SOPO Task 7.0 Data Delivery Efficiency Improvements, Subtask 7.1 – New Technology Value

Phasor Gateway

Final – Revision 1.1
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Peak Reliability Synchrophasor Program

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PRSP Phasor Gateway Evaluation Report

1. Executive Summary

This report was produced as part of Data Efficiency Delivery Improvement studies conducted in the Peak Reliability Synchrophasor Data Program (PRSP) funded by DOE. The objective of this PRSP work stream is to investigate and test alternative technologies for use in the widespread distribution and sharing of synchrophasor data. The testing for this study was conducted by Peak RC personnel with assistance from the Grid Protection Alliance (GPA) and the BRIDGE Energy Group. All tests were conducted on existing infrastructure deployed during the SGIG WISP program and used permutations of transport protocols (TCP and UDP) to evaluate the publish/subscribe Gateway Exchange Protocol as compared to IEEE C37.118 for synchrophasor data exchange. The open-source Gateway Exchange Protocol was developed as part of the SIEGate project (DE-OE-0000536) funded by DOE.

Testing was conducted at Peak RC's Vancouver and Loveland operations centers. To simulate a range of operating conditions, the performance of the protocols was evaluated at three data volumes: (1) small scale – simulating a phasor data flow from one of Peak RC's smaller phasor data contributors, (2) medium scale – simulating a phasor data flow from one of Peak RC's bigger phasor data contributors, and (3) large scale – the aggregated Peak RC synchrophasor data stream from all its members. To assure that the protocols were evaluated under identical conditions, results are based on simultaneous side-by-side tests. Multiple 2-hour tests were run for each data volume to verify that the results were repeatable. In addition, a final long-term test (7-days) was run to substantiate that a 2-hour test was representative of sustained use of one protocol over the other. The raw measurements from each test are provided in this report as Appendix B.

The results from this testing show that using the Gateway Exchange Protocol results in less synchrophasor data loss as compared to the IEEE C37.118 protocol. For the large data volume test with UDP (Peak RC's current method of data transport from its members), IEEE C37.118 was measured to have 2.1% data loss vs. 0.14% for GEP – an improvement factor of 15. Data loss with GEP was about 6 times less in the medium data volume (0.31% data loss vs. 0.04% for GEP) and small data volume (0.12% data loss vs. 0.02% for GEP) tests.

In addition, testing results show that this significant reduction in data loss does not result in large bandwidth utilization penalties. Test results show that GEP over TCP required only 60% of the bandwidth that IEEE C37.118 consumed using either the UDP or TCP transport protocols.

Finally, these tests were used to confirm that GEP security features can effectively manage the distribution of phasor data signals to only those that are authorized as well provide stream encryption. IEEE C37.118 has no security features.

In conclusion, it was found that IEEE C37.118 remains a good choice for transport of small phasor data streams. For medium and large scale phasor data transport, GEP has clear performance and business advantages.

PRSP Phasor Gateway Evaluation Report

Work stream: SOPO Task 7.0 Data Delivery Efficiency Improvements

Subtask 7.1 New Technology Value

2. DOE Deliverable

The primary goal of the Phasor Gateway work stream is to test and research ways to improve the widespread distribution and sharing of synchrophasor data. Peak Reliability (Peak RC) will investigate and report on the performance and potential for the Secure Information Exchange Gateway (SIEGate) application developed by the Grid Protection Alliance (GPA) and the University of Illinois under DOE-OE-0000536 to be employed as a solution.

The success criteria for this work stream are as follows:

- Install and test the SIEGate application.
- Write a white paper on the performance of SIEGate and the potential for use in the exchange of synchrophasor data.

3. Objective

During the deployment of WISP, only a single technology was supported by multiple vendors for distributing synchrophasor data. This technology was the Phasor Data Concentrator (PDC) using the IEEE C37.118-2005 communications protocol. The PDC technology is deployed and working, however there are concerns that this early technology will not scale with the increased use of synchrophasor data. Recent growth in the volume of phasor data and the need to share it among grid operators has shown that the existing technology is bandwidth intensive, and has data delivery losses when used to move data between multiple entities. An alternative technology developed by GPA in their SIEGate product will be evaluated to determine if it offers a better solution for the widespread distribution and sharing of synchrophasor data.

The objective of this work stream is to investigate and test alternative technologies for use in the widespread distribution and sharing of synchrophasor data.

4. Background / Introduction

Wide-Area Data Delivery: The current method of sharing synchrophasor data is a series of point-to-point transmissions among the Participants in the West. One of the objectives of the PRSP proposal is to find pre-commercial methods that could, with some development, provide an interoperable solution to alleviate common issues related to using IEEE C37.118 or IEC 61850-90-5 to exchanging synchrophasor data at scale.

The Grid Protection Alliance has developed an open source appliance called SIEGate that can be used to exchange real-time electric grid operating information. Under this project, the PRSP will review the functionality provided by SIEGate, install the product at Peak RC, and conduct testing to verify its performance, functionality and potential for use within the Peak RC infrastructure. The purpose of this white paper is to document the results and findings of SIEGate testing.

5. Phasor Gateway Evaluation Scope

5.1 In-Scope

	In-Scope - Scope Item
1	Review the SIEGate Functionality
2	Test Phasor Gateway over the WISP WAN
3	Document the scope of the Phasor Gateway Test
4	Document requirements and use cases
5	Develop bandwidth utilization model to compare with existing C37.118
6	Write a white paper on the Gateway performance

5.2 Out-of-Scope

	Out-of-Scope - Scope Item	**Notes**
1	Replacing the existing phasor data sharing implementation	

6. SIEGate Overview

6.1 SIEGate Design

Developed by the Grid Protection Alliance and the University of Illinois at Urbana-Champaign, the Secure Information Exchange Gateway (SIEGate) project was funded by DOE's Office of Electricity Delivery and Energy Reliability under the Cybersecurity for Energy Delivery Systems (CEDS) Program from 2010 to 2014. Other project partners were Alstom Grid, PJM Interconnection, and the Pacific Northwest National Laboratory.

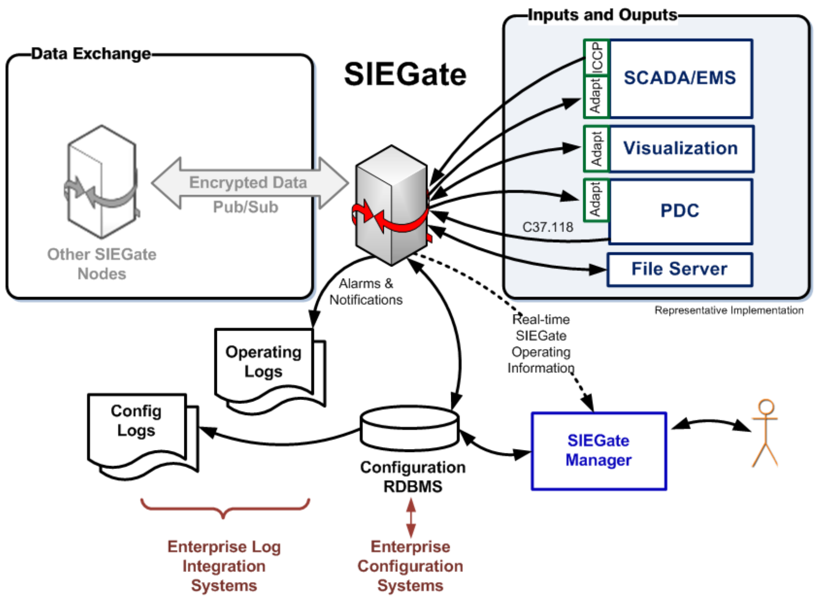


Figure 6.1 – SIEGate Dataflow Overview.

During the design phase of the project, requirements were set on the interoperability, administrative, performance, and security features, among others. These requirements were largely derived from the project objectives and from use cases established by the NERC functional model and by the NIST Interagency Report 7628, *Guidelines for Smart Grid Cyber Security*.

The SIEGate appliance is designed for implementation on standard, high-availability hardware systems to reduce barriers to commercialization and use. It uses the Microsoft Windows operating system, in order to leverage existing open-source software that is currently used for secure synchrophasor data exchange and is written using the Microsoft .NET platform.

SIEGate closed a technology gap so that an increasingly high volume of information with low latency can be shared securely among control centers. This technical gap involved balancing strong security against other challenging goals that included:

- Minimization of latency and maximization of throughput for high-volume data exchange
- Concurrent delivery of data with a broad range of timeliness and priority requirements

- Assurance of exchange of highest-priority data when subjected to common system degradation events

To successfully address these challenges, the SIEGate design includes:

- A processing service, or engine, that consumes inputs, produces outputs, and manages the publication-subscription process between SIEGate nodes
- A data layer that includes a relational database for storage of configuration information
- An application to add and modify configuration information and to monitor gateway performance in real-time with a historian to record these statistics
- An encryption key management subsystem
- An alarming and notification subsystem that can be integrated with existing log management systems and intrusion detection systems

Using GEP, SIEGate was envisioned to exchange at least 1 million points per second. Once developed, SIEGate was measured on the bench by GPA to exchange over 4 million points per second.

6.2 SIEGate in Use

Since the conclusion of the SIEGate project, utilities have been installed SIEGate to support real-time operations. These utilities include Entergy, Oklahoma Gas & Electric, and Southern Company among others. The strongest use cases to date have been:

- The secure exchange of synchrophasor data.
- Use of GEP to support publish-subscribe architectures for routing of synchrophasor data.
- Use of GEP to support out-of-band re-transmission of synchrophasor data to fill missing data gaps.[1]

7. The Gateway Exchange Protocol

The SIEGate project resulted in creation of GPA's open Gateway Exchange Protocol (GEP) with the requirement to move a *continually variable* set of points at low latency.

GEP combines a simple command-driven service with a tightly compressed, fast binary serialization of time-series values. The protocol does not require a predefined or fixed configuration – that is, the time-series values arriving in one data packet can be different than those arriving in another. Each packet of data consists of a collection of time-series values; each time-series value is a structure containing an identifier (ID), a time-stamp, a value and associated flags (see Figure 7.1). The data packet size is dynamically configurable so it can be adjusted at run-time to accommodate varying network conditions to reduce packet fragmentation. The GEP protocol specification includes both subscriber command and publisher response properties. Responses from the publisher include a response code, an in-response-to

[1] This functionality was not tested in this program

command code, payload length and actual payload bytes. Response codes also include the success or failure.

7.1 GEP Protocol Definition

The GEP protocol is designed to send measured values as small atomic units of data, packaged loosely together into small groups to keep network fragmentation to a minimum. As such any one group of measurements may not contain the same values as the next, there is no fixed set of values to be published per group. Additionally, measurements carry their own timestamp and quality, this allows measurements to be published as received without the need to wait for alignment. Since there is no fixed format, measurements also require individual identification.

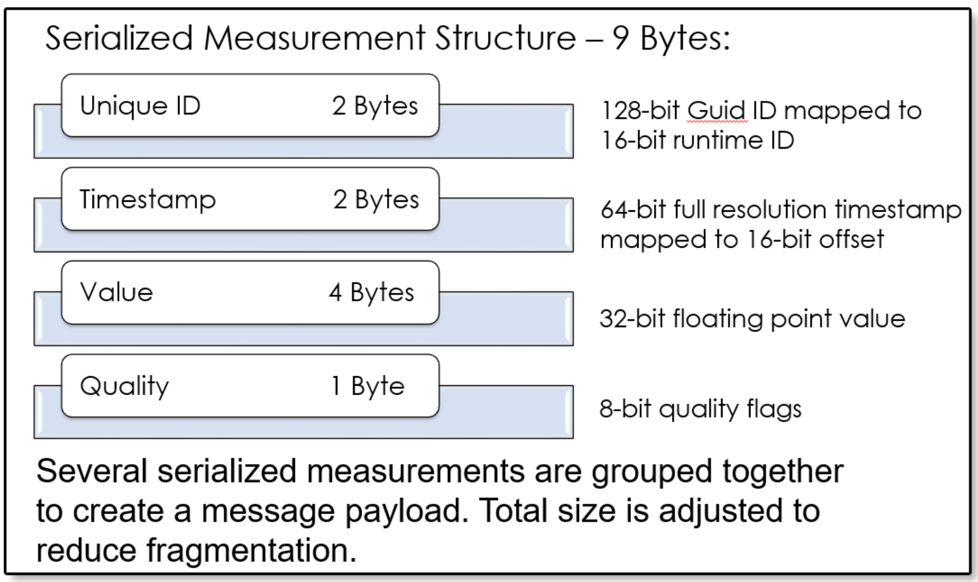


Figure 7.1 – A typical GEP payload.

7.2 GEP Feature Summary

GEP incorporates a signal level publish/subscribe protocol with two available channels: a Command Channel (TCP) and a Data Channel (UDP or TCP) to provide:

- Dynamic data and metadata exchange with automatic change notifications
- The ability for the subscriber to start and stop the data stream as needed and change streaming data values dynamically
- Point-level access control
- Varying exchange or down-sampling rates
- Transport neutrality

7.3 GEP Security

GEP can be implemented with or without its security features. GEP enables implementation of both strong access control and encryption. For GPA's products, security is managed through components in the Grid Solutions Framework (GSF). These features include:

Administrator access control where multiple role-based options are available. This management interface based access control can be implemented to integrate with existing enterprise authentication, such as, Microsoft Active Directory, Kerberos, and local accounts. The GSF also provides the capability for multi-factor authentication strategies using hardware/software tokens, e.g., RSA SecureID Hardware Tokens.

Authentication / access control for data communication includes strong authentication of trusted appliances through the out of band exchange of symmetric keys using transport layer security (TLS). Publishers have a fine-grained mechanism to control access to specific data by authenticated partner (or trusted) GEP appliances.

Integrity-protected logging for operating logs and configuration logs as well as remote log storage capability for additional security. The GSF leverages standardized logging to the OS so that errors and events can be captured through enterprise log integration systems.

Key Management – GEP is configurable to allows use and manage private keys in a highly isolated environment. Using GSF transport security features, GEP is also capable of utilizing key management services that offer X.509 identity certificates for authentication. In the absence of that infrastructure, GSF is able to use self-signed X.509 identity certificates that are securely communicated out-of-band.

7.4 Synchrophasor Protocol Comparisons

By large margin, the dominant method to exchange synchrophasor data both domestically and internationally utilizes the IEEE C37.118-2005 protocol that was designed for efficient substation-to-control room communications – i.e., sending a finite set (a frame) of information between location A and location B. While efficient at all data volumes and effective with small data volumes, when used at scale (e.g., for systems involving hundreds of PMUs) the frame-based nature of IEEE C37.118 presents network design and operations challenges. Even with purpose-built networks, large frame sizes result in an increased probability of overall data loss through the large number of network packet fragments required to send each C37.118 frame. In addition, IEEE C37.118 offers no native security and its methods for management of measurement metadata are prescriptive making extension and modification as phasor data is shared among users complex and costly.

The IEC 61850-90-5 protocol has been demonstrated as an alternative to IEEE C37.118. However, it is also frame-based and has a larger frame size than IEEE C37.118 for the same data. Therefore, the scalability issues with C37.118 will be exacerbated with IEC 61850-90-5.

Because of the extra information required to be transmitted per measurement, the natural bandwidth requirements of GEP will be higher than a fixed format frame based protocol such as IEEE C37.118, however GEP is always deployed with simple lossless compression. When GEP is used over UDP, each group of measurements is compressed before transmission making the bandwidth requirements more comparable to IEEE C37.118 and other synchrophasor frame based protocols. Testing showed that after packet-level compression, GEP/UDP was roughly 1.8 times larger than IEEE C37.118 for the same data. However, when using GEP over TCP, stateful compression is used which allows for better series based compression over many groups of data resulting in the total bandwidth requirement for GEP/TCP actually being less than IEEE C37.118. Test results show that GEP was at least 30% smaller, and often much better, than IEEE C37.118 for the same data.

A table summarizing the three protocols is provided below.

	IEEE C37.118	IEC 61850	GEP
Deployment Zones *Today*	Substation Control Center Inter-company	Substation Control Center	Control Center Inter-company
Preconfigured Data Packet Format	Yes	Yes – but client definable	No
Security Options	No	Yes	Yes
Signal Level Publish / Subscribe	No	Yes – but not dynamic	Yes

Figure 7.4 – Protocol Comparisons

8. Test Plan

A test plan was developed to assure a "real-world" production comparison of GEP to IEEE C37.118. The plan required that as much as the full-volume of Peak RC's real-time synchrophasor data would be used for testing and that the respective protocol's performance would be measured between Peak RC's Vancouver and Loveland operations centers. For details of test plan execution, see Appendix A.

8.1 The Test Setup

Peak RC currently requires its members to use the IEEE C37.118 communications protocol to provide Peak RC synchrophasor data. Peak RC also uses the IEEE C37.118 protocol to distribute real-time phasor data internally among its synchrophasor applications for data analysis, display and storage. As seen in Figure 8.1, the data used for the testing environment is a real-time copy of the synchrophasor data being received by Peak RC from its members – at the time of the test, 3,145 signals. This test data was sent from Vancouver (denoted as upstream or "UP") to Loveland (denoted as downstream or "DN") over the WISP WAN using the GEP and IEEE C37.118 protocols. Since network conditions (even for purpose-built networks like the WISP WAN) and synchrophasor data volumes vary, the GEP and IEEE C37.118 comparison tests were run in parallel. Each protocol was asked to move precisely the same data under the influence of the identical network conditions. All tests were run multiple times to ensure that the results were consistent under the varying conditions.

The hardware was the same for the servers hosting SIEGate and the openPDC. Two servers were in Vancouver (one for SIEGate and one for the openPDC) and two were in Loveland. The Synchrophasor Stream Splitter was used to convert each Peak RC member's data stream to TCP—thereby assuring that the phasor data presented to each protocol was the same without losses between the Stream Splitter and the receiving application on each server, i.e., SIEGate and openPDC.

A pair of openPDCs was used to construct, send and receive a single, aggregated IEEE C37.118 TCP stream of member data from Vancouver to Loveland. Similarly, a pair of SIEGate nodes was used to construct, send and receive all real-time phasor data from Vancouver to Loveland using GEP. Using this configuration, multiple tests were run to compare the two protocols using different transport protocol configuration variations and test conditions. While monitoring server CPU loading and memory use, data volumes were adjusted and overall data loss and transport efficiency was measured.

The original test plan called for measuring aggregate protocol performance every 10 seconds using the PDQTracker application. However, after only a few tests it was clear that the WISP WAN was performing at a high level and that ten seconds was not enough time to provide a basis for a meaningful comparison of the protocols. Therefore, an instance of the openHistorian was installed on each server to archive all received data at each point in the system so that a point-by-point comparison could be used to perform highly accurate comparisons. The 10-second summary style data from PDQTracker results were subsequently used as a secondary source of comparison data to validate the detailed results of the historian-based comparisons.

