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Benchmarking Methodology for IPv6 Transition Technologies
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Abstract

There are benchmarking methodologies addressing the performance of network interconnect devices that are IPv4- or IPv6-capable, but the IPv6 transition technologies are outside of their scope. This document provides complementary guidelines for evaluating the performance of IPv6 transition technologies. More specifically, this document targets IPv6 transition technologies that employ encapsulation or translation mechanisms, as dual-stack nodes can be very well tested using the recommendations of RFC2544 and RFC5180. The methodology also includes a tentative metric for benchmarking load scalability.

Status of this Memo

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1. Introduction

The methodologies described in [RFC2544] and [RFC5180] help vendors and network operators alike analyze the performance of IPv4 and IPv6-capable network devices. The methodology presented in [RFC2544] is mostly IP version independent, while [RFC5180] contains complementary recommendations, which are specific to the latest IP version, IPv6. However, [RFC5180] does not cover IPv6 transition technologies.

IPv6 is not backwards compatible, which means that IPv4-only nodes cannot directly communicate with IPv6-only nodes. To solve this issue, IPv6 transition technologies have been proposed and implemented.

This document presents benchmarking guidelines dedicated to IPv6 transition technologies. The benchmarking tests can provide insights about the performance of these technologies, which can act as useful feedback for developers, as well as for network operators going through the IPv6 transition process.

The document also includes an approach to quantify load scalability. Load scalability can be defined as a system's ability to gracefully accommodate higher loads. Because poor scalability usually leads to poor performance, the proposed approach is to quantify the load scalability by measuring the performance degradation created by a higher number of network flows.

1.1. IPv6 Transition Technologies

Two of the basic transition technologies, dual IP layer (also known as dual stack) and encapsulation, are presented in [RFC4213]. IPv4/IPv6 Translation is presented in [RFC6144]. Most of the transition technologies employ at least one variation of these mechanisms. Some of the more complex ones (e.g. DSLite [RFC6333]) are using all three. In this context, a generic classification of the transition technologies can prove useful.

Tentatively, we can consider a production network transitioning to IPv6 as being constructed using the following IP domains:

- Domain A: IPvX specific domain

- Core domain: which may be IPvY specific or dual-stack(IPvX and IPvY)

- Domain B: IPvX specific domain

Note: X,Y are part of the {4,6} set.

According to the technology used for the core domain traversal the transition technologies can be categorized as follows:

1. Single Translation: In this case, the production network is assumed to have only two domains, Domain A and the Core domain. The core domain is assumed to be IPvY specific. IPvX packets are translated to IPvY at the edge between Domain A and the Core domain.

2. Dual-stack: the core domain devices implement both IP protocols

3. Encapsulation: The production network is assumed to have all three domains, Domains A and B are IPvX specific, while the core domain is IPvY specific. An encapsulation mechanism is used to traverse the core domain. The IPvX packets are encapsulated to IPvY packets at the edge between Domain A and the Core domain. Subsequently, the IPvY packets are decapsulated at the edge between the Core domain and Domain B.

4. Double translation: The production network is assumed to have all three domains, Domains A and B are IPvX specific, while the core domain is IPvY specific. A translation mechanism is employed for the traversal of the core network. The IPvX packets are translated to IPvY packets at the edge between Domain A and the Core domain. Subsequently, the IPvY packets are translated back to IPvX at the edge between the Core domain and Domain B.

The performance of Dual-stack transition technologies can be fully evaluated using the benchmarking methodologies presented by [RFC2544] and [RFC5180]. Consequently, this document focuses on the other 3 categories: Single translation, Encapsulation and Double translation transition technologies.

Another important aspect by which the IPv6 transition technologies can be categorized is their use of stateful or stateless mapping algorithms. The technologies that use stateful mapping algorithms (e.g. Stateful NAT64 [RFC6146]) create dynamic correlations between IP addresses or {IP address, transport protocol, transport port number} tuples, which are stored in a state table. For ease of reference, the IPv6 transition technologies which employ stateful mapping algorithms will be called stateful IPv6 transition technologies. The efficiency with which the state table is managed can be an important performance indicator for these technologies. Hence, for the stateful IPv6 transition technologies additional benchmarking tests are RECOMMENDED.

