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Methodology for IP Multicast Benchmarking
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Abstract

   The purpose of this document is to describe methodology specific to
   the benchmarking of multicast IP forwarding devices. It builds upon
   the tenets set forth in RFC 2544, RFC 2432 and other IETF
   Benchmarking Methodology Working Group (BMWG) efforts. This
   document seeks to extend these efforts to the multicast paradigm.

   The BMWG produces two major classes of documents: Benchmarking
   Terminology documents and Benchmarking Methodology documents. The
   Terminology documents present the benchmarks and other related
   terms. The Methodology documents define the procedures required to
   collect the benchmarks cited in the corresponding Terminology
   documents.

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1. Introduction

This document defines tests for measuring and reporting the
forwarding, latency and IGMP group membership characteristics of
devices that support IP multicast routing protocols. The results
of these tests will provide the user with meaningful data on
multicast performance.

A previous document, " Terminology for IP Multicast Benchmarking"
(RFC 2432), defined many of the terms that are used in this
document. The terminology document should be consulted before
attempting to make use of this document.

This methodology will focus on one source to many destinations,
although many of the tests described may be extended to use
multiple source to multiple destination topologies.

2. Key Words to Reflect Requirements

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL
NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL"
in this document are to be interpreted as described in RFC 2119.
RFC 2119 defines the use of these key words to help make the intent
of standards track documents as clear as possible. While this
document uses these keywords, this document is not a standards
track document.

3. Test set up

The set of methodologies presented in this document are for single
ingress, multiple egress scenarios as exemplified by Figures 1 and
2. Methodologies for multiple ingress and multiple egress
scenarios are beyond the scope of this document.

Figure 1 shows a typical setup for an IP multicast test, with one
source to multiple destinations.

```
                        +-----------+           +--------------+
                        |           |           | destination  |
         +--------+     |    Egress(-)------->|     test     |
         | source |     |           |           |   port(E1)   |
         |  test  |------>(|)Ingress  |           +--------------+
         |  port  |     |           |           +--------------+
         +--------+     |    Egress(-)------->|  destination |
                        |           |           |     test     |
                        |           |           |   port(E2)   |
                        |   DUT     |           +--------------+
                        |           |                . . .
                        |           |           +--------------+
                        |           |           | destination  |
                        |    Egress(-)------->|     test     |
                        |           |           |   port(En)   |
                        +-----------+           +--------------+
```
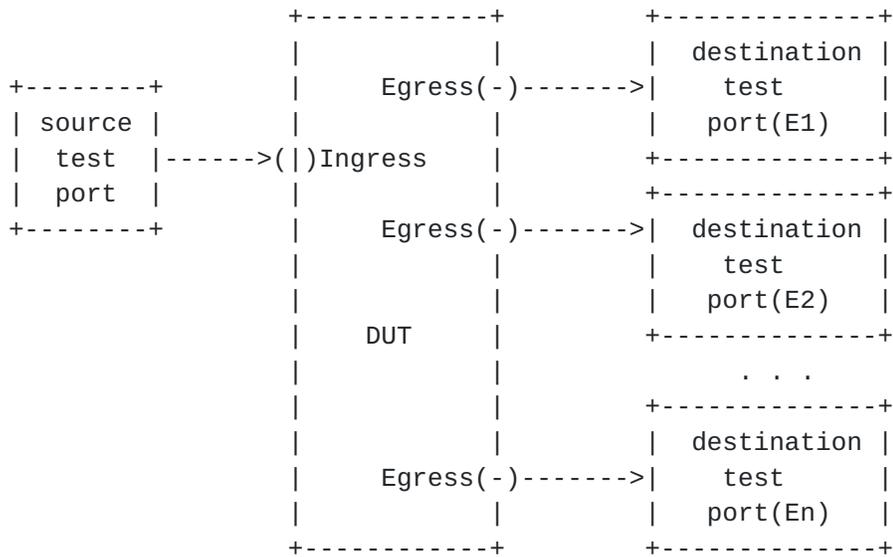
                              Figure 1