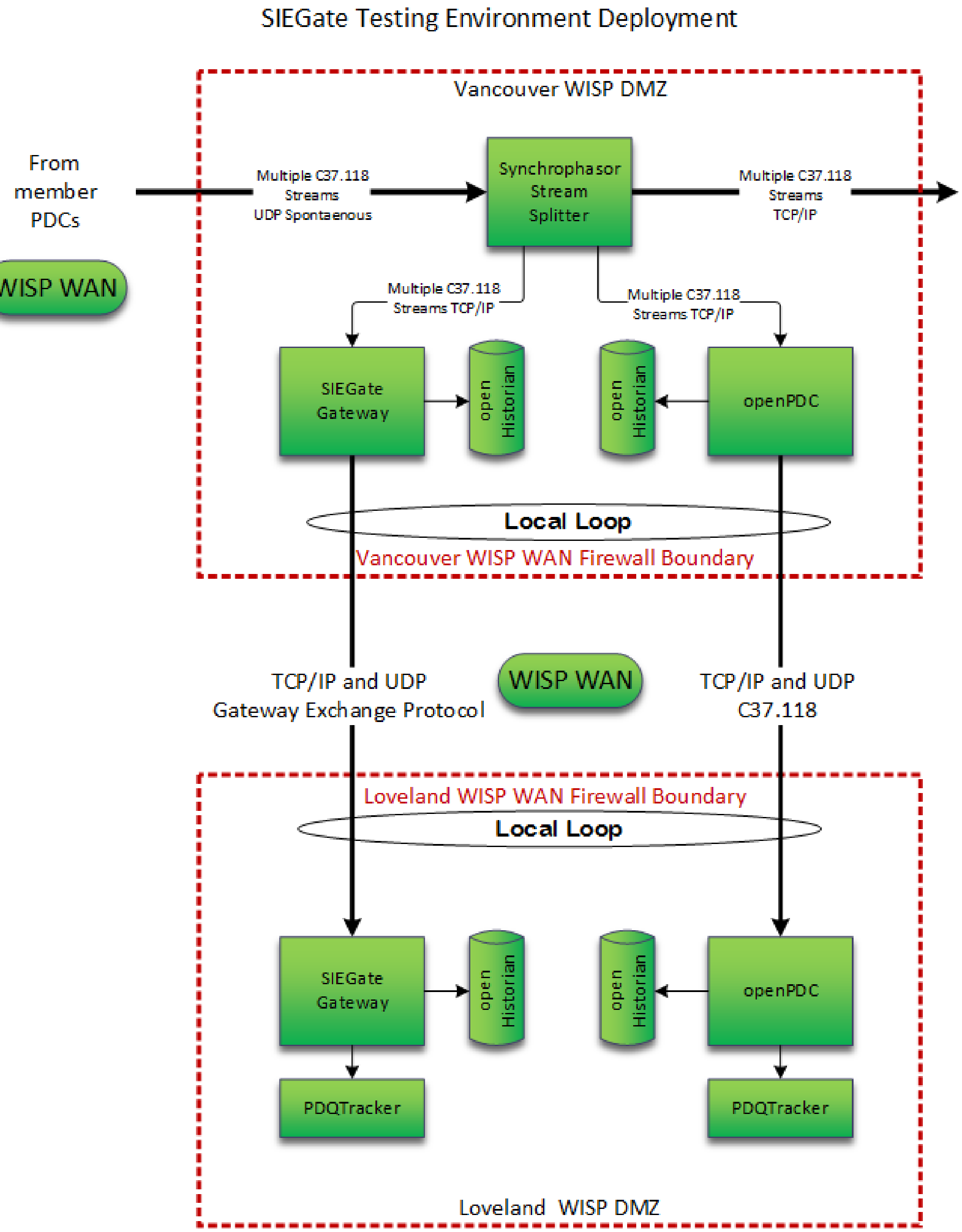


Figure 8.1 – Test Context

8.2 Tests Performed

Tests were broken down into four categories with each test measuring bandwidth utilization, CPU loading and memory utilization. Overall data loss was measured only when using UDP since no data loss is excepted when using TCP.

Primary Tests (Interval Tests) – To assure that the protocols were tested under a range of conditions, three two-hour blocks of data were constructed – large (all data), medium (one Peak RC member – BPA), and small (5 PMUs). For these varying data volumes, tests were run using combinations of both TCP and UDP for data transport.

Duration Tests – To assure that the results were valid over the broadest range of network conditions, a 7-day test was conducted to validate the primary performance and efficiency findings.

Security Tests – Since the IEEE C37.118 protocol does not include security options, the GEP security options were exercised to confirm that they functioned as specified.

Latency Test – GEP and IEEE C37.118 latencies were measured using the local system clocks of the test computers.

9. Test Data

The results below have been constructed from the raw test findings provided in Appendix B.

9.1 Primary Tests (Interval Tests)

Five interval tests were run to compare GEP to IEEE C37.118 using variations of transport protocols and data volumes. Each test was run three times to make sure each the tests were comparable. Averages of these three runs are detailed below. Note that “UP” is the upstream data source in Vancouver, and “DN” is the downstream data destination in Loveland (see Figure 7.1):

- Test 1: Transport all member data using a TCP control channel and a UDP data channel:

Average	***C37.118***	***GEP***
Bandwidth (Mbits/s)	2.71	4.95
Bytes / Packet (TCP)	692.40	67.12
Bytes / Packet (UDP)	1515.06	1138.96
CPU Loading UP	22.67%	13.67%
CPU Loading DN	4.83%	5.93%
Memory Usage UP (MB)	1423.00	494.33
Memory Usage DN (MB)	486.67	470.33
Data Loss	2.12%	0.14%

- Test 2: Transport all member data using a single TCP channel for both control and data:

Average	***C37.118***	***GEP***
Bandwidth (Mbits/s)	2.77	1.58
Bytes / Packet (TCP)	956.32	687.65
CPU Loading UP	21.73%	8.73%
CPU Loading DN	4.90%	6.80%
Memory Usage UP (MB)	1379.67	544.67
Memory Usage DN (MB)	573.00	461.33

- Test 3: Reduce measurements to a single member’s data (BPA) using a TCP control channel and UDP data channel:

Average	***C37.118***	***GEP***
Bandwidth (Mbits/s)	0.89	1.72
Bytes / Packet (TCP)	590.00	113.46
Bytes / Packet (UDP)	1517.95	1012.49
CPU Loading UP	3.10%	3.93%
CPU Loading DN	1.90%	2.00%
Memory Usage UP (MB)	391.33	332.33
Memory Usage DN (MB)	428.00	425.33
Data Loss	0.31%	0.04%

- Test 4: Reduce measurements to single member's data (BPA) using a single TCP channel for both control and data:

Average	***C37.118***	***GEP***
Bandwidth (Mbits/s)	0.89	0.60
Bytes / Packet (TCP)	924.64	897.27
CPU Loading UP	3.10%	2.80%
CPU Loading DN	8.43%	1.87%
Memory Usage UP (MB)	445.33	406.67
Memory Usage DN (MB)	436.67	415.67

- Test 5: Further reduce measurements to five devices using a TCP control channel and a UDP data channel

Average	***C37.118***	***GEP***
Bandwidth (Mbits/s)	0.08	0.15
Bytes / Packet (TCP)	168.22	88.52
Bytes / Packet (UDP)	428.71	730.00
CPU Loading UP	1.17%	1.23%
CPU Loading DN	0.66%	0.86%
Memory Usage UP (MB)	165.33	151.33
Memory Usage DN (MB)	149.33	149.67
Data Loss	0.12%	0.02%

9.2 Duration Test

A single duration test was run over a period of seven days for a single member's data (BPA) using a TCP control channel and a UDP data channel. This long running test was used to help validate the results of the shorter interval tests to make sure typical variations in network traffic and data availability over a normal work week would not adversely affect the test results:

Actual	***C37.118***	***GEP***
Bandwidth (Mbits/s)	0.88	1.70
Bytes / Packet (TCP)	483.1	176.3
Bytes / Packet (UDP)	1518	1517.8
CPU Loading UP	3.12%	3.90%
CPU Loading DN	1.86%	2.03%
Memory Usage UP (MB)	235	195
Memory Usage DN (MB)	208	118
Data Loss	0.30%	0.04%

9.3 Subscription Security Test

Since the IEEE C37.118 protocol does not include security options, the GEP security options were exercised to make sure they function as advertised. Data during this test was transported using Transport Layer Security and availability of data in the publisher for the subscriber was reduced by several methods. See section 9.8 for an overview of results and images that were captured during the testing.

9.4 Data Latency Test

Data latency comparisons for both GEP and IEEE C37.118 were measured using the system time of the test computers. Note that the accuracy of the test results are only valid within the accuracy of local clocks and operating system time reporting precision[2]:

Average Time Delay (sec)	***C37.118***	***GEP***
Interval Test 1	10.449	2.883
Interval Test 2	10.427	3.099
Interval Test 4	1.497	0.054

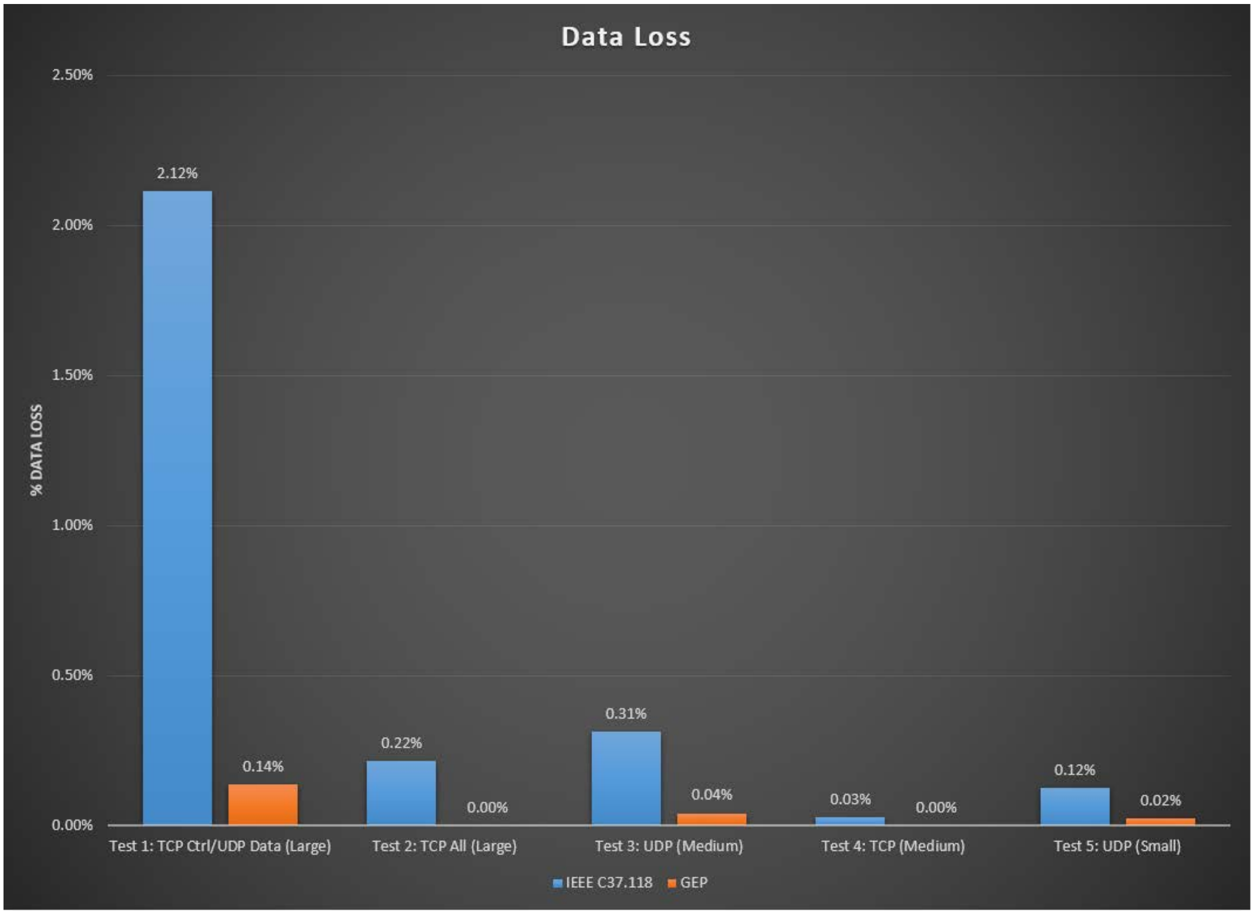
The latency test results for case 1 and 2, i.e., the large data sets, using IEEE C37.118 are indicative of waiting the full wait-time, defined in the tests at 10 seconds. These latencies for the IEEE C37.118 protocol result as a consequence of missing some data in source member data streams. The subsequent tests for smaller data sets that had better data fidelity provide a better comparison of protocol latencies, however, since these results are still only within the accuracy of the local system clocks and are subject to current network conditions the results should not be considered exhaustive.

Since GEP does not require specification of a wait-time, it was always expected that GEP would have lower overall latency that IEEE C37.118. Even though the test results reported here appear to indicate that GEP has lower latencies, the authors believe that the data collected in these tests are not sufficiently precise to include in the report conclusions.

[2] Results for test cases 3, 5 and the duration test were not reported here because the latency averages for these tests produced inconsistent results, see Appendix B for details.

10. Test Results

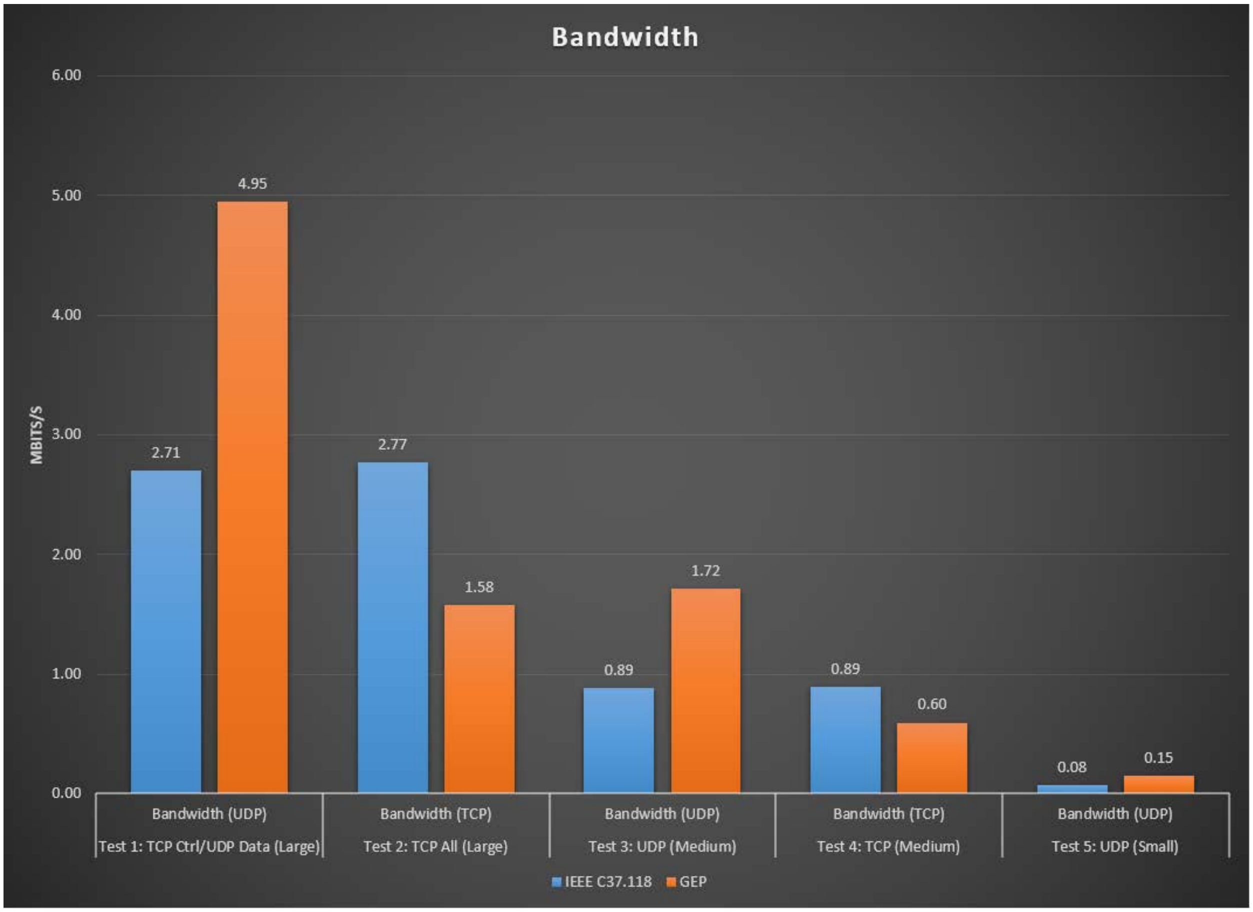
10.1 Data Loss Comparisons



IEEE C37.118 data loss is highest for a UDP data channel. In the chart above, it is shown that the data loss percentage varies proportionally with frame size. Note that even when using TCP, data losses were seen with IEEE C37.118 – this TCP loss was at the application layer where phasor data had not arrived within the specified wait-time window.

The issues with IEEE C37.118 scaling are apparent in this graphic. In the “Medium” test case, representative of a large Transmission Operator, losses are manageable using UDP and can be avoided completely with TCP using either IEEE C37.118 or GEP. However, in the “Large” test case, IEEE C37.118 losses could be viewed as being at unacceptable levels at over 2%.

