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Abstract

The Path Computation Element Communication Protocol (PCEP) defines the mechanisms for the communication between a Path Computation Client (PCC) and a Path Computation Element (PCE), or among PCEs. This document describe the usage of Transport Layer Security (TLS) to enhance PCEP security, hence the PCEPS acronym proposed for it. The additional security mechanisms are provided by the transport protocol supporting PCEP, and therefore they do not affect the flexibility and extensibility of PCEP.

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Table of Contents

1. Introduction 3
2. Requirements Language 3
3. Applying PCEPS 4
3.1. Overview 4
3.2. Initiating the TLS Procedures 4
3.3. The StartTLS Message 5
3.4. TLS Connection Establishment 7
3.5. Peer Identity 9
3.6. Connection Establishment Failure 10
4. Discovery Mechanisms 10
4.1. DANE Applicability 11
5. Backward Compatibility 11
6. IANA Considerations 11
6.1. New PCEP Message 12
6.2. New Error-Values 12
7. Security Considerations 12
8. Manageability Considerations 13
8.1. Control of Function and Policy 13
8.2. Information and Data Models 14
8.3. Liveness Detection and Monitoring 14
8.4. Verify Correct Operations 14
8.5. Requirements on Other Protocols 14
8.6. Impact on Network Operations 14
9. Acknowledgements 14
10. References 14
10.1. Normative References 14
10.2. Informative References 17

1. Introduction

PCEP [RFC5440] defines the mechanisms for the communication between a Path Computation Client (PCC) and a Path Computation Element (PCE), or between two PCEs. These interactions include requests and replies that can be critical for a sustainable network operation and adequate resource allocation, and therefore appropriate security becomes a key element in the PCE infrastructure. As the applications of the PCE framework evolves, and more complex service patterns emerge, the definition of a secure mode of operation becomes more relevant.

[RFC5440] analyzes in its section on security considerations the potential threats to PCEP and their consequences, and discusses several mechanisms for protecting PCEP against security attacks, without making a specific recommendation on a particular one or defining their application in depth. Moreover, [RFC6952] remarks the importance of ensuring PCEP communication privacy, especially when PCEP communication endpoints do not reside in the same Autonomous System (AS), as the interception of PCEP messages could leak sensitive information related to computed paths and resources.

Among the possible solutions mentioned in these documents, Transport Layer Security (TLS) [RFC5246] provides support for peer authentication, and message encryption and integrity. TLS supports the usage of well-know mechanisms to support key configuration and exchange, and means to perform security checks on the results of PCE discovery procedures via Interior Gateway Protocol (IGP) ([RFC5088] and [RFC5089]).

This document describes a security container for the transport of PCEP requests and replies, and therefore they do not affect the flexibility and extensibility of PCEP.

This document describes how to apply TLS in securing PCE interactions, including initiation of the TLS procedures, the TLS handshake mechanisms, the TLS methods for peer authentication, the applicable TLS ciphersuites for data exchange, and the handling of errors in the security checks. In the rest of the document we will refer to this usage of TLS to provide a secure transport for PCEP as "PCEPS".

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Applying PCEPS

3.1. Overview

The steps involved in the PCEPS establishment consists of following successive steps:

1. Establishment of a TCP connection.

2. Initiating the TLS Procedures by the StartTLS message.

3. Establishment of TLS connection.

4. Start exchanging PCEP messages as per [RFC5440].

It should be noted that this procedure update what is defined in section 6.7 of [RFC5440] regarding the processing of messages prior to the Open message. The details of processing including backward compatibility is discussed in the following sections.

3.2. Initiating the TLS Procedures

Since PCEP can operate either with or without TLS, it is necessary for the PCEP speaker to indicate whether it wants to set up a TLS connection or not. For this purpose, this document proposes a new PCEP message called StartTLS. This message MUST be issued by the party willing to use TLS, prior to any other PCEP message. PCEP speaker MAY discover that the PCEP peer supports PCEPS or can be preconfigured to use PCEPS for a given peer (see Section 4 for more details). Thus the PCEP session is secured via TLS from the start before exchange of any other PCEP message including the open message. Securing via TLS, of an existing PCEP session is not permitted, session must be closed and re-established with TLS as per the procedure described in this document.

