ï»¿

Distributed Denial-of-Service Open Threat Signaling (DOTS) Telemetry

Abstract

   This document aims to enrich the Distributed Denial-of-Service Open
   Threat Signaling (DOTS) signal channel protocol with various
   telemetry attributes, allowing for optimal Distributed Denial-of-
   Service (DDoS) attack mitigation. It specifies the normal traffic
   baseline and attack traffic telemetry attributes a DOTS client can
   convey to its DOTS server in the mitigation request, the mitigation
   status telemetry attributes a DOTS server can communicate to a DOTS
   client, and the mitigation efficacy telemetry attributes a DOTS
   client can communicate to a DOTS server. The telemetry attributes
   can assist the mitigator in choosing the DDoS mitigation techniques
   and performing optimal DDoS attack mitigation.

   This document specifies two YANG modules: one for representing DOTS
   telemetry message types and one for sharing the attack mapping
   details over the DOTS data channel.

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/rfc9244.

Table of Contents

1. Introduction

   IT organizations and service providers are facing Distributed Denial-
   of-Service (DDoS) attacks that fall into two broad categories:

1. Network-layer and transport-layer attacks target the victim's
   infrastructure. These attacks are not necessarily aimed at
   taking down the actual delivered services; rather, these attacks
   prevent various network elements (routers, switches, firewalls,
   transit links, and so on) from serving legitimate users' traffic.

   The main method of such attacks is to send a large volume of
   traffic (e.g., high-pps (packets per second) traffic) toward the
   victim's infrastructure. Typically, attack volumes may vary from
   a few hundred Mbps to hundreds of Gbps or even Tbps. Attacks are
   commonly carried out leveraging botnets and attack reflectors for
   amplification attacks (Section 3.1 of [RFC4732]) such as NTP
   (Network Time Protocol), DNS (Domain Name System), SNMP (Simple
   Network Management Protocol), or SSDP (Simple Service Discovery
   Protocol).

2. Application-layer attacks target various applications. Typical
   examples include attacks against HTTP/HTTPS, DNS, SIP (Session
   Initiation Protocol), or SMTP (Simple Mail Transfer Protocol).
   However, all applications with their port numbers open at network
   edges can be attractive attack targets.

   Application-layer attacks are considered more complex and harder
   to categorize and are therefore harder to detect and mitigate
   efficiently.

To compound the problem, attackers also leverage multi-vectored
attacks. These attacks are assembled from dynamic network-layer and
application-layer attack vectors and other tactics. As such,
multiple attack vectors formed by multiple attack types and volumes
are launched simultaneously toward a victim. Multi-vector attacks
are harder to detect and defend against. Multiple and simultaneous
mitigation techniques are needed to defeat such attack campaigns. It
is also common for attackers to change attack vectors right after a
successful mitigation, burdening their opponents with changing their
defense methods.

The conclusion derived from the aforementioned attack scenarios is
that modern attack detection and mitigation are most certainly
complicated and highly convoluted tasks. They demand a comprehensive
knowledge of the attack attributes and the normal behavior of the
targeted systems (including normal traffic patterns), as well as the
attacker's ongoing and past actions. Even more challenging,
retrieving all the analytics needed for detecting these attacks is
not simple with the industry's current reporting capabilities.

The Distributed Denial-of-Service Open Threat Signaling (DOTS) signal
channel protocol [RFC9132] is used to carry information about a
network resource or a network (or a part thereof) that is under a
DDoS attack. Such information is sent by a DOTS client to one or
multiple DOTS servers so that appropriate mitigation actions are
undertaken on traffic deemed suspicious. Various use cases are
discussed in [RFC8903].

DOTS clients can be integrated within a DDoS attack detector or
within network and security elements that have been actively engaged
with ongoing attacks. The DOTS client mitigation environment
determines that it is no longer possible or practical for it to
handle these attacks itself. This can be due to a lack of resources
or security capabilities, as derived from the complexities and
intensity of these attacks. In this circumstance, the DOTS client
has invaluable knowledge about the actual attacks that need to be
handled by its DOTS server(s). By enabling the DOTS client to share
this comprehensive knowledge of an ongoing attack under specific
circumstances, the DOTS server can drastically increase its ability
to accomplish successful mitigation. While the attack is being
handled by the mitigation resources associated with the DOTS server,
the DOTS server has knowledge about the ongoing attack mitigation.
The DOTS server can share this information with the DOTS client so
that the client can better assess and evaluate the actual mitigation
realized.

DOTS clients can send mitigation hints derived from attack details to
DOTS servers, with the full understanding that a DOTS server may
ignore mitigation hints, as described in [RFC8612] (Gen-004).
Mitigation hints will be transmitted across the DOTS signal channel,
as the data channel may not be functional during an attack. How a
DOTS server handles normal and attack traffic attributes, and
mitigation hints, is implementation specific.

Both DOTS clients and servers can benefit from this information by
presenting various information details in relevant management,
reporting, and portal systems.

This document defines DOTS telemetry attributes that can be conveyed
by DOTS clients to DOTS servers, and vice versa. The DOTS telemetry
attributes are not mandatory attributes of the DOTS signal channel
protocol [RFC9132]. When no limitation policy is provided to a DOTS
agent, it can signal available telemetry attributes to its peers in
order to optimize the overall mitigation service provisioned using
DOTS. The aforementioned policy can be, for example, agreed upon
during a service subscription (which is out of scope for this
document) to identify a subset of DOTS clients among those deployed
in a DOTS client domain that are allowed to send or receive telemetry
data.

Section 11.2 of this document specifies a YANG module that augments
the DOTS data channel [RFC8783] with information related to attack
details. Sharing such details during 'idle' time is meant to
optimize the data exchanged over the DOTS signal channel.

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.

   The reader should be familiar with the terms defined in [RFC8612].

   "DOTS telemetry" is defined as the collection of attributes that are
   used to characterize the normal traffic baseline, attacks and their
   mitigation measures, and any related information that may help in
   enforcing countermeasures. "DOTS telemetry" is an optional set of
   attributes that can be signaled in the DOTS signal channel protocol.

   The Telemetry Setup Identifier (tsid) is an identifier that is
   generated by DOTS clients to uniquely identify DOTS telemetry setup
   configuration data. See Section 7.1.2 for more details.

   The Telemetry Identifier (tmid) is an identifier that is generated by
   DOTS clients to uniquely identify DOTS telemetry data that is
   communicated prior to or during a mitigation. See Section 8.2 for
   more details.

   "Overlapped" lower numeric 'tsid' (or 'tmid') refers to the lower
   'tsid' (or 'tmid') value of two overlapping telemetry requests.

   The term "pipe" represents the maximum level of traffic that the DOTS
   client domain can receive. Whether a "pipe" is mapped to one or a
   group of network interfaces is deployment specific. For example,
   each interconnection link may be considered as a specific pipe if the
   DOTS server is hosted by each upstream provider, while the aggregate
   of all links to connect to upstream network providers can be
   considered by a DOTS client domain as a single pipe when
   communicating with a DOTS server not hosted by these upstream
   providers.

   This document uses IANA-assigned Enterprise Numbers. These numbers
   are also known as "Private Enterprise Numbers" and "SMI (Structure of
   Management Information) Network Management Private Enterprise Codes"

[Private-Enterprise-Numbers].

The meanings of the symbols in YANG tree diagrams are defined in
[RFC8340] and [RFC8791].

Consistent with the convention set in Section 2 of [RFC8783], the
examples in Section 8.1.6 use "/restconf" as the discovered RESTCONF
API root path. Within these examples, some protocol header lines are
split into multiple lines for display purposes only. When a line
ends with a backslash ("\") as the last character, the line is
wrapped for display purposes. It is considered to be joined to the
next line by deleting the backslash, the following line break, and
the leading whitespace of the next line.

3. DOTS Telemetry: Overview and Purpose

Timely and effective signaling of up-to-date DDoS telemetry to all
elements involved in the mitigation process is essential and improves
the overall DDoS mitigation service's effectiveness. Bidirectional
feedback between DOTS agents is required for increased awareness by
each party of the attack and mitigation efforts, supporting a
superior and highly efficient attack mitigation service.

3.1. Need for More Visibility

When signaling a mitigation request, it is most certainly beneficial
for DOTS clients to signal to DOTS servers any knowledge regarding
ongoing attacks. This can happen in cases where DOTS clients are
asking DOTS servers for support in defending against attacks that
they have already detected and/or (partially) mitigated.

If attacks are already detected and categorized within a DOTS client
domain, the DOTS server, and its associated mitigation services, can
proactively benefit from this information and optimize the overall
service delivery. It is important to note that DOTS client domains'
and DOTS server domains' detection and mitigation approaches can be
different and can potentially result in different results and attack
classifications. The DDoS mitigation service treats the ongoing
attack details received from DOTS clients as hints and cannot
completely rely on or trust the attack details conveyed by DOTS
clients.

In addition to the DOTS server directly using telemetry data as
operational hints, the DOTS server's security operation team also
benefits from telemetry data. A basic requirement of security
operation teams is to be aware of and get visibility into the attacks
they need to handle. This holds especially for the case of ongoing
attacks, where DOTS telemetry provides data about the current attack
status. Even if some mitigation can be automated, operational teams
can use the DOTS telemetry information to be prepared for attack
mitigation and to assign the correct resources (e.g., operation
staff, networking resources, mitigation resources) for the specific
service. Similarly, security operations personnel at the DOTS client
side ask for feedback about their requests for protection.
Therefore, it is valuable for DOTS servers to share DOTS telemetry
with DOTS clients.

Mutual sharing of information is thus crucial for "closing the
mitigation loop" between DOTS clients and servers. For the server-
side team, it is important to confirm that the same attacks that the
DOTS server's mitigation resources are seeing are those for which a
DOTS client is requesting mitigation. For the DOTS client-side team,
it is important to realize that the DOTS clients receive the required
service -- for example, understanding that "I asked for mitigation of
two attacks, and my DOTS server detects and mitigates only one of
them." Cases of inconsistency in attack classification between DOTS
clients and servers can be highlighted, and maybe handled, using the
DOTS telemetry attributes.

In addition, management and orchestration systems, at both the DOTS
client and server sides, can use DOTS telemetry as feedback to

automate various control and management activities derived from
signaled telemetry information.

If the DOTS server's mitigation resources have the capabilities to
facilitate the DOTS telemetry, the DOTS server adapts its protection
strategy and activates the required countermeasures immediately
(automation enabled) for the sake of optimized attack mitigation
decisions and actions. Discussion regarding the interface from the
DOTS server to the mitigator to signal the telemetry data is out of
scope for this document.

3.2. Enhanced Detection

DOTS telemetry can also be used as input for determining what values
to use for the tuning parameters available on the mitigation
resources. During the last few years, DDoS attack detection
technologies have evolved from threshold-based detection (that is,
cases when all or specific parts of traffic cross a predefined
threshold for a certain period of time is considered as an attack) to
an "anomaly detection" approach. For the latter, it is required to
maintain rigorous learning of "normal" behavior, and an "anomaly" (or
an attack) is identified and categorized based on the knowledge about
the normal behavior and a deviation from this normal behavior.
Statistical and artificial intelligence algorithms (e.g., machine
learning) are used such that the actual traffic thresholds are
automatically calculated by learning the protected entity's normal
traffic behavior during 'idle' time (i.e., no mitigation is active).
The normal traffic characterization learned is referred to as the
"normal traffic baseline". An attack is detected when the victim's
actual traffic is deviating from this normal baseline pattern.

In addition, subsequent activities toward mitigating an attack are
much more challenging. The ability to distinguish legitimate traffic
from attacker traffic on a per-packet basis is complex. For example,
a packet may look "legitimate" and no attack signature can be
identified. The anomaly can be identified only after detailed
statistical analysis. DDoS attack mitigators use the normal baseline
during the mitigation of an attack to identify and categorize the
expected appearance of a specific traffic pattern. Particularly, the
mitigators use the normal baseline to recognize the "level of
normality" that needs to be achieved during the various mitigation
processes.

Normal baseline calculation is performed based on continuous learning
of the normal behavior of the protected entities. The minimum
learning period varies from hours to days and even weeks, depending
on the protected applications' behavior. The baseline cannot be
learned during active attacks because attack conditions do not
characterize the protected entities' normal behavior.

If the DOTS client has calculated the normal baseline of its
protected entities, signaling such information to the DOTS server
along with the attack traffic levels provides value. The DOTS server
benefits from this telemetry by tuning its mitigation resources with
the DOTS client's normal baseline. The DOTS server's mitigators use
the baseline to familiarize themselves with the attack victim's
normal behavior and target the baseline as the level of normality
they need to achieve. Fed with this information, the overall
mitigation performance is expected to be improved in terms of time to
mitigate, accuracy, and false-negative and false-positive rates.

Mitigation of attacks without having certain knowledge of normal
traffic can be inaccurate at best. This is especially true for
recursive signaling (see Section 3.2.3 of [RFC8811]). Given that
DOTS clients can be integrated in a highly diverse set of scenarios
and use cases, this emphasizes the need for knowledge of the behavior
of each DOTS client domain -- especially given that common global
thresholds for attack detection can almost never be realized. Each
DOTS client domain can have its own levels of traffic and normal
behavior. Without facilitating normal baseline signaling, it may be
very difficult for DOTS servers in some cases to detect and mitigate

the attacks accurately:

*   It is important to emphasize that it is practically impossible for
    the DOTS server's mitigators to calculate the normal baseline in
    cases where they do not have any knowledge of the traffic
    beforehand.

Of course, this information can be provided using out-of-band
mechanisms or manual configuration, at the risk of unmaintained
information becoming inaccurate as the network evolves and "normal"
patterns change. The use of a dynamic and collaborative means
between the DOTS client and server to identify and share key
parameters for the sake of efficient DDoS protection is valuable.

3.3. Efficient Mitigation

During a high-volume attack, DOTS client pipes can be totally
saturated. DOTS clients ask their DOTS servers to handle the attack
upstream so that DOTS client pipes return to a reasonable load level
(normal pattern, ideally). At this point, it is essential to ensure
that the mitigator does not overwhelm the DOTS client pipes by
sending back large volumes of "clean traffic", or what it believes is
"clean". This can happen when the mitigator has not managed to
detect and mitigate all the attacks launched toward the DOTS client
domain.

In this case, it can be valuable to DOTS clients to signal to DOTS
servers the total pipe capacity, which is the level of traffic the
DOTS client domain can absorb from its upstream network. This is
usually the circuit size, which includes all the packet overheads.
Dynamic updates of the condition of pipes between DOTS agents while
they are under a DDoS attack are essential (e.g., where multiple DOTS
clients share the same physical connectivity pipes). The DOTS server
should activate other mechanisms to ensure that it does not allow the
DOTS client domain's pipes to be saturated unintentionally. The
rate-limit action defined in [RFC8783] is a reasonable candidate to
achieve this objective; the DOTS client can indicate the type(s) of
traffic (such as ICMP, UDP, TCP port number 80) it prefers to limit.
The rate-limit action can be controlled via the signal channel
[RFC9133] even when the pipe is overwhelmed.

4. Design Overview

4.1. Overview of Telemetry Operations

The DOTS protocol suite is divided into two logical channels: the
signal channel [RFC9132] and data channel [RFC8783]. This division
is due to the vastly different requirements placed upon the traffic
they carry. The DOTS signal channel must remain available and usable
even in the face of attack traffic that might, for example, saturate
one direction of the links involved, rendering acknowledgment-based
mechanisms unreliable and strongly incentivizing messages to be small
enough to be contained in a single IP packet (Section 2.2 of
[RFC8612]). In contrast, the DOTS data channel is available for
high-bandwidth data transfer before or after an attack, using more
conventional transport protocol techniques (Section 2.3 of
[RFC8612]). It is generally preferable to perform advance
configuration over the DOTS data channel, including configuring
aliases for static or nearly static data sets such as sets of network
addresses/prefixes that might be subject to related attacks. This
design helps to optimize the use of the DOTS signal channel for the
small messages that are important to deliver during an attack. As a
reminder, the DOTS signal channel and data channel both require
secure communication channels (Section 11 of [RFC9132] and Section 10
of [RFC8783]).

Telemetry information has aspects that correspond to both operational
modes (i.e., signal channel and data channel): there is certainly a
need to convey updated information about ongoing attack traffic and
targets during an attack, so as to convey detailed information about
mitigation status and inform updates to mitigation strategy in the

face of adaptive attacks. However, it is also useful to provide
mitigation services with a picture of normal or "baseline" traffic
toward potential targets to aid in detecting when incoming traffic
deviates from normal into being an attack. Also, one might populate
a "database" of classifications of known types of attacks so that a
short attack identifier can be used during an attack period to
describe an observed attack. This specification does make provision
for use of the DOTS data channel for the latter function
(Section 8.1.6) but otherwise retains most telemetry functionality in
the DOTS signal channel.

Note that it is a functional requirement to convey information about
ongoing attack traffic during an attack, and information about
baseline traffic uses an essentially identical data structure that is
naturally defined to sit next to the description of attack traffic.
The related telemetry setup information used to parameterize actual
traffic data is also sent over the signal channel, out of expediency.

This document specifies an extension to the DOTS signal channel
protocol. Considerations about how to establish, maintain, and make
use of the DOTS signal channel are specified in [RFC9132].

Once the DOTS signal channel is established, DOTS clients that
support the DOTS telemetry extension proceed with the telemetry setup
configuration (e.g., measurement interval, telemetry notification
interval, pipe capacity, normal traffic baseline) as detailed in
Section 7. DOTS agents can then include DOTS telemetry attributes
using the DOTS signal channel (Section 8.1). A DOTS client can use
separate messages to share with its DOTS server(s) a set of telemetry
data bound to an ongoing mitigation (Section 8.2). Also, a DOTS
client that is interested in receiving telemetry notifications
related to some of its resources follows the procedure defined in
Section 8.3. A DOTS client that receives such notifications can then
decide to send a mitigation request if an attack cannot be mitigated
locally within the DOTS client domain.

Aggregate DOTS telemetry data can also be included in efficacy update
(Section 9.1) or mitigation update (Section 9.2) messages.

4.2. Block-Wise Transfers

DOTS clients can use a block-wise transfer [RFC7959] with the
recommendation detailed in Section 4.4.2 of [RFC9132] to control the
size of a response when the data to be returned does not fit within a
single datagram.

DOTS clients can also use the Constrained Application Protocol (CoAP)
Block1 Option in a PUT request (Section 2.5 of [RFC7959]) to initiate
large transfers, but these Block1 transfers are likely to fail if the
inbound "pipe" is running full because the transfer requires a
message from the server for each block, which would likely be lost in
the incoming flood. Consideration needs to be made to try to fit
this PUT into a single transfer or to separate out the PUT into
several discrete PUTs where each of them fits into a single packet.

Q-Block1 and Q-Block2 Options that are similar to the CoAP Block1 and
Block2 Options, but enable robust transmissions of big blocks of data
with less packet interchanges using NON messages, are defined in
[RFC9177]. DOTS implementations can consider the use of Q-Block1 and
Q-Block2 Options [DOTS-Robust-Blocks].

4.3. DOTS Multihoming Considerations

Considerations for multihomed DOTS clients to select which DOTS
server to contact and which IP prefixes to include in a telemetry
message to a given peer DOTS server are discussed in
[DOTS-Multihoming]. For example, if each upstream network exposes a
DOTS server and the DOTS client maintains DOTS channels with all of
them, only the information related to prefixes assigned by an
upstream network to the DOTS client domain will be signaled via the
DOTS channel established with the DOTS server of that upstream

network.

Considerations related to whether (and how) a DOTS client gleans some
telemetry information (e.g., attack details) it receives from a first
DOTS server and shares it with a second DOTS server are
implementation and deployment specific.

4.4. YANG Considerations

Telemetry messages exchanged between DOTS agents are serialized using
Concise Binary Object Representation (CBOR) [RFC8949]. CBOR-encoded
payloads are used to carry signal-channel-specific payload messages
that convey request parameters and response information such as
errors.

This document specifies a YANG module [RFC7950] for representing DOTS
telemetry message types (Section 11.1). All parameters in the
payload of the DOTS signal channel are mapped to CBOR types as
specified in Section 12. As a reminder, Section 3 of [RFC9132]
defines the rules for mapping YANG-modeled data to CBOR.

The DOTS telemetry module (Section 11.1) is not intended to be used
via the Network Configuration Protocol (NETCONF) / RESTCONF for DOTS
server management purposes. It serves only to provide a data model
and encoding following [RFC8791]. Server deviations (Section 5.6.3
of [RFC7950]) are strongly discouraged, as the peer DOTS agent does
not have the means to retrieve the list of deviations and thus
interoperability issues are likely to be encountered.

The DOTS telemetry module (Section 11.1) uses "enumerations" rather
than "identities" to define units, samples, and intervals because
otherwise the namespace identifier "ietf-dots-telemetry" must be
included when a telemetry attribute is included (e.g., in a
mitigation efficacy update). The use of "identities" is thus
suboptimal from the standpoint of message compactness, as message
compactness is one of the key requirements for DOTS signal channel
messages.

The DOTS telemetry module (Section 11.1) includes some lists for
which no "key" statement is included. This behavior is compliant
with [RFC8791]. The reason for not including these keys is that they
are not included in the message body of DOTS requests; such keys are
included as mandatory Uri-Paths in requests (Sections 7 and 8).
Otherwise, whenever a "key" statement is used in the module, the same
definition as the definition provided in Section 7.8.2 of [RFC7950]
is assumed.

Some parameters (e.g., low-percentile values) may be associated with
different YANG types (e.g., decimal64 and yang:gauge64). To easily
distinguish the types of these parameters while using meaningful
names, the following suffixes are used:

```
+========+===============+==================+
| Suffix | YANG Type     | Example          |
+========+===============+==================+
| -g     | yang:gauge64  | low-percentile-g |
+--------+---------------+------------------+
| -c     | container     | connection-c     |
+--------+---------------+------------------+
| -ps    | per second    | connection-ps    |
+--------+---------------+------------------+
```

Table 1: Suffixes and YANG Types

The full tree diagram of the DOTS telemetry module can be generated
using the "pyang" tool [PYANG]. That tree is not included here
because it is too long (Section 3.3 of [RFC8340]). Instead, subtrees
are provided for the reader's convenience.

In order to optimize the data exchanged over the DOTS signal channel,
this document specifies a second YANG module ("ietf-dots-mapping";

see Section 11.2) that augments the DOTS data channel [RFC8783].
This augmentation can be used during 'idle' time to share the attack
mapping details (Section 8.1.5). DOTS clients can use tools, e.g.,
the YANG Library [RFC8525], to retrieve the list of features and
deviations supported by the DOTS server over the data channel.

