCM_SHA256	0x00,0xA2	[RFC 5288]	2029
TLS_DHE_DSS_WITH_AES_256_GCM_SHA384	0x00,0xA3	[RFC 5288]	2029
TLS_DHE_RSA_WITH_AES_128_CBC_SHA256	0x00,0x67	[RFC 5246]	2029
TLS_DHE_RSA_WITH_AES_256_CBC_SHA256	0x00,0x6B	[RFC 5246]	2029
TLS_DHE_RSA_WITH_AES_128_GCM_SHA256	0x00,0x9E	[RFC 5288]	2029
TLS_DHE_RSA_WITH_AES_256_GCM_SHA384	0x00,0x9F	[RFC 5288]	2029
TLS_DHE_RSA_WITH_AES_128_CCM	0xC0,0x9E	[RFC 6655]	2029
TLS_DHE_RSA_WITH_AES_256_CCM	0xC0,0x9F	[RFC 6655]	2029

Note: The use of cipher suites with CBC mode is only recommended in conjunction with the TLS extension "Encrypt-then-MAC", as soon as suitable implementations are available (see Sections 3.3.4.4 and 3.3.4.5).

3.3.1.2 (EC)DH cipher suites

If the use of the cipher suites with Perfect Forward Secrecy recommended in Section 3.3.1.1 is not possible, the following cipher suites can also be used:

Table 3: Recommended cipher suites for TLS 1.2 without Perfect Forward Secrecy

Cipher suite	*IANA no.*	*Specification*	*Use up to*
TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA256	0xC0,0x25	[RFC 5289]	2026
TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA384	0xC0,0x26	[RFC 5289]	2026
TLS_ECDH_ECDSA_WITH_AES_128_GCM_SHA256	0xC0,0x2D	[RFC 5289]	2026
TLS_ECDH_ECDSA_WITH_AES_256_GCM_SHA384	0xC0,0x2E	[RFC 5289]	2026
TLS_ECDH_RSA_WITH_AES_128_CBC_SHA256	0xC0,0x29	[RFC 5289]	2026
TLS_ECDH_RSA_WITH_AES_256_CBC_SHA384	0xC0,0x2A	[RFC 5289]	2026
TLS_ECDH_RSA_WITH_AES_128_GCM_SHA256	0xC0,0x31	[RFC 5289]	2026

[2] Perfect Forward Secrecy (abbreviated PFS, also Forward Secrecy) means that a connection cannot be decrypted subsequently even if the long-term keys of the communication partners are known. When using TLS in order to protect personal or other sensitive data, Perfect Forward Secrecy is generally recommended.

Cipher suite	*IANA no.*	*Specification*	*Use up to*
TLS_ECDH_RSA_WITH_AES_256_GCM_SHA384	0xC0,0x32	[RFC 5289]	2026
TLS_DH_DSS_WITH_AES_128_CBC_SHA256	0x00,0x3E	[RFC 5246]	2026
TLS_DH_DSS_WITH_AES_256_CBC_SHA256	0x00,0x68	[RFC 5246]	2026
TLS_DH_DSS_WITH_AES_128_GCM_SHA256	0x00,0xA4	[RFC 5288]	2026
TLS_DH_DSS_WITH_AES_256_GCM_SHA384	0x00,0xA5	[RFC 5288]	2026
TLS_DH_RSA_WITH_AES_128_CBC_SHA256	0x00,0x3F	[RFC 5246]	2026
TLS_DH_RSA_WITH_AES_256_CBC_SHA256	0x00,0x69	[RFC 5246]	2026
TLS_DH_RSA_WITH_AES_128_GCM_SHA256	0x00,0xA0	[RFC 5288]	2026
TLS_DH_RSA_WITH_AES_256_GCM_SHA384	0x00,0xA1	[RFC 5288]	2026

Note: The use of cipher suites with CBC mode is only recommended in conjunction with the TLS extension "Encrypt-then-MAC", as soon as suitable implementations are available (see Sections 3.3.4.4 and 3.3.4.5).

Note: Cipher suites of the form TLS_DHE_* are set to be deprecated by the IETF (see https://datatracker.ietf.org/doc/draft-ietf-tls-deprecate-obsolete-kex/). These cipher suites are therefore only recommended in this Technical Guideline until 2029.

