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Optical Systems Performance for Line Protection Schemes

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SUMMARY

Several telecommunication protocols emerge as optimal for data communications; however, they are not holistic solutions from a quality-of-service point of view. Guaranteed bandwidth and resilient connection are not enough for power transmission needs. For this reason, deterministic and fast message delivery in an Operational Technology (OT) network is being defined and required by different industry standards like IEC 61850, IEC 60834-1, among others.

Protection and control applications are based on very strict operating standards that must be maintained in the telecommunications platform that supports their operation.

The key communication requirements of protection schemes should be the starting point in terms of evaluating a telecommunications channel/platform for power transmission.

In this paper, we verify the critical parameters that must be provided by an optical communications link in the Multi-Protocol Label Switching – Transport Profile (MPLS-TP) protocol to meet the demand defined by the protection schemes.

Impedance-based system protection is very sensitive to latency and communication channel availability (it is compromised when a ring changes its communication path from primary to protected), while current differential comparison schemes require symmetry that not all forms of packet-switched platforms can guarantee. In that aspect, Multi-Protocol Label Switching – Transport Profile (MPLS-TP) guarantees the required performance for these applications.

In line with previous requirements, we validate the latency of teleprotection (integrated version) over a hybrid (TDM and packet switched) multiplexer; also over a C37.94 optical port that would allow the interconnection of an external Current Differential Relay or external

teleprotection equipment. Those measurement were performed in the two possible ways the hybrid platform allowed:

- Legacy communication based on Time Division Multiplexing (TDM) format by Synchronous Digital Hierarchy (SDH).
- Packetized OVER Multi-Protocol Label Switching – Transport Profile (MPLS-TP).

In Operational Technology (OT) networks, as is the case of power line protection systems, one of the fundamental requirements is the system availability; one optimal approach to deliver such requirement is the implementation of redundant communication links.

The operating environmental conditions also define specific requirements for the telecommunication devices that are aligned with the Intelligent Electronic Devices (IED), which are the basis of reliability in the protection scheme.

Present paper presents laboratory and field measurements that support above discussed critical parameters that telecommunication platforms require to serve power transmission protection schemes.

The performance for Wide Area Monitoring Systems (WAMS) applications will also be evaluated in order to verify the reliability of the MPLS-TP platform for those applications. In this sense, the latency measurement of Generic Object Oriented Substation Event (GOOSE) messages between differential protection equipment was performed.

To perform delay and fiber switching tests; we used certification grade analyzers which can analyse TDM, and Ethernet based communications.

Also, will be documented practical results measured on Multi-Protocol Label Switching – Transport Profile (MPLS-TP) equipment comparing these with what is defined in the standards to maintain the safety and reliability of electrical protection schemes.

KEYWORDS

MPLS-TP, SDH, Line Differential Protection, Teleprotection, Path Switching delay, Optical, Asymmetry, Latency

INTRODUCTION

Protection, control and monitoring applications are based on strict performance standards that must be maintained in the telecommunications platform that supports their operation.
The key communication requirements of protection schemes should be the starting point in terms of evaluating a telecommunications channel/platform for power transmission.
Impedance-based system protection is very sensitive to latency and communication channel availability (it is compromised when a ring changes its communication path), while current differential comparison schemes require symmetry that not all forms of packet-switched platforms can guarantee. [2]
In present paper, we report validations of the critical parameters that must be provided by an optical communications link based on Multi-Protocol Label Switching – Transport Profile (MPLS-TP) [3] to satisfy the demand defined by the protection schemes.

GENERAL INFORMATION

The protection of a high voltage power transmission line based on impedance analysis is very sensitive to latency (< 3ms [1]) and the availability of the communication channel (it is compromised when a ring changes its communication path).
In this sense, we validated the delay times of the teleprotection integrated in a multiplexer equipment and an optical port that would allow the interconnection of an external Intelligent Electronic Devices (IED) such as Current Differential Relay and/or standalone teleprotection equipment. These measurements were performed in a dual mode as allowed by the hybrid mode that multiplexer operates.
Current differential comparison schemes require an asymmetry <1.5 ms according to current differential IED operational alarms [4] that not all forms of packet-switched platforms can guarantee. In that sense the Multi-Protocol Label Switching–Transport Profile (MPLS-TP) format [3] guarantees the required performance for these applications.

