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Two-Way Active Measurement Protocol (TWAMP) YANG Data Model

Abstract

This document specifies a data model for client and server implementations of the Two-Way Active Measurement Protocol (TWAMP). This document defines the TWAMP data model through Unified Modeling Language (UML) class diagrams and formally specifies it using the YANG data modeling language (RFC 7950). The data model is compliant with the Network Management Datastore Architecture (NMDA).

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc8913.

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1. Introduction

The Two-Way Active Measurement Protocol (TWAMP) [RFC5357] is used to measure network performance parameters such as latency, bandwidth, and packet loss by sending probe packets and measuring their experience in the network. To date, TWAMP implementations do not come with a standard management framework, and, as such, implementers have no choice except to provide a proprietary mechanism. This document addresses this gap by defining the model using Unified Modeling Language (UML) class diagrams [UML] and formally specifying a TWAMP data model that is compliant with the Network Management Datastore Architecture (NMDA) [RFC8342], using YANG 1.1 [RFC7950].

1.1. Motivation

In current TWAMP deployments, the lack of a standardized data model limits the flexibility to dynamically instantiate TWAMP-based measurements across equipment from different vendors. In large, virtualized, and dynamically instantiated infrastructures where

network functions are placed according to orchestration algorithms, proprietary mechanisms for managing TWAMP measurements pose severe limitations with respect to programmability.

Two major trends call for standardizing TWAMP management aspects. First, it is expected that in the coming years large-scale and multi-vendor TWAMP deployments will become the norm. From an operations perspective, using several vendor-specific TWAMP configuration mechanisms when one standard mechanism could provide an alternative is expensive and inefficient. Second, the increasingly software-defined and virtualized nature of network infrastructures, based on dynamic service chains [NSC] and programmable control and management planes [RFC7426], requires a well-defined data model for TWAMP implementations. This document defines such a TWAMP data model and specifies it formally using the YANG 1.1 data modeling language [RFC7950].

1.2. Terminology

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.

1.3. Document Organization

The rest of this document is organized as follows. Section 2 presents the scope and applicability of this document. Section 3 provides a high-level overview of the TWAMP data model. Section 4 details the configuration parameters of the data model, and Section 5 specifies in YANG the TWAMP data model. Section 6 lists illustrative examples that conform to the YANG data model specified in this document. Appendix A elaborates these examples further.

2. Scope, Model, and Applicability

The purpose of this document is the specification of a vendor-independent data model for TWAMP implementations.

Figure 1 illustrates a redrawn version of the TWAMP logical model found in Section 1.2 of TWAMP [RFC5357]. The figure is annotated with pointers to the UML diagrams [UML] provided in this document and associated with the data model of the four logical entities in a TWAMP deployment, namely the TWAMP Control-Client, Server, Session-Sender, and Session-Reflector. A UML Notation Guide is available in Section 5 of UML [UML].

As per TWAMP [RFC5357], unlabeled links in Figure 1 are left unspecified and may be proprietary protocols.

Figure 1: Annotated TWAMP Logical Model

As per TWAMP [RFC5357], a TWAMP implementation may follow a simplified logical model, in which the same node acts as both Control-Client and Session-Sender, while another node acts at the same time as both TWAMP Server and Session-Reflector. Figure 2 illustrates this simplified logical model and indicates the interaction between the TWAMP configuration client and server using, for instance, NETCONF [RFC6241] or RESTCONF [RFC8040].

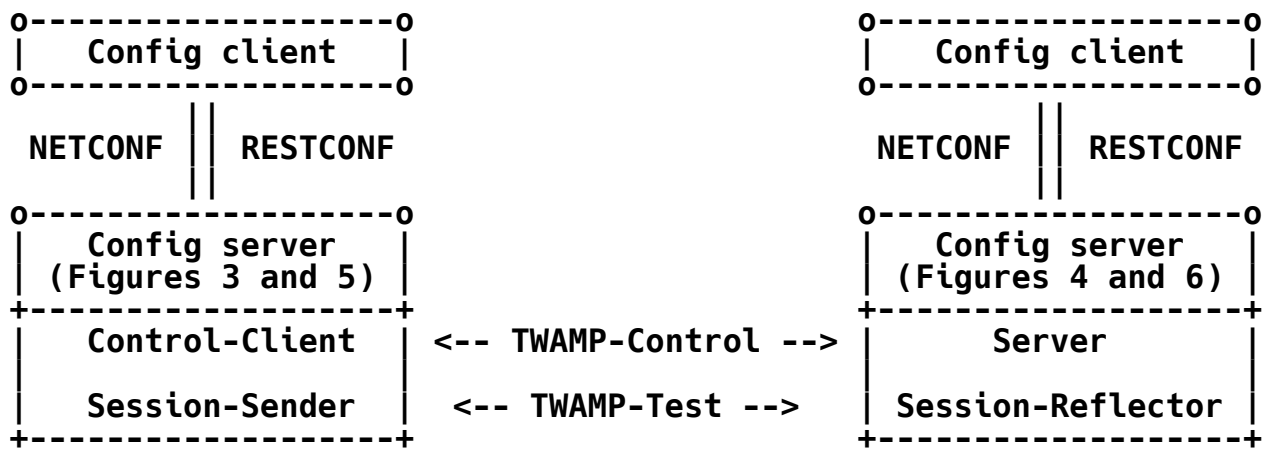


Figure 2: Simplified TWAMP Model and Protocols

The data model defined in this document is orthogonal to the specific protocol used between the Config client and Config server to communicate the TWAMP configuration parameters.

Operational actions such as how TWAMP-Test sessions are started and stopped, how performance measurement results are retrieved, or how stored results are cleared, and so on, are not addressed by the configuration model defined in this document. As noted above, such operational actions are not part of the TWAMP specification [RFC5357] and hence are out of scope for this document. See also Appendix B. In addition, for operational state, the information provided in the Performance Metrics Registry [RFC8911] and [PERF-METRICS] can be used to develop an independent model for the Performance Metrics that need to be captured and retrieved.

3. Data Model Overview

The TWAMP data model includes four categories of configuration items.

First, global configuration items relate to parameters that are set on a per-device level. For example, the administrative status of the device with respect to whether it allows TWAMP sessions and, if so,

in what capacity (e.g., Control-Client, Server, or both) is a typical instance of a global configuration item.

A second category includes attributes that can be configured on a per-TWAMP-Control-connection basis, such as the Server IP address.

A third category includes attributes related to per-TWAMP-Test-session attributes -- for instance, setting different values in the Differentiated Services Code Point (DSCP) field.

Finally, the data model includes attributes that relate to the operational state of the TWAMP implementation.

As the TWAMP data model is described in the remaining sections of this document, readers should keep in mind the functional entity grouping illustrated in Figure 1.

3.1. Control-Client

A TWAMP Control-Client has an administrative status field set at the device level that indicates whether the node is enabled to function as such.

Each TWAMP Control-Client is associated with zero or more TWAMP-Control connections. The main configuration parameters of each control connection are:

* A name that can be used to uniquely identify at the Control-Client a particular control connection. This name is necessary for programmability reasons because at the time of creation of a TWAMP-Control connection not all IP and TCP port number information needed to uniquely identify the connection is available.

* The IP address of the interface the Control-Client will use for connections.

* The IP address of the remote TWAMP Server.

* Authentication and encryption attributes such as KeyID, Token, and the Control-Client Initialization Vector (Client-IV); see also Section 3.1 of "A One-way Active Measurement Protocol (OWAMP)" [RFC4656] and "Randomness Requirements for Security" [RFC4086].

Each TWAMP-Control connection, in turn, is associated with zero or more TWAMP-Test sessions. For each test session, the following configuration items should be noted:

* The test session name, which uniquely identifies a particular test session at the Control-Client and Session-Sender. Similar to the control connections mentioned above, this unique test session name is needed because at the time of creation of a TWAMP-Test session, for example, the source UDP port number is not known to uniquely identify the test session.

* The IP address and UDP port number of the Session-Sender on the

path under test by TWAMP.

* The IP address and UDP port number of the Session-Reflector on said path.

* Information pertaining to the test packet stream, such as the test starting time; which Performance Metric is to be used, as defined in "Registry for Performance Metrics" [RFC8911]; or whether the test should be repeated.

3.2. Server

Each TWAMP Server has an administrative status field set at the device level to indicate whether the node is enabled to function as a TWAMP Server.

Each Server is associated with zero or more TWAMP-Control connections. Each control connection is uniquely identified by the 4-tuple {Control-Client IP address, Control-Client TCP port number, Server IP address, Server TCP port}. Control connection configuration items on a TWAMP Server are read-only.

3.3. Session-Sender

A TWAMP Session-Sender has an administrative status field set at the device level that indicates whether the node is enabled to function as such.

There is one Session-Sender instance for each TWAMP-Test session that is initiated from the sending device. Primary configuration fields include:

* The test session name, which MUST be identical to the corresponding test session name on the TWAMP Control-Client (Section 3.1).

* The control connection name, which, along with the test session name, uniquely identifies the TWAMP Session-Sender instance.

* Information pertaining to the test packet stream, such as the number of test packets and the packet distribution to be employed; see also "Network performance measurement with periodic streams" [RFC3432].

3.4. Session-Reflector

Each TWAMP Session-Reflector has an administrative status field set at the device level to indicate whether the node is enabled to function as such.

Each Session-Reflector is associated with zero or more TWAMP-Test sessions. For each test session, the REFWAIT timeout parameter, which determines whether to discontinue the session if no packets have been received (TWAMP [RFC5357], Section 4.2), can be configured.

Read-only access to other data model parameters, such as the Sender

IP address, is foreseen. Each test session can be uniquely identified by the 4-tuple mentioned in Section 3.2.

4. Data Model Parameters

This section defines the TWAMP data model using UML [UML] and introduces selected parameters associated with the four TWAMP logical entities. The complete TWAMP data model specification is provided in the YANG module presented in Section 5.2.

4.1. Control-Client

The client container (see Figure 3) holds items that are related to the configuration of the TWAMP Control-Client logical entity (recall Figure 1).

The client container includes an administrative configuration parameter (client/admin-state) that indicates whether the device is allowed to initiate TWAMP-Control connections.