3.3.1.3 Key agreement with pre-shared data

If additional data that have been exchanged in advance are to be incorporated into the key agreement, cipher suites with a pre-shared key (abbreviated PSK) can be used. Generally, it is recommended to use cipher suites for which further ephemeral keys or previously exchanged random numbers are incorporated into the key agreement in addition to the pre-shared key.

Using cipher suites of type TLS_PSK_*, i.e. without additional ephemeral keys or random numbers, is **not recommended**, because the security of the connection is based solely on the entropy and confidentiality of the pre-shared keys for these cipher suites.

The use of the following cipher suites with PSK is recommended:

Table 4: Recommended cipher suites for TLS 1.2 with pre-shared key

Cipher suite	*IANA no.*	*Specification*	*Use up to*
TLS_ECDHE_PSK_WITH_AES_128_CBC_SHA256	0xC0,0x37	[RFC 5489]	2030+
TLS_ECDHE_PSK_WITH_AES_256_CBC_SHA384	0xC0,0x38	[RFC 5489]	2030+
TLS_ECDHE_PSK_WITH_AES_128_GCM_SHA256	0xD0,0x01	[RFC 8442]	2030+
TLS_ECDHE_PSK_WITH_AES_256_GCM_SHA384	0xD0,0x02	[RFC 8442]	2030+
TLS_ECDHE_PSK_WITH_AES_128_CCM_SHA256	0xD0,0x05	[RFC 8442]	2030+
TLS_DHE_PSK_WITH_AES_128_CBC_SHA256	0x00,0xB2	[RFC 5487]	2029
TLS_DHE_PSK_WITH_AES_256_CBC_SHA384	0x00,0xB3	[RFC 5487]	2029
TLS_DHE_PSK_WITH_AES_128_GCM_SHA256	0x00,0xAA	[RFC 5487]	2029
TLS_DHE_PSK_WITH_AES_256_GCM_SHA384	0x00,0xAB	[RFC 5487]	2029
TLS_DHE_PSK_WITH_AES_128_CCM	0xC0,0xA6	[RFC 6655]	2029
TLS_DHE_PSK_WITH_AES_256_CCM	0xC0,0xA7	[RFC 6655]	2029
TLS_RSA_PSK_WITH_AES_128_CBC_SHA256	0x00,0xB6	[RFC 5487]	2026
TLS_RSA_PSK_WITH_AES_256_CBC_SHA384	0x00,0xB7	[RFC 5487]	2026
TLS_RSA_PSK_WITH_AES_128_GCM_SHA256	0x00,0xAC	[RFC 5487]	2026
TLS_RSA_PSK_WITH_AES_256_GCM_SHA384	0x00,0xAD	[RFC 5487]	2026

Note: The use of cipher suites with CBC mode is only recommended in conjunction with the TLS extension "Encrypt-then-MAC", as soon as suitable implementations are available (see Sections 3.3.4.4 and 3.3.4.5).

Note: Cipher suites of the form `TLS_DHE_*` are set to be deprecated by the IETF (see https://datatracker.ietf.org/doc/draft-ietf-tls-deprecate-obsolete-kex/). These cipher suites are therefore only recommended in this Technical Guideline until 2029.

Note: The cipher suites `TLS_RSA_PSK_*` in Table 4 do not provide Perfect Forward Secrecy, whereas all other cipher suites from Table 4 do provide Perfect Forward Secrecy.

3.3.2 Diffie-Hellman groups

For cipher suites of type `TLS_DHE_*` or `TLS_ECDHE_*`, the client can use the extension "supported_groups" (formerly also called "elliptic_curves") to inform the server about the Diffie-Hellman groups he wants to use (see [RFC 7919] for DHE and [RFC 8422] for ECDHE).

The use of the extension "supported_groups" for `TLS_ECDHE_*` cipher suites is recommended.

The use of the extension "supported_groups" for `TLS_DHE_*` cipher suites is recommended as soon as suitable implementations are available.