5. Generic Considerations

5.1. DOTS Client Identification

Following the rules in Section 4.4.1 of [RFC9132], a unique
identifier is generated by a DOTS client to prevent request
collisions ('cuid').

As a reminder, Section 4.4.1.3 of [RFC9132] forbids 'cuid' to be
returned in a response message body.

5.2. DOTS Gateways

DOTS gateways may be located between DOTS clients and servers. The
considerations elaborated in Section 4.4.1 of [RFC9132] must be
followed. In particular, the 'cdid' attribute is used to
unambiguously identify a DOTS client domain.

As a reminder, Section 4.4.1.3 of [RFC9132] forbids 'cdid' (if
present) to be returned in a response message body.

5.3. Uri-Path Parameters and Empty Values

Uri-Path parameters and attributes with empty values MUST NOT be
present in a request. The presence of such an empty value renders
the entire containing message invalid.

5.4. Controlling Configuration Data

The DOTS server follows the same considerations discussed in
Section 4.5.3 of [RFC9132] for managing DOTS telemetry configuration
freshness and notifications.

Likewise, a DOTS client may control the selection of configuration
and non-configuration data nodes when sending a GET request by means
of the 'c' (content) Uri-Query option and following the procedure
specified in Section 4.4.2 of [RFC9132]. These considerations are
not reiterated in the following sections.

5.5. Message Validation

The authoritative references for validating telemetry messages
exchanged over the DOTS signal channel are Sections 7, 8, and 9
together with the mapping table provided in Section 12. The
structure of telemetry message bodies is represented as a YANG data
structure (Section 11.1).

5.6. A Note about Examples

Examples are provided for illustration purposes. This document does
not aim to provide a comprehensive list of message examples.

JSON encoding of YANG-modeled data is used to illustrate the various
telemetry operations. To ease readability, parameter names and their
JSON types are thus used in the examples rather than their CBOR key
values and CBOR types following the mappings in Section 12. These
conventions are inherited from [RFC9132].

The examples use Enterprise Number 32473, which is defined for
documentation use; see [RFC5612].

6. Telemetry Operation Paths

As discussed in Section 4.2 of [RFC9132], each DOTS operation is
indicated by a path suffix that indicates the intended operation.

The operation path is appended to the path prefix to form the URI
used with a CoAP request to perform the desired DOTS operation. The
following telemetry path suffixes are defined (Table 2):

```
+=================+================+===========+
| Operation       | Operation Path | Details   |
+=================+================+===========+
| Telemetry Setup | /tm-setup      | Section 7 |
+-----------------+----------------+-----------+
| Telemetry       | /tm            | Section 8 |
+-----------------+----------------+-----------+
```

             Table 2: DOTS Telemetry Operations

Consequently, the "ietf-dots-telemetry" YANG module defined in
Section 11.1 defines a data structure to represent new DOTS message
types called 'telemetry-setup' and 'telemetry'. The tree structure
is shown in Figure 1. More details are provided in Sections 7 and 8
about the exact structure of 'telemetry-setup' and 'telemetry'
message types.

```
   structure dots-telemetry:
     +-- (telemetry-message-type)?
        +--:(telemetry-setup)
        |  ...
        |  +-- telemetry* []
        |     ...
        |     +-- (setup-type)?
        |        +--:(telemetry-config)
        |        |  ...
        |        +--:(pipe)
        |        |  ...
        |        +--:(baseline)
        |           ...
        +--:(telemetry)
           ...
```

        Figure 1: New DOTS Message Types (YANG Tree Structure)

DOTS implementations MUST support the Observe Option [RFC7641] for
'tm' (Section 8).

7. DOTS Telemetry Setup Configuration

In reference to Figure 1, a DOTS telemetry setup message MUST include
only telemetry-related configuration parameters (Section 7.1),
information about DOTS client domain pipe capacity (Section 7.2), or
information about the telemetry traffic baseline (Section 7.3). As
such, requests that include a mix of telemetry configuration, pipe
capacity, and traffic baseline information MUST be rejected by DOTS
servers with a 4.00 (Bad Request) Response Code.

A DOTS client can reset all installed DOTS telemetry setup
configuration data following the considerations detailed in
Section 7.4.

A DOTS server may detect conflicts when processing requests related
to DOTS client domain pipe capacity or telemetry traffic baseline
information with requests from other DOTS clients of the same DOTS
client domain. More details are included in Section 7.5.

Telemetry setup configuration is bound to a DOTS client domain. DOTS
servers MUST NOT expect DOTS clients to send regular requests to
refresh the telemetry setup configuration. Any available telemetry
setup configuration is valid until the DOTS server ceases to service
a DOTS client domain. DOTS servers MUST NOT reset 'tsid' because a
session failed with a DOTS client. DOTS clients update their
telemetry setup configuration upon change of a parameter that may
impact attack mitigation.

DOTS telemetry setup configuration request and response messages are

marked as Confirmable messages (Section 2.1 of [RFC7252]).

7.1. Telemetry Configuration

   DOTS telemetry uses several percentile values to provide a picture of
   a traffic distribution overall, as opposed to just a single snapshot
   of observed traffic at a single point in time. Modeling raw traffic
   flow data as a distribution and describing that distribution entails
   choosing a measurement period that the distribution will describe,
   and a number of sampling intervals, or "buckets", within that
   measurement period. Traffic within each bucket is treated as a
   single event (i.e., averaged), and then the distribution of buckets
   is used to describe the distribution of traffic over the measurement
   period. A distribution can be characterized by statistical measures
   (e.g., mean, median, and standard deviation) and also by reporting
   the value of the distribution at various percentile levels of the
   data set in question (e.g., "quartiles" that correspond to 25th,
   50th, and 75th percentiles). More details about percentile values
   and their computation are found in Section 11.3 of [RFC2330].

   DOTS telemetry uses up to three percentile values, plus the overall
   peak, to characterize traffic distributions. Which percentile
   thresholds are used for these "low-percentile", "mid-percentile", and
   "high-percentile" values is configurable. Default values are defined
   in Section 7.1.2.

   A DOTS client can negotiate with its server(s) a set of telemetry
   configuration parameters to be used for telemetry. Such parameters
   include:

   * Percentile-related measurement parameters. In particular,
      'measurement-interval' defines the period during which percentiles
      are computed, while 'measurement-sample' defines the time
      distribution for measuring values that are used to compute
      percentiles.

   * Measurement units.

   * Acceptable percentile values.

   * Telemetry notification interval.

   * Acceptable server-originated telemetry.

7.1.1. Retrieving the Current DOTS Telemetry Configuration

   A GET request is used to obtain acceptable and current telemetry
   configuration parameters on the DOTS server. This request may
   include a 'cdid' Uri-Path when the request is relayed by a DOTS
   gateway. An example of such a GET request (without a gateway) is
   depicted in Figure 2.

   Header: GET (Code=0.01)
   Uri-Path: ".well-known"
   Uri-Path: "dots"
   Uri-Path: "tm-setup"
   Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"

    Figure 2: GET to Retrieve the Current and Acceptable DOTS Telemetry
                            Configuration

   Upon receipt of such a request, and assuming that no error is
   encountered when processing the request, the DOTS server replies with
   a 2.05 (Content) response that conveys the telemetry parameters that
   are acceptable to the DOTS server, any pipe information
   (Section 7.2), and the current baseline information (Section 7.3)
   maintained by the DOTS server for this DOTS client. The tree
   structure of the response message body is provided in Figure 3.

   DOTS servers that support the capability of sending telemetry
   information to DOTS clients prior to or during a mitigation

(Section 9.2) set 'server-originated-telemetry' under 'max-config-
values' to 'true' ('false' is used otherwise). If 'server-
originated-telemetry' is not present in a response, this is
equivalent to receiving a response with 'server-originated-telemetry'
set to 'false'.

```
structure dots-telemetry:
  +-- (telemetry-message-type)?
      +--:(telemetry-setup)
      |  +-- (direction)?
      |  |  +--:(server-to-client-only)
      |  |     +-- max-config-values
      |  |     |  +-- measurement-interval?        interval
      |  |     |  +-- measurement-sample?          sample
      |  |     |  +-- low-percentile?              percentile
      |  |     |  +-- mid-percentile?              percentile
      |  |     |  +-- high-percentile?             percentile
      |  |     |  +-- server-originated-telemetry? boolean
      |  |     |  +-- telemetry-notify-interval?   uint16
      |  |     +-- min-config-values
      |  |     |  +-- measurement-interval?        interval
      |  |     |  +-- measurement-sample?          sample
      |  |     |  +-- low-percentile?              percentile
      |  |     |  +-- mid-percentile?              percentile
      |  |     |  +-- high-percentile?             percentile
      |  |     |  +-- telemetry-notify-interval?   uint16
      |  |     +-- supported-unit-classes
      |  |     |  +-- unit-config* [unit]
      |  |     |     +-- unit            unit-class
      |  |     |     +-- unit-status     boolean
      |  |     +-- supported-query-type*  query-type
      |  +-- telemetry* []
      |     +-- (direction)?
      |     |  +--:(server-to-client-only)
      |     |     +-- tsid?                    uint32
      |     +-- (setup-type)?
      |        +--:(telemetry-config)
      |        |  +-- current-config
      |        |     +-- measurement-interval?        interval
      |        |     +-- measurement-sample?          sample
      |        |     +-- low-percentile?              percentile
      |        |     +-- mid-percentile?              percentile
      |        |     +-- high-percentile?             percentile
      |        |     +-- unit-config* [unit]
      |        |     |  +-- unit            unit-class
      |        |     |  +-- unit-status     boolean
      |        |     +-- server-originated-telemetry? boolean
      |        |     +-- telemetry-notify-interval?   uint16
      |        +--:(pipe)
      |        |  ...
      |        +--:(baseline)
      |           ...
      +--:(telemetry)
         ...
```

              Figure 3: Telemetry Configuration Tree Structure

When both 'min-config-values' and 'max-config-values' attributes are
present, the values carried in 'max-config-values' attributes MUST be
greater than or equal to their counterparts in 'min-config-values'
attributes.

7.1.2. Conveying the DOTS Telemetry Configuration

A PUT request is used to convey the configuration parameters for the
telemetry data (e.g., low-, mid-, or high-percentile values). For
example, a DOTS client may contact its DOTS server to change the
default percentile values used as the baseline for telemetry data.
Figure 3 lists the attributes that can be set by a DOTS client in
such a PUT request. An example of a DOTS client that modifies all
percentile reference values is shown in Figure 4.

> Note: The payload of the message depicted in Figure 4 is CBOR-
> encoded as indicated by setting the Content-Format entry to
> "application/dots+cbor" (Section 10.3 of [RFC9132]). However,
> and for the sake of better readability, the example (and other
> similar figures depicting a DOTS telemetry message body)
> follows the conventions set in Section 5.6: use the JSON names
> and types defined in Section 12.

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=123"
Content-Format: "application/dots+cbor"

{
  "ietf-dots-telemetry:telemetry-setup": {
    "telemetry": [
      {
        "current-config": {
          "low-percentile": "5.00",
          "mid-percentile": "65.00",
          "high-percentile": "95.00"
        }
      }
    ]
  }
}
```

        Figure 4: PUT to Convey the DOTS Telemetry Configuration,
                    Depicted as per Section 5.6

'cuid' is a mandatory Uri-Path parameter for PUT requests.

The following additional Uri-Path parameter is defined:

tsid: The Telemetry Setup Identifier is an identifier for the DOTS
   telemetry setup configuration data represented as an integer.
   This identifier MUST be generated by DOTS clients. 'tsid' values
   MUST increase monotonically whenever new configuration parameters
   (not just for changed values) need to be conveyed by the DOTS
   client.

   The procedure specified in Section 4.4.1 of [RFC9132] for 'mid'
   rollover MUST also be followed for 'tsid' rollover.

   This is a mandatory attribute. 'tsid' MUST appear after 'cuid' in
   the Uri-Path options.

'cuid' and 'tsid' MUST NOT appear in the PUT request message body.

At least one configurable attribute MUST be present in the PUT
request.

A PUT request with a higher numeric 'tsid' value overrides the DOTS
telemetry configuration data installed by a PUT request with a lower
numeric 'tsid' value. To avoid maintaining a long list of 'tsid'
requests for requests carrying telemetry configuration data from a
DOTS client, the lower numeric 'tsid' MUST be automatically deleted
and no longer be available at the DOTS server.

The DOTS server indicates the result of processing the PUT request
using the following Response Codes:

* If the request is missing a mandatory attribute, does not include
   'cuid' or 'tsid' Uri-Path parameters, or contains one or more
   invalid or unknown parameters, a 4.00 (Bad Request) Response Code
   MUST be returned in the response.

* If the DOTS server does not find the 'tsid' parameter value
      conveyed in the PUT request in its configuration data and if the
      DOTS server has accepted the configuration parameters, then a 2.01
      (Created) Response Code MUST be returned in the response.

   * If the DOTS server finds the 'tsid' parameter value conveyed in
      the PUT request in its configuration data and if the DOTS server
      has accepted the updated configuration parameters, a 2.04
      (Changed) Response Code MUST be returned in the response.

   * If any of the enclosed configurable attribute values are not
      acceptable to the DOTS server (Section 7.1.1), a 4.22
      (Unprocessable Entity) Response Code MUST be returned in the
      response.

      The DOTS client may retry and send the PUT request with updated
      attribute values acceptable to the DOTS server.

By default, low-percentile (10th percentile), mid-percentile (50th
percentile), high-percentile (90th percentile), and peak (100th
percentile) values are used to represent telemetry data.
Nevertheless, a DOTS client can disable some percentile types (low,
mid, high). In particular, setting 'low-percentile' to "0.00"
indicates that the DOTS client is not interested in receiving low-
percentiles. Likewise, setting 'mid-percentile' (or 'high-
percentile') to the same value as 'low-percentile' (or 'mid-
percentile') indicates that the DOTS client is not interested in
receiving mid-percentiles (or high-percentiles). For example, a DOTS
client can send the request depicted in Figure 5 to inform the server
that it is interested in receiving only high-percentiles. This
assumes that the client will only use that percentile type when
sharing telemetry data with the server.

Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=124"
Content-Format: "application/dots+cbor"

{
  "ietf-dots-telemetry:telemetry-setup": {
    "telemetry": [
      {
        "current-config": {
          "low-percentile": "0.00",
          "mid-percentile": "0.00",
          "high-percentile": "95.00"
        }
      }
    ]
  }
}

      Figure 5: PUT to Disable Low- and Mid-Percentiles, Depicted as
                           per Section 5.6

DOTS clients can also configure the unit class(es) to be used for
traffic-related telemetry data among the following supported unit
classes: packets per second, bits per second, and bytes per second.
Supplying both bits per second and bytes per second unit classes is
allowed for a given set of telemetry data. However, receipt of
conflicting values is treated as invalid parameters and rejected with
a 4.00 (Bad Request) Response Code.

DOTS clients that are interested in receiving pre-or-ongoing-
mitigation telemetry ('pre-or-ongoing-mitigation') information from a
DOTS server (Section 9.2) MUST set 'server-originated-telemetry' to
'true'. If 'server-originated-telemetry' is not present in a PUT
request, this is equivalent to receiving a request with 'server-

originated-telemetry' set to 'false'. An example of a request to
enable pre-or-ongoing-mitigation telemetry from DOTS servers is shown
in Figure 6.

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=125"
Content-Format: "application/dots+cbor"

{
  "ietf-dots-telemetry:telemetry-setup": {
    "telemetry": [
      {
        "current-config": {
          "server-originated-telemetry": true
        }
      }
    ]
  }
}
```

   Figure 6: PUT to Enable Pre-or-Ongoing-Mitigation Telemetry from
             the DOTS Server, Depicted as per Section 5.6

7.1.3. Retrieving the Installed DOTS Telemetry Configuration

   A DOTS client may issue a GET message with a 'tsid' Uri-Path
   parameter to retrieve the current DOTS telemetry configuration. An
   example of such a request is depicted in Figure 7.

```
Header: GET (Code=0.01)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=123"
```

    Figure 7: GET to Retrieve the Current DOTS Telemetry Configuration

   If the DOTS server does not find the 'tsid' Uri-Path value conveyed
   in the GET request in its configuration data for the requesting DOTS
   client, it MUST respond with a 4.04 (Not Found) error Response Code.

7.1.4. Deleting the DOTS Telemetry Configuration

   A DELETE request is used to delete the installed DOTS telemetry
   configuration data (Figure 8). 'cuid' and 'tsid' are mandatory Uri-
   Path parameters for such DELETE requests.

```
Header: DELETE (Code=0.04)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=123"
```

                Figure 8: Deleting the Telemetry Configuration

   The DOTS server resets the DOTS telemetry configuration back to the
   default values and acknowledges a DOTS client's request to remove the
   DOTS telemetry configuration using a 2.02 (Deleted) Response Code. A
   2.02 (Deleted) Response Code is returned even if the 'tsid' parameter
   value conveyed in the DELETE request does not exist in its
   configuration data before the request.

   Section 7.4 discusses the procedure to reset all DOTS telemetry setup
   configuration data.

7.2. Total Pipe Capacity

A DOTS client can communicate to the DOTS server(s) its DOTS client
domain pipe information. The tree structure of the pipe information
is shown in Figure 9.

```
structure dots-telemetry:
  +-- (telemetry-message-type)?
     +--:(telemetry-setup)
     |   ...
     |   +-- telemetry* []
     |      +-- (direction)?
     |      |  +--:(server-to-client-only)
     |      |     +-- tsid?                    uint32
     |      +-- (setup-type)?
     |         +--:(telemetry-config)
     |         |  ...
     |         +--:(pipe)
     |         |  +-- total-pipe-capacity* [link-id unit]
     |         |     +-- link-id     nt:link-id
     |         |     +-- capacity    uint64
     |         |     +-- unit        unit
     |         +--:(baseline)
     |            ...
     +--:(telemetry)
        ...
```

Figure 9: Pipe Tree Structure

A DOTS client domain pipe is defined as a list of limits on
(incoming) traffic volume ('total-pipe-capacity') that can be
forwarded over ingress interconnection links of a DOTS client domain.
Each of these links is identified with a 'link-id' [RFC8345].

The unit used by a DOTS client when conveying pipe information is
captured in the 'unit' attribute. The DOTS client MUST auto-scale so
that the appropriate unit is used. That is, for a given unit class,
the DOTS client uses the largest unit that gives a value greater than
one. As such, only one unit per unit class is allowed.

7.2.1. Conveying DOTS Client Domain Pipe Capacity

Considerations similar to those specified in Section 7.1.2 are
followed, with one exception:

* The relative order of two PUT requests carrying DOTS client domain
   pipe attributes from a DOTS client is determined by comparing
   their respective 'tsid' values. If these two requests have
   overlapping 'link-id' and 'unit' settings, the PUT request with a
   higher numeric 'tsid' value will override the request with a lower
   numeric 'tsid' value. The overlapped lower numeric 'tsid' MUST be
   automatically deleted and no longer be available.

DOTS clients SHOULD minimize the number of active 'tsid's used for
pipe information. In order to avoid maintaining a long list of
'tsid's for pipe information, it is RECOMMENDED that DOTS clients
include in any request to update information related to a given link
the information regarding other links (already communicated using a
lower 'tsid' value). By doing so, this update request will override
these existing requests and hence optimize the number of 'tsid'
requests per DOTS client.

   | Note: This assumes that all link information can fit in one
   | single message.

As an example of configuring pipe information, a DOTS client managing
a single-homed domain (Figure 10) can send a PUT request (shown in
Figure 11) to communicate the capacity of "link1" used to connect to
its ISP.

                    ,--,--,--.   ,--,--,--.

```
              ,-'           `-.        ,-'           `-.
             (  DOTS Client   )=====(       ISP#A      )
              `-.  Domain  ,-' link1 `-.           ,-'
                 `--'__'__'             `--'__'__'
```
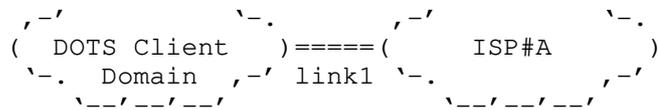
                 Figure 10: Single-Homed DOTS Client Domain

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=126"
Content-Format: "application/dots+cbor"

{
   "ietf-dots-telemetry:telemetry-setup": {
     "telemetry": [
       {
         "total-pipe-capacity": [
           {
             "link-id": "link1",
             "capacity": "500",
             "unit": "megabit-ps"
           }
         ]
       }
     ]
   }
}
```

        Figure 11: Example of a PUT Request to Convey Pipe Information
                 (Single-Homed), Depicted as per Section 5.6

DOTS clients may be instructed to signal a link aggregate instead of
individual links. For example, a DOTS client that manages a DOTS
client domain having two interconnection links with an upstream ISP
(Figure 12) can send a PUT request (shown in Figure 13) to
communicate the aggregate link capacity with its ISP. Signaling
individual or aggregate link capacity is deployment specific.