   If the multicast metrics are to be taken across multiple devices
   forming a System Under Test (SUT), then test frames are offered to
   a single ingress interface on a device of the SUT, subsequently
   forwarded across the SUT topology, and finally forwarded to the
   test apparatus' frame-receiving components by the test egress
   interface(s) of devices in the SUT. Figure 2 offers an example SUT
   test topology. If a SUT is tested, the test topology and all
   relevant configuration details MUST be disclosed with the
   corresponding test results.

```
              *-------------------------------------------*
              |                                           |
 +--------+   |                    +---------------+   |  +--------+
 |        |   |   +------------+    |DUT B Egress E0(-)-|->|        |
 |        |   |   |DUT A       |--->|               | |  |        |
 | Test   |   |   |            |    |    Egress E1(-)-|->| Test   |
 | App.   |--|->(-)Ingress, I |    +---------------+ |  | App.   |
 | Traffic|   |   |            |    +---------------+ |  | Traffic|
 | Src.   |   |   |            |--->|DUT C Egress E2(-)-|->| Dest.  |
 |        |   |   +------------+    |               | |  |        |
 |        |   |                     |    Egress En(-)--|->|        |
 +--------+   |                    +---------------+ |  +--------+
              |                                           |
              *-----------------SUT-------------------*
```
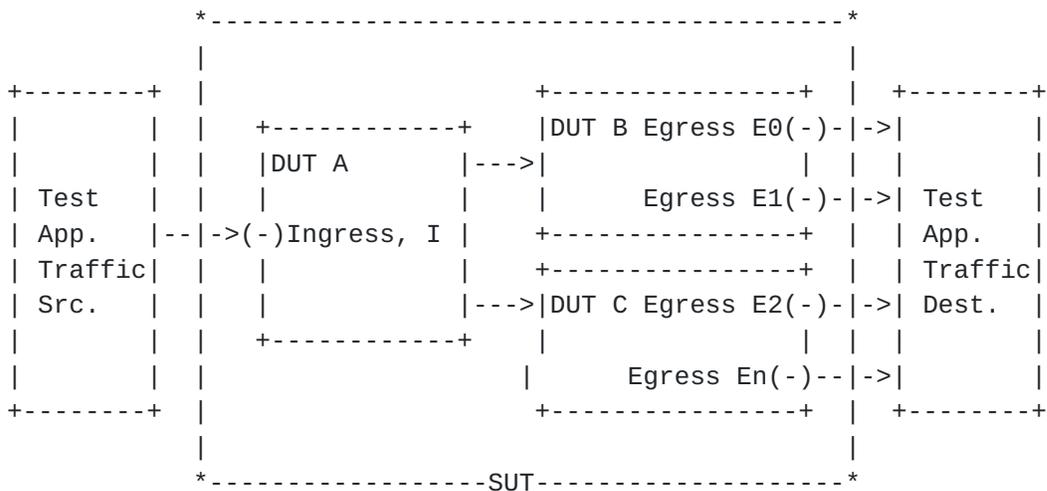
                              Figure 2

Generally, the destination test ports first join the desired number
of multicast groups by sending IGMP Group Report messages to the
DUT/SUT. To verify that all destination test ports successfully
joined the appropriate groups, the source port MUST transmit IP

multicast frames destined for these groups. The destination test
ports MAY send IGMP Leave Group messages after the transmission of
IP Multicast frames to clear the IGMP table of the DUT/SUT.

In addition, test equipment MUST validate the correct and proper
forwarding actions of the devices they test in order to ensure the
receipt of the frames that are involved in the test.

3.1. Test Considerations

The methodology assumes a uniform medium topology. Issues regarding
mixed transmission media, such as speed mismatch, headers
differences, etc., are not specifically addressed. Flow control,
QoS and other non-essential traffic or traffic-affecting mechanisms
affecting the variable under test MUST be disabled. Modifications
to the collection procedures might need to be made to accommodate
the transmission media actually tested. These accommodations MUST
be presented with the test results.

An actual flow of test traffic may be required to prime related
mechanisms, (e.g., process RPF events, build device caches, etc.)
to optimally forward subsequent traffic. Therefore, before an
initial, measured forwarding test trial, the test apparatus MUST
generate test traffic utilizing the same addressing characteristics
to the DUT/SUT that will subsequently be used to measure the
DUT/SUT response. The test monitor should ensure the correct
forwarding of traffic by the DUT/SUT. The priming action need only
be repeated to keep the associated information current.

3.1.1. IGMP Support

All of the ingress and egress interfaces MAY support any version of
IGMP. The IGMP version on the ingress interface MUST be the same
version of IGMP that is being tested on the egress interfaces.

Each of the ingress and egress interfaces SHOULD be able to respond
to IGMP queries during the test.

Each of the ingress and egress interfaces SHOULD also send LEAVE
(running IGMP version 2 or later) after each test.

3.1.2. Group Addresses

It is intended that the collection of benchmarks prescribed in this
document be executed in an isolated lab environment. That is to
say, the test traffic offered the tested devices MUST NOT traverse

a live internet, intranet, or other production network.

Assuming the above, there is no restriction to the use of multicast addresses to compose the test traffic other than those assignments imposed by IANA. The IANA assignments MUST be regarded for operational consistency. For multicast address assignments see:

http://www.iana.org/assignments/multicast-addresses

Address selection does not need to be restricted to Administratively Scoped IP Multicast addresses.

3.1.3. Frame Sizes

Each test SHOULD be run with different multicast frame sizes. For Ethernet, the recommended sizes are 64, 128, 256, 512, 1024, 1280, and 1518 byte frames.

Other link layer technologies MAY be used. The minimum and maximum frame lengths of the link layer technology in use SHOULD be tested.

When testing with different frame sizes, the DUT/SUT configuration MUST remain the same.

3.1.4. TTL

The data plane test traffic should have a TTL value large enough to traverse the DUT/SUT.

The TTL in IGMP control plane messages is in compliance with the version of IGMP in use.

3.1.5. Trial Duration

The duration of the test portion of each trial SHOULD be at least 30 seconds. This parameter MUST be included as part of the results reporting for each methodology.

4. Forwarding and Throughput

This section contains the description of the tests that are related to the characterization of the frame forwarding of a DUT/SUT in a multicast environment. Some metrics extend the concept of throughput presented in RFC 1242. Forwarding Rate is cited in RFC 2285.

4.1. Mixed Class Throughput

Objective:

To determine the throughput of a DUT/SUT when both unicast class
frames and multicast class frames are offered simultaneously to a
fixed number of interfaces as defined in RFC 2432.

Procedure:

Multicast and unicast traffic are mixed together in the same
aggregated traffic stream in order to simulate the non-homogenous
networking environment.