The StartTLS message is a PCEP message sent by a PCC to a PCE and by a PCE to a PCC in order to initiate the TLS procedure for PCEP. The Message-Type field of the PCEP common header for the StartTLS message is set to [TBA].

Once the TCP connection has been successfully established, the first message sent by the PCC to the PCE or by the PCE to the PCC MUST be a StartTLS message for the PCEPS. Note this is a significant change from [RFC5440] where the first PCEP message is Open.

A PCEP speaker receiving a StartTLS message after any other PCEP exchange has taken place (by receiving or sending any other messages from either side) MUST treat it as an unexpected message and reply

with a PCErr message with Error-Type set to [TBA by IANA](PCEP StartTLS failure) and Error-value set to 1 (reception of StartTLS after any PCEP exchange). A PCEP speaker receives any other message apart from StartTLS or PCErr MUST treat it as an unexpected message and reply with a PCErr message with Error-Type set to [TBA by IANA](PCEP StartTLS failure) and Error-value set to 2 (reception of non-StartTLS or non-PCErr message).

If the PCEP speaker that does not support PCEPS, receives a StartTLS message, it MUST behave according to the existing error mechanism described in section 6.2 of [RFC5440] (in case message is received prior to an Open message) or section 6.9 of [RFC5440] (for the case of reception of unknown message).

If the PCEP speaker supports PCEPS but cannot establish a TLS connection for some reason (e.g. the certificate server is not responding) it MUST return a PCErr message with Error-Type set to [TBA by IANA] (PCEP StartTLS failure) and Error-value set to:

- o 3 (not without TLS) if it is not willing to exchange PCEP messages without the solicited TLS connection.

- o 4 (ok without TLS) if it is willing to exchange PCEP messages without the solicited TLS connection.

If the PCEP speaker supports PCEPS and can establish a TLS connection it MUST start the TLS connection establishment steps described in Section 3.4 before the PCEP initialization procedure (section 4.2.1 of [RFC5440]).

These procedures minimize the impact of PCEPS support in PCEP implementations without requiring additional dedicated ports for running PCEP with TLS.

3.3. The StartTLS Message

The StartTLS message is used to initiate the TLS procedure for a PCEP session between the PCEP peers. A PCEP speaker sends the StartTLS message to request negotiation and establishment of TLS connection for PCEP. On receiving a StartTLS message form the PCEP peer (i.e. when PCEP speaker has sent and received StartTLS message) it is ready to start TLS negotiation and establishment and move to steps described in Section 3.4.

The format of a StartTLS message is as follows:

```
<StartTLS Message>::= <Common Header>
```

The StartTLS message MUST contain only the PCEP common header with Message-Type field set to [TBA].

Once the TCP connection has been successfully established, the sender MUST start a timer called StartTLSWait timer, after the expiration of which, if no StartTLS message has been received, it sends a PCErr message and releases the TCP connection with Error-Type set to [TBA by IANA] and Error-value set to 5 (no StartTLS message received before the expiration of the StartTLSWait timer). A RECOMMENDED value for StartTLSWait timer is 60 seconds.

```
+-+-+                 +-+-+
|PCC|                 |PCE|
+-+-+                 +-+-+
  |                     |
  | StartTLS            |
  | msg                 |
  |-------              |
  |       \   StartTLS  |
  |        \  msg       |
  |         \  ---------|
  |          \/         |
  |          /\         |
  |         /  -------->|
  |        /            |
  |<------              |
  |::::::::TLS::::::::::|
  |:::::Establishment:::|
  |                     |
  |                     |
  |:::::::PCEP::::::::::|
  |                     |
```

Figure 1: Both PCEP Speaker supports PCEPS

```
                  +-+-+                 +-+-+
                  |PCC|                 |PCE|
                  +-+-+                 +-+-+
                    |                     | Does not send
                    |      StartTLS       | StartTLS as
                    |-------------------->| cannot establish
                    |                     | TLS
                    |                     |
                    |<--------------------| Send Error
                    |      PCErr          | Error-Value 3/4
                    |                     |
```