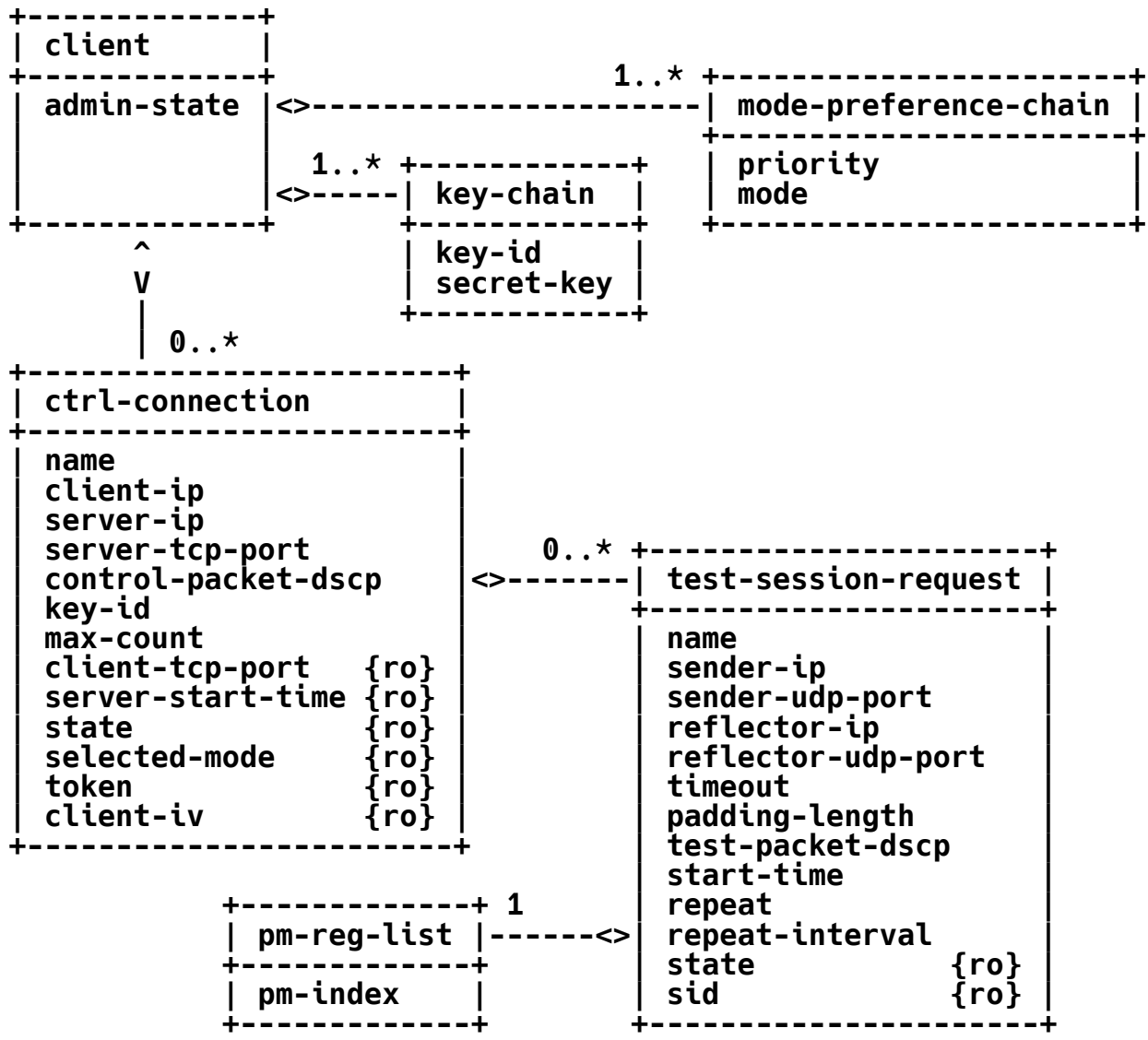


Figure 3: TWAMP Control-Client UML Class Diagram

The client container holds a list (mode-preference-chain) that specifies the mode values according to their preferred order of use by the operator of this Control-Client, including the authentication and encryption modes. Specifically, mode-preference-chain lists the mode and its corresponding priority, expressed as a 16-bit unsigned integer. Values for the priority start with zero, the highest priority, and decreasing priority value is indicated by every increase in value by one.

Depending on the modes available in the Server Greeting, the Control-Client MUST choose the highest-priority mode from the configured mode-preference-chain list.

Note that the list of preferred modes may set multiple bit positions independently, such as when referring to the extended TWAMP features in "Mixed Security Mode for the Two-Way Active Measurement Protocol (TWAMP)" [RFC5618], "Individual Session Control Feature for the Two-Way Active Measurement Protocol (TWAMP)" [RFC5938], "Two-Way Active Measurement Protocol (TWAMP) Reflect Octets and Symmetrical Size Features" [RFC6038], and "IKEv2-Derived Shared Secret Key for the One-Way Active Measurement Protocol (OWAMP) and Two-Way Active Measurement Protocol (TWAMP)" [RFC7717]. If the Control-Client cannot determine an acceptable mode, or when the bit combinations do not make sense, e.g., authenticated and unauthenticated bits are both set, it MUST respond with zero Mode bits set in the Set-Up-Response message, indicating that it will not continue with the control connection.

In addition, the client container holds a list named "key-chain", which relates key-id with the respective secret-key. Both the Server and the Control-Client use the same mappings from key-id to secret-key (in Figure 3); in order for this to work properly, key-id must be unique across all systems in the administrative domain. The Server, being prepared to conduct sessions with more than one Control-Client, uses key-id to choose the appropriate secret-key; a Control-Client would typically have different secret keys for different Servers. The secret-key is the shared secret, of type "binary", and the length SHOULD contain at least 128 bits of entropy. The key-id and secret-key encoding SHOULD follow Section 9.8 of YANG [RFC7950]. The derived key length (dkLen as defined in "PKCS #5: Password-Based Cryptography Specification Version 2.1" [RFC8018]) MUST be 16 octets for the AES Session-key used for encryption and 32 octets for the HMAC-SHA1 Session-key used for authentication; see also Section 6.10 of OWAMP [RFC4656].

Each client container also holds a list of control connections, where each item in the list describes a TWAMP-Control connection initiated by this Control-Client. There SHALL be one ctrl-connection per TWAMP-Control (TCP) connection that is to be initiated from this device.

In turn, each ctrl-connection holds a test-session-request list. Each test-session-request holds information associated with the Control-Client for this test session. This includes information

associated with the Request-TW-Session/Accept-Session message exchange (see Section 3.5 of TWAMP [RFC5357]).

There SHALL be one instance of test-session-request for each TWAMP-Test session that is to be negotiated by this TWAMP-Control connection via a Request-TW-Session/Accept-Session exchange.

The Control-Client is also responsible for scheduling TWAMP-Test sessions; therefore, test-session-request holds information related to these actions (e.g., pm-index, repeat-interval).

4.2. Server

The server container (see Figure 4) holds items that are related to the configuration of the TWAMP Server logical entity (recall Figure 1).

The server container includes an administrative configuration parameter (server/admin-state) that indicates whether the device is allowed to receive TWAMP-Control connections.

A device operating in the Server Role cannot configure attributes on a per-TWAMP-Control-connection basis, as it has no foreknowledge of the incoming TWAMP-Control connections to be received. Consequently, any parameter that the Server might want to apply to an incoming control connection must be configured at the overall Server level and applied to all incoming TWAMP-Control connections.

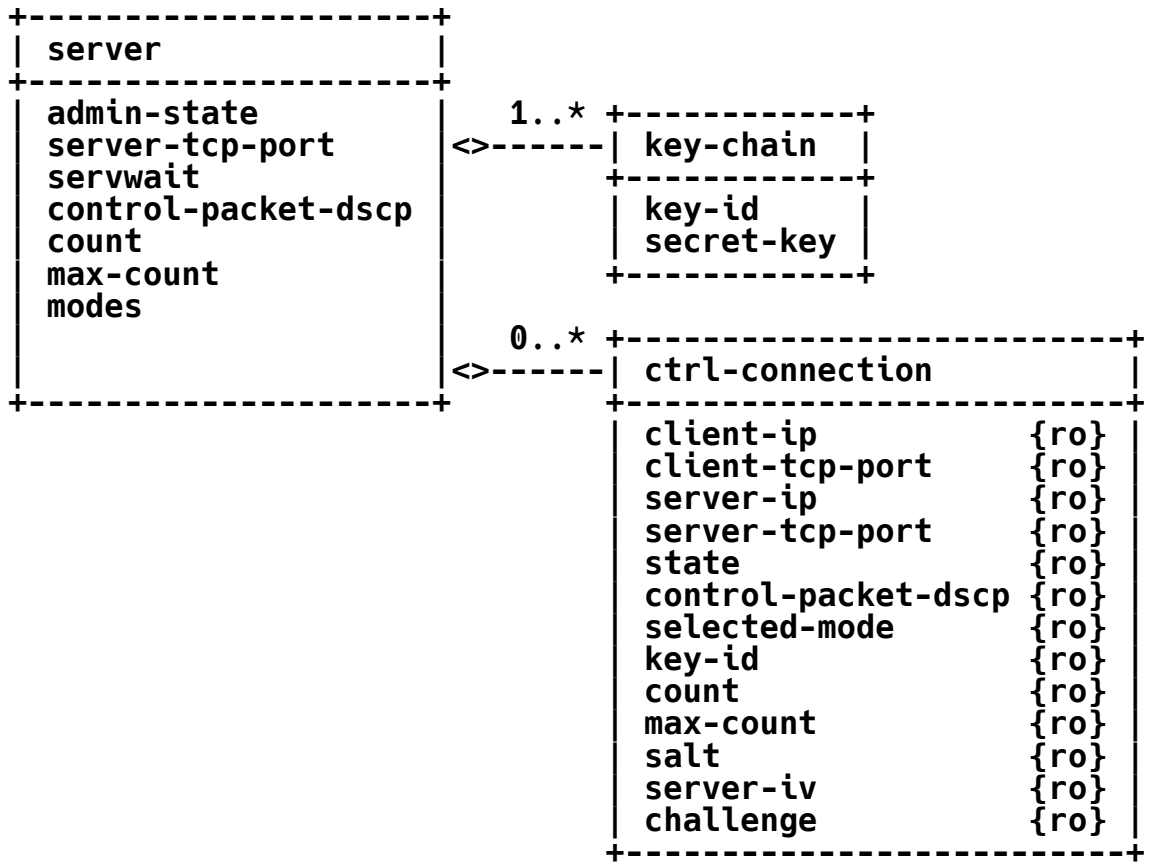


Figure 4: TWAMP Server UML Class Diagram

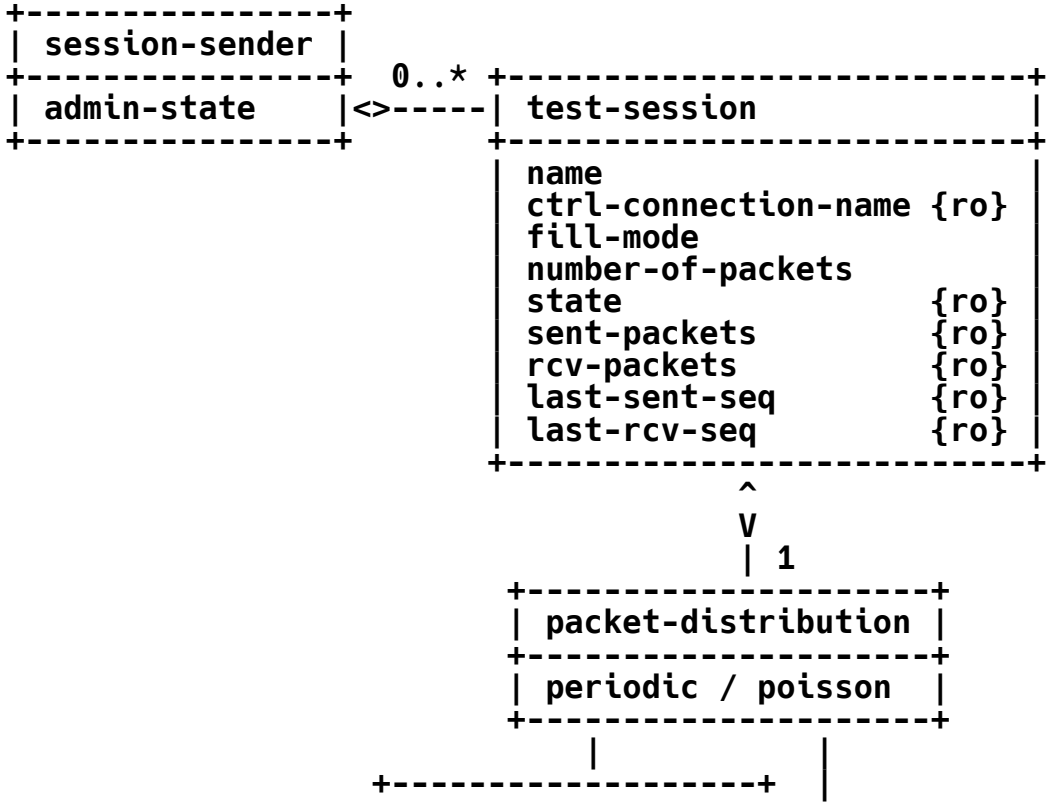
Each server container holds a list named "key-chain", which relates key-id with the respective secret-key. As mentioned in Section 4.1, both the Server and the Control-Client use the same mapping from key-id to the shared secret-key; in order for this to work properly, key-id must be unique across all the systems in the administrative domain. The Server, being prepared to conduct sessions with more than one Control-Client, uses key-id to choose the appropriate secret-key; a Control-Client would typically have different secret keys for different Servers. key-id tells the Server which shared secret-key the Control-Client wishes to use for authentication or encryption.