The following events MUST occur before offering test traffic:

      o All DUT/SUT egress interfaces configured to receive
        multicast traffic MUST join all configured multicast
        groups;
      o The DUT/SUT MUST learn the appropriate unicast addresses;
        and
      o Group membership and unicast address learning MUST be
        verified through some externally observable method.

The intended load [Ma98] SHOULD be configured as alternating
multicast frames and unicast frames to a single ingress interface
in a 50-50 ratio. The unicast frames MUST be configured to
transmit in a round-robin fashion to all of the egress interfaces.
The multicast frames MUST be configured to transmit to all of the
egress interfaces.

Mixed class throughput measurement is defined in RFC2432 [Du98]. A
search algorithm MUST be utilized to determine the throughput for
both unicast class and multicast class traffic in a mixed class
environment.

Reporting Format:

The following configuration parameters MUST be reflected in the
results specific to this methodology:

      o Frame size(s)
      o Number of tested egress interfaces on the DUT/SUT
      o Test duration
      o IGMP version
      o Total number of multicast groups
      o Traffic distribution for unicast and multicast traffic

classes
       o The ratio of multicast and unicast traffic must be declared

The following results MUST be reflected in the results specific to this methodology:

> o Mixed Class Throughput as defined in RFC2432 [Du98], including: Throughput per unicast and multicast traffic classes.

The Mixed Class Throughput results for each test SHOULD be reported in the form of a table with a row for each of the tested frame sizes per the recommendations in section 3.1.3. Each row SHOULD specify the intended load, number of multicast frames offered, number of unicast frames offered and measured throughput per class.

4.2. Scaled Group Forwarding Matrix

Objective:

To determine Forwarding Rate as a function of tested multicast groups for a fixed number of tested DUT/SUT ports.

Procedure:

This is an iterative procedure. The destination test port(s) MUST join an initial number of multicast groups on the first iteration. All DUT/SUT destination test port(s) configured to receive multicast traffic MUST join all configured multicast groups. The recommended number of groups to join on the first iteration is 10 groups. Multicast traffic is subsequently transmitted to all groups joined on this iteration.

The number of multicast groups joined by each destination test port is then incremented, or scaled, by an additional number of multicast groups. The recommended granularity of additional groups to join per iteration is 10, although the tester MAY choose a finer granularity. Multicast traffic is subsequently transmitted to all groups joined during this iteration.

The total number of multicast groups joined MUST not exceed the capacity of the DUT/SUT. Both Group Join Delay and Group Capacity results MUST be known prior to running this test.

Reporting Format:

The following configuration parameters MUST be reflected in the results specific to this methodology:

        o Frame size(s)
        o Number of tested egress interfaces on the DUT/SUT
        o Test duration
        o IGMP version

The following results MUST be reflected in the results specific to
this methodology:

        o The total number of multicast groups joined for that
          iteration
        o Total number of frames transmitted
        o Total number of frames received
        o Offered load
        o Forwarding rate determined for that iteration

The Scaled Group Forwarding results for each test SHOULD be
reported in the form of a table with a row representing each
iteration of the test. Each row or iteration SHOULD specify the
total number of groups joined for that iteration, total number of
frames transmitted, total number of frames received and the
aggregate forwarding rate determined for that iteration.

4.3. Aggregated Multicast Throughput

Objective:

To determine the maximum rate at which none of the offered frames
to be forwarded through N destination interfaces of the same
multicast groups are dropped.

Procedure:

Offer multicast traffic at an initial fixed offered load to a fixed
set of interfaces with a fixed number of groups at a fixed frame
length for a fixed duration of time. All destination test ports
MUST join all specified multicast groups.

If any frame loss is detected, the offered load is decreased and
the sender will transmit again. An iterative search algorithm MUST
be utilized to determine the maximum offered frame rate with a zero
frame loss.

Each iteration will involve varying the offered load of the
multicast traffic, while keeping the set of interfaces, number of
multicast groups, frame length and test duration fixed, until the
maximum rate at which none of the offered frames are dropped is
determined.

Parameters to be measured MUST include the offered load at which no
frame loss occurred.

Reporting Format:

The following configuration parameters MUST be reflected in the
results specific to this methodology:

    o Frame size(s)
    o Number of tested egress interfaces on the DUT/SUT
    o Test duration
    o IGMP version
    o Total number of multicast groups

The following results MUST be reflected in the results specific to
this methodology:

    o Aggregated Multicast Throughput as defined in RFC2432
      [Du98]

The Aggregated Multicast Throughput results SHOULD be reported in
the format of a table with a row for each of the tested frame sizes
per the recommendations in section 3.1.3. Each row or iteration
SHOULD specify offered load, total number of offered frames and the
measured Aggregated Multicast Throughput.

4.4. Encapsulation/Decapsulation (Tunneling) Throughput

This sub-section provides the description of tests that help in
obtaining throughput measurements when a DUT/SUT or a set of DUTs
are acting as tunnel endpoints.

4.4.1. Encapsulation Throughput

Objective:

To determine the maximum rate at which frames offered to one
ingress interface of a DUT/SUT are encapsulated and correctly
forwarded on one or more egress interfaces of the DUT/SUT without
loss.

