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Terminal Access Controller Access-Control System Plus over TLS 1.3 (TACACS+ over TLS)
draft-ietf-opsawg-tacacs-tls13-24

Abstract

This document specifies the use of Transport Layer Security (TLS) version 1.3 to secure the communication channel between a Terminal Access Controller Access-Control System Plus (TACACS+) client and server. TACACS+ is a protocol used for Authentication, Authorization, and Accounting (AAA) in networked environments. The original TACACS+ protocol, does not mandate the use of encryption or secure transport. This specification defines a profile for using TLS 1.3 with TACACS+, including guidance on authentication, connection establishment, and operational considerations. The goal is to enhance the confidentiality, integrity, and authenticity of TACACS+ traffic, aligning the protocol with modern security best practices.

This document updates RFC 8907.

Requirements Language

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

Status of This Memo

This Internet-Draft will expire on 10 January 2026.

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1. Introduction

The Terminal Access Controller Access-Control System Plus (TACACS+) Protocol [RFC8907] provides device administration for routers, network access servers, and other networked computing devices via one or more centralized TACACS+ servers. The protocol provides authentication, authorization and accounting services (AAA) for TACACS+ clients within the device administration use case.

While the content of the protocol is highly sensitive, TACACS+ lacks effective confidentiality, integrity, and authentication of the connection and network traffic between the TACACS+ server and client, requiring secure transport to safeguard a deployment. The security mechanisms as described in Section 10 of [RFC8907] are extremely weak.

To address these deficiencies, this document updates the TACACS+ protocol to use TLS 1.3 [RFC8446] authentication and encryption, and obsoletes the use of TACACS+ obfuscation mechanisms (Section 10.5 of [RFC8907]). The maturity of TLS in version 1.3 and above makes it a suitable choice for the TACACS+ protocol.

2. Technical Definitions

The terms defined in Section 3 of [RFC8907] are fully applicable here and will not be repeated. The following terms are also used in this document.

Obfuscation: TACACS+ was originally intended to incorporate a mechanism for securing the body of its packets. The algorithm is categorized as Obfuscation in Section 10.5.2 of [RFC8907]. The term is used to ensure that the algorithm is not mistaken for encryption. It should not be considered secure.

Non-TLS connection: This term refers to the connection defined in [RFC8907]. It is a connection without TLS, using the unsecure TACACS+ authentication and obfuscation (or the unobfuscated option for test). The use of well-known TCP/IP host port number 49 is specified as the default for Non-TLS connections.

TLS connection: A TLS connection is a TCP/IP connection with TLS authentication and encryption used by TACACS+ for transport. A TLS connection for TACACS+ is always between one TACACS+ client and one TACACS+ server.

TLS TACACS+ server: This document describes a variant of the TACACS+ server, introduced in Section 3.2 of [RFC8907], which utilizes TLS for transport, and makes some associated protocol optimizations. Both server variants respond to TACACS+ traffic, but this document specifically defines a TACACS+ server (whether TLS or Non-TLS) as being bound to specific port number on a particular IP address or hostname. This definition is important in the context of the configuration of TACACS+ clients, to ensure they direct their traffic to the correct TACACS+ servers.

Peer: The peer of a TACACS+ client (or server) in the context of a TACACS+ connection, is a TACACS+ server (or client). Together, the ends of a TACACS+ connection are referred to as peers.

3. TACACS+ over TLS

TACACS+ over TLS takes the protocol defined in [RFC8907], removes the option for MD5 obfuscation, and specifies that TLS 1.3 be used for transport (Section 3.1 elaborates TLS version support). A new well-known default host port number is used. The next sections provide further details and guidance.

TLS is introduced into TACACS+ to fulfill the following requirements:

1. Confidentiality and Integrity: The MD5 algorithm underlying the obfuscation mechanism specified in [RFC8907] has been shown to be insecure [RFC6151] when used for encryption. This prevents TACACS+ being used in a [FIPS-140-3] - compliant deployment. Securing TACACS+ protocol with TLS is intended to provide confidentiality and integrity without requiring the provision of a secured network.

2. Peer authentication: The authentication capabilities of TLS replace the shared secrets of obfuscation for mutual authentication.

