Internet Engineering Task Force (IETF)
Request for Comments: 6808
Category: Informational
ISSN: 2070-1721

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December 2012

# Test Plan and Results Supporting Advancement of RFC 2679 on the Standards Track

## Abstract

This memo provides the supporting test plan and results to advance RFC 2679 on one-way delay metrics along the Standards Track, following the process in RFC 6576. Observing that the metric definitions themselves should be the primary focus rather than the implementations of metrics, this memo describes the test procedures to evaluate specific metric requirement clauses to determine if the requirement has been interpreted and implemented as intended. Two completely independent implementations have been tested against the key specifications of RFC 2679. This memo also provides direct input for development of a revision of RFC 2679.

## Status of This Memo

This document is not an Internet Standards Track specification; it is published for informational purposes.

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Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc6808.

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## 1. Introduction

The IETF IP Performance Metrics (IPPM) working group has considered how to advance their metrics along the Standards Track since 2001, with the initial publication of Bradner/Paxson/Mankin's memo [METRICS-TEST]. The original proposal was to compare the performance of metric implementations. This was similar to the usual procedures for advancing protocols, which did not directly apply. It was found to be difficult to achieve consensus on exactly how to compare implementations, since there were many legitimate sources of

variation that would emerge in the results despite the best attempts to keep the network paths equal, and because considerable variation was allowed in the parameters (and therefore implementation) of each metric. Flexibility in metric definitions, essential for customization and broad appeal, made the comparison task quite difficult.

A renewed work effort investigated ways in which the measurement variability could be reduced and thereby simplify the problem of comparison for equivalence.

The consensus process documented in [RFC6576] is that metric definitions rather than the implementations of metrics should be the primary focus of evaluation. Equivalent test results are deemed to be evidence that the metric specifications are clear and unambiguous. This is now the metric specification equivalent of protocol interoperability. The [RFC6576] advancement process either produces confidence that the metric definitions and supporting material are clearly worded and unambiguous, or it identifies ways in which the metric definitions should be revised to achieve clarity.

The metric RFC advancement process requires documentation of the testing and results. [RFC6576] retains the testing requirement of the original Standards Track advancement process described in [RFC2026] and [RFC5657], because widespread deployment is insufficient to determine whether RFCs that define performance metrics result in consistent implementations.

The process also permits identification of options that were not implemented, so that they can be removed from the advancing specification (this is a similar aspect to protocol advancement along the Standards Track). All errata must also be considered.

This memo's purpose is to implement the advancement process of [RFC6576] for [RFC2679]. It supplies the documentation that accompanies the protocol action request submitted to the Area Director, including description of the test setup, results for each implementation, evaluation of each metric specification, and conclusions.

In particular, this memo documents the consensus on the extent of tolerable errors when assessing equivalence in the results. The IPPM working group agreed that the test plan and procedures should include the threshold for determining equivalence, and that this aspect should be decided in advance of cross-implementation comparisons. This memo includes procedures for same-implementation comparisons that may influence the equivalence threshold.

Although the conclusion reached through testing is that [RFC2679] should be advanced on the Standards Track with modifications, the revised text of RFC 2679 is not yet ready for review. Therefore, this memo documents the information to support [RFC2679] advancement, and the approval of a revision of RFC 2769 is left for future action.

### 1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

## 2. A Definition-Centric Metric Advancement Process

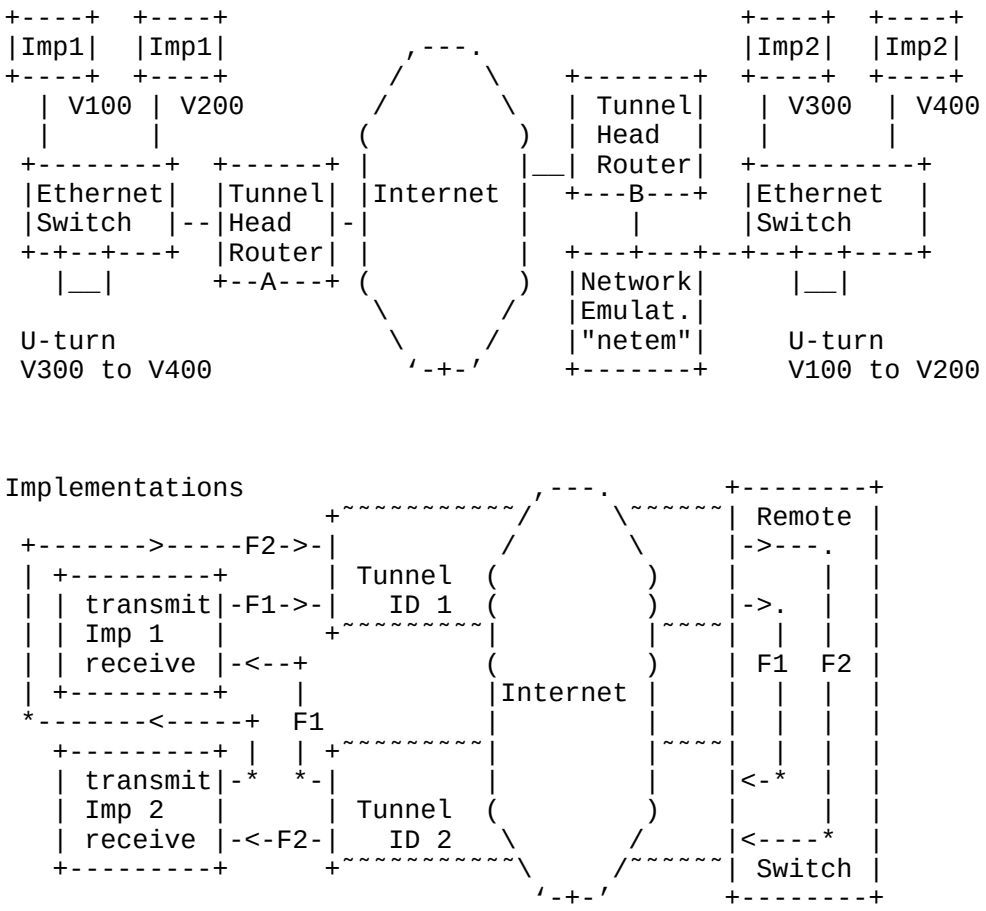
As a first principle, the process described in Section 3.5 of [RFC6576] takes the fact that the metric definitions (embodied in the text of the RFCs) are the objects that require evaluation and possible revision in order to advance to the next step on the Standards Track. This memo follows that process.