Procedure:

```
      Source                 DUT/SUT                Destination
     Test Port                                      Test Port(s)
     +---------+           +-----------+            +---------+
     |         |           |           |            |         |
     |         |           |     Egress|--(Tunnel)-->|         |
     |         |           |           |            |         |
     |         |-------->|Ingress    |            |         |
     |         |           |           |            |         |
     |         |           |     Egress|--(Tunnel)-->|         |
     |         |           |           |            |         |
     +---------+           +-----------+            +---------+
```

                          Figure 3

Figure 3 shows the setup for testing the encapsulation throughput
of the DUT/SUT. One or more tunnels are created between each
egress interface of the DUT/SUT and a destination test port. Non-
Encapsulated multicast traffic will then be offered by the source
test port, encapsulated by the DUT/SUT and forwarded to the
destination test port(s).

The DUT/SUT SHOULD be configured such that the traffic across each
egress interface will consist of either:

     a) A single tunnel encapsulating one or more multicast address
        groups OR
     b) Multiple tunnels, each encapsulating one or more multicast
        address groups.

The number of multicast groups per tunnel MUST be the same when the
DUT/SUT is configured in a multiple tunnel configuration. In
addition, it is RECOMMENDED to test with the same number of tunnels
on each egress interface. All destination test ports MUST join all
multicast group addresses offered by the source test port. Each
egress interface MUST be configured with the same MTU.

A search algorithm MUST be utilized to determine the encapsulation
throughput as defined in [Du98].

Reporting Format:

The following configuration parameters MUST be reflected in the
results specific to this methodology:

     o Number of tested egress interfaces on the DUT/SUT

o Test duration
         o IGMP version
         o Total number of multicast groups
         o MTU size of DUT/SUT interfaces

The following results MUST be reflected in the results specific to
this methodology:

> o Measured Encapsulated Throughput as defined in RFC2432
>   [Du98]
> o Encapsulated frame size
> o Originating un-encapsulated frame size
> o Number of tunnels
> o Number of multicast groups per tunnel

The Encapsulated Throughput results SHOULD be reported in the form
of a table and specific to this test there SHOULD be rows for each
originating un-encapsulated frame size. Each row or iteration
SHOULD specify the offered load, encapsulation method, encapsulated
frame size, total number of offered frames, and the encapsulation
throughput.

4.4.2. **Decapsulation Throughput**

Objective:

To determine the maximum rate at which frames offered to one
ingress interface of a DUT/SUT are decapsulated and correctly
forwarded by the DUT/SUT on one or more egress interfaces without
loss.

Procedure:
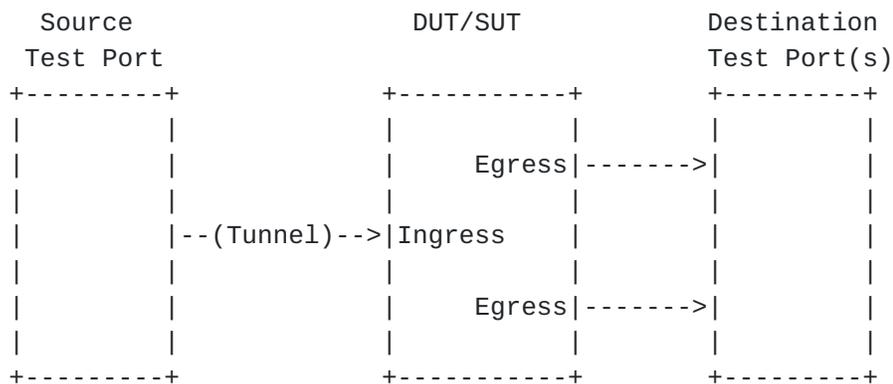
```
      Source                    DUT/SUT            Destination
     Test Port                                     Test Port(s)
    +---------+              +-----------+        +---------+
    |         |              |           |        |         |
    |         |              |     Egress|------->|         |
    |         |              |           |        |         |
    |         |--(Tunnel)-->|Ingress    |        |         |
    |         |              |           |        |         |
    |         |              |     Egress|------->|         |
    |         |              |           |        |         |
    +---------+              +-----------+        +---------+


                         Figure 4
                         ---------
```

Figure 4 shows the setup for testing the decapsulation throughput
of the DUT/SUT. One or more tunnels are created between the source
test port and the DUT/SUT. Encapsulated multicast traffic will

then be offered by the source test port, decapsulated by the
DUT/SUT and forwarded to the destination test port(s).

   The DUT/SUT SHOULD be configured such that the traffic across each
   egress interface will consist of either:

        a) A single tunnel encapsulating one or more multicast address
           groups OR
        b) Multiple tunnels, each encapsulating one or more multicast
           address groups.

   The number of multicast groups per tunnel MUST be the same when the
   DUT/SUT is configured in a multiple tunnel configuration. All
   destination test ports MUST join all multicast group addresses
   offered by the source test port. Each egress interface MUST
   be configured with the same MTU.

   A search algorithm MUST be utilized to determine the decapsulation
   throughput as defined in [Du98].

   Reporting Format:

   The following configuration parameters MUST be reflected in the
   results specific to this methodology:

        o Number of tested egress interfaces on the DUT/SUT
        o Test duration
        o IGMP version
        o Total number of multicast groups
        o MTU size of DUT/SUT interfaces

   The following results MUST be reflected in the results specific to
   this methodology:

        o Measured Decapsulated Throughput as defined in RFC2432
          [Du98]
        o Originating encapsulation format
        o Decapsulated frame size
        o Originating encapsulated frame size
        o Number of tunnels
        o Number of multicast groups per tunnel

   The Decapsulated Throughput results SHOULD be reported in the
   format of a table and specific to this test there SHOULD be rows
   for each originating encapsulated frame size. Each row or
   iteration SHOULD specify the offered load, decapsulated frame size,
   total number of offered frames and the decapsulation throughput.