Each incoming control connection active on the Server is represented by a ctrl-connection. There SHALL be one ctrl-connection per incoming TWAMP-Control (TCP) connection that is received and active on the Server. Each ctrl-connection can be uniquely identified by the 4-tuple {client-ip, client-tcp-port, server-ip, server-tcp-port}. All items in the ctrl-connection list are read-only.

4.3. Session-Sender

The session-sender container, illustrated in Figure 5, holds items that are related to the configuration of the TWAMP Session-Sender logical entity.

The session-sender container includes an administrative parameter (session-sender/admin-state) that controls whether the device is allowed to initiate TWAMP-Test sessions.



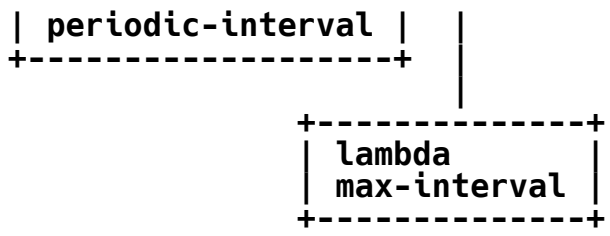


Figure 5: TWAMP Session-Sender UML Class Diagram

Each TWAMP-Test session initiated by the Session-Sender will be represented by an instance of a test-session object. There SHALL be one instance of test-session for each TWAMP-Test session for which packets are being sent.

4.4. Session-Reflector

The session-reflector container, illustrated in Figure 6, holds items that are related to the configuration of the TWAMP Session-Reflector logical entity.

The session-reflector container includes an administrative parameter (session-reflector/admin-state) that controls whether the device is allowed to respond to incoming TWAMP-Test sessions.

A device operating in the Session-Reflector Role cannot configure attributes on a per-session basis, as it has no foreknowledge of what incoming sessions it will receive. As such, any parameter that the Session-Reflector might want to apply to an incoming TWAMP-Test session must be configured at the overall Session-Reflector level and applied to all incoming sessions.

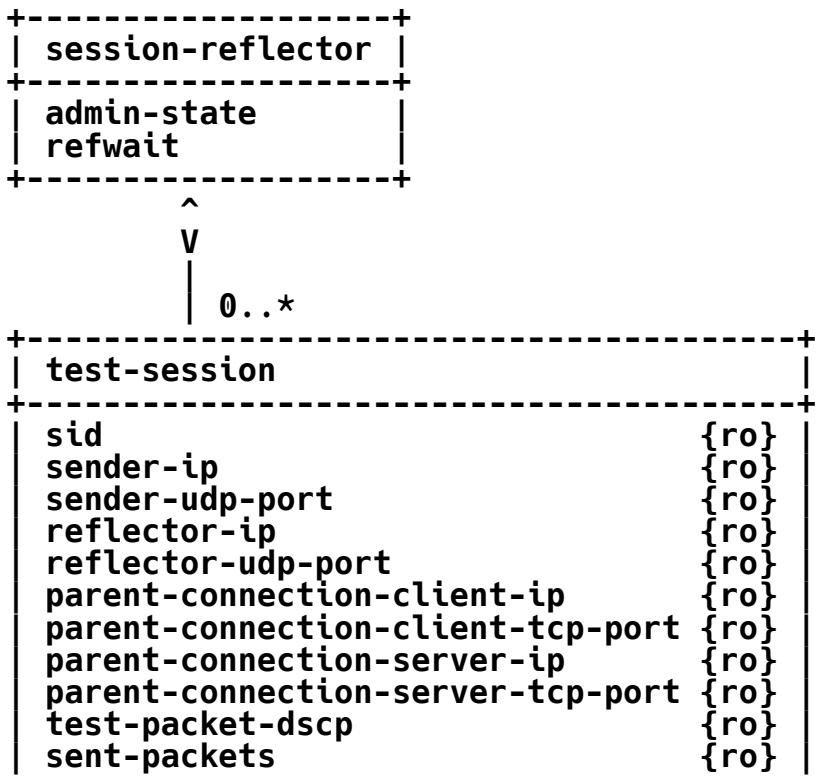


Figure 6: TWAMP Session-Reflector UML Class Diagram

Each incoming TWAMP-Test session that is active on the Session-Reflector SHALL be represented by an instance of a test-session object. All items in the test-session object are read-only.

Instances of test-session are indexed by a Session Identifier (SID) (the sid parameter). This SID value is auto-allocated by the TWAMP Server as test session requests are received and is communicated back to the Control-Client in the SID field of the Accept-Session message; see Section 4.3 of "Two-Way Active Measurement Protocol (TWAMP) Reflect Octets and Symmetrical Size Features" [RFC6038].

When attempting to retrieve operational data for active test sessions from a Session-Reflector device, the user will not know what sessions are currently active on that device or what SIDs have been auto-allocated for these test sessions. If the user has network access to the Control-Client device, then it is possible to read the data for this session under client/ctrl-connection/test-session-request/sid and obtain the SID (see Figure 3). The user may then use this SID value as an index to retrieve an individual session-reflector/test-session instance on the Session-Reflector device.

If the user has no network access to the Control-Client device, then the only option is to retrieve all test-session instances from the Session-Reflector device and then pick out specific test-session instances of interest to the user. This could be problematic if a large number of test sessions are currently active on that device.

Each Session-Reflector TWAMP-Test session contains the following 4-tuple: {parent-connection-client-ip, parent-connection-client-tcp-port, parent-connection-server-ip, parent-connection-server-tcp-port}. This 4-tuple MUST correspond to the equivalent 4-tuple {client-ip, client-tcp-port, server-ip, server-tcp-port} in server/ctrl-connection. This 4-tuple allows the user to trace back from the TWAMP-Test session to the (parent) TWAMP-Control connection that negotiated this test session.

5. Data Model

This section formally specifies the TWAMP data model using YANG.

5.1. YANG Tree Diagram

This section presents a simplified graphical representation of the TWAMP data model using a YANG tree diagram. Readers should keep in mind that the limit of 72 characters per line forces us to introduce artificial line breaks in some tree diagram nodes. Tree diagrams used in this document follow the notation defined in "YANG Tree Diagrams" [RFC8340].

Please note that the backslash ('\') character near the end of the diagram is used for formatting purposes only (i.e., "reflector-udp-port]" should be treated as part of the same line as "[sender-ip sender-udp-port reflector-ip").

```
module: ietf-twamp
  +--rw twamp
     +--rw client {control-client}?
     |  +--rw admin-state?              boolean
     |  +--rw mode-preference-chain* [priority]
     |  |  +--rw priority    uint16
     |  |  +--rw mode?       twamp-modes
     |  +--rw key-chain* [key-id]
     |  |  +--rw key-id        string
     |  |  +--rw secret-key?   binary
     |  +--rw ctrl-connection* [name]
     |     +--rw name                      string
     |     +--rw client-ip?                inet:ip-address
     |     +--rw server-ip                 inet:ip-address
     |     +--rw server-tcp-port?          inet:port-number
     |     +--rw control-packet-dscp?      inet:dscp
     |     +--rw key-id?                   string
     |     +--rw max-count-exponent?       uint8
     |     +--ro client-tcp-port?          inet:port-number
     |     +--ro server-start-time?        uint64
     |     +--ro repeat-count?             uint64
     |     +--ro state?
     |     |       control-client-connection-state
     |     +--ro selected-mode?            twamp-modes
     |     +--ro token?                    binary
     |     +--ro client-iv?                binary
     |     +--rw test-session-request* [name]
     |        +--rw name                    string
     |        +--rw sender-ip?              inet:ip-address
     |        +--rw sender-udp-port?        union
     |        +--rw reflector-ip            inet:ip-address
     |        +--rw reflector-udp-port?     inet:port-number
     |        +--rw timeout?                uint64
     |        +--rw padding-length?         uint32
     |        +--rw test-packet-dscp?       inet:dscp
     |        +--rw start-time?             uint64
     |        +--rw repeat?                 uint32
     |        +--rw repeat-interval?        uint32
     |        +--rw pm-reg-list* [pm-index]
     |        |  +--rw pm-index    uint16
     |        +--ro state?                  test-session-state
     |        +--ro sid?                    string
     +--rw server {server}?
     |  +--rw admin-state?            boolean
     |  +--rw server-tcp-port?        inet:port-number
     |  +--rw servwait?               uint32
     |  +--rw control-packet-dscp?    inet:dscp
     |  +--rw count?                  uint8
     |  +--rw max-count-exponent?     uint8
     |  +--rw modes?                  twamp-modes
     |  +--rw key-chain* [key-id]
```

```
|   |  +--rw key-id        string
|   |  +--rw secret-key?   binary
|   +--ro ctrl-connection*
|           [client-ip client-tcp-port server-ip server-tcp-port]
|      +--ro client-ip               inet:ip-address
|      +--ro client-tcp-port         inet:port-number
|      +--ro server-ip               inet:ip-address
|      +--ro server-tcp-port         inet:port-number
|      +--ro state?                  server-ctrl-connection-state
|      +--ro control-packet-dscp?    inet:dscp
|      +--ro selected-mode?          twamp-modes
|      +--ro key-id?                 string
|      +--ro count?                  uint8
|      +--ro max-count-exponent?     uint8
|      +--ro salt?                   binary
|      +--ro server-iv?              binary
|      +--ro challenge?              binary
+--rw session-sender {session-sender}?
|   +--rw admin-state?    boolean
|   +--rw test-session* [name]
|      +--rw name                      string
|      +--ro ctrl-connection-name?     string
|      +--rw fill-mode?                padding-fill-mode
|      +--rw number-of-packets         uint32
|      +--rw (packet-distribution)?
|      |  +--:(periodic)
|      |  |  +--rw periodic-interval       decimal64
|      |  +--:(poisson)
|      |     +--rw lambda                  decimal64
|      |     +--rw max-interval?           decimal64
|      +--ro state?                    sender-session-state
|      +--ro sent-packets?             uint32
|      +--ro rcv-packets?              uint32
|      +--ro last-sent-seq?            uint32
|      +--ro last-rcv-seq?             uint32
+--rw session-reflector {session-reflector}?
   +--rw admin-state?    boolean
   +--rw refwait?        uint32
   +--ro test-session*
           [sender-ip sender-udp-port reflector-ip \
            reflector-udp-port]
      +--ro sid?                                  string
      +--ro sender-ip                             inet:ip-address
      +--ro sender-udp-port
      |       dynamic-port-number
      +--ro reflector-ip                          inet:ip-address
      +--ro reflector-udp-port                    inet:port-number
      +--ro parent-connection-client-ip?          inet:ip-address
      +--ro parent-connection-client-tcp-port?    inet:port-number
      +--ro parent-connection-server-ip?          inet:ip-address
      +--ro parent-connection-server-tcp-port?    inet:port-number
      +--ro test-packet-dscp?                     inet:dscp
      +--ro sent-packets?                         uint32
      +--ro rcv-packets?                          uint32
      +--ro last-sent-seq?                        uint32
      +--ro last-rcv-seq?                         uint32
```

Figure 7: YANG Tree Diagram

5.2. YANG Module

This section presents the YANG module for the TWAMP data model defined in this document. The module imports definitions from "Common YANG Data Types" [RFC6991] and references "Framework for IP Performance Metrics" [RFC2330], "Network performance measurement with periodic streams" [RFC3432], "A One-way Active Measurement Protocol (OWAMP)" [RFC4656], "A Two-Way Active Measurement Protocol (TWAMP)" [RFC5357], "Mixed Security Mode for the Two-Way Active Measurement Protocol (TWAMP)" [RFC5618], "Network Time Protocol Version 4: Protocol and Algorithms Specification" [RFC5905], "Individual Session Control Feature for the Two-Way Active Measurement Protocol (TWAMP)" [RFC5938], "Two-Way Active Measurement Protocol (TWAMP) Reflect Octets and Symmetrical Size Features" [RFC6038], "Advanced Stream and Sampling Framework for IP Performance Metrics (IPPM)" [RFC7312], "IKEv2-Derived Shared Secret Key for the One-Way Active Measurement Protocol (OWAMP) and Two-Way Active Measurement Protocol (TWAMP)" [RFC7717], "Well-Known Port Assignments for the One-Way Active Measurement Protocol (OWAMP) and the Two-Way Active Measurement Protocol (TWAMP)" [RFC8545], and "Registry for Performance Metrics" [RFC8911].

```
<CODE BEGINS> file "ietf-twamp@2021-11-17.yang"
module ietf-twamp {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-twamp";
  prefix ietf-twamp;

  import ietf-inet-types {
    prefix inet;
    reference
      "RFC 6991: Common YANG Data Types";
  }

  organization
    "IETF IPPM (IP Performance Metrics) Working Group";
  contact
    "WG Web: <https://datatracker.ietf.org/wg/ippm/documents/>
     WG List: <mailto:ippm@ietf.org>

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```

```
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description
  "This YANG module specifies a vendor-independent data
   model for the Two-Way Active Measurement Protocol (TWAMP).