## 3. Test Configuration

One metric implementation used was NetProbe version 5.8.5 (an earlier version is used in AT&T's IP network performance measurement system and deployed worldwide [WIPM]). NetProbe uses UDP packets of variable size, and it can produce test streams with Periodic [RFC3432] or Poisson [RFC2330] sample distributions.

The other metric implementation used was Perfas+ version 3.1, developed by Deutsche Telekom [Perfas]. Perfas+ uses UDP unicast packets of variable size (but also supports TCP and multicast). Test streams with Periodic, Poisson, or uniform sample distributions may be used.

Figure 1 shows a view of the test path as each implementation's test flows pass through the Internet and the Layer 2 Tunneling Protocol, version 3 (L2TPv3) tunnel IDs (1 and 2), based on Figures 2 and 3 of [RFC6576].




Illustrations of a test setup with a bidirectional tunnel. The upper diagram emphasizes the VLAN connectivity and geographical location. The lower diagram shows example flows traveling between two measurement implementations (for simplicity, only two flows are shown).

Figure 1

The testing employs the Layer 2 Tunneling Protocol, version 3 (L2TPv3) [RFC3931] tunnel between test sites on the Internet. The tunnel IP and L2TPv3 headers are intended to conceal the test equipment addresses and ports from hash functions that would tend to spread different test streams across parallel network resources, with likely variation in performance as a result.

At each end of the tunnel, one pair of VLANs encapsulated in the tunnel are looped back so that test traffic is returned to each test site. Thus, test streams traverse the L2TP tunnel twice, but appear to be one-way tests from the test equipment point of view.

The network emulator is a host running Fedora 14 Linux [Fedora14] with IP forwarding enabled and the "netem" Network emulator [netem] loaded and operating as part of the Fedora Kernel 2.6.35.11. Connectivity across the netem/Fedora host was accomplished by bridging Ethernet VLAN interfaces together with "brctl" commands (e.g., eth1.100 <-> eth2.100). The netem emulator was activated on one interface (eth1) and only operates on test streams traveling in one direction. In some tests, independent netem instances operated separately on each VLAN.

The links between the netem emulator host and router and switch were found to be 100baseTx-HD (100 Mbps half duplex) when the testing was complete. Use of half duplex was not intended, but probably added a small amount of delay variation that could have been avoided in full duplex mode.

Each individual test was run with common packet rates (1 pps, 10 pps) Poisson/Periodic distributions, and IP packet sizes of 64, 340, and 500 Bytes. These sizes cover a reasonable range while avoiding fragmentation and the complexities it causes, thus complying with the notion of "standard formed packets" described in Section 15 of [RFC2330].

For these tests, a stream of at least 300 packets were sent from Source to Destination in each implementation. Periodic streams (as per [RFC3432]) with 1 second spacing were used, except as noted.

With the L2TPv3 tunnel in use, the metric name for the testing configured here (with respect to the IP header exposed to Internet processing) is:

Type-IP-protocol-115-One-way-Delay-<StreamType>-Stream

With (Section 4.2 of [RFC2679]) Metric Parameters:

+ Src, the IP address of a host (12.3.167.16 or 193.159.144.8)

+ Dst, the IP address of a host (193.159.144.8 or 12.3.167.16)

+ T0, a time

+ Tf, a time

+ lambda, a rate in reciprocal seconds

+ Thresh, a maximum waiting time in seconds (see Section 3.8.2 of [RFC2679] and Section 4.3 of [RFC2679])

Metric Units: A sequence of pairs; the elements of each pair are:

+ T, a time, and

+ dT, either a real number or an undefined number of seconds.

The values of T in the sequence are monotonic increasing. Note that T would be a valid parameter to Type-P-One-way-Delay and that dT would be a valid value of Type-P-One-way-Delay.

