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Revision 2

Guidelines for the Selection, Configuration, and Use of Transport Layer Security (TLS) Implementations

Kerry McKay
David Cooper

C O M P U T E R   S E C U R I T Y

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Guidelines for the Selection, Configuration, and Use of Transport Layer Security (TLS) Implementations

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November 2017

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Abstract

Transport Layer Security (TLS) provides mechanisms to protect data during electronic dissemination across the Internet. This Special Publication provides guidance to the selection and configuration of TLS protocol implementations while making effective use of Federal Information Processing Standards (FIPS) and NIST-recommended cryptographic algorithms. It requires that TLS 1.2 configured with FIPS-based cipher suites be supported by all government TLS servers and clients and recommends that agencies develop migration plans to support TLS 1.3 by January 1, 2020. This Special Publication also provides guidance on certificates and TLS extensions that impact security.

Keywords

information security; network security; SSL; TLS; Transport Layer Security

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Note to Reviewers

Several developments have occurred since SP 800-52 Revision 1 regarding the use of RSA key transport for key establishment in TLS. Research has shown that prominent TLS implementations are incorrectly handling RSA key transport, leaving the key establishment vulnerable to Bleichenbacher attacks. In addition, SP 800-131A currently disallows the use of RSA key-transport using PKCS #1 v1.5 padding after December 31, 2017 (see https://csrc.nist.gov/News/2017/Transition-Plans-for-Key-Establishment-Schemes). For these reasons, all cipher suites that use RSA key transport to establish the premaster secret have been removed from the recommended cipher suite list.

This may be problematic in architectures that currently rely on static RSA keys to support the decryption of TLS sessions by network monitoring devices. For TLS version 1.2 and below, this use case could be supported by switching to cipher suites that use static Diffie-Hellman (or static Elliptic Curve Diffie-Hellman) keys. However, these cipher suites are not widely supported, and this option is not available in TLS 1.3. Enterprise and datacenter monitoring could theoretically be supported through a TLS 1.3 extension, re-architecting data flows with a man-in-the-middle, or other measures outside the scope of TLS. A document proposing a TLS extension has submitted to the Internet Engineering Task Force (IETF). The National Cybersecurity Center of Excellence (NCCoE) plans to prototype this extension and other solutions that agencies and organizations can use a template.

The Triple Data Encryption Algorithm (TDEA), also known as 3DES, is no longer approved for use with TLS (see Department of Homeland Security Binding Operational Directive BOD-18-01, https://cyber.dhs.gov/assets/report/bod-18-01.pdf). The 64-bit block size does not provide adequate protection in applications such as TLS where large amounts of data are encrypted under the same key.

This draft also requires agencies to develop migration plans to support TLS 1.3 by January 1, 2020.

Executive Summary

Office of Management and Budget (OMB) Circular A-130, *Managing Information as a Strategic Resource*, requires managers of publicly accessible information repositories or dissemination systems that contain sensitive but unclassified data to ensure that sensitive data is protected commensurate with the risk and magnitude of the harm that would result from the loss, misuse, or unauthorized access to or modification of such data. Given the nature of interconnected networks and the use of the Internet to share information, the protection of this sensitive data can become difficult if proper mechanisms are not employed to protect the data. Transport Layer Security (TLS) provides such a mechanism to protect sensitive data during electronic dissemination across the Internet.

TLS is a protocol created to provide authentication, confidentiality, and data integrity protection between two communicating applications. TLS is based on a precursor protocol called the Secure Sockets Layer Version 3.0 (SSL 3.0) and is considered to be an improvement to SSL 3.0. SSL 3.0 is specified in [33]. The Transport Layer Security version 1 (TLS 1.0) specification is an Internet Request for Comments, RFC 2246 [24]. Each document specifies a similar protocol that provides security services over the Internet. TLS 1.0 has been revised to version 1.1, as documented in RFC 4346 [25], and TLS 1.1 has been further revised to version 1.2, as documented in RFC 5246 [26]. In addition, some extensions have been defined to mitigate some of the known security vulnerabilities in implementations using TLS versions 1.0, 1.1, and 1.2. TLS 1.3, described in [56], is a significant update to previous versions that includes protections against security concerns that arose in previous versions of TLS.

This Special Publication provides guidance to the selection and configuration of TLS protocol implementations while making effective use of NIST-approved cryptographic schemes and algorithms. In particular, it requires that TLS 1.2 be configured with cipher suites using NIST-approved schemes and algorithms as the minimum appropriate secure transport protocol.[1] When interoperability with non-government systems is required, TLS 1.1 and TLS 1.0 may be supported. Agencies are required to develop migration plans to support to TLS 1.3 by 2020. This Special Publication also identifies TLS extensions for which mandatory support must be provided and other recommended extensions.

The use of the recommendations provided in this Special Publication would promote:

- More consistent use of authentication, confidentiality and integrity mechanisms for the protection of information transported across the Internet;
- Consistent use of the recommended cipher suites that encompass NIST-approved algorithms and open standards;
- Protection against known and anticipated attacks on the TLS protocol; and

[1] While SSL 3.0 is the most secure of the SSL protocol versions, it is not approved for use in the protection of Federal information because it relies in part on the use of cryptographic algorithms that are not NIST-approved. TLS 1.2 is approved for the protection of Federal information when properly configured. TLS versions 1.1 and 1.0 are approved only when it is required for interoperability with non-government systems and is configured according to these guidelines.

- Informed decisions by system administrators and managers in the integration of TLS implementations.

While these guidelines are primarily designed for Federal users and system administrators to adequately protect sensitive but unclassified U.S. Federal Government data against serious threats on the Internet, they may also be used within closed network environments to segregate data. (The client-server model and security services discussed also apply in these situations). This Special Publication supersedes NIST Special Publication 800-52 Revision 1. This Special Publication should be used in conjunction with existing policies and procedures.

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1 Introduction

Many networked applications rely on the Secure Sockets Layer (SSL) and Transport Layer Security (TLS) protocols to protect data transmitted over insecure channels. The Internet's client-server model and communication protocol design principles have been described in many books, such as [54], [19], and [37]. TLS often works with a public-key infrastructure (PKI) that generates public-key certificates in compliance with [20]. Books such as [1] and [40], as well as technical journal articles (e.g., [53]) and NIST publications (e.g., SP 800-32 [44]), describe how PKI can be used to protect information.

This document assumes that the reader of these guidelines is familiar with TLS protocols and public-key infrastructure concepts, including, for example, X.509 certificates. The references cited above and in Appendix F further explain the background concepts that are not fully explained in these guidelines.

1.1 Background

The TLS protocol is used to secure communications in a wide variety of online transactions such as financial transactions (e.g., banking, trading stocks, e-commerce), healthcare transactions (e.g., viewing medical records or scheduling medical appointments), and social transactions (e.g., email or social networking). Any network service that handles sensitive or valuable data, whether it is personally identifiable information (PII), financial data, or login information, needs to adequately protect that data. TLS provides a protected channel for sending data between the server and the client. The client is often, but not always, a web browser.

TLS is a layered protocol that runs on top of a reliable transport protocol – typically the Transmission Control Protocol (TCP). Application protocols, such as the Hypertext Transfer Protocol (HTTP) and the Internet Message Access Protocol (IMAP), can run above TLS. TLS is application independent, and used to provide security to any two communicating applications that transmit data over a network via an application protocol. It can be used to create a virtual private network (VPN) that connects an external system to an internal network, allowing that system to access a multitude of internal services and resources as if it were in the network.

Memorandum M-15-13[2] requires all publicly accessible Federal websites and web services only provide service through a secure connection.[3] The initiative to secure connections will enhance privacy and prevent modification of the data from government sites in transit.

1.2 History of TLS

The SSL protocol was designed by the Netscape Corporation to meet security needs of client and server applications. Version 1 of SSL was never released. SSL 2.0 was released in 1995, but had well-known security vulnerabilities, which were addressed by the 1996 release of SSL 3.0.

[2] https://obamawhitehouse.archives.gov/sites/default/files/omb/memoranda/2015/m-15-13.pdf

[3] See https://https.cio.gov/ for more details on this initiative.

During this timeframe, the Microsoft Corporation released a protocol known as Private Communications Technology (PCT), and later released a higher performance protocol known as the Secure Transport Layer Protocol (STLP). PCT and STLP never commanded the market share that SSL 2.0 and SSL 3.0 commanded. The Internet Engineering Task Force (IETF), a technical working group responsible for developing Internet standards to ensure communications compatibility across different implementations, attempted to resolve security engineering and protocol incompatibility issues between the protocols as best it could. The IETF standards track Transport Layer Security protocol Version 1.0 (TLS 1.0) emerged and was codified by the IETF as RFC 2246 [24]. While TLS 1.0 is based on SSL 3.0, and the differences between them are not dramatic, they are significant enough that TLS 1.0 and SSL 3.0 do not interoperate.

TLS 1.1, specified in RFC 4346 [25], was developed to address weaknesses discovered in TLS 1.0, primarily in the areas of initialization vector selection and padding error processing. Initialization vectors were made explicit[4] to prevent a certain class of attacks on the Cipher Block Chaining (CBC) mode of operation used by TLS. The handling of padding errors was altered to treat a padding error as a bad message authentication code, rather than a decryption failure. In addition, the TLS 1.1 RFC acknowledges attacks on CBC mode that rely on the time to compute the message authentication code (MAC). The TLS 1.1 specification states that to defend against such attacks, an implementation must process records in the same manner regardless of whether padding errors exist. Further implementation considerations for CBC modes (which were not included in RFC 4346 [25]) are discussed in Section 3.3.2.

TLS 1.2, specified in RFC 5246 [26], made several cryptographic enhancements, particularly in the area of hash functions, with the ability to use or specify the SHA-2 family algorithms for hash, MAC, and Pseudorandom Function (PRF) computations. TLS 1.2 also adds authenticated encryption with associated data (AEAD) cipher suites.

TLS 1.3, specified in [56], represents a significant change to TLS that aims to address threats that have arisen over the years. Among the changes are a new handshake protocol, a new key derivation process that uses the HMAC-based Extract-and-Expand Key Derivation Function (HKDF) [43], and the removal of cipher suites that use static RSA or DH key exchanges, the CBC mode of operation, or SHA-1. The list of extensions that can be used with TLS 1.3 has been reduced considerably.

1.3 Scope

Security is not a single property possessed by a single protocol. Rather, security includes a complex set of related properties that together provide the required information assurance characteristics and information protection services. Security requirements are usually derived from a risk assessment of the threats or attacks that an adversary is likely to mount against a system. The adversary is likely to take advantage of implementation vulnerabilities found in many system components, including computer operating systems, application software systems, and the computer networks that interconnect them. Thus, in order to secure a system against a

[4] The initialization vector (IV) must be sent; it cannot be derived from a state known by both parties, such as the previous message.

myriad of threats, security must be judiciously placed in the various systems and network layers.

These guidelines focus only on network security, and they focus directly on the small portion of the network communications stack that is referred to as the transport layer. Several other NIST publications address security requirements in the other parts of the system and network layers. Adherence to these guidelines only protects the data in transit. Other applicable NIST standards and guidelines should be used to ensure protection of systems and stored data.

These guidelines focus on the common use cases where clients and servers must interoperate with a wide variety of implementations, and authentication is performed using public-key certificates. To promote interoperability, implementations often support a wide array of cryptographic options. However, there are much more constrained TLS implementations where security is needed but broad interoperability is not required, and the cost of implementing unused features may be prohibitive. For example, minimal servers are often implemented in embedded controllers and network infrastructure devices such as routers, and then used with browsers to remotely configure and manage the devices. There are also cases where both the client and server for an application's TLS connection are under the control of the same entity, and therefore allowing a variety of options for interoperability is not necessary. The use of an appropriate subset of the capabilities specified in these guidelines may be acceptable in such cases.

The scope is further limited to TLS when used in conjunction with TCP/IP. For example, Datagram TLS (DTLS) is outside the scope of these guidelines. NIST may issue separate guidelines for DTLS at a later date.

1.3.1 Alternative Configurations

TLS may be used to secure the communications of a wide variety of applications in a diverse set of operating environments. As such, there is not a single configuration that will work well for all scenarios. These guidelines attempt to provide general-use recommendations. However, the needs of an agency or application may differ from general needs. **Deviations from these guidelines are acceptable, provided that agencies and system administrators assess and accept the risks associated with alternative configurations in terms of both security and interoperability.**

1.4 Document Conventions

Throughout this document, key words are used to identify requirements. The key words "**shall**," "**shall not**," "**should**," and "**should not**" are used. These words are a subset of the IETF Request for Comments (RFC) 2119 key words, and have been chosen based on convention in other normative documents [15]. In addition to the key words, the words "need," "can," and "may" are used in this document, but are not intended to be normative. The key word "NIST-approved" is used to indicate that a scheme or algorithm is described in a Federal Information Processing Standard (FIPS) or is recommended by NIST.

The recommendations in this document are grouped by server recommendations and client recommendations. Section 3 provides detailed guidance for the selection and configuration of TLS servers. Section 4 provides detailed guidance for the selection, configuration, and use of TLS clients.

2 TLS Overview

TLS exchanges records via the TLS record protocol. A TLS record contains several fields, including version information, application protocol data, and the higher-level protocol used to process the application data. TLS protects the application data by using a set of cryptographic algorithms to ensure the confidentiality, integrity, and authenticity of exchanged application data. TLS defines several protocols for connection management that sit on top of the record protocol, where each protocol has its own record type. These protocols, discussed in Section 2.1, are used to establish and change security parameters, and to communicate error and warning conditions to the server and client. Sections 2.2 through 2.6 describe the security services provided by the TLS protocol and how those security services are provisioned. Section 2.7 discusses key management.