In operational technologies (OT), as in the case of a protection system, another fundamental parameter is availability. One of the ways to guarantee this requirement is the implementation of redundant communication links. The Multi-Protocol Label Switching – Transport Profile (MPLS-TP) multiplexer allows the implementation of redundant and independent routes for each service to be implemented (Ethernet, IEEE C37.94, DTT).
In following section are shown validation results of the delay, symmetry and channel availability that Integrated Teleprotection and C37.94 port offers to Intelligent Electronic Devices (IED).

TEST SETUP AND RESULTS

Delay tests

The experimental setup is shown in Fig. 1, there were defined two “Hybrid (TDM and Packet switching)” multiplexers, identified as “Node 1” and “Node 2”, which are connected by two Single-mode Fibers (SMF) using a redundant protected scheme known as 1+1. The “Hybrid” characteristic means that this kind of multiplexer can transport traffic simultaneously in Synchronous Digital Hierarchy (SDH) and Multiprotocol Label Switching – Transport Profile (MPLS-TP) formats over the same fiber. Each multiplexer has integrated Teleprotection cards and IEEE C37. 94 interfaces/ports.

To measure delay, the configuration shown in Fig. 1 is implemented, where each analyzer [7] (which must be synchronized) will measure the one-way latencies independently (therefore each of them is connected to a GPS antenna). For Fig.1 setup, test equipment with corresponding test routines were used to analyze both TDM and Ethernet based communications.

It can also be observed that we have one port of each multiplexer whose communication will be on the packet-switched format called Time Division Multiplexing over Packets (TDMoP), i.e., on the Multi-Protocol Label Switching–Transport Profile (MPLS-TP) format; then we have another port whose communication will be on format called Time Division Multiplexing (TDM) specifically formatted as Synchronous Digital Hierarchy (SDH).

The delay test results obtained on the Synchronous Digital Hierarchy (SDH) format can be seen in Fig. 2, while those obtained on the Multi-Protocol Label Switching–Transport Profile (MPLS-TP) format are shown in Fig. 3.

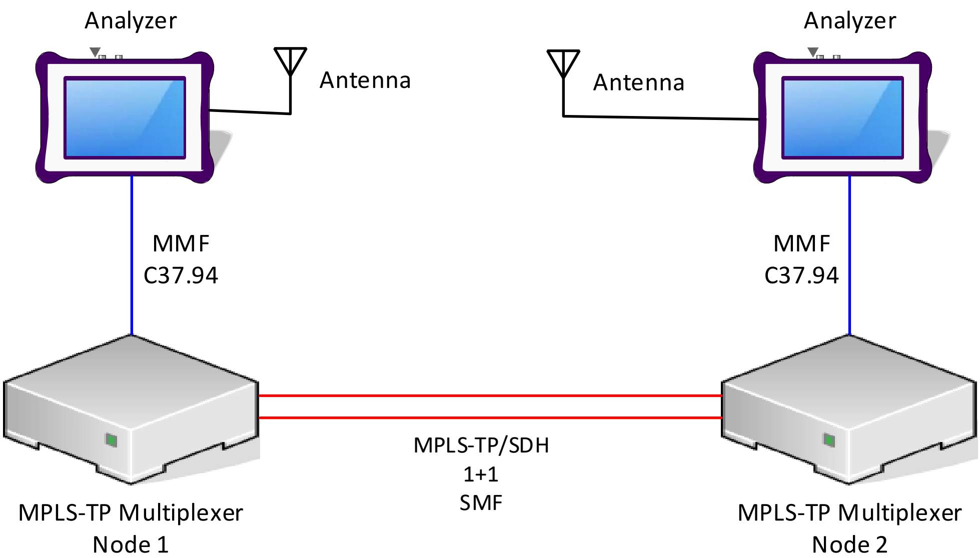


Fig. 1. IEEE C37.94 delay and asymmetry test setup

Delay (Port A)