2. Conventions used in this document

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

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying [RFC2119] significance.

Although these terms are usually associated with protocol requirements, in this doc the terms are requirements for users and systems that intend to implement the test conditions and claim conformance with this specification.

3. Test Setup

The test environment setup options recommended for IPv6 transition technologies benchmarking are very similar to the ones presented in Section 6 of [RFC2544]. In the case of the tester setup, the options presented in [RFC2544] and [RFC5180] can be applied here as well. However, the Device under test (DUT) setup options should be explained in the context of the targeted categories of IPv6 transition technologies: Single translation, Double translation and Encapsulation transition technologies.

Although both single tester and sender/receiver setups are applicable to this methodology, the single tester setup will be used to describe the DUT setup options.

For the test setups presented in this memo, dynamic routing SHOULD be employed. However, the presence of routing and management frames can represent unwanted background data that can affect the benchmarking result. To that end, the procedures defined in [RFC2544] (Sections 11.2 and 11.3) related to routing and management frames SHOULD be used here as well. Moreover, the "Trial description" recommendations presented in [RFC2544] (Section 23) are valid for this memo as well.

In terms of route setup, the recommendations of [RFC2544] Section 13 are valid for this document as well assuming that an IPv6 version of the routing packets shown in appendix C.2.6.2 is used.

3.1. Single translation Transition Technologies

For the evaluation of Single translation transition technologies a single DUT setup (see Figure 1) SHOULD be used. The DUT is responsible for translating the IPvX packets into IPvY packets. In this context, the tester device should be configured to support both IPvX and IPvY.

```
                          +--------------------+
                          |                    |
             +------------|IPvX   tester   IPvY|<-------------+
             |            |                    |              |
             |            +--------------------+              |
             |                                                |
             |            +--------------------+              |
             |            |                    |              |
             +----------->|IPvX     DUT    IPvY|--------------+
                          |                    |
                          +--------------------+
```

Figure 1. Test setup 1

3.2. Encapsulation/Double translation Transition Technologies

For evaluating the performance of Encapsulation and Double translation transition technologies, a dual DUT setup (see Figure 2) SHOULD be employed. The tester creates a network flow of IPvX packets. The first DUT is responsible for the encapsulation or translation of IPvX packets into IPvY packets. The IPvY packets are decapsulated/translated back to IPvX packets by the second DUT and forwarded to the tester.

```
                           +---------------------+
                           |                     |
     +---------------------|IPvX   tester    IPvX|<------------------+
     |                     |                     |                   |
     |                     +---------------------+                   |
     |                                                               |
     |      +---------------------+     +---------------------+      |
     |      |                     |     |                     |      |
     +----->|IPvX    DUT 1  IPvY  |---->|IPvY   DUT 2   IPvX  |------+
            |                     |     |                     |
            +---------------------+     +---------------------+
```

Figure 2. Test setup 2

One of the limitations of the dual DUT setup is the inability to reflect asymmetries in behavior between the DUTs. Considering this, additional performance tests SHOULD be performed using the single DUT setup.

Note: For encapsulation IPv6 transition technologies, in the single DUT setup, in order to test the decapsulation efficiency, the tester SHOULD be able to send IPvX packets encasulated as IPvY.

4. Test Traffic

The test traffic represents the experimental workload and SHOULD meet the requirements specified in this section. The requirements are dedicated to unicast IP traffic. Multicast IP traffic is outside of the scope of this document.

4.1. Frame Formats and Sizes

[RFC5180] describes the frame size requirements for two commonly used media types: Ethernet and SONET (Synchronous Optical Network). [RFC2544] covers also other media types, such as token ring and FDDI. The two documents can be referred for the dual-stack transition technologies. For the rest of the transition technologies the frame overhead introduced by translation or encapsulation MUST be considered.