2.1 Handshake Protocol

There are three subprotocols in the TLS protocol that are used to control the session connection: the handshake, change cipher spec, and alert protocols. The TLS handshake protocol is used to negotiate the session parameters. The alert protocol is used to notify the other party of an error condition. The change cipher spec protocol is used in TLS 1.0, 1.1, and 1.2 to change the cryptographic parameters of a session. In addition, the client and the server exchange application data that is protected by the security services provisioned by the negotiated cipher suite. These security services are negotiated and established with the handshake. The handshake protocol is similar in TLS 1.0, 1.1, and 1.2, whereas the handshake of TLS 1.3 is different than in previous TLS versions.

The handshake protocol consists of a series of message exchanges between the client and the server. The handshake protocol initializes both the client and server to use cryptographic capabilities by negotiating a cipher suite of algorithms and functions, including key establishment, digital signature, confidentiality and integrity algorithms. Clients and servers can be configured so that one or more of the following security services are negotiated during the handshake: confidentiality, message integrity, authentication, and replay protection. A confidentiality service provides assurance that data is kept secret, preventing eavesdropping. A message integrity service provides confirmation that unauthorized data modification is detected, thus preventing undetected deletion, addition, or modification of data. An authentication service provides assurance of the sender or receiver’s identity, thereby detecting forgery. Replay protection ensures that an unauthorized user does not capture and successfully replay previous data. In order to comply with these guidelines, both the client and the server must be configured for data confidentiality and integrity services.

The handshake protocol is used to optionally exchange X.509 public-key certificates[5] to authenticate the server and the client to each other.

The handshake protocol is responsible for establishing the session parameters. The client and server negotiate algorithms for authentication, confidentiality and integrity, as well as derive

[5] The use of X.509 public-key certificates is fundamental to TLS. For a comprehensive explanation of X.509 public-key certificates see [1] or [40]. In these guidelines, the terms “certificate” and “public-key certificate” are used interchangeably.

symmetric keys and establish other session parameters, such as extensions. The negotiated set of cryptographic algorithms is called the cipher suite.

Alerts are used to convey information about the session, such as errors or warnings. For example, an alert can be used to signal a decryption error (decrypt_error) or that access has been denied (access_denied). Some alerts are used for warnings, and others are considered fatal and lead to immediate termination of the session. A close_notify alert message is used to signal normal termination of a session. Like all other messages after the handshake protocol is completed, alert messages are encrypted and optionally compressed.

Details of the handshake, change cipher spec (in TLS versions prior to 1.3) and alert protocols are outside the scope of these guidelines; they are described in RFC 5246 [26] and [56].

2.2 Shared Secret Negotiation

The client and server establish keying material during the TLS handshake protocol. The derivation of the premaster secret depends on the key exchange method that is agreed upon and the version of TLS used. For example, when Diffie-Hellman is used as the key-exchange algorithm in TLS 1.2 and earlier versions, the client and server send each other their parameters, and the resulting key is used as the premaster secret. The premaster secret, along with random values exchanged by the client and server in the hello messages, is used to compute the master secret. In TLS 1.3, the master secret is derived by iteratively invoking an extract-then-expand function with previously derived secrets. The master secret is used to derive session keys, which are used by the negotiated security services to protect the data exchanged between the client and the server, thus providing a secure channel for the client and the server to communicate.

The establishment of these secrets is secure against eavesdroppers. When the TLS protocol is used in accordance with these guidelines, the application data, as well as the secrets, are not vulnerable to attackers who place themselves in the middle of the connection. The attacker cannot modify the handshake messages without being detected by the client and the server because the Finished message, which is exchanged after security parameter establishment, provides integrity protection to the entire exchange. In other words, an attacker cannot modify or downgrade the security of the connection by placing itself in the middle of the negotiation.

2.3 Confidentiality

Confidentiality is provided for a communication session by the negotiated encryption algorithm for the cipher suite and the encryption keys derived from the master secret and random values, one for encryption by the client (the client write key), and another for encryption by the server (the server write key). The sender of a message (client or server) encrypts the message using a derived encryption key; the receiver uses the same (independently derived) key to decrypt the message. Both the client and server know these keys, and decrypt the messages using the same key that was used for encryption. The encryption keys are derived from the shared master secret.

2.4 Integrity

The keyed MAC algorithm, specified by the negotiated cipher suite, provides message integrity. Two MAC keys are derived: 1) a MAC key to be used when the client is the message sender and the server is the message receiver (the client write MAC key), and 2) a second MAC key to be used when the server is the message sender and the client is the message receiver (the server write MAC key). The sender of a message (client or server) calculates the MAC for the message using the appropriate MAC key, and encrypts both the message and the MAC using the appropriate encryption key. The sender then transmits the encrypted message and MAC to the receiver. The receiver decrypts the received message and MAC, and calculates its own version of the MAC using the MAC algorithm and sender's MAC key. The receiver verifies that the MAC that it calculates matches the MAC sent by the sender.

Two types of constructions are used for MAC algorithms in TLS. TLS versions 1.0, 1.1 and 1.2 support the use of the Keyed-Hash Message Authentication Code (HMAC) using the hash algorithm specified by the negotiated cipher suite. With HMAC, MACs for server-to-client messages are keyed by the server write MAC key, while MACs for client-to-server messages are keyed by the client write MAC key. These MAC keys are derived from the shared master secret.

TLS 1.2 added AEAD cipher modes of operation, such as Counter with CBC-MAC (CCM) [47] and Galois Counter Mode (GCM) [55, 59], as an alternative way of providing integrity and confidentiality. In AEAD modes, the sender uses its write key for both encryption and integrity protection. The client and server write MAC keys are not used. The recipient decrypts the message and verifies the integrity information using the sender's write key. In TLS 1.3, only AEAD symmetric algorithms are used for confidentiality and integrity.

2.5 Authentication

Server authentication is performed by the client using the server's public-key certificate, which the server presents during the handshake. The exact nature of the cryptographic operation for server authentication is dependent on the negotiated security parameters and extensions. In most cases, authentication is performed explicitly by verifying digital signatures using public keys that are present in certificates, and implicitly by the use of the server public key by the client during the establishment of the master secret. A successful Finished message implies that both parties calculated the same master secret and thus, the server must have known the private key corresponding to the public key used for key establishment.

Client authentication is optional, and only occurs at the server's request. Client authentication is based on the client's public-key certificate. The exact nature of the cryptographic operation for client authentication depends on the negotiated cipher suite's key-exchange algorithm and the negotiated extensions. For example, when the client's public-key certificate contains an RSA public key, the client signs a portion of the handshake message using the private key corresponding to that public key, and the server verifies the signature using the public key to authenticate the client.

2.6 Anti-Replay

TLS provides inherent protection against replay attacks, except when 0-RTT data (optionally sent in the first flight of handshake messages) is sent in TLS 1.3.[6] The integrity-protected envelope of the message contains a monotonically increasing sequence number. Once the message integrity is verified, the sequence number of the current message is compared with the sequence number of the previous message. The sequence number of the current message must be greater than the sequence number of the previous message in order to further process the message.

2.7 Key Management

The security of the server's private key is critical to the security of TLS. If the server's private key is weak or can be obtained by a third party, the third party can masquerade as the server to all clients. Similarly, if a third party can obtain a public-key certificate for a public key corresponding to its own private key in the name of a legitimate server from a certification authority (CA) trusted by the clients, the third party can masquerade as the server to the clients. Requirements and recommendations to mitigate these concerns are addressed later in these guidelines.

Similar threats exist for clients. If a client's private key is weak or can be obtained by a third party, the third party can masquerade as the client to a server. Similarly, if a third party can obtain a public-key certificate for a public key corresponding to his own private key in the name of a client from a CA trusted by the server, the third party can masquerade as that client to the server. Requirements and recommendations to mitigate these concerns are addressed later in these guidelines.

Since the random numbers generated by the client and server contribute to the randomness of the session keys, the client and server must be capable of generating random numbers with at least 112 bits of security[7] each. The various TLS session keys derived from these random values and other data are valid for the duration of the session. Because the session keys are only used to protect messages exchanged during an active TLS session, and are not used to protect any data at rest, there is no requirement for recovering TLS session keys. However, all versions of TLS provide mechanisms to store a key related to a session, which allows sessions to be resumed in the future. Keys for a resumed session are derived during an abbreviated handshake that uses the stored key as a form of authentication.

[6] While TLS 1.3 does not inherently provide replay protection with 0-RTT data, the TLS 1.3 specification does recommend mechanisms to protect against replay attacks (see Section 8 of [56]).

[7] Bits of security provided by NIST-approved algorithms are described in SP 800-57 part 1 [6], Section 5.6.

3 Minimum Requirements for TLS Servers

This section provides a minimum set of requirements that a server must implement in order to meet these guidelines. Requirements are organized in the following sections: TLS protocol version support; server keys and certificates; cryptographic support; TLS extension support; client authentication; session resumption; compression methods; and operational considerations.

Specific requirements are stated as either implementation requirements or configuration requirements. Implementation requirements indicate that Federal agencies **shall not** procure TLS server implementations unless they include the required functionality, or can be augmented with additional commercial products to meet requirements. Configuration requirements indicate that TLS server administrators are required to verify that particular features are enabled or disabled, or in some cases, configured appropriately, if present.

3.1 Protocol Version Support

Servers that support government-only applications[8] **shall** be configured to use TLS 1.2, and **should** be configured to use TLS 1.3. These servers **should not** be configured to use TLS 1.1, and **shall not** use TLS 1.0, SSL 3.0, or SSL 2.0. TLS versions 1.2 and 1.3 are represented by major and minor number tuples (3, 3) and (3, 4), respectively, and may appear in that format during configuration.[9] Agencies **shall** develop migration plans to support TLS 1.3 by January 1, 2020. After this date, use of TLS 1.3 **shall** be supported in the government's servers.

Servers that support citizen or business-facing applications (i.e., the client may not be part of a government IT system)[10] **shall** be configured to negotiate TLS 1.2, **should** be configured to negotiate TLS 1.3, and may be configured to negotiate TLS versions 1.1 and 1.0 in order to enable interaction with citizens and businesses. See Appendix E for discussion on determining whether to support TLS 1.0 and TLS 1.1. These servers **shall not** allow the use of SSL 2.0 or SSL 3.0.

Some server implementations are known to implement version negotiation incorrectly. For example, there are TLS 1.0 servers that terminate the connection when the client offers a version newer than TLS 1.0. Servers that incorrectly implement TLS version negotiation **shall not** be used.

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[8] A government-only application is an application where the intended users are exclusively government employees or contractors working on behalf of the government. This includes applications that are accessed on a government employee’s bring-your-own-device (BYOD) system. This is in contrast to applications that are publicly accessible.

[9] Historically TLS 1.0 was assigned major and minor tuple (3,1) to align it as SSL 3.1. TLS 1.1 is represented by the major and minor tuple (3,2).

[10] For the purposes of this document, clients that reside on “bring your own device” (BYOD) systems, or privately-owned systems used to perform telework, are considered to be part of the government IT system, as they access services that are not available to the public.

3.2 Server Keys and Certificates

The TLS server **shall** be configured with one or more public-key certificates and the associated private keys. TLS server implementations **should** support the use of multiple server certificates with their associated private keys to support algorithm and key size agility.

Several options for TLS server certificates meet the requirement for NIST-approved cryptography: an RSA signature certificate; an Elliptic Curve Digital Signature Algorithm (ECDSA) signature certificate; a Digital Signature Algorithm (DSA)[11] signature certificate; a Diffie-Hellman (DH) certificate; and an Elliptic Curve Diffie-Hellman (ECDH) certificate.

At a minimum, TLS servers conforming to this specification **shall** be configured with an RSA signature certificate or an ECDSA signature certificate. If the server is configured with an ECDSA signature certificate, a Suite B named curve **should** be used for the public key in the certificate.[12]

TLS servers that are accessible to systems residing on a different network (e.g., connected to the Internet) **shall** be configured with certificates issued by a CA, rather than self-signed certificates. Furthermore, TLS server certificates **shall** be issued by a CA that publishes revocation information in Online Certificate Status Protocol (OCSP) [61] responses. The CA may additionally publish revocation information in a certificate revocation list (CRL) [20]. The source(s) for the revocation information **shall** be included in the CA-issued certificate in the appropriate extension to promote interoperability.

A TLS server that has been issued certificates by multiple CAs can select the appropriate certificate based on the client specified "Trusted CA Keys" TLS extension, as described in Section 3.4.2.7. A TLS server that has been issued certificates for multiple server names can select the appropriate certificate based on the client specified "Server Name" TLS extension, as described in Section 3.4.1.2. A TLS server certificate may also contain multiple names in the Subject Alternative Name extension in order to allow the use of multiple server names of the same name form (e.g., DNS name) or multiple server names of multiple name forms (e.g., DNS names, IP address, etc.).

Application processes for obtaining certificates differ and require different levels of proof when associating certificates to domains. An applicant can obtain a domain-validated (DV) certificate by proving control over a DNS domain. An Organization Validation (OV) certificate requires further vetting, such as verifying the entity's details. An Extended Validation (EV) certificate has the most thorough identity vetting process. This recommendation does not provide guidance on which verification level to use.

Section 3.2.1 specifies a detailed profile for server certificates. Basic guidelines for RSA, ECDSA, DSA, DH, and ECDH certificates are provided. Section 3.2.2 specifies requirements for

[11] In the names for the TLS cipher suites, DSA is referred to as DSS (Digital Signature Standard), for historical reasons.

[12] The Suite B curves are known as P-256 and P-384. These curves are defined in FIPS 186-4 [66], and their inclusion in Suite B is documented in [60].

revocation checking. Section 3.5.4 specifies requirements for the "hints list."

3.2.1 Server Certificate Profile

The server certificate profile, described in this section, provides requirements and recommendations for the format of the server certificate. To comply with these guidelines, the TLS server certificate **shall** be an X.509 version 3 certificate; both the public key contained in the certificate and the signature **shall** provide at least 112 bits of security. Prior to TLS 1.2, the server Certificate message required that the signing algorithm for the certificate be the same as the algorithm for the certificate key (see Section 7.4.2 of [25]). If the server supports TLS versions prior to TLS 1.2, the certificate **should** be signed with an algorithm consistent with the public key:[13,14]

- Certificates containing RSA, ECDSA, or DSA public keys **should** be signed with those same signature algorithms, respectively;
- Certificates containing Diffie-Hellman public keys **should** be signed with DSA; and
- Certificates containing ECDH public keys **should** be signed with ECDSA.