```
              ,--,--,--.              ,--,--,--.
           ,-'           `-.===== ,-'           `-.
          (  DOTS Client   )     (      ISP#C      )
           `-.  Domain  ,-'===== `-.           ,-'
              `--'__'__'              `--'__'__'
```
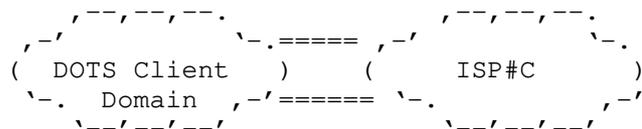
        Figure 12: DOTS Client Domain with Two Interconnection Links

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=hmcpH87lmPGsSTjkhXCbin"
Uri-Path: "tsid=896"
Content-Format: "application/dots+cbor"

{
   "ietf-dots-telemetry:telemetry-setup": {
     "telemetry": [
       {
         "total-pipe-capacity": [
           {
             "link-id": "aggregate",
             "capacity": "700",
             "unit": "megabit-ps"
           }
         ]
       }
     ]
   }
```

}

Now consider that the DOTS client domain was upgraded to connect to
an additional ISP (e.g., ISP#B in Figure 14); the DOTS client can
inform a DOTS server that is not hosted with ISP#A and ISP#B domains
about this update by sending the PUT request depicted in Figure 15.
This request also includes information related to "link1" even if
that link is not upgraded. Upon receipt of this request, the DOTS
server removes the request with 'tsid=126' and updates its
configuration base to maintain two links (link1 and link2).

```
                          ,--,--,--.
                        ,-'          `-.
                       (      ISP#B      )
                        `-.          ,-'
                          `--'--'--'
                              ||
                              || link2
                     ,--,--,--.            ,--,--,--.
                   ,-'          `-.      ,-'          `-.
                  (  DOTS Client   )=====(      ISP#A      )
                   `-.  Domain   ,-' link1 `-.          ,-'
                     `--'--'--'            `--'--'--'
```
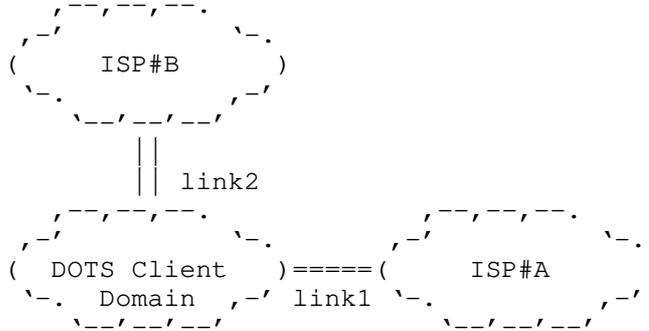
                    Figure 14: Multihomed DOTS Client Domain

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=127"
Content-Format: "application/dots+cbor"

{
  "ietf-dots-telemetry:telemetry-setup": {
    "telemetry": [
      {
        "total-pipe-capacity": [
          {
            "link-id": "link1",
            "capacity": "500",
            "unit": "megabit-ps"
          },
          {
            "link-id": "link2",
            "capacity": "500",
            "unit": "megabit-ps"
          }
        ]
      }
    ]
  }
}
```

      Figure 15: Example of a PUT Request to Convey Pipe Information
                (Multihomed), Depicted as per Section 5.6

A DOTS client can delete a link by sending a PUT request with the
'capacity' attribute set to "0" if other links are still active for
the same DOTS client domain. For example, if a DOTS client domain
re-homes (that is, it changes its ISP), the DOTS client can inform
its DOTS server about this update (e.g., from the network
configuration in Figure 10 to the network configuration shown in
Figure 16) by sending the PUT request depicted in Figure 17. Upon
receipt of this request, and assuming that no error is encountered
when processing the request, the DOTS server removes "link1" from its
configuration bases for this DOTS client domain. Note that if the

DOTS server receives a PUT request with a 'capacity' attribute set to
"0" for all included links, it MUST reject the request with a 4.00
(Bad Request) Response Code. Instead, the DOTS client can use a
DELETE request to delete all links (Section 7.2.3).

```
                    ,--,--,--.
                 ,-'          `-.
                (      ISP#B      )
                 `-.          ,-'
                    `--'--'--'

                       ||
                       || link2
                 ,--,--,--.
                 ,-'          `-.
                (   DOTS Client   )
                 `-.  Domain  ,-'
                    `--'--'--'
```
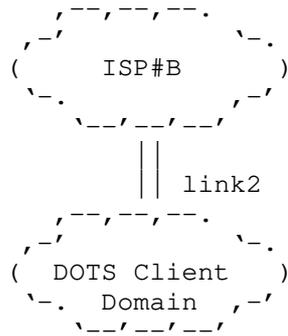
                Figure 16: Multihomed DOTS Client Domain

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=128"
Content-Format: "application/dots+cbor"

{
  "ietf-dots-telemetry:telemetry-setup": {
    "telemetry": [
      {
        "total-pipe-capacity": [
          {
            "link-id": "link1",
            "capacity": "0",
            "unit": "megabit-ps"
          },
          {
            "link-id": "link2",
            "capacity": "500",
            "unit": "megabit-ps"
          }
        ]
      }
    ]
  }
}
```

        Figure 17: Example of a PUT Request to Convey Pipe Information
                (Multihomed), Depicted as per Section 5.6

7.2.2. Retrieving Installed DOTS Client Domain Pipe Capacity

   A GET request with a 'tsid' Uri-Path parameter is used to retrieve
   the specific information related to an installed DOTS client domain
   pipe. The same procedure as that defined in Section 7.1.3 is
   followed.

   To retrieve all pipe information bound to a DOTS client, the DOTS
   client proceeds as specified in Section 7.1.1.

7.2.3. Deleting Installed DOTS Client Domain Pipe Capacity

   A DELETE request is used to delete the specific information related
   to an installed DOTS client domain pipe. The same procedure as that
   defined in Section 7.1.4 is followed.

7.3. Telemetry Baseline

   A DOTS client can communicate to its DOTS server(s) its normal

traffic baseline and connection capacity:

Total traffic normal baseline: Total traffic normal baseline data
   provides the percentile values representing the total traffic
   normal baseline. It can be represented for a target using 'total-
   traffic-normal'.

   The traffic normal per-protocol ('total-traffic-normal-per-
   protocol') baseline is represented for a target and is transport-
   protocol specific.

   The traffic normal per-port-number ('total-traffic-normal-per-
   port') baseline is represented for each port number bound to a
   target.

   If the DOTS client negotiated percentile values and units
   (Section 7.1), these negotiated parameters will be used instead of
   the default parameters. For each unit class used, the DOTS client
   MUST auto-scale so that the appropriate unit is used.

Total connection capacity: If the target is susceptible to resource-
   consuming DDoS attacks, the following optional attributes for the
   target per transport protocol are useful for detecting resource-
   consuming DDoS attacks:

   * The maximum number of simultaneous connections that are allowed
      to the target.

   * The maximum number of simultaneous connections that are allowed
      to the target per client.

   * The maximum number of simultaneous embryonic connections that
      are allowed to the target. The term "embryonic connection"
      refers to a connection whose connection handshake is not
      finished. Embryonic connections are only possible in
      connection-oriented transport protocols like TCP or the Stream
      Control Transmission Protocol (SCTP) [RFC9260].

   * The maximum number of simultaneous embryonic connections that
      are allowed to the target per client.

   * The maximum number of connections allowed per second to the
      target.

   * The maximum number of connections allowed per second to the
      target per client.

   * The maximum number of requests (e.g., HTTP/DNS/SIP requests)
      allowed per second to the target.

   * The maximum number of requests allowed per second to the target
      per client.

   * The maximum number of outstanding partial requests allowed to
      the target. Attacks relying upon partial requests create a
      connection with a target but do not send a complete request
      (e.g., an HTTP request).

   * The maximum number of outstanding partial requests allowed to
      the target per client.

   The aggregate per transport protocol is captured in 'total-
   connection-capacity', while port-specific capabilities are
   represented using 'total-connection-capacity-per-port'.

Note that a target resource is identified using the attributes
'target-prefix', 'target-port-range', 'target-protocol', 'target-
fqdn', 'target-uri', or 'alias-name' as defined in Section 4.4.1.1 of
[RFC9132].

The tree structure of the normal traffic baseline is shown in

```
Figure 18.

structure dots-telemetry:
  +-- (telemetry-message-type)?
    +--:(telemetry-setup)
    |  ...
    |  +-- telemetry* []
    |    +-- (direction)?
    |    |  +--:(server-to-client-only)
    |    |    +-- tsid?                   uint32
    |    +-- (setup-type)?
    |      +--:(telemetry-config)
    |      |  ...
    |      +--:(pipe)
    |      |  ...
    |      +--:(baseline)
    |        +-- baseline* [id]
    |          +-- id                     uint32
    |          +-- target-prefix*
    |          |       inet:ip-prefix
    |          +-- target-port-range* [lower-port]
    |          |  +-- lower-port     inet:port-number
    |          |  +-- upper-port?    inet:port-number
    |          +-- target-protocol*                       uint8
    |          +-- target-fqdn*
    |          |       inet:domain-name
    |          +-- target-uri*
    |          |       inet:uri
    |          +-- alias-name*
    |          |       string
    |          +-- total-traffic-normal* [unit]
    |          |  +-- unit                unit
    |          |  +-- low-percentile-g?   yang:gauge64
    |          |  +-- mid-percentile-g?   yang:gauge64
    |          |  +-- high-percentile-g?  yang:gauge64
    |          |  +-- peak-g?             yang:gauge64
    |          +-- total-traffic-normal-per-protocol*
    |          |       [unit protocol]
    |          |  +-- protocol            uint8
    |          |  +-- unit                unit
    |          |  +-- low-percentile-g?   yang:gauge64
    |          |  +-- mid-percentile-g?   yang:gauge64
    |          |  +-- high-percentile-g?  yang:gauge64
    |          |  +-- peak-g?             yang:gauge64
    |          +-- total-traffic-normal-per-port* [unit port]
    |          |  +-- port                inet:port-number
    |          |  +-- unit                unit
    |          |  +-- low-percentile-g?   yang:gauge64
    |          |  +-- mid-percentile-g?   yang:gauge64
    |          |  +-- high-percentile-g?  yang:gauge64
    |          |  +-- peak-g?             yang:gauge64
    |          +-- total-connection-capacity* [protocol]
    |          |  +-- protocol                    uint8
    |          |  +-- connection?                 uint64
    |          |  +-- connection-client?          uint64
    |          |  +-- embryonic?                  uint64
    |          |  +-- embryonic-client?           uint64
    |          |  +-- connection-ps?              uint64
    |          |  +-- connection-client-ps?       uint64
    |          |  +-- request-ps?                 uint64
    |          |  +-- request-client-ps?          uint64
    |          |  +-- partial-request-max?        uint64
    |          |  +-- partial-request-client-max? uint64
    |          +-- total-connection-capacity-per-port*
    |          |       [protocol port]
    |          |  +-- port
    |          |  |       inet:port-number
    |          |  +-- protocol                    uint8
    |          |  +-- connection?                 uint64
    |          |  +-- connection-client?          uint64
    |          |  +-- embryonic?                  uint64
```

```
                   |                 +-- embryonic-client?          uint64
                   |                 +-- connection-ps?             uint64
                   |                 +-- connection-client-ps?      uint64
                   |                 +-- request-ps?                uint64
                   |                 +-- request-client-ps?         uint64
                   |                 +-- partial-request-max?       uint64
                   |                 +-- partial-request-client-max? uint64
             +--:(telemetry)
                ...
```

              Figure 18: Telemetry Baseline Tree Structure

   A DOTS client can share one or multiple normal traffic baselines
   (e.g., aggregate or per-prefix baselines); each is uniquely
   identified within the DOTS client domain with an identifier ('id').
   This identifier can be used to update a baseline entry, delete a
   specific entry, etc.

7.3.1. Conveying DOTS Client Domain Baseline Information

   Considerations similar to those specified in Section 7.1.2 are
   followed, with one exception:

   *   The relative order of two PUT requests carrying DOTS client domain
       baseline attributes from a DOTS client is determined by comparing
       their respective 'tsid' values. If these two requests have
       overlapping targets, the PUT request with a higher numeric 'tsid'
       value will override the request with a lower numeric 'tsid' value.
       The overlapped lower numeric 'tsid' MUST be automatically deleted
       and no longer be available.

   Two PUT requests from a DOTS client have overlapping targets if there
   is a common IP address, IP prefix, FQDN, URI, or alias name. Also,
   two PUT requests from a DOTS client have overlapping targets from the
   perspective of the DOTS server if the addresses associated with the
   FQDN, URI, or alias are overlapping with each other or with 'target-
   prefix'.

   DOTS clients SHOULD minimize the number of active 'tsid's used for
   baseline information. In order to avoid maintaining a long list of
   'tsid's for baseline information, it is RECOMMENDED that DOTS clients
   include in any request to update information related to a given
   target the information regarding other targets (already communicated
   using a lower 'tsid' value) (assuming that this information fits
   within one single datagram). This update request will override these
   existing requests and hence optimize the number of 'tsid' requests
   per DOTS client.

   If no target attribute is included in the request, this is an
   indication that the baseline information applies for the DOTS client
   domain as a whole.

   An example of a PUT request to convey the baseline information is
   shown in Figure 19.

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tsid=129"
Content-Format: "application/dots+cbor"

{
  "ietf-dots-telemetry:telemetry-setup": {
    "telemetry": [
      {
        "baseline": [
          {
            "id": 1,
            "target-prefix": [
```

```
                "2001:db8:6401::1/128",
                "2001:db8:6401::2/128"
              ],
              "total-traffic-normal": [
                {
                  "unit": "megabit-ps",
                  "peak-g": "60"
                }
              ]
            }
          ]
        }
      ]
    }
  }
}
```

        Figure 19: PUT to Convey DOTS Traffic Baseline Information,
                      Depicted as per Section 5.6

    The DOTS client may share protocol-specific baseline information
    (e.g., TCP and UDP) as shown in Figure 20.

    Header: PUT (Code=0.03)
    Uri-Path: ".well-known"
    Uri-Path: "dots"
    Uri-Path: "tm-setup"
    Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
    Uri-Path: "tsid=130"
    Content-Format: "application/dots+cbor"

```
{
  "ietf-dots-telemetry:telemetry-setup": {
    "telemetry": [
      {
        "baseline": [
          {
            "id": 1,
            "target-prefix": [
              "2001:db8:6401::1/128",
              "2001:db8:6401::2/128"
            ],
            "total-traffic-normal-per-protocol": [
              {
                "unit": "megabit-ps",
                "protocol": 6,
                "peak-g": "50"
              },
              {
                "unit": "megabit-ps",
                "protocol": 17,
                "peak-g": "10"
              }
            ]
          }
        ]
      }
    ]
  }
}
```

      Figure 20: PUT to Convey DOTS Traffic Baseline Information (2),
                      Depicted as per Section 5.6

    The normal traffic baseline information should be updated to reflect
    legitimate overloads (e.g., flash crowds) to prevent unnecessary
    mitigation.

7.3.2. Retrieving Installed Normal Traffic Baseline Information

    A GET request with a 'tsid' Uri-Path parameter is used to retrieve a
    specific installed DOTS client domain's baseline traffic information.

The same procedure as that defined in Section 7.1.3 is followed.

To retrieve all baseline information bound to a DOTS client, the DOTS client proceeds as specified in Section 7.1.1.

7.3.3. Deleting Installed Normal Traffic Baseline Information

A DELETE request is used to delete the installed DOTS client domain's normal traffic baseline information. The same procedure as that defined in Section 7.1.4 is followed.

7.4. Resetting the Installed Telemetry Setup

Upon bootstrapping (or reboot or any other event that may alter the DOTS client setup), a DOTS client MAY send a DELETE request to set the telemetry parameters to default values. Such a request does not include any 'tsid' parameters. An example of such a request is depicted in Figure 21.

```
Header: DELETE (Code=0.04)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm-setup"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
```

Figure 21: Deleting the Telemetry Configuration

7.5. Conflict with Other DOTS Clients of the Same Domain

A DOTS server may detect conflicts between requests conveying pipe and baseline information received from DOTS clients of the same DOTS client domain. 'conflict-information' is used to report the conflict to the DOTS client, following guidelines for conflict handling similar to those discussed in Section 4.4.1 of [RFC9132]. The conflict cause can be set to one of these values:

1: Overlapping targets (Section 4.4.1 of [RFC9132]).

5: Overlapping pipe scope (see Section 13).

8. DOTS Pre-or-Ongoing-Mitigation Telemetry

There are two broad types of DDoS attacks: bandwidth-consuming attacks and target-resource-consuming attacks. This section outlines the set of DOTS telemetry attributes (Section 8.1) that covers both types of attacks. The objective of these attributes is to allow for the complete knowledge of attacks and the various particulars that can best characterize attacks.

The "ietf-dots-telemetry" YANG module (Section 11.1) defines the data structure of a new message type called 'telemetry'. The tree structure of the 'telemetry' message type is shown in Figure 22.

```
  structure dots-telemetry:
    +-- (telemetry-message-type)?
       +--:(telemetry-setup)
       |   ...
       |  +-- telemetry* []
       |     +-- (direction)?
       |     |  +--:(server-to-client-only)
       |     |     +-- tsid?                   uint32
       |     +-- (setup-type)?
       |        +--:(telemetry-config)
       |        |  ...
       |        +--:(pipe)
       |        |  ...
       |        +--:(baseline)
       |           ...
       +--:(telemetry)
          +-- pre-or-ongoing-mitigation* []
             +-- (direction)?
```

```
               │   +--:(server-to-client-only)
               │      +-- tmid?                        uint32
            +-- target
            │  ...
            +-- total-traffic* [unit]
            │  ...
            +-- total-traffic-protocol* [unit protocol]
            │  ...
            +-- total-traffic-port* [unit port]
            │  ...
            +-- total-attack-traffic* [unit]
            │  ...
            +-- total-attack-traffic-protocol* [unit protocol]
            │  ...
            +-- total-attack-traffic-port* [unit port]
            │  ...
            +-- total-attack-connection-protocol* [protocol]
            │  ...
            +-- total-attack-connection-port* [protocol port]
            │  ...
            +-- attack-detail* [vendor-id attack-id]
               ...
```

               Figure 22: Telemetry Message Type Tree Structure

The pre-or-ongoing-mitigation telemetry attributes are indicated by
the path suffix '/tm'. '/tm' is appended to the path prefix to form
the URI used with a CoAP request to signal the DOTS telemetry. Pre-
or-ongoing-mitigation telemetry attributes as specified in
Section 8.1 can be signaled between DOTS agents.

Pre-or-ongoing-mitigation telemetry attributes may be sent by a DOTS
client or a DOTS server.

DOTS agents SHOULD bind pre-or-ongoing-mitigation telemetry data to
mitigation requests associated with the resources under attack. In
particular, a telemetry PUT request sent after a mitigation request
may include a reference to that mitigation request ('mid-list') as
shown in Figure 23. An example illustrating request correlation by
means of 'target-prefix' is shown in Figure 24.

Much of the pre-or-ongoing-mitigation telemetry data uses a unit that
falls under the unit class that is configured following the procedure
described in Section 7.1.2. When generating telemetry data to send
to a peer, the DOTS agent MUST auto-scale so that one or more
appropriate units are used.

```
 +-----------+                              +-----------+
 |DOTS client|                              |DOTS server|
 +-----------+                              +-----------+
      |                                           |
      |==============Mitigation Request (mid)============>|
      |                                           |
      |==============Telemetry (mid-list{mid})============>|
      |                                           |
```
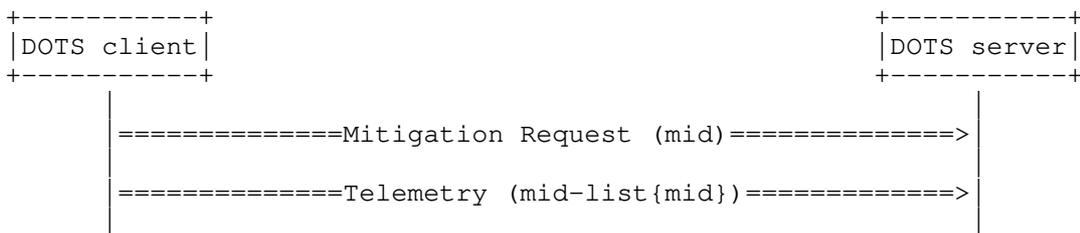
          Figure 23: Example of Request Correlation Using 'mid'

```
 +-----------+                              +-----------+
 |DOTS client|                              |DOTS server|
 +-----------+                              +-----------+
      |                                           |
      |<==============Telemetry (target-prefix)===========|
      |                                           |
      |========Mitigation Request (target-prefix)=========>|
      |                                           |
```
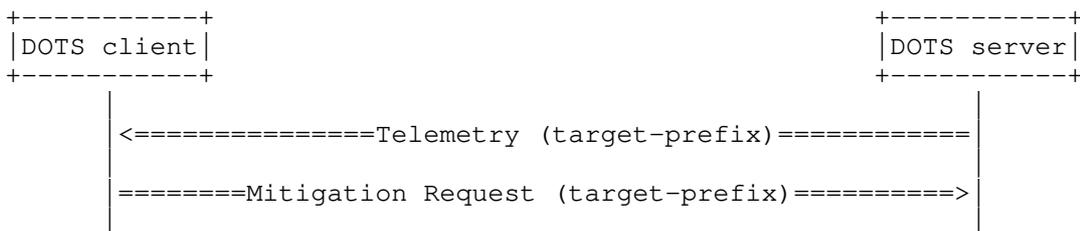
   Figure 24: Example of Request Correlation Using 'target-prefix'

DOTS agents MUST NOT send pre-or-ongoing-mitigation telemetry
notifications to the same peer more frequently than once every

'telemetry-notify-interval' (Section 7.1). If a telemetry
notification is sent using a block-like transfer mechanism (e.g.,
[RFC9177]), this rate-limit policy MUST NOT consider these individual
blocks as separate notifications, but as a single notification.

DOTS pre-or-ongoing-mitigation telemetry request and response
messages MUST be marked as Non-confirmable messages (Section 2.1 of
[RFC7252]).

8.1. Pre-or-Ongoing-Mitigation DOTS Telemetry Attributes

Section 3 discusses the motivation for using the DOTS telemetry
attributes. These attributes are specified in the following
subsections.

8.1.1. Target

A target resource (Figure 25) is identified using the attributes
'target-prefix', 'target-port-range', 'target-protocol', 'target-
fqdn', 'target-uri', 'alias-name', or a pointer to a mitigation
request ('mid-list').

```
      +--:(telemetry)
         +-- pre-or-ongoing-mitigation* []
            +-- (direction)?
            |  +--:(server-to-client-only)
            |     +-- tmid?                    uint32
            +-- target
            |  +-- target-prefix*       inet:ip-prefix
            |  +-- target-port-range* [lower-port]
            |  |  +-- lower-port    inet:port-number
            |  |  +-- upper-port?   inet:port-number
            |  +-- target-protocol*    uint8
            |  +-- target-fqdn*        inet:domain-name
            |  +-- target-uri*         inet:uri
            |  +-- alias-name*         string
            |  +-- mid-list*           uint32
            +-- total-traffic* [unit]
            |  ...
            +-- total-traffic-protocol* [unit protocol]
            |  ...
            +-- total-traffic-port* [unit port]
            |  ...
            +-- total-attack-traffic* [unit]
            |  ...
            +-- total-attack-traffic-protocol* [unit protocol]
            |  ...
            +-- total-attack-traffic-port* [unit port]
            |  ...
            +-- total-attack-connection-protocol* [protocol]
            |  ...
            +-- total-attack-connection-port* [protocol port]
            |  ...
            +-- attack-detail* [vendor-id attack-id]
               ...
```

                   Figure 25: Target Tree Structure

At least one of the attributes 'target-prefix', 'target-fqdn',
'target-uri', 'alias-name', or 'mid-list' MUST be present in the
target definition.

If the target is susceptible to bandwidth-consuming attacks, the
attributes representing the percentile values of the 'attack-id'
attack traffic are included.

If the target is susceptible to resource-consuming DDoS attacks, the
attributes defined in Section 8.1.4 are applicable for representing
the attack.

At least the 'target' attribute and one other pre-or-ongoing-

mitigation attribute MUST be present in the DOTS telemetry message.

8.1.2. Total Traffic

   The 'total-traffic' attribute (Figure 26) conveys the percentile
   values (including peak and current observed values) of the total
   observed traffic. More fine-grained information about the total
   traffic can be conveyed in the 'total-traffic-protocol' and 'total-
   traffic-port' attributes.

   The 'total-traffic-protocol' attribute represents the total traffic
   for a target and is transport-protocol specific.

   The 'total-traffic-port' attribute represents the total traffic for a
   target per port number.