4.4.3. Re-encapsulation Throughput

Objective:

   To determine the maximum rate at which frames of one encapsulated
   format offered to one ingress interface of a DUT/SUT are converted

to another encapsulated format and correctly forwarded by the
DUT/SUT to one or more egress interfaces without loss.


Procedure:

```
         Source               DUT/SUT              Destination
        Test Port                                 Test Port(s)
       +---------+           +---------+           +---------+
       |         |           |         |           |         |
       |         |           | Egress|-(Tunnel)->|         |
       |         |           |         |           |         |
       |         |-(Tunnel)->|Ingress  |           |         |
       |         |           |         |           |         |
       |         |           | Egress|-(Tunnel)->|         |
       |         |           |         |           |         |
       +---------+           +---------+           +---------+
```
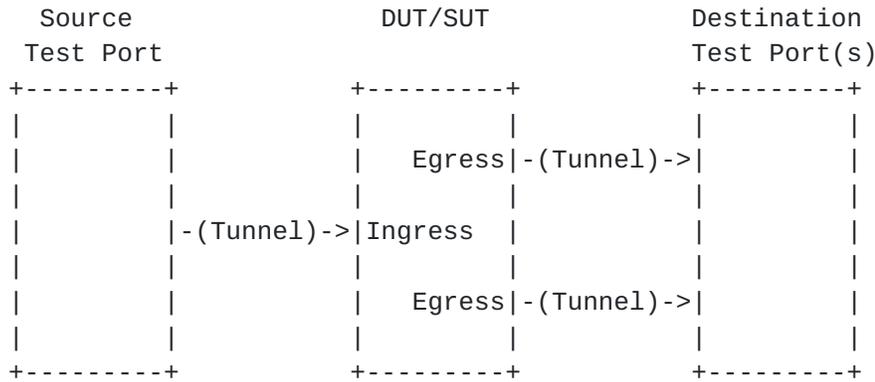
                        Figure 5

Figure 5 shows the setup for testing the Re-encapsulation
throughput of the DUT/SUT. The source test port will offer
encapsulated traffic of one type to the DUT/SUT, which has been
configured to re-encapsulate the offered frames using a different
encapsulation format. The DUT/SUT will then forward the re-
encapsulated frames to the destination test port(s).

The DUT/SUT SHOULD be configured such that the traffic across each
egress interface will consist of either:

     a) A single tunnel encapsulating one or more multicast address
        groups OR
     b) Multiple tunnels, each encapsulating one or more multicast
        address groups.

The number of multicast groups per tunnel MUST be the same when the
DUT/SUT is configured in a multiple tunnel configuration.

In addition, the DUT/SUT SHOULD be configured such that the number
of tunnels on the ingress and each egress interface are the same.
All destination test ports MUST join all multicast group addresses
offered by the source test port. Each egress interface MUST be
configured with the same MTU.

A search algorithm MUST be utilized to determine the re-
encapsulation throughput as defined in [Du98].

Reporting Format:

The following configuration parameters MUST be reflected in the
results specific to this methodology:

        o Number of tested egress interfaces on the DUT/SUT
        o Test duration
        o IGMP version
        o Total number of multicast groups
        o MTU size of DUT/SUT interfaces

   The following results MUST be reflected in the results specific to
   this methodology:

        o Measured Re-encapsulated Throughput as defined in RFC2432
          [Du98]
        o Originating encapsulation format
        o Decapsulated frame size
        o Originating encapsulated frame size
        o Number of tunnels
        o Number of multicast groups per tunnel

   The Decapsulated Throughput results SHOULD be reported in the
   format of a table and specific to this test there SHOULD be rows
   for each originating encapsulated frame size. Each row or
   iteration SHOULD specify the offered load, decapsulated frame size,
   total number of offered frames and the decapsulation throughput

5. **Forwarding Latency**

   This section presents methodologies relating to the
   characterization of the forwarding latency of a DUT/SUT in a
   multicast environment. It extends the concept of latency
   characterization presented in RFC 2544.

   To lessen the effect of frame buffering in the DUT/SUT, the latency
   tests MUST be run at the measured multicast throughput level of the
   DUT; multicast latency at other offered loads is optional.

   Lastly, RFC 1242 and RFC 2544 draw a distinction between device
   types: "store and forward" and "bit-forwarding." Each type impacts
   how latency is collected and subsequently presented. See the
   related RFCs for more information. In practice, much of the test
   equipment will collect the latency measurement for one type or the
   other, and, if needed, mathematically derive the reported value by
   the addition or subtraction of values accounting for medium
   propagation delay of the frame, bit times to the timestamp trigger
   within the frame, etc.

5.1. Multicast Latency

Objective:

To produce a set of multicast latency measurements from a single, multicast ingress interface of a DUT/SUT through multiple, egress multicast interfaces of that same DUT/SUT as provided for by the metric "Multicast Latency" in RFC 2432.

The Procedures highlighted below attempt to draw from the collection methodology for latency in RFC 2544 to the degree possible. The methodology addresses two topological scenarios: one for a single device (DUT) characterization; a second scenario is presented or multiple device (SUT) characterization.

Procedure:

If the test trial is to characterize latency across a single Device Under Test (DUT), an example test topology might take the form of Figure 1 in section 3. That is, a single DUT with one ingress interface receiving the multicast test traffic from frame-transmitting component of the test apparatus and n egress interfaces on the same DUT forwarding the multicast test traffic back to the frame-receiving component of the test apparatus. Note that n reflects the number of TESTED egress interfaces on the DUT actually expected to forward the test traffic (as opposed to configured but untested, non-forwarding interfaces, for example).