10.2 Bandwidth Comparisons



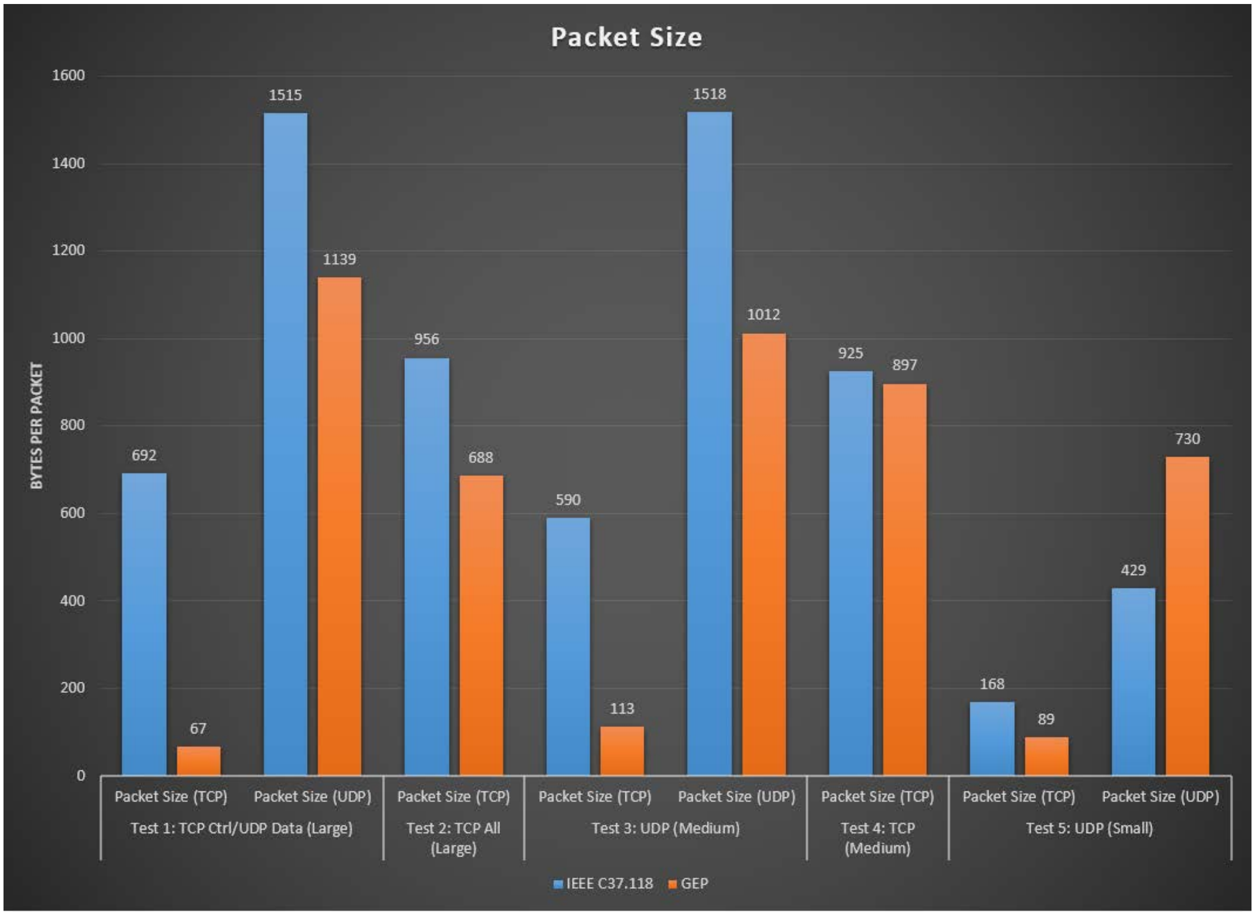
As seen in the bandwidth[3] comparison chart above, IEEE C37.118 is an efficient way to transfer synchrophasor data via UDP. GEP has increased overhead of per measurement for time and identification as well as needed information to support publish/subscribe methods, security and other functions.

However, and importantly, GEP over TCP has lower bandwidth requirements than IEEE C37.118 for either TCP or UDP. GEP accomplishes this through use of lossless, stateful data compression.

In the large test case, GEP/TCP requires about 60% of the bandwidth as needed for IEEE C37.118 for either transport protocol. In the medium case, which had much higher data fidelity, the bandwidth reduction in GEP is not as large but still an improvement over IEEE C37.118 with GEP/TCP requiring roughly 70% of the bandwidth of IEEE C37.118.

[3] Bandwidth calculations were estimated using total bytes of data transmitted over the testing interval. Layer 3 packet overheads were not taken into account which would increase the actual bandwidth requirements for all protocol permutations. The authors felt that byte count per unit time was sufficient for *relative* comparison of protocol bandwidth requirements

10.3 Packet Size Comparisons

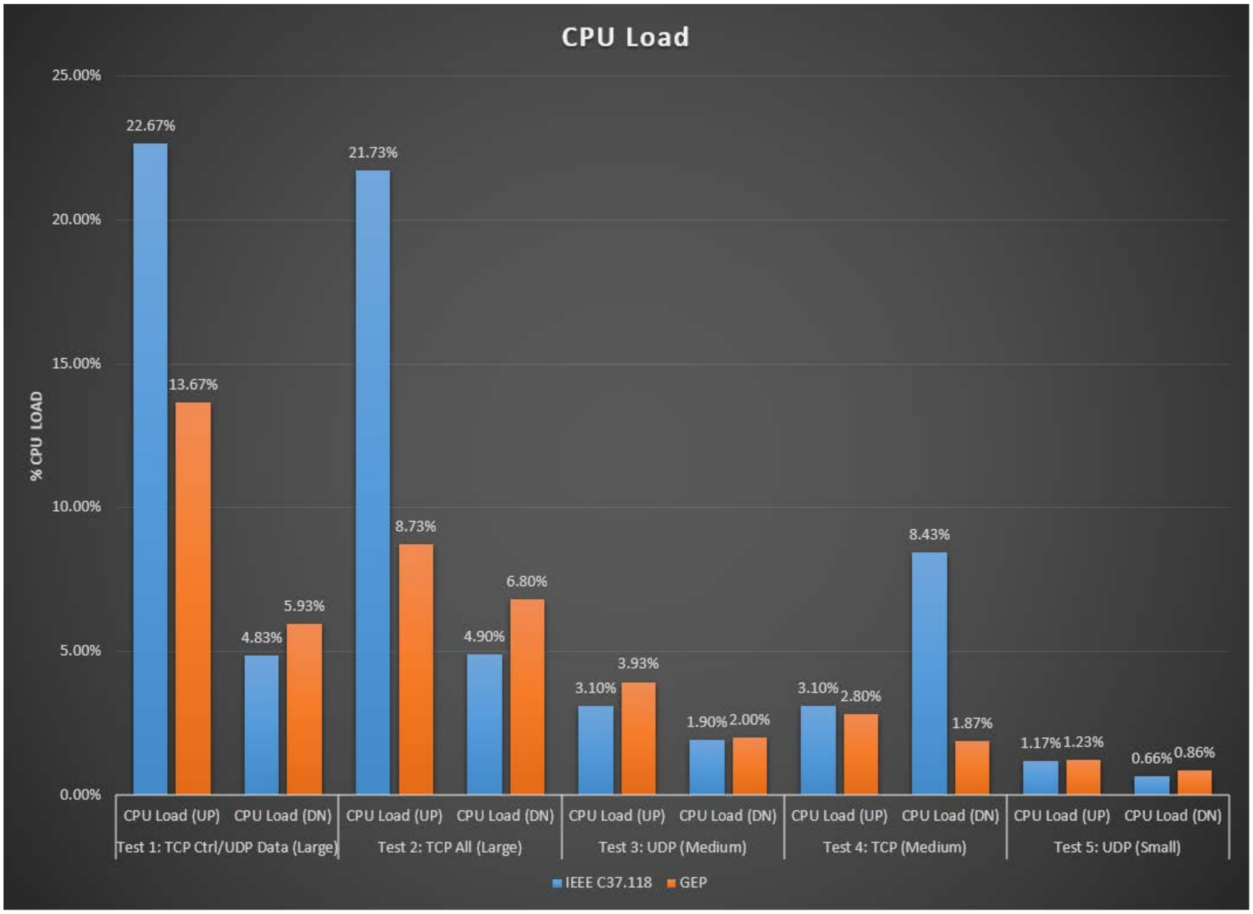


Average network packet sizes measured over the two-hour test period are shown in the chart above.

In all cases but the small UDP case, IEEE C37.118 packets were measured to have a larger number of bytes per network packet than GEP. IEEE C37.118 network packet size is maximized to accommodate the frame (i.e., number of signals) being sent. GEP network packet sizes are constructed to be of an optimal size regardless of the number of signals being sent.

While not normally a measure of protocol effectiveness, this chart highlights the ability of GEP to minimize the packet size when using UDP for data transfer thereby minimizing the impact of dropped packets.

10.4 CPU Loading Comparisons

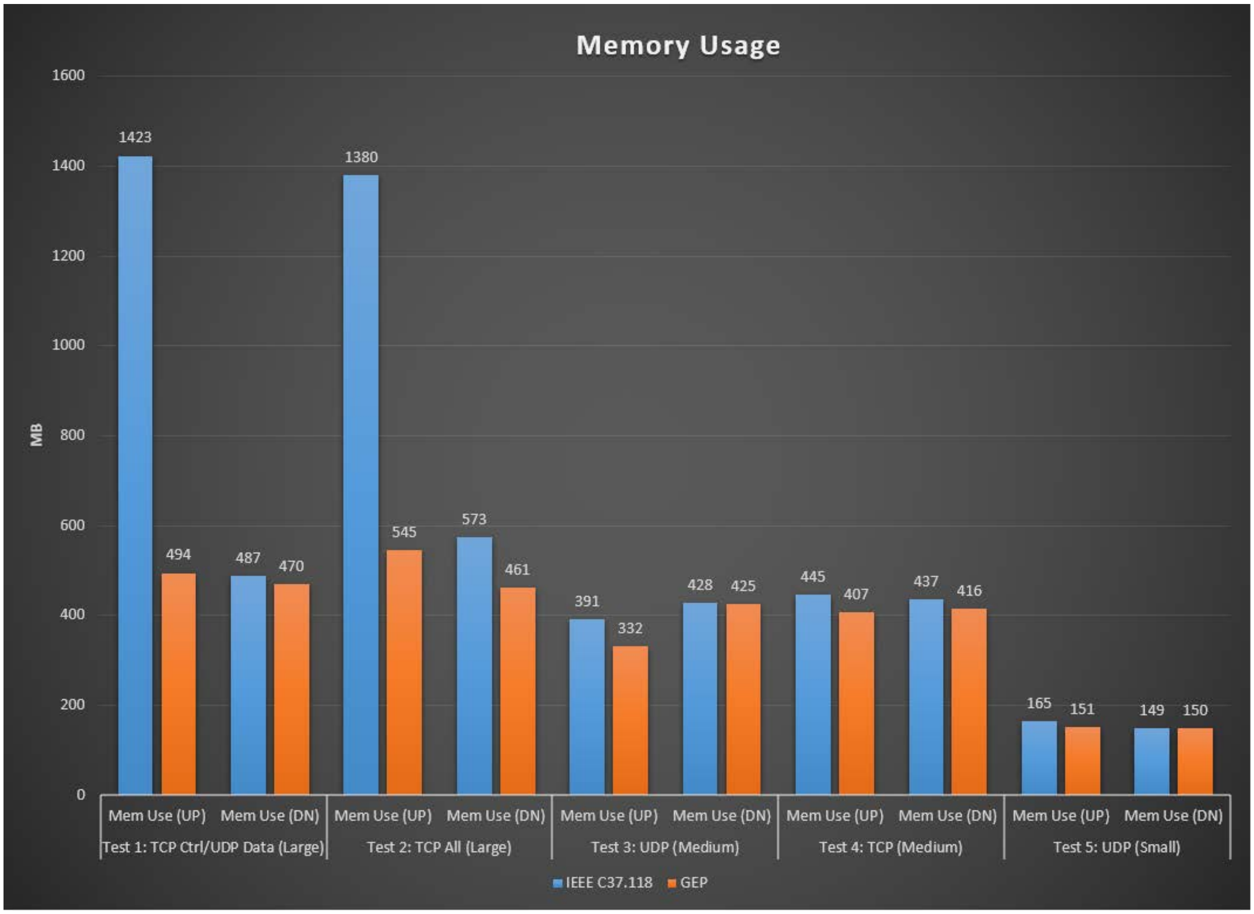


Host system CPU loading was measured during the comparison tests as an indicator of the impact on server hardware on use of one protocol over the other – this measurement was of particular interest since GEP's data compression will require some additional computational effort. The results show that there is minimal CPU impact for compression activities when using GEP as compared to IEEE C37.118[4].

The outlier in this data is for test case 4, downstream CPU loading of IEEE C37.118. We have no clear explanation why this value was larger than the other medium cases and draw no conclusions based on this reading.

[4] Note that this compares CPU loading based on the openPDC's implementation of IEEE C37.118 which uses a measurement based algorithm for parsing, data alignment and frame reconstruction – other vendor implementations of IEEE C37.118, which are often frame based, could produce different results.

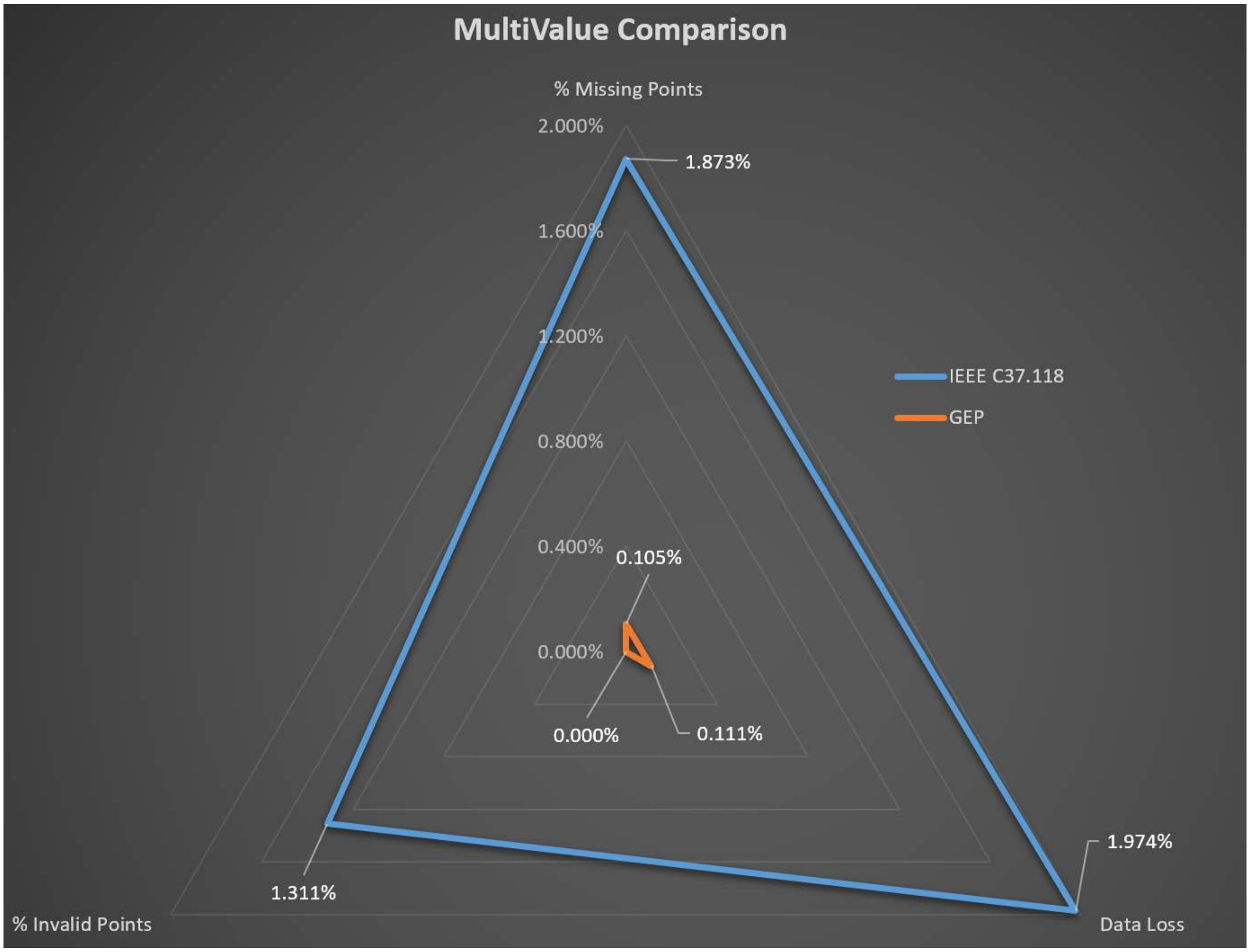
10.5 Memory Usage Comparisons



Memory utilization comparisons were included to show how concentration and wait-time handling of IEEE C37.118 impacts the host platform as compared to GEP.

The pattern shown above is generally the same as for CPU loading. Note that for the large test case that IEEE C37.118 places considerably more stress on memory resources, this is due to wait-time operations and in-memory frame construction.

10.6 Other Comparisons



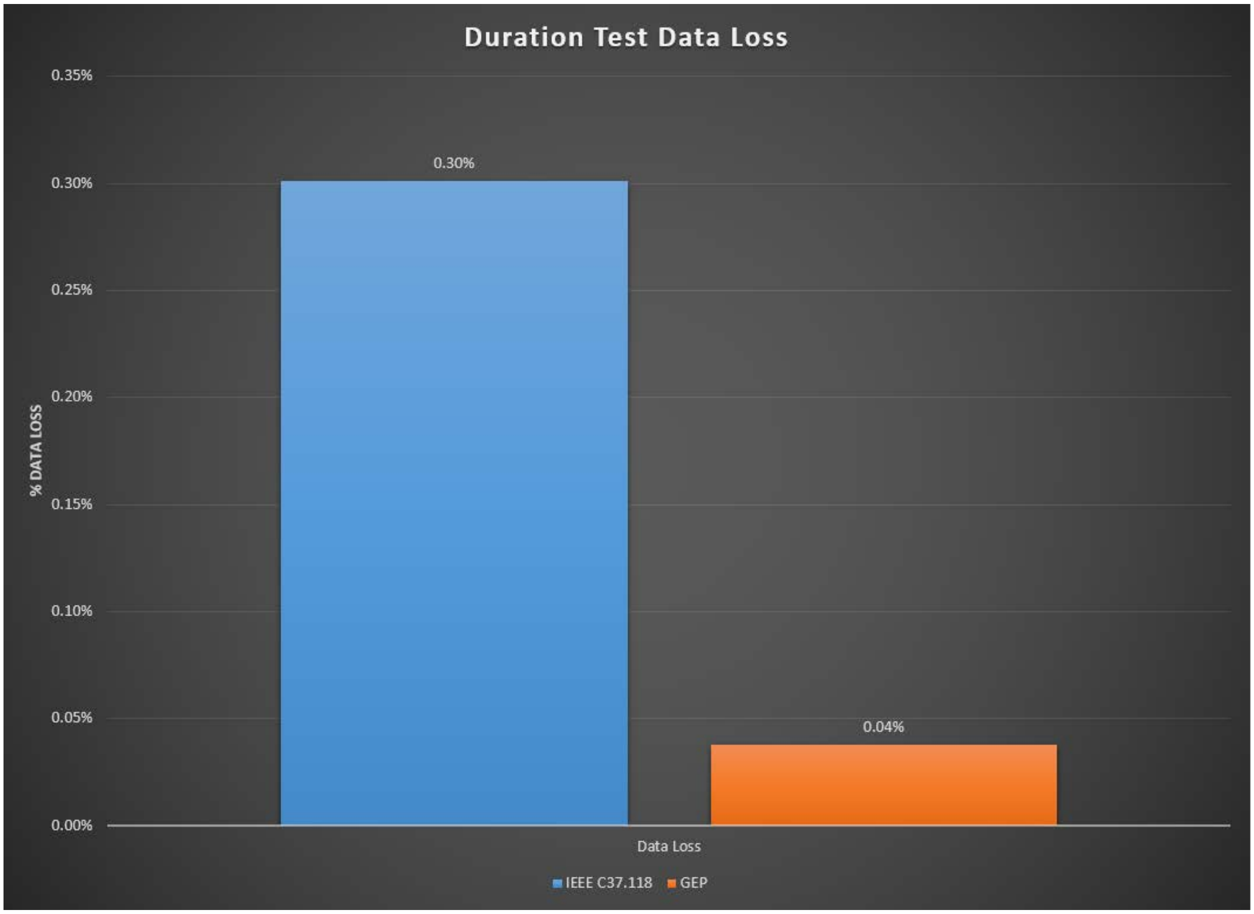
In the radar chart above, three dimensions of test data are shown. Clockwise from the top – missing data points at the destination, data loss, and invalid points for both IEEE C37.118 and GEP from the large test case.