The use of the following Diffie-Hellman groups is recommended:

Table 5: Recommended Diffie-Hellman groups for TLS 1.2

Diffie-Hellman group	*IANA no.*	*Specification*	*Use up to*
`secp256r1`	23	[RFC 8422]	2030+
`secp384r1`	24	[RFC 8422]	2030+
`secp521r1`	25	[RFC 8422]	2030+
`brainpoolP256r1`	26	[RFC 7027]	2030+
`brainpoolP384r1`	27	[RFC 7027]	2030+
`brainpoolP512r1`	28	[RFC 7027]	2030+
`ffdhe3072`	257	[RFC 7919]	2029
`ffdhe4096`	258	[RFC 7919]	2029

In general, Section 3.6 has to be taken into consideration for the choice of domain parameters and key lengths.

3.3.3 Signature algorithms

In TLS 1.2, the client can use the extension "signature_algorithms" (see [RFC 5246]) to inform the server about the signature algorithms he wants to use for key agreement and certificates. In case of mutual authentication, the server informs the client about the signature algorithms it accepts with the CertificateRequest message. In both cases, the algorithms have to be specified as combination of signature algorithm and hash function.

The use of the extension "signature_algorithms" is recommended.

The use of the following signature algorithms is recommended:

Table 6: Recommended signature algorithms for TLS 1.2

Signature algorithm	*IANA no.*	*Specification*	*Use up to*
`rsa`	1	[RFC 5246]	2025
`dsa`	2	[RFC 5246]	2029
`ecdsa`	3	[RFC 5246]	2030+

For domain parameters and key lengths Section 3.6 has to be taken into consideration.

Note: The use of the signature algorithm `rsa` (IANA no. 1) is recommended only up to 2025, because it uses the PKCS #1 v1.5 padding scheme (see also Section 1.5 in [TR-02102-1]). For the use of RSA signatures with

PSS padding in TLS 1.2 according to Sections 1.3 and 4.2.3 of [RFC 8446], the recommendations of Table 10 and Table 11 apply.

Note: The use of the signature algorithm `dsa` (IANA no. 2) is recommended only up to 2029, because it is not widely employed and no longer approved in [FIPS 186-5] (see also Remark 5.7 in [TR-02102-1]).

The use of the following hash functions (combined with a signature algorithm in Table 6) is recommended:

Table 7: Recommended hash functions for signature algorithms in TLS 1.2

Hash function	*IANA no.*	*Specification*	*Use up to*
`sha256`	4	[RFC 5246]	2030+
`sha384`	5	[RFC 5246]	2030+
`sha512`	6	[RFC 5246]	2030+

3.3.4 Further recommendations

3.3.4.1 Session renegotiation

It is recommended to use *session renegotiation* only on the basis of [RFC 5746]. Renegotiation initiated by the client should by rejected by the server.

3.3.4.2 Truncated HMAC output

The extension “truncated_hmac” defined in [RFC 6066] to truncate the HMAC output to 80 bits should *not* be used.

3.3.4.3 TLS compression and the CRIME attack

TLS offers the option of compressing the transmitted data prior to encryption. This results in a possible side-channel attack on the encryption by exploiting the length of the encrypted data (see [CRIME]).

In order to prevent this, it must be ensured that all data of a data packet come from correct and legitimate connection partners and that the attacker cannot perform a plaintext injection. If this cannot be ensured, it is recommended not to use TLS data compression.

3.3.4.4 The Lucky 13 attack

Lucky 13 is a side-channel attack (timing) against CBC-mode cipher suites, in which the attacker exploits very small time differences when processing the padding on the server. For this attack, it is necessary that the attacker can measure the time in the network very accurately. The attacker sends manipulated cipher texts to the server and measures the time which the server takes to check the padding or to report an error. The network jitter, however, can very easily lead to measurement errors when measuring the time so that an attack generally appears to be difficult, since the attacker in the network has to be “very close” to the server in order to be able to measure sufficiently accurately.

The attack can also be fended off if

- authenticated encryption, such as AES-GCM or AES-CCM, or
- encrypt-then-MAC (see also following Section)

is used.

3.3.4.5 The Encrypt-then-MAC extension

According to the TLS specification (see [RFC 5246]), the transmitted data are protected with a Message Authentication Code (MAC) first and then provided with a padding; afterwards, the data and the padding are

encrypted. In the past, this order (“MAC-then-encrypt”) has been a common reason for attacks on the encryption, since the padding is not protected by the MAC.