	Current	Minimum	Maximum
Round-trip delay	922 us.	920 us.	922 us.
Forward path delay	431 us.	430 us.	431 us.
Return path delay	491 us.	490 us.	491 us.
Asymmetry	-60 us.	-60 us.	-59 us.
Remote host	xxx0524P		

Fig. 2. IEEE C37.94 communications delay over SDH format

Delay (Port A)

	Current	Minimum	Maximum
Round-trip delay	4.174 ms.	4.166 ms.	4.187 ms.
Forward path delay	2.182 ms.	2.174 ms.	2.182 ms.
Return path delay	1.992 ms.	1.992 ms.	2.005 ms.
Asymmetry	190 us.	177 us.	190 us.
Remote host	xxx0524P		

Fig. 3. IEEE C37.94 communications delay over MPLS-TP format

Above results shows that the latency through Synchronous Digital Hierarchy (SDH) 0.5 ms is much lower than that obtained with Multi-Protocol Label Switching–Transport Profile (MPLS-TP) 2.2 ms. That is due to the fact that when transmitting through a packet network as is the case of MPLS-TP, it takes time to convert the IEEE C37.94 frame into packets at the transmitter, and the reverse process at the receiver. Furthermore, although MPLS-TP is a connection-oriented protocol, it is not a synchronous transmission method as is the case with Time Division Multiplexing (TDM)-based communications such as T1/E1, IEEE C37.94 and Synchronous Digital Hierarchy (SDH). However, in both cases, the latency is below that specified by IEC TR 61850-90-12. (< 3ms)

This bundling is also reflected in the asymmetry, which is also higher for communications over MPLS-TP. However, for both cases the asymmetry values are acceptable because the protection relays available on the market are configured to withstand a threshold value from 1 to 1.5 ms [4].

Path Switching Test

For the availability test it is possible to use the setup shown in Fig. 1 with 1+1 configuration in which the communication passes through both fibers (MAIN and BACKUP), being the receiver the one that selects the communication (*working path*). For this purpose, was disconnected the MAIN path fiber and measure the time in which the communication switched to the BACKUP fiber (*protection path*) as shown in Fig. 4. The IEEE C37.94 services then reverted to the main communication path once it was reestablished.

Fig. 4. Switching fiber test setup

When dealing with service disruptions in TDM networks, we can notice that many problems are caused by events that can be accounted for in time scales of seconds but some others, like the ones related with protection switching happen in time scales of milliseconds.

The analyzer [7] allow to perform the measurement in which a certain service is interrupted, which is possible by enabling all the triggers as shown in Fig. 5, and then to perform the subsequent disconnections. This test is called as a service disruption time (SDT) which allows to find short service interruptions over TDM interfaces like IEEE C37.94.