If the multicast latencies are to be taken across multiple devices forming a System Under Test (SUT), an example test topology might take the form of Figure 2 in section 3.

The trial duration SHOULD be 120 seconds to be consistent with RFC 2544. The nature of the latency measurement, "store and forward" or "bit forwarding," MUST be associated with the related test trial(s) and disclosed in the results report.

End-to-end reachability of the test traffic path MUST be verified prior to the engagement of a test trial. This implies that subsequent measurements are intended to characterize the latency across the tested device's or devices' normal traffic forwarding path (e.g., faster hardware-based engines) of the device(s) as opposed a non-standard traffic processing path (e.g. slower, software-based exception handlers). If the test trial is to be executed with the intent of characterizing a non-optimal, forwarding condition, then a description of the exception processing conditions being characterized MUST be included with the trial's results.

A test traffic stream is presented to the DUT. It is RECOMMENDED to
offer traffic at the measured aggregated multicast throughput rate

(Section 4.3). At the mid-point of the trial's duration, the test
apparatus MUST inject a uniquely identifiable ("tagged") frame into
the test traffic frames being presented. This tagged frame will be
the basis for the latency measurements. By "uniquely identifiable,"
it is meant that the test apparatus MUST be able to discern the
"tagged" frame from the other frames comprising the test traffic
set. A frame generation timestamp, Timestamp A, reflecting the
completion of the transmission of the tagged frame by the test
apparatus, MUST be determined.

The test apparatus then monitors frames from the DUT's tested
egress interface(s) for the expected tagged frame(s) until the
cessation of traffic generation at the end of the configured trial
duration.

The test apparatus MUST record the time of the successful detection
of a tagged frame from a tested egress interface with a timestamp,
Timestamp B. A set of Timestamp B values MUST be collected for all
tested egress interfaces of the DUT/SUT. See RFC 1242 [Br91] for
additional discussion regarding store and forward devices and bit
forwarding devices.

A trial MUST be considered INVALID should any of the following
conditions occur in the collection of the trial data:

     o Forwarded test frames directed to improper destinations.
     o Unexpected differences between Intended Load and Offered
       Load or unexpected differences between Offered Load and the
       resulting Forwarding Rate(s) on the DUT/SUT egress ports.
     o Forwarded test frames improperly formed or frame header
       fields improperly manipulated.
     o Failure to forward required tagged frame(s) on all expected
       egress interfaces.
     o Reception of a tagged frame by the test apparatus outside
       the configured test duration interval or 5 seconds,
       whichever is greater.

Data from invalid trials SHOULD be considered inconclusive. Data
from invalid trials MUST not form the basis of comparison.

The set of latency measurements, M, composed from each latency
measurement taken from every ingress/tested egress interface
pairing MUST be determined from a valid test trial:

      M = { (Timestamp B(E0) - Timestamp A),
            (Timestamp B(E1) - Timestamp A), ...
            (Timestamp B(En) - Timestamp A) }

where (E0 ... En) represents the range of all tested egress
interfaces and Timestamp B represents a tagged frame detection
event for a given DUT/SUT tested egress interface.

A more continuous profile MAY be built from a series of individual
measurements.

Reporting Format:

The following configuration parameters MUST be reflected in the
results specific to this methodology:

> o Frame size(s)
> o Number of tested egress interfaces on the DUT/SUT
> o Test duration
> o IGMP version
> o Offered load
> o Total number of multicast groups

The following results MUST be reflected in the results specific to
this methodology:

> o The time units of the presented latency MUST be uniform and
>   with sufficient precision for the medium or media being
>   tested.
> o Specifically, when reporting the results of a valid test
>   trial, the set of all latencies related to the tested
>   ingress and each tested egress DUT/SUT interface of MUST be
>   presented.

The latency results for each test SHOULD be reported in the form of
a table, with a row for each of the tested frame sizes per the
recommended frame sizes in section 3.1.3, and SHOULD preserve the
relationship of latency to ingress/egress interface(s) to assist in
trending across multiple trials.

5.2. Min/Max Multicast Latency

Objective:

To determine the difference between the maximum latency measurement
and the minimum latency measurement from a collected set of
latencies produced by the Multicast Latency benchmark.

Procedure:

Collect a set of multicast latency measurements over a single test
duration, as prescribed in [section 5.1](). This will produce a set of

multicast latencies, M, where M is composed of individual
forwarding latencies between DUT frame ingress and DUT frame egress
port pairs. E.g.:

$$M = \{L(I,E1),L(I,E2), ..., L(I,En)\}$$

where L is the latency between a tested ingress interface, I, of
the DUT, and Ex a specific, tested multicast egress interface of
the DUT. E1 through En are unique egress interfaces on the DUT.

From the collected multicast latency measurements in set M,
identify MAX(M), where MAX is a function that yields the largest
latency value from set M.

Identify MIN(M), when MIN is a function that yields the smallest
latency value from set M.

The Max/Min value is determined from the following formula:

$$Result = MAX(M) - MIN(M)$$

A more continuous profile MAY be built from a series of individual
measurements.