Also, Section 3.8.4 of [RFC2679] recommends that the path SHOULD be reported. In this test setup, most of the path details will be concealed from the implementations by the L2TPv3 tunnels; thus, a more informative path trace route can be conducted by the routers at each location.

When NetProbe is used in production, a traceroute is conducted in parallel with, and at the outset of, measurements.

Perfas+ does not support traceroute.

```
IPLGW#traceroute 193.159.144.8

Type escape sequence to abort.
Tracing the route to 193.159.144.8

  1 12.126.218.245 [AS 7018] 0 msec 0 msec 4 msec
  2 cr84.n54ny.ip.att.net (12.123.2.158) [AS 7018] 4 msec 4 msec
    cr83.n54ny.ip.att.net (12.123.2.26) [AS 7018] 4 msec
  3 cr1.n54ny.ip.att.net (12.122.105.49) [AS 7018] 4 msec
    cr2.n54ny.ip.att.net (12.122.115.93) [AS 7018] 0 msec
    cr1.n54ny.ip.att.net (12.122.105.49) [AS 7018] 0 msec
  4 n54ny02jt.ip.att.net (12.122.80.225) [AS 7018] 4 msec 0 msec
    n54ny02jt.ip.att.net (12.122.80.237) [AS 7018] 4 msec
  5 192.205.34.182 [AS 7018] 0 msec
    192.205.34.150 [AS 7018] 0 msec
    192.205.34.182 [AS 7018] 4 msec
  6 da-rg12-i.DA.DE.NET.DTAG.DE (62.154.1.30) [AS 3320] 88 msec 88 msec
88 msec
  7 217.89.29.62 [AS 3320] 88 msec 88 msec 88 msec
  8 217.89.29.55 [AS 3320] 88 msec 88 msec 88 msec
  9  *  *  *
```

It was only possible to conduct the traceroute for the measured path on one of the tunnel-head routers (the normal trace facilities of the measurement systems are confounded by the L2TPv3 tunnel encapsulation).

## 4. Error Calibration, RFC 2679

An implementation is required to report on its error calibration in Section 3.8 of [RFC2679] (also required in Section 4.8 for sample metrics). Sections 3.6, 3.7, and 3.8 of [RFC2679] give the detailed formulation of the errors and uncertainties for calibration. In summary, Section 3.7.1 of [RFC2679] describes the total time-varying uncertainty as:

Esynch(t)+ Rsource + Rdest

where:

Esynch(t) denotes an upper bound on the magnitude of clock synchronization uncertainty.

Rsource and Rdest denote the resolution of the source clock and the destination clock, respectively.

Further, Section 3.7.2 of [RFC2679] describes the total wire-time uncertainty as:

Hsource + Hdest

referring to the upper bounds on host-time to wire-time for source and destination, respectively.

Section 3.7.3 of [RFC2679] describes a test with small packets over an isolated minimal network where the results can be used to estimate systematic and random components of the sum of the above errors or uncertainties. In a test with hundreds of singletons, the median is the systematic error and when the median is subtracted from all singletons, the remaining variability is the random error.

The test context, or Type-P of the test packets, must also be reported, as required in Section 3.8 of [RFC2679] and all metrics defined there. Type-P is defined in Section 13 of [RFC2330] (as are many terms used below).

### 4.1. NetProbe Error and Type-P

Type-P for this test was IP-UDP with Best Effort Differentiated Services Code Point (DSCP). These headers were encapsulated according to the L2TPv3 specifications [RFC3931]; thus, they may not influence the treatment received as the packets traversed the Internet.

In general, NetProbe error is dependent on the specific version and installation details.

NetProbe operates using host-time above the UDP layer, which is different from the wire-time preferred in [RFC2330], but it can be identified as a source of error according to Section 3.7.2 of [RFC2679].

Accuracy of NetProbe measurements is usually limited by NTP synchronization performance (which is typically taken as ~+/-1 ms error or greater), although the installation used in this testing often exhibits errors much less than typical for NTP. The primary stratum 1 NTP server is closely located on a sparsely utilized network management LAN; thus, it avoids many concerns raised in Section 10 of [RFC2330] (in fact, smooth adjustment, long-term drift analysis and compensation, and infrequent adjustment all lead to stability during measurement intervals, the main concern).

The resolution of the reported results is 1 us (us = microsecond) in the version of NetProbe tested here, which contributes to at least +/-1 us error.

NetProbe implements a timekeeping sanity check on sending and receiving time-stamping processes. When a significant process interruption takes place, individual test packets are flagged as possibly containing unusual time errors, and they are excluded from the sample used for all "time" metrics.