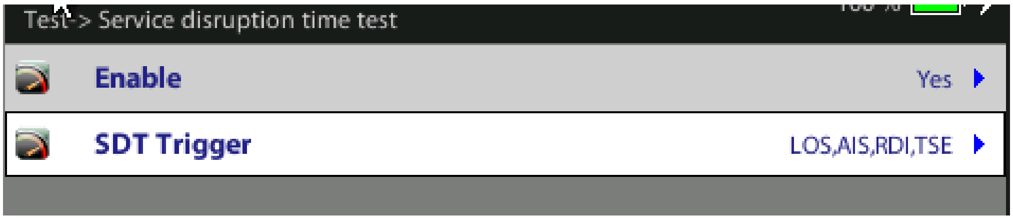
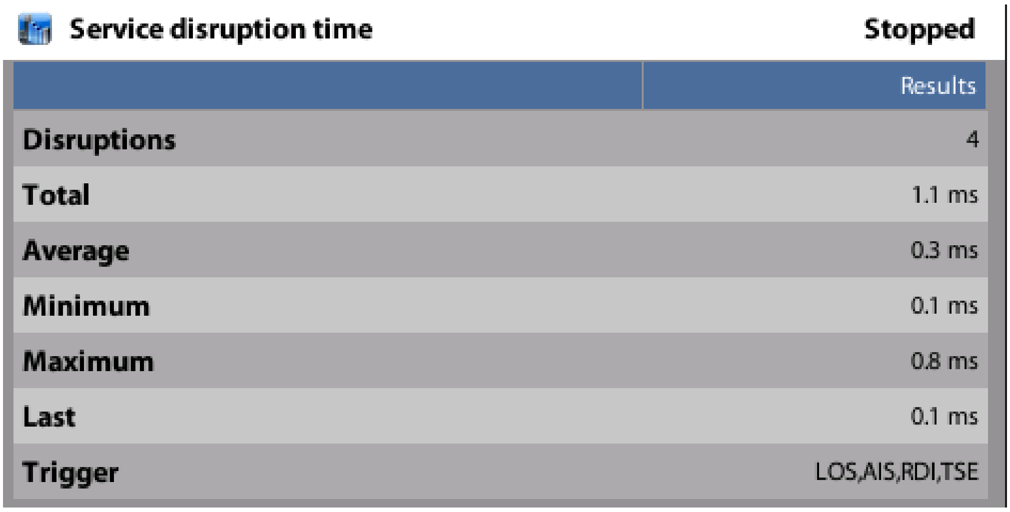


Fig. 5. Service disruption time test setup

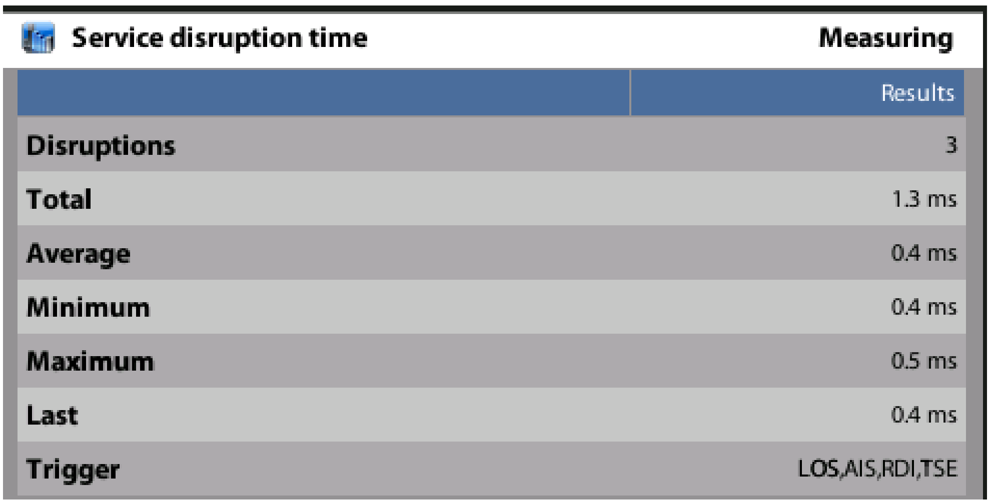
The results of the switching test over Multi-Protocol Label Switching–Transport Profile (MPLS-TP) can be seen in Fig. 6 and Fig. 7, for the disconnection and reconnection tests respectively; where it can be seen that the total time taken for switching upon disconnection of the *working path* is 1.1 ms; and the total time taken for its reconnection from *backup path* is 1.3 ms.