Reporting Format:

The following configuration parameters MUST be reflected in the
results specific to this methodology:

    o Frame size(s)
    o Number of tested egress interfaces on the DUT/SUT
    o Test duration
    o IGMP version
    o Offered load
    o Total number of multicast groups

The following results MUST be reflected in the results specific to
this methodology:

    o The result of the min/max value represented as a single
      numerical value in time units consistent with the
      corresponding latency measurements.
    o Specifically, when reporting the results of a valid test
      trial, the set of all latencies related to the tested
      ingress interface MUST be reported.

The time units of the presented latency MUST be uniform and with
sufficient precision for the medium or media being tested. The

latency results for each test SHOULD be reported in the form of a
table, with a row for each of the tested frame sizes per the
recommendations in section 3.1.3, and SHOULD preserve the

relationship of latency to ingress/egress interface(s) to assist in trending across multiple trials.

6. Overhead

This section presents methodology relating to the characterization of the overhead delays associated with explicit operations found in multicast environments.

6.1. Group Join Delay

Objective:

To determine the time duration it takes a DUT/SUT to start forwarding multicast frames from the time a successful IGMP group membership report has been issued to the DUT/SUT.

Procedure:

Prior to sending any IGMP Group Membership Reports used to calculate the group join delay, it MUST be verified through externally observable means that the destination test ports are not currently a member of any of the specified multicast groups. If any of the egress interfaces forward multicast frames, the test is not valid.

Once verification is complete, multicast traffic for all relevant multicast group addresses MUST be offered to the ingress interface prior to receipt or processing of any IGMP Group Membership Report messages. It is RECOMMENDED to offer traffic at the measured aggregated multicast throughput rate (Section 4.3).

After the multicast traffic has been started, each destination test port (See Figure 1) SHOULD send one IGMP Group Membership Report with one or more (IGMP V3) multicast group(s) specified. All destination test ports MUST join all multicast groups offered on the ingress interface of the DUT/SUT. The test MUST be performed with one multicast group and SHOULD be performed with multiple groups.

The join delay is the difference in time from when the IGMP Group Membership message is sent (timestamp A) and the first frame of the multicast group is forwarded to a receiving egress interface (timestamp B).

        Group Join delay time = timestamp B - timestamp A

Timestamp A MUST be the time the last bit of the IGMP group
   membership report is sent from the destination test port; timestamp

B MUST be the time the first bit of the first valid multicast frame
is forwarded on the egress interface of the DUT/SUT.

Reporting Format:

The following configuration parameters MUST be reflected in the
results specific to this methodology:

     o Frame size(s)
     o Number of tested egress interfaces on the DUT/SUT
     o Test duration
     o IGMP version
     o Total number of multicast groups

The following results MUST be reflected in the results specific to
this methodology:

     o The group join delay time per multicast group address
     o The group join delay time per egress interface(s)

The Group Join Delay results for each test SHOULD be reported in
the form of a table, with a row for each of the tested frame sizes
per the recommendations in section 3.1.3. Each row or iteration
SHOULD specify the group join delay time for each multicast group
per destination interface, number of frames transmitted and number
of frames received for that iteration.

6.2. Group Leave Delay

Objective:

To determine the time duration it takes a DUT/SUT to cease
forwarding multicast frames after a corresponding IGMP Leave Group
message has been successfully offered to the DUT/SUT.

Procedure:

Prior to sending any IGMP Group Leave Group messages used to
calculate the group leave delay, it MUST be verified through
externally observable means that the destination test ports are
currently a member of all the specified multicast groups. If any
of the destination test ports do not receive multicast frames, the
test is not valid.

Once verification is complete, multicast traffic for all relevant
multicast group addresses MUST be offered to the ingress interface

prior to receipt or processing of any IGMP Leave Group messages.
It is RECOMMENDED to offer traffic at the measured aggregated
multicast throughput rate (Section 4.3).

After the multicast traffic has been started, each destination test
port (See Figure 1) MUST send one IGMP Leave Group message for each
multicast group specified. All destination test ports MUST leave
all relevant multicast groups offered on the ingress interface of
the DUT/SUT. The test MUST be performed with one multicast group
and SHOULD be performed with multiple groups.

The leave delay is the difference in time from when the IGMP Leave
Group message is sent (timestamp A) and the last frame of the
multicast group is forwarded to a receiving egress interface
(timestamp B).

        Group Leave delay time = timestamp B - timestamp A

Timestamp A MUST be the time the last bit of the IGMP Leave Group
message is sent from the destination test port; timestamp B MUST be
the time the last bit of the last valid multicast frame is
forwarded on the egress interface of the DUT/SUT.

Reporting Format:

The following configuration parameters MUST be reflected in the
results specific to this methodology:

    o Frame size(s)
    o Number of tested egress interfaces on the DUT/SUT
    o Test duration
    o IGMP version
    o Total number of multicast groups

The following results MUST be reflected in the results specific to
this methodology:

    o The group leave delay time per multicast group address
    o The group leave delay time per egress interface(s)

The Group Leave Delay results for each test SHOULD be reported in
the form of a table, with a row for each of the tested frame sizes
per the recommendations in section 3.1.3. Each row or iteration
SHOULD specify the group leave delay time for each multicast group
per destination interface, number of frames transmitted and number
of frames received for that iteration.

7. Capacity

   This section offers terms relating to the identification of
   multicast group limits of a DUT/SUT.

7.1. Multicast Group Capacity

   Objective:

   To determine the maximum number of multicast groups a DUT/SUT can
   support while maintaining the ability to forward multicast frames
   to all multicast groups registered to that DUT/SUT.