   The data model defines four TWAMP logical entities, namely
   Control-Client, Server, Session-Sender, and Session-Reflector,
   as illustrated in the annotated TWAMP logical model (Figure 1
   of RFC 8913).

   This YANG module uses features to indicate which of the four
   logical entities are supported by a TWAMP implementation.

   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 (RFC 2119) (RFC 8174) when, and only when,
   they appear in all capitals, as shown here.

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   (https://trustee.ietf.org/license-info).

   This version of this YANG module is part of RFC 8913; see the
   RFC itself for full legal notices.";

revision 2021-11-17 {
  description
    "Initial revision.

     References RFC 5357, RFC 5618, RFC 5938, RFC 6038, RFC 7717,
     and RFC 8911.";
  reference
    "RFC 8913: Two-Way Active Measurement Protocol (TWAMP) YANG
     Data Model";
}

/*
 * Typedefs
 */

typedef twamp-modes {
  type bits {
    bit unauthenticated {
      position 0;
      description
        "Unauthenticated mode, in which no encryption or
         authentication is applied in TWAMP-Control and
         TWAMP-Test.  KeyID, Token, and Client-IV are not used in
         the Set-Up-Response message.  See Section 3.1 of
```

```
      RFC 4656.";
    reference
      "RFC 4656: A One-way Active Measurement Protocol (OWAMP),
                 Section 3.1";
  }
  bit authenticated {
    position 1;
    description
      "Authenticated mode, in which the Control-Client and
       Server possess a shared secret, thus prohibiting
       'theft of service'.  As per Section 6 of RFC 4656,
       in 'authenticated mode, the timestamp is in the clear
       and is not protected cryptographically in any way,
       while the rest of the message has the same protection
       as in encrypted mode.  This mode allows one to trade off
       cryptographic protection against accuracy of
       timestamps.'";
    reference
      "RFC 4656: A One-way Active Measurement Protocol (OWAMP),
                 Section 6";
  }
  bit encrypted {
    position 2;
    description
      "Encrypted mode 'makes it impossible to alter
       timestamps undetectably' (Section 1 of RFC 4656).
       See also Section 4 of RFC 7717.";
    reference
      "RFC 4656: A One-way Active Measurement Protocol (OWAMP),
                 Section 6
       RFC 7717: IKEv2-Derived Shared Secret Key for the One-Way
       Active Measurement Protocol (OWAMP) and Two-Way Active
       Measurement Protocol (TWAMP), Section 4";
  }
  bit unauth-test-encrypt-control {
    position 3;
    description
      "When using the mixed security mode, the TWAMP-Test
       protocol operates in unauthenticated mode and the
       TWAMP-Control protocol operates in encrypted mode.";
    reference
      "RFC 5618: Mixed Security Mode for the Two-Way Active
       Measurement Protocol (TWAMP)";
  }
  bit individual-session-control {
    position 4;
    description
      "This mode enables individual test sessions using
       Session Identifiers.";
    reference
      "RFC 5938: Individual Session Control Feature
       for the Two-Way Active Measurement Protocol (TWAMP)";
  }
  bit reflect-octets {
    position 5;
    description
```

```
        "This mode indicates the reflect octets capability.";
      reference
        "RFC 6038: Two-Way Active Measurement Protocol (TWAMP)
         Reflect Octets and Symmetrical Size Features";
    }
    bit symmetrical-size {
      position 6;
      description
        "This mode indicates support for the symmetrical size
         sender test packet format.";
      reference
        "RFC 6038: Two-Way Active Measurement Protocol (TWAMP)
         Reflect Octets and Symmetrical Size Features";
    }
    bit IKEv2Derived {
      position 7;
      description
        "In this mode, the shared key is derived
         from an Internet Key Exchange Protocol Version 2 (IKEv2)
         security association (SA).";
      reference
        "RFC 7717: IKEv2-Derived Shared Secret Key for
         the One-Way Active Measurement Protocol (OWAMP)
         and Two-Way Active Measurement Protocol (TWAMP)";
    }
  }
  description
    "Specifies the configurable TWAMP-Modes supported during a
     TWAMP-Control connection setup between a Control-Client
     and a Server.  Section 7 of RFC 7717 summarizes the
     'TWAMP-Modes' Registry and points to their
     formal specification.";
}

typedef control-client-connection-state {
  type enumeration {
    enum active {
      description
        "Indicates an active TWAMP-Control connection to the
         Server.";
    }
    enum idle {
      description
        "Indicates an idle TWAMP-Control connection to the
         Server.";
    }
  }
  description
    "Indicates the Control-Client TWAMP-Control connection
     state.";
}

typedef test-session-state {
  type enumeration {
    enum accepted {
      value 0;
```

```
      description
        "Indicates an accepted TWAMP-Test session request.";
    }
    enum failed {
      value 1;
      description
        "Indicates a TWAMP-Test session failure due to
         some unspecified reason (catch-all).";
    }
    enum internal-error {
      value 2;
      description
        "Indicates a TWAMP-Test session failure due to
         an internal error.";
    }
    enum not-supported {
      value 3;
      description
        "Indicates a TWAMP-Test session failure because
         some aspect of the TWAMP-Test session request
         is not supported.";
    }
    enum permanent-resource-limit {
      value 4;
      description
        "Indicates a TWAMP-Test session failure due to
         permanent resource limitations.";
    }
    enum temp-resource-limit {
      value 5;
      description
        "Indicates a TWAMP-Test session failure due to
         temporary resource limitations.";
    }
  }
  description
    "Indicates the Control-Client TWAMP-Test session state.";
}

typedef server-ctrl-connection-state {
  type enumeration {
    enum active {
      description
        "Indicates an active TWAMP-Control connection
         to the Control-Client.";
    }
    enum servwait {
      description
        "Indicates that the TWAMP-Control connection to the
         Control-Client is in SERVWAIT as per the definition in
         Section 3.1 of RFC 5357.";
      reference
        "RFC 5357: A Two-Way Active Measurement Protocol (TWAMP),
                   Section 3.1";
    }
  }
```

```
  description
    "Indicates the Server TWAMP-Control connection state.";
}

typedef sender-session-state {
  type enumeration {
    enum active {
      description
        "Indicates that the TWAMP-Test session is active.";
    }
    enum failure {
      description
        "Indicates that the TWAMP-Test session has failed.";
    }
  }
  description
    "Indicates the Session-Sender TWAMP-Test session state.";
}

typedef padding-fill-mode {
  type enumeration {
    enum zero {
      description
        "TWAMP-Test packets are padded with all zeros.";
    }
    enum random {
      description
        "TWAMP-Test packets are padded with pseudorandom
         numbers.";
    }
  }
  description
    "Indicates what type of packet padding is used in the
     TWAMP-Test packets.";
}

typedef dynamic-port-number {
  type inet:port-number {
    range "49152..65535";
  }
  description
    "Dynamic range for port numbers.";
}

/*
 * Features
 */

feature control-client {
  description
    "Indicates that the device supports configuration of the
     TWAMP Control-Client logical entity.";
}

feature server {
  description
```

```
    "Indicates that the device supports configuration of the
     TWAMP Server logical entity.";
}

feature session-sender {
  description
    "Indicates that the device supports configuration of the
     TWAMP Session-Sender logical entity.";
}

feature session-reflector {
  description
    "Indicates that the device supports configuration of the
     TWAMP Session-Reflector logical entity.";
}

/*
 * Reusable node groups
 */

grouping key-management {
  list key-chain {
    key "key-id";
    leaf key-id {
      type string {
        length "1..80";
      }
      description
        "KeyID used for a TWAMP-Control connection.  As per
         Section 3.1 of RFC 4656, KeyID is 'a UTF-8 string, up to
         80 octets in length' and is used to select which 'shared
         secret the client' (Control-Client) 'wishes to use to
         authenticate or encrypt'.";
    }
    leaf secret-key {
      type binary;
      description
        "The secret key corresponding to the KeyID for this
         TWAMP-Control connection.";
    }
    description
      "Relates KeyIDs with their respective secret keys
       in a TWAMP-Control connection.";
  }
  description
    "Used by the Control-Client and Server for TWAMP-Control
     key management.";
}

grouping maintenance-statistics {
  leaf sent-packets {
    type uint32;
    config false;
    description
      "Indicates the number of packets sent.";
  }
```

```
  leaf rcv-packets {
    type uint32;
    config false;
    description
      "Indicates the number of packets received.";
  }
  leaf last-sent-seq {
    type uint32;
    config false;
    description
      "Indicates the last sent sequence number.";
  }
  leaf last-rcv-seq {
    type uint32;
    config false;
    description
      "Indicates the last received sequence number.";
  }
  description
    "Used for TWAMP-Test maintenance statistics.";
}

grouping count {
  leaf count {
    type uint8 {
      range "10..31";
    }
    default "15";
    description
      "Parameter communicated to the Control-Client as part of
       the Server Greeting message and used for deriving a key
       from a shared secret as per Section 3.1 of RFC 4656:
       MUST be a power of 2 and at least 1024.  It is configured
       by providing said power.  For example, configuring 20 here
       means count 2^20 = 1048576.  The default is 15,
       meaning 2^15 = 32768.";
  }
  description
    "Reusable data structure for count, which is used in both the
     Server and the Control-Client.";
}

grouping max-count-exponent {
  leaf max-count-exponent {
    type uint8 {
      range "10..31";
    }
    default "20";
    description
      "This parameter limits the maximum Count value, which MUST
       be a power of 2 and at least 1024 as per RFC 5357.  It is
       configured by providing said power.  For example,
       configuring 10 here means max count 2^10 = 1024.
       The default is 20, meaning 2^20 = 1048576.

       A TWAMP Server uses this configured value in the
```

```
        Server Greeting message sent to the Control-Client.

        A TWAMP Control-Client uses this configured value to
        prevent denial-of-service (DoS) attacks by closing the
        control connection to the Server if it 'receives a
        Server-Greeting message with Count greater that [sic] its
        maximum configured value', as per Section 6 of RFC 5357.

        Further, note that according to Section 6 of RFC 5357:

        'If an attacking system set the maximum value in Count
        (2**32), then the system under attack would stall for a
        significant period of time while it attempts to generate
        keys.  Therefore, TWAMP-compliant systems SHOULD have a
        configuration control to limit the maximum Count value.
        The default maximum Count value SHOULD be 32768.'

        In the case of this document, the default max-count-exponent
        value SHOULD be 15, which corresponds to a maximum value of
        2**15 or 32768.

        RFC 5357 does not qualify 'significant period' in terms of
        time, but it is clear that this depends on the processing
        capacity available, and operators need to pay attention to
        this security consideration.";
    }
    description
      "Reusable data structure for max-count that is used in both
       the client (Control-Client) container and the server
       container.";
}

/*
 * Configuration data nodes
 */

container twamp {
  description
    "TWAMP logical entity configuration grouping of four models
     that correspond to the four TWAMP logical entities
     Control-Client, Server, Session-Sender, and Session-Reflector
     as illustrated in Figure 1 of RFC 8913.";
  container client {
    if-feature "control-client";
    description
      "Configuration of the TWAMP Control-Client logical entity.";
    leaf admin-state {
      type boolean;
      default "true";
      description
        "Indicates whether the device is allowed to operate as a
         TWAMP Control-Client.";
    }
    list mode-preference-chain {
      key "priority";
      unique "mode";
```

```
    leaf priority {
      type uint16;
      description
        "Indicates the Control-Client mode preference priority,
         expressed as a 16-bit unsigned integer.  Values for the
         priority start with zero, the highest priority, and
         decreasing priority value is indicated by every increase
         in value by one.";
    }
    leaf mode {
      type twamp-modes;
      description
        "The supported TWAMP-Modes matching the corresponding
         priority.";
    }
    description
      "Indicates the Control-Client preferred order of use of
       the supported TWAMP-Modes.