The encapsulation/translation process generates different size frames on different segments of the test setup. For instance, the single translation transition technologies will create different frame sizes on the receiving segment of the test setup, as IPvX packets are translated to IPvY. This is not a problem if the bandwidth of the employed media is not exceeded. To prevent exceeding the limitations imposed by the media, the frame size overhead needs to be taken into account when calculating the maximum theoretical frame rates. The calculation method for the Ethernet, as well as a calculation example are detailed in Appendix A. The details of the media employed for the benchmarking tests MUST be noted in all test reports.

In the context of frame size overhead, MTU recommendations are needed in order to avoid frame loss due to MTU mismatch between the virtual encapsulation/translation interfaces and the physical network interface controllers (NICs). To avoid this situation, the larger MTU between the physical NICs and virtual encapsulation/translation interfaces SHOULD be set for all interfaces of the DUT and tester. To be more specific, the minimum IPv6 MTU size (1280 bytes) plus the encapsulation/translation overhead is the RECOMMENDED value for the physical interfaces as well as virtual ones.

4.1.1. Frame Sizes to Be Used over Ethernet

Based on the recommendations of [RFC5180], the following frame sizes SHOULD be used for benchmarking IPvX/IPvY traffic on Ethernet links: 64, 128, 256, 512, 1024, 1280, 1518, 1522, 2048, 4096, 8192 and 9216.

The theoretical maximum frame rates considering an example of frame overhead are presented in Appendix A1.

4.2. Protocol Addresses

The selected protocol addresses should follow the recommendations of [RFC5180](Section 5) for IPv6 and [RFC2544](Section 12) for IPv4.

Note: testing traffic with extension headers might not be possible for the transition technologies which employ translation. Proposed IPvX/IPvY translation algorithms such as IP/ICMP translation [RFC6145] do not support the use of extension headers.

4.3. Traffic Setup

Following the recommendations of [RFC5180], all tests described SHOULD be performed with bi-directional traffic. Uni-directional traffic tests MAY also be performed for a fine grained performance assessment.

Because of the simplicity of UDP, UDP measurements offer a more reliable basis for comparison than other transport layer protocols. Consequently, for the benchmarking tests described in Section 6 of this document UDP traffic SHOULD be employed.

Considering that the stateful transition technologies need to manage the state table for each connection, a connection-oriented transport layer protocol needs to be used with the test traffic. Consequently, TCP test traffic SHOULD be employed for the tests described in Section 7 of this document.

5. Modifiers

The idea of testing under different operational conditions was first introduced in [RFC2544](Section 11) and represents an important aspect of benchmarking network elements, as it emulates to some extent the conditions of a production environment. [RFC5180] describes complementary testing conditions specific to IPv6. Their recommendations can be referred for IPv6 transition technologies testing as well.

6. Benchmarking Tests

The following sub-sections contain the list of all recommended benchmarking tests.

6.1. Throughput

Objective: To determine the DUT throughput as defined in [RFC1242].

Procedure: As described by [RFC2544].

Reporting Format: As described by [RFC2544].

6.2. Latency

Objective: To determine the latency as defined in [RFC1242].

Procedure: As described by [RFC2544].

Reporting Format: As described by [RFC2544].

6.3. Packet Delay Variation

Considering two of the metrics presented in [RFC5481], Packet Delay Variation (PDV) and Inter Packet Delay Variation (IPDV), it is RECOMMENDED to measure PDV. For a fine grain analysis of delay variation, IPDV measurements MAY be performed as well.

6.3.1. PDV

Objective: To determine the Packet Delay Variation as defined in [RFC5481].

Procedure: As described by [RFC2544], first determine the throughput for the DUT at each of the listed frame sizes. Send a stream of frames at a particular frame size through the DUT at the determined throughput rate to a specific destination. The stream SHOULD be at least 60 seconds in duration. Measure the One-way delay as described by [RFC3393] for all frames in the stream. Calculate the PDV of the stream using the formula:

PDV=D99.9thPercentile - Dmin

Where: D99.9thPercentile - the 99.9th Percentile (as it was described in [RFC5481]) of the One-way delay for the stream

Dmin - the minimum One-way delay in the stream

As recommended in [RFC 2544], the test MUST be repeated at least 20 times with the reported value being the average of the recorded values. Moreover, the margin of error from the average MAY be evaluated following the formula:

$$MoE = alpha * \frac{StDev}{sqrt(N)}$$

Where: alpha   - critical value; the recommended value is 2.576 for a 99% level of confidence

StDev   - standard deviation

N   - number of test iterations

Reporting Format: The PDV results SHOULD be reported in a table with a row for each of the tested frame sizes and columns for the frame size and the applied frame rate for the tested media types. A column for the margin of error values MAY as well be displayed. Following the recommendations of [RFC5481], the RECOMMENDED units of measurement are milliseconds.

