

## MPLS-TP AS PACKET PLATFORM FOR CRITICAL SERVICES IN POWER TRANSMISSION

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### SUMMARY

*Beyond the trend of using IP as the “up to date technology” for SCADA (IEC 60870-5-104) and protections scheme integrated to a centralized management of the load (Sinchrophasors PMU), there is the need to approach the automatic switching and intrinsic autonomy of routing algorithms to provide smart capability to the communications network [1]. For long time IP equipment manufacturers have been trying to penetrate the electrical utilities with partial success, they were able to support only added value services as IP Video, VoIP and corporate IP traffic which is are not “critical” or essential to the electrical power system operation.*

*On this paper is presented a theoretical-practical evaluation of the MPLS-TP protocol which offers an IP platform according to the complimentary services requirements (high bandwidth) as well for reliable channels features through the emulation of TDM systems with delay, symmetry and self-healing switching in order to warrant the correct operation of critical services as Teleprotection, Differential Relays and Sinchrophasors.*

*Key time measurements will be presented which certifies the theoretical reliability of MPLS-TP as main IP communication platform in electrical transmission systems.*

### KEYWORDS

MPLS-TP, DIFERENTIAL PROTECTION, TELEPROTECTION, SMART COMMUNICATION SYSTEM, CRITICAL SERVICES, PSEUDO-WIRE, TDM EMULATION, SYMETRICAL PATH

## 1 TECNOLOGICAL EVOLUTION OF COMMUNICATION SYSTEMS

It is described with some detail the case in Venezuela that is not very different of actual systems in Latin America, Middle East and part of Asia. In the beginning, telecommunications at electrical utilities was characterized by an extended use of analog Power Line Carrier (figure 1) and it use exclusive for operations proper of the electrical network: teleprotection, SCADA and voice to/from dispatch center (control centers). The limitations of bandwidth that was shared among different links (40 to 500 kHz) [2], determined the transmission of information between substations and generator plants to the control centers, to be done at bit rates as low as 600 baud and in some cases at 300 baud in analog channels, sharing the bandwidth among voice and Data, these channels were named Speech-Plus (see Fig. 2).

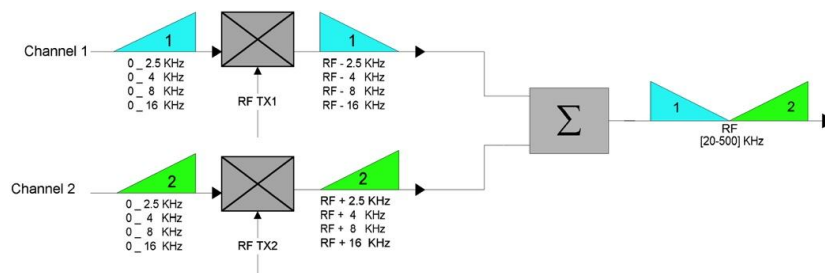


Fig. 1. SSB modulation scheme in Analog Power Line Carrier

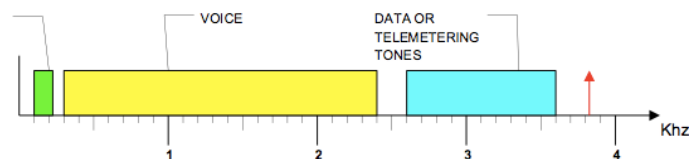


Fig. 2. Speech-Plus Channel in SSB systems

In some cases, it was deployed microwave systems with PDH technology, from 2 mbps to 34 mbps, its use depended upon limitations of frequencies and also restrictions imposed by preference policy of the National Public Telephonic Company, that imposed the procurement of services in its coverage areas.

In Venezuela, in 1984, the country's Electrical Company install the first fiber optic link consisting of a submarine cable of 9.6 km and OPGW type fiber optic of 45km, additionally a microwave backup system, both of them with PDH technology.

It is at 1994 when due to the introduction of SDH technology, it is possible to overcome the lack of flexibility of PDF devices, related to the long multiplexing chains.

In 2006, there was another step in evolution of communications technology, that year begins the migration of TDM systems (circuit switched) to packet switched (IP). At that moment the migration was considered relatively free of incompatibility issues, for that reason MPLS was discarded due to its complexity and inexistency of standards widely accepted and certified for its operation in electrical utilities.

Special care in this migration was given to the critical services, such as teleprotection and transmission of information of SCADA systems.