```
         +--:(telemetry)
            +-- pre-or-ongoing-mitigation* []
               +-- (direction)?
               |  +--:(server-to-client-only)
               |     +-- tmid?                      uint32
               +-- target
               |  ...
               +-- total-traffic* [unit]
               |  +-- unit               unit
               |  +-- low-percentile-g?   yang:gauge64
               |  +-- mid-percentile-g?   yang:gauge64
               |  +-- high-percentile-g?  yang:gauge64
               |  +-- peak-g?            yang:gauge64
               |  +-- current-g?         yang:gauge64
               +-- total-traffic-protocol* [unit protocol]
               |  +-- protocol           uint8
               |  +-- unit               unit
               |  +-- low-percentile-g?   yang:gauge64
               |  +-- mid-percentile-g?   yang:gauge64
               |  +-- high-percentile-g?  yang:gauge64
               |  +-- peak-g?            yang:gauge64
               |  +-- current-g?         yang:gauge64
               +-- total-traffic-port* [unit port]
               |  +-- port               inet:port-number
               |  +-- unit               unit
               |  +-- low-percentile-g?   yang:gauge64
               |  +-- mid-percentile-g?   yang:gauge64
               |  +-- high-percentile-g?  yang:gauge64
               |  +-- peak-g?            yang:gauge64
               |  +-- current-g?         yang:gauge64
               +-- total-attack-traffic* [unit]
               |  ...
               +-- total-attack-traffic-protocol* [unit protocol]
               |  ...
               +-- total-attack-traffic-port* [unit port]
               |  ...
               +-- total-attack-connection-protocol* [protocol]
               |  ...
               +-- total-attack-connection-port* [protocol port]
               |  ...
               +-- attack-detail* [vendor-id attack-id]
                  ...
```

                   Figure 26: Total Traffic Tree Structure

8.1.3. Total Attack Traffic

   The 'total-attack-traffic' attribute (Figure 27) conveys the total
   observed attack traffic. More fine-grained information about the
   total attack traffic can be conveyed in the 'total-attack-traffic-
   protocol' and 'total-attack-traffic-port' attributes.

   The 'total-attack-traffic-protocol' attribute represents the total
   attack traffic for a target and is transport-protocol specific.

The 'total-attack-traffic-port' attribute represents the total attack
traffic for a target per port number.

```
+--:(telemetry)
   +-- pre-or-ongoing-mitigation* []
      +-- (direction)?
      |  +--:(server-to-client-only)
      |     +-- tmid?                          uint32
      +-- target
      |  ...
      +-- total-traffic* [unit]
      |  ...
      +-- total-traffic-protocol* [unit protocol]
      |  ...
      +-- total-traffic-port* [unit port]
      |  ...
      +-- total-attack-traffic* [unit]
      |  +-- unit                 unit
      |  +-- low-percentile-g?    yang:gauge64
      |  +-- mid-percentile-g?    yang:gauge64
      |  +-- high-percentile-g?   yang:gauge64
      |  +-- peak-g?              yang:gauge64
      |  +-- current-g?           yang:gauge64
      +-- total-attack-traffic-protocol* [unit protocol]
      |  +-- protocol             uint8
      |  +-- unit                 unit
      |  +-- low-percentile-g?    yang:gauge64
      |  +-- mid-percentile-g?    yang:gauge64
      |  +-- high-percentile-g?   yang:gauge64
      |  +-- peak-g?              yang:gauge64
      |  +-- current-g?           yang:gauge64
      +-- total-attack-traffic-port* [unit port]
      |  +-- port                 inet:port-number
      |  +-- unit                 unit
      |  +-- low-percentile-g?    yang:gauge64
      |  +-- mid-percentile-g?    yang:gauge64
      |  +-- high-percentile-g?   yang:gauge64
      |  +-- peak-g?              yang:gauge64
      |  +-- current-g?           yang:gauge64
      +-- total-attack-connection-protocol* [protocol]
      |  ...
      +-- total-attack-connection-port* [protocol port]
      |  ...
      +-- attack-detail* [vendor-id attack-id]
         ...
```

Figure 27: Total Attack Traffic Tree Structure

8.1.4. Total Attack Connections

If the target is susceptible to resource-consuming DDoS attacks, the
'total-attack-connection-protocol' attribute is used to convey the
percentile values (including peak and current observed values) of
various attributes related to the total attack connections. The
following optional sub-attributes for the target per transport
protocol are included to represent the attack characteristics:

* The number of simultaneous attack connections to the target.

* The number of simultaneous embryonic connections to the target.

* The number of attack connections per second to the target.

* The number of attack requests per second to the target.

* The number of attack partial requests to the target.

The total attack connections per port number are represented using
the 'total-attack-connection-port' attribute.

```
+--:(telemetry)
```

```
      +-- pre-or-ongoing-mitigation* []
         +-- (direction)?
         |  +--:(server-to-client-only)
         |     +-- tmid?                      uint32
         +-- target
         |  ...
         +-- total-traffic* [unit]
         |  ...
         +-- total-traffic-protocol* [unit protocol]
         |  ...
         +-- total-traffic-port* [unit port]
         |  ...
         +-- total-attack-traffic* [unit]
         |  ...
         +-- total-attack-traffic-protocol* [unit protocol]
         |  ...
         +-- total-attack-traffic-port* [unit port]
         |  ...
         +-- total-attack-connection-protocol* [protocol]
         |  +-- protocol              uint8
         |  +-- connection-c
         |  |  +-- low-percentile-g?     yang:gauge64
         |  |  +-- mid-percentile-g?     yang:gauge64
         |  |  +-- high-percentile-g?    yang:gauge64
         |  |  +-- peak-g?               yang:gauge64
         |  |  +-- current-g?            yang:gauge64
         |  +-- embryonic-c
         |  |  +-- low-percentile-g?     yang:gauge64
         |  |  +-- mid-percentile-g?     yang:gauge64
         |  |  +-- high-percentile-g?    yang:gauge64
         |  |  +-- peak-g?               yang:gauge64
         |  |  +-- current-g?            yang:gauge64
         |  +-- connection-ps-c
         |  |  +-- low-percentile-g?     yang:gauge64
         |  |  +-- mid-percentile-g?     yang:gauge64
         |  |  +-- high-percentile-g?    yang:gauge64
         |  |  +-- peak-g?               yang:gauge64
         |  |  +-- current-g?            yang:gauge64
         |  +-- request-ps-c
         |  |  +-- low-percentile-g?     yang:gauge64
         |  |  +-- mid-percentile-g?     yang:gauge64
         |  |  +-- high-percentile-g?    yang:gauge64
         |  |  +-- peak-g?               yang:gauge64
         |  |  +-- current-g?            yang:gauge64
         |  +-- partial-request-c
         |     +-- low-percentile-g?     yang:gauge64
         |     +-- mid-percentile-g?     yang:gauge64
         |     +-- high-percentile-g?    yang:gauge64
         |     +-- peak-g?               yang:gauge64
         |     +-- current-g?            yang:gauge64
         +-- total-attack-connection-port* [protocol port]
         |  +-- protocol              uint8
         |  +-- port                  inet:port-number
         |  +-- connection-c
         |  |  +-- low-percentile-g?     yang:gauge64
         |  |  +-- mid-percentile-g?     yang:gauge64
         |  |  +-- high-percentile-g?    yang:gauge64
         |  |  +-- peak-g?               yang:gauge64
         |  |  +-- current-g?            yang:gauge64
         |  +-- embryonic-c
         |  |  +-- low-percentile-g?     yang:gauge64
         |  |  +-- mid-percentile-g?     yang:gauge64
         |  |  +-- high-percentile-g?    yang:gauge64
         |  |  +-- peak-g?               yang:gauge64
         |  |  +-- current-g?            yang:gauge64
         |  +-- connection-ps-c
         |  |  +-- low-percentile-g?     yang:gauge64
         |  |  +-- mid-percentile-g?     yang:gauge64
         |  |  +-- high-percentile-g?    yang:gauge64
         |  |  +-- peak-g?               yang:gauge64
         |  |  +-- current-g?            yang:gauge64
```

```
                 │     +-- request-ps-c
                 │     │  +-- low-percentile-g?    yang:gauge64
                 │     │  +-- mid-percentile-g?    yang:gauge64
                 │     │  +-- high-percentile-g?   yang:gauge64
                 │     │  +-- peak-g?              yang:gauge64
                 │     │  +-- current-g?           yang:gauge64
                 │     +-- partial-request-c
                 │        +-- low-percentile-g?    yang:gauge64
                 │        +-- mid-percentile-g?    yang:gauge64
                 │        +-- high-percentile-g?   yang:gauge64
                 │        +-- peak-g?              yang:gauge64
                 │        +-- current-g?           yang:gauge64
                 +-- attack-detail* [vendor-id attack-id]
                    ...
```

            Figure 28: Total Attack Connections Tree Structure

8.1.5. Attack Details

   This attribute (depicted in Figure 29) is used to signal a set of
   details characterizing an attack. The following sub-attributes
   describing the ongoing attack can be signaled as attack details:

   vendor-id: Vendor ID. This parameter represents a security vendor's
      enterprise number as registered in the IANA "Private Enterprise
      Numbers" registry [Private-Enterprise-Numbers].

   attack-id: Unique identifier assigned for the attack by a vendor.
      This parameter MUST be present, independently of whether 'attack-
      description' is included or not.

   description-lang: Indicates the language tag that is used for the
      text that is included in the 'attack-description' attribute. This
      attribute is encoded following the rules in Section 2.1 of
      [RFC5646]. The default language tag is "en-US".

   attack-description: Textual representation of the attack
      description. This description is related to the class of attack
      rather than a specific instance of it. Natural Language
      Processing techniques (e.g., word embedding) might provide some
      utility in mapping the attack description to an attack type.
      Textual representation of an attack solves two problems: it avoids
      the need to (a) create mapping tables manually between vendors and
      (b) standardize attack types that keep evolving.

   attack-severity: Attack severity level. This attribute takes one of
      the values defined in Section 3.12.2 of [RFC7970].

   start-time: The time the attack started. The attack's start time is
      expressed in seconds relative to 1970-01-01T00:00Z (Section 3.4.2
      of [RFC8949]). The CBOR encoding is modified so that the leading
      tag 1 (epoch-based date/time) MUST be omitted.

   end-time: The time the attack ended. The attack's end time is
      expressed in seconds relative to 1970-01-01T00:00Z (Section 3.4.2
      of [RFC8949]). The CBOR encoding is modified so that the leading
      tag 1 (epoch-based date/time) MUST be omitted.

   source-count: A count of sources involved in the attack targeting
      the victim.

   top-talker: A list of attack sources that are involved in an attack
      and that are generating an important part of the attack traffic.
      The top talkers are represented using 'source-prefix'.

      'spoofed-status' indicates whether a top talker is a spoofed IP
      address (e.g., reflection attacks) or not. If no 'spoofed-status'
      data node is included, this means that the spoofing status is
      unknown.

      If the target is being subjected to a bandwidth-consuming attack,
```

a statistical profile of the attack traffic from each of the top
talkers is included ('total-attack-traffic'; see Section 8.1.3).

If the target is being subjected to a resource-consuming DDoS
attack, the same attributes as those defined in Section 8.1.4 are
applicable for characterizing the attack on a per-talker basis.

```
    +--:(telemetry)
      +-- pre-or-ongoing-mitigation* []
         +-- (direction)?
         |  +--:(server-to-client-only)
         |     +-- tmid?                      uint32
         +-- target
         |  ...
         +-- total-traffic* [unit]
         |  ...
         +-- total-traffic-protocol* [unit protocol]
         |  ...
         +-- total-traffic-port* [unit port]
         |  ...
         +-- total-attack-traffic* [unit]
         |  ...
         +-- total-attack-traffic-protocol* [unit protocol]
         |  ...
         +-- total-attack-traffic-port* [unit port]
         |  ...
         +-- total-attack-connection-protocol* [protocol]
         |  ...
         +-- total-attack-connection-port* [protocol port]
         |  ...
         +-- attack-detail* [vendor-id attack-id]
            +-- vendor-id            uint32
            +-- attack-id            uint32
            +-- description-lang?    string
            +-- attack-description?  string
            +-- attack-severity?     attack-severity
            +-- start-time?          uint64
            +-- end-time?            uint64
            +-- source-count
            |  +-- low-percentile-g?   yang:gauge64
            |  +-- mid-percentile-g?   yang:gauge64
            |  +-- high-percentile-g?  yang:gauge64
            |  +-- peak-g?             yang:gauge64
            |  +-- current-g?          yang:gauge64
            +-- top-talker
               +-- talker* [source-prefix]
                  +-- spoofed-status?            boolean
                  +-- source-prefix              inet:ip-prefix
                  +-- source-port-range* [lower-port]
                  |  +-- lower-port    inet:port-number
                  |  +-- upper-port?   inet:port-number
                  +-- source-icmp-type-range* [lower-type]
                  |  +-- lower-type   uint8
                  |  +-- upper-type?  uint8
                  +-- total-attack-traffic* [unit]
                  |  +-- unit                unit
                  |  +-- low-percentile-g?   yang:gauge64
                  |  +-- mid-percentile-g?   yang:gauge64
                  |  +-- high-percentile-g?  yang:gauge64
                  |  +-- peak-g?             yang:gauge64
                  |  +-- current-g?          yang:gauge64
                  +-- total-attack-connection-protocol*
                          [protocol]
                     +-- protocol             uint8
                     +-- connection-c
                     |  +-- low-percentile-g?   yang:gauge64
                     |  +-- mid-percentile-g?   yang:gauge64
                     |  +-- high-percentile-g?  yang:gauge64
                     |  +-- peak-g?             yang:gauge64
                     |  +-- current-g?          yang:gauge64
                     +-- embryonic-c
```

```
                          |  +-- low-percentile-g?      yang:gauge64
                          |  +-- mid-percentile-g?      yang:gauge64
                          |  +-- high-percentile-g?     yang:gauge64
                          |  +-- peak-g?                yang:gauge64
                          |  +-- current-g?             yang:gauge64
                          +-- connection-ps-c
                          |  +-- low-percentile-g?      yang:gauge64
                          |  +-- mid-percentile-g?      yang:gauge64
                          |  +-- high-percentile-g?     yang:gauge64
                          |  +-- peak-g?                yang:gauge64
                          |  +-- current-g?             yang:gauge64
                          +-- request-ps-c
                          |  +-- low-percentile-g?      yang:gauge64
                          |  +-- mid-percentile-g?      yang:gauge64
                          |  +-- high-percentile-g?     yang:gauge64
                          |  +-- peak-g?                yang:gauge64
                          |  +-- current-g?             yang:gauge64
                          +-- partial-request-c
                             +-- low-percentile-g?      yang:gauge64
                             +-- mid-percentile-g?      yang:gauge64
                             +-- high-percentile-g?     yang:gauge64
                             +-- peak-g?                yang:gauge64
                             +-- current-g?             yang:gauge64
```

                  Figure 29: Attack Details Tree Structure

   In order to optimize the size of telemetry data conveyed over the
   DOTS signal channel, DOTS agents MAY use the DOTS data channel
   [RFC8783] to exchange vendor-specific attack mapping details (that
   is, {vendor identifier, attack identifier} ==> textual representation
   of the attack description). As such, DOTS agents do not have to
   convey an attack description systematically in their telemetry
   messages over the DOTS signal channel. Refer to Section 8.1.6.

8.1.6. Vendor Attack Mapping

   Multiple mappings for different vendor identifiers may be used; the
   DOTS agent transmitting telemetry information can elect to use one or
   more vendor mappings even in the same telemetry message.

   | Note: It is possible that a DOTS server is making use of
   | multiple DOTS mitigators, each from a different vendor. How
   | telemetry information and vendor mappings are exchanged between
   | DOTS servers and DOTS mitigators is outside the scope of this
   | document.

   DOTS clients and servers may be provided with mappings from different
   vendors and so have their own different sets of vendor attack
   mappings. A DOTS agent MUST accept receipt of telemetry data with a
   vendor identifier that is different than the identifier it uses to
   transmit telemetry data. Furthermore, it is possible that the DOTS
   client and DOTS server are provided by the same vendor but the vendor
   mapping tables are at different revisions. The DOTS client SHOULD
   transmit telemetry information using any vendor mapping(s) that it
   provided to the DOTS server (e.g., using a POST as depicted in
   Figure 30), and the DOTS server SHOULD use any vendor mappings(s)
   provided to the DOTS client when transmitting telemetry data to the
   peer DOTS agent.

   POST /restconf/data/ietf-dots-data-channel:dots-data\
        /dots-client=dz6pHjaADkaFTbjr0JGBpw HTTP/1.1
   Host: example.com
   Content-Type: application/yang-data+json

   {
     "ietf-dots-mapping:vendor-mapping": {
       "vendor": [
         {
           "vendor-id": 345,
           "vendor-name": "mitigator-c",
           "last-updated": "1629898958",
```

```
          "attack-mapping": [
            {
              "attack-id": 1,
              "attack-description":
                "Include a description of this attack"
            },
            {
              "attack-id": 2,
              "attack-description":
                "Again, include a description of the attack"
            }
          ]
        }
      ]
    }
}
```

                Figure 30: POST to Install Vendor Attack Mapping Details

The "ietf-dots-mapping" YANG module defined in Section 11.2 augments
the "ietf-dots-data-channel" module [RFC8783]. The tree structure of
the "ietf-dots-mapping" module is shown in Figure 31.

```
module: ietf-dots-mapping
  augment /data-channel:dots-data/data-channel:dots-client:
    +--rw vendor-mapping {dots-telemetry}?
       +--rw vendor* [vendor-id]
          +--rw vendor-id          uint32
          +--rw vendor-name?       string
          +--rw description-lang?  string
          +--rw last-updated       uint64
          +--rw attack-mapping* [attack-id]
             +--rw attack-id           uint32
             +--rw attack-description  string
  augment /data-channel:dots-data/data-channel:capabilities:
    +--ro vendor-mapping-enabled?  boolean {dots-telemetry}?
  augment /data-channel:dots-data:
    +--ro vendor-mapping {dots-telemetry}?
       +--ro vendor* [vendor-id]
          +--ro vendor-id          uint32
          +--ro vendor-name?       string
          +--ro description-lang?  string
          +--ro last-updated       uint64
          +--ro attack-mapping* [attack-id]
             +--ro attack-id           uint32
             +--ro attack-description  string
```

                Figure 31: Vendor Attack Mapping Tree Structure

A DOTS client sends a GET request over the DOTS data channel to
retrieve the capabilities supported by a DOTS server as per
Section 7.1 of [RFC8783]. This request is meant to assess whether
the capability of sharing vendor attack mapping details is supported
by the server (i.e., check the value of 'vendor-mapping-enabled').

If 'vendor-mapping-enabled' is set to 'true', a DOTS client MAY send
a GET request to retrieve the DOTS server's vendor attack mapping
details. An example of such a GET request is shown in Figure 32.

```
GET /restconf/data/ietf-dots-data-channel:dots-data\
    /ietf-dots-mapping:vendor-mapping HTTP/1.1
Host: example.com
Accept: application/yang-data+json
```

      Figure 32: GET to Retrieve the Vendor Attack Mappings of a DOTS
                                 Server

A DOTS client can retrieve only the list of vendors supported by the
DOTS server. It does so by setting the "depth" parameter
(Section 4.8.2 of [RFC8040]) to "3" in the GET request as shown in
Figure 33. An example of a response body received from the DOTS

server as a response to such a request is illustrated in Figure 34.

```
GET /restconf/data/ietf-dots-data-channel:dots-data\
    /ietf-dots-mapping:vendor-mapping?depth=3 HTTP/1.1
Host: example.com
Accept: application/yang-data+json
```

   Figure 33: GET to Retrieve the Vendors List Used by a DOTS Server

```
{
  "ietf-dots-mapping:vendor-mapping": {
    "vendor": [
      {
        "vendor-id": 32473,
        "vendor-name": "mitigator-s",
        "last-updated": "1629898758",
        "attack-mapping": []
      }
    ]
  }
}
```

   Figure 34: Response Message Body to a GET to Retrieve the Vendors
                        List Used by a DOTS Server

The DOTS client repeats the above procedure regularly (e.g., once a
week) to update the DOTS server's vendor attack mapping details.

If the DOTS client concludes that the DOTS server does not have any
reference to the specific vendor attack mapping details, the DOTS
client uses a POST request to install its vendor attack mapping
details. An example of such a POST request is depicted in Figure 30.

The DOTS server indicates the result of processing the POST request
using the status-line. A "201 Created" status-line MUST be returned
in the response if the DOTS server has accepted the vendor attack
mapping details. If the request is missing a mandatory attribute or
contains an invalid or unknown parameter, a "400 Bad Request" status-
line MUST be returned by the DOTS server in the response. The error-
tag is set to "missing-attribute", "invalid-value", or "unknown-
element" as a function of the encountered error.

If the request is received via a server-domain DOTS gateway but the
DOTS server does not maintain a 'cdid' for this 'cuid' while a 'cdid'
is expected to be supplied, the DOTS server MUST reply with a "403
Forbidden" status-line and the error-tag "access-denied". Upon
receipt of this message, the DOTS client MUST register (Section 5.1
of [RFC8783]).

The DOTS client uses the PUT request to modify its vendor attack
mapping details maintained by the DOTS server (e.g., add a new
mapping entry, update an existing mapping).

A DOTS client uses a GET request to retrieve its vendor attack
mapping details as maintained by the DOTS server (Figure 35).

```
GET /restconf/data/ietf-dots-data-channel:dots-data\
    /dots-client=dz6pHjaADkaFTbjr0JGBpw\
    /ietf-dots-mapping:vendor-mapping?\
    content=all HTTP/1.1
Host: example.com
Accept: application/yang-data+json
```

   Figure 35: GET to Retrieve Installed Vendor Attack Mapping Details

When conveying attack details in DOTS telemetry messages
(Sections 8.2, 8.3, and 9), DOTS agents MUST NOT include the 'attack-
description' attribute unless the corresponding attack mapping
details were not previously shared with the peer DOTS agent.

8.2. From DOTS Clients to DOTS Servers

DOTS clients use PUT requests to signal pre-or-ongoing-mitigation
telemetry to DOTS servers. An example of such a request is shown in
Figure 36.

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tmid=123"
Content-Format: "application/dots+cbor"

{
  "ietf-dots-telemetry:telemetry": {
    "pre-or-ongoing-mitigation": [
      {
        "target": {
          "target-prefix": [
            "2001:db8::1/128"
          ]
        },
        "total-attack-traffic-protocol": [
          {
            "protocol": 17,
            "unit": "megabit-ps",
            "mid-percentile-g": "900"
          }
        ],
        "attack-detail": [
          {
            "vendor-id": 32473,
            "attack-id": 77,
            "start-time": "1608336568",
            "attack-severity": "high"
          }
        ]
      }
    ]
  }
}
```

       Figure 36: PUT to Send Pre-or-Ongoing-Mitigation Telemetry,
                     Depicted as per Section 5.6

'cuid' is a mandatory Uri-Path parameter for DOTS PUT requests.