This document adheres to the recommendations in [I-D.ietf-uta-require-tls13].

3.1. Separating TLS Connections

Peers implementing the TACACS+ protocol variant defined in this document MUST apply mutual authentication and encrypt all data exchanged between them. Therefore, when a TCP connection is established for the service, a TLS handshake begins immediately. Options which upgrade an initial Non-TLS connection, MUST NOT be used, see Section 5.3.

To ensure clear separation between TACACS+ traffic using TLS and that which does not (see Section 5.3), servers supporting TACACS+ over TLS MUST listen on a TCP/IP port distinct from that used by non-TLS TACACS+ servers. It is further RECOMMENDED to deploy the TLS and non-TLS services on separate hosts, as discussed in Section 5.1.1.

Given the prevalence of default port usage in existing TACACS+ client implementations, this specification assigns a well-known TCP port number for TACACS+ over TLS: [TBD] (Section 7), with the associated service name "tacacss" Section 7. This allows clients to unambiguously distinguish between TLS and non-TLS connections, even in the absence of an explicitly configured port number.

While the use of the designated port number is strongly encouraged, deployments with specific requirements MAY use alternative TCP port numbers. In such cases, operators must carefully consider the operational implications described in Section 5.3.

3.2. TLS Connection

A TACACS+ client initiates a TLS connection by making a TCP connection to a configured TLS TACACS+ server on the TACACS+ TLS port number. Once the TCP connection is established, the client MUST immediately begin the TLS negotiation before sending any TACACS+ protocol data.

Minimum TLS 1.3 [RFC8446] MUST be used for transport, it is expected that TACACS+ as described in this document will work with future versions of TLS. Earlier versions of TLS MUST NOT be used.

Once the TLS connection has been successfully established, the exchange of TACACS+ data MUST proceed in accordance with the procedures defined in [RFC8907], However, all TACACS+ messages SHALL be transmitted as TLS application data. The TACACS+ obfuscation mechanism defined in [RFC8907] MUST NOT be applied when operating over TLS (Section 4).

The connection persists until the TLS TACACS+ peer closes it, either due to an error, or at the conclusion of the TACACS+ session, or, if Single Connection Mode (Section 4.3 of [RFC8907]) has been negotiated, when an inactivity timeout occurs. Why it closed has no bearing on TLS resumption, unless closed by a TLS error, in which case it is possible that the ticket has been invalidated.

TACACS+ connections are generally not long-lived. For connections not operating in Single Connection Mode (as defined in Section 4.3 of [RFC8907]) the TCP session SHALL be closed upon completion of the associated TACACS+ session. Connections operating in Single Connection Mode MAY persist for a longer duration but are typically subject to timeout and closure after a brief period of inactivity. Consequently, support for transport-layer keepalive mechanisms is not required.

TACACS+ clients and servers widely support IPv6 configuration in addition to IPv4. This document makes no changes to recommendations in this area.

3.3. TLS Authentication Options

Implementations MUST support certificate-based mutual authentication, to provide a core option for interoperability between deployments. This authentication option is specified in Section 3.4.

In addition to certificate-based TLS authentication, implementations MAY support the following alternative authentication mechanisms:

* Pre-Shared Keys (PSKs) (Section 3.5), also known as external PSKs in TLS 1.3.

* Raw Public Keys (RPKs). The details of RPK are considered out-of-scope for this document. Refer to [RFC7250] and Section 4.4.2 of [RFC8446] for implementation, deployment, and security considerations.

3.4. TLS Certificate-Based Authentication

TLS certificate authentication is the primary authentication option for TACACS+ over TLS. This section covers certificate-based authentication only.

Deploying TLS certificate-based authentication correctly will considerably improve the security of TACACS+ deployments. It is essential for implementers and operators to understand the implications of a TLS certificate-based authentication solution, including the correct handling of certificates, Certificate Authorities (CAs), and all elements of TLS configuration. For guidance, start with [BCP195].

Each peer MUST validate the certificate path of its remote peer, including revocation checking, as described in Section 3.4.1.