The deployed solution was the Gigabit Ethernet Network with the use of DWDM equipment, where the data and the teleprotection system use independent wavelengths, for the interconnection from protection relay to relay between both ends (see Fig. 3).

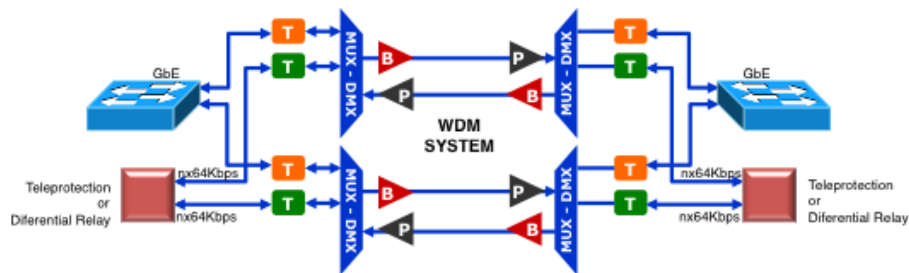


Fig. 3. IP System and Teleprotection over DWDM

In parallel to evolution of telecommunication systems, the protection relay's technology developed to the IED.

In first stage, the teleprotection schemes used wiring from relay's IO contacts to a teleprotection equipment (Power Line Carrier, PDH, SDH) through electrical connection of 4-Wire audio channels. By pursuing more reliability and simplicity, some telecommunication equipment specialized for the utility sector, had a teleprotection interface built-in.

In a more advanced stage, protection relays incorporated C37.94 optical ports, which interfaced with the same type of interface in the DWDM system. For those Power Lines of critical importance, the protection relay was added a 1550 nm optical port with optical power enough to overcome distances of about 100 km, connected through an exclusive pair of fiber optics to the relay at the remote substation. This option has the advantage to avoid transit through a multiplexer equipment, but losing the backup path feature provided by communication systems with Ring topology, additionally this alternative is costly because a pair of fibers is reserved for primary protection and a second pair of fiber for secondary protection.

## 2 MPLS TECHNOLOGY

### 2.1 Expectations about MPLS-TP technology

Although the Gigabit Ethernet network deployed in conjunction with optical teleprotection has been efficient and dependable, it is costly and complex to establish a proposal for rerouting in case of total fail of OPGW. This motivates the development of a telecommunication proposal associated to the operation of electrical sector that comply with the following premises:

- Based on packet switching, to include the capability to switch to alternative routes defined in the network in case of primary or priority path fail.
- Multiplatform, that allow us to integrate legacy technologies (PDH, SDH, SONET), being transparent to traffic and the operation of existing TDM systems.

- Support for new synchronization protocols, such as IEEE 1588v2. Ensuring network synchronization and support to external synchronous systems.
- Connection oriented, to ensure proper transmission time for critical services.
- Minimal Latency and Jitter to be used for communication of critical mission, such as teleprotection between generator plants and substations. Symmetrical Bidirectional communication, to allow the application for differential line protection.
- Management capacity levels (OAM), functionality and switch protection similar to transport networks TDM (SDH) to be deployed by the same technical staff existing on the electrical utility industry, requiring the same expertise level as any other transport technology.
- High voltage substation hardened equipment, that comply with environmental requirements such as: high temperatures and electromagnetic fields as defined in IEEE 1613[3]
- Must be scalable to bigger networks, allowing partial provisioning that allow gradual integration of different systems as they are deployed.

After multiple analysis summarize in table 1, it is considered that MPLS-TP technology, developed in a joint effort between ITU-T and IETF, currently represent the solution for flexibility, economy and homologation that suffices the necessity of telecommunications related to the electrical utility.

Table 1. TDM and MPLS-IP technology comparison

FEATURE	SDH/SONET	MPLS-TP
Alternative backup paths in case of primary path failure	1	N+1
Interoperability with TDM or IP technologies in a transparent fashion.	YES	YES
Precision Time Protocol IEEE 1588v2	NO	YES
Connection Oriented	YES	YES
Symmetrical path switch, log delay and low jitter	YES	YES
OAM (Operation, Administration and Maintenance) simplicity	YES	YES
IEEE 1613 certified	YES	YES
Scalable from a minimal configuration available	YES	YES
Spare parts availability for 10+ years	YES	YES
Certified equipment and with immediate availability	YES	YES

## 2.2 MPLS-TP and its features

MPLS-TP is built upon MPLS, basing in the necessity of a simplified OAM in the packet network and to optimize its use as Access Network, but also considering that not all characteristics of MPLS are necessary or consistent with transport networks, MPLS-TP can be considered a library of MPLS with some enhancements to provide support for traditional transport operational models that provide transport to critical services.