The following additional Uri-Path parameter is defined:

tmid: The Telemetry Identifier is an identifier for the DOTS pre-or-
   ongoing-mitigation telemetry data represented as an integer. This
   identifier MUST be generated by DOTS clients. 'tmid' values MUST
   increase monotonically whenever a DOTS client needs to convey a
   new set of pre-or-ongoing-mitigation telemetry data.

   The procedure specified in Section 4.4.1 of [RFC9132] for 'mid'
   rollover MUST be followed for 'tmid' rollover.

   This is a mandatory attribute. 'tmid' MUST appear after 'cuid' in
   the Uri-Path options.

'cuid' and 'tmid' MUST NOT appear in the PUT request message body.

At least the 'target' attribute and another pre-or-ongoing-mitigation
attribute (Section 8.1) MUST be present in the PUT request. If only
the 'target' attribute is present, this request is handled as per
Section 8.3.

The relative order of two PUT requests carrying DOTS pre-or-ongoing-
mitigation telemetry from a DOTS client is determined by comparing
their respective 'tmid' values. If these two requests have an

overlapping 'target', the PUT request with a higher numeric 'tmid' value will override the request with a lower numeric 'tmid' value. The overlapped lower numeric 'tmid' MUST be automatically deleted and no longer be available.

The DOTS server indicates the result of processing a PUT request using CoAP Response Codes. In particular, the 2.04 (Changed) Response Code is returned if the DOTS server has accepted the pre-or-ongoing-mitigation telemetry. The 5.03 (Service Unavailable) Response Code is returned if the DOTS server has erred. The 5.03 Response Code uses the Max-Age Option to indicate the number of seconds after which to retry.

How long a DOTS server maintains a 'tmid' as active or logs the enclosed telemetry information is implementation specific. Note that if a 'tmid' is still active, then logging details are updated by the DOTS server as a function of the updates received from the peer DOTS client.

A DOTS client that lost the state of its active 'tmid's or has to set 'tmid' back to zero (e.g., crash or restart) MUST send a GET request to the DOTS server to retrieve the list of active 'tmid' values. The DOTS client may then delete 'tmid's that should not be active anymore (Figure 37). Sending a DELETE with no 'tmid' indicates that all 'tmid's must be deactivated (Figure 38).

```
Header: DELETE (Code=0.04)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tmid=123"
```

      Figure 37: Deleting Specific Pre-or-Ongoing-Mitigation Telemetry
                                Information

```
Header: DELETE (Code=0.04)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
```

        Figure 38: Deleting All Pre-or-Ongoing-Mitigation Telemetry
                                Information

8.3. From DOTS Servers to DOTS Clients

   The pre-or-ongoing-mitigation data (attack details in particular) can
   also be signaled from DOTS servers to DOTS clients. For example, a
   DOTS server co-located with a DDoS detector can collect monitoring
   information from the target network, identify a DDoS attack using
   statistical analysis or deep learning techniques, and signal the
   attack details to the DOTS client.

   The DOTS client can use the attack details to decide whether to
   trigger a DOTS mitigation request or not. Furthermore, the security
   operations personnel at the DOTS client domain can use the attack
   details to determine the protection strategy and select the
   appropriate DOTS server for mitigating the attack.

   In order to receive pre-or-ongoing-mitigation telemetry notifications
   from a DOTS server, a DOTS client MUST send a PUT (followed by a GET)
   with the target filter. An example of such a PUT request is shown in
   Figure 39. In order to avoid maintaining a long list of such
   requests, it is RECOMMENDED that DOTS clients include all targets in
   the same request (assuming that this information fits within one
   single datagram). DOTS servers may be instructed to restrict the
   number of pre-or-ongoing-mitigation requests per DOTS client domain.
   The pre-or-ongoing-mitigation requests MUST be maintained in an
   active state by the DOTS server until a DELETE request is received
   from the same DOTS client to clear this pre-or-ongoing-mitigation

telemetry or when the DOTS client is considered inactive (e.g.,
Section 3.5 of [RFC8783]).

The relative order of two PUT requests carrying DOTS pre-or-ongoing-
mitigation telemetry from a DOTS client is determined by comparing
their respective 'tmid' values. If these two requests have an
overlapping 'target', the PUT request with a higher numeric 'tmid'
value will override the request with a lower numeric 'tmid' value.
The overlapped lower numeric 'tmid' MUST be automatically deleted and
no longer be available.

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tmid=567"
Content-Format: "application/dots+cbor"

{
  "ietf-dots-telemetry:telemetry": {
    "pre-or-ongoing-mitigation": [
      {
        "target": {
          "target-prefix": [
            "2001:db8::/32"
          ]
        }
      }
    ]
  }
}
```

          Figure 39: PUT to Request Pre-or-Ongoing-Mitigation Telemetry,
                        Depicted as per Section 5.6

DOTS clients of the same domain can ask to receive pre-or-ongoing-
mitigation telemetry bound to the same target without being
considered to be "overlapping" and in conflict.

Once the PUT request to instantiate request state on the server has
succeeded, the DOTS client issues a GET request to receive ongoing
telemetry updates. The client uses the Observe Option, set to "0"
(register), in the GET request to receive asynchronous notifications
carrying pre-or-ongoing-mitigation telemetry data from the DOTS
server. The GET request can specify a specific 'tmid' (Figure 40) or
omit the 'tmid' (Figure 41) to receive updates on all active requests
from that client.

```
Header: GET (Code=0.01)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "tmid=567"
Observe: 0
```

          Figure 40: GET to Subscribe to Telemetry Asynchronous
                    Notifications for a Specific 'tmid'

```
Header: GET (Code=0.01)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Observe: 0
```

          Figure 41: GET to Subscribe to Telemetry Asynchronous
                      Notifications for All 'tmid's

The DOTS client can use a filter to request a subset of the

asynchronous notifications from the DOTS server by indicating one or
more Uri-Query options in its GET request. A Uri-Query option can
include the following parameters to restrict the notifications based
on the attack target: 'target-prefix', 'target-port', 'target-
protocol', 'target-fqdn', 'target-uri', 'alias-name', 'mid', and 'c'
(content) (Section 5.4). Furthermore:

* If more than one Uri-Query option is included in a request, these
   options are interpreted in the same way as when multiple target
   attributes are included in a message body (Section 4.4.1 of
   [RFC9132]).

* If multiple values of a query parameter are to be included in a
   request, these values MUST be included in the same Uri-Query
   option and separated by a "," character without any spaces.

* Range values (i.e., a contiguous inclusive block) can be included
   for the 'target-port', 'target-protocol', and 'mid' parameters by
   indicating the two boundary values separated by a "-" character.

* Wildcard names (i.e., a name with the leftmost label is the "*"
   character) can be included in 'target-fqdn' or 'target-uri'
   parameters. DOTS clients MUST NOT include a name in which the "*"
   character is included in a label other than the leftmost label.
   "*.example.com" is an example of a valid wildcard name that can be
   included as a value of the 'target-fqdn' parameter in a Uri-Query
   option.

DOTS clients may also filter out the asynchronous notifications from
the DOTS server by indicating information about a specific attack
source. To that aim, a DOTS client may include 'source-prefix',
'source-port', or 'source-icmp-type' in a Uri-Query option. The same
considerations (ranges, multiple values) specified for target
attributes apply for source attributes. Special care SHOULD be taken
when using these filters, as their use may cause some attacks to be
hidden from the requesting DOTS client (e.g., if the attack changes
its source information).

Requests with invalid query types (e.g., not supported, malformed)
received by the DOTS server MUST be rejected with a 4.00 (Bad
Request) Response Code.

An example of a request to subscribe to asynchronous telemetry
notifications regarding UDP traffic is shown in Figure 42. This
filter will be applied for all 'tmid's.

Header: GET (Code=0.01)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "tm"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Query: "target-protocol=17"
Observe: 0

        Figure 42: GET Request to Receive Telemetry Asynchronous
                 Notifications Filtered Using Uri-Query

The DOTS server will send asynchronous notifications to the DOTS
client when an attack event is detected, following considerations
similar to those discussed in Section 4.4.2.1 of [RFC9132]. An
example of a pre-or-ongoing-mitigation telemetry notification is
shown in Figure 43.

```
{
  "ietf-dots-telemetry:telemetry": {
    "pre-or-ongoing-mitigation": [
      {
        "tmid": 567,
        "target": {
          "target-prefix": [
            "2001:db8::1/128"
```

```
          ]
        },
        "target-protocol": [
          17
        ],
        "total-attack-traffic": [
          {
            "unit": "megabit-ps",
            "mid-percentile-g": "900"
          }
        ],
        "attack-detail": [
          {
            "vendor-id": 32473,
            "attack-id": 77,
            "start-time": "1618339785",
            "attack-severity": "high"
          }
        ]
      }
    ]
  }
}
```

   Figure 43: Message Body of a Pre-or-Ongoing-Mitigation Telemetry
     Notification from the DOTS Server, Depicted as per Section 5.6

   A DOTS server sends the aggregate data for a target using the 'total-
   attack-traffic' attribute. The aggregate assumes that Uri-Query
   filters are applied on the target. The DOTS server MAY include more
   fine-grained data when needed (that is, 'total-attack-traffic-
   protocol' and 'total-attack-traffic-port'). If a port filter (or
   protocol filter) is included in a request, 'total-attack-traffic-
   protocol' (or 'total-attack-traffic-port') conveys the data with the
   port (or protocol) filter applied.

   A DOTS server may aggregate pre-or-ongoing-mitigation data (e.g.,
   'top-talker') for all targets of a domain or, when justified, send
   specific information (e.g., 'top-talker') for a specific target.

   The DOTS client may log pre-or-ongoing-mitigation telemetry data with
   an alert sent to an administrator or a network controller. The DOTS
   client may send a mitigation request if the attack cannot be handled
   locally.

   A DOTS client that is not interested in receiving pre-or-ongoing-
   mitigation telemetry data for a target sends a DELETE request similar
   to the DELETE request depicted in Figure 37.

9. DOTS Telemetry Mitigation Status Update

9.1. From DOTS Clients to DOTS Servers: Mitigation Efficacy DOTS
      Telemetry Attributes

   The mitigation efficacy telemetry attributes can be signaled from
   DOTS clients to DOTS servers as part of the periodic mitigation
   efficacy updates to the server (Section 4.4.3 of [RFC9132]).

   Total attack traffic: The overall attack traffic as observed from
      the DOTS client's perspective during an active mitigation. See
      Figure 27.

   Attack details: The overall attack details as observed from the DOTS
      client's perspective during an active mitigation. See
      Section 8.1.5.

   The "ietf-dots-telemetry" YANG module (Section 11.1) augments the
   'mitigation-scope' message type defined in the "ietf-dots-signal-
   channel" module [RFC9132] so that these attributes can be signaled by
   a DOTS client in a mitigation efficacy update (Figure 44).

```
   augment-structure /dots-signal:dots-signal/dots-signal:message-type
                     /dots-signal:mitigation-scope/dots-signal:scope:
     +-- total-attack-traffic* [unit]
     |  +-- unit                   unit
     |  +-- low-percentile-g?      yang:gauge64
     |  +-- mid-percentile-g?      yang:gauge64
     |  +-- high-percentile-g?     yang:gauge64
     |  +-- peak-g?                yang:gauge64
     |  +-- current-g?             yang:gauge64
     +-- attack-detail* [vendor-id attack-id]
        +-- vendor-id             uint32
        +-- attack-id             uint32
        +-- attack-description?   string
        +-- attack-severity?      attack-severity
        +-- start-time?           uint64
        +-- end-time?             uint64
        +-- source-count
        |  +-- low-percentile-g?      yang:gauge64
        |  +-- mid-percentile-g?      yang:gauge64
        |  +-- high-percentile-g?     yang:gauge64
        |  +-- peak-g?                yang:gauge64
        |  +-- current-g?             yang:gauge64
        +-- top-talker
           +-- talker* [source-prefix]
              +-- spoofed-status?             boolean
              +-- source-prefix              inet:ip-prefix
              +-- source-port-range* [lower-port]
              |  +-- lower-port    inet:port-number
              |  +-- upper-port?   inet:port-number
              +-- source-icmp-type-range* [lower-type]
              |  +-- lower-type    uint8
              |  +-- upper-type?   uint8
              +-- total-attack-traffic* [unit]
              |  +-- unit                   unit
              |  +-- low-percentile-g?      yang:gauge64
              |  +-- mid-percentile-g?      yang:gauge64
              |  +-- high-percentile-g?     yang:gauge64
              |  +-- peak-g?                yang:gauge64
              |  +-- current-g?             yang:gauge64
              +-- total-attack-connection
                 +-- connection-c
                 |  +-- low-percentile-g?    yang:gauge64
                 |  +-- mid-percentile-g?    yang:gauge64
                 |  +-- high-percentile-g?   yang:gauge64
                 |  +-- peak-g?              yang:gauge64
                 |  +-- current-g?           yang:gauge64
                 +-- embryonic-c
                 |  ...
                 +-- connection-ps-c
                 |  ...
                 +-- request-ps-c
                 |  ...
                 +-- partial-request-c
                    ...
```

               Figure 44: Telemetry Efficacy Update Tree Structure

In order to signal telemetry data in a mitigation efficacy update, it
is RECOMMENDED that the DOTS client have already established a DOTS
telemetry setup session with the server in 'idle' time. Such a
session is primarily meant to assess whether the peer DOTS server
supports telemetry extensions and to thus prevent message processing
failure (Section 3.1 of [RFC9132]).

An example of an efficacy update with telemetry attributes is
depicted in Figure 45.

```
Header: PUT (Code=0.03)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "mitigate"
```

```
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "mid=123"
If-Match:
Content-Format: "application/dots+cbor"

{
  "ietf-dots-signal-channel:mitigation-scope": {
    "scope": [
      {
        "alias-name": [
          "https1",
          "https2"
        ],
        "attack-status": "under-attack",
        "ietf-dots-telemetry:total-attack-traffic": [
          {
            "unit": "megabit-ps",
            "mid-percentile-g": "900"
          }
        ]
      }
    ]
  }
}
```

Figure 45: Example of Mitigation Efficacy Update with Telemetry
Attributes, Depicted as per Section 5.6

9.2. From DOTS Servers to DOTS Clients: Mitigation Status DOTS
      Telemetry Attributes

   The mitigation status telemetry attributes can be signaled from the
   DOTS server to the DOTS client as part of the periodic mitigation
   status update (Section 4.4.2 of [RFC9132]). In particular, DOTS
   clients can receive asynchronous notifications of the attack details
   from DOTS servers using the Observe Option defined in [RFC7641].

   In order to make use of this feature, DOTS clients MUST establish a
   telemetry session with the DOTS server in 'idle' time and MUST set
   the 'server-originated-telemetry' attribute to 'true'.

   DOTS servers MUST NOT include telemetry attributes in mitigation
   status updates sent to DOTS clients for telemetry sessions in which
   the 'server-originated-telemetry' attribute is set to 'false'.

   As defined in [RFC8612], the actual mitigation activities can include
   several countermeasure mechanisms. The DOTS server signals the
   current operational status of relevant countermeasures. A list of
   attacks detected by these countermeasures MAY also be included. The
   same attributes as those defined in Section 8.1.5 are applicable for
   describing the attacks detected and mitigated at the DOTS server
   domain.

   The "ietf-dots-telemetry" YANG module (Section 11.1) augments the
   'mitigation-scope' message type defined in the "ietf-dots-signal-
   channel" module [RFC9132] with telemetry data as depicted in
   Figure 46.

```
     augment-structure /dots-signal:dots-signal/dots-signal:message-type
                       /dots-signal:mitigation-scope/dots-signal:scope:
       +-- (direction)?
       |  +--:(server-to-client-only)
       |     +-- total-traffic* [unit]
       |     |  +-- unit                 unit
       |     |  +-- low-percentile-g?    yang:gauge64
       |     |  +-- mid-percentile-g?    yang:gauge64
       |     |  +-- high-percentile-g?   yang:gauge64
       |     |  +-- peak-g?              yang:gauge64
       |     |  +-- current-g?           yang:gauge64
       |     +-- total-attack-connection
       |        +-- connection-c
```

```
   |         |        +-- low-percentile-g?    yang:gauge64
   |         |        +-- mid-percentile-g?    yang:gauge64
   |         |        +-- high-percentile-g?   yang:gauge64
   |         |        +-- peak-g?              yang:gauge64
   |         |        +-- current-g?           yang:gauge64
   |         +-- embryonic-c
   |         |   ...
   |         +-- connection-ps-c
   |         |   ...
   |         +-- request-ps-c
   |         |   ...
   |         +-- partial-request-c
   |             ...
   +-- total-attack-traffic* [unit]
   |   +-- unit                 unit
   |   +-- low-percentile-g?    yang:gauge64
   |   +-- mid-percentile-g?    yang:gauge64
   |   +-- high-percentile-g?   yang:gauge64
   |   +-- peak-g?              yang:gauge64
   |   +-- current-g?           yang:gauge64
   +-- attack-detail* [vendor-id attack-id]
       +-- vendor-id            uint32
       +-- attack-id            uint32
       +-- attack-description?   string
       +-- attack-severity?     attack-severity
       +-- start-time?          uint64
       +-- end-time?            uint64
       +-- source-count
       |   +-- low-percentile-g?    yang:gauge64
       |   +-- mid-percentile-g?    yang:gauge64
       |   +-- high-percentile-g?   yang:gauge64
       |   +-- peak-g?              yang:gauge64
       |   +-- current-g?           yang:gauge64
       +-- top-talker
           +-- talker* [source-prefix]
               +-- spoofed-status?            boolean
               +-- source-prefix              inet:ip-prefix
               +-- source-port-range* [lower-port]
               |   +-- lower-port     inet:port-number
               |   +-- upper-port?    inet:port-number
               +-- source-icmp-type-range* [lower-type]
               |   +-- lower-type    uint8
               |   +-- upper-type?   uint8
               +-- total-attack-traffic* [unit]
               |   +-- unit                 unit
               |   +-- low-percentile-g?    yang:gauge64
               |   +-- mid-percentile-g?    yang:gauge64
               |   +-- high-percentile-g?   yang:gauge64
               |   +-- peak-g?              yang:gauge64
               |   +-- current-g?           yang:gauge64
               +-- total-attack-connection
                   +-- connection-c
                   |   +-- low-percentile-g?    yang:gauge64
                   |   +-- mid-percentile-g?    yang:gauge64
                   |   +-- high-percentile-g?   yang:gauge64
                   |   +-- peak-g?              yang:gauge64
                   |   +-- current-g?           yang:gauge64
                   +-- embryonic-c
                   |   ...
                   +-- connection-ps-c
                   |   ...
                   +-- request-ps-c
                   |   ...
                   +-- partial-request-c
                       ...
```

           Figure 46: DOTS Server-to-Client Mitigation Status Telemetry Tree
                                  Structure

   Figure 47 shows an example of an asynchronous notification of attack
   mitigation status from the DOTS server. This notification signals

both the mid-percentile value of processed attack traffic and the
peak count of unique sources involved in the attack.

```
{
  "ietf-dots-signal-channel:mitigation-scope": {
    "scope": [
      {
        "mid": 12332,
        "mitigation-start": "1507818434",
        "alias-name": [
          "https1",
          "https2"
        ],
        "lifetime": 1600,
        "status": "attack-successfully-mitigated",
        "bytes-dropped": "134334555",
        "bps-dropped": "43344",
        "pkts-dropped": "333334444",
        "pps-dropped": "432432",
        "ietf-dots-telemetry:total-attack-traffic": [
          {
            "unit": "megabit-ps",
            "mid-percentile-g": "752"
          }
        ],
        "ietf-dots-telemetry:attack-detail": [
          {
            "vendor-id": 32473,
            "attack-id": 77,
            "source-count": {
              "peak-g": "12683"
            }
          }
        ]
      }
    ]
  }
}
```

        Figure 47: Response Body of a Mitigation Status with Telemetry
                  Attributes, Depicted as per Section 5.6

DOTS clients can filter out the asynchronous notifications from the
DOTS server by indicating one or more Uri-Query options in its GET
request. A Uri-Query option can include the following parameters:
'target-prefix', 'target-port', 'target-protocol', 'target-fqdn',
'target-uri', 'alias-name', and 'c' (content) (Section 5.4). The
considerations discussed in Section 8.3 MUST be followed to include
multiple query values, ranges ('target-port', 'target-protocol'), and
wildcard names ('target-fqdn', 'target-uri').

An example of a request to subscribe to asynchronous notifications
bound to the "https1" alias is shown in Figure 48.

```
Header: GET (Code=0.01)
Uri-Path: ".well-known"
Uri-Path: "dots"
Uri-Path: "mitigate"
Uri-Path: "cuid=dz6pHjaADkaFTbjr0JGBpw"
Uri-Path: "mid=12332"
Uri-Query: "target-alias=https1"
Observe: 0
```

        Figure 48: GET Request to Receive Asynchronous Notifications
                          Filtered Using Uri-Query

If the target query does not match the target of the enclosed 'mid'
as maintained by the DOTS server, the latter MUST respond with a 4.04
(Not Found) error Response Code. The DOTS server MUST NOT add a new
Observe entry if this query overlaps with an existing Observe entry.
In such a case, the DOTS server replies with a 4.09 (Conflict)

Response Code.

10. Error Handling

   A list of common CoAP errors that are implemented by DOTS servers is
   provided in Section 9 of [RFC9132]. The following additional error
   cases apply for the telemetry extension:

   * 4.00 (Bad Request) is returned by the DOTS server when the DOTS
      client has sent a request that violates the DOTS telemetry
      extension.

   * 4.04 (Not Found) is returned by the DOTS server when the DOTS
      client is requesting a 'tsid' or 'tmid' that is not valid.

   * 4.00 (Bad Request) is returned by the DOTS server when the DOTS
      client has sent a request with invalid query types (e.g., not
      supported, malformed).

   * 4.04 (Not Found) is returned by the DOTS server when the DOTS
      client has sent a request with a target query that does not match
      the target of the enclosed 'mid' as maintained by the DOTS server.

   As indicated in Section 9 of [RFC9132], an additional plaintext
   diagnostic payload (Section 5.5.2 of [RFC7252]) to help with
   troubleshooting is returned in the body of the response.

11. YANG Modules

11.1. DOTS Signal Channel Telemetry YANG Module

   This module uses types defined in [RFC6991] and [RFC8345]. It also
   reuses a grouping from [RFC8783].