Service disruption time — Stopped

	Results
Disruptions	4
Total	1.1 ms
Average	0.3 ms
Minimum	0.1 ms
Maximum	0.8 ms
Last	0.1 ms
Trigger	LOS,AIS,RDI,TSE

Fig. 6. Working path disconnection over MPLS-TP format



Service disruption time — Measuring

	Results
Disruptions	3
Total	1.3 ms
Average	0.4 ms
Minimum	0.4 ms
Maximum	0.5 ms
Last	0.4 ms
Trigger	LOS,AIS,RDI,TSE

Fig. 7. Working path reconnection over MPLS-TP format

The results of the switching test over Synchronous Digital Hierarchy (SDH) can be seen in Fig. 8 and Fig. 9, for the disconnection and reconnection tests respectively; where it can be seen that the total time taken for switching upon disconnection of the main link is 1.3 ms; and the total time taken for reconnection is 0.6 ms.

Service disruption time — Stopped

	Results
Disruptions	1
Total	1.3 ms
Average	1.3 ms
Minimum	1.3 ms
Maximum	1.3 ms
Last	1.3 ms
Trigger	LOS,AIS,RDI,TSE

Fig. 8. Working path disconnection over SDH format

Service disruption time — Stopped

	Results
Disruptions	2
Total	0.6 ms
Average	0.3 ms
Minimum	0.1 ms
Maximum	0.5 ms
Last	0.1 ms
Trigger	LOS,AIS,RDI,TSE

Fig. 9. Working path reconnection over SDH format

It can also be observed that the service interruption periods maintain similar values at the MPLS-TP format and at the SDH format, being in both cases very small values.

Generic Object Oriented Substation Event (GOOSE) messaging tests

The performance for Wide Area Monitoring Systems (WAMS) applications and/or GOOSE Teleprotection commands was also evaluated in order to corroborate the reliability of the MPLS-TP platform for these applications. In this sense, delay measurement of GOOSE messages between two IEDs was performed.
It is possible to configure the multiplexer Ethernet access ports that will receive GOOSE messages, giving priority 6 to these messages as shown in Fig. 10.

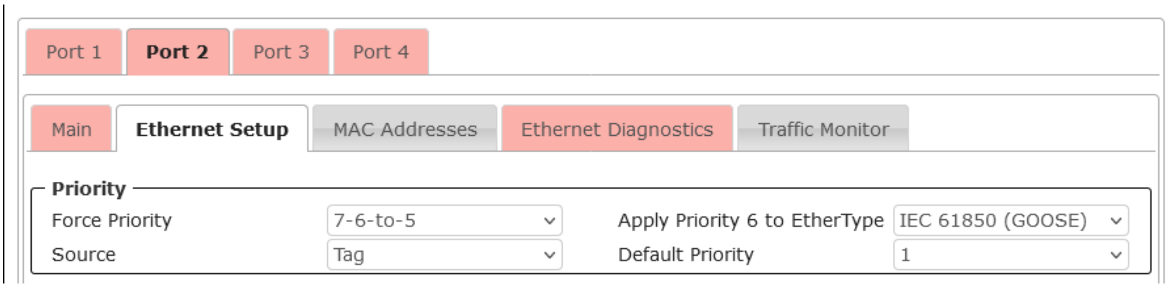


Fig. 10. GOOSE traffic prioritizing over Multiplexer Ethernet access interface.

The Generic Object Oriented Substation Event (GOOSE) messaging tests require that the traffic analyzer set is previously synchronized. Once the clock reference is ready, it is possible to make the setup shown in Fig. 11. For this purpose, two IEDs will be used, where one of them will be the publisher and the other one will be the subscriber.

The results of the GOOSE tests are shown in Fig. 12, where it is possible to observe that the delay values are low for the GOOSE messages sent, being within the values defined by the IEC 61850-5 standard [5].

The test equipment can capture the frames sent by the network. Fig. 13 shows the capture of frames generated by GOOSE messaging; where it can be observed that delay is only observed in some frames, this is due to the fact that any event generated generates a burst of frames repeating in increasingly longer periods of time.