The extended key usage extension limits how the keys in a certificate are used. There is a key purpose specifically for server authentication, and the server **should** be configured to allow its use. The use of the extended key usage extension will facilitate successful server authentication, as some clients may require the presence of an extended key usage extension. The use of the server DNS name in the Subject Alternative Name field ensures that any name constraints on the certification path will be properly enforced.

The server certificate profile is listed in Table 3-1. In the absence of agency-specific certificate profile requirements, this certificate profile **should** be used for the server certificate.

Table 3-1: TLS Server Certificate Profile

Field	Critical	Value	Description
Version	N/A	2	Version 3
Serial Number	N/A	Unique positive integer	Must be unique

[13] This recommendation is an artifact of requirements in TLS 1.0 and 1.1.

[14] Algorithm-dependent guidelines exist for the generation of public and private key pairs. For guidance on the generation of DH and ECDH key pairs, see SP 800-56A [8]. For guidance regarding the generation of RSA, DSA and ECDSA key pairs, see [66].

Field	Critical	Value	Description
Issuer Signature Algorithm	N/A	*Values by CA key type:*	
		sha256WithRSAEncryption {1 2 840 113549 1 1 11}, or stronger	CA with RSA key
		ecdsa-with-SHA256 {1 2 840 10045 4 3 2}, or stronger	CA with elliptic curve key
		id-dsa-with-sha256 {2 16 840 1 101 3 4 3 2}, or stronger	CA with DSA key
Issuer Distinguished Name (DN)	N/A	Unique X.500 issuing CA DN	A single value **shall** be encoded in each Relative Distinguished Name (RDN). All attributes that are of DirectoryString type **shall** be encoded as a PrintableString.
Validity Period	N/A	3 years or less	Dates through 2049 expressed in UTCTime
Subject Distinguished Name	N/A	Unique X.500 subject DN per agency requirements	A single value **shall** be encoded in each RDN. All attributes that are of DirectoryString type **shall** be encoded as a PrintableString. CN={host IP address | host DNS name}
Field	**Critical**	**Value**	**Description**
Subject Public Key Information	N/A	*Values by certificate type:*	
		rsaEncryption {1 2 840 113549 1 1 1}	RSA signature certificate 2048-bit RSA key modulus, or other approved lengths as defined in [66] and [6] Parameters: NULL
		ecPublicKey {1 2 840 10045 2 1}	ECDSA signature certificate or ECDH certificate Parameters: namedCurve OID for named curve specified in [66]. The curve **should** be P-256 or P-384 SubjectPublic Key: Uncompressed EC Point.
		id-dsa {1 2 840 10040 4 1}	DSA signature certificate Parameters: p, q, g (2048-bit large prime, i.e., p)
		dhpublicnumber {1 2 840 10046 2 1}	DH certificate Parameters: p, g, q (2048-bit large prime, i.e., p)
Issuer's Signature	N/A	Same value as in Issuer Signature Algorithm	
Extensions			

Field	Critical	Value	Description
Authority Key Identifier	No	Octet String	Same as subject key identifier in issuing CA certificate Prohibited: Issuer DN, Serial Number tuple
Subject Key Identifier	No	Octet String	Same as in PKCS-10 request or calculated by the issuing CA
Key Usage	Yes	*Values by certificate type:*	
		digitalSignature	RSA signature certificate, ECDSA signature certificate, or DSA signature certificate
		keyAgreement	ECDH certificate, DH certificate
Extended Key Usage	No	id-kp-serverAuth {1 3 6 1 5 5 7 3 1}	Required
		id-kp-clientAuth {1 3 6 1 5 5 7 3 2}	Optional
			Prohibited: anyExtendedKeyUsage; all others unless consistent with key usage extension
Certificate Policies	No		Optional
Subject Alternative Name	No	DNS host name, or IP address if there is no DNS name assigned	Multiple SANs are permitted, e.g., for load balanced environments.
Authority Information Access	No	id-ad-caIssuers	Required. Access method entry contains HTTP URL for certificates issued to issuing CA
		id-ad-ocsp	Required. Access method entry contains HTTP URL for the issuing CA OCSP responder
CRL Distribution Points	No	See comments	Optional. HTTP value in distributionPoint field pointing to a full and complete CRL. Prohibited: reasons and cRLIssuer fields, and nameRelativetoCRLIssuer CHOICE
Signed Certificate Timestamps List	No	See comments	Optional. This extension contains a sequence of Signed Certificate Timestamps, which provide evidence that the certificate has been submitted to Certificate Transparency logs.

3.2.2 Obtaining Revocation Status Information for the Client Certificate

The server **shall** perform revocation checking of the client certificate when client authentication is used. Revocation information **shall** be obtained by the server from one or more of the following locations:

1. Certificate Revocation List (CRL) or OCSP [61] response in the server's local store;
2. OCSP response from a locally configured OCSP responder;
3. OCSP response from the OCSP responder location identified in the OCSP field in the Authority Information Access extension in the client certificate; or
4. CRL from the CRL Distribution Points extension in the client certificate.

When the local store does not have the current or a cogent[15] CRL or OCSP response, and the OCSP responder and the CRL distribution point are unavailable or inaccessible at the time of TLS session establishment, the server will either deny the connection or accept a potentially revoked or compromised certificate. The decision to accept or reject a certificate in this situation **should** be made according to agency policy.

3.2.3 Server Public-Key Certificate Assurance

The policies, procedures, and security controls under which a public-key certificate is issued by a CA are documented in a certificate policy. The use of a certificate policy that is designed with the secure operation of PKI in mind and adherence to the stipulated certificate policy mitigates the threat that the issuing CA can be compromised or that the registration system, persons or process can be compromised to obtain an unauthorized certificate in the name of a legitimate entity, and thus compromise the clients. With this in mind, the CA Browser Forum, a private-sector organization, has carried out some efforts in this area by writing the Extended Validation guideline [17]. Under another effort, the CA Browser Forum published requirements for issuing certificates from publicly trusted CAs in order for those CAs and their trust anchor to remain in browser trust stores [16].

Several concepts are under development that further mitigate the risks associated with the compromise of a CA or X.509 certificate registration system, process or personnel. These include the Certificate Transparency project (see Section 3.4.2.11) and other emerging concepts, which are discussed in Appendix D.

The policy under which a certificate has been issued may optionally be represented in the certificate using the certificatePolicies extension, specified in [20] and updated in [73]. When used, one or more certificate policy object identifiers (OID) are asserted in this extension, with each OID representing a specific certificate policy. Many TLS clients (e.g., browsers), however, do not offer the ability to accept or reject certificates based on the policies under which they were issued. Therefore, it is generally necessary for TLS server certificates to be issued by CAs that only issue certificates in accordance with a certificate policy that specifies adequate security controls.

When an agency is obtaining a certificate for a TLS server for which all the clients are under the agency's control, the agency may issue the certificate from its own CA if it can configure the clients to trust that CA. In other cases, the agency should obtain a certificate from a publicly-trusted CA; a CA that clients that will be connecting to the server have already been configured to trust.

3.3 Cryptographic Support

Cryptographic support in TLS is provided through the use of various cipher suites. A cipher suite

[15] A CRL is considered "cogent" when the "CRL Scope" [20] is appropriate for the certificate in question.

specifies a collection of algorithms for key exchange (in TLS 1.2 and earlier only), and for providing confidentiality and integrity services to application data. The cipher suite negotiation occurs during the TLS handshake protocol. The client presents cipher suites that it supports to the server, and the server selects one of them to secure the session data.

In addition to the selection of appropriate cipher suites, system administrators may also have additional considerations specific to the implementation of the cryptographic algorithms, as well as cryptographic module validation requirements. Acceptable cipher suites are listed in Section 3.3.1, grouped by certificate type and protocol version. Implementation considerations are discussed in Section 3.3.2, and recommendations regarding cryptographic module validation are described in Section 3.3.3.

3.3.1 Cipher Suites

Cipher suites specify the cryptographic algorithms that will be used for a session. Cipher suites in TLS 1.0 through TLS 1.2 have the form:

TLS_*KeyExchangeAlg*_WITH_*EncryptionAlg_MessageAuthenticationAlg*

For example, the cipher suite TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA uses ephemeral ECDH key establishment, with parameters signed using RSA, confidentiality is provided by AES-128 in cipher block chaining mode, and message authentication is performed using HMAC_SHA.[16] For further information on cipher suite interpretation, see Appendix B.

Cipher suites are formatted differently in TLS 1.3. These cipher suites do not specify the key exchange algorithm, and have the form:

TLS_*AEAD_HASH*

For example, the cipher suite TLS_AES_128_GCM_SHA256 uses AES-128 in Galois Counter Mode for confidentiality and message authentication, and uses SHA-256 for the HKDF. TLS 1.3 cipher suites cannot be used for TLS 1.2 connections, and TLS 1.2 cipher suites cannot be negotiated with TLS 1.3.

When negotiating a cipher suite, the client sends a handshake message with a list of cipher suites it will accept. The server chooses from the list and sends a handshake message back indicating which cipher suite it will accept. Although the client may order the list with the strongest cipher suites listed first, the server may choose ***any*** of the cipher suites proposed by the client. Therefore, there is ***no*** guarantee that the negotiation will settle on the strongest common suite. If no cipher suites are common to the client and server, the connection is aborted.

The server **shall** be configured to only use cipher suites that are composed entirely of NIST-approved algorithms (i.e., [7, 8, 11, 27-29, 65-67, 69]). A complete list of acceptable cipher suites for general use is provided in this section, grouped by certificate type and TLS protocol

[16] SHA indicates the use of the SHA-1 hash algorithm.

version. The Internet Assigned Numbers Authority (IANA) value for each cipher suite is given after its text description, in parentheses.[17]

In some situations, such as closed environments, it may be appropriate to use pre-shared keys. Pre-shared keys are symmetric keys that are already in place prior to the initiation of a TLS session, which are used in the derivation of the premaster secret. For cipher suites that are acceptable in pre-shared key environments, see Appendix C.

The following cipher suite listings are grouped by certificate type and TLS protocol version. The cipher suites in these lists include the cipher suites that contain NIST-approved cryptographic algorithms. Cipher suites that do not appear in this section or in Appendix C **shall not** be used.

Cipher suites using ephemeral DH and ephemeral ECDH (i.e., those with DHE or ECDHE in the second mnemonic) provide perfect forward secrecy.[18] When ephemeral keys are used to establish the master secret, each ephemeral key-pair (i.e., the server ephemeral key-pair and the client ephemeral key-pair) **shall** have at least 112 bits of security.

3.3.1.1 Cipher Suites for TLS 1.2 and Earlier Versions

The first revision of this guidance required support for a small set of cipher suites to promote interoperability and align with TLS specifications. There are no longer any mandatory cipher suite requirements. Cipher suites that comprise AES and other NIST-approved algorithms are acceptable to use, although they are not necessarily equal in terms of security. Cipher suites that use TDEA (3DES) are no longer allowed, due to the limited amounts of data that can be processed under a single key. The server **shall** be configured to only use cipher suites for which it has a valid certificate containing a signature providing at least 112 bits of security.

By removing requirements that specific cipher suites be supported, system administrators have more freedom to meet the needs of their environment and applications. It also increases agility by allowing administrators to immediately disable cipher suites when attacks are discovered without breaking compliance.

If a subset of the cipher suites that are acceptable for the server certificate(s) are supported, the following list gives general guidance on choosing the strongest options:

1. Prefer ephemeral keys over static keys (i.e., prefer DHE over DH, and prefer ECDHE over ECDH). Ephemeral keys provide perfect forward secrecy.
2. Prefer GCM or CCM modes over CBC mode. The use of an authenticated encryption mode prevents several attacks (see Section 3.3.2 for more information). Note that these are not available in versions prior to TLS 1.2.

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[17] The full list of IANA values for TLS parameters can be found at https://www.iana.org/assignments/tls-parameters/tls-parameters.xhtml.

[18] Perfect forward secrecy is the condition in which the compromise of a long-term private key used in deriving a session key subsequent to the derivation does not cause the compromise of the session key.

3. Prefer CCM over CCM_8. The latter contains a shorter authentication tag, which provides a lower authentication strength.

This list does not have to be strictly followed, as some environments or applications may have special circumstances. Note that this list may become outdated if an attack emerges on one of the preferred components. If an attack significantly impacts the recommended cipher suites, NIST will address the issue in an announcement on the NIST Computer Security Resource Center.

3.3.1.1.1 Cipher Suites for ECDSA Certificates

TLS version 1.2 includes authenticated encryption modes, and support for the SHA-256 and SHA-384 hash algorithms, which are not supported in prior versions of TLS. These cipher suites are described in [59] and [55]. TLS 1.2 servers that are configured with ECDSA certificates may be configured to support the following cipher suites, which are only supported by TLS 1.2:

- TLS_ECDHE_ECDSA_WITH_AES_128_GCM_SHA256 (0xC0, 0x2B)
- TLS_ECDHE_ECDSA_WITH_AES_256_GCM_SHA384 (0xC0, 0x2C)
- TLS_ECDHE_ECDSA_WITH_AES_128_CCM (0xC0, 0xAC)
- TLS_ECDHE_ECDSA_WITH_AES_256_CCM (0xC0, 0xAD)
- TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 (0xC0, 0xAE)
- TLS_ECDHE_ECDSA_WITH_AES_256_CCM_8 (0xC0, 0xAF)
- TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA256 (0xC0, 0x23)
- TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA384 (0xC0, 0x24)

TLS servers may be configured to support the following cipher suites when ECDSA certificates are used with TLS versions 1.2, 1.1, or 1.0:

- TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA[19] (0xC0, 0x09)
- TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA (0xC0, 0x0A)

3.3.1.1.2 Cipher Suites for RSA Certificates

TLS 1.2 servers that are configured with RSA certificates may be configured to support the following cipher suites:

- TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256 (0xC0, 0x2F)
- TLS_ECDHE_RSA_WITH_AES_256_GCM_SHA384 (0xC0, 0x30)
- TLS_DHE_RSA_WITH_AES_128_GCM_SHA256 (0x00, 0x9E)

[19] In TLS versions 1.0 and 1.1, DHE and ECDHE cipher suites use SHA-1 for signature generation on the ephemeral parameters (including keys) in the ServerKeyExchange message. While the use of SHA-1 for digital signature generation is generally disallowed by [10], exceptions can be granted by protocol-specific guidance. SHA-1 is allowed for generating digital signatures on ephemeral parameters in TLS. Due to the random nature of the ephemeral keys, a third party is unlikely to cause effective collision. The server and client do not have anything to gain by causing a collision for the connection. Because of the client random and server random values, the server, the client, or a third party cannot use a colliding set of messages to masquerade as the client or server in future connections. Any modification to the parameters by a third party during the handshake will ultimately result in a failed connection.