If the verification succeeds, the authentication is successful and the connection is permitted. Policy may impose further constraints upon the peer, allowing or denying the connection based on certificate fields or any other parameters exposed by the implementation.

Unless disabled by configuration, a peer MUST NOT permit connection of any peer that presents an invalid TLS certificate.

3.4.1. TLS Certificate Path Verification

The implementation of certificate-based mutual authentication MUST support certificate path verification as described in Section 6 of [RFC5280].

In some deployments, a peer may be isolated from a remote peer’s CA. Implementations for these deployments MUST support certificate chains (a.k.a. bundles or chains of trust), where the entire chain of the remote’s certificate is stored on the local peer.

TLS Cached Information Extension [RFC7924] SHOULD be implemented. This MAY be augmented with RPKs [RFC7250], though revocation must be handled as it is not part of the standard.

Other approaches may be used for loading the intermediate certificates onto the client, but MUST include support for revocation checking. For example, [RFC5280] details the Authority Information Access (AIA) extension to provide information about the issuer of the certificate in which the extension appears. It can be used to provide the address of the Online Certificate Status Protocol (OCSP) responder from where revocation status of the certificate (which includes the extension) can be checked.

3.4.2. TLS Certificate Identification

For the client-side validation of presented TLS TACACS+ server identities, implementations MUST follow [RFC9525] validation techniques. Identifier types DNS-ID, IP-ID, or SRV-ID are applicable for use with the TLS TACACS+ protocol, selected by operators depending upon the deployment design. TLS TACACS+ does not use URI-IDs for TLS TACACS+ server identity verification.

Wildcards in TLS TACACS+ server identities simplify certificate management by allowing a single certificate to secure multiple servers in a deployment. However, this introduces security risks, as compromising the private key of a wildcard certificate impacts all servers using it. To address these risks, the guidelines in Section 6.3 of [RFC9525] MUST be followed, and the wildcard SHOULD be confined to a subdomain dedicated solely to TACACS+ servers.

For the TLS TACACS+ server-side validation of client identities, implementations MUST support the ability to configure which fields of a certificate are used for client identification, to verify that the client is a valid source for the received certificate and that it is permitted access to TACACS+. Implementations MUST support either:

Network address based validation methods as described in Section 5.2 of [RFC5425].

or

Client Identity validation of a shared identity in the certificate subjectAltName. This is applicable in deployments where the client securely supports an identity which is shared with the TLS TACACS+ server. Matching of dNSName and iPAddress MUST be supported. Other options defined in Section 4.2.1.6 of [RFC5280] MAY be supported. This approach allows a client’s network location to be reconfigured without issuing a new client certificate.

Implementations MUST support the TLS Server Name Indication extension (SNI) (Section 3 of [RFC6066]). TLS TACACS+ clients MUST support the ability to configure the TLS TACACS+ server’s domain name, so that it may be included in the SNI "server_name" extension of the client hello (This is distinct from the IP Address or hostname configuration used for the TCP connection). Refer to Section 5.1.5 for security related operator considerations.

Certificate provisioning is out of scope of this document.

3.4.3. Cipher Suites Requirements

Implementations MUST support the TLS 1.3 mandatory cipher suites (Section 9.1 of [RFC8446]). Readers should refer to [BCP195]. The cipher suites offered or accepted SHOULD be configurable so that operators can adapt.

3.5. TLS PSK Authentication

As an alternative to certificate-based authentication, implementations MAY support PSKs, also known as External PSKs in TLS 1.3 [RFC8446]. These should not be confused with resumption PSKs.

The use of External PSKs is less well established than certificate-based authentication. It is RECOMMENDED that systems follow the directions of [RFC9257] and Section 4 of [RFC8446].

Where PSK Authentication is implemented, PSK lengths of at least 16 octets MUST be supported.

PSK Identity MUST follow recommendations of Section 6.1 of [RFC9257]. Implementations MUST support PSK identities of at least 16 octets.

Although this document removes the option of MD5 obfuscation (Section 4), it is still possible that the TLS and Non-TLS versions of TACACS+ may exist in an organization, for example, during migration (Section 6.1). In such cases, the shared secrets configured for TACACS+ obfuscation clients MUST NOT be the same as the PSKs configured for TLS clients.