6.3.2. IPDV

Objective: To determine the Inter Packet Delay Variation as defined in [RFC5481].

Procedure: As described by [RFC2544], first determine the throughput for the DUT at each of the listed frame sizes. Send a stream of frames at a particular frame size through the DUT at the determined throughput rate to a specific destination. The stream SHOULD be at least 60 seconds in duration. Measure the One-way delay as described by [RFC3393] for all frames in the stream. Calculate the IPDV for each of the frames using the formula:

IPDV(i)=D(i) - D(i-1)

Where: D(i)   - the One-way delay of the i th frame in the stream

D(i-1) - the One-way delay of i-1 th frame in the stream

Given the nature of IPDV, reporting a single number might lead to over-summarization. In this context, the report for each measurement SHOULD include 3 values: Dmin, Davg, and Dmax

Where: Dmin - the minimum One-way delay in the stream

Davg - the average One-way delay of the stream

Dmax - the maximum One-way delay in the stream

As recommended in RFC 2544, the test MUST be repeated at least 20 times.

Reporting format: The average of the 3 proposed values SHOULD be reported. The IPDV results SHOULD be reported in a table with a row for each of the tested frame sizes. The columns SHOULD include the frame size and associated frame rate for the tested media types and sub-columns for the three proposed reported values. A column for the margin of error values MAY as well be displayed. Following the recommendations of [RFC5481], the RECOMMENDED units of measurement are milliseconds.

6.4. Frame Loss Rate

Objective: To determine the frame loss rate, as defined in [RFC1242], of a DUT throughout the entire range of input data rates and frame sizes.

Procedure: As described by [RFC2544].

Reporting Format: As described by [RFC2544].

6.5. Back-to-back Frames

Objective: To characterize the ability of a DUT to process back-to-back frames as defined in [RFC1242].

Procedure: As described by [RFC2544].

Reporting Format: As described by [RFC2544].

6.6. System Recovery

Objective: To characterize the speed at which a DUT recovers from an overload condition.

Procedure: As described by [RFC2544].

Reporting Format: As described by [RFC2544].

6.7. Reset

Objective: To characterize the speed at which a DUT recovers from a device or software reset.

Procedure: As described by [RFC2544].

Reporting Format: As described by [RFC6201].

7. Additional Benchmarking Tests for Stateful IPv6 Transition Technologies

This section describes additional tests dedicated to the stateful IPv6 transition technologies. For the tests described in this section the DUT devices SHOULD follow the test setup and test parameters recommendations presented in [RFC3511] (Sections 4, 5).

In addition to the IPv4/IPv6 transition function a network node can have a firewall function. This document is targeting only the network devices that do not have a firewall function, as this function can be benchmarked using the recommendations of [RFC3511]. Consequently, only the tests described in [RFC3511] (Sections 5.2, 5.3) are RECOMMENDED. Namely, the following additional tests SHOULD be performed:

7.1. Concurrent TCP Connection Capacity

Objective: To determine the maximum number of concurrent TCP connections supported through or with the DUT, as defined in [RFC 2647]. This test is supposed to find the maximum number of entries the DUT can store in its state table.

Procedure: As described by [RFC3511].

Reporting Format: As described by [RFC3511].

7.2. Maximum TCP Connection Establishment Rate

Objective: To determine the maximum TCP connection establishment rate through or with the DUT, as defined by RFC [2647]. This test is expected to find the maximum rate at which the DUT can update its connection table.

Procedure: As described by [RFC3511].

Reporting Format: As described by [RFC3511].