Note that an “invalid point” is counted as a point where the original up-stream source measurement and the down-stream per-protocol destination measurement are not equal as compared by time, value and quality information.

10.7 Duration Test Comparisons

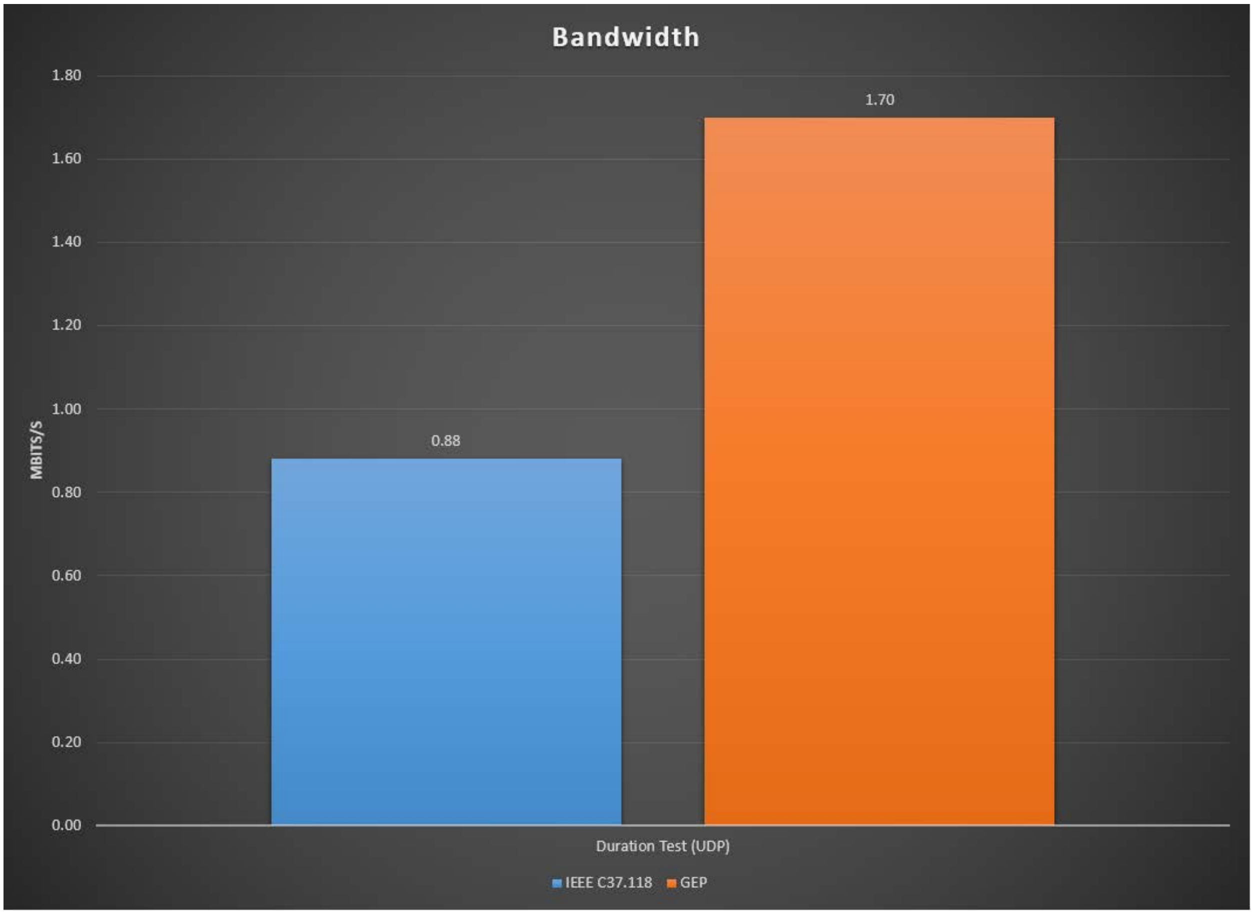
Duration tests were run using UDP against the medium sized data set – representing a large Transmission Operator, in this case BPA. The duration test was run to see if any day-to-day anomalies with network conditions over a longer period would adversely affect protocol performance.

Duration Test Data Loss Comparisons



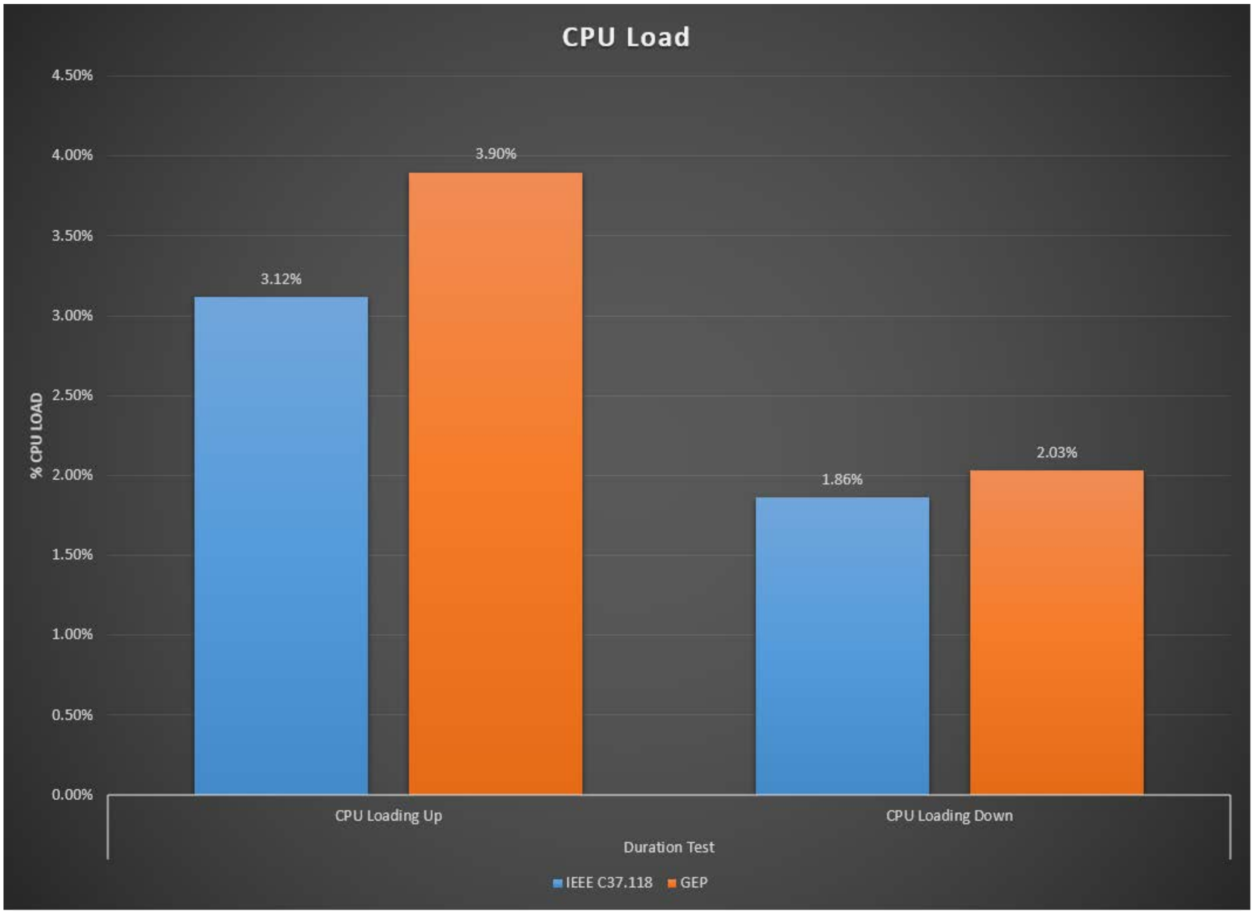
Data loss for IEEE C37.118 and GEP over the seven-day period are extremely consistent with the two-hour run. IEEE C37.118 data loss was reduced over the longer period by a statistically insignificant 0.01%, GEP loss remained the same, 0.04%.

Duration Bandwidth Comparisons



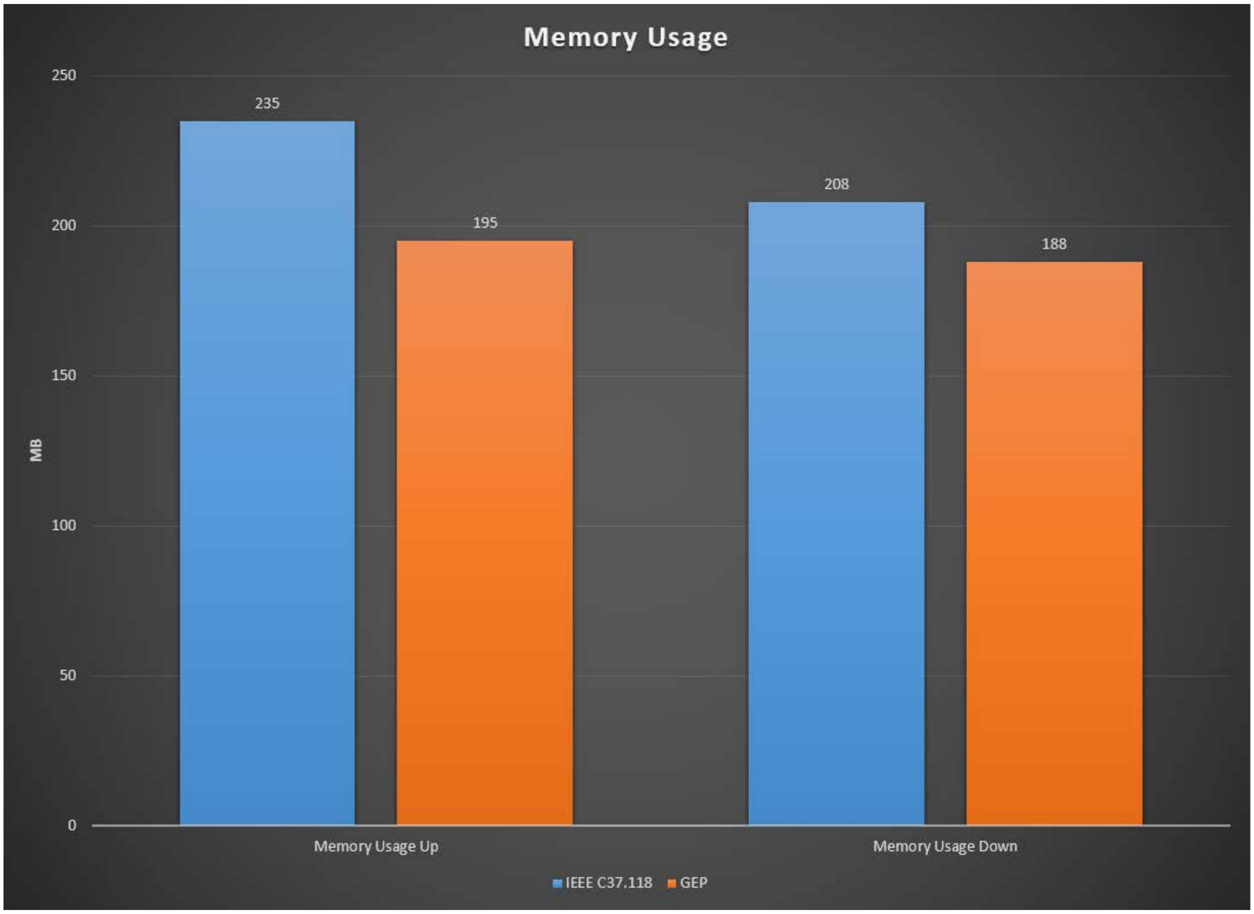
Like with data loss, UDP based bandwidth utilization for IEEE C37.118 and GEP over the seven-day period are extremely consistent with the two-hour run. Overall bandwidth requirements for the longer period were reduced by a statistically insignificant amount of 0.01 Megabits/second for IEEE C37.118 and 0.02 Megabits/second for GEP.

Duration Test CPU Load Comparisons



CPU loading for IEEE C37.118 and GEP over the seven-day period are consistent with the two-hour run. All deviations of CPU loading in the duration run for either protocol are within 0.04% of the associated interval run.

Duration Test Memory Use Comparisons



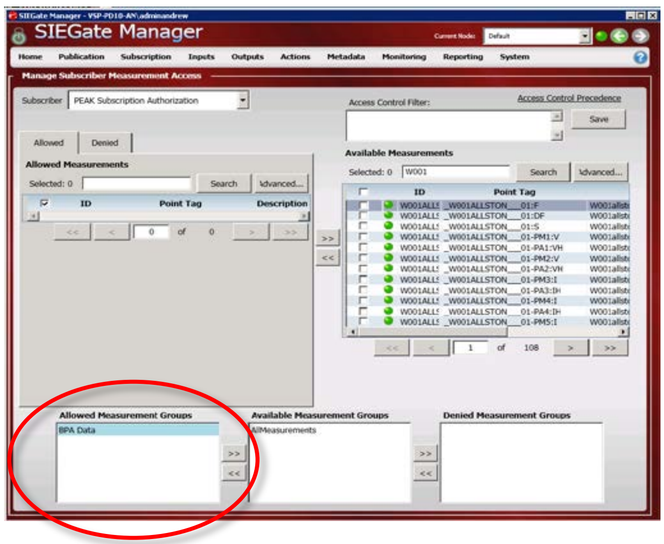
Memory utilization for IEEE C37.118 and GEP over the seven-day period are slightly smaller than the two-hour runs, for all platforms and protocols. This is likely due to the systems settling into a consistent set of activities for the longer period. The statistics for the shorter run would be more influenced by startup and initialization operations which tend to use more memory while the systems are starting up.

10.8 Security Test Results

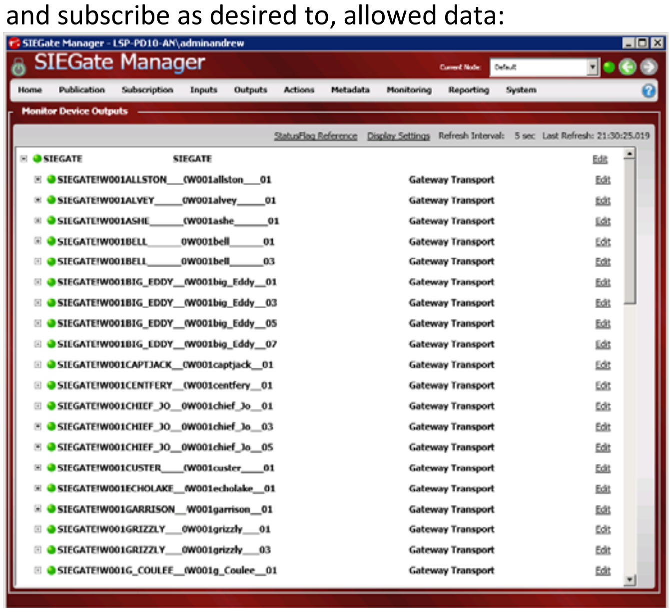
Comparisons to the IEEE C37.118 protocol for security do not apply as the synchrophasor protocol does not include any native security options. Consequently, the GEP security options were simply exercised to make sure they functioned as advertised. Tests focused on applying various available options for publisher data access control and validating results in subscriber data streams. All tests were executed with encryption enabled using Transport Layer Security (TLS).

Publisher Allows Access to a Group of Signals

Using the “Subscriber Measurement Access” screen, the publisher “allows” a group of signals (in this case all BPA data) for a specific subscriber:

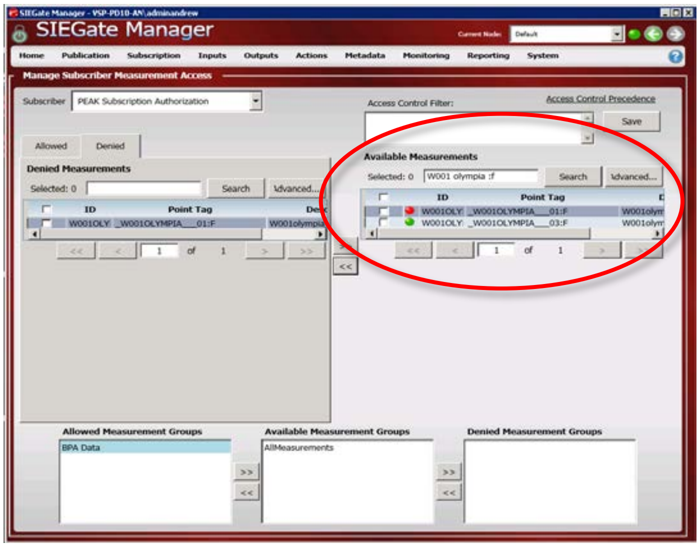


Subscriber can now see, and subscribe as desired to, allowed data:

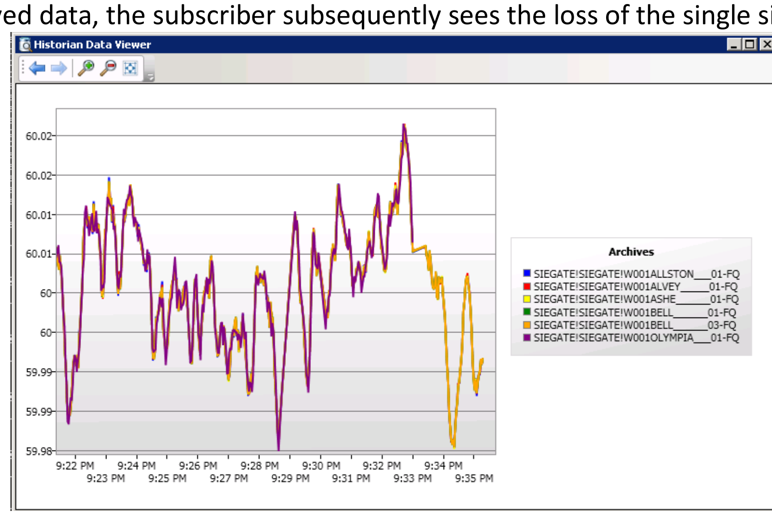


Publisher Denies Access to a Single Signal

Using the “Subscriber Measurement Access” screen, the publisher “denies” a single signal that the subscriber previously had access to:



Trending the archived data, the subscriber subsequently sees the loss of the single signal:

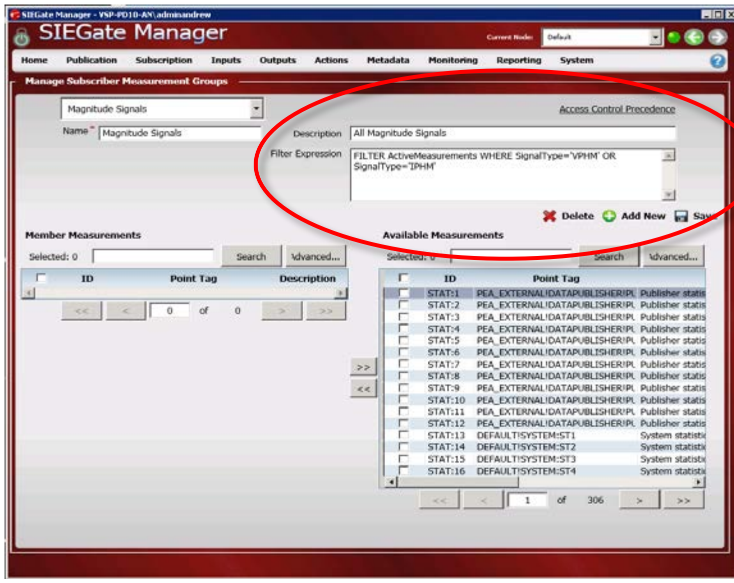


It should be noted that these effects are cumulative based on the access control precedence (see below), in other words the subscriber now has access to all BPA signals minus this one frequency.