   Procedure:

   One or more egress interfaces of DUT/SUT will join an initial
   number of multicast groups.

   After a delay as determined by section 6.1, the ingress interface
   MUST transmit to each group at a specified offered load.

   If at least one frame for each multicast group is forwarded
   properly by the DUT/SUT to each participating egress interface, the
   iteration is said to pass at the current capacity.

   If the iteration passes, the test will add a user defined
   incremental value of groups to each egress interface. At the new
   group level and resultant capacity as stated above, run the
   iteration again.

   Once the test fails, the last/previous iteration capacity that
   passed is the stated Maximum Group Capacity result.

   Reporting Format:

   The following configuration parameters MUST be reflected in the
   results specific to this methodology:

        o Frame size(s)
        o Number of tested egress interfaces on the DUT/SUT
        o Test duration
        o IGMP version
        o Offered load

   The following results MUST be reflected in the results specific to
   this methodology:

o The total number of multicast group addresses that were
  successfully forwarded through the DUT/SUT

The Multicast Group Capacity results for each test SHOULD be
reported in the form of a table, with a row for each of the tested
frame sizes per the recommendations in section 3.1.3. Each row or
iteration SHOULD specify the number of multicast groups joined per
destination interface, number of frames transmitted and number of
frames received for that iteration.

8. Interaction

Network forwarding devices are generally required to provide more
functionality than just the forwarding of traffic. Moreover,
network-forwarding devices may be asked to provide those functions
in a variety of environments. This section offers procedures to
assist in the characterization of DUT/SUT behavior in consideration
of potentially interacting factors.

8.1. Forwarding Burdened Multicast Latency

Objective:

To produce a set of multicast latency measurements from a single
multicast ingress interface of a DUT/SUT through multiple egress
multicast interfaces of that same DUT/SUT as provided for by the
metric "Multicast Latency" in RFC 2432 while under the influence of
a traffic forwarding requirement.

Procedure:

The Multicast Latency metrics can be influenced by forcing the
DUT/SUT to perform extra processing of packets while multicast
class traffic is being forwarded for latency measurements.

The Burdened Forwarding Latency test MUST follow the described
setup in Section 5.1.

Perform a baseline measurement of latency as described in Section
5.1. After the baseline measurement is obtained, the test is
repeated with the ingress interface offering an additional set of
user specified multicast group addresses which have not been joined
by the destination test port(s). The offered load MUST be the same
as was used in the baseline measurement.

By sending such multicast class traffic, the DUT/SUT may perform a
lookup on the frames that may affect the processing of traffic
destined for the egress interface(s).

Reporting Format:

Similar to Section 5.1, the following configuration parameters MUST
be reflected in the results specific to this methodology:

    o Frame size(s)
    o Number of tested egress interfaces on the DUT/SUT
    o Test duration
    o IGMP version
    o Total number of multicast groups in the baseline setup
    o Total number of additional multicast groups used to burden
      the setup

The following results MUST be reflected in the results specific to
this methodology:

    o The time units of the presented latency MUST be uniform and
      with sufficient precision for the medium or media being
      tested
    o Specifically, when reporting the results of a valid test
      trial, the set of all latencies related to the tested
      ingress and each tested egress DUT/SUT interface of MUST be
      presented
    o Reported results from baseline measurement; section 5.1

The latency results for each test SHOULD be reported in the form of
a table, with a row for each of the tested frame sizes per the
recommended frame sizes in section 3.1.3, and SHOULD preserve the
relationship of latency to ingress/egress interface(s) to assist in
trending across multiple trials.

8.2. **Forwarding Burdened Group Join Delay**

   Objective:

   To determine the time duration it takes a DUT/SUT to start
   forwarding multicast frames from the time a successful IGMP Group
   Membership Report has been issued to the DUT/SUT while under the
   influence of a traffic forwarding requirement.

   Procedure:

   The Group Join Delay metrics can be influenced by forcing the
   DUT/SUT to perform extra process of packets while attempting to
   update and maintain the IP multicast address forwarding table.

   The Forwarding Burdened Group Join Delay test MUST follow the

described setup in Section 6.1.

Perform a baseline measurement of group join delay as described in Section 6.1. After the baseline measurement is obtained, the test is repeated with the ingress interface offering an additional set of user specified multicast group address which have not been joined by the destination test port(s). The offered load MUST be the same as was used in the baseline measurement.

By sending such multicast class traffic, the DUT/SUT may perform a lookup on the frames that may affect the processing of the IGMP Group Report messages.

Reporting Format:

Similar to Section 6.1, the following configuration parameters MUST be reflected in the results specific to this methodology:

    o Frame size(s)
    o Number of tested egress interfaces on the DUT/SUT
    o Test duration
    o IGMP version
    o Total number of multicast groups in the baseline setup
    o Total number of additional multicast groups used to burden
      the setup

The following results MUST be reflected in the results specific to this methodology:

    o The group join delay time per multicast group address
    o The group join delay time per egress interface(s)
    o Reported results from baseline measurement; section 6.1

The Group Join Delay results for each test SHOULD be reported in the form of a table, with a row for each of the tested frame sizes per the recommendations in section 3.1.3. Each row or iteration SHOULD specify the group join delay time for each multicast group per destination interface, number of frames transmitted and number of frames received for that iteration.

9. Security Considerations

As this document is solely for the purpose of providing metric methodology and describes neither a protocol nor a protocol's implementation, there are no security considerations associated with this document.

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