We performed a NetProbe calibration of the type described in Section 3.7.3 of [RFC2679], using 64-Byte packets over a cross-connect cable. The results estimate systematic and random components of the sum of the Hsource + Hdest errors or uncertainties. In a test with 300 singletons conducted over 30 seconds (periodic sample with 100 ms spacing), the median is the systematic error and the remaining variability is the random error. One set of results is tabulated below:

```
(Results from the "R" software environment for statistical computing
and graphics - http://www.r-project.org/ )
> summary(XD4CAL)
      CAL1            CAL2            CAL3
 Min.   : 89.0   Min.   : 68.00   Min.   : 54.00
 1st Qu.: 99.0   1st Qu.: 77.00   1st Qu.: 63.00
 Median :110.0   Median : 79.00   Median : 65.00
 Mean   :116.8   Mean   : 83.74   Mean   : 69.65
 3rd Qu.:127.0   3rd Qu.: 88.00   3rd Qu.: 74.00
 Max.   :205.0   Max.   :177.00   Max.   :163.00
>
NetProbe Calibration with Cross-Connect Cable, one-way delay values
in microseconds (us)

The median or systematic error can be as high as 110 us, and the
range of the random error is also on the order of 116 us for all
streams.

Also, anticipating the Anderson-Darling K-sample (ADK) [ADK]
comparisons to follow, we corrected the CAL2 values for the
difference between the means of CAL2 and CAL3 (as permitted in
Section 3.2 of [RFC6576]), and found strong support (for the Null
Hypothesis) that the samples are from the same distribution
(resolution of 1 us and alpha equal 0.05 and 0.01)

> XD4CVCAL2 <- XD4CAL$CAL2 - (mean(XD4CAL$CAL2)-mean(XD4CAL$CAL3))
> boxplot(XD4CVCAL2,XD4CAL$CAL3)
> XD4CV2_ADK <- adk.test(XD4CVCAL2, XD4CAL$CAL3)
> XD4CV2_ADK
Anderson-Darling k-sample test.

Number of samples:  2
Sample sizes: 300 300
Total number of values: 600
Number of unique values: 97

Mean of Anderson Darling Criterion: 1
Standard deviation of Anderson Darling Criterion: 0.75896

T = (Anderson-Darling Criterion - mean)/sigma

Null Hypothesis: All samples come from a common population.

                      t.obs P-value extrapolation
not adj. for ties  0.71734 0.17042             0
adj. for ties     -0.39553 0.44589             1
>
using [Rtool] and [Radk].
```

### 4.2. Perfas+ Error and Type-P

Perfas+ is configured to use GPS synchronization and uses NTP synchronization as a fall-back or default. GPS synchronization worked throughout this test with the exception of the calibration stated here (one implementation was NTP synchronized only). The time stamp accuracy typically is 0.1 ms.

The resolution of the results reported by Perfas+ is 1 us (us = microsecond) in the version tested here, which contributes to at least +/-1 us error.

| Port | 5001 | 5002 | 5003 |
|---|---|---|---|
| Min. | -227 | -226 | 294 |
| Median | -169 | -167 | 323 |
| Mean | -159 | -157 | 335 |
| Max. | 6 | -52 | 376 |
| s | 102 | 102 | 93 |

Perfas+ Calibration with Cross-Connect Cable, one-way delay values in microseconds (us)

The median or systematic error can be as high as 323 us, and the range of the random error is also less than 232 us for all streams.

## 5. Predetermined Limits on Equivalence

This section provides the numerical limits on comparisons between implementations, in order to declare that the results are equivalent and therefore, the tested specification is clear. These limits have their basis in Section 3.1 of [RFC6576] and the Appendix of [RFC2330], with additional limits representing IP Performance Metrics (IPPM) consensus prior to publication of results.

A key point is that the allowable errors, corrections, and confidence levels only need to be sufficient to detect misinterpretation of the tested specification resulting in diverging implementations.

Also, the allowable error must be sufficient to compensate for measured path differences. It was simply not possible to measure fully identical paths in the VLAN-loopback test configuration used, and this practical compromise must be taken into account.

For Anderson-Darling K-sample (ADK) comparisons, the required confidence factor for the cross-implementation comparisons SHALL be the smallest of:

- o 0.95 confidence factor at 1 ms resolution, or

- o the smallest confidence factor (in combination with resolution) of the two same-implementation comparisons for the same test conditions.

A constant time accuracy error of as much as +/-0.5 ms MAY be removed from one implementation's distributions (all singletons) before the ADK comparison is conducted.

A constant propagation delay error (due to use of different sub-nets between the switch and measurement devices at each location) of as much as +2 ms MAY be removed from one implementation's distributions (all singletons) before the ADK comparison is conducted.

For comparisons involving the mean of a sample or other central statistics, the limits on both the time accuracy error and the propagation delay error constants given above also apply.

## 6. Tests to Evaluate RFC 2679 Specifications

This section describes some results from real-world (cross-Internet) tests with measurement devices implementing IPPM metrics and a network emulator to create relevant conditions, to determine whether the metric definitions were interpreted consistently by implementors.

The procedures are slightly modified from the original procedures contained in Appendix A.1 of [RFC6576]. The modifications include the use of the mean statistic for comparisons.

Note that there are only five instances of the requirement term "MUST" in [RFC2679] outside of the boilerplate and [RFC2119] reference.

### 6.1. One-Way Delay, ADK Sample Comparison: Same- and Cross-Implementation

This test determines if implementations produce results that appear to come from a common delay distribution, as an overall evaluation of Section 4 of [RFC2679], "A Definition for Samples of One-way Delay". Same-implementation comparison results help to set the threshold of equivalence that will be applied to cross-implementation comparisons.