Figure 2: Both PCEP Speaker supports PCEPS, But cannot establish TLS

```
                  +-+-+                 +-+-+
                  |PCC|                 |PCE|
                  +-+-+                 +-+-+
                    |                     |  Does not support
                    | StartTLS            |  PCEPS and thus
                    | msg                 |  sends open
                    |-------              |
                    |       \   open      |
                    |        \  msg       |
                    |         \  ---------|
                    |          \/         |
                    |          /\         |
                    |         /  -------->|
                    |        /            |
                    |<------              |
                    |                     |
                    |<--------------------| Send Error
                    |       PCErr         | (non-open message
                    |                     |  received)
```

Figure 3: One PCEP Speaker does not support PCEPS

3.4. TLS Connection Establishment

Once the establishment of TLS has been agreed by the PCEP peers, the connection establishment SHALL follow the following steps:

1. Immediately negotiate TLS sessions according to [RFC5246]. The following restrictions apply:

   * Support for TLS v1.2 [RFC5246] or later is REQUIRED.

   * Support for certificate-based mutual authentication is REQUIRED.

   * Negotiation of mutual authentication is REQUIRED.

   * Negotiation of a ciphersuite providing for integrity protection is REQUIRED.

   * Negotiation of a ciphersuite providing for confidentiality is RECOMMENDED.

   * Support for and negotiation of compression is OPTIONAL.

   * PCEPS implementations MUST, at a minimum, support negotiation of the TLS_RSA_WITH_3DES_EDE_CBC_SHA, and SHOULD support TLS_RSA_WITH_RC4_128_SHA and TLS_RSA_WITH_AES_128_CBC_SHA as well. In addition, PCEPS implementations MUST support negotiation of the mandatory-to-implement ciphersuites required by the versions of TLS that they support.

2. Peer authentication can be performed in any of the following two REQUIRED operation models:

   * TLS with X.509 certificates using Public-Key Infrastructure Exchange (PKIX) trust models:

     + Implementations MUST allow the configuration of a list of trusted Certification Authorities (CAs) for incoming connections.

     + Certificate validation MUST include the verification rules as per [RFC5280].

     + Implementations SHOULD indicate their trusted CAs. For TLS 1.2, this is done using [RFC5246], Section 7.4.4, "certificate_authorities" (server side) and [RFC6066], Section 6 "Trusted CA Indication" (client side).

     + Peer validation always SHOULD include a check on whether the locally configured expected DNS name or IP address of the peer that is contacted matches its presented certificate. DNS names and IP addresses can be contained in the Common Name (CN) or subjectAltName entries. For

verification, only one of these entries is to be considered. The following precedence applies: for DNS name validation, subjectAltName:DNS has precedence over CN; for IP address validation, subjectAltName:iPAddr has precedence over CN.

+ Implementations MAY allow the configuration of a set of additional properties of the certificate to check for a peer's authorization to communicate (e.g., a set of allowed values in subjectAltName:URI or a set of allowed X509v3 Certificate Policies)

* TLS with X.509 certificates using certificate fingerprints: Implementations MUST allow the configuration of a list of trusted certificates, identified via fingerprint of the Distinguished Encoding Rules (DER) encoded certificate octets. Implementations MUST support SHA-256 as the hash algorithm for the fingerprint.

3. Start exchanging PCEP messages.

To support TLS re-negotiation both peers MUST support the mechanism described in [RFC5746]. Any attempt of initiate a TLS handshake to establish new cryptographic parameters not aligned with [RFC5746] SHALL be considered a TLS negotiation failure.

3.5. Peer Identity

Depending on the peer authentication method in use, PCEPS supports different operation modes to establish peer's identity and whether it is entitled to perform requests or can be considered authoritative in its replies. PCEPS implementations SHOULD provide mechanisms for associating peer identities with different levels of access and/or authoritativeness, and they MUST provide a mechanism for establish a default level for properly identified peers. Any connection established with a peer that cannot be properly identified SHALL be terminated before any PCEP exchange takes place.