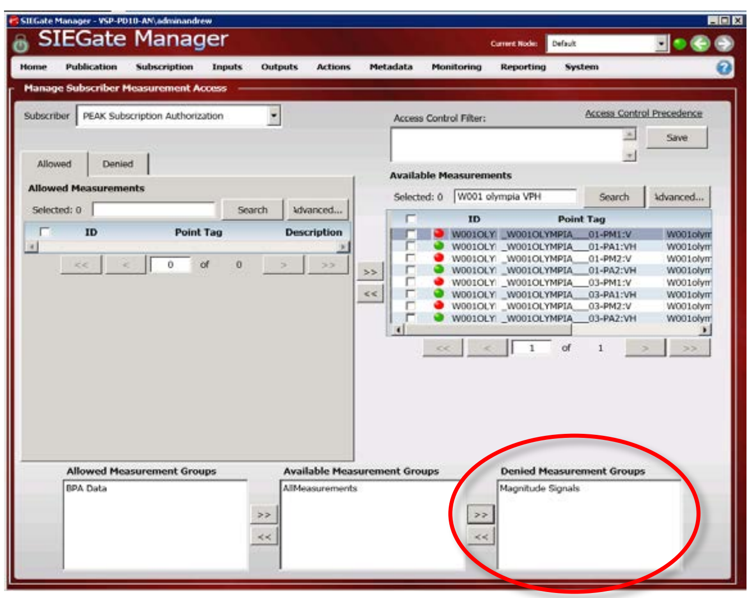
Precedence	Access Control Type	Description	Example
1	Explicit	Rights are applied directly to signals via measurement pick lists.	
2	Group Explicit	Rights are applied by allowing or denying a group of measurements which were explicitly added to the group via measurement pick lists.	
3	Filter Implicit	Rights are applied using an access control filter applied directly to the subscriber.	ALLOW WHERE SignalType = 'FREQ'; ALLOW WHERE SignalType = 'DFDT'; DENY WHERE Company = 'GPA'
4	Group Implicit	Rights are applied by allowing or denying a group of measurements which were implicitly added to the group via a filter expression.	FILTER ActiveMeasurements WHERE SignalType = 'FREQ'

Publisher Denies Access to a Group of Signals

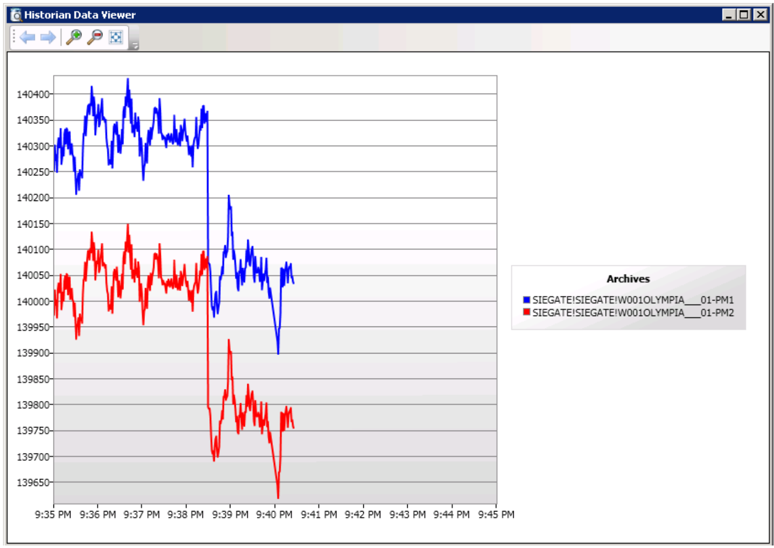
Using the “Subscriber Measurement Groups” screen, the publisher creates a group of signals based on an expression that filters all active current and voltage magnitudes:



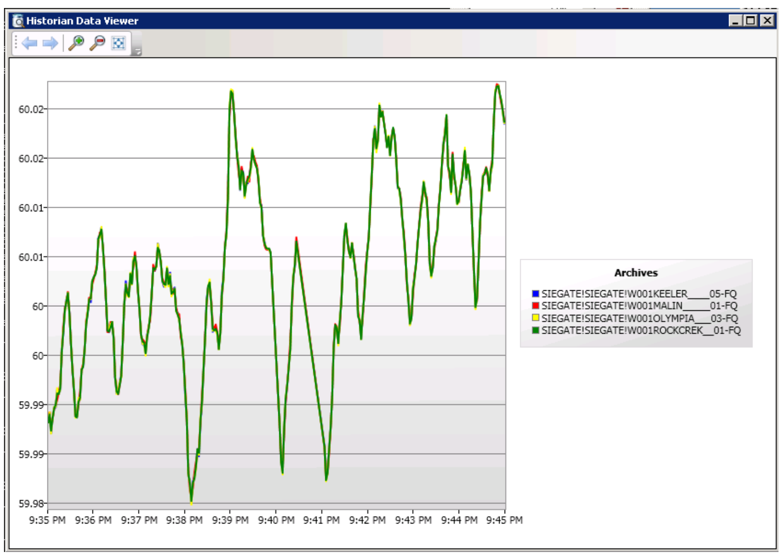
Using the “Subscriber Measurement Access” screen, the publisher “denies” the group of magnitude signals for a specific subscriber:



Trending the archived data, the subscriber subsequently sees the loss of the magnitude signals:



While other data is still flowing for the same time period:



11. Conclusions

The objective of this paper is to compare IEEE C37.118 to GPA's Gateway Exchange Protocol as a practical alternative for transport of synchrophasor data.

Conclusion 1: **IEEE C37.118 is a good choice for small scale phasor data volumes** (81 signal test).

Not surprisingly, the ubiquitous IEEE C37.118 (Version 2005, and the same would be true for Version 2011) is an effective, compact and efficient method for sending small volumes of synchrophasor data from one system to another – such as in the case for sending synchrophasor data from a substation to the control center.

While significantly more susceptible to data loss (0.12% loss for IEEE C37.118 vs. 0.02% loss for GEP) at least when using UDP, testing results showed that IEEE C37.118 was more efficient than GEP requiring 1.7 times less bandwidth.

Conclusion 2: **IEEE C37.118 is challenged at medium scale phasor data volumes** (999 signal test).

As synchrophasor data systems begin to scale up, the IEEE C37.118 protocol begins to bump into limitations that require workarounds. Among these are: (1) the maximum TCP/UDP frame size, by protocol specification, is 65K – this includes the configuration frame which can hit the limit quickly; (2) from a data distribution perspective, horizontal scaling options are limited since concentration wait times for C37.118 compound and can produce large latencies; and (3) from a business perspective, there is increased procedural burden to maintain multiple output streams that must be maintained on a connection-by-connection basis as new measurement devices (PMUs) are added or removed.

The impact of large scale IEEE C37.118 issues are highlighted throughout the results of this testing, of particular relevance is UDP data loss for medium scale data that was more than 7 times higher (0.31% vs. 0.04%) for IEEE C37.118 than that which was measured for GEP.

Conclusion 3: **GEP is the preferred protocol for large scale phasor data volumes** (3,145 signal test) or as the complexity of the synchrophasor data infrastructure increases.

For large synchrophasor data systems such as is the case for Reliability Coordinators or Independent System Operators, the advantages provided by GEP become more evident. These benefits, listed below, mirror the design intention of NASPInet (circa 2009) and provide the foundation for improved synchrophasor data system performance and interoperability.

Bandwidth advantage – When using GEP over TCP, which allows for lossless stateful compression, GEP consumes less bandwidth than IEEE C37.118, at least 30% less in the tested cases. In high-bandwidth, large scale environments, TCP is a common transport protocol choice for synchrophasor data exchange since it results in lossless data delivery.

Data loss advantage – For large data volumes, there were measured losses for IEEE C37.118 even when using TCP (0.22%). This TCP data loss occurs at the application layer where phasor data that has not arrived within the specified wait-time window is lost. Using UDP, IEEE C37.118 had 15 times more data loss than GEP (2.12% vs. 0.14%) for large scale data. Two percent data loss is significant since data loss is particularly problematic for most phasor data analytics.

Security advantage – IEEE C37.118 includes no native security features. GEP offers both authenticated data access controls and data encryption. Data access control is provided to a data publisher on a per-subscriber basis and allows various levels of data access granularity, such as, expression based data groups, signal types, or even down to a specific signal.

While encryption can be implemented at the network layer through encrypted tunnels for both protocols, GEP includes the ability to directly implement industry standard security such as transport layer security (TLS) through use of symmetric encryption with X509 certificate based keys allowing the data to be securely transmitted over public channels, such as the Internet.

In the testing, GEP security features were exercised and found to function as expected.

Host system (server) advantage – To produce the outgoing protocol, CPU loading was significantly less in the case of GEP, 13.67% vs. 22.67% for IEEE C37.118. Memory utilization was also greatly reduced, 494 MB vs 1,423 MB for IEEE C37.118; note that for IEEE C37.118 larger wait times result in increased memory utilization. To parse and consume the protocols, GEP required about 1% more server CPU resources than C37.118, 5.93% vs. 4.83%; GEP has to decompress packets before parsing, which likely accounts for the slight increase in CPU.

Long-term configuration advantage – The GEP protocol uses GUID-based measurement identifiers so that measurement information can be easily merged into a unified registry at an ISO or regulatory level. GEP also has the ability to implement simple operational name translations (internal name versus external name, or internal name to custom tag name) with sufficient information in the meta-data such that measurements can be easily reconstituted back into IEEE C37.118 as necessary without loss of meta-data.

Meta-data and configuration options of GEP compared to IEEE C37.118 were evaluated during setup of the testing environment and configuration changes.

Business advantage – The net impact of reduced data losses, reduced bandwidth over TCP, and significantly reduced configuration burden is reduced costs. GEP automatically maintains and merges metadata sets based on a signal's generated unique identifier; this means a host organization can easily look at the entire set of up-to-date measurement metadata from all of its subscriptions. As device availability and meta-data from a remote party change, these updates will automatically flow to the subscriber (as allowed by the publisher), which results in less per-connection configuration changes. Measurements can be managed in groups using simple expressions (e.g., a group for all frequency values), and publisher configuration changes to do not need to be manually updated in order for subscribers to see new information.

In conclusion, testing confirmed that exchanging large synchrophasor volumes can benefit greatly from a measurement based protocol like GEP resulting in less data loss, quicker delivery of data, comparable bandwidth utilization, reduced CPU and memory requirements, available transport security and data access controls.

12. Whitepaper Contributors

This whitepaper was contributed to by the following industry experts:

Contributor	Industry Title	Organization
Ritchie Carroll	Senior Systems Architect	Grid Protection Alliance (GPA)
Dayna Aronson	Enterprise Solutions Architect	Peak Reliability
Andrew Esselman	Application Support Analyst	Peak Reliability
Dan Brancaccio	Technical Architect	Peak Reliability, Bridge Energy Group Inc.

Appendix A – Test Plan

A.1 Testing Approach

A.1.1 Overview

Test runs will consist of sending the same source data over two separate communication sessions, each using a different communication protocol (C37.118 and GEP) and running between separate sets of servers/endpoints. The Baseline session is using C37.118 and is running between the two openPDC endpoints, and the Comparison session is using GEP and is running between the two SIEGate endpoints.

An instance of the openHistorian was installed on each server to archive all received data at each point in the system so that a point-by-point comparison could be used to perform accurate comparisons.

Test types include Interval, Duration, Security, and Latency tests.

A.1.2 Interval Tests

Interval Test runs are performed in parallel between the SIEGate devices and between the openPDC devices. Each test will run for a duration of two hours to create a stable run-time data exchange scenario (e.g., getting past configuration exchange, establishing communication and using local software tools to validate that both data exchanges are operating as expected). Each test run will use a specific data set for the duration of the run (see below).

During the test runs, the server and network metric data capture tools collect data and statistics for analysis. Each data set is collected over 3 different but identical runs and the collected statistics are averaged. If the deviation between runs is determined to be too large, additional runs will be conducted to reduce the deviation to within an acceptable margin.

A.1.3 Interval Test Cases

1. **Interval TC 1:** <u>All Measurements, TCP control channel, UDP data channel</u>

   Data set: All signals arriving at the Vancouver WA location are rebroadcast to Loveland CO location. Note: In this type of configuration, there will not be a once-per-minute spontaneous C37.118 configuration frame transmitted over the data channel which would interfere with captured stats.

2. **Interval TC 2:** <u>All Measurements, TCP control channel, TCP data channel</u>

   Data set: All signals arriving at the Vancouver WA location are rebroadcast to Loveland CO location.

3. **Interval TC 3:** <u>BPA Measurements, TCP control channel, UDP data channel</u>

   Data set: BPA signals arriving at the Vancouver WA location are rebroadcast to Loveland CO location. Note: In this type of configuration, there will not be a once-per-minute spontaneous

C37.118 configuration frame transmitted over the data channel which would interfere with captured stats.

4. **Interval TC 4:** BPA Measurements, TCP control channel, TCP data channel

   Data set: All signals arriving at the Vancouver WA location are rebroadcast to Loveland CO location.

5. **Interval TC 5:** Signal Reduction, TCP control channel, UDP data channel

   Data set: The set of signals from BPA are reduced incrementally until the network performance between GEP and C37.118 are as equal as possible. We're looking for the point of diminishing returns, here.

Note that result validation requires that Dropped Packets and Network Errors as measured by Network Tools should be comparable for both C37.118 and GEP in order for other collected results to be considered valid.

A.1.4 Interval Test Steps - General

Test Steps:

1. Verify variable test data.
   - Record all relevant data for each test run.
2. Verify configuration.
   - Record or capture source-to-destination application configuration for all components.
3. Initialize data flow & process monitoring.
   - Execute and monitor data flow and machine statistics for test duration.
4. Start network data capture (2 steps).
   - Communicate and coordinate with IT to initialize network capture at infrastructure level.
   - Continue network capture at local machine level.
5. Stop data flow.
   - At least 2 hours of data flow required.
6. Stop network data capture.
   - Both local system and IT's infrastructure capture.
7. Gather and publish data.
   - Place captured network and Perfmon bin of statistics and reports in public location.
   - Include documented configuration settings for all components.

A.1.5 Interval Test Validation

As mentioned above, each data set is collected over 3 different runs and the collected statistics are averaged. It is expected that the network conditions (as captured by the network tool tests) are virtually identical except for bandwidth utilization during each interval test run. If lag times or network collisions are substantially different for a particular test run, or if conditions fall outside of acceptable limits for a significant portion of a test run, then that test run will be considered *invalid*. Invalid test runs will not be used in final statistics gathering, and any invalid test runs must be performed again such that there are 3 successful, valid test runs for each data set.

A.1.6 Duration Test

Once the interval tests are complete, duration testing can proceed. Long-run duration testing uses a combination of openHistorian and PDQTracker to measure data availability and is useful for test scenarios using UDP where there is capability to compare loss – no network loss is expected when using TCP. A single test scenario is established using the WISP WAN where data is sent from the Peak RC location in Vancouver WA to the Peak RC location in Loveland CO.

Duration TC 1: Un-authorized Subscription Validation

> The duration test scenario uses both C37.118 and GEP with a TCP command channel and a UDP data channel. This way, all the configuration traffic is over TCP, and this allows duration testing to focus on data availability by comparing UDP channels for data loss. This test also allows for a rough comparison of bandwidth utilization over the same period using locally collected system statistics.
>
> All data is collected for a single data set, i.e., all signals arriving at the Vancouver WA location. This data is rebroadcast to Loveland CO location, and the test runs over a period of 7 days. All results collected are averaged to produce a final result.

A.1.7 Subscription Security Tests

These tests only involve use of the SIEGate endpoints.

Security TC 1: Un-authorized Subscription Validation

> Test the capability of SIEGate to block signal availability to unauthorized subscribers.

Security TC 2: Signal Subset Subscription

> Test the capability to restrict the receipt of PMU signals to a subset of what is available in a given communication stream. This is a capability of standard PDCs.
>
> Create a subscription to a communication stream that has signals from multiple PMUs but only subscribe to a subset of them. Verify that only the subset is received by the subscription.

Security TC 3: Phasor Component Subscription

> Test the capability of GEP to separate the angle and magnitude components of a phasor measurement and provide only one of the component types to a subscriber.

Create a subscription to a PMU signal but subscribe only to the magnitude component of the phasor measurements. Verify that only the magnitude values of the phasor are received by the subscriber.

A.1.8 Application Latency Test

Application latency is defined for this test as the difference between the time stamp of the phasor measurement and the time the measurement arrives at the receiving SIEGate or openPDC node. Since the receiving node will not have a GPS clock, time reference will be relative.

Data latency metrics for both GEP and IEEE C37.118 were measured using the system time of the test computers. The openPDC and SIEGate built in statistics historian collects latency information in 10 second intervals which is then averaged over each test run.

A.1.9 Test Methodology

For all tests except for Security and Subscription, system statistics are continually collected by SIEGate and openPDC during testing. Additionally, openHistorian is configured on each machine to archive all data so a accurate comparison can be done. Data collected for both the sending and receiving machines is used to compare how CPU and memory are affected by the different protocols in terms of senders and receivers. For the receiving machines, protocol based comparisons are made for data latency and loss. Data is extracted from the local statistic historians over the same run-time periods for the interval and duration tests with the final results being averaged over the same testing periods.

A.2 Tools

The following tools are used to collect data from the various components.