This test is intended to evaluate measurements in Sections 3 and 4 of [RFC2679].

By testing the extent to which the distributions of one-way delay singletons from two implementations of [RFC2679] appear to be from the same distribution, we economize on comparisons, because comparing a set of individual summary statistics (as defined in Section 5 of [RFC2679]) would require another set of individual evaluations of equivalence. Instead, we can simply check which statistics were implemented, and report on those facts.

1. Configure an L2TPv3 path between test sites, and each pair of measurement devices to operate tests in their designated pair of VLANs.

2. Measure a sample of one-way delay singletons with two or more implementations, using identical options and network emulator settings (if used).

3. Measure a sample of one-way delay singletons with *four* instances of the *same* implementations, using identical options, noting that connectivity differences SHOULD be the same as for the cross-implementation testing.

4. Apply the ADK comparison procedures (see Appendices A and B of [RFC6576]) and determine the resolution and confidence factor for distribution equivalence of each same-implementation comparison and each cross-implementation comparison.

5. Take the coarsest resolution and confidence factor for distribution equivalence from the same-implementation pairs, or the limit defined in Section 5 above, as a limit on the equivalence threshold for these experimental conditions.

6. Apply constant correction factors to all singletons of the sample distributions, as described and limited in Section 5 above.

7. Compare the cross-implementation ADK performance with the equivalence threshold determined in step 5 to determine if equivalence can be declared.

The common parameters used for tests in this section are:

- IP header + payload = 64 octets

- Periodic sampling at 1 packet per second

- Test duration = 300 seconds (March 29, 2011)

The netem emulator was set for 100 ms average delay, with uniform delay variation of +/-50 ms. In this experiment, the netem emulator was configured to operate independently on each VLAN; thus, the emulator itself is a potential source of error when comparing streams that traverse the test path in different directions.

In the result analysis of this section:

- All comparisons used 1 microsecond resolution.
- No correction factors were applied.
- The 0.95 confidence factor (1.960 for paired stream comparison) was used.

### 6.1.1. NetProbe Same-Implementation Results

A single same-implementation comparison fails the ADK criterion (s1 <-> sB). We note that these streams traversed the test path in opposite directions, making the live network factors a possibility to explain the difference.

All other pair comparisons pass the ADK criterion.

| ti.obs (P) | s1 | s2 | sA |
|---|---|---|---|
| s2 | 0.25 (0.28) | | |
| sA | 0.60 (0.19) | -0.80 (0.57) | |
| sB | 2.64 (0.03) | 0.07 (0.31) | -0.52 (0.48) |

NetProbe ADK results for same-implementation

### 6.1.2. Perfas+ Same-Implementation Results

All pair comparisons pass the ADK criterion.

| ti.obs (P) | p1 | p2 | p3 |
|---|---|---|---|
| p2 | 0.06 (0.32) | | |
| p3 | 1.09 (0.12) | 0.37 (0.24) | |
| p4 | -0.81 (0.57) | -0.13 (0.37) | 1.36 (0.09) |

Perfas+ ADK results for same-implementation

### 6.1.3. One-Way Delay, Cross-Implementation ADK Comparison

The cross-implementation results are compared using a combined ADK analysis [Radk], where all NetProbe results are compared with all Perfas+ results after testing that the combined same-implementation results pass the ADK criterion.

When 4 (same) samples are compared, the ADK criterion for 0.95 confidence is 1.915, and when all 8 (cross) samples are compared it is 1.85.

Combination of Anderson-Darling K-Sample Tests.

Sample sizes within each data set:
Data set 1 : 299 297 298 300 (NetProbe)
Data set 2 : 300 300 298 300 (Perfas+)
Total sample size per data set: 1194 1198
Number of unique values per data set: 1188 1192
...
Null Hypothesis:
All samples within a data set come from a common distribution.
The common distribution may change between data sets.

| NetProbe | ti.obs | P-value | extrapolation |
|---|---|---|---|
| not adj. for ties | 0.64999 | 0.21355 | 0 |
| adj. for ties | 0.64833 | 0.21392 | 0 |
| Perfas+ | | | |
| not adj. for ties | 0.55968 | 0.23442 | 0 |
| adj. for ties | 0.55840 | 0.23473 | 0 |

Combined Anderson-Darling Criterion:

| | tc.obs | P-value | extrapolation |
|---|---|---|---|
| not adj. for ties | 0.85537 | 0.17967 | 0 |
| adj. for ties | 0.85329 | 0.18010 | 0 |

The combined same-implementation samples and the combined cross-implementation comparison all pass the ADK criterion at P>=0.18 and support the Null Hypothesis (both data sets come from a common distribution).

We also see that the paired ADK comparisons are rather critical. Although the NetProbe s1-sB comparison failed, the combined data set from four streams passed the ADK criterion easily.