8. DNS Resolution Performance

This section describes benchmarking tests dedicated to DNS64 (see [RFC6147]), used as DNS support for single translation technologies such as NAT64.

8.1. Test and Traffic Setup

The test setup follows the setup proposed for single translation IPv6 transition technologies in Figure 1.

```
   1:AAAA query    +--------------------+
      +------------|                    |<-------------+
      |            |IPv6   tester   IPv4|              |
      |  +-------->|                    |----------+   |
      |  |         +--------------------+ 3:empty  |   |
      |  | 6:synt'd                         AAAA,  |   |
      |  |   AAAA  +--------------------+ 5:valid A|   |
      |  +---------|                    |<---------+   |
      |            |IPv6     DUT    IPv4|              |
      +----------->|       (DNS64)      |--------------+
                   +--------------------+ 2:AAAA query, 4:A query
```

The test traffic SHOULD follow the following steps.

1. Query for the AAAA record of a domain name (from client to DNS64 server)

2. Query for the AAAA record of the same domain name (from DNS64 server to authoritative DNS server)

3. Empty AAAA record answer (from authoritative DNS server to DNS64 server)

4. Query for the A record of the same domain name (from DNS64 server to authoritative DNS server)

5. Valid A record answer (from authoritative DNS server to DNS64 server)

6. Synthesized AAAA record answer (from DNS64 server to client)

The tester plays the role of DNS client as well as authoritative DNS server.

Please note that:

- If the DNS64 server implements caching and there is a cache hit then step 1 is followed by step 6 (and steps 2 through 5 are omitted).
- If the domain name has an AAAA record then it is returned in step 3 by the authoritative DNS server, steps 4 and 5 are omitted, and the DNS64 server does not synthesizes an AAAA record, but returns the received AAAA record to the client.
- As for the IP version used between the tester and the DUT, IPv6 MUST be used between the client and the DNS64 server (as a DNS64 server provides service for an IPv6-only client), but either IPv4 or IPv6 MAY be used between the DNS64 server and the authoritative DNS server.

8.2. Benchmarking DNS Resolution Performance

Objective: To determine DNS64 performance by means of the number of successfully processed DNS requests per second.

Procedure: Send a specific number of DNS queries at a specific rate to the DUT and then count the replies received in time (within a predefined timeout period from the sending time of the corresponding query, having the default value 1 second) from the DUT. If the count of sent queries is equal to the count of received replies, the rate of the queries is raised and the test is rerun. If fewer replies are received than queries were sent, the rate of the queries is reduced and the test is rerun.

The number of processed DNS queries per second is the fastest rate at which the count of DNS replies sent by the DUT is equal to the number of DNS queries sent to it by the test equipment.

The test SHOULD be repeated at least 20 times and the average and margin of error (as described by Section 6.3.1) of the number of processed DNS queries per second SHOULD be calculated.

Details and parameters:

1. Caching
First, all the DNS queries MUST contain different domain names (or domain names MUST NOT be repeated before the cache of the DUT is exhausted). Then new tests MAY be executed with 10%, 20%, 30%, etc.

domain names which are repeated (early enough to be still in the cache).

2. Existence of AAAA record
First, all the DNS queries MUST contain domain names which do not have an AAAA record and have exactly one A record.
Then new tests MAY be executed with 10%, 20%, 30%, etc. domain names which have an AAAA record.

Please note that the two conditions above are orthogonal, thus all their combinations are possible and MAY be tested. The testing with 0% repeated DNS names and with 0% existing AAAA record is REQUIRED and the other combinations are OPTIONAL.

Reporting format: The primary result of the DNS64/DNS46 test is the average of the number of processed DNS queries per second measured with the above mentioned "0% + 0% combination". The average SHOULD be complemented with the margin of error to show the stability of the result. If optional tests are done, the average and margin of error pairs MAY be presented in a two dimensional table where the dimensions are the proportion of the repeated domain names and the proportion of the DNS names having AAAA records. The two table headings SHOULD contain these percentage values. Alternatively, the results MAY be presented as the corresponding two dimensional graph, too. In this case the graph SHOULD show the average values with the margin of error as error bars. From both the table and the graph, one dimensional excerpts MAY be made at any given fixed percentage value of the other dimension. In this case, the fixed value MUST be given together with a one dimensional table or graph.