In the case of so-called padding oracle attacks, the encrypted TLS packets are manipulated by a man-in-the-middle attacker in order to exploit the verification of the padding as a side channel. For example, this may lead to an attacker being able to decrypt an HTTPS session cookie and thus take over the session of the victim.

[RFC 7366] specifies the TLS extension “encrypt-then-MAC”. Here, the data to be transmitted are provided with a padding first, then encrypted and protected with an MAC afterwards. Thus, manipulations of the padding are impossible, since it is also protected by the MAC.

The use of the TLS extension “encrypt-then-MAC” according to [RFC 7366] is recommended as soon as suitable implementations are available.

3.3.4.6 The Heartbeat extension

The Heartbeat extension is specified in [RFC 6520]. It allows to maintain a TLS connection over a longer period of time without having to perform a renegotiation of the connection. Due to the so-called Heartbleed bug, the attacker is able to access certain memory areas of the server which might contain secret key material. This may result in a complete compromise of the server if the private key of the server becomes known.

It is recommended not to use the Heartbeat extension.

3.3.4.7 The Extended Master Secret extension

In order to fend off attacks such as the triple handshake attack (see [BDF14]), it is very useful to incorporate further connection parameters into the TLS handshake to ensure that different TLS connections also use different master secrets (from which the symmetric keys are derived).

[RFC 7627] specifies the TLS extension *Extended Master Secret* which incorporates a hash value over all messages of the TLS handshake when calculating the "extended" master secret.

Using the TLS extension *Extended Master Secret* according to [RFC 7627] is recommended as soon as suitable implementations are available.

3.4 Recommendations for TLS 1.3

In TLS 1.3, the cryptographic mechanisms of a connection are defined by a handshake mode, a Diffie-Hellman group (if (EC)DHE is used), a signature algorithm (if certificate-based authentication is used), and a cipher suite. In contrast to earlier versions of TLS, a cipher suite specifies only an authenticated encryption algorithm for the record protocol and a hash function for key derivation.

3.4.1 Handshake modes

Besides Diffie-Hellman key agreement over finite fields (DHE) or elliptic curves (ECDHE), TLS 1.3 offers additional handshake modes using pre-shared keys (PSK). In this context, pre-shared keys either refer to keys which are provisioned out-of-band or to key material that has been established in a previous session via the session ticket mechanism.

The use of the following PSK modes is recommended:

Table 8: Recommended pre-shared key modes for TLS 1.3

PSK mode	*IANA no.*	*Specification*	*Use up to*
`psk_ke`	0	[RFC 8446]	2026
`psk_dhe_ke`	1	[RFC 8446]	2030+

Note: The PSK mode `psk_ke` does not offer Perfect Forward Secrecy. This mode should only be used in special applications after consultation of an expert.

Note: TLS 1.3 offers an option to include application data already in the first message of a PSK handshake (*zero round-trip time* data, abbreviated 0-RTT data). This data is not protected against replay attacks. Therefore, sending or accepting 0-RTT data is **not recommended**.

3.4.2 Diffie-Hellman groups

In TLS 1.3, client and server can use the extension "supported_groups" to inform each other about the Diffie-Hellman groups they want to use for (EC)DHE.

The use of the following Diffie-Hellman groups is recommended:

Table 9: Recommended Diffie-Hellman groups for TLS 1.3

Diffie-Hellman group	*IANA no.*	*Specification*	*Use up to*
`secp256r1`	23	[RFC 8422]	2030+
`secp384r1`	24	[RFC 8422]	2030+
`secp521r1`	25	[RFC 8422]	2030+
`brainpoolP256r1tls13`	31	[RFC 8734]	2030+
`brainpoolP384r1tls13`	32	[RFC 8734]	2030+
`brainpoolP512r1tls13`	33	[RFC 8734]	2030+
`ffdhe3072`	257	[RFC 7919]	2030+
`ffdhe4096`	258	[RFC 7919]	2030+

Note: In general, the Brainpool curves are recommended.

Note: In [RFC 8446], the IANA numbers of some EC groups, that are either obsolete or have had little usage according to [RFC 8446], have been marked as "obsolete_RESERVED". Among those are the IANA numbers 26, 27, 28, which are allocated for the Brainpool curves for usage in TLS 1.2 and earlier TLS versions. For using the Brainpool curves in TLS 1.3, the IANA numbers 31, 32, 33 have been allocated (see [RFC 8734]).