#### 6.1.4. Conclusions on the ADK Results for One-Way Delay

Similar testing was repeated many times in the months of March and April 2011. There were many experiments where a single test stream from NetProbe or Perfas+ proved to be different from the others in paired comparisons (even same-implementation comparisons). When the outlier stream was removed from the comparison, the remaining streams passed combined ADK criterion. Also, the application of correction factors resulted in higher comparison success.

We conclude that the two implementations are capable of producing equivalent one-way delay distributions based on their interpretation of [RFC2679].

#### 6.1.5. Additional Investigations

On the final day of testing, we performed a series of measurements to evaluate the amount of emulated delay variation necessary to achieve successful ADK comparisons. The need for correction factors (as permitted by Section 5) and the size of the measurement sample (obtained as sub-sets of the complete measurement sample) were also evaluated.

The common parameters used for tests in this section are:

- IP header + payload = 64 octets

- Periodic sampling at 1 packet per second

- Test duration = 300 seconds at each delay variation setting, for a total of 1200 seconds (May 2, 2011 at 1720 UTC)

The netem emulator was set for 100 ms average delay, with (emulated) uniform delay variation of:

- +/-7.5 ms

- +/-5.0 ms

- +/-2.5 ms

- 0 ms

In this experiment, the netem emulator was configured to operate independently on each VLAN; thus, the emulator itself is a potential source of error when comparing streams that traverse the test path in different directions.

In the result analysis of this section:

- All comparisons used 1 microsecond resolution.

- Correction factors *were* applied as noted (under column heading "mean adj"). The difference between each sample mean and the lowest mean of the NetProbe or Perfas+ stream samples was subtracted from all values in the sample. ("raw" indicates no correction factors were used.) All correction factors applied met the limits described in Section 5.

- The 0.95 confidence factor (1.960 for paired stream comparison) was used.

When 8 (cross) samples are compared, the ADK criterion for 0.95 confidence is 1.85. The Combined ADK test statistic ("TC observed") must be less than 1.85 to accept the Null Hypothesis (all samples in the data set are from a common distribution).

| Emulated Delay | Sub-Sample size | | | |
|---|---|---|---|---|
| Variation 0ms | | | | |
| adk.combined (all) | 300 values | | 75 values | |
| Adj. for ties | raw | mean adj | raw | mean adj |
| TC observed | 226.6563 | 67.51559 | 54.01359 | 21.56513 |
| P-value | 0 | 0 | 0 | 0 |
| Mean std dev (all),us | 719 | | 635 | |
| Mean diff of means,us | 649 | 0 | 606 | 0 |

| Variation +/- 2.5ms | | | | |
|---|---|---|---|---|
| adk.combined (all) | 300 values | | 75 values | |
| Adj. for ties | raw | mean adj | raw | mean adj |
| TC observed | 14.50436 | -1.60196 | 3.15935 | -1.72104 |
| P-value | 0 | 0.873 | 0.00799 | 0.89038 |
| Mean std dev (all),us | 1655 | | 1702 | |
| Mean diff of means,us | 471 | 0 | 513 | 0 |

| Variation +/- 5ms | | | | |
|---|---|---|---|---|
| adk.combined (all) | 300 values | | 75 values | |
| Adj. for ties | raw | mean adj | raw | mean adj |
| TC observed | 8.29921 | -1.28927 | 0.37878 | -1.81881 |
| P-value | 0 | 0.81601 | 0.29984 | 0.90305 |
| Mean std dev (all),us | 3023 | | 2991 | |
| Mean diff of means,us | 582 | 0 | 513 | 0 |

| Variation +/- 7.5ms | | | | |
|---|---|---|---|---|
| adk.combined (all) | 300 values | | 75 values | |
| Adj. for ties | raw | mean adj | raw | mean adj |
| TC observed | 2.53759 | -0.72985 | 0.29241 | -1.15840 |
| P-value | 0.01950 | 0.66942 | 0.32585 | 0.78686 |
| Mean std dev (all),us | 4449 | | 4506 | |
| Mean diff of means,us | 426 | 0 | 856 | 0 |

From the table above, we conclude the following:

1. None of the raw or mean adjusted results pass the ADK criterion with 0 ms emulated delay variation. Use of the 75 value sub-sample yielded the same conclusion. (We note the same results when comparing same-implementation samples for both NetProbe and Perfas+.)

2. When the smallest emulated delay variation was inserted (+/-2.5 ms), the mean adjusted samples pass the ADK criterion and the high P-value supports the result. The raw results do not pass.

3. At higher values of emulated delay variation (+/-5.0 ms and +/-7.5 ms), again the mean adjusted values pass ADK. We also see that the 75-value sub-sample passed the ADK in both raw and mean adjusted cases. This indicates that sample size may have played a role in our results, as noted in the Appendix of [RFC2330] for Goodness-of-Fit testing.

We note that 150 value sub-samples were also evaluated, with ADK conclusions that followed the results for 300 values. Also, same-implementation analysis was conducted with results similar to the above, except that more of the "raw" or uncorrected samples passed the ADK criterion.

### 6.2. One-Way Delay, Loss Threshold, RFC 2679

This test determines if implementations use the same configured maximum waiting time delay from one measurement to another under different delay conditions, and correctly declare packets arriving in excess of the waiting time threshold as lost.