9. Scalability

Scalability has been often discussed; however, in the context of network devices, a formal definition or a measurement method has not yet been approached.

Scalability can be defined as the ability of each transition technology to accommodate network growth.

Poor scalability usually leads to poor performance. Considering this, scalability can be measured by quantifying the network performance degradation while the network grows.

The following subsections describe how the test setups can be modified to create network growth and how the associated performance degradation can be quantified.

9.1. Test Setup

The test setups defined in Section 3 have to be modified to create network growth.

9.1.1. Single Translation Transition Technologies

In the case of single translation transition technologies the network growth can be generated by increasing the number of network flows generated by the tester machine (see Figure 3).

```
                        +-------------------------+
           +------------|NF1                   NF1|<--------------+
           |  +---------|NF2      tester      NF2|<----------+   |
           |  |      ...|                         |           |   |
           |  |   +-----|NFn                   NFn|<------+   |   |
           |  |   |     +-------------------------+       |   |   |
           |  |   |                                       |   |   |
           |  |   |     +-------------------------+       |   |   |
           |  |   +---->|NFn                   NFn|-------+   |   |
           |  |      ...|           DUT           |           |   |
           |  +-------->|NF2    (translator)   NF2|-----------+   |
           +----------->|NF1                   NF1|---------------+
                        +-------------------------+
```

Figure 3. Test setup 3

9.1.2. Encapsulation/Double Translation Transition Technologies

Similarly, for the encapsulation/double translation technologies a multi-flow setup is recommended. Considering a multipoint-to-point scenario, for most transition technologies, one of the edge nodes is designed to support more than one connecting devices. Hence, the recommended test setup is a n:1 design, where n is the number of "client" DUTs connected to the same "server" DUT (See Figure 4).

```
                          +-------------------------+
     +--------------------|NF1                   NF1|<--------------+
     |  +-----------------|NF2      tester       NF2|<-----------+  |
     |  |              ...|                         |            |  |
     |  |   +-------------|NFn                   NFn|<-------+   |  |
     |  |   |             +-------------------------+        |   |  |
     |  |   |                                                |   |  |
     |  |   |    +-----------------+    +---------------+    |   |  |
     |  |   +--->| NFn  DUT n  NFn |--->|NFn         NFn| ---+   |  |
     |  |        +-----------------+    |               |        |  |
     |  |     ...                       |               |        |  |
     |  |        +-----------------+    |     DUT n+1   |        |  |
     |  +------->| NF2  DUT 2  NF2 |--->|NF2         NF2|--------+  |
     |           +-----------------+    |               |           |
     |           +-----------------+    |               |           |
     +---------->| NF1  DUT 1  NF1 |--->|NF1         NF1|-----------+
                 +-----------------+    +---------------+
```

Figure 4. Test setup 4

This test setup can help to quantify the scalability of the "server" device. However, for testing the scalability of the "client" DUTs additional recommendations are needed.
For encapsulation transition technologies a m:n setup can be created, where m is the number of flows applied to the same "client" device and n the number of "client" devices connected to the same "server" device.
For the translation based transition technologies the "client" devices can be separately tested with n network flows using the test setup presented in Figure 3.

9.2. Benchmarking Performance Degradation

Objective: To quantify the performance degradation introduced by n parallel network flows.

Procedure: First, the benchmarking tests presented in Section 6 have to be performed for one network flow.

The same tests have to be repeated for n network flows. The performance degradation of the X benchmarking dimension SHOULD be calculated as relative performance change between the 1-flow results and the n-flow results, using the following formula:

$$Xpd = \frac{Xn - X1}{X1} * 100$$

where: X1 - result for 1-flow
Xn - result for n-flows

Reporting Format: The performance degradation SHOULD be expressed as a percentage. The number of tested parallel flows n MUST be clearly specified. For each of the performed benchmarking tests, there SHOULD be a table containing a column for each frame size. The table SHOULD also state the applied frame rate.