```
   <CODE BEGINS> file "ietf-dots-telemetry@2022-06-20.yang"
   module ietf-dots-telemetry {
     yang-version 1.1;
     namespace "urn:ietf:params:xml:ns:yang:ietf-dots-telemetry";
     prefix dots-telemetry;

     import ietf-dots-signal-channel {
       prefix dots-signal;
       reference
         "RFC 9132: Distributed Denial-of-Service Open Threat
                    Signaling (DOTS) Signal Channel Specification";
     }
     import ietf-dots-data-channel {
       prefix data-channel;
       reference
         "RFC 8783: Distributed Denial-of-Service Open Threat
                    Signaling (DOTS) Data Channel Specification";
     }
     import ietf-yang-types {
       prefix yang;
       reference
         "RFC 6991: Common YANG Data Types, Section 3";
     }
     import ietf-inet-types {
       prefix inet;
       reference
         "RFC 6991: Common YANG Data Types, Section 4";
     }
     import ietf-network-topology {
       prefix nt;
       reference
         "RFC 8345: A YANG Data Model for Network Topologies,
                    Section 6.2";
     }
     import ietf-yang-structure-ext {
       prefix sx;
       reference
```

```
       "RFC 8791: YANG Data Structure Extensions";
}

organization
  "IETF DDoS Open Threat Signaling (DOTS) Working Group";
contact
  "WG Web:   <https://datatracker.ietf.org/wg/dots/>
   WG List:  <mailto:dots@ietf.org>

   Author:   Mohamed Boucadair
             <mailto:mohamed.boucadair@orange.com>

   Author:   Konda, Tirumaleswar Reddy.K
             <mailto:kondtir@gmail.com>";
description
  "This module contains YANG definitions for the signaling
   of DOTS telemetry data exchanged between a DOTS client and
   a DOTS server by means of the DOTS signal channel.

   Copyright (c) 2022 IETF Trust and the persons identified as
   authors of the code.  All rights reserved.

   Redistribution and use in source and binary forms, with or
   without modification, is permitted pursuant to, and subject to
   the license terms contained in, the Revised BSD License set
   forth in Section 4.c of the IETF Trust's Legal Provisions
   Relating to IETF Documents
   (https://trustee.ietf.org/license-info).

   This version of this YANG module is part of RFC 9244; see the
   RFC itself for full legal notices.";

revision 2022-06-20 {
  description
    "Initial revision.";
  reference
    "RFC 9244: Distributed Denial-of-Service Open Threat
              Signaling (DOTS) Telemetry";
}

typedef attack-severity {
  type enumeration {
    enum none {
      value 1;
      description
        "No effect on the DOTS client domain.";
    }
    enum low {
      value 2;
      description
        "Minimal effect on the DOTS client domain.";
    }
    enum medium {
      value 3;
      description
        "A subset of DOTS client domain resources is
         out of service.";
    }
    enum high {
      value 4;
      description
        "The DOTS client domain is under extremely severe
         conditions.";
    }
    enum unknown {
      value 5;
      description
        "The impact of the attack is not known.";
    }
  }
  description
```

```
        "Enumeration for attack severity.";
    reference
      "RFC 7970: The Incident Object Description Exchange
                Format Version 2, Section 3.12.2";
}

typedef unit-class {
  type enumeration {
    enum packet-ps {
      value 1;
      description
        "Packets per second (pps).";
    }
    enum bit-ps {
      value 2;
      description
        "Bits per second (bps).";
    }
    enum byte-ps {
      value 3;
      description
        "Bytes per second (Bps).";
    }
  }
  description
    "Enumeration to indicate which unit class is used.
     These classes are supported: pps, bps, and Bps.";
}

typedef unit {
  type enumeration {
    enum packet-ps {
      value 1;
      description
        "Packets per second (pps).";
    }
    enum bit-ps {
      value 2;
      description
        "Bits per second (bps).";
    }
    enum byte-ps {
      value 3;
      description
        "Bytes per second (Bps).";
    }
    enum kilopacket-ps {
      value 4;
      description
        "Kilo packets per second (kpps).";
    }
    enum kilobit-ps {
      value 5;
      description
        "Kilobits per second (kbps).";
    }
    enum kilobyte-ps {
      value 6;
      description
        "Kilobytes per second (kBps).";
    }
    enum megapacket-ps {
      value 7;
      description
        "Mega packets per second (Mpps).";
    }
    enum megabit-ps {
      value 8;
      description
        "Megabits per second (Mbps).";
    }
```

```
enum megabyte-ps {
  value 9;
  description
    "Megabytes per second (MBps).";
}
enum gigapacket-ps {
  value 10;
  description
    "Giga packets per second (Gpps).";
}
enum gigabit-ps {
  value 11;
  description
    "Gigabits per second (Gbps).";
}
enum gigabyte-ps {
  value 12;
  description
    "Gigabytes per second (GBps).";
}
enum terapacket-ps {
  value 13;
  description
    "Tera packets per second (Tpps).";
}
enum terabit-ps {
  value 14;
  description
    "Terabits per second (Tbps).";
}
enum terabyte-ps {
  value 15;
  description
    "Terabytes per second (TBps).";
}
enum petapacket-ps {
  value 16;
  description
    "Peta packets per second (Ppps).";
}
enum petabit-ps {
  value 17;
  description
    "Petabits per second (Pbps).";
}
enum petabyte-ps {
  value 18;
  description
    "Petabytes per second (PBps).";
}
enum exapacket-ps {
  value 19;
  description
    "Exa packets per second (Epps).";
}
enum exabit-ps {
  value 20;
  description
    "Exabits per second (Ebps).";
}
enum exabyte-ps {
  value 21;
  description
    "Exabytes per second (EBps).";
}
enum zettapacket-ps {
  value 22;
  description
    "Zetta packets per second (Zpps).";
}
enum zettabit-ps {
```

```
          value 23;
          description
            "Zettabits per second (Zbps).";
        }
        enum zettabyte-ps {
          value 24;
          description
            "Zettabytes per second (ZBps).";
        }
      }
      description
        "Enumeration to indicate which unit is used.
         Only one unit per unit class is used owing to
         unit auto-scaling.";
    }

    typedef interval {
      type enumeration {
        enum 5-minutes {
          value 1;
          description
            "5 minutes.";
        }
        enum 10-minutes {
          value 2;
          description
            "10 minutes.";
        }
        enum 30-minutes {
          value 3;
          description
            "30 minutes.";
        }
        enum hour {
          value 4;
          description
            "Hour.";
        }
        enum day {
          value 5;
          description
            "Day.";
        }
        enum week {
          value 6;
          description
            "Week.";
        }
        enum month {
          value 7;
          description
            "Month.";
        }
      }
      description
        "Enumeration to indicate the overall measurement period.";
    }

    typedef sample {
      type enumeration {
        enum second {
          value 1;
          description
            "One-second measurement period.";
        }
        enum 5-seconds {
          value 2;
          description
            "5-second measurement period.";
        }
        enum 30-seconds {
```

```
          value 3;
          description
            "30-second measurement period.";
        }
        enum minute {
          value 4;
          description
            "One-minute measurement period.";
        }
        enum 5-minutes {
          value 5;
          description
            "5-minute measurement period.";
        }
        enum 10-minutes {
          value 6;
          description
            "10-minute measurement period.";
        }
        enum 30-minutes {
          value 7;
          description
            "30-minute measurement period.";
        }
        enum hour {
          value 8;
          description
            "One-hour measurement period.";
        }
      }
    description
      "Enumeration to indicate the sampling period.";
  }

  typedef percentile {
    type decimal64 {
      fraction-digits 2;
    }
    description
      "The nth percentile of a set of data is the
       value at which n percent of the data is below it.";
  }

  typedef query-type {
    type enumeration {
      enum target-prefix {
        value 1;
        description
          "Query based on target prefix.";
      }
      enum target-port {
        value 2;
        description
          "Query based on target port number.";
      }
      enum target-protocol {
        value 3;
        description
          "Query based on target protocol.";
      }
      enum target-fqdn {
        value 4;
        description
          "Query based on target FQDN.";
      }
      enum target-uri {
        value 5;
        description
          "Query based on target URI.";
      }
      enum target-alias {
```

```
        value 6;
        description
          "Query based on target alias.";
      }
      enum mid {
        value 7;
        description
          "Query based on mitigation identifier (mid).";
      }
      enum source-prefix {
        value 8;
        description
          "Query based on source prefix.";
      }
      enum source-port {
        value 9;
        description
          "Query based on source port number.";
      }
      enum source-icmp-type {
        value 10;
        description
          "Query based on ICMP type.";
      }
      enum content {
        value 11;
        description
          "Query based on the 'c' (content) Uri-Query option,
           which is used to control the selection of configuration
           and non-configuration data nodes.";
        reference
          "RFC 9132: Distributed Denial-of-Service Open Threat
                     Signaling (DOTS) Signal Channel
                     Specification, Section 4.4.2";
      }
    }
    description
      "Enumeration of support for query types that can be used
       in a GET request to filter out data.  Requests with
       invalid query types (e.g., not supported, malformed)
       received by the DOTS server are rejected with
       a 4.00 (Bad Request) Response Code.";
  }

  grouping telemetry-parameters {
    description
      "A grouping that includes a set of parameters that
       are used to prepare the reported telemetry data.

       The grouping indicates a measurement interval,
       a measurement sample period, and
       low-percentile/mid-percentile/high-percentile values.";
    leaf measurement-interval {
      type interval;
      description
        "Defines the period during which percentiles are
         computed.";
    }
    leaf measurement-sample {
      type sample;
      description
        "Defines the time distribution for measuring
         values that are used to compute percentiles.

         The measurement sample value must be less than the
         measurement interval value.";
    }
    leaf low-percentile {
      type percentile;
      default "10.00";
      description
```

```
        "Low-percentile.  If set to '0', this means that
         the use of low-percentile values is disabled.";
    }
    leaf mid-percentile {
      type percentile;
      must '. >= ../low-percentile' {
        error-message
          "The mid-percentile must be greater than
           or equal to the low-percentile.";
      }
      default "50.00";
      description
        "Mid-percentile.  If set to the same value as
         'low-percentile', this means that the use of
         mid-percentile values is disabled.";
    }
    leaf high-percentile {
      type percentile;
      must '. >= ../mid-percentile' {
        error-message
          "The high-percentile must be greater than
           or equal to the mid-percentile.";
      }
      default "90.00";
      description
        "High-percentile.  If set to the same value as
         'mid-percentile', this means that the use of
         high-percentile values is disabled.";
    }
  }

  grouping percentile-and-peak {
    description
      "Generic grouping for percentile and peak values.";
    leaf low-percentile-g {
      type yang:gauge64;
      description
        "Low-percentile value.";
    }
    leaf mid-percentile-g {
      type yang:gauge64;
      description
        "Mid-percentile value.";
    }
    leaf high-percentile-g {
      type yang:gauge64;
      description
        "High-percentile value.";
    }
    leaf peak-g {
      type yang:gauge64;
      description
        "Peak value.";
    }
  }

  grouping percentile-peak-and-current {
    description
      "Generic grouping for percentile and peak values.";
    uses percentile-and-peak;
    leaf current-g {
      type yang:gauge64;
      description
        "Current value.";
    }
  }

  grouping unit-config {
    description
      "Generic grouping for unit configuration.";
    list unit-config {
```

```
       key "unit";
       description
         "Controls which unit classes are allowed when sharing
          telemetry data.";
       leaf unit {
         type unit-class;
         description
           "Can be 'packet-ps', 'bit-ps', or 'byte-ps'.";
       }
       leaf unit-status {
         type boolean;
         mandatory true;
         description
           "Enable/disable the use of the measurement unit class.";
       }
     }
   }

   grouping traffic-unit {
     description
       "Grouping of traffic as a function of the
        measurement unit.";
     leaf unit {
       type unit;
       description
         "The traffic can be measured using unit classes:
          'packet-ps', 'bit-ps', or 'byte-ps'.  DOTS agents
          auto-scale to the appropriate units (e.g., 'megabit-ps',
          'kilobit-ps').";
     }
     uses percentile-and-peak;
   }

   grouping traffic-unit-all {
     description
       "Grouping of traffic as a function of the measurement unit,
        including current values.";
     uses traffic-unit;
     leaf current-g {
       type yang:gauge64;
       description
         "Current observed value.";
     }
   }

   grouping traffic-unit-protocol {
     description
       "Grouping of traffic of a given transport protocol as
        a function of the measurement unit.";
     leaf protocol {
       type uint8;
       description
         "The transport protocol.
          Values are taken from the IANA 'Protocol Numbers'
          registry:
          <https://www.iana.org/assignments/protocol-numbers/>.

          For example, this parameter contains 6 for TCP,
          17 for UDP, 33 for the Datagram Congestion Control
          Protocol (DCCP), or 132 for the Stream Control
          Transmission Protocol (SCTP).";
     }
     uses traffic-unit;
   }

   grouping traffic-unit-protocol-all {
     description
       "Grouping of traffic of a given transport protocol as
        a function of the measurement unit, including current
        values.";
     uses traffic-unit-protocol;
```

```
    leaf current-g {
      type yang:gauge64;
      description
        "Current observed value.";
    }
  }

  grouping traffic-unit-port {
    description
      "Grouping of traffic bound to a port number as
       a function of the measurement unit.";
    leaf port {
      type inet:port-number;
      description
        "Port number used by a transport protocol.";
    }
    uses traffic-unit;
  }

  grouping traffic-unit-port-all {
    description
      "Grouping of traffic bound to a port number as
       a function of the measurement unit, including
       current values.";
    uses traffic-unit-port;
    leaf current-g {
      type yang:gauge64;
      description
        "Current observed value.";
    }
  }

  grouping total-connection-capacity {
    description
      "Total connection capacities for various types of
       connections, as well as overall capacity.  These data nodes
       are useful for detecting resource-consuming DDoS attacks.";
    leaf connection {
      type uint64;
      description
        "The maximum number of simultaneous connections that
         are allowed to the target server.";
    }
    leaf connection-client {
      type uint64;
      description
        "The maximum number of simultaneous connections that
         are allowed to the target server per client.";
    }
    leaf embryonic {
      type uint64;
      description
        "The maximum number of simultaneous embryonic connections
         that are allowed to the target server.  The term
         'embryonic connection' refers to a connection whose
         connection handshake is not finished.  Embryonic
         connections are only possible in connection-oriented
         transport protocols like TCP or SCTP.";
    }
    leaf embryonic-client {
      type uint64;
      description
        "The maximum number of simultaneous embryonic connections
         that are allowed to the target server per client.";
    }
    leaf connection-ps {
      type uint64;
      description
        "The maximum number of new connections allowed per second
         to the target server.";
    }
```

```
  leaf connection-client-ps {
    type uint64;
    description
      "The maximum number of new connections allowed per second
       to the target server per client.";
  }
  leaf request-ps {
    type uint64;
    description
      "The maximum number of requests allowed per second
       to the target server.";
  }
  leaf request-client-ps {
    type uint64;
    description
      "The maximum number of requests allowed per second
       to the target server per client.";
  }
  leaf partial-request-max {
    type uint64;
    description
      "The maximum number of outstanding partial requests
       that are allowed to the target server.";
  }
  leaf partial-request-client-max {
    type uint64;
    description
      "The maximum number of outstanding partial requests
       that are allowed to the target server per client.";
  }
}

grouping total-connection-capacity-protocol {
  description
    "Total connection capacity per protocol.  These data nodes
     are useful for detecting resource-consuming DDoS attacks.";
  leaf protocol {
    type uint8;
    description
      "The transport protocol.
       Values are taken from the IANA 'Protocol Numbers'
       registry:
       <https://www.iana.org/assignments/protocol-numbers/>.";
  }
  uses total-connection-capacity;
}

grouping connection-percentile-and-peak {
  description
    "A set of data nodes that represent the attack
     characteristics.";
  container connection-c {
    uses percentile-and-peak;
    description
      "The number of simultaneous attack connections to
       the target server.";
  }
  container embryonic-c {
    uses percentile-and-peak;
    description
      "The number of simultaneous embryonic connections to
       the target server.";
  }
  container connection-ps-c {
    uses percentile-and-peak;
    description
      "The number of attack connections per second to
       the target server.";
  }
  container request-ps-c {
    uses percentile-and-peak;
```

```
      description
        "The number of attack requests per second to
         the target server.";
    }
    container partial-request-c {
      uses percentile-and-peak;
      description
        "The number of attack partial requests to
         the target server.";
    }
  }

  grouping connection-all {
    description
      "Total attack connections, including current values.";
    container connection-c {
      uses percentile-peak-and-current;
      description
        "The number of simultaneous attack connections to
         the target server.";
    }
    container embryonic-c {
      uses percentile-peak-and-current;
      description
        "The number of simultaneous embryonic connections to
         the target server.";
    }
    container connection-ps-c {
      uses percentile-peak-and-current;
      description
        "The number of attack connections per second to
         the target server.";
    }
    container request-ps-c {
      uses percentile-peak-and-current;
      description
        "The number of attack requests per second to
         the target server.";
    }
    container partial-request-c {
      uses percentile-peak-and-current;
      description
        "The number of attack partial requests to
         the target server.";
    }
  }

  grouping connection-protocol {
    description
      "Total attack connections.";
    leaf protocol {
      type uint8;
      description
        "The transport protocol.
         Values are taken from the IANA 'Protocol Numbers'
         registry:
         <https://www.iana.org/assignments/protocol-numbers/>.";
    }
    uses connection-percentile-and-peak;
  }

  grouping connection-port {
    description
      "Total attack connections per port number.";
    leaf protocol {
      type uint8;
      description
        "The transport protocol.
         Values are taken from the IANA 'Protocol Numbers'
         registry:
         <https://www.iana.org/assignments/protocol-numbers/>.";
```

```
        }
        leaf port {
          type inet:port-number;
          description
            "Port number.";
        }
        uses connection-percentile-and-peak;
      }

      grouping connection-protocol-all {
        description
          "Total attack connections per protocol, including current
           values.";
        leaf protocol {
          type uint8;
          description
            "The transport protocol.
             Values are taken from the IANA 'Protocol Numbers'
             registry:
             <https://www.iana.org/assignments/protocol-numbers/>.";
        }
        uses connection-all;
      }

      grouping connection-protocol-port-all {
        description
          "Total attack connections per port number, including current
           values.";
        leaf protocol {
          type uint8;
          description
            "The transport protocol.
             Values are taken from the IANA 'Protocol Numbers'
             registry:
             <https://www.iana.org/assignments/protocol-numbers/>.";
        }
        leaf port {
          type inet:port-number;
          description
            "Port number.";
        }
        uses connection-all;
      }

      grouping attack-detail {
        description
          "Various details that describe the ongoing
           attacks that need to be mitigated by the DOTS server.
           The attack details need to cover well-known and common
           attacks (such as a SYN flood) along with new emerging or
           vendor-specific attacks.";
        leaf vendor-id {
          type uint32;
          description
            "The Vendor ID is a security vendor's Private Enterprise
             Number as registered with IANA.";
          reference
            "IANA: Private Enterprise Numbers
             (https://www.iana.org/assignments/enterprise-numbers/)";
        }
        leaf attack-id {
          type uint32;
          description
            "Unique identifier assigned by the vendor for the attack.";
        }
        leaf description-lang {
          type string {
            pattern '((([A-Za-z]{2,3}(-[A-Za-z]{3}(-[A-Za-z]{3})'
                  + '{0,2})?)|[A-Za-z]{4}|[A-Za-z]{5,8})(-[A-Za-z]{4})'
                  + '?(-([A-Za-z]{2}|[0-9]{3}))?(-([A-Za-z0-9]{5,8}'
                  + '|([0-9][A-Za-z0-9]{3})))*(-[0-9A-WYZa-wyz]'
```