3.6. TLS Resumption

The TLS Resumption protocol, detailed in [RFC8446], can minimize the number of round trips required during the handshake process. If a TLS client holds a ticket previously extracted from a NewSessionTicket message from the TLS TACACS+ server, it can use the PSK identity tied to that ticket. If the TLS TACACS+ server consents, the resumed session is acknowledged as authenticated and securely linked to the initial session.

The client SHOULD use resumption when it holds a valid unused ticket from the TLS TACACS+ server, as each ticket is intended for a single use only and will be refreshed during resumption. The TLS TACACS+ server can reject a resumption request, but the TLS TACACS+ server SHOULD allow resumption if the ticket in question has not expired and has not been used before.

When a TLS TACACS+ server is presented with a resumption request from the TLS client, it MAY still choose to require a full handshake. In this case, the negotiation proceeds as if the session was a new authentication, and the resumption attempt is ignored. As described in Appendix C.4 of [RFC8446], reuse of a ticket allows passive observers to correlate different connections. TLS TACACS+ clients and servers SHOULD follow the client tracking preventions in Appendix C.4 of [RFC8446].

When processing TLS resumption, certificates must be verified to check for revocation during the period since the last NewSessionTicket Message.

The resumption ticket_lifetime SHOULD be configurable, including a zero seconds lifetime. Refer to Section 4.6.1 of [RFC8446] for guidance on ticket lifetime.

4. Obsolescence of TACACS+ Obfuscation

[RFC8907] describes the obfuscation mechanism, documented in Section 5.2 of [RFC5425]. Such a method is weak.

The introduction of TLS authentication and encryption to TACACS+ replaces this former mechanism and so obfuscation is hereby obsoleted. This section describes how the TACACS+ client and servers MUST operate regarding the obfuscation mechanism.

Peers MUST NOT use obfuscation with TLS.

A TACACS+ client initiating a TACACS+ TLS connection MUST set the TAC_PLUS_UNENCRYPTED_FLAG bit, thereby asserting that obfuscation is not used for the session. All subsequent packets MUST have the TAC_PLUS_UNENCRYPTED_FLAG bit set to 1.

A TLS TACACS+ server that receives a packet with the TAC_PLUS_UNENCRYPTED_FLAG bit not set to 1 over a TLS connection, MUST return an error of TAC_PLUS_AUTHEN_STATUS_ERROR, TAC_PLUS_AUTHOR_STATUS_ERROR, or TAC_PLUS_ACCT_STATUS_ERROR as appropriate for the TACACS+ message type, with the TAC_PLUS_UNENCRYPTED_FLAG bit set to 1, and terminate the session. This behavior corresponds to that defined in Section 4.5 of [RFC8907] Data Obfuscation for TAC_PLUS_UNENCRYPTED_FLAG or key mismatches.

A TACACS+ client that receives a packet with the TAC_PLUS_UNENCRYPTED_FLAG bit not set to 1 MUST terminate the session, and SHOULD log this error.

5. Security Considerations

5.1. TLS

This document improves the confidentiality, integrity, and authentication of the connection and network traffic between TACACS+ peers by adding TLS support.

Simply adding TLS support to the protocol does not guarantee the protection of the TLS TACACS+ server and clients. It is essential for the operators and equipment vendors to adhere to the latest best practices for ensuring the integrity of network devices and selecting secure TLS key and encryption algorithms.

[BCP195] offers substantial guidance for implementing protocols that use TLS and their deployment. Those implementing and deploying Secure TACACS+ must adhere to the recommendations relevant to TLS 1.3 outlined in [BCP195] or its subsequent versions.

This document outlines additional restrictions permissible under [BCP195] For example, any recommendations referring to TLS 1.2, including the mandatory support, are not relevant for Secure TACACS+ as TLS 1.3 or above is mandated.

This document concerns the use of TLS as transport for TACACS+, and does not make any changes to the core TACACS+ protocol, other than the direct implications of deprecating obfuscation. Operators MUST be cognizant of the security implications of the TACACS+ protocol itself. Further documents are planned, for example, to address the security implications of password based authentication and enhance the protocol to accommodate alternative schemes.