       Depending on the modes available in the TWAMP Server
       Greeting message (see Figure 2 of RFC 7717), the
       Control-Client MUST choose the highest-priority
       mode from the configured mode-preference-chain list.";
  }
  uses key-management;
  list ctrl-connection {
    key "name";
    description
      "List of TWAMP Control-Client control connections.
       Each item in the list describes a control connection
       that will be initiated by this Control-Client.";
    leaf name {
      type string;
      description
        "A unique name used as a key to identify this
         individual TWAMP-Control connection on the
         Control-Client device.";
    }
    leaf client-ip {
      type inet:ip-address;
      description
        "The IP address of the local Control-Client device,
         to be placed in the source IP address field of the
         IP header in TWAMP-Control (TCP) packets belonging
         to this control connection.  If not configured, the
         device SHALL choose its own source IP address.";
    }
    leaf server-ip {
      type inet:ip-address;
      mandatory true;
      description
        "The IP address of the remote Server device to which
         the TWAMP-Control connection will be initiated.";
    }
    leaf server-tcp-port {
      type inet:port-number;
```

```
      default "862";
      description
        "This parameter defines the TCP port number that is
         to be used by this outgoing TWAMP-Control connection.
         Typically, this is the well-known TWAMP-Control
         port number (862) as per RFC 5357.  However, there are
         known realizations of TWAMP in the field that were
         implemented before this well-known port number was
         allocated.  These early implementations allowed the
         port number to be configured.  This parameter is
         therefore provided for backward-compatibility
         reasons.";
    }
    leaf control-packet-dscp {
      type inet:dscp;
      default "0";
      description
        "The Differentiated Services Code Point (DSCP) value
         to be placed in the IP header of TWAMP-Control (TCP)
         packets generated by this Control-Client.";
    }
    leaf key-id {
      type string {
        length "1..80";
      }
      description
        "Indicates the KeyID value selected for this
         TWAMP-Control connection.";
    }
    uses max-count-exponent;
    leaf client-tcp-port {
      type inet:port-number;
      config false;
      description
        "Indicates the source TCP port number used in the
         TWAMP-Control packets belonging to this control
         connection.";
    }
    leaf server-start-time {
      type uint64;
      config false;
      description
        "Indicates the Start-Time advertised by the Server in
         the Server-Start message (RFC 4656, Section 3.1),
         representing the time when the current
         instantiation of the Server started operating.
         The timestamp format follows RFC 5905, according to
         Section 4.1.2 of RFC 4656.";
      reference
        "RFC 4656: A One-way Active Measurement Protocol (OWAMP),
         Sections 3.1 and 4.1.2
         RFC 5905: Network Time Protocol Version 4: Protocol and
         Algorithms Specification";
    }
    leaf repeat-count {
      type uint64;
```

```
  config false;
  description
    "Indicates how many times the test session has been
     repeated.  When a test is running, this value will be
     greater than 0.  If the repeat parameter is non-zero,
     this value is smaller than or equal to the repeat
     parameter.";
}
leaf state {
  type control-client-connection-state;
  config false;
  description
    "Indicates the current TWAMP-Control connection state.";
}
leaf selected-mode {
  type twamp-modes;
  config false;
  description
    "The TWAMP-Modes that the Control-Client has chosen for
     this control connection as set in the Mode field of
     the Set-Up-Response message.";
  reference
    "RFC 4656: A One-way Active Measurement Protocol (OWAMP),
                Section 3.1";
}
leaf token {
  type binary {
    length "64";
  }
  config false;
  description
    "This parameter holds the 64 octets containing the
     concatenation of a 16-octet Challenge, a 16-octet AES
     Session-key used for encryption, and a 32-octet
     HMAC-SHA1 Session-key used for authentication; see
     also the last paragraph of Section 6.10 of RFC 4656.

     If the mode defined in RFC 7717 is selected
     (selected-mode), Token is limited to 16 octets.";
  reference
    "RFC 4656: A One-way Active Measurement Protocol (OWAMP),
                Section 6.10
     RFC 7717: IKEv2-Derived Shared Secret Key for the
     One-Way Active Measurement Protocol (OWAMP) and
     Two-Way Active Measurement Protocol (TWAMP)";
}
leaf client-iv {
  type binary {
    length "16";
  }
  config false;
  description
    "Indicates the Control-Client Initialization Vector
     (Client-IV), which is generated randomly by the
     Control-Client.  As per RFC 4656:
```

```
        'Client-IV merely needs to be unique (i.e., it MUST
        never be repeated for different sessions using the
        same secret key; a simple way to achieve that without
        the use of cumbersome state is to generate the
        Client-IV values using a cryptographically secure
        pseudo-random number source.'

        If the mode defined in RFC 7717 is selected
        (selected-mode), Client-IV is limited to 12 octets.";
    reference
      "RFC 4656: A One-way Active Measurement Protocol (OWAMP)
       RFC 7717: IKEv2-Derived Shared Secret Key for the
       One-Way Active Measurement Protocol (OWAMP) and
       Two-Way Active Measurement Protocol (TWAMP)";
  }
  list test-session-request {
    key "name";
    description
      "Information associated with the Control-Client
       for this test session.";
    leaf name {
      type string;
      description
        "A unique name to be used for identification of
         this TWAMP-Test session on the Control-Client.";
    }
    leaf sender-ip {
      type inet:ip-address;
      description
        "The IP address of the Session-Sender device,
         which is to be placed in the source IP address
         field of the IP header in TWAMP-Test (UDP) packets
         belonging to this test session.  This value will be
         used to populate the Sender Address field of the
         Request-TW-Session message.

         If not configured, the device SHALL choose its own
         source IP address.";
    }
    leaf sender-udp-port {
      type union {
        type dynamic-port-number;
        type enumeration {
          enum autoallocate {
            description
              "Indicates that the Control-Client will
               auto-allocate the TWAMP-Test (UDP) port number
               from the dynamic port range.";
          }
        }
      }
      default "autoallocate";
      description
        "The UDP port number that is to be used by
         the Session-Sender for this TWAMP-Test session.
         The number is restricted to the dynamic port range.
```

```
        By default, the Control-Client SHALL auto-allocate a
        UDP port number for this TWAMP-Test session.

        The configured (or auto-allocated) value is
        advertised in the Sender Port field of the
        Request-TW-Session message (see Section 3.5 of
        RFC 5357).  Note that in the scenario where a device
        auto-allocates a UDP port number for a session and
        the repeat parameter for that session indicates that
        it should be repeated, the device is free to
        auto-allocate a different UDP port number when it
        negotiates the next (repeated) iteration of this
        session.";
    }
    leaf reflector-ip {
      type inet:ip-address;
      mandatory true;
      description
        "The IP address belonging to the remote
        Session-Reflector device to which the TWAMP-Test
        session will be initiated.  This value will be
        used to populate the Receiver Address field of
        the Request-TW-Session message.";
    }
    leaf reflector-udp-port {
      type inet:port-number {
        range "862 | 49152..65535";
      }
      description
        "This parameter defines the UDP port number that
        will be used by the Session-Reflector for
        this TWAMP-Test session.  The default number is
        within the dynamic port range and is to be placed
        in the Receiver Port field of the Request-TW-Session
        message.  The well-known port (862) MAY be used.";
      reference
        "RFC 8545: Well-Known Port Assignments for the One-Way
        Active Measurement Protocol (OWAMP) and the Two-Way
        Active Measurement Protocol (TWAMP)";
    }
    leaf timeout {
      type uint64;
      units "seconds";
      default "2";
      description
        "The length of time (in seconds) that the
        Session-Reflector should continue to respond to
        packets belonging to this TWAMP-Test session after
        a Stop-Sessions TWAMP-Control message has been
        received.

        This value will be placed in the Timeout field of
        the Request-TW-Session message.";
      reference
        "RFC 5357: A Two-Way Active Measurement Protocol
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      (TWAMP), Section 3.5";
  }
  leaf padding-length {
    type uint32 {
      range "64..4096";
    }
    description
      "The number of padding bytes to be added to the
       TWAMP-Test (UDP) packets generated by the
       Session-Sender.

       This value will be placed in the Padding Length
       field of the Request-TW-Session message.";
    reference
      "RFC 4656: A One-way Active Measurement Protocol
       (OWAMP), Section 3.5";
  }
  leaf test-packet-dscp {
    type inet:dscp;
    default "0";
    description
      "The DSCP value to be placed in the IP header
       of TWAMP-Test packets generated by the
       Session-Sender and in the UDP header of the
       TWAMP-Test response packets generated by the
       Session-Reflector for this test session.

       This value will be placed in the Type-P Descriptor
       field of the Request-TW-Session message.";
    reference
      "RFC 5357: A Two-Way Active Measurement Protocol
       (TWAMP)";
  }
  leaf start-time {
    type uint64;
    default "0";
    description
      "Time when the session is to be started
       (but not before the TWAMP Start-Sessions command
       is issued; see Section 3.4 of RFC 5357).

       The start-time value is placed in the Start Time
       field of the Request-TW-Session message.

       The timestamp format follows RFC 5905 as per
       Section 3.5 of RFC 4656.

       The default value of 0 indicates that the session
       will be started as soon as the Start-Sessions
       message is received.";
  }
  leaf repeat {
    type uint32 {
      range "0..4294967295";
    }
    default "0";
```

```
    description
      "This value determines if the TWAMP-Test session must
       be repeated.  When a test session has completed, the
       repeat parameter is checked.

       The default value of 0 indicates that the session
       MUST NOT be repeated.

       If the repeat value is 1 through 4,294,967,294,
       then the test session SHALL be repeated using the
       information in the repeat-interval parameter, and the
       parent TWAMP-Control connection for this test
       session is restarted to negotiate a new instance
       of this TWAMP-Test session.

       A value of 4,294,967,295 indicates that the test
       session SHALL be repeated *forever* using the
       information in the repeat-interval parameter and
       SHALL NOT decrement the value.";
  }
  leaf repeat-interval {
    when "../repeat!='0'" {
      description
        "This parameter determines the timing of repeated
         TWAMP-Test sessions when repeat is more than 0.

         When the value of repeat-interval is 0, the
         negotiation of a new test session SHALL begin
         immediately after the previous test session
         completes.  Otherwise, the Control-Client will
         wait for the number of seconds specified in the
         repeat-interval parameter before negotiating the
         new instance of this TWAMP-Test session.";
    }
    type uint32;
    units "seconds";
    default "0";
    description
      "Repeat interval (in seconds).";
  }
  list pm-reg-list {
    key "pm-index";
    leaf pm-index {
      type uint16;
      description
        "Numerical index value of a Registered Metric in
         the Performance Metrics Registry (see RFC 8911).
         Output statistics are specified in the
         corresponding Registry Entry.";
    }
    description
      "A list of one or more Performance Metrics Registry
       Index values, which communicate packet stream
       characteristics along with one or more metrics
       to be measured.
```

```
            All members of the pm-reg-list MUST have the same
            stream characteristics, such that they combine
            to specify all metrics that shall be measured on
            a single stream.";
          reference
            "RFC 8911: Registry for Performance Metrics";
        }
        leaf state {
          type test-session-state;
          config false;
          description
            "Indicates the TWAMP-Test session state -- an accepted
             request or an indication of an error.";
          reference
            "RFC 5357: A Two-Way Active Measurement Protocol
             (TWAMP), Section 3.5";
        }
        leaf sid {
          type string;
          config false;
          description
            "The Session Identifier (SID) allocated by the Server
             for this TWAMP-Test session and communicated back to
             the Control-Client in the SID field of the
             Accept-Session message.";
          reference
            "RFC 6038: Two-Way Active Measurement Protocol (TWAMP)
             Reflect Octets and Symmetrical Size
             Features, Section 4.3";
        }
      }
    }
  }
  container server {
    if-feature "server";
    description
      "Configuration of the TWAMP Server logical entity.";
    leaf admin-state {
      type boolean;
      default "true";
      description
        "Indicates whether the device is allowed to operate
         as a TWAMP Server.";
    }
    leaf server-tcp-port {
      type inet:port-number;
      default "862";
      description
        "This parameter defines the well-known TCP port number
         that is used by TWAMP-Control.  The Server will listen
         on this port number for incoming TWAMP-Control
         connections.  Although this is defined as a fixed value
         (862) in RFC 5357, there are several realizations of
         TWAMP in the field that were implemented before this
         well-known port number was allocated.  These early
         implementations allowed the port number to be
```

```
      configured.  This parameter is therefore provided for
      backward-compatibility reasons.";
  }
  leaf servwait {
    type uint32 {
      range "1..604800";
    }
    units "seconds";
    default "900";
    description
      "TWAMP-Control (TCP) session timeout, in seconds.
       According to Section 3.1 of RFC 5357:

       'The Server MAY discontinue any established control
       connection when no packet associated with that
       connection has been received within SERVWAIT seconds.'";
  }
  leaf control-packet-dscp {
    type inet:dscp;
    description
      "The DSCP value to be placed in the IP header of
       TWAMP-Control (TCP) packets generated by the Server.