In TLS-X.509 mode using fingerprints, a peer is uniquely identified by the fingerprint of the presented client certificate.

There are numerous trust models in PKIX environments, and it is beyond the scope of this document to define how a particular deployment determines whether a client is trustworthy. Implementations that want to support a wide variety of trust models should expose as many details of the presented certificate to the administrator as possible so that the trust model can be implemented by the administrator. As a suggestion, at least the following

parameters of the X.509 client certificate should be exposed:

- o Peer's IP address
- o Peer's fully qualified domain name (FQDN)
- o Certificate Fingerprint
- o Issuer
- o Subject
- o All X509v3 Extended Key Usage
- o All X509v3 Subject Alternative Name
- o All X509v3 Certificate Policies

In addition, a PCC MAY apply the procedures described in [RFC6698] DNS-Based Authentication of Named Entities (DANE) to verify its peer identity when using DNS discovery. See section Section 4.1 for further details.

3.6. Connection Establishment Failure

In case the initial TLS negotiation or the peer identity check fail according to the procedures listed in this document, the peer MUST immediately terminate the session. It SHOULD follow the procedure listed in [RFC5440] to retry session setup along with an exponential back-off session establishment retry procedure.

4. Discovery Mechanisms

A PCE can advertise its capability to support PCEPS using the IGP advertisement and discovery mechanism. The PCE-CAP-FLAGS sub-TLV is an optional sub-TLV used to advertise PCE capabilities. It MAY be present within the PCE Discovery (PCED) sub-TLV carried by OSPF or IS-IS. [RFC5088] and [RFC5089] provide the description and processing rules for this sub-TLV when carried within OSPF and IS-IS, respectively. PCE capability bits are defined in [RFC5088]. A new capability flag bit for the PCE-CAP-FLAGS sub-TLV that can be announced as attribute to distribute PCEP security support information is proposed in [I-D.wu-pce-discovery-pceps-support]

When DNS is used by a PCC (or a PCE acting as a client, for the rest of the section, PCC refers to both) willing to use PCEPS to locate an appropriate PCE [I-D.wu-pce-dns-pce-discovery], the PCC as an initiating entity, chooses at least one of the returned FQDNs to

resolve, which it does by performing DNS "A" or "AAAA" lookups on the FDQN. This will eventually result in an IPv4 or IPv6 address. The PCC SHALL use the IP address(es) from the successfully resolved FDQN (with the corresponding port number returned by the DNS Service Record (SRV) lookup) as the connection address(es) for the receiving entity.

If the PCC fails to connect using an IP address but the "A" or "AAAA" lookups returned more than one IP address, then the PCC SHOULD use the next resolved IP address for that FDQN as the connection address. If the PCC fails to connect using all resolved IP addresses for a given FDQN, then it SHOULD repeat the process of resolution and connection for the next FQDN returned by the SRV lookup based on the priority and weight.

If the PCC receives a response to its SRV query but it is not able to establish a PCEPS connection using the data received in the response, as initiating entity it MAY fall back to lookup a PCE that uses TCP as transport.

4.1. DANE Applicability

DANE [RFC6698] defines a secure method to associate the certificate that is obtained from a TLS server with a domain name using DNS, i.e., using the TLSA DNS resource record (RR) to associate a TLS server certificate or public key with the domain name where the record is found, thus forming a "TLSA certificate association". The DNS information needs to be protected by DNS Security (DNSSEC). A PCC willing to apply DANE to verify server identity MUST conform to the rules defined in section 4 of [RFC6698].

5. Backward Compatibility

The procedures described in this document define a security container for the transport of PCEP requests and replies carried by a TLS connection initiated by means of a specific extended message (StartTLS) that does not interfere with PCEP speaker implementations not supporting it.

If a PCEP implementation that does not support PCEPS receives a StartTLS message it MUST behave according to the existing error mechanism of [RFC5440].