5.1.1. TLS Use

New TACACS+ production deployments SHOULD use TLS authentication and encryption. Also see [RFC3365].

TLS TACACS+ servers (as defined in Section 2) MUST NOT allow Non-TLS connections, because of the threat of downgrade attacks or misconfiguration described in Section 5.3. Instead, separate Non-TLS TACACS+ servers SHOULD be set up to cater for these clients.

It is NOT RECOMMENDED that TLS TACACS+ servers and Non-TLS TACACS+ servers be deployed on the same host, for reasons discussed in Section 5.3. Non-TLS connections would be better served by deploying the required Non-TLS TACACS+ servers on separate hosts.

TACACS+ Clients MUST NOT fail back to a Non-TLS connection if a TLS connection fails. This prohibition includes during the migration of a deployment (Section 6.1).

5.1.2. TLS 0-RTT

TLS 1.3 resumption and PSK techniques make it possible to send Early Data, aka. 0-RTT data, data that is sent before the TLS handshake completes. Replay of this data is a risk. Given the sensitivity of TACACS+ data, clients MUST NOT send data until the full TLS handshake completes; that is, clients MUST NOT send 0-RTT data and TLS TACACS+ servers MUST abruptly disconnect clients that do.

TLS TACACS+ clients and servers MUST NOT include the "early_data" extension. See sections 2.3 and 4.2.10 of [RFC8446] for security concerns.

5.1.3. TLS Options

Recommendations in [BCP195] MUST be followed to determine which TLS versions and algorithms should be supported, deprecated, obsoleted, or abandoned.

Also, Section 9 of [RFC8446] prescribes mandatory supported options.

5.1.4. Unreachable Certification Authority (CA)

Operators should be cognizant of the potential of TLS TACACS+ server and/or client isolation from their peer’s CA by network failures. Isolation from a public key certificate’s CA will cause the verification of the certificate to fail and thus TLS authentication of the peer to fail. The approach mentioned in Section 3.4.1 can help address this and should be considered where implemented.

5.1.5. TLS Server Name Indicator (SNI)

Operators should be aware that the TLS SNI extension is part of the TLS client hello, which is sent in cleartext. It is, therefore, subject to eavesdropping. Also see Section 11.1 of [RFC6066].

5.1.6. Server Identity Wildcards

The use of wildcards in TLS server identities creates a single point of failure: a compromised private key of a wildcard certificate impacts all servers using it. Their use MUST follow recommendations of Section 7.1 of [RFC9525]. Operators MUST ensure that the wildcard is limited to a subdomain dedicated solely to TLS TACACS+ servers. Further, operators MUST ensure that the TLS TACACS+ servers covered

by a wildcard certificate MUST be impervious to redirection of traffic to a different server (for example, due to on-path attacks or DNS cache poisoning).

5.2. TACACS+ Configuration

Implementors must ensure that the configuration scheme introduced for enabling TLS is straightforward and leaves no room for ambiguity regarding whether TLS or Non-TLS will be used between the TACACS+ client and the TACACS+ server.

This document recommends the use of a separate port number that TLS TACACS+ servers will listen to. Where deployments have not overridden the defaults explicitly, TACACS+ client implementations MUST use the correct values:

* for Non-TLS connection TACACS+: Port number 49.

* for TLS connection TACACS+: (TBD).

Implementors may offer a single option for TACACS+ clients and servers to disable all Non-TLS TACACS+ operations. When enabled on a TACACS+ server, it will not respond to any requests from Non-TLS TACACS+ client connections. When enabled on a TACACS+ client, it will not establish any Non-TLS TACACS+ server connections.

5.3. Well-Known TCP/IP Port Number

A new port number is considered appropriate (rather than a mechanism that negotiates an upgrade from an initial Non-TLS TACACS+ Connection) because it allows:

* ease of blocking the unobfuscated or obfuscated connections by the TCP/IP port number,

* passive Intrusion Detection Systems (IDSs) monitoring the unobfuscated to be unaffected by the introduction of TLS,

* avoidance of on-path attacks that can interfere with upgrade, and

* prevention of the accidental exposure of sensitive information due to misconfiguration.