```
                       + '(-([A-Za-z0-9]{2,8}))+)*(-[Xx](-([A-Za-z0-9]'
                       + '{1,8}))+)?|[Xx](-([A-Za-z0-9]{1,8}))+|'
                       + '(([Ee][Nn]-[Gg][Bb]-[Oo][Ee][Dd]|[Ii]-'
                       + '[Aa][Mm][Ii]|[Ii]-[Bb][Nn][Nn]|[Ii]-'
                       + '[Dd][Ee][Ff][Aa][Uu][Ll][Tt]|[Ii]-'
                       + '[Ee][Nn][Oo][Cc][Hh][Ii][Aa][Nn]'
                       + '|[Ii]-[Hh][Aa][Kk]|'
                       + '[Ii]-[Kk][Ll][Ii][Nn][Gg][Oo][Nn]|'
                       + '[Ii]-[Ll][Uu][Xx]|[Ii]-[Mm][Ii][Nn][Gg][Oo]|'
                       + '[Ii]-[Nn][Aa][Vv][Aa][Jj][Oo]|[Ii]-[Pp][Ww][Nn]|'
                       + '[Ii]-[Tt][Aa][Oo]|[Ii]-[Tt][Aa][Yy]|'
                       + '[Ii]-[Tt][Ss][Uu]|[Ss][Gg][Nn]-[Bb][Ee]-[Ff][Rr]|'
                       + '[Ss][Gg][Nn]-[Bb][Ee]-[Nn][Ll]|[Ss][Gg][Nn]-'
                       + '[Cc][Hh]-[Dd][Ee])|([Aa][Rr][Tt]-'
                       + '[Ll][Oo][Jj][Bb][Aa][Nn]|[Cc][Ee][Ll]-'
                       + '[Gg][Aa][Uu][Ll][Ii][Ss][Hh]|'
                       + '[Nn][Oo]-[Bb][Oo][Kk]|[Nn][Oo]-'
                       + '[Nn][Yy][Nn]|[Zz][Hh]-[Gg][Uu][Oo][Yy][Uu]|'
                       + '[Zz][Hh]-[Hh][Aa][Kk][Kk][Aa]|[Zz][Hh]-'
                       + '[Mm][Ii][Nn]|[Zz][Hh]-[Mm][Ii][Nn]-'
                       + '[Nn][Aa][Nn]|[Zz][Hh]-[Xx][Ii][Aa][Nn][Gg])))';
          }
          default "en-US";
          description
            "Indicates the language tag that is used for
             'attack-description'.";
          reference
            "RFC 5646: Tags for Identifying Languages, Section 2.1";
        }
      leaf attack-description {
        type string;
        description
          "Textual representation of the attack description.
           Natural Language Processing techniques (e.g.,
           word embedding) might provide some utility in mapping
           the attack description to an attack type.";
      }
      leaf attack-severity {
        type attack-severity;
        description
          "Severity level of an attack.  How this level is
           determined is implementation specific.";
      }
      leaf start-time {
        type uint64;
        description
          "The time the attack started.  The start time is
           represented in seconds relative to
           1970-01-01T00:00:00Z.";
      }
      leaf end-time {
        type uint64;
        description
          "The time the attack ended.  The end time is represented
           in seconds relative to 1970-01-01T00:00:00Z.";
      }
      container source-count {
        description
          "Indicates the count of unique sources involved
           in the attack.";
        uses percentile-and-peak;
        leaf current-g {
          type yang:gauge64;
          description
            "Current observed value.";
        }
      }
    }
  }

  grouping talker {
    description
```

```
        "Defines generic data related to top talkers.";
      leaf spoofed-status {
        type boolean;
        description
          "When set to 'true', it indicates whether this address
           is spoofed.";
      }
      leaf source-prefix {
        type inet:ip-prefix;
        description
          "IPv4 or IPv6 prefix identifying the attacker(s).";
      }
      list source-port-range {
        key "lower-port";
        description
          "Port range.  When only 'lower-port' is
           present, it represents a single port number.";
        leaf lower-port {
          type inet:port-number;
          description
            "Lower port number of the port range.";
        }
        leaf upper-port {
          type inet:port-number;
          must '. >= ../lower-port' {
            error-message
              "The upper port number must be greater than
               or equal to the lower port number.";
          }
          description
            "Upper port number of the port range.";
        }
      }
      list source-icmp-type-range {
        key "lower-type";
        description
          "ICMP type range.  When only 'lower-type' is
           present, it represents a single ICMP type.";
        leaf lower-type {
          type uint8;
          description
            "Lower ICMP type of the ICMP type range.";
        }
        leaf upper-type {
          type uint8;
          must '. >= ../lower-type' {
            error-message
              "The upper ICMP type must be greater than
               or equal to the lower ICMP type.";
          }
          description
            "Upper type of the ICMP type range.";
        }
      }
      list total-attack-traffic {
        key "unit";
        description
          "Total attack traffic issued from this source.";
        uses traffic-unit-all;
      }
    }

    grouping top-talker-aggregate {
      description
        "An aggregate of top attack sources.  This aggregate is
         typically used when included in a mitigation request.";
      list talker {
        key "source-prefix";
        description
          "Refers to a top talker that is identified by an IPv4
           or IPv6 prefix identifying the attacker(s).";
```

```
      uses talker;
      container total-attack-connection {
        description
          "Total attack connections issued from this source.";
        uses connection-all;
      }
    }
  }

  grouping top-talker {
    description
      "Top attack sources with detailed per-protocol
       structure.";
    list talker {
      key "source-prefix";
      description
        "Refers to a top talker that is identified by an IPv4
         or IPv6 prefix identifying the attacker(s).";
      uses talker;
      list total-attack-connection-protocol {
        key "protocol";
        description
          "Total attack connections issued from this source.";
        uses connection-protocol-all;
      }
    }
  }

  grouping baseline {
    description
      "Grouping for the telemetry baseline.";
    uses data-channel:target;
    leaf-list alias-name {
      type string;
      description
        "An alias name that points to an IP resource.
         An IP resource can be a router, a host,
         an Internet of Things (IoT) object, a server, etc.";
    }
    list total-traffic-normal {
      key "unit";
      description
        "Total traffic normal baselines.";
      uses traffic-unit;
    }
    list total-traffic-normal-per-protocol {
      key "unit protocol";
      description
        "Total traffic normal baselines per protocol.";
      uses traffic-unit-protocol;
    }
    list total-traffic-normal-per-port {
      key "unit port";
      description
        "Total traffic normal baselines per port number.";
      uses traffic-unit-port;
    }
    list total-connection-capacity {
      key "protocol";
      description
        "Total connection capacity.";
      uses total-connection-capacity-protocol;
    }
    list total-connection-capacity-per-port {
      key "protocol port";
      description
        "Total connection capacity per port number.";
      leaf port {
        type inet:port-number;
        description
          "The target port number.";
```

```
        }
        uses total-connection-capacity-protocol;
      }
    }

    grouping pre-or-ongoing-mitigation {
      description
        "Grouping for the telemetry data.";
      list total-traffic {
        key "unit";
        description
          "Total traffic.";
        uses traffic-unit-all;
      }
      list total-traffic-protocol {
        key "unit protocol";
        description
          "Total traffic per protocol.";
        uses traffic-unit-protocol-all;
      }
      list total-traffic-port {
        key "unit port";
        description
          "Total traffic per port number.";
        uses traffic-unit-port-all;
      }
      list total-attack-traffic {
        key "unit";
        description
          "Total attack traffic.";
        uses traffic-unit-all;
      }
      list total-attack-traffic-protocol {
        key "unit protocol";
        description
          "Total attack traffic per protocol.";
        uses traffic-unit-protocol-all;
      }
      list total-attack-traffic-port {
        key "unit port";
        description
          "Total attack traffic per port number.";
        uses traffic-unit-port-all;
      }
      list total-attack-connection-protocol {
        key "protocol";
        description
          "Total attack connections.";
        uses connection-protocol-all;
      }
      list total-attack-connection-port {
        key "protocol port";
        description
          "Total attack connections per target port number.";
        uses connection-protocol-port-all;
      }
      list attack-detail {
        key "vendor-id attack-id";
        description
          "Provides a set of attack details.";
        uses attack-detail;
        container top-talker {
          description
            "Lists the top attack sources.";
          uses top-talker;
        }
      }
    }

    sx:augment-structure "/dots-signal:dots-signal"
                       + "/dots-signal:message-type"
```

```
                     + "/dots-signal:mitigation-scope"
                     + "/dots-signal:scope" {
    description
      "Extends mitigation scope with telemetry update data.";
    choice direction {
      description
        "Indicates the communication direction in which the
         data nodes can be included.";
      case server-to-client-only {
        description
          "These data nodes appear only in a mitigation message
           sent from the server to the client.";
        list total-traffic {
          key "unit";
          description
            "Total traffic.";
          uses traffic-unit-all;
        }
        container total-attack-connection {
          description
            "Total attack connections.";
          uses connection-all;
        }
      }
    }
    list total-attack-traffic {
      key "unit";
      description
        "Total attack traffic.";
      uses traffic-unit-all;
    }
    list attack-detail {
      key "vendor-id attack-id";
      description
        "Attack details.";
      uses attack-detail;
      container top-talker {
        description
          "Top attack sources.";
        uses top-talker-aggregate;
      }
    }
  }
}
sx:structure dots-telemetry {
  description
    "Main structure for DOTS telemetry messages.";
  choice telemetry-message-type {
    description
      "Can be 'telemetry-setup' or telemetry data.";
    case telemetry-setup {
      description
        "Indicates that the message is about telemetry setup.";
      choice direction {
        description
          "Indicates the communication direction in which the
           data nodes can be included.";
        case server-to-client-only {
          description
            "These data nodes appear only in a telemetry message
             sent from the server to the client.";
          container max-config-values {
            description
              "Maximum acceptable configuration values.";
            uses telemetry-parameters;
            leaf server-originated-telemetry {
              type boolean;
              default "false";
              description
                "Indicates whether the DOTS server can be
                 instructed to send pre-or-ongoing-mitigation
                 telemetry.  If set to 'false' or the data node
```

```
                        is not present, this is an indication that
                        the server does not support this capability.";
              }
            leaf telemetry-notify-interval {
              type uint16 {
                range "1 .. 3600";
              }
              units "seconds";
              must '. >= ../../min-config-values'
                  + '/telemetry-notify-interval' {
                error-message
                  "The value must be greater than or equal
                   to the 'telemetry-notify-interval' value in
                   the 'min-config-values' attribute";
              }
              description
                "Minimum number of seconds between successive
                 telemetry notifications.";
            }
          }
        }
        container min-config-values {
          description
            "Minimum acceptable configuration values.";
          uses telemetry-parameters;
          leaf telemetry-notify-interval {
            type uint16 {
              range "1 .. 3600";
            }
            units "seconds";
            description
              "Minimum number of seconds between successive
               telemetry notifications.";
          }
        }
        container supported-unit-classes {
          description
            "Supported unit classes and default activation
             status.";
          uses unit-config;
        }
        leaf-list supported-query-type {
          type query-type;
          description
            "Indicates which query types are supported by
             the server.  If the server does not announce
             the query types it supports, the client will
             be unable to use any of the potential
             'query-type' values to reduce the returned data
             content from the server.";
        }
      }
    }
    list telemetry {
      description
        "The telemetry data per DOTS client.  The keys
         of the list are 'cuid' and 'tsid', but these keys are
         not represented here because these keys are conveyed
         as mandatory Uri-Paths in requests.  Omitting keys
         is compliant with RFC 8791.";
      reference
        "RFC 8791: YANG Data Structure Extensions";
      choice direction {
        description
          "Indicates the communication direction in which the
           data nodes can be included.";
        case server-to-client-only {
          description
            "These data nodes appear only in a telemetry
             message sent from the server to the client.";
          leaf tsid {
            type uint32;
```

```
              description
                "A client-assigned identifier for the DOTS
                 telemetry setup data.";
            }
          }
        }
        choice setup-type {
          description
            "Can be a mitigation configuration, a pipe capacity,
             or a baseline message.";
          case telemetry-config {
            description
              "Used to set telemetry parameters such as setting
               low-, mid-, and high-percentile values.";
            container current-config {
              description
                "Current telemetry configuration values.";
              uses telemetry-parameters;
              uses unit-config;
              leaf server-originated-telemetry {
                type boolean;
                description
                  "Used by a DOTS client to enable/disable
                   whether it requests pre-or-ongoing-mitigation
                   telemetry from the DOTS server.";
              }
              leaf telemetry-notify-interval {
                type uint16 {
                  range "1 .. 3600";
                }
                units "seconds";
                description
                  "Minimum number of seconds between successive
                   telemetry notifications.";
              }
            }
          }
          case pipe {
            description
              "Total pipe capacity of a DOTS client domain.";
            list total-pipe-capacity {
              key "link-id unit";
              description
                "Total pipe capacity of a DOTS client domain.";
              leaf link-id {
                type nt:link-id;
                description
                  "Identifier of an interconnection link of
                   the DOTS client domain.";
              }
              leaf capacity {
                type uint64;
                mandatory true;
                description
                  "Pipe capacity.  This attribute is mandatory
                   when 'total-pipe-capacity' is included in a
                   message.";
              }
              leaf unit {
                type unit;
                description
                  "The traffic can be measured using unit
                   classes: packets per second (pps), bits per
                   second (bps), and/or bytes per second
                   (Bps).

                   For a given unit class, the DOTS agents
                   auto-scale to the appropriate units (e.g.,
                   'megabit-ps', 'kilobit-ps').";
              }
            }
```

```
            }
            case baseline {
              description
                "Traffic baseline information related to a DOTS
                 client domain.";
              list baseline {
                key "id";
                description
                  "Traffic baseline information related to a DOTS
                   client domain.";
                leaf id {
                  type uint32;
                  must '. >= 1';
                  description
                    "An identifier that uniquely identifies a
                     baseline entry communicated by a
                     DOTS client.";
                }
                uses baseline;
              }
            }
          }
        }
      }
    }
    case telemetry {
      description
        "Telemetry information.";
      list pre-or-ongoing-mitigation {
        description
          "Pre-or-ongoing-mitigation telemetry per DOTS client.
           The keys of the list are 'cuid' and 'tmid', but these
           keys are not represented here because these keys are
           conveyed as mandatory Uri-Paths in requests.
           Omitting keys is compliant with RFC 8791.";
        reference
          "RFC 8791: YANG Data Structure Extensions";
        choice direction {
          description
            "Indicates the communication direction in which the
             data nodes can be included.";
          case server-to-client-only {
            description
              "These data nodes appear only in a telemetry
               message sent from the server to the client.";
            leaf tmid {
              type uint32;
              description
                "A client-assigned identifier for the DOTS
                 telemetry data.";
            }
          }
        }
        container target {
          description
            "Indicates the target.  At least one of the
             attributes 'target-prefix', 'target-fqdn',
             'target-uri', 'alias-name', or 'mid-list'
             must be present in the target definition.";
          uses data-channel:target;
          leaf-list alias-name {
            type string;
            description
              "An alias name that points to a resource.";
          }
          leaf-list mid-list {
            type uint32;
            description
              "Reference to a list of associated mitigation
               requests.";
            reference
              "RFC 9132: Distributed Denial-of-Service Open
```

```
                                 Threat Signaling (DOTS) Signal Channel
                                 Specification, Section 4.4.1";
                 }
               }
               uses pre-or-ongoing-mitigation;
             }
           }
         }
       }
     }
     <CODE ENDS>

11.2.  Vendor Attack Mapping Details YANG Module

     <CODE BEGINS> file "ietf-dots-mapping@2022-06-20.yang"
     module ietf-dots-mapping {
       yang-version 1.1;
       namespace "urn:ietf:params:xml:ns:yang:ietf-dots-mapping";
       prefix dots-mapping;

       import ietf-dots-data-channel {
         prefix data-channel;
         reference
           "RFC 8783: Distributed Denial-of-Service Open Threat
                     Signaling (DOTS) Data Channel Specification";
       }

       organization
         "IETF DDoS Open Threat Signaling (DOTS) Working Group";
       contact
         "WG Web:   <https://datatracker.ietf.org/wg/dots/>
          WG List:  <mailto:dots@ietf.org>

          Author:   Mohamed Boucadair
                    <mailto:mohamed.boucadair@orange.com>

          Author:   Jon Shallow
                    <mailto:supjps-ietf@jpshallow.com>";
       description
         "This module contains YANG definitions for the sharing
          of DDoS attack mapping details between a DOTS client and
          a DOTS server by means of the DOTS data channel.

          Copyright (c) 2022 IETF Trust and the persons identified as
          authors of the code.  All rights reserved.

          Redistribution and use in source and binary forms, with or
          without modification, is permitted pursuant to, and subject to
          the license terms contained in, the Revised BSD License set
          forth in Section 4.c of the IETF Trust's Legal Provisions
          Relating to IETF Documents
          (https://trustee.ietf.org/license-info).

          This version of this YANG module is part of RFC 9244; see the
          RFC itself for full legal notices.";

       revision 2022-06-20 {
         description
           "Initial revision.";
         reference
           "RFC 9244: Distributed Denial-of-Service Open Threat
                     Signaling (DOTS) Telemetry";
       }

       feature dots-telemetry {
         description
           "This feature indicates that DOTS telemetry data can be
            shared between DOTS clients and servers.";
       }

       grouping attack-mapping {
```

```
     description
       "A set of information used for sharing vendor attack mapping
        information with a peer.";
     list vendor {
       key "vendor-id";
       description
         "Vendor attack mapping information related to the
          client/server.";
       leaf vendor-id {
         type uint32;
         description
           "The Vendor ID is a security vendor's Private Enterprise
            Number as registered with IANA.";
         reference
           "IANA: Private Enterprise Numbers
            (https://www.iana.org/assignments/enterprise-numbers/)";
       }
       leaf vendor-name {
         type string;
         description
           "The name of the vendor (e.g., company A).";
       }
       leaf description-lang {
         type string {
           pattern '((([A-Za-z]{2,3}(-[A-Za-z]{3}(-[A-Za-z]{3})'
                  + '{0,2})?)|[A-Za-z]{4}|[A-Za-z]{5,8})(-[A-Za-z]{4})'
                  + '?(-([A-Za-z]{2}|[0-9]{3}))?(-([A-Za-z0-9]{5,8}'
                  + '|([0-9][A-Za-z0-9]{3})))*(-[0-9A-WYZa-wyz]'
                  + '(-([A-Za-z0-9]{2,8}))+)*(-[Xx](-([A-Za-z0-9]'
                  + '{1,8}))+)?|[Xx](-([A-Za-z0-9]{1,8}))+|'
                  + '(([Ee][Nn]-[Gg][Bb]-[Oo][Ee][Dd]|[Ii]-'
                  + '[Aa][Mm][Ii]|[Ii]-[Bb][Nn][Nn]|[Ii]-'
                  + '[Dd][Ee][Ff][Aa][Uu][Ll][Tt]|[Ii]-'
                  + '[Ee][Nn][Oo][Cc][Hh][Ii][Aa][Nn]'
                  + '|[Ii]-[Hh][Aa][Kk]|'
                  + '[Ii]-[Kk][Ll][Ii][Nn][Gg][Oo][Nn]|'
                  + '[Ii]-[Ll][Uu][Xx]|[Ii]-[Mm][Ii][Nn][Gg][Oo]|'
                  + '[Ii]-[Nn][Aa][Vv][Aa][Jj][Oo]|[Ii]-[Pp][Ww][Nn]|'
                  + '[Ii]-[Tt][Aa][Oo]|[Ii]-[Tt][Aa][Yy]|'
                  + '[Ii]-[Tt][Ss][Uu]|[Ss][Gg][Nn]-[Bb][Ee]-[Ff][Rr]|'
                  + '[Ss][Gg][Nn]-[Bb][Ee]-[Nn][Ll]|[Ss][Gg][Nn]-'
                  + '[Cc][Hh]-[Dd][Ee])|([Aa][Rr][Tt]-'
                  + '[Ll][Oo][Jj][Bb][Aa][Nn]|[Cc][Ee][Ll]-'
                  + '[Gg][Aa][Uu][Ll][Ii][Ss][Hh]|'
                  + '[Nn][Oo]-[Bb][Oo][Kk]|[Nn][Oo]-'
                  + '[Nn][Yy][Nn]|[Zz][Hh]-[Gg][Uu][Oo][Yy][Uu]|'
                  + '[Zz][Hh]-[Hh][Aa][Kk][Kk][Aa]|[Zz][Hh]-'
                  + '[Mm][Ii][Nn]|[Zz][Hh]-[Mm][Ii][Nn]-'
                  + '[Nn][Aa][Nn]|[Zz][Hh]-[Xx][Ii][Aa][Nn][Gg])))';
         }
         default "en-US";
         description
           "Indicates the language tag that is used for
            'attack-description'.";
         reference
           "RFC 5646: Tags for Identifying Languages, Section 2.1";
       }
       leaf last-updated {
         type uint64;
         mandatory true;
         description
           "The time the mapping table was updated.  It is
            represented in seconds relative to
            1970-01-01T00:00:00Z.";
       }
       list attack-mapping {
         key "attack-id";
         description
           "Attack mapping details.";
         leaf attack-id {
           type uint32;
```

```
            description
              "Unique identifier assigned by the vendor for the
               attack.";
          }
          leaf attack-description {
            type string;
            mandatory true;
            description
              "Textual representation of the attack description.
               Natural Language Processing techniques (e.g.,
               word embedding) might provide some utility in
               mapping the attack description to an attack type.";
          }
        }
      }
    }

    augment "/data-channel:dots-data/data-channel:dots-client" {
      if-feature "dots-telemetry";
      description
        "Augments the data channel with a vendor attack
         mapping table of the DOTS client.";
      container vendor-mapping {
        description
          "Used by DOTS clients to share their vendor
           attack mapping information with DOTS servers.";
        uses attack-mapping;
      }
    }

    augment "/data-channel:dots-data/data-channel:capabilities" {
      if-feature "dots-telemetry";
      description
        "Augments the DOTS server capabilities with a
         parameter to indicate whether they can share
         attack mapping details.";
      leaf vendor-mapping-enabled {
        type boolean;
        config false;
        description
          "Indicates that the DOTS server supports sharing
           attack vendor mapping details with DOTS clients.";
      }
    }

