Summary of the IEC 61850 GOOSE Message vs. Hardwire Time Stamp Deviation and Performance Test:

Key Conclusions:

> Using GOOSE Subscriptions to process events is more consistent than expected across various devices and manufacturers when compared to hardwired input event processing.

> GOOSE publishing performance differences exist among manufacturers and device models.

> Test averaged 3 to 4 ms end-to-end event information transmission times using GOOSE, which conforms to the IEC 61850 standard.

> Hardwired events are not always a consistent means of capturing event data when 1 ms accuracy is required.

WELCOME TO THE Q2 2015 EDITION OF THE NEXSTATION LAB REPORT

This quarter, we performed comparison testing to determine the differences in transfer times of GOOSE messages between IEDs and hardwired I/O. We took the results from our last quarter comparison report and focused on the devices that were performing out of our expected range to determine if the devices could be configured differently to improve the performance. For these tests, two different publishing devices were used. We compared the standard deviation of each subscriber's GOOSE timestamp with the timestamp of the same paralleled physical input contact closure time stamp.

For the non-technical reader: The left-hand sidebar provides a summary of our results, while the report below describes the technical details, including test setup, execution and the results.

IEC 61850 GOOSE Message vs. Hardwire Time Stamp Deviation and Performance

OVERVIEW

This test connected two separate common events to a pool of 12 devices representing six different manufacturers configured to use IEC 61850 GOOSE messaging. Each of the devices was connected to the same GPS clock using an IRIG-B connection. An event was generated by opening and closing a latching interpose relay, providing a 130 VDC wetting source to the physical inputs on all the devices.

Two of the devices (representing two different manufacturers) were selected to publish a GOOSE message when they detected the event using their physical input. Each of the two publishing devices had their own latching interpose relay connection. This represented two breaker merging units that detected a breaker

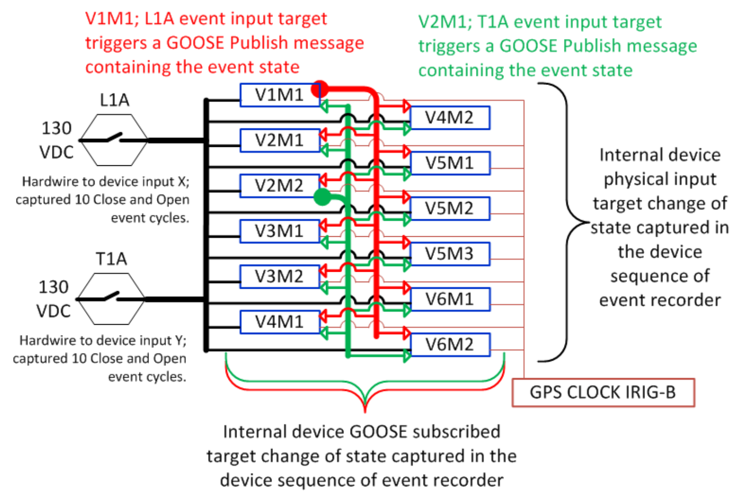

Figure 1: Test Configuration

change of state and then published a GOOSE message reporting the state change. In this scenario, our test included a parallel hardwired solution that also transmitted the state change. Each of the devices used in this test subscribed to the GOOSE message published by both of the test units and had a hardware connection to each of the event latching relays.

This setup allowed us to look at the time tags generated from the single event by the hardwire input and the subscribed GOOSE message from two different publishing units. All of the devices had an internal target that indicated the change of state from both sources.

TEST SYSTEM OVERVIEW

Figure 1 (above) shows the complete system setup and lists all of the devices used in our testing by their coded names. The figure shows the physical input event triggers connected to all of the devices, along with the IRIG-B connection for time synchronization.

The red line indicates the V1M1 device publishing the GOOSE message that contains the L1A input state change information, and the green indicates the same for T1A from V2M1. This was accomplished by creating a simple logic formula within the device that caused the value of the physical input to be equal to

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FUTURE TESTING:
Future tests will expand this basic test bed by:

> Adding additional devices
> Adding a GPS clock event capture to the test to tie event time tag data comparisons to actual time
> Using device network redundancy features into a redundant network configuration
> Exploring using Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR) Ethernet redundancy features
> Exploring performance during device and network failure modes
> Message performance under heavy ethernet load scenarios
> Exploring the use of multiple VLANs vs. MAC Filtering a combination of both
> Integrating the event triggers into real protection scenarios

the GOOSE message dataset target. All other devices in the test setup subscribed to both the V1M1 and V2M1 GOOSE message, receiving the same event information as they did from their physical input.