MPLS-TP is connection oriented, deterministic set of packet switching transport protocol. It is having more and more acceptance around the globe, among other reasons, because it is being developed as a joint effort from ITU-T and IETF to develop a standardized optimized version of MPLS for transport networks.

MPLS-TP is oriented to Access/aggregation of SDH.

The essential features of MPLS-TP defined by IETF and ITU-T are:

- MPLS forwarding plane with restrictions
- PWE3 Pseudowire Architecture
- Control Plane: static or dynamic, Generalized MPLS (G-MPLS)
- Enhanced OAM functionality
- OAM monitors and drives protection switching
- Use of Generic Associate Channels (G-ACh) to support fault, configuration, accounting, performance and security (FCAPS) functions.
- Multicasting is under further study.

MPLS-TP has deleted a set of features of MPLS which are not compatible with Connection Oriented networks.

- Disabled Penultimate Hop Popping (PHP) to reduce processing on the edge router.
- The capability to send traffic through other path of equal cost (Equal Cost Multi Path -ECMP) which is incompatible with the requirement of being deterministic. MPLS-TP is bidirectional LSP, it is, the traffic between two nodes of the electric system use the same path in both directions.
- Prohibited Label-Switched Paths (LSPs) merge, it leads to loss of information about the origin of the traffic and make complex the supervision of each individual path.

### **3 COMMUNICATION PLATFORM REQUIRED FOR ELECTRICAL UTILITY**

#### **3.1 Mission-Critical Communications in MPLS-TP**

The critical teleprotection/protection communication are implemented over MPLS-TP emulating a ring (a logical ring), to guarantee in that way a path symmetry along which a packet is send and received.

If we consider the communication traffic along the operative electrical system, the teleprotection scheme, where the teleprotection commands are transferred between neighbor substations and supported by Gigabit Ethernet links through fiber optic, it generally does not suffer issues related to latency or delay, nevertheless, we need to consider the worst-case scenario when the OPGW fails between the substations. Under this circumstance, it should be triggered a path switch in the communication equipment that allows a rerouting through several substations that are part of the logical ring previously defined, with a possible increase of traffic as a result of the contingency of the electrical system.

The MPLS-TP architecture is based on server-client model, in which the MPLS-TP operate independently of: its clients, related Management and control networks.

The MPLS-TP channels are based in the Pseudo wire Emulation Edge-to-Edge (PWE3) model. A PWE3 emulates the essential attributes of a Permanent Connectivity Service over a packet switched network, similar to a dedicated TDM line or circuit. From the client point of view, the pseudo-wire is perceived as a link or circuit not shared. An MPLS-TP tunnel can contain multiple pseudo wires.

Several MPLS-TP paths can be used to build Meshed infrastructures connecting the packet transport networks.

The Internal transfer and traffic switch inside the packet network, is independent of the specific protocol stack and the Application Service from the client side, whereas

the edge mapping could be optimally configured and tuned according to customer requirements.

An MPLS-TP network can achieve the interconnection of IP-routed devices with a group of point-to-point pseudo-wires or E-LAN transport services. The real interoperability exist in the Ethernet link or in the Media Access Control (MAC).

With MPLS-TP, one packet network can emulate the features of legacy services while new connectivity services that are in synergy with All-IP oriented advanced services.

As premises, it is considered the following objectives.

- It must support the migration from primary and secondary distance protection relay in both schemes (21/21N/67/67N – 21/21N/67/67N) to primary differential protection and secondary distance protection (87L - 21/21N/67/67N). This last scheme is more reliable because by having differential and distance protection relays which operate under different philosophies, facilitating the detection of an atypical failure in the Power Transmission Line.
- It will be preserved for line protection the interface C37.94
- Support of communication for WAMS (Wide-Area Measurement Systems), used to perform the real time monitoring and dynamic control of the Power System Status. Typically they consist of: PMUs (Phasor Measurement Unit) to guarantee the security and stability of the power systems, PDC (Phasor Data Concentrator), Control Centers, as well as high speed data communication networks.

The “mission critical” communications are fundamental to define the technology to be used in the transition from TDM networks to packet switched networks in the transport system. Due to the critical nature of this type of communications for a reliable operation of the Power System, it is necessary a communications infrastructure that comply with the requirements of high availability with a minimum delay.