Software Tool	Installed On	Measures
PDQ Tracker	Destination SIEGate and openPDC servers	Phasor data / signal data from the PMUs Data Availability / Data Loss
openHistorian	All machines	Historizes all PMU data
Network Tools	WISP WAN Firewalls Loveland and Vancouver	Average/Peak Bandwidth utilization using CISCO NAM
Windows Perfmon	Source and Destination SIEGate and openPDC servers Template Below:	Processor Memory Network Interface Per Processor Network Interface Card Physical Disk (Per disk, not total) Processor Information TCPv4 UDPv4 Paging File

A.2.1 Tool Setup

A.2.2 CISCO NAM

Save output in .CSV format.

A.2.3 Windows Perfmon

Save output in .CSV format.

A.2.4 PDQ Tracker

Standard PDQTracker reports

A.3 Test Case Scripts – Interval: Configuration Validation, Variable Control & Execution

A.3.1 Interval TC 1: All Measurements, TCP control channel, UDP data channel

Data set: All signals arriving at the Vancouver WA location are rebroadcast to Loveland CO location.
Note: In this type of configuration, there will not be a once-per-minute spontaneous C37.118 configuration frame transmitted over the data channel which would interfere with captured stats.

➥ *Include documented configuration settings for all components or location of data.*

12.1.1.1 SIEGate Endpoints Setup

Testing Environment Configuration Settings			
Type	Settings		Notes
IPs	Source IP		
	Destination IP		
Network Protocol/Port configuration	TCP Control Channel Port	3650	
	UCP Data Channel Port	6300	
Input streams from StreamSplitter if Source endpoint	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA		
Source Outputs	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA		

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of <u>Active</u> input streams from above from StreamSplitter			
If destination, confirm number of <u>Active</u> input			

streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	
Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

12.1.1.2 OpenPDC Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP	10.206.1.70		
	Destination IP	10.206.9.70		
Network Protocol/Port configuration	TCP Control Channel Port	6351		
	UCP Data Channel Port	6301		
Input streams from StreamSplitter if Source endpoint	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			
Source Outputs	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			

Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

Test Execution Steps

Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes

Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		

Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Add additional Iterations here if required:

A.3.2 Interval TC 2: All Measurements, TCP control channel, TCP data channel

Data set: All signals arriving at the Vancouver WA location are rebroadcast to Loveland CO location.

➥ *Include documented configuration settings for all components or location of data.*

SIEGate Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP			
	Destination IP			
Network Protocol/Port configuration	TCP Control Channel Port	6350		
	TCP Data Channel Port	6350		
Input streams from StreamSplitter if Source endpoint	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			
Source Outputs	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			
Variable Control				

List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes

☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

OpenPDC Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP	10.206.1.70		
	Destination IP	10.206.9.70		
Network Protocol/Port configuration	TCP Control Channel Port	6351		
	TCP Data Channel Port	6351		
Input streams from StreamSplitter if Source endpoint	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			
Source Outputs	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			

If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist

Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist

Validate that all data, environment conditions and file locations are documented.

Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

Test Execution Steps

Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		

Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Add additional Iterations here if required:

A.3.3 Interval TC 3: BPA Measurements, TCP control channel, UDP data channel

Data set: BPA signals arriving at the Vancouver WA location are rebroadcast to Loveland CO location.
Note: In this type of configuration, there will not be a once-per-minute spontaneous C37.118 configuration frame transmitted over the data channel which would interfere with captured stats.

➥ *Include documented configuration settings for all components or location of data.*

SIEGate Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP			
	Destination IP			
Network Protocol/Port configuration	TCP Control Channel Port	3650		
	UCP Data Channel Port	6300		
Input streams from	BPA			

StreamSplitter if Source endpoint		
Source Outputs	BPA	

Variable Control List any other variables that should be controlled and verified prior to test execution

Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			

Verify endpoints CPU utilization is similar
Verify endpoints memory utilization is similar
Verify endpoints Disk
Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	

☐ Variable Control	
Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

OpenPDC Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP	10.206.1.70		
	Destination IP	10.206.9.70		
Network Protocol/Port configuration	TCP Control Channel Port	6351		
	UCP Data Channel Port	6301		
Input streams from StreamSplitter if Source endpoint	BPA			
Source Outputs	BPA			

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of <u>Active</u> input streams			

from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?

☐ Metrics Capture Windows Perfmon Destination	Published?

Test Execution Steps

Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		

Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Add additional Iterations here if required:

A.3.4 Interval TC 4: BPA Measurements, TCP control channel, TCP data channel

Data set: All signals arriving at the Vancouver WA location are rebroadcast to Loveland CO location.
➥ *Include documented configuration settings for all components or location of data.*

SIEGate Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP			
	Destination IP			
Network Protocol/Port configuration	TCP Control Channel Port	6350		
	TCP Data Channel Port	6350		
Input streams from	BPA			

StreamSplitter if Source endpoint		
Source Outputs	BPA	

Variable Control

List any other variables that should be controlled and verified prior to test execution

Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			

Verify endpoints CPU utilization is similar

Verify endpoints memory utilization is similar

Verify endpoints Disk

Pre-test Validation Checklist

Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	

☐ Variable Control	
Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

OpenPDC Endpoints Setup

Testing Environment Configuration Settings					
Type	Settings				Notes
IPs	Source IP	10.206.1.70			
	Destination IP	10.206.9.70			
Network Protocol/Port configuration	TCP Control Channel Port	6351			
	TCP Data Channel Port	6351			
Input streams from StreamSplitter if Source endpoint	BPA				
Source Outputs	BPA				

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of <u>Active</u> input streams			

from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist

Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist

Validate that all data, environment conditions and file locations are documented.

Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?

☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

Test Execution Steps

Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		

Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Add additional Iterations here if required:

A.3.5 Interval TC 5: Signal Reduction, TCP control channel, UDP data channel

Data set: The set of signals from BPA are reduced incrementally until the network performance between GEP and C37.118 are as equal as possible. We're looking for the point of diminishing returns, here.

➥ *Include documented configuration settings for all components or location of data.*

SIEGate Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP			
	Destination IP			
Network Protocol/Port configuration	TCP Control Channel Port	6350		

	UCP Data Channel Port	6300		
Input streams from StreamSplitter if Source endpoint	BPA			
Source Outputs	BPA			
Tier 1 test	75% of available signals: Count: ???		We do not have to do 100% of available signals because that test has been performed in TC3	
Tier 2 test	50% of available signals: Count: ???			
Tier 3 test	25% of available signals: Count: ???			

Variable Control

List any other variables that should be controlled and verified prior to test execution

Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Total number of active signals at start of test tier 1			
Total number of active signals at start of test tier 2			

Total number of active signals at start of test tier 3			
Total number of active signals at start of test tier 4			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist

Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist

Validate that all data, environment conditions and file locations are documented.

Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

OpenPDC Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP	10.206.1.70		
	Destination IP	10.206.9.70		
Network Protocol/Port configuration	TCP Control Channel Port	6351		
	UCP Data Channel Port	6301		
Input streams from StreamSplitter if Source endpoint	BPA			
Source Outputs	BPA			
Tier 1 test	75% of available signals: Count: ???		We do not have to do 100% of available signals because that test has been performed in TC3	
Tier 2 test	50% of available signals: Count: ???			
Tier 3 test	25% of available signals: Count: ???			
Tier 4 test	TBD		We will do this if needed based on the analysis of the results of the other tier tests	

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			

If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test tier 1			
Total number of active signals at start of test tier 2			
Total number of active signals at start of test tier 3			
Total number of active signals at start of test tier 4			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist

Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist

Validate that all data, environment conditions and file locations are documented.

Item	Notes
☐ Testing process success	

☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

Test Execution Steps

Tier 1 Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Tier 1 Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes

Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Add additional Iterations here if required:

Tier 2 Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		

Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Tier 2 Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Add additional Iterations here if required:

Tier 3 Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Tier 3 Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		

Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Add additional Iterations here if required:

Tier 4 Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		

Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Tier 4 Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

A.3.6 Interval TC 6: Multi-channel: PGAE & WAPA Measurements, TCP control channel, UDP data channel

Data set: All signals from PGAE & WAPA are rebroadcast over a separate channels, simultaneously.
➥ *Include documented configuration settings for all components or location of data.*

SIEGate Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP			
	Destination IP			
Network Protocol/Port configuration	PGAE TCP Control Channel Port	6350		
	PGAE UCP Data Channel Port	6300		
	WAPA TCP Control Channel Port	6350		
	WAPA UCP Data Channel Port	6303		
Input streams from StreamSplitter if Source endpoint	PGAE, WAPA			
Source Outputs	PGAE, WAPA			

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input			

streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test for PGAE			
Total number of active signals at start of test for WAPA			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐	
☐ Variable Control	

Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?

☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

OpenPDC Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP	10.206.1.70		
	Destination IP	10.206.9.70		
Network Protocol/Port configuration	PGAE TCP Control Channel Port	6351		
	PGAE UCP Data Channel Port	6301		
	WAPA TCP Control Channel Port	6352		
	WAPA UCP Data Channel Port	6302		
Input streams from StreamSplitter if Source endpoint	PGAE, WAPA			
Source Outputs	PGAE, WAPA			

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input			

streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test for PGAE			
Total number of active signals at start of test for WAPA			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist

Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist

Validate that all data, environment conditions and file locations are documented.

Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?

☐ Metrics Capture Windows Perfmon Destination	Published?

Test Execution Steps

Iteration 1:

This test iteration has a planned duration of: 2 hours

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Iteration 2:

This test iteration has a planned duration of: Document here the duration chosen for this interaction

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		

Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Add additional Iterations here if required:

A.4 Test Case Scripts – Duration: Configuration Validation, Variable Control & Execution

SIEGate Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP			
	Destination IP			
Network Protocol/Port configuration	TCP Control Channel Port	????		
	UCP Data Channel Port	????		
Input streams from	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			

StreamSplitter if Source endpoint		
Source Outputs	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA	

Variable Control

List any other variables that should be controlled and verified prior to test execution

Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Total number of active signals at start of test			

Verify endpoints CPU utilization is similar

Verify endpoints memory utilization is similar

Verify endpoints Disk

Pre-test Validation Checklist

Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	

☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Metrics Capture PDQ Tracker	
☐ Variable Control	
Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

OpenPDC Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP	10.206.1.70		
	Destination IP	10.206.9.70		
Network Protocol/Port configuration	TCP Control Channel Port	????		
	UCP Data Channel Port	????		
Input streams from StreamSplitter if Source endpoint	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			
Source Outputs	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			
If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Total number of active signals at start of test			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Metrics Capture PDQ Tracker	
☐ Variable Control	

Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

Test Execution Steps

Iteration 1: Only 1 is planned

This test iteration has a planned duration of: 5 days

Step	Complete?	Notes
Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
PDQ Tracker reports		

Actual Test Duration:		

A.5 Test Case Scripts – Subscription Security: Configuration Validation, Variable Control & Execution

These tests only involve use of the SIEGate endpoints.

A.5.1 Security TC 1: Un-authorized Subscription Validation

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
The variable controls used for other test cases like the Interval tests are not relevant for this test			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Subscription Configuration	

Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐	

- No Perfmon, network NAM or PDQ Tracker metrics capture are required for this test.
- Document here the communication stream to be used in this test.
- Document here the full set of signals in the selected communication stream.
- Document here the subset of signals in the communication stream to be subscribed to.

Test Execution Steps

Iteration 1: Test has only 1 iteration

Step	Complete?	Notes

Configure the subscription on the SIEGate receiving endpoint as documented above		
Fill in the "Expected Results" section in the table below		
Activate the subscription		
Verify results		
Fill in the "Actual Results" section in the table below		

Expected Results	Actual Results

A.5.2 Security TC 2: Signal Subset Subscription

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
The variable controls used for other test cases like the Interval tests are not relevant for this test			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Subscription Configuration	
Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐	

- No Perfmon, network NAM or PDQ Tracker metrics capture are required for this test.

- Document here the communication stream to be used in this test.
- Document here the full set of signals in the selected communication stream.
- Document here the subset of signals in the communication stream to be subscribed to.

Test Execution Steps

Iteration 1: Test has only 1 iteration

Step	Complete?	Notes
Configure the subscription on the SIEGate receiving endpoint as documented above		
Fill in the "Expected Results" section in the table below		
Activate the subscription		
Verify results		
Fill in the "Actual Results" section in the table below		

Expected Results	Actual Results

A.5.3 Security TC 3: Phasor Component Subscription

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
The variable controls used for other test cases like the Interval tests are not relevant for this test			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes

☐ Subscription Configuration	
Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐	

- No Perfmon, network NAM or PDQ Tracker metrics capture are required for this test.
- Document here the communication stream to be used in this test.
- Document here the full set of signals in the selected communication stream.
- Document here the subset of signals in the communication stream to be subscribed to.

Test Execution Steps

Iteration 1: Test has only 1 iteration

Step	Complete?	Notes
Configure the subscription on the SIEGate receiving endpoint as documented above		
Fill in the "Expected Results" section in the table below		
Activate the subscription		
Verify results		
Fill in the "Actual Results" section in the table below		

Expected Results	Actual Results

A.6 Test Case Scripts – Application Latency: Configuration Validation, Variable Control & Execution

Application latency is defined for this test as the difference between the time stamp of the phasor measurement and the time the measurement arrives at the receiving SIEGate or openPDC node. Since the receiving node will not have a GPS clock, time reference will be relative. **Manual capture of sent and receive time will need to be configured and analyzed as PDQ Tracker only computes averages.**

SIEGate Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP			
	Destination IP			
Network Protocol/Port configuration	TCP Control Channel Port	????		
	UCP Data Channel Port	????		
Input streams from StreamSplitter if Source endpoint	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			
Source Outputs	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of Active input streams from above from StreamSplitter			
If destination, confirm number of Active input streams from Source Outputs above			

If source, confirm number of Active output streams from Source Outputs above to destination			
Total number of active signals at start of test			
Total number of active signals at start of test			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist

Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.

Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	

Post-test Validation Checklist

Validate that all data, environment conditions and file locations are documented.

Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

OpenPDC Endpoints Setup

Testing Environment Configuration Settings				
Type	Settings		Notes	
IPs	Source IP	10.206.1.70		
	Destination IP	10.206.9.70		
Network Protocol/Port configuration	TCP Control Channel Port	????		
	UCP Data Channel Port	????		
Input streams from StreamSplitter if Source endpoint	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			
Source Outputs	AESO, APS, BCHA, BPA, IPCO, LDWP, NVE, NEW, PAC, PGAE, PNM, SCE, SDGE, SRP, TEPC, TSGT, WAPA			

Variable Control List any other variables that should be controlled and verified prior to test execution			
Variable	Desired State	Actual	Notes
If source, confirm number of <u>Active</u> input streams from above from StreamSplitter			
If destination, confirm number of <u>Active</u> input streams from Source Outputs above			
If source, confirm number of <u>Active</u> output streams from Source Outputs above to destination			
Total number of <u>active</u> signals at start of test			

Total number of active signals at start of test			
Verify endpoints CPU utilization is similar			
Verify endpoints memory utilization is similar			
Verify endpoints Disk			

Pre-test Validation Checklist Using the information from the preceding sections, validate that all configurations, environment conditions and variables are what they should be.	
Item	Notes
☐ Testing Environment Configuration Settings	
☐ Metrics Capture Network NAM Source	
☐ Metrics Capture Network NAM Destination	
☐ Metrics Capture Windows Perfmon Source	
☐ Metrics Capture Windows Perfmon Destination	
☐ Variable Control	
Post-test Validation Checklist Validate that all data, environment conditions and file locations are documented.	
Item	Notes
☐ Testing process success	
☐ Metrics Capture Network NAM Source	Gathered from IT? Published?
☐ Metrics Capture Network NAM Destination	Gathered from IT? Published?
☐ Metrics Capture Windows Perfmon Source	Published?
☐ Metrics Capture Windows Perfmon Destination	Published?

Test Execution Steps

Iteration 1: Only 1 is planned

This test iteration has a planned duration of:

Step	Complete?	Notes

Complete pre-test validation checklists in the preceding endpoint tables		
Actual start time:		
Start Perfmon capture, both ends		
Start CISCO NAM capture, both ends		
Initiate data flow, run for test duration		
Stop data flow		
Stop CISCO NAM capture		
Stop Perfmon capture		
Actual Stop Time:		
Publish all data captures and document locations and file names in notes column		
Source Perfmon Export (csv)		
Destination Perfmon Export (csv)		
Source NAM Export (csv)		
Destination NAM Export (csv)		
Actual Test Duration:		

Appendix B – Raw Data

The following are the detailed summary reports for comparisons of the collected historian data for each of the interval tests (each with three runs) and the seven-day duration test. Also included are the statistical summary data as collected by the systems for each test run, i.e., PDQTracker style data. In whole, these statistics were used to calculate the results presented in this document. Note that many other runtime statistics were simultaneously collected during these tests including network traffic analysis and system level performance monitoring (PerfMon). For brevity, these additional statistics were not included in these reports, however, during data analysis the additional collected statistics were consistently cross-referenced to validate the accuracy of the primary statistics used in this report.

For the purpose of interpreting the summary statistics below, when a test was using UDP as a transport for data, the primary data loss statistic is the comparison where *data is missing from destination archive (Loveland, downstream) where it exists in the source archive (Vancouver, upstream)*.

The summary statistics also measure where data is missing from the source that exists in the destination. In the case of SIEGate, which uses the GEP protocol, only the data that is received or measured locally is sent to the destination, so these stats are near 0%. However, in the case of the PDC which uses the IEEE C37.118 protocol, any "missing" data are filled with NaN values which indicates a missing The local historian archives the NaN value and the comparison tool notes that this is data that exists in the downstream archive that does not exist in the source, as a result many of these stats hover around 5%. The comparison tool also counts NaN values received in the source and destination to provide more detail when analyzing the comparison results.

The full source code for the data comparison tool can be found as part of the openHistorian on GitHub:

https://github.com/GridProtectionAlliance/openHistorian/blob/master/Source/Tools/ComparisonUtility/ComparisonUtility.cs

B.1 Interval Tests

Test Case 1 – All Data with TCP Control Channel and UDP Data Channel

Run 1

PDC Results

```
Total compare time 6 hours 42 minutes 7.12 seconds at 28,156 points per second.

           Meta-data points: 3145
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 679,320,000
           Processed points: 666,158,362
            Compared points: 631,678,705
               Valid points: 622,769,637
             Invalid points: 8,909,068
 Received NaN source points: 11,877,852
```

```
    Received NaN dest points: 13,708,720
       Missing source points: 34,267,822
  Missing destination points: 12,719,354
      Base source point loss: 34,270,780
 Base destination point loss: 214,793
           Source duplicates: 1,849
      Destination duplicates: 2,977
       Overall data accuracy: 98.590%

  Missing source sub-seconds: 342, outage of 11.4 seconds
      Total base source loss: 47,224,222: 6.952%
         Network source loss: 35,346,370: 5.203%
      Received source points: 632,107,343
         Source completeness: 93.050%

    Missing dest sub-seconds: 4,184, outage of 2 minutes 19.47 seconds
 Total base destination loss: 27,082,193: 3.987%
    Network destination loss: 13,373,473: 1.969%
 Received destination points: 666,161,320
    Destination completeness: 98.063%

>> 5.146% missing from source that exists in destination
>> 1.974% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	22.221%	4.775%
Avg Mem (MB)	1419.9178	487.4528
Total Bytes	2579408718	2559689664
Bytes/Value	4.4468	4.5029
Avg Time Delay (ms)	2924.6102	10449.7167

SIEGate Results

Total compare time 6 hours 41 minutes 50.533 seconds at 28,175 points per second.