6. IANA Considerations

6.1. New PCEP Message

Each PCEP message has a message type value.

One new PCEP messages is defined in this document:

Value	Description	Reference
TBA	The Start TLS Message (StartTLS)	This document

6.2. New Error-Values

A registry was created for the Error-type and Error-value of the PCEP Error Object. Following new Error-Types and Error-Values are defined:

Error-Type	Meaning	Error-value	Reference
TBA	StartTLS Failure	0:Unassigned	This document
		1:Reception of StartTLS after any PCEP exchange	This document
		2:Reception of non-StartTLS or non-PCErr message	This document
		3:Failure, connection without TLS not possible	This document
		4:Failure, connection without TLS possible	This document
		5:No StartTLS message before StartTLSWait timer expiry	This document

7. Security Considerations

While the application of TLS satisfies the requirement on privacy as well as fine-grained, policy-based peer authentication, there are security threats that it cannot address. It is advisable to apply additional protection measures, in particular in what relates to attacks specifically addressed to forging the TCP connection underpinning TLS. TCP-AO (TCP Authentication Option [RFC5925]) is fully compatible with and deemed as complementary to TLS, so its usage is to be considered as a security enhancement whenever any of the PCEPS peers require it, especially in the case of long-lived connections. The mechanisms to configure the requirements to use TCP-AO and other lower-layer protection measures, as well as the association of the required crypto material (MKT in the case of

TCP-AO) with a particular peer are outside the scope of this document. [I-D.chunduri-karp-using-ikev2-with-tcp-ao] defines a method to perform such association.

Since computational resources required by TLS handshake and ciphersuite are higher than unencrypted TCP, clients connecting to a PCEPS server can more easily create high load conditions and a malicious client might create a Denial-of-Service attack more easily.

Some TLS ciphersuites only provide integrity validation of their payload, and provide no encryption. This specification does not forbid the use of such ciphersuites, but administrators must weight carefully the risk of relevant internal data leakage that can occur in such a case, as explicitly stated by [RFC6952].

When using certificate fingerprints to identify PCEPS peers, any two certificates that produce the same hash value will be considered the same peer. Therefore, it is important to make sure that the hash function used is cryptographically uncompromised so that attackers are very unlikely to be able to produce a hash collision with a certificate of their choice. This document mandates support for SHA-256, but a later revision may demand support for stronger functions if suitable attacks on it are known.

8. Manageability Considerations

All manageability requirements and considerations listed in [RFC5440] apply to PCEP protocol extensions defined in this document. In addition, requirements and considerations listed in this section apply.

8.1. Control of Function and Policy

A PCE or PCC implementation MUST allow configuring the PCEP security via TLS capabilities as described in this document.

A PCE or PCC implementation supporting PCEP security via TLS MUST support general TLS configuration as per [RFC5246]. At least the configuration of one of the trust models and its corresponding parameters, as described in Section 3.4 and Section 3.5, MUST be supported by the implementation.

A PCEP implementation SHOULD allow configuring the following PCEP security parameters:

o StartTLSWait timer value

8.2. Information and Data Models

The PCEP MIB module SHOULD be extended to include PCEPS capabilities, information, and status.

8.3. Liveness Detection and Monitoring

Mechanisms defined in this document do not imply any new liveness detection and monitoring requirements in addition to those already listed in [RFC5440] and [RFC5246].

8.4. Verify Correct Operations

A PCEPS implementation SHOULD log error events and provide PCEPS failure statistics with reasons.

8.5. Requirements on Other Protocols

Mechanisms defined in this document do not imply any new requirements on other protocols.

8.6. Impact on Network Operations

Mechanisms defined in this document do not have any impact on network operations in addition to those already listed in [RFC5440].

9. Acknowledgements

This specification relies on the analysis and profiling of TLS included in [RFC6614] and the procedures described for the STARTTLS command in [RFC2830].

We would like to thank Joe Touch for his suggestions and support regarding the TLS start mechanisms.

Thanks to Dan King for reminding the authors about manageability considerations.

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