- TLS_DHE_RSA_WITH_AES_256_GCM_SHA384 (0x00, 0x9F)
- TLS_DHE_RSA_WITH_AES_128_CCM (0xC0, 0x9E)
- TLS_DHE_RSA_WITH_AES_256_CCM (0xC0, 0x9F)
- TLS_DHE_RSA_WITH_AES_128_CCM_8 (0xC0, 0xA2)
- TLS_DHE_RSA_WITH_AES_256_CCM_8 (0xC0, 0xA3)
- TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA256 (0xC0, 0x27)
- TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA384 (0xC0, 0x28)
- TLS_DHE_RSA_WITH_AES_128_CBC_SHA256 (0x00, 0x67)
- TLS_DHE_RSA_WITH_AES_256_CBC_SHA256 (0x00, 0x6B)

TLS servers may be configured to support the following cipher suites when RSA certificates are used with TLS versions 1.2, 1.1, or 1.0:

- TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA (0xC0, 0x13)
- TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA (0xC0, 0x14)
- TLS_DHE_RSA_WITH_AES_128_CBC_SHA (0x00, 0x33)
- TLS_DHE_RSA_WITH_AES_256_CBC_SHA (0x00, 0x39)

3.3.1.1.3 Cipher Suites for DSA Certificates

TLS 1.2 servers that are configured with DSA certificates may be configured to support the following cipher suites:

- TLS_DHE_DSS_WITH_AES_128_GCM_SHA256 (0x00, 0xA2)
- TLS_DHE_DSS_WITH_AES_256_GCM_SHA384 (0x00, 0xA3)
- TLS_DHE_DSS_WITH_AES_128_CBC_SHA256 (0x00, 0x40)
- TLS_DHE_DSS_WITH_AES_256_CBC_SHA256 (0x00, 0x6A)

TLS servers may be configured to support the following cipher suites when DSA certificates are used with TLS versions 1.2, 1.1, or 1.0:

- TLS_DHE_DSS_WITH_AES_128_CBC_SHA (0x00, 0x32)
- TLS_DHE_DSS_WITH_AES_256_CBC_SHA (0x00, 0x38)

3.3.1.1.4 Cipher Suites for DH Certificates

DH certificates contain a static key, and are signed using either DSA or RSA. Unlike cipher suites that use ephemeral DH, these cipher suites contain static DH parameters. While the use of static keys is technically acceptable, the use of ephemeral key cipher suites is encouraged and preferred over the use of the cipher suites listed in this section.

TLS 1.2 servers that are configured with DSA-signed DH certificates may be configured to support the following cipher suites:

- TLS_DH_DSS_WITH_AES_128_GCM_SHA256 (0x00, 0xA4)
- TLS_DH_DSS_WITH_AES_256_GCM_SHA384 (0x00, 0xA5)
- TLS_DH_DSS_WITH_AES_128_CBC_SHA256 (0x00, 0x3E)

- TLS_DH_DSS_WITH_AES_256_CBC_SHA256 (0x00, 0x68)

TLS servers may be configured to support the following cipher suites when DSA-signed DH certificates are used with TLS versions 1.2, 1.1, or 1.0:

- TLS_DH_DSS_WITH_AES_128_CBC_SHA (0x00, 0x30)
- TLS_DH_DSS_WITH_AES_256_CBC_SHA (0x00, 0x36)

TLS 1.2 servers that are configured with RSA-signed DH certificates may be configured to support the following cipher suites:

- TLS_DH_RSA_WITH_AES_128_GCM_SHA256 (0x00, 0xA0)
- TLS_DH_RSA_WITH_AES_256_GCM_SHA384 (0x00, 0xA1)
- TLS_DH_RSA_WITH_AES_128_CBC_SHA256 (0x00, 0x3F)
- TLS_DH_RSA_WITH_AES_256_CBC_SHA256 (0x00, 0x69)

TLS servers may be configured to support the following cipher suites when RSA-signed DH certificates are used with TLS versions 1.2, 1.1, or 1.0:

- TLS_DH_RSA_WITH_AES_128_CBC_SHA (0x00, 0x31)
- TLS_DH_RSA_WITH_AES_256_CBC_SHA (0x00, 0x37)

3.3.1.1.5 Cipher Suites for ECDH Certificates

ECDH certificates contain a static key, and are signed using either ECDSA or RSA. Unlike cipher suites that use ephemeral ECDH, these cipher suites contain static ECDH parameters. The use of ephemeral key cipher suites is encouraged and preferred over the use of the cipher suites listed in this section.

TLS 1.2 servers that are configured with ECDSA-signed ECDH certificates may be configured to support the following cipher suites:

- TLS_ECDH_ECDSA_WITH_AES_128_GCM_SHA256 (0xC0, 0x2D)
- TLS_ECDH_ECDSA_WITH_AES_256_GCM_SHA384 (0xC0, 0x2E)
- TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA256 (0xC0, 0x25)
- TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA384 (0xC0, 0x26)

TLS servers may be configured to support the following cipher suites when ECDSA-signed ECDH certificates are used with TLS versions 1.2, 1.1, or 1.0:

- TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA (0xC0, 0x04)
- TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA (0xC0, 0x05)

TLS 1.2 servers that are configured with RSA-signed ECDH certificates may be configured to support the following cipher suites:

- TLS_ECDH_RSA_WITH_AES_128_GCM_SHA256 (0xC0, 0x31)

- TLS_ECDH_RSA_WITH_AES_256_GCM_SHA384 (0xC0, 0x32)
- TLS_ECDH_RSA_WITH_AES_128_CBC_SHA256 (0xC0, 0x29)
- TLS_ECDH_RSA_WITH_AES_256_CBC_SHA384 (0xC0, 0x2A)

TLS servers may be configured to support the following cipher suites when RSA-signed ECDH certificates are used with TLS versions 1.2, 1.1, or 1.0:

- TLS_ECDH_RSA_WITH_AES_128_CBC_SHA (0xC0, 0x0E)
- TLS_ECDH_RSA_WITH_AES_256_CBC_SHA (0xC0, 0x0F)

3.3.1.2 Cipher Suites for TLS 1.3

TLS 1.3 servers may be configured to support the following cipher suites:

- TLS_AES_128_GCM_SHA256 (013x, 0x01)
- TLS_AES_256_GCM_SHA384 (0x13, 0x02)
- TLS_AES_128_CCM_SHA256 (0x13, 0x04)
- TLS_AES_128_CCM_8_SHA256 (0x13, 0x05)

These cipher suites may be used with either RSA or ECDSA server certificates; DSA and DH certificates cannot be used with TLS 1.3. These cipher suites may also be used with pre-shared keys, as specified in Appendix C.

3.3.2 Implementation Considerations

System administrators need to fully understand the ramifications of selecting cipher suites and configuring applications to support only those cipher suites. The security guarantees of the cryptography are limited to the weakest cipher suite supported by the configuration. When configuring an implementation, there are several factors that affect the selection of supported cipher suites.

RFC 4346 [25] describes timing attacks on CBC cipher suites, as well mitigation techniques. TLS implementations **shall** use the bad_record_mac error to indicate a padding error when communications are secured using a CBC cipher suite. Implementations **shall** compute the MAC regardless of whether padding errors exist.

In addition to the CBC attacks addressed in RFC 4346 [25], the Lucky 13 attack [2] demonstrates that a constant-time decryption routine is also needed to prevent timing attacks. TLS implementations **should** support constant-time decryption, or near constant-time decryption.

The POODLE attack exploits nondeterministic padding in SSL 3.0 [49]. The vulnerability does not exist in the TLS protocols, but the vulnerability can exist in a TLS implementation when the SSL decoder code is reused to process TLS data [45]. TLS implementations **shall** correctly decode the CBC padding bytes.

Note that CBC-based attacks can be prevented by using AEAD cipher suites (e.g., GCM, CCM), which are supported in TLS 1.2.

3.3.2.1 Algorithm Support

Many TLS servers and clients support cipher suites that are not composed of only NIST-approved algorithms. If the server were configured to support cipher suites that are not recommended in this document, they may be chosen during the handshake. Therefore, it is important that the server is configured to only use recommended cipher suites. This is particularly important for server implementations that do not allow the server administrator to specify preference order. In such servers, the only way to ensure that a server uses NIST-approved algorithms for encryption is to disable cipher suites that use other encryption algorithms.

If the server implementation does allow the server administrator to specify a preference, the system administrator is encouraged to use the preference recommendations listed in Section 3.3.1.1.

3.3.2.2 Cipher Suite Scope

The selection of a cryptographic algorithm may be system-wide and not application specific for some implementations. For example, disabling an algorithm for one application on a system might disable that algorithm for all applications on that system.

3.3.3 Validated Cryptography

The cryptographic module used by the server **shall** be a FIPS 140-validated cryptographic module [70]. All cryptographic algorithms that are included in the configured cipher suites **shall** be within the scope of the validation, as well as the random number generator. Note that the TLS 1.1 pseudorandom function (PRF) uses MD5 and SHA-1 in parallel so that if one hash function is broken, security is not compromised. While MD5 is not a NIST-approved algorithm, the TLS 1.1 PRF is specified as acceptable in SP 800-135 [22]. TLS 1.3 uses the HMAC-based Extract-and-Expand Key Derivation Function (HKDF), described in RFC 5869 [43], to derive the session keys. Note that in TLS 1.1, the use of SHA-1 is found acceptable for specific cases of signing ephemeral keys and for signing for client authentication. This is acceptable due the difficulty for a third party to cause a collision that is not detected, and the client and server cannot exploit the collision they can cause, as further explained in footnote 19. In TLS 1.2, the default hash function in the PRF is SHA-256. Other than the SHA-1 exception listed for specific instances above, all cryptography used **shall** provide at least 112 bits of security. All server and client certificates **shall** contain public keys that offer at least 112 bits of security. All server and client certificates and certificates in their certification paths **shall** be signed using key pairs that offer at least 112 bits of security and SHA-224 or a stronger hashing algorithm. All ephemeral keys used by the client and server **shall** offer at least 112 bits of security. All symmetric algorithms used to protect the TLS data **shall** use keys that offer at least 112 bits of security.

The random number generator **shall** be tested and validated in accordance with SP 800-90A [9] under the NIST Cryptographic Algorithm Validation Program (CAVP) and successful results of this testing **shall** be indicated on the cryptographic module's FIPS 140 validation certificate.

The server random value, sent in the ServerHello message, contains a 4-byte timestamp[20] value and 28-byte random value in TLS version 1.0, 1.1, and 1.2, and contains a 32-byte random value in TLS 1.3. The validated random number generator **shall** be used to generate the random bytes of the server random value.[21] The validated random number generator **should** be used to generate the 4-byte timestamp of the server random value.

3.4 TLS Extension Support

Several TLS extensions are described in RFCs. This section contains recommendations for a subset of the TLS extensions that the Federal agencies **shall**, **should**, or **should not** use as they become prevalent in commercially available TLS servers and clients.

System administrators must carefully consider the risks of supporting extensions that are not listed as mandatory. Only extensions whose specification have an impact on security are discussed here, but the reader is advised that supporting any extension can have unintended security consequences. In particular, enabling extensions increases the potential for implementation flaws and could leave a system vulnerable. For example, the Heartbleed bug [72] was a flaw in an implementation of the heartbeat extension [62]. Although the extension has no inherent security implications, the implementation flaw exposed server data, including private keys, to attackers.

In general, it is advised that servers only be configured to support extensions that are required by the application or enhance security. Extensions that are not needed **should not** be enabled.

3.4.1 Mandatory TLS Extensions

The server **shall** support the use of the following TLS extensions.

1. Renegotiation Indication
2. Server Name Indication
3. Session Hash and Extended Master Secret
4. Signature Algorithms
5. Certificate Status Request extension

3.4.1.1 Renegotiation Indication

In TLS versions 1.0 to 1.2, session renegotiation is vulnerable to an attack in which the attacker forms a TLS connection with the target server, injects content of its choice, and then splices in a new TLS connection from a legitimate client. The server treats the legitimate client's initial TLS handshake as a renegotiation of the attacker's negotiated session and thus believes that the initial

[20] The timestamp value does not need to be correct in TLS. It can be any 4-byte value, unless otherwise restricted by higher-level or application protocols.

[21] TLS 1.3 implementations include a downgrade protection mechanism embedded in the random value that overwrites the last eight bytes of the server random value with a fixed value. When negotiating TLS 1.2, the last eight bytes of the server random will be set to 44 4F 57 4E 47 52 44 01. When TLS 1.1 or below is negotiated, the last eight bytes of the random value will be set to 44 4F 57 4E 47 52 44 00. This overwrite is separate from the validated random bit generator.

data transmitted by the attacker is from the legitimate client. The session renegotiation extension is defined to prevent such a session splicing or session interception. The extension uses the concept of cryptographically binding the initial session negotiation and session renegotiation.

Server implementations **shall** perform initial and subsequent renegotiations in accordance with RFC 5746 [57] and [56].