```
            Meta-data points: 3145
           Time-span covered: 7,200 seconds: 2 hours
             Expected points: 679,320,000
            Processed points: 644,110,554
             Compared points: 643,395,768
                Valid points: 643,395,149
              Invalid points: 619
  Received NaN source points: 11,848,770
    Received NaN dest points: 11,841,505
       Missing source points: 245
```

```
 Missing destination points: 714,541
     Base source point loss: 35,209,691
Base destination point loss: 35,923,987
          Source duplicates: 262
     Destination duplicates: 106
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 0, outage of 0 seconds
     Total base source loss: 47,058,461: 6.927%
        Network source loss: 35,209,691: 5.183%
     Received source points: 644,329,709
        Source completeness: 94.849%

   Missing dest sub-seconds: 0, outage of 0 seconds
Total base destination loss: 47,765,492: 7.031%
   Network destination loss: 35,923,987: 5.288%
Received destination points: 643,612,119
   Destination completeness: 94.744%

>> 0.000% missing from source that exists in destination
>> 0.111% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	13.799%	5.897%
Avg Mem (MB)	492.4181	470.462
Total Bytes	2577642934	4676208129
Bytes/Value	4.4459	8.0734
Avg Time Delay (ms)	3511.4743	2883.8889

Run 2

PDC Results

```
Total compare time 6 hours 41 minutes 19.953 seconds at 28,211 points per
second.

           Meta-data points: 3145
          Time-span covered: 7,200 seconds: 2 hours
           Expected points: 679,320,000
          Processed points: 667,489,177
           Compared points: 632,507,367
              Valid points: 623,777,287
            Invalid points: 8,730,080
 Received NaN source points: 11,359,486
```

```
    Received NaN dest points: 13,237,416
       Missing source points: 34,772,049
  Missing destination points: 11,379,978
      Base source point loss: 34,774,527
 Base destination point loss: 212,239
           Source duplicates: 394
      Destination duplicates: 0
       Overall data accuracy: 98.620%

  Missing source sub-seconds: 338, outage of 11.27 seconds
      Total base source loss: 47,197,023: 6.948%
         Network source loss: 35,837,537: 5.276%
      Received source points: 632,932,452
         Source completeness: 93.171%

    Missing dest sub-seconds: 3,761, outage of 2 minutes 5.37 seconds
 Total base destination loss: 25,278,000: 3.721%
    Network destination loss: 12,040,584: 1.772%
 Received destination points: 667,491,655
    Destination completeness: 98.259%

 >> 5.211% missing from source that exists in destination
 >> 1.767% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	22.960%	4.747%
Avg Mem (MB)	1424.668	484.6026
Total Bytes	2577813306	2553282284
Bytes/Value	4.4429	4.48
Avg Time Delay (ms)	2952.3057	10455.6083

SIEGate Results

```
Total compare time 6 hours 41 minutes 28.925 seconds at 28,201 points per
second.

           Meta-data points: 3145
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 679,320,000
           Processed points: 644,271,038
            Compared points: 643,510,867
               Valid points: 643,510,629
             Invalid points: 238
  Received NaN source points: 11,410,466
```

```
     Received NaN dest points: 11,403,038
        Missing source points: 260
   Missing destination points: 759,911
       Base source point loss: 35,049,222
  Base destination point loss: 35,808,873
            Source duplicates: 258
       Destination duplicates: 448
        Overall data accuracy: 100.000%

   Missing source sub-seconds: 0, outage of 0 seconds
       Total base source loss: 46,459,688: 6.839%
          Network source loss: 35,049,222: 5.159%
       Received source points: 644,489,727
          Source completeness: 94.873%

     Missing dest sub-seconds: 0, outage of 0 seconds
  Total base destination loss: 47,211,911: 6.950%
     Network destination loss: 35,808,873: 5.271%
  Received destination points: 643,727,575
     Destination completeness: 94.761%

>> 0.000% missing from source that exists in destination
>> 0.118% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	13.644%	5.923%
Avg Mem (MB)	493.4671	470.1672
Total Bytes	2580037080	4678009955
Bytes/Value	4.4449	8.0666
Avg Time Delay (ms)	3640.4306	2982.9208

Run 3

PDC Results

```
Total compare time 6 hours 42 minutes 16.325 seconds at 28,145 points per
second.

            Meta-data points: 3145
           Time-span covered: 7,200 seconds: 2 hours
             Expected points: 679,320,000
            Processed points: 661,903,492
             Compared points: 626,720,401
                Valid points: 617,844,687
              Invalid points: 8,875,714
```

```
 Received NaN source points: 11,429,822
   Received NaN dest points: 13,239,883
      Missing source points: 34,972,912
 Missing destination points: 16,777,750
     Base source point loss: 34,975,555
Base destination point loss: 212,822
          Source duplicates: 206
     Destination duplicates: 2,359
      Overall data accuracy: 98.584%

 Missing source sub-seconds: 335, outage of 11.17 seconds
     Total base source loss: 47,458,952: 6.986%
        Network source loss: 36,029,130: 5.304%
     Received source points: 627,143,940
        Source completeness: 92.319%

   Missing dest sub-seconds: 5,537, outage of 3 minutes 4.57 seconds
Total base destination loss: 30,866,570: 4.544%
   Network destination loss: 17,626,687: 2.595%
Received destination points: 661,906,135
   Destination completeness: 97.437%

>> 5.285% missing from source that exists in destination
>> 2.607% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	22.831%	4.914%
Avg Mem (MB)	1424.2439	487.7249
Total Bytes	2576434566	2548081970
Bytes/Value	4.4447	4.5124
Avg Time Delay (ms)	2945.7786	10468.3139

SIEGate Results

```
Total compare time 6 hours 42 minutes 27.468 seconds at 28,132 points per
second.

           Meta-data points: 3145
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 679,320,000
           Processed points: 643,769,479
            Compared points: 642,593,477
               Valid points: 642,593,458
             Invalid points: 19
 Received NaN source points: 11,418,912
```

```
    Received NaN dest points: 11,406,036
       Missing source points: 157
  Missing destination points: 1,175,845
      Base source point loss: 35,550,678
 Base destination point loss: 36,726,366
           Source duplicates: 156
      Destination duplicates: 0
       Overall data accuracy: 100.000%

  Missing source sub-seconds: 0, outage of 0 seconds
      Total base source loss: 46,969,590: 6.914%
         Network source loss: 35,550,678: 5.233%
      Received source points: 643,988,169
         Source completeness: 94.799%

    Missing dest sub-seconds: 0, outage of 0 seconds
 Total base destination loss: 48,132,402: 7.085%
    Network destination loss: 36,726,366: 5.406%
 Received destination points: 642,809,634
    Destination completeness: 94.625%

>> 0.000% missing from source that exists in destination
>> 0.183% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	13.643%	5.977%
Avg Mem (MB)	497.9738	471.4531
Total Bytes	2576228876	4657671878
Bytes/Value	4.4419	8.0431
Avg Time Delay (ms)	3607.5649	3003.3861

Test Case 2 – All Data with TCP Channel for Both Control and Data

Run 1

PDC Results

```
Total compare time 6 hours 44 minutes 48.529 seconds at 27,969 points per
second.
           Meta-data points: 3145
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 679,320,000
           Processed points: 675,599,594
            Compared points: 640,595,927
               Valid points: 631,213,157
             Invalid points: 9,382,770
 Received NaN source points: 11,815,297
   Received NaN dest points: 13,842,051
      Missing source points: 34,791,865
 Missing destination points: 3,737,793
     Base source point loss: 34,794,881
Base destination point loss: 214,818
          Source duplicates: 1,347
     Destination duplicates: 0
      Overall data accuracy: 98.535%

 Missing source sub-seconds: 1, outage of 33.33 milliseconds
     Total base source loss: 46,613,323: 6.862%
        Network source loss: 34,798,026: 5.122%
     Received source points: 641,027,032
        Source completeness: 94.363%

   Missing dest sub-seconds: 1,182, outage of 39.4 seconds
Total base destination loss: 17,774,259: 2.616%
   Network destination loss: 3,932,208: 0.579%
Received destination points: 675,602,610
   Destination completeness: 99.453%

>> 5.151% missing from source that exists in destination
>> 0.580% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	22.205%	4.768%
Avg Mem (MB)	1341.8752	620.731
Total Bytes	2578953322	2604040418
Bytes/Value	4.4473	4.5166
Avg Time Delay (ms)	3000.5414	10427.758

SIEGate Results

```
Total compare time 6 hours 44 minutes 46.362 seconds at 27,971 points per
second.

           Meta-data points: 3145
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 679,320,000
           Processed points: 644,287,207
            Compared points: 644,287,095
               Valid points: 644,287,095
             Invalid points: 0
 Received NaN source points: 11,796,120
   Received NaN dest points: 11,796,132
      Missing source points: 111
 Missing destination points: 1
     Base source point loss: 35,032,904
Base destination point loss: 35,032,794
          Source duplicates: 110
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 0, outage of 0 seconds
     Total base source loss: 46,829,024: 6.894%
        Network source loss: 35,032,904: 5.157%
     Received source points: 644,506,344
        Source completeness: 94.875%

   Missing dest sub-seconds: 0, outage of 0 seconds
Total base destination loss: 46,828,926: 6.894%
   Network destination loss: 35,032,794: 5.157%
Received destination points: 644,503,206
   Destination completeness: 94.875%

>> 0.000% missing from source that exists in destination
>> 0.000% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	9.157%	6.173%
Avg Mem (MB)	547.0712	473.5626
Total Bytes	2579911568	1516118035
Bytes/Value	4.4486	2.6138
Avg Time Delay (ms)	3518.6778	3099.8944

Run 2

PDC Results

```
Total compare time 6 hours 44 minutes 21.151 seconds at 28,000 points per
second.

              Meta-data points: 3145
             Time-span covered: 7,200 seconds: 2 hours
               Expected points: 679,320,000
              Processed points: 679,317,529
               Compared points: 644,067,732
                  Valid points: 634,773,779
                Invalid points: 9,293,953
     Received NaN source points: 11,337,607
       Received NaN dest points: 13,430,353
          Missing source points: 35,036,268
     Missing destination points: 213,529
         Base source point loss: 35,038,739
    Base destination point loss: 216,000
              Source duplicates: 2,497
         Destination duplicates: 0
          Overall data accuracy: 98.557%

     Missing source sub-seconds: 0, outage of 0 seconds
         Total base source loss: 46,376,346: 6.827%
            Network source loss: 35,038,739: 5.158%
         Received source points: 644,502,896
            Source completeness: 94.875%

       Missing dest sub-seconds: 0, outage of 0 seconds
    Total base destination loss: 13,646,353: 2.009%
       Network destination loss: 216,000: 0.032%
    Received destination points: 679,320,000
       Destination completeness: 100.000%

>> 5.159% missing from source that exists in destination
>> 0.033% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	22.006%	4.944%
Avg Mem (MB)	1357.9842	563.2315
Total Bytes	2577375490	2616135410
Bytes/Value	4.444	4.5055
Avg Time Delay (ms)	2908.5525	10430

SIEGate Results

```
Total compare time 6 hours 44 minutes 15.877 seconds at 28,006 points per
second.

           Meta-data points: 3145
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 679,320,000
           Processed points: 644,094,757
            Compared points: 644,093,690
               Valid points: 644,092,702
             Invalid points: 988
 Received NaN source points: 11,362,401
   Received NaN dest points: 11,362,465
      Missing source points: 1,067
 Missing destination points: 0
     Base source point loss: 35,226,310
Base destination point loss: 35,225,243
          Source duplicates: 1,067
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 0, outage of 0 seconds
     Total base source loss: 46,588,711: 6.858%
        Network source loss: 35,226,310: 5.186%
     Received source points: 644,313,895
        Source completeness: 94.847%

   Missing dest sub-seconds: 0, outage of 0 seconds
Total base destination loss: 46,587,708: 6.858%
   Network destination loss: 35,225,243: 5.185%
Received destination points: 644,310,757
   Destination completeness: 94.846%

>> 0.000% missing from source that exists in destination
>> 0.000% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	9.251%	6.404%
Avg Mem (MB)	545.571	472.9862
Total Bytes	2578968368	1452199500
Bytes/Value	4.4452	2.506
Avg Time Delay (ms)	3579.0757	2951.2545

Run 3

PDC Results

```
Total compare time 6 hours 44 minutes 17.857 seconds at 28,004 points per
second.

          Meta-data points: 3145
         Time-span covered: 7,200 seconds: 2 hours
          Expected points: 679,320,000
         Processed points: 679,317,916
          Compared points: 643,874,209
             Valid points: 634,643,611
           Invalid points: 9,230,598
 Received NaN source points: 11,738,984
   Received NaN dest points: 13,829,137
      Missing source points: 35,229,791
 Missing destination points: 213,916
     Base source point loss: 35,231,875
Base destination point loss: 216,000
         Source duplicates: 1,808
    Destination duplicates: 0
      Overall data accuracy: 98.566%

 Missing source sub-seconds: 0, outage of 0 seconds
     Total base source loss: 46,970,859: 6.914%
        Network source loss: 35,231,875: 5.186%
     Received source points: 644,308,624
        Source completeness: 94.846%

   Missing dest sub-seconds: 0, outage of 0 seconds
Total base destination loss: 14,045,137: 2.068%
   Network destination loss: 216,000: 0.032%
Received destination points: 679,320,000
   Destination completeness: 100.000%

>> 5.118% missing from source that exists in destination
>> 0.033% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	20.996%	4.968%
Avg Mem (MB)	1441.332	561.8254
Total Bytes	2576780706	2616849900
Bytes/Value	4.4497	4.5126
Avg Time Delay (ms)	2856.4863	10425.0903

SIEGate Results

```
Total compare time 6 hours 44 minutes 4.335 seconds at 28,020 points per
second.

           Meta-data points: 3145
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 679,320,000
           Processed points: 643,934,634
            Compared points: 643,934,530
               Valid points: 643,934,530
             Invalid points: 0
 Received NaN source points: 11,688,553
   Received NaN dest points: 11,688,558
      Missing source points: 104
 Missing destination points: 0
     Base source point loss: 35,385,470
Base destination point loss: 35,385,366
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 0, outage of 0 seconds
     Total base source loss: 47,074,023: 6.930%
        Network source loss: 35,385,470: 5.209%
     Received source points: 644,153,221
        Source completeness: 94.823%

   Missing dest sub-seconds: 0, outage of 0 seconds
Total base destination loss: 47,073,924: 6.930%
   Network destination loss: 35,385,366: 5.209%
Received destination points: 644,150,634
   Destination completeness: 94.823%

>> 0.000% missing from source that exists in destination
>> 0.000% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	9.245%	6.453%
Avg Mem (MB)	541.4001	472.5079
Total Bytes	2578210192	1507467890
Bytes/Value	4.4465	2.5999
Avg Time Delay (ms)	3602.2401	2985.0861

Test Case 3 – Single Member's Data with TCP Control Channel and UDP Data Channel

Run 1

PDC Results

```
Total compare time 2 hours 14 minutes 40.405 seconds at 26,705 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,151,834
            Compared points: 215,151,834
               Valid points: 215,151,828
             Invalid points: 6
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 374,625
     Base source point loss: 215,583
Base destination point loss: 215,583
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 105, outage of 3.5 seconds
     Total base source loss: 320,478: 0.149%
        Network source loss: 320,478: 0.149%
     Received source points: 215,368,415
        Source completeness: 99.807%

   Missing dest sub-seconds: 417, outage of 13.9 seconds
Total base destination loss: 632,166: 0.293%
   Network destination loss: 632,166: 0.293%
Received destination points: 215,367,417
   Destination completeness: 99.807%

>> 0.000% missing from source that exists in destination
>> 0.174% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.128%	1.871%
Avg Mem (MB)	484.7813	427.964
Total Bytes	842359800	839392866
Bytes/Value	4.1505	4.1425
Avg Time Delay (ms)	-1259.3839	-651.0376

SIEGate Results

```
Total compare time 2 hours 14 minutes 37.88 seconds at 26,713 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,441,254
            Compared points: 215,441,254
               Valid points: 215,441,250
             Invalid points: 4
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 84,915
     Base source point loss: 215,873
Base destination point loss: 215,873
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 126, outage of 4.2 seconds
     Total base source loss: 341,747: 0.158%
        Network source loss: 341,747: 0.158%
     Received source points: 215,658,125
        Source completeness: 99.942%

   Missing dest sub-seconds: 127, outage of 4.23 seconds
Total base destination loss: 342,746: 0.159%
   Network destination loss: 342,746: 0.159%
Received destination points: 215,657,127
   Destination completeness: 99.941%

>> 0.000% missing from source that exists in destination
>> 0.039% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.920%	1.982%
Avg Mem (MB)	421.6381	424.9386
Total Bytes	842048120	1619713409
Bytes/Value	4.1505	7.9849
Avg Time Delay (ms)	351.6022	181.6912

Run 2

PDC Results

```
Total compare time 2 hours 14 minutes 42.263 seconds at 26,698 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,177,782
            Compared points: 215,177,782
               Valid points: 215,177,774
             Invalid points: 8
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 329,670
     Base source point loss: 215,609
Base destination point loss: 215,609
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 123, outage of 4.1 seconds
     Total base source loss: 338,486: 0.157%
        Network source loss: 338,486: 0.157%
     Received source points: 215,394,389
        Source completeness: 99.819%

   Missing dest sub-seconds: 391, outage of 13.03 seconds
Total base destination loss: 606,218: 0.281%
   Network destination loss: 606,218: 0.281%
Received destination points: 215,393,391
   Destination completeness: 99.819%

>> 0.000% missing from source that exists in destination
>> 0.153% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.120%	1.873%
Avg Mem (MB)	490.3583	430.5237
Total Bytes	841615664	839291622
Bytes/Value	4.1479	4.1424
Avg Time Delay (ms)	-1354.5313	-713.5202

SIEGate Results

```
Total compare time 2 hours 14 minutes 36.302 seconds at 26,718 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,440,256
            Compared points: 215,440,256
               Valid points: 215,440,251
             Invalid points: 5
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 66,933
     Base source point loss: 215,872
Base destination point loss: 215,872
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 128, outage of 4.27 seconds
     Total base source loss: 343,744: 0.159%
        Network source loss: 343,744: 0.159%
     Received source points: 215,657,126
        Source completeness: 99.941%

   Missing dest sub-seconds: 128, outage of 4.27 seconds
Total base destination loss: 343,744: 0.159%
   Network destination loss: 343,744: 0.159%
Received destination points: 215,656,128
   Destination completeness: 99.941%