However, co-existence of inferior authentication and obfuscated, whether a Non-TLS connection or deprecated parts that compose TLS, also presents opportunity for down-grade attacks. Causing failure of connections to the TLS-enabled service or the negotiation of shared algorithm support are two such down-grade attacks.

The simplest mitigation exposure from Non-TLS connection methods is to refuse Non-TLS connections at the host entirely, perhaps using separate hosts for Non-TLS connections and TLS.

Another approach is mutual configuration that requires TLS. TACACS+ clients and servers SHOULD support configuration that requires peers, globally and individually, use TLS. Furthermore, peers SHOULD be configurable to limit offered or recognized TLS versions and algorithms to those recommended by standards bodies and implementers.

6. Operational Considerations

Operational and deployment considerations are spread throughout the document. While avoiding repetition, it is useful for the impatient to direct particular attention to Sections 5.2 and 5.1.5. However, it is important that the entire Section 5 is observed.

It is essential for operators to understand the implications of a TLS certificate-based authentication solution, including the correct handling of certificates, CAs, and all elements of TLS configuration. Refer to [BCP195] for guidance. Attention is drawn to the provisioning of Certificates to all peers, including TACACS+ TLS clients, to permit the mandatory mutual authentication.

6.1. Migration

Section 5.2 mentions that for an optimal deployment of TLS TACACS+, TLS should be universally applied throughout the deployment. However, during the migration process from a Non-TLS TACACS+ deployment, operators may need to support both TLS and Non-TLS TACACS+ servers. This migration phase allows operators to gradually transition their deployments from an insecure state to a more secure one, but it is important to note that it is vulnerable to downgrade attacks. Therefore, the migration phase should be considered insecure until it is fully completed. To mitigate this hazard:

* The period where any client is configured with both TLS and Non-TLS TACACS+ servers should be minimized.

* The operator must consider the impact of mixed TLS and Non-TLS on security, as mentioned above.

6.2. Maintaining Non-TLS TACACS+ Clients

Some TACACS+ client devices in a deployment may not implement TLS. These devices will require access to Non-TLS TACACS+ servers. Operators must follow the recommendation of Section 5.1.1 and deploy separate Non-TLS TACACS+ servers for these Non-TLS clients from those used for the TLS clients.

6.3. YANG Model for TACACS+ Clients

[ietf-opsawg-secure-tacacs-yang] specifies a YANG model for managing TACACS+ clients, including TLS support.

7. IANA Considerations

IANA (has allocated) is requested to allocate a new well-known system TCP/IP port number ([TBD]) for the service name "tacacss", described as "TACACS+ over TLS". The service name "tacacss" follows the common practice of appending an "s" to the name given to the Non-TLS well-known port name. This allocation is justified in Section 5.3.

IANA (has added) is requested to add tacacss as a new entry to the "Service name and Transport Protocol Port Number Registry" available at https://www.iana.org/assignments/service-names-port-numbers/

Service Name: tacacss

Port Number: [TBD]

Transport Protocol: TCP

Description: TLS Secure Login Host Protocol (TACACSS)

Assignee: IESG

Contact: IETF Chair

Reference: [TBD] (This Document)

RFC EDITOR: this port number should replace "[TBD]" within this document.

Considerations about service discovery are out of scope of this document.

8. Acknowledgments

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9. Normative References

[BCP195] Best Current Practice 195, <https://www.rfc-editor.org/info/bcp195>. At the time of writing, this BCP comprises the following:

Sheffer, Y., Saint-Andre, P., and T. Fossati, "Recommendations for Secure Use of Transport Layer Security (TLS) and Datagram Transport Layer Security (DTLS)", BCP 195, RFC 9325, DOI 10.17487/RFC9325, November 2022, <https://www.rfc-editor.org/info/rfc9325>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC5280] Cooper, D., Santesson, S., Farrell, S., Boeyen, S., Housley, R., and W. Polk, "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", RFC 5280, DOI 10.17487/RFC5280, May 2008, <https://www.rfc-editor.org/info/rfc5280>.