EXECUTION

We first checked the internal device diagnostics to verify that the internal clock on each device was being updated by the IRIG-B connection. We ran a few cycles of the event triggers and verified that both the hardwired and GOOSE target change of state information was recorded in the test device's event recorder.

Our test generated a total of 80 data points for each device by closing and opening each of the latching interpose relays 10 times and recording the hardwire input target for both the L1A and T1A interpose relay and the generated GOOSE subscription time tags.

We found that the V1M1 and V2M2 internal input target and published GOOSE output targets always had the same time stamp. This was expected, given the process time required by the device to perform the logic is much faster than a millisecond (ms). This also gave us a common starting point to compare the response times between a hardwire input and the GOOSE message data exchange.

During each triggered event, the hardwired input target and the subscribed GOOSE message device's incoming GOOSE target time stamps were recorded. This gave us the event time stamp from each of the two information transfer methods using two different manufacturers' devices.

Standard Dev	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Avg
L1A Close HW	0.002	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002
L1A Open HW	0.004	0.005	0.004	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004
T1A Close HW	0.003	0.002	0.002	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.003
T1A Open HW	0.003	0.004	0.004	0.004	0.004	0.003	0.004	0.004	0.004	0.004	0.004
L1A Close GOOSE	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.002	0.001
L1A Open GOOSE	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.002	0.002
T1A Close GOOSE	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002
T1A Open GOOSE	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.002

Table 1: Normalized Standard Deviation Data: Device Standard Deviation Values for Each of the Time Trials and Tests

TEST RESULTS

First, we normalized the data by removing the most significant value, leaving only the data to the right of the decimal point. This was done to make it easier to perform an analysis across all the test runs and display the results in milliseconds. We then took the standard deviation across all 12 of the devices for each of the test runs.

Table 1 (above) shows the results of these calculations. We can see by looking at the average of the 10 test runs that there was a greater deviation in the hardwired event time tags for the devices than for the GOOSE subscription time tags. This is to be expected due to the differences between device and manufacturer input scan rates for picking up the events. The average time stamp deviation for GOOSE subscription time stamps were very close, indicating a more consistent means of processing GOOSE messages across the various devices and manufacturers when compared to hardwired input events.

In this analysis, we wanted to first determine the average hardwire time stamp from all 12 devices for the same event. We took this information and calculated the difference to the GOOSE published output target for each of the sending units, V1M1 and V2M2. Given that we wanted to compare the GOOSE subscription times to hardwired events, this gave us an idea of the variance that existed right out of the starting block.

The results in **Table 2** (below) demonstrate a clear difference between the two manufacturers and how their published time stamp compared to how all the devices saw the hardwired event.

Average HW Delta from Published HW Timestamp	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Avg
L1A Close HW	-0.003	-0.001	-0.002	-0.002	-0.001	-0.001	-0.001	-0.003	-0.003	-0.003	-0.002
L1A Open HW	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001
T1A Close HW	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002
T1A Open HW	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.003	0.002	0.002

Table 2: Average Device HW Event Time Difference to GOOSE Published Time

Next, we looked at the GOOSE-published output target time stamp from each of the two publishing devices and compared it to the average subscription time stamp from the 11 devices receiving the information.

Table 3 (below) shows an average of 4 ms for Vendor 1 and 3 ms for Vendor 2. Both of these times are within the IEC 61850 standards performance range, but it shows that performance differences do exist between manufacturers.

Average GOOSE RX Delta from Published Timestamp	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Avg
L1A Close GOOSE	0.004	0.004	0.005	0.004	0.004	0.003	0.004	0.003	0.005	0.003	0.004
L1A Open GOOSE	0.004	0.004	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.004
T1A Close GOOSE	0.002	0.002	0.002	0.003	0.003	0.005	0.003	0.003	0.003	0.004	0.003
T1A Open GOOSE	0.002	0.002	0.002	0.003	0.002	0.002	0.004	0.005	0.002	0.003	0.003

Table 3: GOOSE Published Time Compared to the Average Subscription Receive Time

Next, we looked at each individual device and compared the average hardwired event time to the associated GOOSE subscription time stamp (**Table 4**, right).

The results did not match our expectations, given the previous data analysis showed the average GOOSE event transmission time was 3 to 4 ms. The L1A testing showed a 5 to 6 ms difference between the devices' event timestamps through a hardwired input vs. the GOOSE Subscription. But there was only a 1 ms difference in the T1A event.