       Section 3.1 of RFC 5357 specifies that the Server
       SHOULD use the DSCP value from the Control-Client's
       TCP SYN.  However, for practical purposes, TWAMP will
       typically be implemented using a general-purpose TCP
       stack provided by the underlying operating system,
       and such a stack may not provide this information to the
       user.  Consequently, it is not always possible to
       implement the behavior described in RFC 5357 in an
       OS-portable version of TWAMP.

       The default behavior if this item is not set is to use
       the DSCP value from the Control-Client's TCP SYN.";
    reference
      "RFC 5357: A Two-Way Active Measurement Protocol (TWAMP),
       Section 3.1";
  }
  uses count;
  uses max-count-exponent;
  leaf modes {
    type twamp-modes;
    description
      "The bit mask of TWAMP-Modes this Server instance is
       willing to support; see the IANA 'TWAMP-Modes' Registry.";
  }
  uses key-management;
  list ctrl-connection {
    key "client-ip client-tcp-port server-ip server-tcp-port";
    config false;
    description
      "List of all incoming TWAMP-Control (TCP) connections.";
    leaf client-ip {
      type inet:ip-address;
      description
```

```
      "The IP address on the remote Control-Client device,
       which is the source IP address used in the
       TWAMP-Control (TCP) packets belonging to this control
       connection.";
  }
  leaf client-tcp-port {
    type inet:port-number;
    description
      "The source TCP port number used in the TWAMP-Control
       (TCP) packets belonging to this control connection.";
  }
  leaf server-ip {
    type inet:ip-address;
    description
      "The IP address of the local Server device, which is
       the destination IP address used in the
       TWAMP-Control (TCP) packets belonging to this control
       connection.";
  }
  leaf server-tcp-port {
    type inet:port-number;
    description
      "The destination TCP port number used in the
       TWAMP-Control (TCP) packets belonging to this
       control connection.  This will usually be the
       same value as the server-tcp-port configured
       under twamp/server.  However, in the event that
       the user reconfigured server/server-tcp-port
       after this control connection was initiated, this
       value will indicate the server-tcp-port that is
       actually in use for this control connection.";
  }
  leaf state {
    type server-ctrl-connection-state;
    description
      "Indicates the Server TWAMP-Control connection state.";
  }
  leaf control-packet-dscp {
    type inet:dscp;
    description
      "The DSCP value used in the IP header of the
       TWAMP-Control (TCP) packets sent by the Server
       for this control connection.  This will usually
       be the same value as is configured in the
       control-packet-dscp parameter under the twamp/server
       container.  However, in the event that the user
       reconfigures server/dscp after this control
       connection is already in progress, this read-only
       value will show the actual DSCP value in use by this
       TWAMP-Control connection.";
  }
  leaf selected-mode {
    type twamp-modes;
    description
      "The mode that was chosen for this TWAMP-Control
       connection as set in the Mode field of the
```

```
          Set-Up-Response message.";
      }
      leaf key-id {
        type string {
          length "1..80";
        }
        description
          "The KeyID value that is in use by this TWAMP-Control
           connection as selected by the Control-Client.";
      }
      uses count {
        description
          "The Count value that is in use by this TWAMP-Control
           connection.  This will usually be the same value
           as is configured under twamp/server.  However, in the
           event that the user reconfigures server/count
           after this control connection is already in progress,
           this read-only value will show the actual count that
           is in use for this TWAMP-Control connection.";
      }
      uses max-count-exponent {
        description
          "This read-only value indicates the actual max-count in
           use for this control connection.  Usually, this would be
           the same value as is configured under twamp/server.";
      }
      leaf salt {
        type binary {
          length "16";
        }
        description
          "A parameter used in deriving a key from a
           shared secret, as described in Section 3.1 of RFC 4656.
           It is communicated to the Control-Client as part of
           the Server Greeting message.";
      }
      leaf server-iv {
        type binary {
          length "16";
        }
        description
          "The Server Initialization Vector (Server-IV)
           generated randomly by the Server.";
      }
      leaf challenge {
        type binary {
          length "16";
        }
        description
          "A random sequence of octets generated by the Server.
           As described in client/token, a Challenge is used
           by the Control-Client to prove possession of a
           shared secret.";
      }
    }
  }
```

```
container session-sender {
  if-feature "session-sender";
  description
    "Configuration of the TWAMP Session-Sender logical entity.";
  leaf admin-state {
    type boolean;
    default "true";
    description
      "Indicates whether the device is allowed to operate
       as a TWAMP Session-Sender.";
  }
  list test-session {
    key "name";
    description
      "List of TWAMP Session-Sender test sessions.";
    leaf name {
      type string;
      description
        "A unique name for this TWAMP-Test session to be used
         for identifying this test session by the
         Session-Sender logical entity.";
    }
    leaf ctrl-connection-name {
      type string;
      config false;
      description
        "The name of the parent TWAMP-Control connection that
         is responsible for negotiating this TWAMP-Test
         session.";
    }
    leaf fill-mode {
      type padding-fill-mode;
      default "zero";
      description
        "Indicates whether the padding added to the
         TWAMP-Test (UDP) packets (1) will contain pseudorandom
         numbers or (2) should consist of all zeros, as per
         Section 4.2.1 of RFC 5357.";
    }
    leaf number-of-packets {
      type uint32;
      mandatory true;
      description
        "The overall number of TWAMP-Test (UDP) packets to be
         transmitted by the Session-Sender for this test
         session.";
    }
    choice packet-distribution {
      description
        "Indicates the distribution to be used for transmitting
         the TWAMP-Test (UDP) packets.";
      case periodic {
        leaf periodic-interval {
          type decimal64 {
            fraction-digits 5;
          }
```

```
            units "seconds";
            mandatory true;
            description
              "Indicates the time to wait (in seconds) between
               the first bits of TWAMP-Test (UDP) packet
               transmissions for this test session.";
            reference
              "RFC 3432: Network performance measurement with
               periodic streams";
          }
        }
        case poisson {
          leaf lambda {
            type decimal64 {
              fraction-digits 5;
            }
            units "seconds";
            mandatory true;
            description
              "Indicates the average time interval (in seconds)
               between packets in the Poisson distribution.
               The packet is calculated using the reciprocal of
               lambda and the TWAMP-Test packet size (which
               depends on the selected mode and the packet
               padding).";
            reference
              "RFC 2330: Framework for IP Performance Metrics";
          }
          leaf max-interval {
            type decimal64 {
              fraction-digits 5;
            }
            units "seconds";
            description
              "Indicates the maximum time (in seconds)
               between packet transmissions.";
            reference
              "RFC 7312: Advanced Stream and Sampling Framework
               for IP Performance Metrics (IPPM)";
          }
        }
      }
      leaf state {
        type sender-session-state;
        config false;
        description
          "Indicates the Session-Sender test session state.";
      }
      uses maintenance-statistics;
    }
  }
  container session-reflector {
    if-feature "session-reflector";
    description
      "Configuration of the TWAMP Session-Reflector logical
       entity.";
```

```
leaf admin-state {
  type boolean;
  default "true";
  description
    "Indicates whether the device is allowed to operate
     as a TWAMP Session-Reflector.";
}
leaf refwait {
  type uint32 {
    range "1..604800";
  }
  units "seconds";
  default "900";
  description
    "The Session-Reflector MAY discontinue any session that
     has been started when no packet associated with that
     session has been received for REFWAIT seconds.  As per
     Section 3.1 of RFC 5357, this timeout allows a
     Session-Reflector to free up resources in case of
     failure.";
}
list test-session {
  key "sender-ip sender-udp-port
       reflector-ip reflector-udp-port";
  config false;
  description
    "TWAMP Session-Reflector test sessions.";
  leaf sid {
    type string;
    description
      "An auto-allocated identifier for this TWAMP-Test
       session that is unique within the context of this
       Server/Session-Reflector device only.  This value
       is communicated to the Control-Client that
       requested the test session in the SID field of the
       Accept-Session message.";
  }
  leaf sender-ip {
    type inet:ip-address;
    description
      "The IP address on the remote device, which is the
       source IP address used in the TWAMP-Test (UDP) packets
       belonging to this test session.";
  }
  leaf sender-udp-port {
    type dynamic-port-number;
    description
      "The source UDP port used in the TWAMP-Test packets
       belonging to this test session.";
  }
  leaf reflector-ip {
    type inet:ip-address;
    description
      "The IP address of the local Session-Reflector
       device, which is the destination IP address used
       in the TWAMP-Test (UDP) packets belonging to this test
```

```
            session.";
        }
        leaf reflector-udp-port {
          type inet:port-number {
            range "862 | 49152..65535";
          }
          description
            "The destination UDP port number used in the
             TWAMP-Test (UDP) test packets belonging to this
             test session.";
        }
        leaf parent-connection-client-ip {
          type inet:ip-address;
          description
            "The IP address on the Control-Client device, which
             is the source IP address used in the TWAMP-Control
             (TCP) packets belonging to the parent control
             connection that negotiated this test session.";
        }
        leaf parent-connection-client-tcp-port {
          type inet:port-number;
          description
            "The source TCP port number used in the TWAMP-Control
             (TCP) packets belonging to the parent control
             connection that negotiated this test session.";
        }
        leaf parent-connection-server-ip {
          type inet:ip-address;
          description
            "The IP address of the Server device, which is the
             destination IP address used in the TWAMP-Control
             (TCP) packets belonging to the parent control
             connection that negotiated this test session.";
        }
        leaf parent-connection-server-tcp-port {
          type inet:port-number;
          description
            "The destination TCP port number used in the
             TWAMP-Control (TCP) packets belonging to the parent
             control connection that negotiated this test
             session.";
        }
        leaf test-packet-dscp {
          type inet:dscp;
          description
            "The DSCP value present in the IP header of
             TWAMP-Test (UDP) packets belonging to this session.";
        }
        uses maintenance-statistics;
      }
    }
  }
}
<CODE ENDS>
```

6. Data Model Examples

This section presents simple but complete examples of configuring all four entities in Figure 1, based on the YANG module specified in Section 5. The examples are illustrative in nature but aim to be self-contained, i.e., were they to be executed in a real TWAMP implementation, they would lead to correctly configured test sessions. For completeness, examples are provided for both IPv4 and IPv6. The examples are shown using XML [W3C.REC-xml-20081126].

More elaborate examples, which also include authentication parameters, are provided in Appendix A.

6.1. Control-Client

Figure 8 shows a configuration example for a Control-Client with client/admin-state enabled. In a real implementation following Figure 2, this would permit the initiation of TWAMP-Control connections and TWAMP-Test sessions.