3.4.1.2 Server Name Indication

Multiple virtual servers may exist at the same network address. The server name indication extension allows the client to specify which of the servers located at the address it is trying to connect with. This extension is available in all versions of TLS. The server **shall** be able to process and respond to the server name indication extension received in a ClientHello message as described in [30].

3.4.1.3 Session Hash and Extended Master Secret

Bhargavan et al. have shown that an active attacker can synchronize two TLS sessions such that they share the same master secret, thus allowing the attacker to perform a man-in-the-middle attack [13]. The Session Hash and Extended Master Secret extension, specified in RFC 7627 [42], prevents such attacks by binding the master secret to a hashed log of the full handshake. The server **shall** support the use of this extension.

3.4.1.4 Signature Algorithms

Servers **shall** support the processing of the signature algorithms extension received in a ClientHello message. The extension, its syntax, and processing rules are described in Sections 7.4.1.4.1, 7.4.2, and 7.4.3 of RFC 5246 [26] and Section 4.2.3 of the TLS 1.3 specification [56]. Note that the extension described in the TLS 1.3 specification updates the extension described in RFC 5246 by adding an additional signature scheme.

3.4.1.5 Certificate Status Request

When the client wishes to receive the revocation status of the TLS server certificate from the TLS server, the client includes the Certificate Status Request (status_request) extension in the ClientHello message. Upon receipt of the status_request extension, a server with a certificate issued by a CA that supports OCSP **shall** include the certificate status along with its certificate by sending a CertificateStatus message immediately following the Certificate message.[22] While the extension itself is extensible, only OCSP-type certificate status is defined in [30]. This extension is also called OCSP stapling.

3.4.2 Conditional TLS Extensions

Support the use of the following TLS extensions under the circumstances described in the

[22] In TLS 1.3 the server includes the certificate status in the Certificate message.

following paragraphs:

1. The Fallback Signaling Cipher Suite Value (SCSV) extension **shall** be supported if the server supports versions of TLS prior to TLS 1.2 and does not support TLS 1.3.
2. The Encrypt-then-MAC extension **shall** be supported if the server is configured to negotiate CBC cipher suites.
3. The Negotiated Groups extension **shall be** supported if the server supports ephemeral ECDH cipher suites or if the server supports TLS 1.3.
4. The EC Point Format extension **shall** be supported if the server supports EC cipher suites.
5. The Multiple Certificate Status extension **should** be supported if status information for the server's certificate is available via OCSP, and the extension is supported by the server implementation.
6. The Trusted CA Indication extension **shall** be supported if the server communicates with memory-constrained clients (e.g., low-memory client devices in the Internet of Things), and the server has been issued certificates by multiple CAs.
7. The Truncated HMAC extension may be supported if the server communicates with constrained device clients and the server implementation does not support variable-length padding.
8. The Signed Certificate Timestamps extension **should** be supported if the server's certificate was issued by a publicly trusted CA, and the certificate does not include a Signed Certificate Timestamps List extension.
9. The Supported Versions, Cookie, and Key Share extensions **shall** be supported if the server supports TLS 1.3.
10. The Pre-Shared Key extension may be supported if the server supports TLS 1.3.
11. The Pre-Shared Key Exchange Modes extension **shall** be supported if the server supports TLS 1.3 and the Pre-Shared Key extension.

3.4.2.1 Fallback Signaling Cipher Suite Value (SCSV)

TLS 1.3 includes a downgrade protection mechanism that previous versions do not. In versions prior to TLS 1.3, an attacker can use an external version negotiation means to force unnecessary protocol downgrades on a connection. In particular, the attacker can make it appear that the connection failed with the requested TLS version, and some client implementations will try the connection again with a downgraded protocol version. This extension, described in RFC 7507 [48], provides a mechanism to prevent unintended protocol downgrades. Clients signal when a connection is a fallback, and if the server deems it inappropriate (i.e., the server supports a higher TLS version), the server returns a fatal alert.

When TLS versions prior to TLS 1.2 are supported by the server, and TLS version 1.3 is not supported, the fallback SCSV extension **shall** be supported.

3.4.2.2 Encrypt-then-MAC

Several attacks on CBC cipher suites have been possible due to the MAC-then-encrypt order of operations used in TLS versions 1.0, 1.1, and 1.2. The Encrypt-then-MAC extension alters the order that the encryption and MAC operations are applied to the data. This is believed to provide stronger security, and mitigate or prevent several known attacks on CBC cipher suites. Servers that are configured to negotiate CBC cipher suites **shall** support this extension as described in [36].

3.4.2.3 Negotiated Groups

The Negotiated Groups extension[23] (supported_groups) allows the client to indicate the groups that it supports to the server. The extension was originally called the Supported Elliptic Curves extension (elliptic_curves), and was only used for elliptic curve groups, but it may now also be used to negotiate finite field groups. In TLS 1.3, the Negotiated Groups extension must be used to negotiate both elliptic curve and finite field groups. Servers that support either ephemeral ECDH cipher suites or TLS 1.3 **shall** support this extension. When elliptic curve cipher suites are configured, at least one of the NIST-approved curves, P-256 (secp256r1) and P-384 (secp384r1), **shall** be supported as described in RFC 4492 [14]. The finite field groups ffdhe2048, ffdhe3072, ffdhe4096, ffdhe6144, and ffdhe8192 may be supported (see RFC 7919 [35]).

3.4.2.4 Key Share

The Key Share extension is used in TLS 1.3 to send cryptographic parameters. Servers that support TLS 1.3 **shall** support this extension as described in Section 4.2.7 of the TLS 1.3 specification [56].

3.4.2.5 EC Point Format

Servers that support EC cipher suites **shall** be able to process the supported EC point format received in the ClientHello message by the client. The servers **shall** process this extension in accordance with Section 5.1 of RFC 4492 [14].

Servers that support EC cipher suites **shall** also be able to send the supported EC point format in the ServerHello message as described in Section 5.2 of RFC 4492 [14].

3.4.2.6 Multiple Certificate Status

The multiple certificate status extension improves on the Certificate Status Request extension described in Section 3.4.1.5 by allowing the client to request the status of all certificates provided by the server in the TLS handshake. When the server returns the revocation status of all the certificates in the server certificate chain, the client does not need to query any revocation service providers, such as OCSP responders. This extension is documented in RFC 6961 [51]. Servers that have this capability and that have certificates issued by CAs that support OCSP **should** be configured to support this extension.

3.4.2.7 Trusted CA Indication

The trusted CA indication (trusted_ca_keys) extension allows a client to specify which CA root

[23] Called "Supported Groups" in RFC 7919.

keys it possesses. This is useful for sessions where the client is memory-constrained and possesses a small number of root CA keys. Servers that communicate with memory-constrained clients and that have been issued certificates by multiple CAs **shall** be able to process and respond to the trusted CA indication extension received in a ClientHello message as described in [30].

3.4.2.8 Truncated HMAC

The Truncated HMAC extension allows a truncation of the HMAC output to 80 bits for use as a MAC tag. An 80-bit MAC tag complies with the recommendations in SP 800-107 [21], but reduces the security provided by the integrity algorithm. Because forging a MAC tag is an online attack, and the TLS session will terminate immediately when an invalid MAC tag is encountered, the risk introduced by using this extension is low. However, truncated MAC tags **shall not** be used in conjunction with variable-length padding, due to attacks described by Paterson et al. [50]. This extension cannot be used with TLS 1.3.

3.4.2.9 Pre-Shared Key

The Pre-Shared Key extension (pre_shared_key), available in TLS 1.3, is used to indicate the identity of the pre-shared key to be used for PSK key establishment. In TLS 1.3 pre-shared keys may either be established out-of-band, as in TLS 1.2 are below, or in a previous connection, in which case they are used for session resumption. Servers that support TLS 1.3 may be configured to support this extension in order to support session resumption or to support the use of pre-shared keys that are established out-of-band.

3.4.2.10 Pre-Shared Key Exchange Modes

A TLS 1.3 client must send the Pre-Shared Key Exchange Modes extension (psk_key_exchange_modes) if it sends the Pre-Shared Key extension. TLS 1.3 servers use the list of key exchange modes present in the extension to select an appropriate key exchange method. TLS servers that support TLS 1.3 and the Pre-Shared Key extension **shall** support this extension.

3.4.2.11 Signed Certificate Timestamps

The Certificate Transparency project (described in RFC 6962 [46]) strives to reduce the impact of certificate-based threats by making the issuance of CA-signed certificates more transparent. This is done through the use of public logs of certificates, public log monitoring, and public certificate auditing. Certificate logs are cryptographically assured records of certificates that are open to public scrutiny. Certificates may be appended to logs, but they cannot be removed, modified, or inserted into the middle of a log. Monitors watch certificate logs for suspicious certificates, such as those that were not authorized by the domain they claim to represent. Auditors have the ability to check the membership of a particular certificate in a log, as well as verify the integrity and consistency of logs.

Evidence that the server's certificate has been submitted to Certificate Transparency logs may be provided to clients either in the certificate itself or in a Signed Certificate Timestamps TLS extension (signed_certificate_timestamp). Servers with certificates issued by publicly trusted

CAs that do not include a Signed Certificate Timestamps List extension **should** support the Signed Certificate Timestamps TLS extension.

3.4.2.12 Supported Versions

The supported versions extension was added in TLS 1.3. The extension is sent in the ClientHello message to indicate which versions of TLS the client supports. A TLS 1.3 server **shall** be able to process this extension. When it is absent from the ClientHello message, the server **shall** use the version negotiation specified in TLS 1.2 and earlier.

3.4.2.13 Cookie

The cookie extension was added in TLS 1.3. It allows the server to force the client to prove that it is reachable at its apparent network address, and offload state to the client. Servers that support TLS 1.3 may support the cookie extension in accordance with the TLS 1.3 specification [56].

3.4.3 Discouraged TLS Extensions

The following extension **should not** be used:

1. Client Certificate URL
2. Early Data Indication

3.4.3.1 Client Certificate URL

The Client Certificate URL extension allows a client to send a URL pointing to a certificate, rather than sending a certificate to the server during mutual authentication. This can be very useful for mutual authentication with constrained clients. However, this extension can be used for malicious purposes. The URL could belong to an innocent server on which the client would like to perform a denial of service attack, turning the TLS server into an attacker. A server that supports this extension also acts as a client while retrieving a certificate, and therefore becomes subject to additional security concerns. For these reasons, the Client Certificate URL extension **should not** be supported. However, if an agency determines that the risks are minimal, and this extension is needed for environments where clients are in constrained devices, the extension may be supported. If the client certificate URL extension is supported, the server **shall** be configured to mitigate the security concerns described above and in Section 11.3 of [30].

3.4.3.2 Early Data Indication

In TLS 1.3, the Early Data Indication extension (early_data) allows the client to send application data in the ClientHello message when pre-shared keys are used. This includes pre-shared keys that are established out-of-band, as well those used for session resumption. TLS does not protect this early data against replay attacks. Servers **should not** process early data received in the ClientHello message. If the server is configured to send the Early Data Indication extension, the server **shall** use methods of replay protection, such as those described in Section 8 of the TLS 1.3 specification [56].

3.5 Client Authentication

Where strong cryptographic client authentication is required, TLS servers may use the TLS protocol client authentication option to request a client certificate to cryptographically authenticate the client.[24] For example, the Personal Identity Verification (PIV) Authentication certificate [68] (and the associated private key) provides a suitable option for strong authentication of Federal employees and contractors. To ensure that agencies are positioned to take full advantage of the PIV Card, all TLS servers that perform client authentication **shall** implement certificate-based client authentication.

The client authentication option requires the server to implement the X.509 path validation mechanism and a trust anchor store. Requirements for these mechanisms are specified in Sections 3.5.1 and 3.5.2, respectively. To ensure that cryptographic authentication actually results in strong authentication, client keys **shall** contain at least 112 bits of security. Section 3.5.3 describes mechanisms that can contribute, albeit indirectly, to enforcing this requirement. Section 3.5.4 describes the client's use of the server hints list.

The TLS server **shall** be configurable to terminate the connection with a fatal "handshake failure" alert when a client certificate is requested, and the client does not have a suitable certificate.

3.5.1 Path Validation

The client certificate **shall** be validated in accordance with the certification path validation rules specified in Section 6 of [20]. In addition, the revocation status of each certificate in the certification path **shall** be validated using the Online Certificate Status Protocol (OCSP) or a certificate revocation list (CRL). OCSP checking **shall** be in compliance with RFC 6960 [61].

Revocation information **shall** be obtained as described in Section 3.2.2.

The server **shall** be able to determine the certificate policies that the client certificate is trusted for by using the certification path validation rules specified in Section 6 of [20]. Server and backend applications may use this determination to accept or reject the certificate. Checking certificate policies assures the server that only client certificates that have been issued with acceptable assurance, in terms of CA and registration system and process security, are accepted.

Not all commercial products may support the public-key certification path validation and certificate policy processing rules listed and cited above. When implementing client authentication, the Federal agencies **shall** either use the commercial products that meet these

[24] The CertificateVerify message is sent to explicitly verify a client certificate that has a signing capability. In TLS 1.1 (and TLS 1.0), this message uses SHA-1 to generate a signature on all handshake messages that came before it. SP 800-131A [10] states that the use of SHA-1 for digital signature generation is disallowed after 2013. Even if a collision is found, the client must use its private key to authenticate itself by signing the hash. Due to the client random and server random values, the server, the client, or a third party cannot use a colliding set of messages to masquerade as the client or server in future connections. Any modification to this message, preceding messages, or subsequent messages will ultimately result in a failed connection. Therefore, SHA-1 is allowed for generating digital signatures in the TLS CertificateVerify message.

requirements or augment commercial products to meet these requirements.

The server **shall** be able to provide the client certificate, and the certificate policies for which the client certification path is valid, to the applications in order to support access control decisions.

3.5.2 Trust Anchor Store

Having an excessive number of trust anchors installed in the TLS application can expose the application to all the PKIs emanating from those trust anchors. The best way to minimize the exposure is to only include the trust anchors in the trust anchor store that are absolutely necessary for client public-key certificate authentication.

