Considering that the basic concept of network monitoring is related to systematic verification in search of anomalies that could compromise its proper functioning, IEC 61850 network monitoring is necessary throughout the life cycle of the digital substation. Which means that monitoring must be carried out in the commissioning test stages such as Factory Acceptance Test (FAT) and Site Acceptance Test (SAT), and maintenance tests.

The importance of network monitoring is related to early detection of errors, network operating conditions, reducing network unavailability by tracking problematic elements, logging all network events, and security and stability of the power system. Specialized devices are necessary to monitor these network aspects, acting as a "network oscillograph" / “digital network recorder”. This monitoring system must be implemented both in hardware and software in order to cover all the time-critical requirements of the GOOSE and Sampled Values (SV) protocols. Thus, the monitoring system must be able to tag the receiving timestamps by hardware.

Several network aspects must be analyzed to guarantee the security, reliability, speed and availability of the information being transmitted, warning potential communication failures or invasions. These network aspects are related to message integrity, configuration and data security, system's time synchronism and the message timing statistics, considering the interval between frames, transfer time, packets losses and etc.

The Figure 1 illustrates several monitoring events that could be verified related to SV, GOOSE, PTP and PRP protocols.

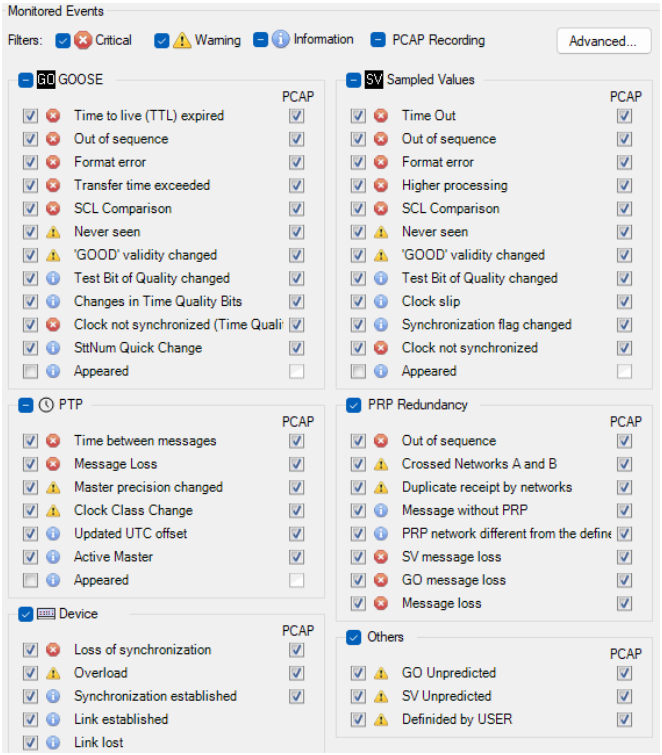

Figure 1 - Monitoring Events

In order to exemplify an application of a monitoring system in action, Figure 2 illustrates the test setup of case studies based on forced changes in the GrandMaster (GM) PTP clocks, comparing the behavior

of different manufacturers present in the setup. A GNSS simulator with an atomic clock was used to simulate time drifts and served as the global time reference to calibrate the system's two GM clocks, as the network featured PRP redundancy. Additionally, an IEC 61850 network diagnostic and monitoring system, was employed. Five MUs, from 4 different vendors, were connected to the system.

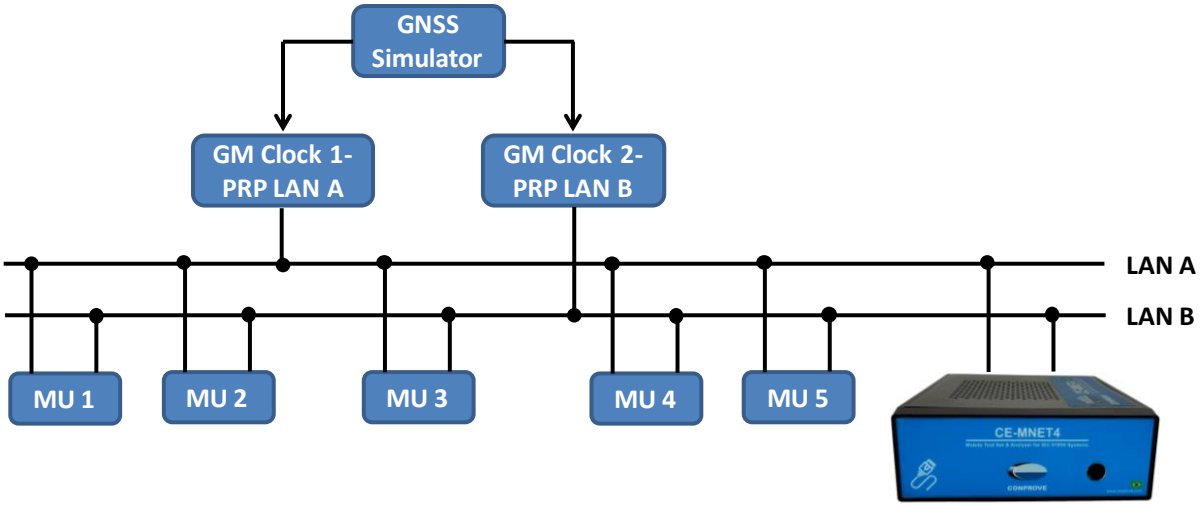

Figure 2 - Test Setup

The implementation of the Process Bus in the context of digital substations also implies a paradigm shift in asset management. Considering that the Ethernet network itself is one of the most critical assets of the substation, it is important to account for the costs associated with adopting specialized network monitoring and diagnostic tools. As such, initial costs can be significant, as they may involve purchase, installation, operation, maintenance, and training. A reduction in these costs is expected as procurement volumes increase, which is why long-term strategies should be taken into account.