    augment "/data-channel:dots-data" {
      if-feature "dots-telemetry";
      description
        "Augments the data channel with a vendor attack
         mapping table of the DOTS server.";
      container vendor-mapping {
        config false;
        description
          "Includes the list of vendor attack mapping details
           that will be shared with DOTS clients upon request.";
        uses attack-mapping;
      }
    }
  }
  <CODE ENDS>
```

12. YANG/JSON Mapping Parameters to CBOR

   All DOTS telemetry parameters in the payload of the DOTS signal
   channel MUST be mapped to CBOR types as shown in Table 3:

   | Note: Implementers must check that the mapping output provided
   | by their YANG-to-CBOR encoding schemes is aligned with the
   | contents of Table 3.

   +=====================+=============+======+=============+========+

Parameter Name	YANG Type	CBOR Key	CBOR Major Type & Information	JSON Type
================	===========	==========	===============================	===========
tsid	uint32	128	0 unsigned	Number
telemetry	list	129	4 array	Array
low-percentile	decimal64	130	6 tag 4 [-2, integer]	String
mid-percentile	decimal64	131	6 tag 4 [-2, integer]	String
high-percentile	decimal64	132	6 tag 4 [-2, integer]	String
unit-config	list	133	4 array	Array
unit	enumeration	134	0 unsigned	String
unit-status	boolean	135	7 bits 20	False
			7 bits 21	True
total-pipe-capacity	list	136	4 array	Array
link-id	string	137	3 text string	String
pre-or-ongoing-mitigation	list	138	4 array	Array
total-traffic-normal	list	139	4 array	Array
low-percentile-g	yang:gauge64	140	0 unsigned	String
mid-percentile-g	yang:gauge64	141	0 unsigned	String
high-percentile-g	yang:gauge64	142	0 unsigned	String
peak-g	yang:gauge64	143	0 unsigned	String
total-attack-traffic	list	144	4 array	Array
total-traffic	list	145	4 array	Array
total-connection-capacity	list	146	4 array	Array
connection	uint64	147	0 unsigned	String
connection-client	uint64	148	0 unsigned	String
embryonic	uint64	149	0 unsigned	String
embryonic-client	uint64	150	0 unsigned	String
connection-ps	uint64	151	0 unsigned	String
connection-client-ps	uint64	152	0 unsigned	String
request-ps	uint64	153	0 unsigned	String
request-client-ps	uint64	154	0 unsigned	String
partial-request-max	uint64	155	0 unsigned	String
partial-request-client-max	uint64	156	0 unsigned	String
total-attack-	container	157	5 map	Object

connection				
connection-c	container	158	5 map	Object
embryonic-c	container	159	5 map	Object
connection-ps-c	container	160	5 map	Object
request-ps-c	container	161	5 map	Object
attack-detail	list	162	4 array	Array
id	uint32	163	0 unsigned	Number
attack-id	uint32	164	0 unsigned	Number
attack-description	string	165	3 text string	String
attack-severity	enumeration	166	0 unsigned	String
start-time	uint64	167	0 unsigned	String
end-time	uint64	168	0 unsigned	String
source-count	container	169	5 map	Object
top-talker	container	170	5 map	Object
spoofed-status	boolean	171	7 bits 20	False
			7 bits 21	True
partial-request-c	container	172	5 map	Object
total-attack-connection-protocol	list	173	4 array	Array
baseline	list	174	4 array	Array
current-config	container	175	5 map	Object
max-config-values	container	176	5 map	Object
min-config-values	container	177	5 map	Object
supported-unit-classes	container	178	5 map	Object
server-originated-telemetry	boolean	179	7 bits 20	False
			7 bits 21	True
telemetry-notify-interval	uint16	180	0 unsigned	Number
tmid	uint32	181	0 unsigned	Number
measurement-interval	enumeration	182	0 unsigned	String
measurement-sample	enumeration	183	0 unsigned	String
talker	list	184	4 array	Array
source-prefix	inet:ip-prefix	185	3 text string	String
mid-list	leaf-list	186	4 array	Array
	uint32		0 unsigned	Number
source-port-range	list	187	4 array	Array
source-icmp-type-range	list	188	4 array	Array

target	container	189	5 map	Object
capacity	uint64	190	0 unsigned	String
protocol	uint8	191	0 unsigned	Number
total-traffic-normal-per-protocol	list	192	4 array	Array
total-traffic-normal-per-port	list	193	4 array	Array
total-connection-capacity-per-port	list	194	4 array	Array
total-traffic-protocol	list	195	4 array	Array
total-traffic-port	list	196	4 array	Array
total-attack-traffic-protocol	list	197	4 array	Array
total-attack-traffic-port	list	198	4 array	Array
total-attack-connection-port	list	199	4 array	Array
port	inet:port-number	200	0 unsigned	Number
supported-query-type	leaf-list	201	4 array	Array
			0 unsigned	String
vendor-id	uint32	202	0 unsigned	Number
ietf-dots-telemetry:telemetry-setup	container	203	5 map	Object
ietf-dots-telemetry:total-traffic	list	204	4 array	Array
ietf-dots-telemetry:total-attack-traffic	list	205	4 array	Array
ietf-dots-telemetry:total-attack-connection	container	206	5 map	Object
ietf-dots-telemetry:attack-detail	list	207	4 array	Array
ietf-dots-telemetry:telemetry	container	208	5 map	Object
current-g	yang:gauge64	209	0 unsigned	String
description-lang	string	210	3 text string	String
lower-type	uint8	32771	0 unsigned	Number
upper-type	uint8	32772	0 unsigned	Number

Table 3: YANG/JSON Mapping Parameters to CBOR

13. IANA Considerations

13.1. DOTS Signal Channel CBOR Key Values

   This specification registers the following comprehension-optional
   parameters in the IANA "DOTS Signal Channel CBOR Key Values" registry
   [Key-Map].

Parameter Name	CBOR Key Value	CBOR Major Type	Change Controller	Reference
tsid	128	0	IESG	RFC 9244
telemetry	129	4	IESG	RFC 9244
low-percentile	130	6tag4	IESG	RFC 9244
mid-percentile	131	6tag4	IESG	RFC 9244
high-percentile	132	6tag4	IESG	RFC 9244
unit-config	133	4	IESG	RFC 9244
unit	134	0	IESG	RFC 9244
unit-status	135	7	IESG	RFC 9244
total-pipe-capacity	136	4	IESG	RFC 9244
link-id	137	3	IESG	RFC 9244
pre-or-ongoing-mitigation	138	4	IESG	RFC 9244
total-traffic-normal	139	4	IESG	RFC 9244
low-percentile-g	140	0	IESG	RFC 9244
mid-percentile-g	141	0	IESG	RFC 9244
high-percentile-g	142	0	IESG	RFC 9244
peak-g	143	0	IESG	RFC 9244
total-attack-traffic	144	4	IESG	RFC 9244
total-traffic	145	4	IESG	RFC 9244
total-connection-capacity	146	4	IESG	RFC 9244
connection	147	0	IESG	RFC 9244
connection-client	148	0	IESG	RFC 9244
embryonic	149	0	IESG	RFC 9244
embryonic-client	150	0	IESG	RFC 9244
connection-ps	151	0	IESG	RFC 9244
connection-client-ps	152	0	IESG	RFC 9244
request-ps	153	0	IESG	RFC 9244
request-client-ps	154	0	IESG	RFC 9244
partial-request-max	155	0	IESG	RFC 9244

partial-request-client-max	156	0	IESG	RFC 9244
total-attack-connection	157	5	IESG	RFC 9244
connection-c	158	5	IESG	RFC 9244
embryonic-c	159	5	IESG	RFC 9244
connection-ps-c	160	5	IESG	RFC 9244
request-ps-c	161	5	IESG	RFC 9244
attack-detail	162	4	IESG	RFC 9244
id	163	0	IESG	RFC 9244
attack-id	164	0	IESG	RFC 9244
attack-description	165	3	IESG	RFC 9244
attack-severity	166	0	IESG	RFC 9244
start-time	167	0	IESG	RFC 9244
end-time	168	0	IESG	RFC 9244
source-count	169	5	IESG	RFC 9244
top-talker	170	5	IESG	RFC 9244
spoofed-status	171	7	IESG	RFC 9244
partial-request-c	172	5	IESG	RFC 9244
total-attack-connection-protocol	173	4	IESG	RFC 9244
baseline	174	4	IESG	RFC 9244
current-config	175	5	IESG	RFC 9244
max-config-values	176	5	IESG	RFC 9244
min-config-values	177	5	IESG	RFC 9244
supported-unit-classes	178	5	IESG	RFC 9244
server-originated-telemetry	179	7	IESG	RFC 9244
telemetry-notify-interval	180	0	IESG	RFC 9244
tmid	181	0	IESG	RFC 9244
measurement-interval	182	0	IESG	RFC 9244
measurement-sample	183	0	IESG	RFC 9244
talker	184	4	IESG	RFC 9244
source-prefix	185	3	IESG	RFC 9244
mid-list	186	4	IESG	RFC 9244
source-port-range	187	4	IESG	RFC 9244

source-icmp-type-range	188	4	IESG	RFC 9244
target	189	5	IESG	RFC 9244
capacity	190	0	IESG	RFC 9244
protocol	191	0	IESG	RFC 9244
total-traffic-normal-per-protocol	192	4	IESG	RFC 9244
total-traffic-normal-per-port	193	4	IESG	RFC 9244
total-connection-capacity-per-port	194	4	IESG	RFC 9244
total-traffic-protocol	195	4	IESG	RFC 9244
total-traffic-port	196	4	IESG	RFC 9244
total-attack-traffic-protocol	197	4	IESG	RFC 9244
total-attack-traffic-port	198	4	IESG	RFC 9244
total-attack-connection-port	199	4	IESG	RFC 9244
port	200	0	IESG	RFC 9244
supported-query-type	201	4	IESG	RFC 9244
vendor-id	202	0	IESG	RFC 9244
ietf-dots-telemetry:telemetry-setup	203	5	IESG	RFC 9244
ietf-dots-telemetry:total-traffic	204	4	IESG	RFC 9244
ietf-dots-telemetry:total-attack-traffic	205	4	IESG	RFC 9244
ietf-dots-telemetry:total-attack-connection	206	5	IESG	RFC 9244
ietf-dots-telemetry:attack-detail	207	4	IESG	RFC 9244
ietf-dots-telemetry:telemetry	208	5	IESG	RFC 9244
current-g	209	0	IESG	RFC 9244
description-lang	210	3	IESG	RFC 9244

Table 4: Registered DOTS Signal Channel CBOR Key Values

13.2. DOTS Signal Channel Conflict Cause Codes

Per this document, IANA has assigned a new code from the "DOTS Signal

Channel Conflict Cause Codes" registry [Cause].

```
+======+==================+=========================+==========+
| Code | Label            | Description             | Reference |
+======+==================+=========================+==========+
| 5    | overlapping-pipes | Overlapping pipe scope | RFC 9244  |
+------+------------------+-------------------------+----------+
```

        Table 5: Registered DOTS Signal Channel Conflict Cause Code

13.3. DOTS Telemetry URIs and YANG Module Registrations

   Per this document, IANA has registered the following URIs in the "ns"
   subregistry within the "IETF XML Registry" [RFC3688]:

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

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

   Per this document, IANA has registered the following YANG modules in
   the "YANG Module Names" subregistry [RFC6020] within the "YANG
   Parameters" registry.

   Name: ietf-dots-telemetry
   Namespace: urn:ietf:params:xml:ns:yang:ietf-dots-telemetry
   Maintained by IANA: N
   Prefix: dots-telemetry
   Reference: RFC 9244

   Name: ietf-dots-mapping
   Namespace: urn:ietf:params:xml:ns:yang:ietf-dots-mapping
   Maintained by IANA: N
   Prefix: dots-mapping
   Reference: RFC 9244

14. Security Considerations

14.1. DOTS Signal Channel Telemetry

   The security considerations for the DOTS signal channel protocol are
   discussed in Section 11 of [RFC9132]. The following discusses the
   security considerations that are specific to the DOTS signal channel
   extension defined in this document.

   The DOTS telemetry information includes DOTS client network topology,
   DOTS client domain pipe capacity, normal traffic baseline and
   connection capacity, and threat and mitigation information. Such
   information is sensitive; it MUST be protected at rest by the DOTS
   server domain to prevent data leakage. Note that sharing this
   sensitive data with a trusted DOTS server does not introduce any new
   significant considerations other than the need for the aforementioned
   protection. Such a DOTS server is already trusted to have access to
   that kind of information by being in the position to observe and
   mitigate attacks.

   DOTS clients are typically considered to be trusted devices by the
   DOTS client domain. DOTS clients may be co-located on network
   security services (e.g., firewall devices), and a compromised
   security service potentially can do a lot more damage to the network
   than just the DOTS client component. This assumption differs from
   the often-held view (often referred to as the "zero-trust model")
   that devices are untrusted. A compromised DOTS client can send fake
   DOTS telemetry data to a DOTS server to mislead the DOTS server.
   This attack can be prevented by monitoring and auditing DOTS clients
   to detect misbehavior and to deter misuse, and by only authorizing
   the DOTS client to convey DOTS telemetry information for specific
   target resources (e.g., an application server is authorized to

exchange DOTS telemetry for its IP addresses but a DDoS mitigator can exchange DOTS telemetry for any target resource in the network). As a reminder, this is a variation of dealing with compromised DOTS clients as discussed in Section 11 of [RFC9132].

DOTS servers must be capable of defending themselves against DoS attacks from compromised DOTS clients. The following non-comprehensive list of mitigation techniques can be used by a DOTS server to handle misbehaving DOTS clients:

* The probing rate (defined in Section 4.5 of [RFC9132]) can be used to limit the average data rate to the DOTS server.

* Rate-limiting DOTS telemetry, including packets with new 'tmid' values from the same DOTS client, defends against DoS attacks that would result in varying the 'tmid' to exhaust DOTS server resources. Likewise, the DOTS server can enforce a quota and time limit on the number of active pre-or-ongoing-mitigation telemetry data items (identified by 'tmid') from the DOTS client.

Note also that the telemetry notification interval may be used to rate-limit the pre-or-ongoing-mitigation telemetry notifications received by a DOTS client domain.

14.2. Vendor Attack Mapping

The security considerations for the DOTS data channel protocol are discussed in Section 10 of [RFC8783]. The following discusses the security considerations that are specific to the DOTS data channel extension defined in this document.

All data nodes defined in the YANG module specified in Section 11.2 that can be created, modified, and deleted (i.e., config true, which is the default) are considered sensitive. Write operations to these data nodes without proper protection can have a negative effect on network operations. Appropriate security measures are recommended to prevent illegitimate users from invoking DOTS data channel primitives as discussed in [RFC8783]. Nevertheless, an attacker who can access a DOTS client is technically capable of undertaking various attacks, such as:

* Communicating invalid attack mapping details to the server ('/data-channel:dots-data/data-channel:dots-client/dots-telemetry:vendor-mapping'), which will mislead the server when correlating attack details.

Some of the readable data nodes in the YANG module specified in Section 11.2 may be considered sensitive. It is thus important to control read access to these data nodes. These are the data nodes and their sensitivity:

* '/data-channel:dots-data/data-channel:dots-client/dots-telemetry:vendor-mapping' can be misused to infer the DDoS protection technology deployed in a DOTS client domain.

* '/data-channel:dots-data/dots-telemetry:vendor-mapping' can be used by a compromised DOTS client to leak the attack detection capabilities of the DOTS server. This is a variation of the compromised DOTS client attacks discussed in Section 14.1.

15. References

15.1. Normative References

[Private-Enterprise-Numbers]
          IANA, "Private Enterprise Numbers",
          <https://www.iana.org/assignments/enterprise-numbers/>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate
          Requirement Levels", BCP 14, RFC 2119,
          DOI 10.17487/RFC2119, March 1997,

                  <https://www.rfc-editor.org/info/rfc2119>.

[RFC3688]   Mealling, M., "The IETF XML Registry", BCP 81, RFC 3688,
             DOI 10.17487/RFC3688, January 2004,
             <https://www.rfc-editor.org/info/rfc3688>.

[RFC5646]   Phillips, A., Ed. and M. Davis, Ed., "Tags for Identifying
             Languages", BCP 47, RFC 5646, DOI 10.17487/RFC5646,
             September 2009, <https://www.rfc-editor.org/info/rfc5646>.

[RFC6020]   Bjorklund, M., Ed., "YANG - A Data Modeling Language for
             the Network Configuration Protocol (NETCONF)", RFC 6020,
             DOI 10.17487/RFC6020, October 2010,
             <https://www.rfc-editor.org/info/rfc6020>.

[RFC6991]   Schoenwaelder, J., Ed., "Common YANG Data Types",
             RFC 6991, DOI 10.17487/RFC6991, July 2013,
             <https://www.rfc-editor.org/info/rfc6991>.

[RFC7252]   Shelby, Z., Hartke, K., and C. Bormann, "The Constrained
             Application Protocol (CoAP)", RFC 7252,
             DOI 10.17487/RFC7252, June 2014,
             <https://www.rfc-editor.org/info/rfc7252>.

[RFC7641]   Hartke, K., "Observing Resources in the Constrained
             Application Protocol (CoAP)", RFC 7641,
             DOI 10.17487/RFC7641, September 2015,
             <https://www.rfc-editor.org/info/rfc7641>.

[RFC7950]   Bjorklund, M., Ed., "The YANG 1.1 Data Modeling Language",
             RFC 7950, DOI 10.17487/RFC7950, August 2016,
             <https://www.rfc-editor.org/info/rfc7950>.

[RFC7959]   Bormann, C. and Z. Shelby, Ed., "Block-Wise Transfers in
             the Constrained Application Protocol (CoAP)", RFC 7959,
             DOI 10.17487/RFC7959, August 2016,
             <https://www.rfc-editor.org/info/rfc7959>.

[RFC7970]   Danyliw, R., "The Incident Object Description Exchange
             Format Version 2", RFC 7970, DOI 10.17487/RFC7970,
             November 2016, <https://www.rfc-editor.org/info/rfc7970>.

[RFC8040]   Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF
             Protocol", RFC 8040, DOI 10.17487/RFC8040, January 2017,
             <https://www.rfc-editor.org/info/rfc8040>.

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

[RFC8345]   Clemm, A., Medved, J., Varga, R., Bahadur, N.,
             Ananthakrishnan, H., and X. Liu, "A YANG Data Model for
             Network Topologies", RFC 8345, DOI 10.17487/RFC8345, March
             2018, <https://www.rfc-editor.org/info/rfc8345>.

[RFC8783]   Boucadair, M., Ed. and T. Reddy.K, Ed., "Distributed
             Denial-of-Service Open Threat Signaling (DOTS) Data
             Channel Specification", RFC 8783, DOI 10.17487/RFC8783,
             May 2020, <https://www.rfc-editor.org/info/rfc8783>.

[RFC8791]   Bierman, A., Björklund, M., and K. Watsen, "YANG Data
             Structure Extensions", RFC 8791, DOI 10.17487/RFC8791,
             June 2020, <https://www.rfc-editor.org/info/rfc8791>.

[RFC8949]   Bormann, C. and P. Hoffman, "Concise Binary Object
             Representation (CBOR)", STD 94, RFC 8949,
             DOI 10.17487/RFC8949, December 2020,
             <https://www.rfc-editor.org/info/rfc8949>.

[RFC9132]   Boucadair, M., Ed., Shallow, J., and T. Reddy.K,
             "Distributed Denial-of-Service Open Threat Signaling

                  (DOTS) Signal Channel Specification", RFC 9132,
                  DOI 10.17487/RFC9132, September 2021,
                  <https://www.rfc-editor.org/info/rfc9132>.

15.2. Informative References

   [Cause]   IANA, "DOTS Signal Channel Conflict Cause Codes",
                  <https://www.iana.org/assignments/dots/>.

   [DOTS-Multihoming]
                  Boucadair, M., Reddy.K, T., and W. Pan, "Multi-homing
                  Deployment Considerations for Distributed-Denial-of-
                  Service Open Threat Signaling (DOTS)", Work in Progress,
                  Internet-Draft, draft-ietf-dots-multihoming-13, 26 April
                  2022, <https://datatracker.ietf.org/doc/html/draft-ietf-
                  dots-multihoming-13>.

   [DOTS-Robust-Blocks]
                  Boucadair, M. and J. Shallow, "Distributed Denial-of-
                  Service Open Threat Signaling (DOTS) Signal Channel
                  Configuration Attributes for Robust Block Transmission",
                  Work in Progress, Internet-Draft, draft-ietf-dots-robust-
                  blocks-03, 11 February 2022,
                  <https://datatracker.ietf.org/doc/html/draft-ietf-dots-
                  robust-blocks-03>.

   [DOTS-Telemetry-Specs]
                  Doron, E., Reddy, T., Andreasen, F., Xia, L., and K.
                  Nishizuka, "Distributed Denial-of-Service Open Threat
                  Signaling (DOTS) Telemetry Specifications", Work in
                  Progress, Internet-Draft, draft-doron-dots-telemetry-00,
                  30 October 2016, <https://datatracker.ietf.org/doc/html/
                  draft-doron-dots-telemetry-00>.

   [Key-Map]   IANA, "DOTS Signal Channel CBOR Key Values",
                  <https://www.iana.org/assignments/dots/>.

   [PYANG]   "pyang", commit dad5c68, April 2022,
                  <https://github.com/mbj4668/pyang>.

   [RFC2330]   Paxson, V., Almes, G., Mahdavi, J., and M. Mathis,
                  "Framework for IP Performance Metrics", RFC 2330,
                  DOI 10.17487/RFC2330, May 1998,
                  <https://www.rfc-editor.org/info/rfc2330>.

   [RFC4732]   Handley, M., Ed., Rescorla, E., Ed., and IAB, "Internet
                  Denial-of-Service Considerations", RFC 4732,
                  DOI 10.17487/RFC4732, December 2006,
                  <https://www.rfc-editor.org/info/rfc4732>.

   [RFC5612]   Eronen, P. and D. Harrington, "Enterprise Number for
                  Documentation Use", RFC 5612, DOI 10.17487/RFC5612, August
                  2009, <https://www.rfc-editor.org/info/rfc5612>.

   [RFC8340]   Bjorklund, M. and L. Berger, Ed., "YANG Tree Diagrams",
                  BCP 215, RFC 8340, DOI 10.17487/RFC8340, March 2018,
                  <https://www.rfc-editor.org/info/rfc8340>.

   [RFC8525]   Bierman, A., Bjorklund, M., Schoenwaelder, J., Watsen, K.,
                  and R. Wilton, "YANG Library", RFC 8525,
                  DOI 10.17487/RFC8525, March 2019,
                  <https://www.rfc-editor.org/info/rfc8525>.

   [RFC8612]   Mortensen, A., Reddy, T., and R. Moskowitz, "DDoS Open
                  Threat Signaling (DOTS) Requirements", RFC 8612,
                  DOI 10.17487/RFC8612, May 2019,
                  <https://www.rfc-editor.org/info/rfc8612>.

   [RFC8811]   Mortensen, A., Ed., Reddy.K, T., Ed., Andreasen, F.,
                  Teague, N., and R. Compton, "DDoS Open Threat Signaling
                  (DOTS) Architecture", RFC 8811, DOI 10.17487/RFC8811,

              August 2020, <https://www.rfc-editor.org/info/rfc8811>.

   [RFC8903] Dobbins, R., Migault, D., Moskowitz, R., Teague, N., Xia,
              L., and K. Nishizuka, "Use Cases for DDoS Open Threat
              Signaling", RFC 8903, DOI 10.17487/RFC8903, May 2021,
              <https://www.rfc-editor.org/info/rfc8903>.

   [RFC9133] Nishizuka, K., Boucadair, M., Reddy.K, T., and T. Nagata,
              "Controlling Filtering Rules Using Distributed Denial-of-
              Service Open Threat Signaling (DOTS) Signal Channel",
              RFC 9133, DOI 10.17487/RFC9133, September 2021,
              <https://www.rfc-editor.org/info/rfc9133>.

   [RFC9177] Boucadair, M. and J. Shallow, "Constrained Application
              Protocol (CoAP) Block-Wise Transfer Options Supporting
              Robust Transmission", RFC 9177, DOI 10.17487/RFC9177,
              March 2022, <https://www.rfc-editor.org/info/rfc9177>.

   [RFC9260] Stewart, R., Tüxen, M., and K. Nielsen, "Stream Control
              Transmission Protocol", RFC 9260, DOI 10.17487/RFC9260,
              June 2022, <https://www.rfc-editor.org/info/rfc9260>.

Contributors

   The following individuals have contributed to this document:

   Li Su
   CMCC
   Email: suli@chinamobile.com

   Pan Wei
   Huawei
   Email: william.panwei@huawei.com

Authors' Addresses

   Mohamed Boucadair (editor)
   Orange
   35000 Rennes
   France
   Email: mohamed.boucadair@orange.com

   Tirumaleswar Reddy.K (editor)
   Akamai
   Embassy Golf Link Business Park

Bangalore 560071
Karnataka
India
Email: kondtir@gmail.com

Ehud Doron
Radware Ltd.
Raoul Wallenberg Street
Tel-Aviv 69710
Israel
Email: ehudd@radware.com

Meiling Chen
CMCC
32 Xuanwumen West Street
Beijing
100053
China
Email: chenmeiling@chinamobile.com

Jon Shallow
United Kingdom
Email: supjps-ietf@jpshallow.com