The server **shall** be configured with only the trust anchors that the server trusts, and of those, only the ones that are required to authenticate the clients, in the case where the server supports client authentication in TLS. These trust anchors are typically a small subset of the trust anchors that may be included on the server by default. Also, note that this trust anchor store is distinct from the machine trust anchor store. Thus, the default set of trust anchors **shall** be examined to determine if any of them are required for client authentication. Some specific enterprise and/or PKI service provider trust anchor may need to be added.

In the U.S. Federal environment, in most situations, the Federal Common Policy Root or the agency root (if cross certified with the Federal Bridge Certification Authority or the Federal Common Policy Root) should be sufficient to build a certification path to the client certificates.

System administrators of a TLS server that supports certificate-based client authentication **shall** perform an analysis of the client certificate issuers and use that information to determine the minimum set of trust anchors required for the server. The server **shall** be configured to only use those trust anchors.

3.5.3 Checking the Client Key Size

The only direct mechanism for a server to check whether the key size and algorithms presented in a client public-key certificate are acceptable is for the server to examine the public key and algorithm in the client's certificate. An indirect mechanism is to check that the certificate policies extension in the client public-key certificate indicates the minimum cryptographic strength of the signature and hashing algorithms used, and for the server to perform certificate policy processing and checking. The server **shall** check the client key length if client authentication is performed, and the server implementation provides a mechanism to do so. Federal Agencies **shall** use the key size guidelines provided in [10] to check the client key size.

3.5.4 Server Hints List

Clients may use the list of trust anchors sent by the server in the CertificateRequest message to determine if the client's certification path terminates at one of these trust anchors. The list sent by the server is known as a "hints list." When the server and client are in different PKI domains, and the trust is established via direct cross-certification between the two PKI domains (i.e., the server PKI domain and the client PKI domain) or via transitive cross-certification (i.e., through cross-certifications among multiple PKI domains), the client may erroneously decide that its certificate will not be accepted by the server since the client's trust anchor is not sent in the hints list. To mitigate this failure, the server **shall** either 1) maintain the trust anchors of the various PKIs whose subscribers are the potential clients for the server, and include them in the hints list, or 2) be configured to send an empty hints list so that the client can always provide a certificate it possesses. The hints list **shall** be distinct from the server's trust anchor store.[25] In other words, the server **shall** continue to only populate its trust anchor store with the trust anchor of the server's PKI domain and the domains it needs to trust directly for client authentication. Note that the distinction between the server hints list and the server's own trust store is as follows: 1) the hints list is the list of trust anchors that a potential client might trust; and 2) the server's trust store is the list of trust anchors that the server explicitly trusts.

3.6 Session Resumption

Previous TLS sessions can be resumed, allowing for a connection to be established using an abbreviated handshake. All versions of TLS offer session resumption, although the mechanism for performing resumption differs. A server may be configured to ignore requests to resume a session, if the implementation allows it.

TLS 1.3 allows the client to send data in the first flight of handshake, known as 0-RTT data. This practice may provide opportunities for attackers, such as replay attacks.[26] The TLS 1.3 specification describes two mechanisms to mitigate threats introduced by 0-RTT data. One of these mechanisms is single-use tickets, which allows each session ticket to be used only once. It may be difficult to implement this mechanism in an environment with distributed servers, as a session database must be shared between servers. ClientHello recording is a second mechanism that defends against replay attacks by recording a unique value derived from the ClientHello and rejecting duplicates. To limit the size of the list, the server can maintain a list only within a specified time window. In general, 0-RTT data **should not** be accepted by the server. If the server does allow 0-RTT data, then the server **should** use the single-use ticket mechanism in accordance with the TLS 1.3 specification (see Section 8 of [56]).

3.7 Compression Methods

The use of compression may enable attackers to perform attacks using compression-based side channels (e.g., [58], [12]). Because of this, only the null compression method, which disables TLS compression, **should** be used. If compression is used, the methods defined in RFC 3749 [39] or RFC 3943 [34] may be used.

3.8 Operational Considerations

The sections above specify TLS-specific functionality. This functionality is necessary, but is not sufficient, to achieve security in an operational environment.

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[25] Depending on the server and client trust anchors, the two lists could be identical, could have some trust anchors in common, or have no trust anchors in common.

[26] TLS does not inherently provide replay protection for 0-RTT data.

Federal agencies **shall** ensure that TLS servers include appropriate network security protections as specified in other NIST guidelines, such as SP 800-53 [41].

The server **shall** operate on a secure operating system.[27] Where the server relies on a FIPS 140 Level 1 cryptographic module, the software and private key **shall** be protected using the operating system identification, authentication and access control mechanisms. In some highly sensitive applications, server private keys may require protection using a FIPS 140 Level 2 or higher hardware cryptographic module.

The server and associated platform **shall** be kept up-to-date in terms of security patches. This is critical to various aspects of security.

[27] A secure operating system contains and uses the following features: operating system protection from applications and processes; operating system mediated isolation among applications and processes; user identification and authentication; access control based on authenticated user identity, and event logging of security-relevant activities.

4 Minimum Requirements for TLS Clients

This section provides a minimum set of requirements that a TLS client must meet in order to adhere to these guidelines. Requirements are organized as follows: TLS protocol version support; client keys and certificates; cryptographic support; TLS extension support; server authentication; session resumption; compression methods; and operational considerations.

Specific requirements are stated as either implementation requirements or configuration requirements. Implementation requirements indicate that Federal agencies **shall not** procure TLS client implementations unless they include the required functionality. Configuration requirements indicate that system administrators are required to verify that particular features are enabled, or in some cases, configured appropriately if present.

4.1 Protocol Version Support

The client **shall** be configured to use TLS 1.2 and **should** be configured to use TLS 1.3. The client may be configured to use TLS 1.1 and TLS 1.0 to facilitate communication with private sector servers. The client **shall not** be configured to use SSL 2.0 or SSL 3.0. Agencies **shall** develop migration plans to support TLS 1.3 by January 1, 2020.

4.2 Client Keys and Certificates

Some applications may require client authentication. For TLS, this can be achieved by performing mutual authentication using certificates.

4.2.1 Client Certificate Profile

When certificate-based client authentication is needed, the client **shall** be configured with a certificate that adheres to the recommendations presented in this section. A client certificate may be configured on the system or located on an external device (e.g., a PIV Card). For this specification, the TLS client certificate **shall** be an X.509 version 3 certificate; both the public key contained in the certificate and the signature **shall** provide at least 112 bits of security. If the client supports TLS versions prior to TLS 1.2, the certificate **should** be signed with an algorithm that is consistent with the public key:[28]

- Certificates containing RSA (signature), ECDSA, or DSA public keys **should** be signed with those same signature algorithms, respectively;
- Certificates containing Diffie-Hellman certificates **should** be signed with DSA; and
- Certificates containing ECDH public keys **should** be signed with ECDSA.

The client certificate profile is listed in Table 4-1. In the absence of an agency-specific client certificate profile, this profile **should** be used for client certificates.

[28] This recommendation is an artifact of requirements in TLS 1.0 and 1.1.

Table 4-1: TLS Client Certificate Profile

Field	**Critical**	**Value**	**Description**
Version	N/A	2	Version 3
Serial Number	N/A	Unique positive integer	Must be unique
Issuer Signature Algorithm	N/A	*Values by CA key type:*	
		sha256WithRSAEncryption {1 2 840 113549 1 1 11}, or stronger	CA with RSA key
		ecdsa-with-SHA256 {1 2 840 10045 4 3 2}, or stronger	CA with elliptic curve key
		id-dsa-with-sha256 {2 16 840 1 101 3 4 3 2}, or stronger	CA with DSA key
Issuer Distinguished Name	N/A	Unique X.500 Issuing CA DN	A single value **shall** be encoded in each RDN. All attributes that are of directoryString type **shall** be encoded as a printable string.
Validity Period	N/A	3 years or less	Dates through 2049 expressed in UTCTime
Subject Distinguished Name	N/A	Unique X.500 subject DN per agency requirements	A single value **shall** be encoded in each RDN. All attributes that are of directoryString type **shall** be encoded as a printable string.
Subject Public Key Information	N/A	*Values by certificate type:*	
		rsaEncryption {1 2 840 113549 1 1 1}	RSA signature certificate 2048-bit RSA key modulus, or other approved lengths as defined in [FIPS186-4] and [6] Parameters: NULL
		ecPublicKey {1 2 840 10045 2 1}	ECDSA signature certificate or ECDH certificate Parameters: namedCurve OID for names curve specified in FIPS 186-4. The curve **shall** be P-256 or P-384 SubjectPublic Key: Uncompressed EC Point.
		id-dsa {1 2 840 10040 4 1}	DSA signature certificate Parameters: p, q, g
		dhpublicnumber {1 2 840 10046 2 1}	DH certificate Parameters: p, g, q
Issuer's Signature	N/A	Same value as in Issuer Signature Algorithm	
Extensions			
Authority Key Identifier	No	Octet String	Same as subject key identifier in issuing CA certificate Prohibited: Issuer DN, Serial Number tuple

Field	Critical	Value	Description
Subject Key Identifier	No	Octet String	Same as in PKCS-10 request or calculated by the issuing CA
Key Usage	Yes	digitalSignature	RSA certificate, DSA certificate, ECDSA certificate
		keyAgreement	ECDH certificate, DH certificate
Extended Key Usage	No	id-kp-clientAuth {1 3 6 1 5 5 7 3 2}	Required
		anyExtendedKeyUsage {2 5 29 37 0}	The anyExtendedKeyUsage OID **should** be present if the extended key usage extension is included, but there is no intention to limit the types of applications with which the certificate may be used (e.g., the certificate is a general-purpose authentication certificate).
			Prohibited: all others unless consistent with key usage extension
Certificate Policies	No	Per issuer's X.509 certificate policy	
Subject Alternative Name	No	RFC 822 e-mail address, Universal Principal Name (UPN), DNS Name, and/or others	Optional
Authority Information Access	No	id-ad-caIssuers	Required. Access method entry contains HTTP URL for certificates issued to issuing CA
		id-ad-ocsp	Optional. Access method entry contains HTTP URL for the issuing CA OCSP responder
CRL Distribution Points	No	See comments	Optional: HTTP value in distributionPoint field pointing to a full and complete CRL. Prohibited: reasons and cRLIssuer fields, and nameRelativetoCRLIssuer CHOICE

If a client has multiple certificates that meet the requirements of the TLS server, the TLS client (e.g., a browser) may ask the user to select from a list of certificates. The extended key usage (EKU) extension limits the operations for which the keys in a certificate may be used, and so the use of the EKU extension in client certificates may eliminate this request. If the EKU extension is included in client certificates, then the id-kp-client-auth key purpose OID **should** be included in the certificates to be used for TLS client authentication and **should** be omitted from any other certificates.

Client certificates are also filtered by TLS clients on the basis of an ability to build a path to one of the trust anchors in the hints list sent by the server, as described in Section 3.5.4.

4.2.2 Obtaining Revocation Status Information for the Server Certificate

The client **shall** perform revocation checking of the server certificate. Revocation information can be obtained by the client from one of the following locations:

1. OCSP response or responses in the server's CertificateStatus message ([30], [51]) (or Certificate message in TLS 1.3);

2. Certificate Revocation List (CRL) or OCSP response in the client's local certificate store;
3. OCSP response from a locally configured OCSP responder;
4. OCSP response from the OCSP responder location identified in the OCSP field in the Authority Information Access extension in the server certificate; or
5. CRL from the CRL Distribution Point extension in the server certificate.

When the server does not provide the revocation status, the local certificate store does not have the current or a cogent CRL or OCSP response, and the OCSP responder and the CRL distribution point are unavailable or inaccessible at the time of TLS session establishment, the client will either terminate the connection or accept a potentially revoked or compromised certificate. The decision to accept or reject a certificate in this situation **should** be made according to agency policy.

Other emerging concepts that can be useful in lieu of revocation checking are further discussed in Appendix D.2.

4.2.3 Client Public-Key Certificate Assurance

The client public-key certificate may be trusted by the servers on the basis of the policies, procedures and security controls used to issue the client public-key certificate as described in Section 3.5.1. For example, these guidelines recommend that the PIV Authentication certificate be the norm for authentication of Federal employees and long-term contractors. PIV Authentication certificate policy is defined in the Federal PKI Common Policy Framework [32], and PIV-I Authentication certificate policy is defined in the X.509 Certificate Policy for the Federal Bridge Certification Authority [64]. Depending on the requirements of the server-side application, other certificate policies may also be acceptable. Guidance regarding other certificate policies is outside the scope of these guidelines.

4.3 Cryptographic Support

4.3.1 Cipher Suites

The acceptable cipher suites for a TLS client are the same as those for a TLS server. General-purpose cipher suites are listed in Section 3.3.1, and cipher suites appropriate for pre-shared key environments for TLS 1.2 and prior versions are listed in Appendix C. When ephemeral keys are used to establish the master secret, each ephemeral key-pair (i.e., the server ephemeral key-pair and the client ephemeral key-pair) **shall** have at least 112 bits of security.

The client **should not** be configured to use cipher suites other than those listed in Section 3.3.1 or Appendix C.

To mitigate attacks against CBC mode, TLS implementations that support versions prior to TLS 1.3 **shall** use the bad_record_mac error to indicate a padding error. Implementations **shall** compute the MAC regardless of whether padding errors exist. TLS implementations **should** support constant-time decryption, or near constant-time decryption. This does not apply to TLS 1.3 implementations, as they do not support cipher suites that use CBC mode.

4.3.2 Validated Cryptography

The client **shall** use validated cryptography, as described for the server in Section 3.3.3.

The validated random number generator **shall** be used to generate the random bytes (32 bytes in TLS 1.3; 28 bytes in prior TLS versions) of the client random value. The validated random number generator **should** be used to generate the 4-byte timestamp of the client random value for TLS versions prior to TLS 1.3.