[RFC5425] Miao, F., Ed., Ma, Y., Ed., and J. Salowey, Ed., "Transport Layer Security (TLS) Transport Mapping for Syslog", RFC 5425, DOI 10.17487/RFC5425, March 2009, <https://www.rfc-editor.org/info/rfc5425>.

[RFC6066] Eastlake 3rd, D., "Transport Layer Security (TLS) Extensions: Extension Definitions", RFC 6066, DOI 10.17487/RFC6066, January 2011, <https://www.rfc-editor.org/info/rfc6066>.

[RFC7250] Wouters, P., Ed., Tschofenig, H., Ed., Gilmore, J., Weiler, S., and T. Kivinen, "Using Raw Public Keys in Transport Layer Security (TLS) and Datagram Transport Layer Security (DTLS)", RFC 7250, DOI 10.17487/RFC7250, June 2014, <https://www.rfc-editor.org/info/rfc7250>.

[RFC7924] Santesson, S. and H. Tschofenig, "Transport Layer Security (TLS) Cached Information Extension", RFC 7924, DOI 10.17487/RFC7924, July 2016, <https://www.rfc-editor.org/info/rfc7924>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8446] Rescorla, E., "The Transport Layer Security (TLS) Protocol Version 1.3", RFC 8446, DOI 10.17487/RFC8446, August 2018, <https://www.rfc-editor.org/info/rfc8446>.

[RFC8907] Dahm, T., Ota, A., Medway Gash, D.C., Carrel, D., and L. Grant, "The Terminal Access Controller Access-Control System Plus (TACACS+) Protocol", RFC 8907, DOI 10.17487/RFC8907, September 2020, <https://www.rfc-editor.org/info/rfc8907>.

[RFC9525] Saint-Andre, P. and R. Salz, "Service Identity in TLS", RFC 9525, DOI 10.17487/RFC9525, November 2023, <https://www.rfc-editor.org/info/rfc9525>.

10. Informative References

[FIPS-140-3] National Institute of Standards and Technology, U.S. Department of Commerce, "NIST Federal Information Processing Standards (FIPS) Publication 140-3", <https://csrc.nist.gov/pubs/fips/140-3/final>.

[I-D.ietf-radext-tls-psk] DeKok, A., "Operational Considerations for RADIUS and TLS-PSK", Work in Progress, Internet-Draft, draft-ietf-radext-tls-psk-12, 21 January 2025, <https://datatracker.ietf.org/doc/html/draft-ietf-radext-tls-psk-12>.

[I-D.ietf-uta-require-tls13]
Salz, R. and N. Aviram, "New Protocols Using TLS Must Require TLS 1.3", Work in Progress, Internet-Draft, draft-ietf-uta-require-tls13-12, 14 April 2025, <https://datatracker.ietf.org/doc/html/draft-ietf-uta-require-tls13-12>.

[ietf-opsawg-secure-tacacs-yang]
Boucadair, M., Ed., Wu, B., Zheng, G., and M. Wang, "A YANG Data Model for Terminal Access Controller Access-Control System Plus (TACACS+)", <https://datatracker.ietf.org/doc/draft-ietf-opsawg-secure-tacacs-yang/>.

[RFC3365] Schiller, J., "Strong Security Requirements for Internet Engineering Task Force Standard Protocols", BCP 61, RFC 3365, DOI 10.17487/RFC3365, August 2002, <https://www.rfc-editor.org/info/rfc3365>.

[RFC6151] Turner, S. and L. Chen, "Updated Security Considerations for the MD5 Message-Digest and the HMAC-MD5 Algorithms", RFC 6151, DOI 10.17487/RFC6151, March 2011, <https://www.rfc-editor.org/info/rfc6151>.

[RFC9190] Preu Mattsson, J. and M. Sethi, "EAP-TLS 1.3: Using the Extensible Authentication Protocol with TLS 1.3", RFC 9190, DOI 10.17487/RFC9190, February 2022, <https://www.rfc-editor.org/info/rfc9190>.

[RFC9257] Housley, R., Hoyland, J., Sethi, M., and C. A. Wood, "Guidance for External Pre-Shared Key (PSK) Usage in TLS", RFC 9257, DOI 10.17487/RFC9257, July 2022, <https://www.rfc-editor.org/info/rfc9257>.

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