	L1A Close	L1A Open	T1A Close	T1A Open
V1M1			-0.001	0.001
V2M1	0.005	0.005	0.000	0.001
V2M2	0.007	0.008		
V3M1	0.006	0.006	0.000	0.002
V3M2	0.008	0.007	0.003	0.003
V4M1	0.006	0.005	0.002	0.002
V4M2	0.005	0.005	0.001	0.002
V5M1	0.004	0.000	-0.002	-0.004
V5M2	0.005	0.000	0.000	-0.003
V5M3	0.003	0.000	-0.001	-0.004
V6M1	0.009	0.009	0.004	0.005
V6M2	0.011	0.009	0.003	0.005
AVG VALUES	0.006	0.005	0.001	0.001

Table 4: Hardwired vs. GOOSE Subscription Time Target Time Stamp Difference

Why was there such a difference? Further investigation into the raw data showed a number of identical or close to identical time stamps in the device's SOE log for both methods. Logic would dictate that the hardwire event should be captured first.

We went back into all the event logs and reverified the data. Finding no problems,. we checked all the event capture settings, de-bounce and other parameters that may have affected the performance between the two different physical inputs. We found nothing. After this investigation, we ran another series of tests that turned up similar results, shown in **Table 5** (left).

The retest verified our findings and points to a big performance difference between the two publishing devices.

	L1A Close	L1A Open	T1A Close	T1A Open
V1M1			-0.001	0.000
V2M1	0.005	0.005	0.001	0.002
V2M2	0.007	0.009		
V3M1	0.006	0.006	0.001	0.003
V3M2	0.007	0.009	0.003	0.003
V4M1	0.006	0.006	0.001	0.003
V4M2	0.005	0.005	0.000	0.002
V5M1	0.005	0.004	-0.001	0.000
V5M2	0.004	0.004	-0.002	0.000
V5M3	0.005	0.004	-0.002	0.001
V6M1	0.010	0.009	0.004	0.005
V6M2	0.010	0.009	0.005	0.005
AVG VALUES	0.006	0.006	0.001	0.002

Table 5: Retest-Hardwired vs. GOOSE Subscription Time Target Time Stamp Difference

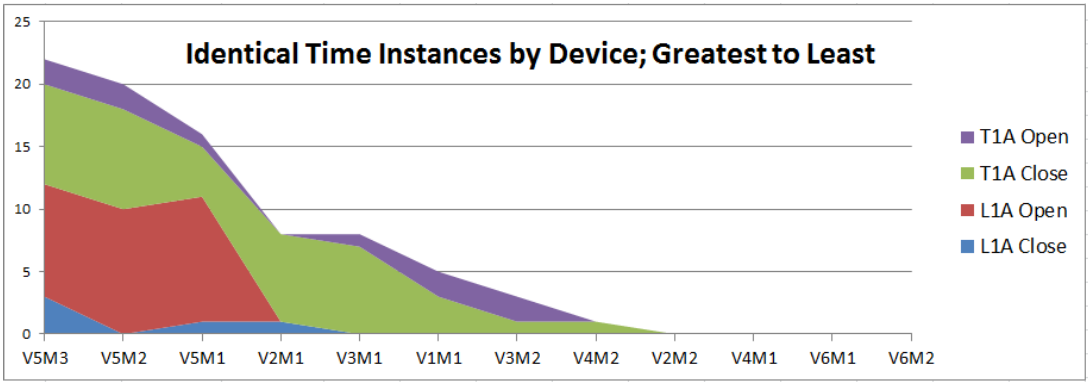

Figure 2: Exact matching hardwire and GOOSE target time stamps by device

There were a total of 67 exact or nearly exact time stamps seen in the device data, as shown in **Figure 2** (above).

Further investigation shows that the L1A GOOSE publishing device takes approximately 2 ms after the event to publish the GOOSE message and the T1A GOOSE publishing device immediately publishes the GOOSE message.

This, combined with all the various input scan rates, inter-process delays and other factors, explains why we see these results from this test.

SUMMARY

In short, this test allowed us to come to the following conculsions:

- Using GOOSE Subscriptions to process events is more consistent than expected across various devices and manufacturers when compared to hardwired input event processing.
- GOOSE publishing performance differences exist among manufacturers and device models.
- Test averaged 3 to 4 ms end-to-end event information transmission times using GOOSE, which conforms to the IEC 61850 standard.
- Hardwired events are not always a consistent means of capturing event data when 1 ms accuracy is required.