10. Summarizing function and repeatability

To ensure the stability of the benchmarking scores obtained using the tests presented in Sections 6-9, multiple test iterations are recommended. Following the recommendations of RFC2544, the average was chosen to be the summarizing function for the reported values. While median can be an alternative summarizing function, a rationale for using one or the other is needed.

The median can be useful for summarizing especially when outliers are not a desired quantity. However, in the overall performance of a network device the outliers can represent a malfunction or misconfiguration in the DUT, which should be taken into account.

The average is a more inclusive summarizing function. Moreover, as underlined in [DeNijs], the average is less exposed to statistical uncertainty. These reasons make it the RECOMMENDED summarizing function for the results of different test iterations, unless stated otherwise.

To express the repeatability of the benchmarking tests through a number, the Margin of error (MoE) can be used. Of course, other functions, such as standard error could be employed as well. The advantage the MoE has is expressing an associated confidence interval by using the alpha parameter.

The recommended formula for calculating the MoE is presented in Section 6.3.1.

11. Security Considerations

Benchmarking activities as described in this memo are limited to technology characterization using controlled stimuli in a laboratory environment, with dedicated address space and the constraints specified in the sections above.

The benchmarking network topology will be an independent test setup and MUST NOT be connected to devices that may forward the test traffic into a production network, or misroute traffic to the test management network.

Further, benchmarking is performed on a "black-box" basis, relying solely on measurements observable external to the DUT/SUT. Special capabilities SHOULD NOT exist in the DUT/SUT specifically for benchmarking purposes. Any implications for network security arising from the DUT/SUT SHOULD be identical in the lab and in production networks.

12. IANA Considerations

The IANA has allocated the prefix 2001:0002::/48 [RFC5180] for IPv6 benchmarking. For IPv4 benchmarking, the 198.18.0.0/15 prefix was reserved, as described in [RFC6890]. The two ranges are sufficient for benchmarking IPv6 transition technologies.

13. Conclusions

The methodologies described in [RFC2544] and [RFC5180] can be used for benchmarking the performance of IPv4-only, IPv6-only and dual-stack supporting network devices. This document presents complementary recommendations dedicated to IPv6 transition technologies. Furthermore, the methodology includes a tentative approach for benchmarking load scalability by quantifying the performance degradation associated with network growth.

14. References

14.1. Normative References

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Appendix A. Theoretical Maximum Frame Rates

This appendix describes the recommended calculation formulas for the theoretical maximum frame rates to be employed over Ethernet as example media. The formula takes into account the frame size overhead created by the encapsulation or the translation process. For example, the 6in4 encapsulation described in [RFC4213] adds 20 bytes of overhead to each frame.

Considering X to be the frame size and O to be the frame size overhead created by the encapsulation on translation process, the maximum theoretical frame rate for Ethernet can be calculated using the following formula:

```
              Line Rate (bps)
      ------------------------------
      (8bits/byte)*(X+O+20)bytes/frame
```

The calculation is based on the formula recommended by RFC5180 in Appendix A1. As an example, the frame rate recommended for testing a 6in4 implementation over 10Mb/s Ethernet with 64 bytes frames is:

```
              10,000,000(bps)
      ------------------------------      = 12,019 fps
      (8bits/byte)*(64+20+20)bytes/frame
```

The complete list of recommended frame rates for 6in4 encapsulation can be found in the following table:

Frame size (bytes)	10 Mb/s (fps)	100 Mb/s (fps)	1000 Mb/s (fps)	10000 Mb/s (fps)
64	12,019	120,192	1,201,923	12,019,231
128	7,440	74,405	744,048	7,440,476
256	4,223	42,230	422,297	4,222,973
512	2,264	22,645	226,449	2,264,493
1024	1,175	11,748	117,481	1,174,812
1280	947	9,470	94,697	946,970
1518	802	8,023	80,231	802,311
1522	800	8,003	80,026	800,256
2048	599	5,987	59,866	598,659
4096	302	3,022	30,222	302,224
8192	152	1,518	15,185	151,846
9216	135	1,350	13,505	135,048

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