4.4 TLS Extension Support

Some servers will refuse the connection if any TLS extensions are included in the ClientHello message. Interoperability with servers that do not properly handle TLS extensions may require multiple connection attempts by the client.

4.4.1 Mandatory TLS Extensions

The client **shall** be configured to use the following extensions:

1. Renegotiation Indication
2. Server Name Indication
3. Session Hash and Extended Master Secret
4. Signature Algorithms
5. Certificate Status Request

4.4.1.1 Renegotiation Indication

The Renegotiation Indication extension is required by these guidelines as described in Section 3.4.1.1. Clients **shall** perform the initial and subsequent renegotiations in accordance with RFC 5746 [57].

4.4.1.2 Server Name Indication

The server name indication extension is described in Section 3.4.1.2. The client **shall** be capable of including this extension in a ClientHello message, as described in RFC 6066 [30].

4.4.1.3 Session Hash and Extended Master Secret

The Session Hash and Extended Master Secret extension, described in Section 3.4.1.3, prevents man-in-the-middle attacks by binding the master secret to a hashed log of the full handshake. The client **shall** support this extension.

4.4.1.4 Signature Algorithms

The clients **shall** assert acceptable hashing and signature algorithm pairs in this extension in TLS 1.2 and TLS 1.3 ClientHello messages. The extension, its syntax, and processing rules are described in Sections 7.4.1.4.1, 7.4.4, 7.4.6 and 7.4.8 of RFC 5246 [26] and in Section 4.2.3 of the TLS 1.3 specification [56]. Note that the extension described in the TLS 1.3 specification updates the extension described in RFC 5246 by adding an additional signature scheme.

4.4.1.5 Certificate Status Request

The client **shall** include the "status_request" extension in the ClientHello message.

4.4.2 Conditional TLS Extensions

A TLS client supports the following TLS extensions under the circumstances described:

1. The Fallback Signaling Cipher Suite Value (SCSV) extension **shall** be supported if the client supports versions of TLS prior to TLS 1.2 and does not support TLS 1.3.
2. The Negotiated Groups extension **shall** be supported if the client supports ephemeral ECDH cipher suites or if the client supports TLS 1.3.
3. The EC Point Format TLS extension **shall** be supported if the client supports EC cipher suite(s).
4. The Multiple Certificate Status extension **should** be enabled if the extension is supported by the client implementation.
5. The Trusted CA Indication extension **should** be supported by clients that run on memory-constrained devices where only a small number of CA root keys are stored.
6. The Encrypt-then-MAC extension **shall** be supported when CBC mode cipher suites are configured.
7. The Truncated HMAC extension may be supported by clients that run on constrained devices when variable-length padding is not supported.
8. The Supported versions, Cookie, and Key Share extensions **shall** be supported by TLS 1.3 clients.
9. The Pre-Shared Key extension may be supported by TLS 1.3 clients.
10. The Pre-Shared Key Exchange Modes extension **shall** be supported by TLS 1.3 clients that support the Pre-Shared Key extension.

4.4.2.1 Fallback Signaling Cipher Suite Value (SCSV)

This extension, described in Section 3.4.2.1, provides a mechanism to prevent unintended protocol downgrades in TLS versions prior to TLS 1.3. Clients signal when a connection is a fallback, and if the server supports a higher TLS version, the server returns a fatal alert. If the client does not support TLS 1.3, and is attempting to connect with a TLS version prior to TLS 1.2, the client **shall** include TLS_FALLBACK_SCSV at the end of the cipher suite list in the ClientHello message.

4.4.2.2 Negotiated Groups

The Negotiated Groups extension (supported_groups) is described in Section 3.4.2.3. Client implementations **shall** send this extension in TLS 1.3 ClientHello messages and in ClientHello messages that include ephemeral ECDH cipher suites. When elliptic curve cipher suites are configured, at least one of the NIST-approved curves, P-256 (secp256r1) and P-384 (secp384r1), **shall** be supported as described in RFC 4492 [14]. The finite field groups ffdhe2048, ffdhe3072, ffdhe4096, ffdhe6144, and ffdhe8192 may be supported (see RFC 7919 [35]).

4.4.2.3 Key Share

The Key Share extension is used to send cryptographic parameters. Clients that support TLS 1.3 **shall** support this extension as described in Section 4.2.7 of the TLS 1.3 specification [56].

4.4.2.4 EC Point Format

The clients that support EC cipher suites **shall** be capable of specifying supported EC point formats in the ClientHello message, in accordance with Section 5.1 of [14].

Clients that support EC cipher suites **shall** support the processing of at least one[29] of the EC point formats received in the ServerHello message, as described in Section 5.2 of [14].

4.4.2.5 Multiple Certificate Status

The multiple certificate status extension is described in Section 3.4.2.6. This extension improves on the Certificate Status Request extension described in Section 3.4.1.5 by allowing the client to request the status of all certificates provided by the server in the TLS handshake. This extension is documented in RFC 6961 [51]. Client implementations that have this capability **should** be configured to include this extension in the ClientHello message.

4.4.2.6 Trusted CA Indication

Clients that run on memory-constrained devices where only a small number of CA root keys are stored **should** be capable of including the trusted CA indication (trusted_ca_keys) extension in a ClientHello message as described in [30].

4.4.2.7 Encrypt-then-MAC

The Encrypt-then-MAC extension, described in Section 3.4.2.2, can mitigate or prevent several known attacks on CBC cipher suites. In order for this modified order of operations to be applied, both server and client need to implement the Encrypt-then-MAC extension and negotiate its use. When CBC mode cipher suites are configured, clients **shall** support this extension as described in RFC 7366 [36]. The client **shall** include this extension in the ClientHello message whenever the ClientHello message includes CBC cipher suites.

4.4.2.8 Truncated HMAC

The Truncated HMAC extension is described in Section 3.4.2.8. Clients running on constrained devices may support this extension. The Truncated HMAC extension **shall not** be used in conjunction with variable-length padding, due to attacks described by Paterson et al. [50]. This extension cannot be used with TLS 1.3.

[29] The uncompressed point format must be supported, as described in Sections 5.1.2 and 5.2 of [14].

4.4.2.9 Supported Versions

The supported versions extension was added in TLS 1.3. The client sends this extension in the ClientHello message to indicate which versions of TLS it is able to negotiate. A TLS 1.3 client **shall** send this extension in the ClientHello message.

4.4.2.10 Cookie

The cookie extension, added in TLS 1.3, allows the server to force the client to prove that it is reachable at its apparent network address, and offload state to the client. Clients that support TLS 1.3 **shall** support the cookie extension in accordance with the TLS 1.3 specification [56].

4.4.2.11 Pre-shared Key

The Pre-Shared Key extension (pre_shared_key), available in TLS 1.3, is used to indicate the identity of the pre-shared key to be used for PSK key establishment. In TLS 1.3 pre-shared keys may either be established out-of-band, as in TLS 1.2 and prior versions, or in a previous connection, in which case they are used for session resumption. Clients that support TLS 1.3 may be configured to use this extension in order to allow session resumption or to allow the use of pre-shared keys that are established out-of-band.

4.4.2.12 Pre-Shared Key Exchange Modes

A TLS 1.3 client must send the Pre-Shared Key Exchange Modes extension (psk_key_exchange_modes) if it sends the Pre-Shared Key extension, otherwise the server will abort the handshake. TLS clients that support TLS 1.3 and the Pre-Shared Key extension **shall** implement this extension.

4.4.3 Discouraged TLS Extension

The following extensions **should not** be used:

1. Client Certificate URL
2. Early Data Indication

The reasons for discouraging the use of these extensions can be found in Section 3.4.3.

4.5 Server Authentication

The client **shall** be able to build the certification path for the server certificate presented in the TLS handshake with at least one of the trust anchors in the client trust store, if an appropriate trust anchor is present in the store. The client may use all or a subset of the following resources to build the certification path: local certificate store, certificates received from the server during the handshake, LDAP, resources declared in CA Repository field of the Subject Information Access extension in various CA certificates, and resources declared in the CA Issuers field of the Authority Information Access extension in various certificates.

4.5.1 Path Validation

The client **shall** validate the server certificate in accordance with the certification path validation rules specified in Section 6 of [20]. The revocation status of each certificate in the certification path **shall** be checked using Online Certificate Status Protocol (OCSP) or a certificate revocation list (CRL). OCSP checking **shall** be in compliance with [61]. Revocation information **shall** be obtained as described in Section 4.2.2.

Not all clients support name constraint checking. The Federal agencies **should** only procure clients that perform name constraint checking in order to obtain assurance that unauthorized certificates are properly rejected. As an alternative, the Federal agency may procure clients that use one or more of the features discussed in Appendix D.1.

The client **shall** terminate the TLS connection if path validation fails.

Federal agencies **shall** only use clients that check that the DNS name or IP address, whichever is presented in the client TLS request, matches a DNS name or IP address contained in the server certificate. The client **shall** terminate the TLS connection if the name check fails.

4.5.2 Trust Anchor Store

Having an excessive number of trust anchors installed in the TLS client can increase the chances for the client to be spoofed. As the number of trust anchors increase, the number of CAs that the client trusts increases, and the chances that one of these CAs or its registration system or process will be compromised to issue TLS server certificates also increases.

Clients **shall not** overpopulate their trust stores with various CA certificates that can be verified via cross-certification. Direct trust of these certificates can expose the clients unduly to a variety of situations, including but not limited to, revocation or compromise of these trust anchors. Direct trust also increases the operational and security burden on the clients to promulgate addition and deletion of trust anchors. Instead, the client **shall** rely on the server overpopulating or not providing the hints list to mitigate the client certificate selection and path-building problem as discussed in Section 3.5.4.

4.5.3 Checking the Server Key Size

The only direct mechanism for a client to check if the key size presented in a server public certificate is acceptable is for the client to examine the server public key in the certificate. An indirect mechanism is to ensure that the server public-key certificate was issued under a policy that indicates the minimum cryptographic strength of the signature and hashing algorithms used. In some cases, this can be done by the client performing certificate policy processing and checking. However, since many TLS clients cannot be configured to accept or reject certificates based on the policies under which they were issued, this may require ensuring that the trust anchor store only contains CAs that issue certificates under acceptable policies. The client **shall** check the server public key length if the client implementation provides a mechanism to do so. The client **shall** also check the server public key length if the server uses ephemeral keys for the creation of the master secret, and the client implementation provides a mechanism to do so.

The length of each write key is determined by the negotiated cipher suite. Restrictions on the length of the shared session keys can be enforced by configuring the client to only support cipher suites that meet the key length requirements.

4.5.4 User Interface

When the TLS client is a browser, the browser interface can be used to determine if a TLS session is in effect. The indication that a TLS session is in effect varies by browser. Examples of indicators include a padlock in the URL bar, the word “secure” preceding the URL, or a different color for the URL bar. Some clients, such as browsers, may allow further investigation of the server certificate and negotiated session parameters by clicking on the lock (or other indicator). Users **should** examine the interface for the presence of the indicator to ensure that the TLS session is in force and **should** also visually examine web site URLs to ensure that the user intended to visit the indicated web site. Users **should** be aware that URLs can appear to be legitimate, but still not be valid. For example, the numeric “1” and the letter “l” appear quite similar or the same to the human eye.

Client authentication keys may be located outside of the client (e.g., PIV Cards). Users **shall** follow the policies and procedures for protecting client authentication keys outside of the client.

4.6 Session Resumption

Session resumption considerations and server recommendations were given in Section 3.6. There are no specific recommendations for clients regarding session resumption when using TLS 1.2, 1.1, or 1.0. Clients typically will not know if any anti-replay mechanisms are in place to prevent replay attacks on 0-RTT data in TLS 1.3. Therefore, clients using TLS 1.3 **should not** send 0-RTT data.

4.7 Compression Methods

The client **shall** follow the same compression recommendations as the server, which are described in Section 3.7.

4.8 Operational Considerations

The client and associated platform **shall** be kept up-to-date in terms of security patches. This is critical to various aspects of security.

Once the TLS-protected data is received at the client, and decrypted and authenticated by the TLS layer of the client system, the unencrypted data is available to the applications on the client platform.

These guidelines do not mitigate the threats against the misuse or exposure of the client credentials that resides on the client machine. These credentials could contain the private key used for client authentication or other credentials (e.g., a one-time password (OTP) or user ID and password) for authenticating to a server-side application.

For these reasons, the use of TLS does not obviate the need for the client to use appropriate security measures, as described in applicable Federal Information Processing Standards and NIST Special Publications, to protect computer systems and applications. Users **shall** operate client systems in accordance with agency and administrator instructions.

Appendix A—Acronyms

Selected acronyms and abbreviations used in this paper are defined below.

3DES	Triple Data Encryption Algorithm (TDEA)
AEAD	Authenticated Encryption with Associated Data
AES	Advanced Encryption Standard
CA	Certification Authority
CBC	Cipher Block Chaining
CCM	Counter with CBC-MAC
CRL	Certificate Revocation List
DES	Data Encryption Standard
DH	Diffie-Hellman key exchange
DHE	Ephemeral Diffie-Hellman key exchange
DNS	Domain Name System
DNSSEC	DNS Security Extensions
DSA	Digital Signature Algorithm
DSS	Digital Signature Standard (implies DSA)
EC	Elliptic Curve
ECDHE	Ephemeral Elliptic Curve Diffie-Hellman
ECDSA	Elliptic Curve Digital Signature Algorithm
FIPS	Federal Information Processing Standard
GCM	Galois Counter Mode
HKDF	HMAC-based Extract-and-Expand Key Derivation Function
HMAC	Keyed-hash Message Authentication Code
IETF	Internet Engineering Task Force
KDF	Key derivation function
MAC	Message Authentication Code
OCSP	Online Certificate Status Protocol
OID	Object Identifier
PIV	Personal Identity Verification
PKI	Public Key Infrastructure
PRF	Pseudo-random Function
PSK	Pre-shared Key

RFC	Request for Comments
SHA	Secure Hash Algorithm
SSL	Secure Sockets Layer
TLS	Transport Layer Security
URL	Uniform Resource Locator

Appendix B—Interpreting Cipher Suite Names

TLS cipher suite names consist of a set of mnemonics separated by underscores (i.e., "_"). The naming convention in TLS 1.3 differs from the convention shared in TLS 1.0, 1.1, and 1.2. Section B.1 provides guidance for interpreting the names of cipher suites that are recommended in these guidelines for TLS versions 1.0, 1.1, and 1.2. Section B.2 provides guidance for interpreting the names of cipher suites for TLS 1.3. In all TLS cipher suites, the first mnemonic is the protocol name, i.e., "TLS".