3.4.3 Signature algorithms

In TLS 1.3, client and server can use the extensions "signature_algorithms" and "signature_algorithms_cert" to inform each other about the signature algorithms they want to use for certificate-based authentication. The extension "signature_algorithms" refers to signatures which are generated by client or server for their CertificateVerify message and the extension "signature_algorithms_cert" refers to signatures in certificates.

The use of the following signature algorithms for the extension "signature_algorithms" is recommended:

Table 10: Recommended signature algorithms for TLS 1.3 (client/server signatures)

Signature algorithm	*IANA no.*	*Specification*	*Use up to*
`rsa_pss_rsae_sha256`	0x0804	[RFC 8446]	2030+
`rsa_pss_rsae_sha384`	0x0805	[RFC 8446]	2030+
`rsa_pss_rsae_sha512`	0x0806	[RFC 8446]	2030+
`rsa_pss_pss_sha256`	0x0809	[RFC 8446]	2030+
`rsa_pss_pss_sha384`	0x080A	[RFC 8446]	2030+
`rsa_pss_pss_sha512`	0x080B	[RFC 8446]	2030+
`ecdsa_secp256r1_sha256`	0x0403	[RFC 8446]	2030+
`ecdsa_secp384r1_sha384`	0x0503	[RFC 8446]	2030+
`ecdsa_secp521r1_sha512`	0x0603	[RFC 8446]	2030+
`ecdsa_brainpoolP256r1tls13_sha256`	0x081A	[RFC 8734]	2030+

Signature algorithm	*IANA no.*	*Specification*	*Use up to*
ecdsa_brainpoolP384r1tls13_sha384	0x081B	[RFC 8734]	2030+
ecdsa_brainpoolP512r1tls13_sha512	0x081C	[RFC 8734]	2030+

The use of the following signature algorithms for the extension “signature_algorithms_cert” is recommended:

Table 11: Recommended signature algorithms for TLS 1.3 (signatures in certificates)

Signature algorithm	*IANA no.*	*Specification*	*Use up to*
rsa_pkcs1_sha256	0x0401	[RFC 8446]	2025
rsa_pkcs1_sha384	0x0501	[RFC 8446]	2025
rsa_pkcs1_sha512	0x0601	[RFC 8446]	2025
rsa_pss_rsae_sha256	0x0804	[RFC 8446]	2030+
rsa_pss_rsae_sha384	0x0805	[RFC 8446]	2030+
rsa_pss_rsae_sha512	0x0806	[RFC 8446]	2030+
rsa_pss_pss_sha256	0x0809	[RFC 8446]	2030+
rsa_pss_pss_sha384	0x080A	[RFC 8446]	2030+
rsa_pss_pss_sha512	0x080B	[RFC 8446]	2030+
ecdsa_secp256r1_sha256	0x0403	[RFC 8446]	2030+
ecdsa_secp384r1_sha384	0x0503	[RFC 8446]	2030+
ecdsa_secp521r1_sha512	0x0603	[RFC 8446]	2030+
ecdsa_brainpoolP256r1tls13_sha256	0x081A	[RFC 8734]	2030+
ecdsa_brainpoolP384r1tls13_sha384	0x081B	[RFC 8734]	2030+
ecdsa_brainpoolP512r1tls13_sha512	0x081C	[RFC 8734]	2030+

For key lengths of RSA-signatures, Section 3.6 has to be taken into consideration.

Note: The use of the signature algorithms `rsa_pkcs1_*` (IANA no. 0x0401, 0x0501, and 0x0601) is recommended only up to 2025, because they use the PKCS #1 v1.5 padding scheme (see also Section 1.5 in [TR-02102-1]).

3.4.4 Cipher suites

For cipher suites in TLS 1.3, the naming convention `TLS_`*`AEAD`*`_`*`Hash`* is used, where *`AEAD`* denotes an authenticated encryption algorithm (*authenticated encryption with associated data*, abbreviated AEAD) for the record protocol and *`Hash`* denotes a hash function for usage with HMAC (*Keyed-Hash Message Authentication Code*) and HKDF (*HMAC-based Extract-and-Expand Key Derivation Function*) in the handshake protocol.