```
<?xml version="1.0" encoding="utf-8"?>
<config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <client>
      <admin-state>true</admin-state>
    </client>
  </twamp>
</config>
```

Figure 8: XML Instance Enabling Control-Client Operation

The following example shows a Control-Client with two instances of client/ctrl-connection -- one called "RouterA" and another called "RouterB". Each TWAMP-Control connection is to a different Server. The control connection named "RouterA" has two test session requests. The TWAMP-Control connection named "RouterB" has no TWAMP-Test session requests.

```
<?xml version="1.0" encoding="utf-8"?>
<config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <client>
      <admin-state>true</admin-state>
      <ctrl-connection>
        <name>RouterA</name>
        <client-ip>203.0.113.1</client-ip>
        <server-ip>203.0.113.2</server-ip>
        <test-session-request>
          <name>Test1</name>
          <sender-ip>203.0.113.3</sender-ip>
          <sender-udp-port>54001</sender-udp-port>
          <reflector-ip>203.0.113.4</reflector-ip>
          <reflector-udp-port>50001</reflector-udp-port>
          <start-time>0</start-time>
        </test-session-request>
        <test-session-request>
          <name>Test2</name>
```

```
            <sender-ip>203.0.113.1</sender-ip>
            <sender-udp-port>54001</sender-udp-port>
            <reflector-ip>203.0.113.2</reflector-ip>
            <reflector-udp-port>50001</reflector-udp-port>
            <start-time>0</start-time>
          </test-session-request>
        </ctrl-connection>
        <ctrl-connection>
          <name>RouterB</name>
          <client-ip>203.0.113.1</client-ip>
          <server-ip>203.0.113.3</server-ip>
        </ctrl-connection>
      </client>
    </twamp>
  </config>

  <?xml version="1.0" encoding="utf-8"?>
  <config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
    <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
      <client>
        <admin-state>true</admin-state>
        <ctrl-connection>
          <name>RouterA</name>
          <client-ip>2001:db8:203:0:113::1</client-ip>
          <server-ip>2001:db8:203:0:113::2</server-ip>
          <test-session-request>
            <name>Test1</name>
            <sender-ip>2001:db8:203:1:113::3</sender-ip>
            <sender-udp-port>54000</sender-udp-port>
            <reflector-ip>2001:db8:203:1:113::4</reflector-ip>
            <reflector-udp-port>55000</reflector-udp-port>
            <start-time>0</start-time>
          </test-session-request>
          <test-session-request>
            <name>Test2</name>
            <sender-ip>2001:db8:203:0:113::1</sender-ip>
            <sender-udp-port>54001</sender-udp-port>
            <reflector-ip>2001:db8:203:0:113::2</reflector-ip>
            <reflector-udp-port>55001</reflector-udp-port>
            <start-time>0</start-time>
          </test-session-request>
        </ctrl-connection>
        <ctrl-connection>
          <name>RouterB</name>
          <client-ip>2001:db8:203:0:113::1</client-ip>
          <server-ip>2001:db8:203:0:113::3</server-ip>
        </ctrl-connection>
      </client>
    </twamp>
  </config>
```

6.2. Server

Figure 9 shows a configuration example for a Server with server/admin-state enabled, which permits a device following Figure 2 to respond to TWAMP-Control connections and TWAMP-Test sessions.

```
<?xml version="1.0" encoding="utf-8"?>
<config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <server>
      <admin-state>true</admin-state>
    </server>
  </twamp>
</config>
```

Figure 9: XML Instance Enabling Server Operation

The following example presents a Server with the TWAMP-Control connection corresponding to the control connection name (client/ctrl-connection/name) "RouterA" presented in Section 6.1.

```
<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <server>
      <admin-state>true</admin-state>
      <ctrl-connection>
        <client-ip>203.0.113.1</client-ip>
        <client-tcp-port>16341</client-tcp-port>
        <server-ip>203.0.113.2</server-ip>
        <server-tcp-port>862</server-tcp-port>
        <state>active</state>
      </ctrl-connection>
    </server>
  </twamp>
</data>

<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <server>
      <admin-state>true</admin-state>
      <ctrl-connection>
        <client-ip>2001:db8:203:0:113::1</client-ip>
        <client-tcp-port>16341</client-tcp-port>
        <server-ip>2001:db8:203:0:113::2</server-ip>
        <server-tcp-port>862</server-tcp-port>
        <state>active</state>
      </ctrl-connection>
    </server>
  </twamp>
</data>
```

6.3. Session-Sender

Figure 10 shows a configuration example for a Session-Sender with session-sender/admin-state enabled, which permits a device following Figure 2 to initiate TWAMP-Test sessions.

```
<?xml version="1.0" encoding="utf-8"?>
<config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
```

```
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <session-sender>
      <admin-state>true</admin-state>
    </session-sender>
  </twamp>
</config>
```

Figure 10: XML Instance Enabling Session-Sender Operation

The following configuration example shows a Session-Sender with the two TWAMP-Test sessions presented in Section 6.1.

```
<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <session-sender>
      <admin-state>true</admin-state>
      <test-session>
        <name>Test1</name>
        <ctrl-connection-name>RouterA</ctrl-connection-name>
        <number-of-packets>900</number-of-packets>
        <periodic-interval>1</periodic-interval>
      </test-session>
      <test-session>
        <name>Test2</name>
        <ctrl-connection-name>RouterA</ctrl-connection-name>
        <number-of-packets>900</number-of-packets>
        <lambda>1</lambda>
        <max-interval>2</max-interval>
      </test-session>
    </session-sender>
  </twamp>
</data>
```

6.4. Session-Reflector

This configuration example shows a Session-Reflector with session-reflector/admin-state enabled, which permits a device following Figure 2 to respond to TWAMP-Test sessions.

```
<?xml version="1.0" encoding="utf-8"?>
<config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <session-reflector>
      <admin-state>true</admin-state>
    </session-reflector>
  </twamp>
</config>
```

Figure 11: XML Instance Enabling Session-Reflector Operation

The following example shows the two Session-Reflector TWAMP-Test sessions corresponding to the test sessions presented in Section 6.3.

| Note: '\' line wrapping is for formatting only.

```
<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <session-reflector>
      <admin-state>true</admin-state>
      <test-session>
        <sender-ip>203.0.113.3</sender-ip>
        <sender-udp-port>54000</sender-udp-port>
        <reflector-ip>203.0.113.4</reflector-ip>
        <reflector-udp-port>50001</reflector-udp-port>
        <sid>1232</sid>
        <parent-connection-client-ip>203.0.113.1</parent-connection-\
client-ip>
        <parent-connection-client-tcp-port>16341</parent-connection-\
client-tcp-port>
        <parent-connection-server-ip>203.0.113.2</parent-connection-\
server-ip>
        <parent-connection-server-tcp-port>862</parent-connection-se\
rver-tcp-port>
        <sent-packets>2</sent-packets>
        <rcv-packets>2</rcv-packets>
        <last-sent-seq>1</last-sent-seq>
        <last-rcv-seq>1</last-rcv-seq>
      </test-session>
      <test-session>
        <sender-ip>203.0.113.1</sender-ip>
        <sender-udp-port>54001</sender-udp-port>
        <reflector-ip>192.0.2.2</reflector-ip>
        <reflector-udp-port>50001</reflector-udp-port>
        <sid>178943</sid>
        <parent-connection-client-ip>203.0.113.1</parent-connection-\
client-ip>
        <parent-connection-client-tcp-port>16341</parent-connection-\
client-tcp-port>
        <parent-connection-server-ip>203.0.113.2</parent-connection-\
server-ip>
        <parent-connection-server-tcp-port>862</parent-connection-se\
rver-tcp-port>
        <sent-packets>21</sent-packets>
        <rcv-packets>21</rcv-packets>
        <last-sent-seq>20</last-sent-seq>
        <last-rcv-seq>20</last-rcv-seq>
      </test-session>
    </session-reflector>
  </twamp>
</data>

   |  Note: '\' line wrapping is for formatting only.

<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <session-reflector>
      <admin-state>true</admin-state>
      <test-session>
        <sender-ip>203.0.113.3</sender-ip>
```

```
        <sender-udp-port>54000</sender-udp-port>
        <reflector-ip>203.0.113.4</reflector-ip>
        <reflector-udp-port>54001</reflector-udp-port>
        <sid>1232</sid>
        <parent-connection-client-ip>203.0.113.1</parent-connection-\
client-ip>
        <parent-connection-client-tcp-port>16341</parent-connection-\
client-tcp-port>
        <parent-connection-server-ip>203.0.113.2</parent-connection-\
server-ip>
        <parent-connection-server-tcp-port>862</parent-connection-se\
rver-tcp-port>
        <sent-packets>2</sent-packets>
        <rcv-packets>2</rcv-packets>
        <last-sent-seq>1</last-sent-seq>
        <last-rcv-seq>1</last-rcv-seq>
      </test-session>
      <test-session>
        <sender-ip>203.0.113.1</sender-ip>
        <sender-udp-port>54001</sender-udp-port>
        <reflector-ip>192.0.2.2</reflector-ip>
        <reflector-udp-port>55001</reflector-udp-port>
        <sid>178943</sid>
        <parent-connection-client-ip>203.0.113.1</parent-connection-\
client-ip>
        <parent-connection-client-tcp-port>16341</parent-connection-\
client-tcp-port>
        <parent-connection-server-ip>203.0.113.2</parent-connection-\
server-ip>
        <parent-connection-server-tcp-port>862</parent-connection-se\
rver-tcp-port>
        <sent-packets>21</sent-packets>
        <rcv-packets>21</rcv-packets>
        <last-sent-seq>20</last-sent-seq>
        <last-rcv-seq>20</last-rcv-seq>
      </test-session>
    </session-reflector>
  </twamp>
</data>
```

7. Security Considerations

Virtually all existing measurement systems using TWAMP [RFC5357] are administered by the same network operator. For example, attacks on the measurement infrastructure could be launched by third parties to commandeer the packet generation capability, corrupt the measurements, or perform other nefarious acts.

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The Network Configuration Access Control Model (NACM) [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in this YANG module that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. These are the subtrees and data nodes and their sensitivity/vulnerability:

* If written, the 'admin-state' node can cause unintended test sessions to be created.

* If the node 'number-of-packets', which dictates how many packets are sent in any particular test session, is written with a large value, it can cause a test session to run longer than expected.

* Nodes that are particularly vulnerable include several timeout values put in the protocol to protect against sessions that are not active but are consuming resources. These are the REFWAIT timeout parameter, which determines whether to discontinue the session if no packets are received; and the nodes 'count' and 'max-count-exponent', which can cause a long time to be spent on Password-Based Key Derivation Function 2 (PBKDF2) iterations.

* In addition, a 'dscp' node marked with different DSCP markings can cause the test traffic on the network to be skewed and the result manipulated.

* Finally, nodes within 'mode-preference-chain', which specifies the 'mode' and 'priority' values and indicates the preferred order of use by an operator, can be manipulated to send unauthenticated or non-encrypted traffic, enabling an on-path attack.

* Limiting access to these nodes will limit the ability to launch an attack in network environments.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via get, get-config, or notification) to these data nodes. This is the subtree and data node and its sensitivity/vulnerability:

* The 'token' node defined in the model, containing a concatenation of a Challenge, an AES Session-key used for encryption, and an HMAC-SHA1 Session-key used for authentication, is sensitive from a privacy perspective and can be used to disrupt a test session. The ability to read the field should be limited to the administrator of the test network.

The TWAMP YANG data model does not define RPC operations, as detailed in Appendix B, and defers the definition of NETCONF RPC operations to each implementation. These RPC operations, when defined, may be

considered sensitive or vulnerable in some network environments. It is thus important to control access to these operations.

8. IANA Considerations

IANA has registered the following URI in the "IETF XML Registry" [RFC3688].

URI: urn:ietf:params:xml:ns:yang:ietf-twamp
Registrant Contact: The IESG.
XML: N/A; the requested URI is an XML namespace.

IANA has registered the following YANG module in the "YANG Module Names" registry [RFC6020].

Name: ietf-twamp
Namespace: urn:ietf:params:xml:ns:yang:ietf-twamp
Prefix: twamp
Reference: RFC 8913

9. References

9.1. Normative References

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Appendix A. Detailed Data Model Examples

This appendix extends the examples presented in Section 6 by configuring more fields, such as authentication parameters, DSCP values, and so on.

A.1. Control-Client