B.1 Interpreting Cipher Suites Names in TLS 1.0, 1.1, and 1.2

One or two mnemonics follow the protocol name, indicating the key-exchange algorithm. If there is only one mnemonic, it must be PSK, based on the recommendations in these guidelines. The single mnemonic PSK indicates that the premaster secret is established using only symmetric algorithms with pre-shared keys, as described in RFC 4279 [31]. Pre-shared key cipher suites that are approved for use with TLS 1.2 are listed in Appendix C. If there are two mnemonics following the protocol name, the first key exchange mnemonic should be DH, ECDH, DHE, or ECDHE. When the first key exchange mnemonic is DH or ECDH, it indicates that the server's public key in its certificate is for either DH or ECDH key exchange, and the second mnemonic indicates the signature algorithm that was used by the issuing CA to sign the server certificate. When the first key exchange mnemonic is DHE or ECDHE, it indicates that ephemeral DH or ECDH will be used for key exchange, with the second mnemonic indicating the server signature public key type that will be used to authenticate the server's ephemeral public key.[30]

Next is the word WITH, followed by the mnemonic for the symmetric encryption algorithm and associated mode of operations.

The last mnemonic is generally the hashing algorithm to be used for HMAC, if applicable.[31] In cases where HMAC is not applicable (e.g., AES-GCM), or the cipher suite was defined after the release of the TLS 1.2 RFC, this mnemonic represents the hashing algorithm used with the PRF.

The following examples illustrate how to interpret the cipher suite names:

- TLS_DH_DSS_WITH_AES_256_CBC_SHA256: The server is using a DH certificate. If the signature algorithms extension is provided by the client, then the certificate is signed using one of the algorithms specified by the extension. Otherwise, the certificate is signed using DSA. Once the handshake is completed, the messages are encrypted using AES-256 in CBC mode. SHA-256 is used for both the PRF and HMAC computations. Cipher

[30] In this case, the signature algorithm used by the CA to sign the certificate is not articulated in the cipher suite.

[31] HMAC is not applicable when the symmetric encryption mode of operation is authenticated encryption. Note that the CCM mode cipher suites do not specify the last mnemonic and require that SHA-256 be used for the PRF.

suites that specify secure hash algorithms other than SHA-1 are not supported prior to TLS 1.2.

- TLS_ECDHE_ECDSA_WITH_AES_256_GCM_SHA384: Ephemeral ECDH is used for key exchange. The server's ephemeral public key is authenticated using the server's ECDSA public key. The CA signature algorithm used to certify the server's ECDSA public key is not specified by the cipher suite. Once the handshake is completed, the messages are encrypted and authenticated using AES-256 in GCM mode, and SHA-384 is used for the PRF. Since an authenticated encryption mode is used, messages neither have nor require an HMAC message authentication code.

B.2 Interpreting Cipher Suites Names in TLS 1.3

TLS 1.3 cipher suites are formatted differently from those described in the previous section. In particular, these cipher suites only specify an authenticated encryption algorithm (which provides confidentiality, integrity, and message authentication) and a hash algorithm for use with the HKDF. The negotiation of the key exchange method is handled elsewhere in the TLS handshake.

The following examples illustrate how to interpret TLS 1.3 cipher suite names.

- TLS_AES_256_GCM_SHA384: messages are encrypted and authenticated with AES-256 in GCM mode, and SHA-384 is used with the HKDF.
- TLS_AES_128_CCM_SHA256: messages are encrypted and authenticated with AES-128 in CCM mode, and SHA-256 is used with the HKDF.

Appendix C—Pre-shared Keys

Pre-shared keys (PSK) are symmetric keys that are already in place prior to the initiation of a TLS session (e.g., as the result of a manual distribution). The use of PSKs in TLS versions prior to TLS 1.3 is described in RFC 4279 [31], RFC 5487 [4], and RFC 5489 [5]. Pre-shared keys are used for session resumption in TLS 1.3. In general, pre-shared keys **should not** be used in TLS versions prior to TLS 1.3, or for initial session establishment in TLS 1.3. However, the use of pre-shared keys may be appropriate for some closed environments that have adequate key management support. For example, they might be appropriate for constrained environments with limited processing, memory, or power. If PSKs are appropriate and supported, then the following additional guidelines **shall** be followed.

Recommended pre-shared key (PSK) cipher suites for TLS 1.2 are listed below. Cipher suites for TLS 1.3 (see Section 3.3.1.2) can all be used with pre-shared keys. Pre-shared keys **shall** be distributed in a secure manner, such as a secure manual distribution or using a key-establishment certificate. These cipher suites employ a pre-shared key for entity authentication (for both the server and the client) and may also use ephemeral Diffie-Hellman (DHE) or ephemeral Elliptic Curve Diffie-Hellman (ECDHE) algorithms for key establishment. For example, when DHE is used, the result of the Diffie-Hellman computation is combined with the pre-shared key and other input to determine the premaster secret.

The pre-shared key **shall** have a minimum security strength of 112 bits. Because these cipher suites require pre-shared keys, these suites are not generally applicable to common secure web site applications and are not expected to be widely supported in TLS clients or TLS servers. NIST suggests that these suites be considered for infrastructure applications, particularly if frequent authentication of the network entities is required.

Pre-shared key cipher suites may only be used in networks where both the client and server belong to an organization. Cipher suites using pre-shared keys **shall not** be used with TLS 1.0 or TLS 1.1, and **shall not** be used when a government client or server communicates with non-government systems.

TLS 1.2 servers and clients using pre-shared keys may support the following cipher suites:

- TLS_DHE_PSK_WITH_AES_128_GCM_SHA256 (0x00, 0xAA)
- TLS_DHE_PSK_WITH_AES_256_GCM_SHA384 (0x00, 0xAB)
- TLS_ECDHE_PSK_WITH_AES_128_CBC_SHA256 (0xC0, 0x37)
- TLS_ECDHE_PSK_WITH_AES_256_CBC_SHA384 (0xC0, 0x38)
- TLS_DHE_PSK_WITH_AES_128_CCM (0xC0, 0xA6)
- TLS_DHE_PSK_WITH_AES_256_CCM (0xC0, 0xA7)
- TLS_PSK_DHE_WITH_AES_128_CCM_8 (0xC0, 0xAA)
- TLS_PSK_DHE_WITH_AES_256_CCM_8 (0xC0, 0xAB)
- TLS_DHE_PSK_WITH_AES_128_CBC_SHA256 (0x00, 0xB2)
- TLS_DHE_PSK_WITH_AES_256_CBC_SHA384 (0x00, 0xB3)
- TLS_PSK_WITH_AES_128_GCM_SHA256 (0x00, 0xA8)
- TLS_PSK_WITH_AES_256_GCM_SHA384 (0x00, 0xA9)
- TLS_PSK_WITH_AES_128_CCM (0xC0, 0xA4)

- TLS_PSK_WITH_AES_256_CCM (0xC0, 0xA5)
- TLS_PSK_WITH_AES_128_CCM_8 (0xC0, 0xA8)
- TLS_PSK_WITH_AES_256_CCM_8 (0xC0, 0xA9)
- TLS_PSK_WITH_AES_128_CBC_SHA256 (0x00, 0xAE)
- TLS_PSK_WITH_AES_256_CBC_SHA384 (0x00, 0xAF)
- TLS_ECDHE_PSK_WITH_AES_128_CBC_SHA (0xC0, 0x35)
- TLS_ECDHE_PSK_WITH_AES_256_CBC_SHA (0xC0, 0x36)
- TLS_DHE_PSK_WITH_AES_128_CBC_SHA (0x00, 0x90)
- TLS_DHE_PSK_WITH_AES_256_CBC_SHA (0x00, 0x91)
- TLS_PSK_WITH_AES_128_CBC_SHA (0x00, 0x8C)
- TLS_PSK_WITH_AES_256_CBC_SHA (0x00, 0x8D)

Appendix D—Future Capabilities

This section identifies emerging concepts and capabilities that are applicable to TLS. As these concepts mature, and commercial products are available to support them, these guidelines will be revised to provide specific recommendations.

D.1 U.S. Federal Public Trust PKI

The Identity, Credential, and Access Management (ICAM) Subcommittee of the Federal CIO Council's Information Security and Identity Management Committee is developing a new public trust root and issuing CA infrastructure to issue TLS server certificates for Federal web services on the public Internet. The intent is for this new root to be included in all of the commonly used trust stores so that Federal agencies can obtain their TLS server certificates from this PKI rather than from commercial CAs. The certificate policy for this PKI is being developed at https://devicepki.idmanagement.gov.

Once this PKI is operational and is included in the commonly used trust stores, Federal agencies should consider obtaining their TLS server certificates from this PKI.

D.2 DANE

DNS-based Authentication of Named Entities (DANE) leverages DNS security extensions (DNSSEC) to provide mechanisms for securely obtaining information about TLS server certificates from the DNS. RFC 6698 [38] specifies a resource record that may be made available in DNS that includes a certificate (or the public key of a certificate), along with an indicator of how the certificate is to be used. There are four options:

1. The DNS record contains an end-entity certificate. In addition to the server public-key certificate validation as specified in Section 4.5, the client verifies that the TLS server certificate matches the certificate provided in the DNS records.
2. The DNS record contains a domain-issued end-entity certificate.[32] The client can use the certificate if it verifies that the TLS server certificate matches the one provided in the DNS records (i.e., the client forgoes server public-key certificate validation as specified in Section 4.5).
3. The DNS record contains a CA certificate. In addition to the server public-key certificate validation as specified in Section 4.5, the client verifies that the certification path for the TLS server certificate includes the CA certificate provided in the DNS records.
4. The DNS record contains a certificate that is to be used as a trust anchor. The client validates the TLS server certificate as specified in Section 4.5 using the trust anchor provided in the DNS records instead of the trust anchors in the client's local trust anchor store.

[32] In this context, a "domain-issued" certificate is one that is issued by the domain name administrator without involving a third-party CA. It corresponds to usage case 3 in Section 2.1.1 of RFC 6698.

In each case, the client verifies the digital signatures on the DNS records in accordance with the DNSSEC, as described in RFC 4033 [3].

Appendix E—Determining the Need for TLS 1.0 and 1.1

Enabling TLS 1.0 when it is not needed may leave systems and users vulnerable to attacks (such as the BEAST attack and the Klima attack [63]). However, disabling TLS 1.0 when there is a need may deny access to users who are unable to install or upgrade to a browser that is capable of TLS 1.3, 1.2 or 1.1.

The system administrator must consider the benefits and risks of using TLS 1.0, in the context of applications supported by the server, and decide whether the benefits of using TLS 1.0 outweigh the risks. This decision should be driven by the service(s) running on the server and the versions supported by clients accessing the server. Services that do not access high-value information (such as personally identifiable information or financial data) may benefit from using TLS 1.0 by increasing accessibility with little increased risk. On the other hand, services that do access high-value data may increase the likelihood of a breach for relatively little gain in terms of accessibility. The decision to support TLS 1.0 must be assessed on a case-by-case basis by the system administrator.

These guidelines do not give specific recommendations on steps that can be taken to make this determination. There are tools available (such as the Data Analytics Program [71]) that can provide information to system administrators that can be used to assess the impact of supporting, or not supporting, TLS 1.0. For example, DAP data on visitor OS and browser versions can help administrators determine what percentage of visitors to agency websites cannot negotiate TLS 1.2 (or TLS 1.1) by default.

Many products that implement TLS 1.1 also implement TLS 1.2. Because of this, it may be unnecessary for servers to support TLS 1.1. Administrators can determine whether TLS 1.1 is needed by assessing whether it must support connections with clients where 1.1 is the highest TLS version available.

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Appendix G—Revision History

G.1 Original

The original version of SP 800-52 was published in June 2005 [18]. At the time, only TLS 1.0 was final (TLS 1.1 was still under development). TLS 1.1 became a standard in April 2006, and TLS 1.2 became a standard in August 2008. SP 800-52 became outdated, and guidance on keys and cipher suites was incorporated into SP 800-57 Part 3 [23]. In March 2013, SP 800-52 was withdrawn.

G.2 Revision 1

The first revision of SP 800-52 was published in April 2014 [52]. The revision was a new document that bore little resemblance to the original. At the time, TLS 1.2 was still not prevalent and the Federal PKI consisted mainly of RSA certificates. Recommendations were made with this in mind so that federal agencies could follow the guidelines with either existing technology or technology that was under development. Agencies were advised to develop a plan to migrate to TLS 1.2.

After revision 1 was posted, the guidance on keys and cipher suites was removed from SP 800-57 Part 3.

G.3 Revision 2

Since revision 1, support for TLS 1.2 and cipher suites using ephemeral key exchanges has increased, and new attacks have come to light. Revision 2 (this document) requires that TLS 1.2 be supported, and contains several changes to certificate and cipher suite recommendations.

Revision 2 includes recommendations for TLS 1.3. TLS 1.3 is not yet widely supported, but many vendors are working to quickly add support for it to their products. TLS 1.3 offers many improvements over previous versions of TLS, so revision 2 advises agencies to develop a plan to migrate to TLS 1.3.

Revision 2 also has increased discussion on TLS attacks and guidance on mitigation.

Certificate requirements have also changed in this revision. In particular, status information for TLS server certificates is required to be made available via the Online Certificate Status Protocol. This revision of the TLS guidelines relaxes requirements on which signature algorithms can sign which key types in certificates.