The use of the following cipher suites is recommended:

Table 12: Recommended cipher suites for TLS 1.3

Cipher suite	*IANA no.*	*Specification*	*Use up to*
TLS_AES_128_GCM_SHA256	0x13,0x01	[RFC 8446]	2030+
TLS_AES_256_GCM_SHA384	0x13,0x02	[RFC 8446]	2030+
TLS_AES_128_CCM_SHA256	0x13,0x04	[RFC 8446]	2030+

3.4.5 Further recommendations

3.4.5.1 The Heartbeat extension

It is recommended not to use the Heartbeat extension specified in [RFC 6520] (see Section 3.3.4.6).

3.5 Authentication of the communication partners

The TLS protocol offers the following three ways of authenticating the communication partners:

- Authentication of both communication partners
- Authentication on the server side only
- No authentication

The necessity of authentication depends on the application. When using TLS on the web, at least an authentication of the server is generally necessary. When using TLS in closed systems (VPN or the like), authentication on both sides is usually required.

The Technical Guideline [TR-02103] contains recommendations on X.509 certificates and certification path validation.

For authentication within Federal Government projects, the requirements of Technical Guideline [TR-03116-4] in its currently valid version must be taken into account.

3.6 Domain parameters and key lengths

The domain parameters and key lengths for

- static key pairs of the communication partners,
- ephemeral key pairs when using cipher suites with Forward Secrecy, and
- key pairs for the signature of certificates

must comply with the recommendations in Part 1 of this Technical Guideline (see [TR-02102-1]).

3.6.1 Key lengths

It is recommended to use at least the following key lengths:

Table 13: Recommended minimum key lenghts for the TLS handshake protocol

Algorithm	***Minimum key length***	***Use from (at the latest)***	***Use up to***
Signature keys for certificates and key agreement			
ECDSA	250 Bit		2030+
DSS	3000 Bit	2023	2029
RSA	3000 Bit	2023	2030+
Static and ephemeral Diffie-Hellman keys			
ECDH	250 Bit		2030+
DH	3000 Bit	2023	2030+

Note: If a key pair is *static*, it is reused several times for new connections. In contrast to this, *ephemeral* means that a new key pair is created and used for each new connection. Ephemeral keys must be deleted securely after the connection is terminated, see Section 4.2. If the connection shall provide Perfect Forward Secrecy, then only ephemeral keys must be used.

Note: The recommendations in this Technical Guideline are suitable to reach the security level stated in Section 3.1.2, which is 120 bits.

The prediction period for the recommendations at hand is 7 years. Appropriate recommendations for larger periods, as they can be found in other publicly available documents, are naturally very hard to make because future cryptographic developments cannot be predicted precisely for larger periods. In such cases, these recommendations contain parameters and key lengths that might exceed those given in this Technical Guideline.

3.6.2 Use of elliptic curves

When using elliptic curves, cryptographically strong curves over finite fields of the form F_p (p prime) are always recommended. In addition, it is recommended to only use *named curves* (see Section “Supported Groups Registry” in [IANA]) in order to avoid attacks via unverified weak domain parameters. The following named curves are recommended:

- brainpoolP256r1, brainpoolP384r1, brainpoolP512r1 (see [RFC 5639] and [RFC 7027])

If these curves are not available, the following curves can also be used:

- secp256r1, secp384r1, secp521r1

4 Keys and random numbers

4.1 Key storage

Private cryptographic keys, especially static keys and signature keys, must be stored and processed in a secure manner. This includes, among other things, the protection against copying, misuse and manipulation of the keys. Secure storage of the keys can be achieved, for example by using certified hardware (chip card, HSM).

The public keys of trusted bodies (trust anchors) must also be stored in such a manner that they cannot be manipulated.

4.2 Handling of ephemeral keys

If a cipher suite with Perfect Forward Secrecy is used, it must be ensured that all ephemeral keys are deleted irrevocably after they have been used and that no copies of these keys were made. Ephemeral or session keys may only be used for *one* connection and generally not be stored persistently.

4.3 Random numbers

For the generation of random numbers, for example for cryptographic keys or for creating signatures, appropriate random number generators must be used.

A random number generator from one of the classes DRG.3, DRG.4, PTG.3 or NTG.1 according to [AIS 20/31] is recommended, see also Chapter 8 in Part 1 of this Technical Guideline [TR-02102-1].

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