See the requirements of Section 3.5 of [RFC2679], third bullet point, and also Section 3.8.2 of [RFC2679].

1. configure an L2TPv3 path between test sites, and each pair of measurement devices to operate tests in their designated pair of VLANs.

2. configure the network emulator to add 1.0 sec. one-way constant delay in one direction of transmission.

3. measure (average) one-way delay with two or more implementations, using identical waiting time thresholds (Thresh) for loss set at 3 seconds.

4. configure the network emulator to add 3 sec. one-way constant delay in one direction of transmission equivalent to 2 seconds of additional one-way delay (or change the path delay while test is in progress, when there are sufficient packets at the first delay setting).

5. repeat/continue measurements.

6. observe that the increase measured in step 5 caused all packets with 2 sec. additional delay to be declared lost, and that all packets that arrive successfully in step 3 are assigned a valid one-way delay.

The common parameters used for tests in this section are:

- IP header + payload = 64 octets
- Poisson sampling at lambda = 1 packet per second
- Test duration = 900 seconds total (March 21, 2011)

The netem emulator was set to add constant delays as specified in the procedure above.

#### 6.2.1. NetProbe Results for Loss Threshold

In NetProbe, the Loss Threshold is implemented uniformly over all packets as a post-processing routine. With the Loss Threshold set at 3 seconds, all packets with one-way delay >3 seconds are marked "Lost" and included in the Lost Packet list with their transmission time (as required in Section 3.3 of [RFC2680]). This resulted in 342 packets designated as lost in one of the test streams (with average delay = 3.091 sec.).

#### 6.2.2. Perfas+ Results for Loss Threshold

Perfas+ uses a fixed Loss Threshold that was not adjustable during this study. The Loss Threshold is approximately one minute, and emulation of a delay of this size was not attempted. However, it is possible to implement any delay threshold desired with a post-processing routine and subsequent analysis. Using this method, 195 packets would be declared lost (with average delay = 3.091 sec.).

#### 6.2.3. Conclusions for Loss Threshold

Both implementations assume that any constant delay value desired can be used as the Loss Threshold, since all delays are stored as a pair <Time, Delay> as required in [RFC2679]. This is a simple way to enforce the constant loss threshold envisioned in [RFC2679] (see specific section references above). We take the position that the assumption of post-processing is compliant and that the text of the RFC should be revised slightly to include this point.

### 6.3. One-Way Delay, First Bit to Last Bit, RFC 2679

This test determines if implementations register the same relative change in delay from one packet size to another, indicating that the first-to-last time-stamping convention has been followed. This test tends to cancel the sources of error that may be present in an implementation.

See the requirements of Section 3.7.2 of [RFC2679], and Section 10.2 of [RFC2330].

1. configure an L2TPv3 path between test sites, and each pair of measurement devices to operate tests in their designated pair of VLANs, and ideally including a low-speed link (it was not possible to change the link configuration during testing, so the lowest speed link present was the basis for serialization time comparisons).

2. measure (average) one-way delay with two or more implementations, using identical options and equal size small packets (64-octet IP header and payload).

3. maintain the same path with additional emulated 100 ms one-way delay.

4. measure (average) one-way delay with two or more implementations, using identical options and equal size large packets (500 octet IP header and payload).

5. observe that the increase measured between steps 2 and 4 is equivalent to the increase in ms expected due to the larger serialization time for each implementation. Most of the measurement errors in each system should cancel, if they are stationary.

The common parameters used for tests in this section are:

- IP header + payload = 64 octets

- Periodic sampling at l packet per second

- Test duration = 300 seconds total (April 12)

The netem emulator was set to add constant 100 ms delay.

### 6.3.1. NetProbe and Perfas+ Results for Serialization

When the IP header + payload size was increased from 64 octets to 500 octets, there was a delay increase observed.

Mean Delays in us
NetProbe

| Payload | s1 | s2 | sA | sB |
|---|---|---|---|---|
| 500 | 190893 | 191179 | 190892 | 190971 |
| 64 | 189642 | 189785 | 189747 | 189467 |
| Diff | 1251 | 1394 | 1145 | 1505 |

Perfas

| Payload | p1 | p2 | p3 | p4 |
|---|---|---|---|---|
| 500 | 190908 | 190911 | 191126 | 190709 |
| 64 | 189706 | 189752 | 189763 | 190220 |
| Diff | 1202 | 1159 | 1363 | 489 |

Serialization tests, all values in microseconds

The typical delay increase when the larger packets were used was 1.1 to 1.5 ms (with one outlier). The typical measurements indicate that a link with approximately 3 Mbit/s capacity is present on the path.

Through investigation of the facilities involved, it was determined that the lowest speed link was approximately 45 Mbit/s, and therefore the estimated difference should be about 0.077 ms. The observed differences are much higher.

The unexpected large delay difference was also the outcome when testing serialization times in a lab environment, using the NIST Net Emulator and NetProbe [ADV-METRICS].

### 6.3.2. Conclusions for Serialization

Since it was not possible to confirm the estimated serialization time increases in field tests, we resort to examination of the implementations to determine compliance.