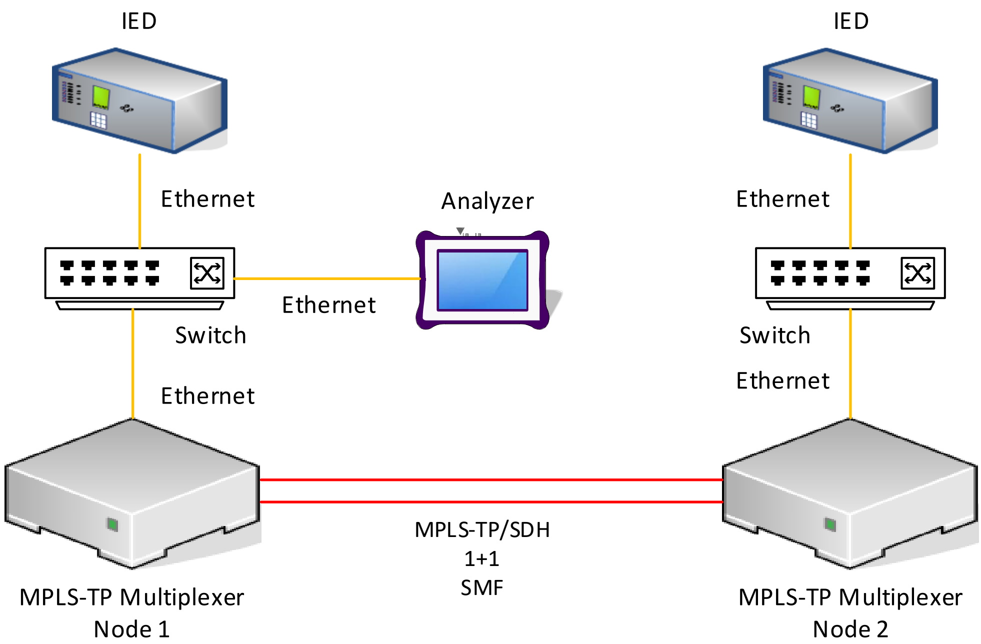


Fig. 11. GOOSE messaging test setup.

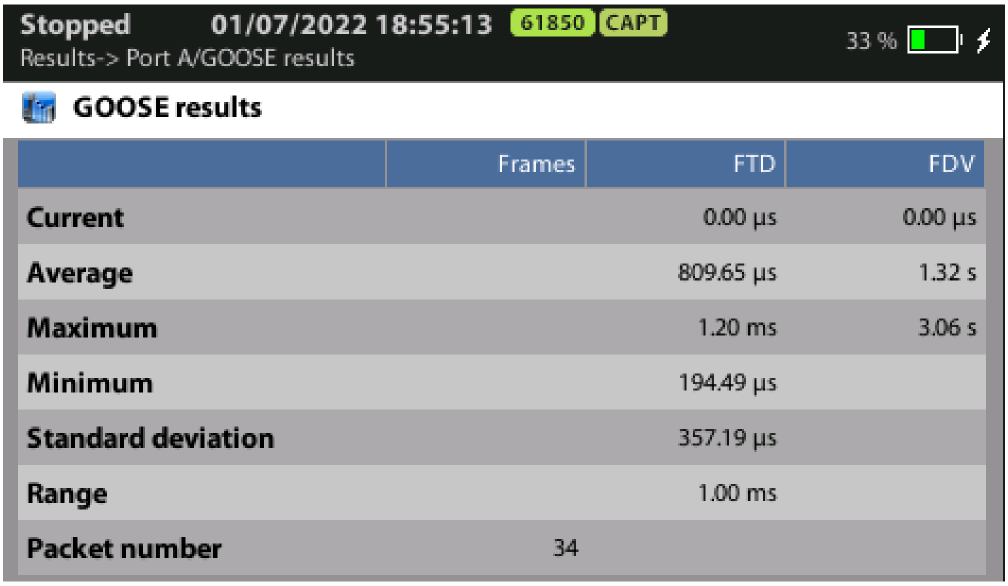


Fig. 12. GOOSE messaging test results.