>> 0.000% missing from source that exists in destination
>> 0.031% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.931%	2.052%
Avg Mem (MB)	410.7176	426.775
Total Bytes	842013056	1623131739
Bytes/Value	4.1506	7.991
Avg Time Delay (ms)	318.9471	-0.8306

Run 3

PDC Results

```
Total compare time 2 hours 13 minutes 36.297 seconds at 26,918 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 213,447,250
            Compared points: 213,447,250
               Valid points: 213,447,241
             Invalid points: 9
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 1,318,680
     Base source point loss: 213,875
Base destination point loss: 213,875
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 868, outage of 28.93 seconds
     Total base source loss: 1,081,007: 0.501%
        Network source loss: 1,081,007: 0.501%
     Received source points: 213,662,123
        Source completeness: 99.017%

   Missing dest sub-seconds: 2,125, outage of 1 minute 10.83 seconds
Total base destination loss: 2,336,750: 1.083%
   Network destination loss: 2,336,750: 1.083%
Received destination points: 213,661,125
   Destination completeness: 99.016%

>> 0.000% missing from source that exists in destination
>> 0.614% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.141%	1.888%
Avg Mem (MB)	198.9705	426.0896
Total Bytes	839705210	834148764
Bytes/Value	4.1518	4.1498
Avg Time Delay (ms)	-1226.0737	-590.0334

SIEGate Results

```
Total compare time 2 hours 13 minutes 43.154 seconds at 26,895 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 214,664,810
            Compared points: 214,664,810
               Valid points: 214,664,810
             Invalid points: 0
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 115,884
     Base source point loss: 215,095
Base destination point loss: 215,095
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 864, outage of 28.8 seconds
     Total base source loss: 1,078,231: 0.500%
        Network source loss: 1,078,231: 0.500%
     Received source points: 214,880,903
        Source completeness: 99.581%

   Missing dest sub-seconds: 905, outage of 30.17 seconds
Total base destination loss: 1,119,190: 0.519%
   Network destination loss: 1,119,190: 0.519%
Received destination points: 214,879,905
   Destination completeness: 99.581%

>> 0.000% missing from source that exists in destination
>> 0.054% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.984%	1.998%
Avg Mem (MB)	165.6658	425.6127
Total Bytes	838871466	1614346792
Bytes/Value	4.149	7.985
Avg Time Delay (ms)	562.8985	39.5056

Test Case 4 – Single Member's Data with TCP Channel for Both Control and Data

Run 1

PDC Results

```
Total compare time 2 hours 14 minutes 6.424 seconds at 26,817 points per
second.

           Meta-data points: 999
         Time-span covered: 7,200 seconds: 2 hours
           Expected points: 215,784,000
          Processed points: 215,527,082
           Compared points: 215,527,082
              Valid points: 215,527,070
            Invalid points: 12
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 0
     Base source point loss: 215,959
Base destination point loss: 215,959
         Source duplicates: 0
    Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 41, outage of 1.37 seconds
     Total base source loss: 256,918: 0.119%
        Network source loss: 256,918: 0.119%
     Received source points: 215,744,039
        Source completeness: 99.981%

   Missing dest sub-seconds: 41, outage of 1.37 seconds
Total base destination loss: 256,918: 0.119%
   Network destination loss: 256,918: 0.119%
Received destination points: 215,743,041
   Destination completeness: 99.981%
```

```
>> 0.000% missing from source that exists in destination
>> 0.000% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.028%	8.387%
Avg Mem (MB)	436.6931	440.9339
Total Bytes	842392382	841146834
Bytes/Value	4.1511	4.142
Avg Time Delay (ms)	-1413.331	1497.6542

SIEGate Results

```
Total compare time 2 hours 14 minutes 7.051 seconds at 26,815 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,526,085
            Compared points: 215,526,084
               Valid points: 215,525,146
             Invalid points: 938
 Received NaN source points: 0
   Received NaN dest points: 1
      Missing source points: 1
 Missing destination points: 999
     Base source point loss: 215,958
Base destination point loss: 215,957
          Source duplicates: 0
     Destination duplicates: 998
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 42, outage of 1.4 seconds
     Total base source loss: 257,916: 0.120%
        Network source loss: 257,916: 0.120%
     Received source points: 215,743,040
        Source completeness: 99.981%

   Missing dest sub-seconds: 42, outage of 1.4 seconds
Total base destination loss: 257,916: 0.120%
   Network destination loss: 257,915: 0.120%
Received destination points: 215,743,041
   Destination completeness: 99.981%

>> 0.000% missing from source that exists in destination
>> 0.000% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	2.726%	1.964%
Avg Mem (MB)	407.9453	413.4293
Total Bytes	842653414	561264148
Bytes/Value	4.1531	2.7661
Avg Time Delay (ms)	-255.0612	54.993

Run 2

PDC Results

```
Total compare time 2 hours 14 minutes 7.252 seconds at 26,815 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,510,116
            Compared points: 215,510,116
               Valid points: 215,510,099
             Invalid points: 17
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 0
     Base source point loss: 215,942
Base destination point loss: 215,942
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 58, outage of 1.93 seconds
     Total base source loss: 273,884: 0.127%
        Network source loss: 273,884: 0.127%
     Received source points: 215,727,056
        Source completeness: 99.974%

   Missing dest sub-seconds: 58, outage of 1.93 seconds
Total base destination loss: 273,884: 0.127%
   Network destination loss: 273,884: 0.127%
Received destination points: 215,726,058
   Destination completeness: 99.973%
```

```
>> 0.000% missing from source that exists in destination
>> 0.000% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.182%	8.387%
Avg Mem (MB)	452.1568	430.9872
Total Bytes	842193686	841579068
Bytes/Value	4.1501	4.1441
Avg Time Delay (ms)	-1387.6036	1572.2889

SIEGate Results

```
Total compare time 2 hours 14 minutes 5.392 seconds at 26,821 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,510,116
            Compared points: 215,510,116
               Valid points: 215,510,116
             Invalid points: 0
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 0
     Base source point loss: 215,942
Base destination point loss: 215,942
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 58, outage of 1.93 seconds
     Total base source loss: 273,884: 0.127%
        Network source loss: 273,884: 0.127%
     Received source points: 215,727,056
        Source completeness: 99.974%

   Missing dest sub-seconds: 58, outage of 1.93 seconds
Total base destination loss: 273,884: 0.127%
   Network destination loss: 273,884: 0.127%
Received destination points: 215,726,058
   Destination completeness: 99.973%

>> 0.000% missing from source that exists in destination
```

```
>> 0.000% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	2.867%	1.836%
Avg Mem (MB)	408.7345	415.3496
Total Bytes	842174206	555195829
Bytes/Value	4.1508	2.7365
Avg Time Delay (ms)	-254.9541	69.5994

Run 3

PDC Results

```
Total compare time 2 hours 13 minutes 58.027 seconds at 26,845 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,086,964
            Compared points: 215,086,964
               Valid points: 215,086,959
             Invalid points: 5
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 176,823
     Base source point loss: 215,518
Base destination point loss: 215,518
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 306, outage of 10.2 seconds
     Total base source loss: 521,212: 0.242%
        Network source loss: 521,212: 0.242%
     Received source points: 215,303,480
        Source completeness: 99.777%

   Missing dest sub-seconds: 482, outage of 16.07 seconds
Total base destination loss: 697,036: 0.323%
   Network destination loss: 697,036: 0.323%
Received destination points: 215,302,482
   Destination completeness: 99.777%
```

```
>> 0.000% missing from source that exists in destination
>> 0.082% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.109%	8.496%
Avg Mem (MB)	446.9334	437.6993
Total Bytes	841732544	840272910
Bytes/Value	4.1525	4.1433
Avg Time Delay (ms)	-1388.121	1614.2833

SIEGate Results

```
Total compare time 2 hours 13 minutes 53.258 seconds at 26,861 points per
second.

           Meta-data points: 999
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 215,784,000
           Processed points: 215,200,736
            Compared points: 215,200,736
               Valid points: 215,200,736
             Invalid points: 0
 Received NaN source points: 0
   Received NaN dest points: 2,301
      Missing source points: 38,961
 Missing destination points: 0
     Base source point loss: 215,632
Base destination point loss: 215,632
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 368, outage of 12.27 seconds
     Total base source loss: 583,264: 0.270%
        Network source loss: 583,264: 0.270%
     Received source points: 215,417,366
        Source completeness: 99.830%

   Missing dest sub-seconds: 330, outage of 11 seconds
Total base destination loss: 547,603: 0.254%
   Network destination loss: 545,302: 0.253%
Received destination points: 215,416,368
   Destination completeness: 99.830%
```

```
>> 0.018% missing from source that exists in destination
>> 0.000% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	2.828%	1.853%
Avg Mem (MB)	403.7458	419.0023
Total Bytes	842628624	569192537
Bytes/Value	4.1521	2.8087
Avg Time Delay (ms)	-289.5333	56.2392

Test Case 5 – Five Devices with TCP Control Channel and UDP Data Channel

Run 1

PDC Results

```
Total compare time 11 minutes 20.174 seconds at 25,723 points per second.

           Meta-data points: 81
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 17,496,000
           Processed points: 17,182,080
            Compared points: 17,182,080
               Valid points: 17,182,080
             Invalid points: 0
  Received NaN source points: 0
    Received NaN dest points: 125
       Missing source points: 2,025
  Missing destination points: 33,615
      Base source point loss: 214,776
Base destination point loss: 214,776
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 811, outage of 27.03 seconds
     Total base source loss: 280,467: 1.603%
        Network source loss: 280,467: 1.603%
     Received source points: 17,396,936
        Source completeness: 99.434%

   Missing dest sub-seconds: 1,200, outage of 40 seconds
Total base destination loss: 312,101: 1.784%
   Network destination loss: 311,976: 1.783%
Received destination points: 17,396,856
   Destination completeness: 99.433%

>> 0.012% missing from source that exists in destination
>> 0.195% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	1.189%	0.667%
Avg Mem (MB)	163.0025	148.9245
Total Bytes	837392010	70961898
Bytes/Value	51.2606	4.3457
Avg Time Delay (ms)	-663.5097	666.6898

SIEGate Results

```
Total compare time 11 minutes 20.178 seconds at 25,723 points per second.

           Meta-data points: 81
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 17,496,000
           Processed points: 17,210,000
            Compared points: 17,210,000
               Valid points: 17,210,000
             Invalid points: 0
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 7,209
     Base source point loss: 215,125
Base destination point loss: 215,125
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 788, outage of 26.27 seconds
     Total base source loss: 278,953: 1.594%
        Network source loss: 278,953: 1.594%
     Received source points: 17,425,205
        Source completeness: 99.595%

   Missing dest sub-seconds: 875, outage of 29.17 seconds
Total base destination loss: 286,000: 1.635%
   Network destination loss: 286,000: 1.635%
Received destination points: 17,425,125
   Destination completeness: 99.595%

>> 0.000% missing from source that exists in destination
>> 0.042% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	1.155%	0.936%
Avg Mem (MB)	150.5577	149.4259
Total Bytes	838589694	139687165
Bytes/Value	51.26	8.538
Avg Time Delay (ms)	-601.8581	-290.4395

Run 2

PDC Results

```
Total compare time 11 minutes 19.883 seconds at 25,734 points per second.

           Meta-data points: 81
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 17,496,000
           Processed points: 17,214,960
            Compared points: 17,214,960
               Valid points: 17,214,960
             Invalid points: 0
 Received NaN source points: 0
   Received NaN dest points: 105
      Missing source points: 1,701
 Missing destination points: 17,172
     Base source point loss: 215,187
Base destination point loss: 215,187
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 607, outage of 20.23 seconds
     Total base source loss: 264,354: 1.511%
        Network source loss: 264,354: 1.511%
     Received source points: 17,430,227
        Source completeness: 99.624%

   Missing dest sub-seconds: 793, outage of 26.43 seconds
Total base destination loss: 279,525: 1.598%
   Network destination loss: 279,420: 1.597%
Received destination points: 17,430,147
   Destination completeness: 99.624%

>> 0.010% missing from source that exists in destination
>> 0.100% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	1.152%	0.627%
Avg Mem (MB)	166.6069	149.4412
Total Bytes	839888064	70959414
Bytes/Value	51.2972	4.3436
Avg Time Delay (ms)	-982.3978	-451.1574

SIEGate Results

```
Total compare time 11 minutes 20.021 seconds at 25,729 points per second.

           Meta-data points: 81
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 17,496,000
           Processed points: 17,232,320
            Compared points: 17,232,320
               Valid points: 17,232,320
             Invalid points: 0
 Received NaN source points: 0
   Received NaN dest points: 130
      Missing source points: 2,106
 Missing destination points: 4,050
     Base source point loss: 215,404
Base destination point loss: 215,404
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 550, outage of 18.33 seconds
     Total base source loss: 259,954: 1.486%
        Network source loss: 259,954: 1.486%
     Received source points: 17,447,804
        Source completeness: 99.725%

   Missing dest sub-seconds: 571, outage of 19.03 seconds
Total base destination loss: 261,785: 1.496%
   Network destination loss: 261,655: 1.496%
Received destination points: 17,447,724
   Destination completeness: 99.724%

>> 0.012% missing from source that exists in destination
>> 0.023% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	1.248%	0.840%
Avg Mem (MB)	150.9784	149.9388
Total Bytes	839642742	139547502
Bytes/Value	51.2836	8.5194
Avg Time Delay (ms)	-745.1015	-896.8206

Run 3

PDC Results

```
Total compare time 11 minutes 19.732 seconds at 25,740 points per second.

           Meta-data points: 81
          Time-span covered: 7,200 seconds: 2 hours
           Expected points: 17,496,000
          Processed points: 17,218,480
           Compared points: 17,218,480
              Valid points: 17,218,480
            Invalid points: 0
 Received NaN source points: 0
   Received NaN dest points: 0
      Missing source points: 0
 Missing destination points: 13,203
     Base source point loss: 215,231
Base destination point loss: 215,231
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 607, outage of 20.23 seconds
     Total base source loss: 264,398: 1.511%
        Network source loss: 264,398: 1.511%
     Received source points: 17,433,791
        Source completeness: 99.644%

   Missing dest sub-seconds: 769, outage of 25.63 seconds
Total base destination loss: 277,520: 1.586%
   Network destination loss: 277,520: 1.586%
Received destination points: 17,433,711
   Destination completeness: 99.644%

>> 0.000% missing from source that exists in destination
>> 0.077% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	1.133%	0.669%
Avg Mem (MB)	165.5311	149.9344
Total Bytes	839436360	71073264
Bytes/Value	51.2798	4.3443
Avg Time Delay (ms)	-1107.4951	-887.9471

SIEGate Results

```
Total compare time 11 minutes 19.409 seconds at 25,752 points per second.

           Meta-data points: 81
          Time-span covered: 7,200 seconds: 2 hours
            Expected points: 17,496,000
           Processed points: 17,231,600
            Compared points: 17,231,600
               Valid points: 17,231,600
             Invalid points: 0
 Received NaN source points: 0
   Received NaN dest points: 155
      Missing source points: 2,511
 Missing destination points: 810
     Base source point loss: 215,395
Base destination point loss: 215,395
          Source duplicates: 0
     Destination duplicates: 0
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 596, outage of 19.87 seconds
     Total base source loss: 263,671: 1.507%
        Network source loss: 263,671: 1.507%
     Received source points: 17,447,075
        Source completeness: 99.720%

   Missing dest sub-seconds: 575, outage of 19.17 seconds
Total base destination loss: 262,125: 1.498%
   Network destination loss: 261,970: 1.497%
Received destination points: 17,446,995
   Destination completeness: 99.720%

>> 0.015% missing from source that exists in destination
>> 0.005% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	1.264%	0.815%
Avg Mem (MB)	152.2123	149.1959
Total Bytes	839728410	139681194
Bytes/Value	51.301	8.5331
Avg Time Delay (ms)	-696.7844	-1185.541

B.2 Duration Test

PDC Results

```
Total compare time 7 days 23 hours 16 minutes 59.311 seconds at 26,322 points
per second.

           Meta-data points: 999
          Time-span covered: 604,800 seconds: 7 days
            Expected points: 18,125,856,000
           Processed points: 17,865,020,365
            Compared points: 17,865,017,502
               Valid points: 17,864,991,394
             Invalid points: 26,108
 Received NaN source points: 22,679
   Received NaN dest points: 54,712
      Missing source points: 542,391
 Missing destination points: 53,920,032
     Base source point loss: 17,903,670
Base destination point loss: 17,900,819
          Source duplicates: 4,848
     Destination duplicates: 2,994
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 193,901, outage of 1 hour 47 minutes 43.36 seconds
     Total base source loss: 211,633,448: 1.168%
        Network source loss: 211,610,769: 1.167%
     Received source points: 17,882,924,176
        Source completeness: 98.660%

   Missing dest sub-seconds: 242,654, outage of 2 hours 14 minutes 48.46
seconds
Total base destination loss: 260,366,877: 1.436%
   Network destination loss: 260,312,165: 1.436%
Received destination points: 17,882,924,175
   Destination completeness: 98.660%

>> 0.003% missing from source that exists in destination
>> 0.301% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.117%	1.863%
Avg Mem (MB)	235.3345	207.5948
Total Bytes	70052550816	69760334898
Bytes/Value	4.1504	4.1453
Avg Time Delay (ms)	106.7564	3.9569

SIEGate Results

```
Total compare time 7 days 23 hours 17 minutes 56.995 seconds at 26,320 points
per second.

           Meta-data points: 999
          Time-span covered: 604,800 seconds: 7 days
            Expected points: 18,125,856,000
           Processed points: 17,915,061,080
            Compared points: 17,915,047,700
               Valid points: 17,915,045,571
             Invalid points: 2,129
 Received NaN source points: 22,679
   Received NaN dest points: 138,381
      Missing source points: 1,959,042
 Missing destination points: 6,757,626
     Base source point loss: 17,950,960
Base destination point loss: 17,964,334
          Source duplicates: 2,994
     Destination duplicates: 1,263
      Overall data accuracy: 100.000%

 Missing source sub-seconds: 192,663, outage of 1 hour 47 minutes 2.09 seconds
     Total base source loss: 210,443,976: 1.161%
        Network source loss: 210,421,297: 1.161%
     Received source points: 17,933,016,032
        Source completeness: 98.936%

   Missing dest sub-seconds: 191,139, outage of 1 hour 46 minutes 11.29 seconds
Total base destination loss: 209,050,576: 1.153%
   Network destination loss: 208,912,195: 1.153%
Received destination points: 17,932,999,929
   Destination completeness: 98.936%

>> 0.011% missing from source that exists in destination
>> 0.038% missing from destination that exists in source
```

	Upstream	Downstream
Avg CPU	3.899%	2.032%
Avg Mem (MB)	194.571	118.2638
Total Bytes	70054757046	134784601815
Bytes/Value	4.1499	7.9881
Avg Time Delay (ms)	799.9801	-285.8055