NetProbe performs all time stamping above the IP layer, accepting that some compromises must be made to achieve extreme portability and measurement scale. Therefore, the first-to-last bit convention is supported because the serialization time is included in the one-way delay measurement, enabling comparison with other implementations.

Perfas+ is optimized for its purpose and performs all time stamping close to the interface hardware. The first-to-last bit convention is supported because the serialization time is included in the one-way delay measurement, enabling comparison with other implementations.

### 6.4. One-Way Delay, Difference Sample Metric

This test determines if implementations register the same relative increase in delay from one measurement to another under different delay conditions. This test tends to cancel the sources of error that may be present in an implementation.

This test is intended to evaluate measurements in Sections 3 and 4 of [RFC2679].

1. configure an L2TPv3 path between test sites, and each pair of measurement devices to operate tests in their designated pair of VLANs.

2. measure (average) one-way delay with two or more implementations, using identical options.

3. configure the path with X+Y ms one-way delay.

4. repeat measurements.

5. observe that the (average) increase measured in steps 2 and 4 is ~Y ms for each implementation. Most of the measurement errors in each system should cancel, if they are stationary.

In this test, X = 1000 ms and Y = 1000 ms.

The common parameters used for tests in this section are:

- IP header + payload = 64 octets

- Poisson sampling at lambda = 1 packet per second

- Test duration = 900 seconds total (March 21, 2011)

The netem emulator was set to add constant delays as specified in the procedure above.

#### 6.4.1. NetProbe Results for Differential Delay

| | |
|---|---|
| Average pre-increase delay, microseconds | 1089868.0 |
| Average post 1 s additional, microseconds | 2089686.0 |
| Difference (should be ~= Y = 1 s) | 999818.0 |

Average delays before/after 1 second increase

The NetProbe implementation observed a 1 second increase with a 182 microsecond error (assuming that the netem emulated delay difference is exact).

We note that this differential delay test has been run under lab conditions and published in prior work [ADV-METRICS]. The error was 6 microseconds.

### 6.4.2. Perfas+ Results for Differential Delay

| | |
|---|---|
| Average pre-increase delay, microseconds | 1089794.0 |
| Average post 1 s additional, microseconds | 2089801.0 |
| Difference (should be ~= Y = 1 s) | 1000007.0 |

Average delays before/after 1 second increase

The Perfas+ implementation observed a 1 second increase with a 7 microsecond error.

### 6.4.3. Conclusions for Differential Delay

Again, the live network conditions appear to have influenced the results, but both implementations measured the same delay increase within their calibration accuracy.

## 6.5. Implementation of Statistics for One-Way Delay

The ADK tests the extent to which the sample distributions of one-way delay singletons from two implementations of [RFC2679] appear to be from the same overall distribution. By testing this way, we economize on the number of comparisons, because comparing a set of individual summary statistics (as defined in Section 5 of [RFC2679]) would require another set of individual evaluations of equivalence. Instead, we can simply check which statistics were implemented, and report on those facts, noting that Section 5 of [RFC2679] does not specify the calculations exactly, and gives only some illustrative examples.

| | NetProbe | Perfas+ |
|---|---|---|
| 5.1. Type-P-One-way-Delay-Percentile | yes | no |
| 5.2. Type-P-One-way-Delay-Median | yes | no |
| 5.3. Type-P-One-way-Delay-Minimum | yes | yes |
| 5.4. Type-P-One-way-Delay-Inverse-Percentile | no | no |

Implementation of Section 5 Statistics

Only the Type-P-One-way-Delay-Inverse-Percentile has been ignored in both implementations, so it is a candidate for removal or deprecation in a revision of RFC 2679 (this small discrepancy does not affect candidacy for advancement).

## 7. Conclusions and RFC 2679 Errata

The conclusions throughout Section 6 support the advancement of [RFC2679] to the next step of the Standards Track, because its requirements are deemed to be clear and unambiguous based on evaluation of the test results for two implementations. The results indicate that these implementations produced statistically equivalent results under network conditions that were configured to be as close to identical as possible.

Sections 6.2.3 and 6.5 indicate areas where minor revisions are warranted in RFC 2679. The IETF has reached consensus on guidance for reporting metrics in [RFC6703], and this memo should be referenced in the revision to RFC 2679 to incorporate recent experience where appropriate.

We note that there is currently one erratum with status "Held for Document Update" for [RFC2679], and it appears this minor revision and additional text should be incorporated in a revision of RFC 2679.

The authors that revise [RFC2679] should review all errata filed at the time the document is being written. They should not rely upon this document to indicate all relevant errata updates.

## 8. Security Considerations

The security considerations that apply to any active measurement of live networks are relevant here as well. See [RFC4656] and [RFC5357].

## 9. Acknowledgements

The authors thank Lars Eggert for his continued encouragement to advance the IPPM metrics during his tenure as AD Advisor.

Nicole Kowalski supplied the needed CPE router for the NetProbe side of the test setup, and graciously managed her testing in spite of issues caused by dual-use of the router. Thanks Nicole!

The "NetProbe Team" also acknowledges many useful discussions with Ganga Maguluri.

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