MPLS-TP comply this requirements, for it is compatible with traffic engineering, guarantying deterministic delays for high priority traffic.

Therefore, it is required improved protection features. MPLS-TP OAM (Operation, Administration and Maintenance) achieve the end-to-end protection, by providing the feature of switching protection, controlled by the Bidirectional Forwarding Detection (BFD) and Protection State Coordination Protocols. BFD detects failures in labels of switched paths (LSP) and PSC coordinates the protection switching.

MPLS-TP has been designed with the goal to ensure that operators and applications in substations can improve the goal sub-50ms for path protection in a variety of physical network configuration, in this case “Zero packet Loss” represents a solution equivalent to the feature <3mS that offer very few manufactures of SDH for electric systems.

The key features must include:

- Deterministic end-to-end path protection
- Protection switching <20 ms (based on the signal degradation or fail)
- Support for several protection designs (1:1,1+1,1: N)

- Hitless switching (Zero Packet Loss) for protection and teleprotection connections.

### 3.2 MPLS-TP compatibility with line protection schemes

Communication paths are essential for the protection schemes where the reliability, symmetry and speed are critical parameters to allow the reliable operation of protection schemes.

For CORPOELEC system, the following two are the cases where communications are required:

- Distance protection (21): Trip, Blocking, Unblocking, etc
- Differential protection (87L): Measurement transmission of Current, Voltage, Angle

These protection schemes establish from the communications the following challenges:

- Low delay for fast communication.
- End to end delay to be as maximum 10 ms.
- Symmetric delay over same communication path Tx/Rx.
- Direct interface of all substation applications (legacy and IP interfaces).
- Path switching of the emulated TDM paths to be manually predefined.
- High availability of the channel path.
- Low Jitter.
- Transport requirements of circuit emulation (CESoPSN, SATOP) for traditional teleprotection and EoMPLS for IEC61850 based teleprotection.
- Frequency synchronization (Synch-E, 1588v2 PTP) of the MPLS-TP devices for TDM transport.

## 4 MEASUREMENT OF DELAY OF A TELEPROTECTION SIGNAL OVER MPLS-TP

To determine the transmission time of a teleprotection signal through a communications system based on MPLS-TP and the contribution of the MPLS-TP equipment only to this total transmission time, it was performed a couple of measurement tests using a scope meter suitable to capture the transmission and the reception of a teleprotection signal consisting of a pulse signal:

In a first scenario, two teleprotection equipment were connected directly through fiber optic while located in the same room (zero fiber optic delay) using C37.94 interfaces as shown in figure 4:

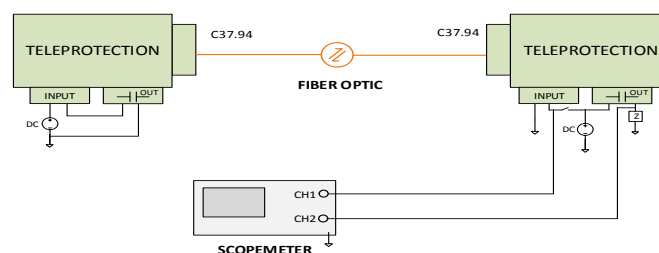


Fig. 4. Test diagram for measurement of transmission time (TP equipment back to back)

The transmission time is measured from the activation of the teleprotection input until the closure of the solid state output in the same equipment; this is, there is a “wire loopback” in the remote equipment, so the signal is returned by that, and this loopback includes the whole system from I/O interface at local to I/O interface at the remote equipment. With both directions having the same delay the transmission time in one direction is obtained by dividing the captured time difference by 2, in this example: 8.0 ms / 2 = 4 ms.

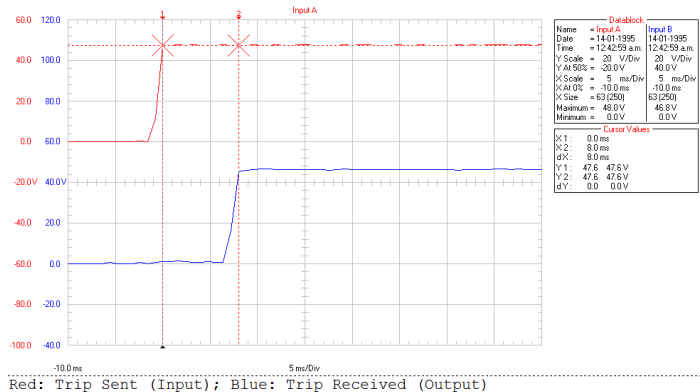


Fig. 5. Measurement of Transmission time. TP equipment back to back

In a second scenario, the C37.94 interfaces were connected through MPLS-TP equipment, the communication between both MPLS-TP units is also through fiber optic with 1Gbps interface, both equipment in the same room (zero fiber optic delay) as shown in figure 6:

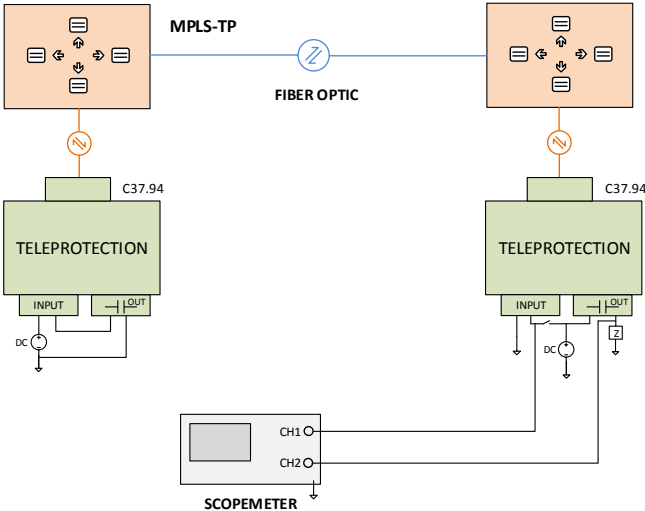


Fig. 6. Test diagram for measurement of transmission time (Including MPLS-TP)

The delay on the teleprotection and MPLS-TP equipment is affected by parameters like timers and buffers; with a typical configuration that works in the field, the following capture shows a round trip time of 15ms, then the transmission time in one direction is 7.5 ms:



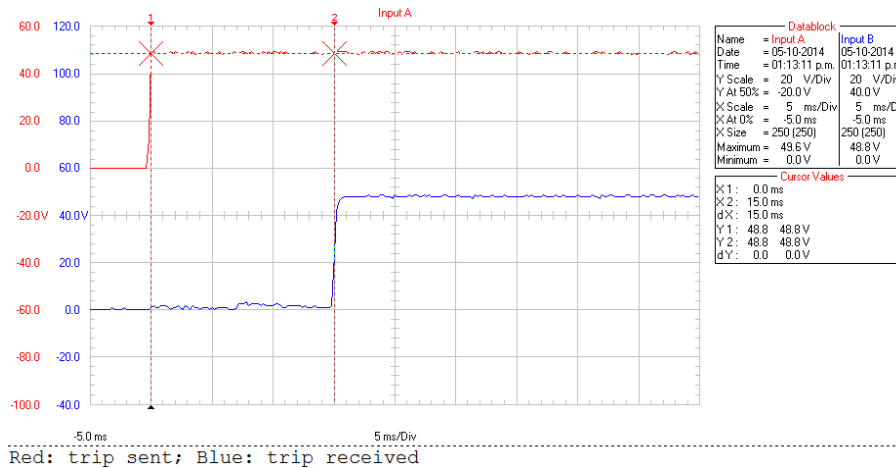


Fig. 7. Measurement of Transmission time. Including MPLS-TP delay

For this test, the teleprotection equipment is using solid state outputs.

Based on the tests done in these two scenarios, we can determine that the contribution to the total transmission time added by the MPLS-TP with the interfaces described is:

$$\text{Delay added by MPLS-TP equipment: } 7.5 \text{ ms} - 4 \text{ ms} = 3.5 \text{ ms}$$

The total delay of teleprotection service through this communication system is 7.5 ms which is lower than the requirement of 10ms mentioned hereinabove.

## 5 CONCLUSIONS

MPLS-TP seems to be suitable as main platform for Communications of control centers, substations and generation plants in order to have reliable Exchange of information related to Measurement data, control and protection signaling.

Based on the analysis performed to the MPLS-TP technology and the time response of the performed lab test, we consider this technology suitable for the Energy transport network as an optimized path of the progressive migration from the legacy TDM platform to the modern and reliable packet switched network.

The MPLS-TP equipment to be deployed should perform as multiplatform nodes keeping available legacy interfaces as E1, STM-1 and C37.94 which could be supported by emulation of TDM rings through Pseudo-Wires. This feature together with the high capacity Ethernet interfaces will provide a strong backbone and access facilities that smoothly allows the update of existing investments until the end of its lifetime.

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