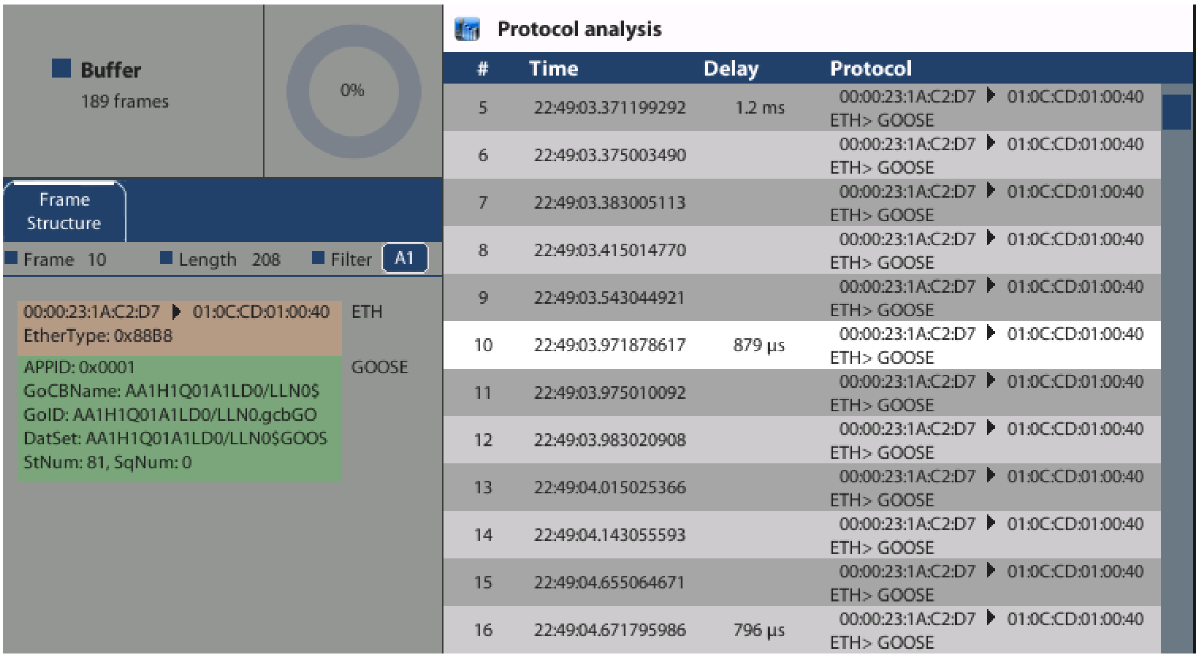


Fig. 13. GOOSE messaging frame capture.

CONCLUSIONS

This document proves that the Multi-Protocol Label Switching–Transport Profile (MPLS-TP) Multiplexer under evaluation represents a secure, reliable, and efficient communication platform which allows preserving the integrity of the information exchanged between network nodes with higher priority in critical services such as teleprotection, differential protection and Generic Object Oriented Substation Event (GOOSE) messaging.

Was certified that presented *hybrid communication scheme* allows the exchange of critical substation information based on packet switching and circuit switching through a pair of fiber

optic wires (single wire for TX and single wire for RX) delivering corresponding performance differentiated according to each format.
The data transmission capacity in hybrid format (Time Division Multiplexing-TDM and Packets) although the latencies obtained in communications in the Multi-Protocol Label Switching–Transport Profile (MPLS-TP) format are higher than those obtained in the SDH format; these results continue to be acceptable because they are within the ranges specified by the aforementioned international norms and/or standards of the electrical industry.
In summary, we have verified on the evaluated platform [6] the following critical parameters that must be met by optical transmission platforms for power systems:

- C37.94 protection channel delay: < 3 ms according to IEC61850-90-12.
- C37.94 channel symmetry < 1500 µs
- Main/backup fiber path switching < 3 ms
- Ethernet channel speed for GOOSE message < 1.5 ms

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