Abstract—This letter presents a technique to assess the overall network performance of sampled value process buses based on IEC 61850-9-2 using measurements from a single location in the network. The method is based upon the use of Ethernet cards with externally synchronized time stamping, and characteristics of the process bus protocol. The application and utility of the method is demonstrated by measuring latency introduced by Ethernet switches. Network latency can be measured from a single set of captures, rather than comparing source and destination captures. Absolute latency measures will greatly assist the design testing, commissioning and maintenance of these critical data networks.

Index Terms—Ethernet networks, IEC 61850, performance evaluation, power transmission, protective relaying, smart grids.

I. INTRODUCTION

SAMPLED value process buses provide a digital connection between high voltage switchyards and Substation Automation Systems. IEC 61850-9-2 specifies how instantaneous sampled value (SV) measurements shall be transmitted over an Ethernet network by a “merging unit” or instrument transformer with electronic interface [1]. The “9-2 Light Edition” (“9-2LE”) implementation guideline reduces the complexity and difficulty of implementing an interoperable process bus based on IEC 61850-9-2 [2]. This is achieved by specifying the data sets that are transmitted, sampling rates, time synchronization requirements and the physical interfaces to be used.

Performance requirements specified in IEC 61850-5 require that SV messages be delivered within 3.0 ms in transmission substations, including the communications processing time at each end and the media transfer time [3].

Each IEC 61850-9-2 SV message includes a sample counter, SmpCnt. This counter is reset to zero when the time synchronizing signal occurs. The SmpCnt counter will range from 0 to 3999 (50 Hz) or 4799 (60 Hz) for protection applications using 9-2LE with 80 samples per nominal power system cycle.

A precision Ethernet capture card records the time an Ethernet frame was received and prepends a precise time stamp to the captured frame [4]. Until now there has not been a method to check the time synchronization behavior and performance of a merging unit [5]. This letter presents an experiment that validates the method and demonstrates its utility.

II. METHOD

The source of one pulse per second (1-PPS) signals used to synchronize sampling of the merging unit is used to synchronize the time stamping unit in the Ethernet capture card. The propagation delay of the synchronizing signal through cables and any media or level converters needs to be quantified when assessing performance, and is typically less than 200 ns for cable lengths under 20 m.

Precise delay measurements are best taken on the SmpCnt = 0 event, as this is the only sample that is precisely aligned to the synchronization source. A network capture is initiated and SmpCnt = 0 frames extracted for further analysis.

Two validating experiments were performed. The first was the direct capture of SV frames from the three GTNET-SV cards with three separate ports on the Ethernet capture card. One GTNET-SV card generated the 1-PPS clock for the other two cards, and for the Ethernet capture card. This arrangement is shown in Fig. 1(a). A second experiment examined network latency when two
Ethernet switches were placed between the merging units and the Ethernet capture card, which is representative of a large substation. These switches provided time synchronization using IEEE Std 1588 over Ethernet, Fig. 1(b).

III. RESULTS

Over a fifteen minute period 900 measurements were taken for each experiment. The time delay between the 1PPS pulse and the arrival of the SV frame with $Sm\text{-}pCnt = 0$ was consistent between the GTNET-SV cards for any given measurement, but there was approximately 60 µs variation between measurements. This is an artifact of the RTDS simulation engine. Fig. 2(a) shows the delay as a probability density function. This particular measurement is ‘best case’ and can be used to determine additional network delays created by Ethernet switches and cabling.

Fig. 2(b) shows that Ethernet switches introduce a delay, with queuing effects apparent. The minimum delay between the 1PPS event and the frame being received increases from 84 µs to 114 µs. This 30 µs switching delay ($T_{sw}$) is expected as each of the two switches has a 3 µs overhead and 12 µs transmission time. Fig. 2(a) shows that “GTNET-SV 3” has slightly less delay than the other two cards (on average 900 ns), and consequently its frames are generally the first into the Ethernet switch output queue, resulting in a queuing advantage ($T_{q}$) of approximately 12 µs. Some variation in $T_{q}$ exists due to backgound traffic.

The time synchronization performance of the PTPv2 clocks was measured during the capture test with a digital sampling oscilloscope. The measured synchronization error ranged between ~96 ns and 144 ns throughout the fifteen minute observation period with 16 Mb/s of SV traffic on the same Ethernet switches.

IV. CONCLUSION

This method of measuring the network performance of sampled value process buses uses the IEC 61850-9-2 protocol and synchronization of an Ethernet card to the time source used by a merging unit. This allows for single point measurements, which is the key benefit for type testing and commissioning process buses in transmission substations. Network performance can be evaluated in absolute terms and compliance with transfer times specified in IEC 61850-5 determined during commissioning where cable distances are significant.

REFERENCES