```
<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <client>
      <admin-state>true</admin-state>
      <mode-preference-chain>
        <priority>0</priority>
        <mode>authenticated</mode>
      </mode-preference-chain>
      <mode-preference-chain>
        <priority>1</priority>
        <mode>unauthenticated</mode>
      </mode-preference-chain>
      <key-chain>
        <key-id>KeyClient1ToRouterA</key-id>
        <secret-key>c2VjcmV0MQ==</secret-key>
      </key-chain>
      <key-chain>
        <key-id>KeyForRouterB</key-id>
        <secret-key>c2VjcmV0Mg0K</secret-key>
      </key-chain>
      <ctrl-connection>
        <name>RouterA</name>
        <client-ip>203.0.113.1</client-ip>
        <server-ip>203.0.113.2</server-ip>
        <control-packet-dscp>32</control-packet-dscp>
        <key-id>KeyClient1ToRouterA</key-id>
        <test-session-request>
          <name>Test1</name>
          <sender-ip>203.0.113.3</sender-ip>
          <sender-udp-port>54000</sender-udp-port>
```

```
          <reflector-ip>203.0.113.4</reflector-ip>
          <reflector-udp-port>55000</reflector-udp-port>
          <padding-length>64</padding-length>
          <start-time>0</start-time>
        </test-session-request>
        <test-session-request>
          <name>Test2</name>
          <sender-ip>203.0.113.1</sender-ip>
          <sender-udp-port>54001</sender-udp-port>
          <reflector-ip>203.0.113.2</reflector-ip>
          <reflector-udp-port>55001</reflector-udp-port>
          <padding-length>128</padding-length>
          <start-time>0</start-time>
        </test-session-request>
      </ctrl-connection>
    </client>
  </twamp>
</data>

<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <client>
      <admin-state>true</admin-state>
      <mode-preference-chain>
        <priority>0</priority>
        <mode>authenticated</mode>
      </mode-preference-chain>
      <mode-preference-chain>
        <priority>1</priority>
        <mode>unauthenticated</mode>
      </mode-preference-chain>
      <key-chain>
        <key-id>KeyClient1ToRouterA</key-id>
        <secret-key>c2VjcmV0MQ==</secret-key>
      </key-chain>
      <key-chain>
        <key-id>KeyForRouterB</key-id>
        <secret-key>c2VjcmV0Mg0K</secret-key>
      </key-chain>
      <ctrl-connection>
        <name>RouterA</name>
        <client-ip>2001:db8:203:0:113::1</client-ip>
        <server-ip>2001:db8:203:0:113::2</server-ip>
        <control-packet-dscp>32</control-packet-dscp>
        <key-id>KeyClient1ToRouterA</key-id>
        <test-session-request>
          <name>Test1</name>
          <sender-ip>2001:db8:10:1:1::1</sender-ip>
          <sender-udp-port>54000</sender-udp-port>
          <reflector-ip>2001:db8:10:1:1::2</reflector-ip>
          <reflector-udp-port>55000</reflector-udp-port>
          <padding-length>64</padding-length>
          <start-time>0</start-time>
        </test-session-request>
        <test-session-request>
```

```
            <name>Test2</name>
            <sender-ip>2001:db8:203:0:113::1</sender-ip>
            <sender-udp-port>54001</sender-udp-port>
            <reflector-ip>2001:db8:203:0:113::2</reflector-ip>
            <reflector-udp-port>55001</reflector-udp-port>
            <padding-length>128</padding-length>
            <start-time>0</start-time>
          </test-session-request>
        </ctrl-connection>
      </client>
    </twamp>
  </data>
```

A.2. Server

```
  <?xml version="1.0" encoding="utf-8"?>
  <data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
    <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
      <server>
        <admin-state>true</admin-state>
        <servwait>1800</servwait>
        <control-packet-dscp>32</control-packet-dscp>
        <modes>authenticated unauthenticated</modes>
        <count>15</count>
        <key-chain>
          <key-id>KeyClient1ToRouterA</key-id>
          <secret-key>c2VjcmV0MQ==</secret-key>
        </key-chain>
        <key-chain>
          <key-id>KeyClient10ToRouterA</key-id>
          <secret-key>c2VjcmV0MTANCg==</secret-key>
        </key-chain>
        <ctrl-connection>
          <client-ip>203.0.113.1</client-ip>
          <client-tcp-port>16341</client-tcp-port>
          <server-ip>203.0.113.2</server-ip>
          <server-tcp-port>862</server-tcp-port>
          <control-packet-dscp>32</control-packet-dscp>
          <selected-mode>unauthenticated</selected-mode>
          <key-id>KeyClient1ToRouterA</key-id>
          <count>15</count>
        </ctrl-connection>
      </server>
    </twamp>
  </data>

  <?xml version="1.0" encoding="utf-8"?>
  <data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
    <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
      <server>
        <admin-state>true</admin-state>
        <servwait>1800</servwait>
        <control-packet-dscp>32</control-packet-dscp>
        <modes>authenticated unauthenticated</modes>
        <count>15</count>
        <key-chain>
```

```
          <key-id>KeyClient1ToRouterA</key-id>
          <secret-key>c2VjcmV0MQ==</secret-key>
        </key-chain>
        <key-chain>
          <key-id>KeyClient10ToRouterA</key-id>
          <secret-key>c2VjcmV0MTANCg==</secret-key>
        </key-chain>
        <ctrl-connection>
          <client-ip>2001:db8:203:0:113::1</client-ip>
          <client-tcp-port>16341</client-tcp-port>
          <server-ip>2001:db8:203:0:113::2</server-ip>
          <server-tcp-port>862</server-tcp-port>
          <control-packet-dscp>32</control-packet-dscp>
          <selected-mode>unauthenticated</selected-mode>
          <key-id>KeyClient1ToRouterA</key-id>
          <count>15</count>
        </ctrl-connection>
      </server>
    </twamp>
  </data>
```

A.3. Session-Sender

```
  <?xml version="1.0" encoding="utf-8"?>
  <data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
    <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
      <session-sender>
        <admin-state>true</admin-state>
        <test-session>
          <name>Test1</name>
          <ctrl-connection-name>RouterA</ctrl-connection-name>
          <fill-mode>zero</fill-mode>
          <number-of-packets>900</number-of-packets>
          <periodic-interval>1</periodic-interval>
          <sent-packets>2</sent-packets>
          <rcv-packets>2</rcv-packets>
          <last-sent-seq>1</last-sent-seq>
          <last-rcv-seq>1</last-rcv-seq>
        </test-session>
        <test-session>
          <name>Test2</name>
          <ctrl-connection-name>RouterA</ctrl-connection-name>
          <fill-mode>random</fill-mode>
          <number-of-packets>900</number-of-packets>
          <lambda>1</lambda>
          <max-interval>2</max-interval>
          <sent-packets>21</sent-packets>
          <rcv-packets>21</rcv-packets>
          <last-sent-seq>20</last-sent-seq>
          <last-rcv-seq>20</last-rcv-seq>
        </test-session>
      </session-sender>
    </twamp>
  </data>
```

A.4. Session-Reflector

```
   |  Note: '\' line wrapping is for formatting only.

<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
    <session-reflector>
      <admin-state>true</admin-state>
      <test-session>
        <sender-ip>203.0.113.3</sender-ip>
        <sender-udp-port>54000</sender-udp-port>
        <reflector-ip>203.0.113.4</reflector-ip>
        <reflector-udp-port>55000</reflector-udp-port>
        <sid>1232</sid>
        <parent-connection-client-ip>203.0.113.1</parent-connection-\
client-ip>
        <parent-connection-client-tcp-port>16341</parent-connection-\
client-tcp-port>
        <parent-connection-server-ip>203.0.113.2</parent-connection-\
server-ip>
        <parent-connection-server-tcp-port>862</parent-connection-se\
rver-tcp-port>
        <test-packet-dscp>32</test-packet-dscp>
        <sent-packets>2</sent-packets>
        <rcv-packets>2</rcv-packets>
        <last-sent-seq>1</last-sent-seq>
        <last-rcv-seq>1</last-rcv-seq>
      </test-session>
      <test-session>
        <sender-ip>203.0.113.1</sender-ip>
        <sender-udp-port>54001</sender-udp-port>
        <reflector-ip>192.0.2.2</reflector-ip>
        <reflector-udp-port>55001</reflector-udp-port>
        <sid>178943</sid>
        <parent-connection-client-ip>203.0.113.1</parent-connection-\
client-ip>
        <parent-connection-client-tcp-port>16341</parent-connection-\
client-tcp-port>
        <parent-connection-server-ip>203.0.113.2</parent-connection-\
server-ip>
        <parent-connection-server-tcp-port>862</parent-connection-se\
rver-tcp-port>
        <test-packet-dscp>32</test-packet-dscp>
        <sent-packets>21</sent-packets>
        <rcv-packets>21</rcv-packets>
        <last-sent-seq>20</last-sent-seq>
        <last-rcv-seq>20</last-rcv-seq>
      </test-session>
    </session-reflector>
  </twamp>
</data>

   |  Note: '\' line wrapping is for formatting only.

<?xml version="1.0" encoding="utf-8"?>
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
```

```
      <twamp xmlns="urn:ietf:params:xml:ns:yang:ietf-twamp">
        <session-reflector>
          <admin-state>true</admin-state>
          <test-session>
            <sender-ip>2001:db8:10:1:1::1</sender-ip>
            <sender-udp-port>54000</sender-udp-port>
            <reflector-ip>2001:db8:10:1:1::2</reflector-ip>
            <reflector-udp-port>55000</reflector-udp-port>
            <sid>1232</sid>
            <parent-connection-client-ip>2001:db8:203:0:113::1</parent-c\
    onnection-client-ip>
            <parent-connection-client-tcp-port>16341</parent-connection-\
    client-tcp-port>
            <parent-connection-server-ip>2001:db8:203:0:113::2</parent-c\
    onnection-server-ip>
            <parent-connection-server-tcp-port>862</parent-connection-se\
    rver-tcp-port>
            <test-packet-dscp>32</test-packet-dscp>
            <sent-packets>2</sent-packets>
            <rcv-packets>2</rcv-packets>
            <last-sent-seq>1</last-sent-seq>
            <last-rcv-seq>1</last-rcv-seq>
          </test-session>
          <test-session>
            <sender-ip>2001:db8:203:0:113::1</sender-ip>
            <sender-udp-port>54001</sender-udp-port>
            <reflector-ip>2001:db8:192:68::2</reflector-ip>
            <reflector-udp-port>55001</reflector-udp-port>
            <sid>178943</sid>
            <parent-connection-client-ip>2001:db8:203:0:113::1</parent-c\
    onnection-client-ip>
            <parent-connection-client-tcp-port>16341</parent-connection-\
    client-tcp-port>
            <parent-connection-server-ip>2001:db8:203:0:113::2</parent-c\
    onnection-server-ip>
            <parent-connection-server-tcp-port>862</parent-connection-se\
    rver-tcp-port>
            <test-packet-dscp>32</test-packet-dscp>
            <sent-packets>21</sent-packets>
            <rcv-packets>21</rcv-packets>
            <last-sent-seq>20</last-sent-seq>
            <last-rcv-seq>20</last-rcv-seq>
          </test-session>
        </session-reflector>
      </twamp>
    </data>
```

Appendix B. TWAMP Operational Commands

TWAMP operational commands could be performed programmatically or manually, e.g., using a command-line interface (CLI).

With respect to programmability, YANG can be used to define NETCONF Remote Procedure Calls (RPCs); therefore, it would be, in principle, possible to define TWAMP RPC operations for actions such as starting or stopping control connections, test sessions, or groups of

sessions; retrieving results; clearing stored results; and so on.

However, TWAMP [RFC5357] does not attempt to describe such operational actions. Refer also to Section 2 and the unlabeled links in Figure 1. In actual deployments, different TWAMP implementations may support different sets of operational commands, with different restrictions. Therefore, this document considers it the responsibility of the individual implementation to define its corresponding data model for TWAMP operational commands.

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