Power Utilities **Architectures**




IEC 61850 is a Power Grid a standard was that defines a set of Ethernet-based protocols to be used by power devices to exchange data, send commands, measure values and get synchronized

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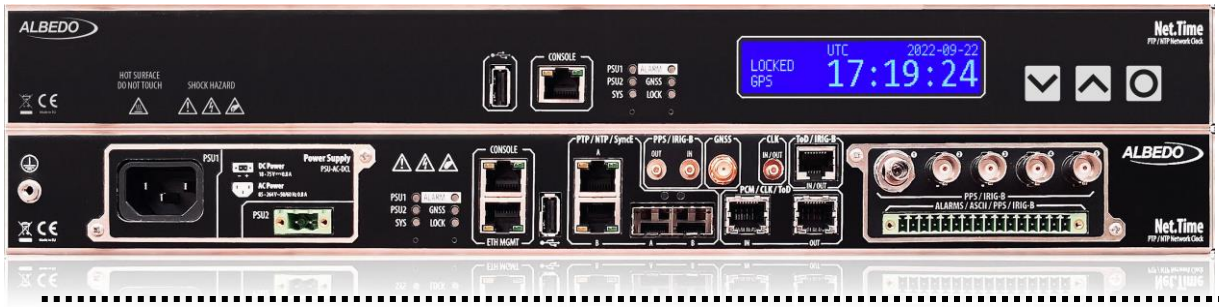
ALBEDO: a **global** player of **telecom** appliances

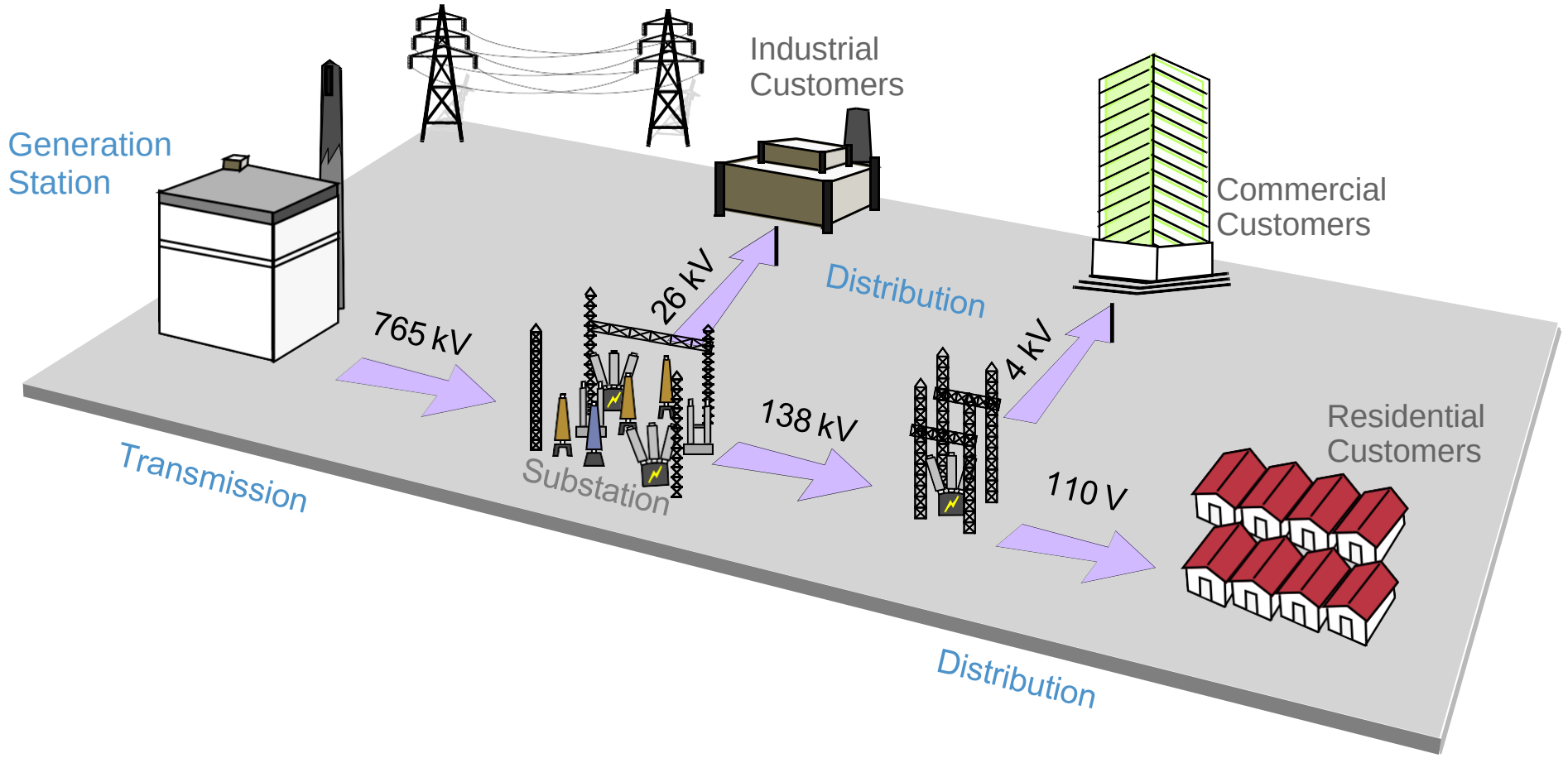
ICT electronics (1983)

Trend Comms (2001)



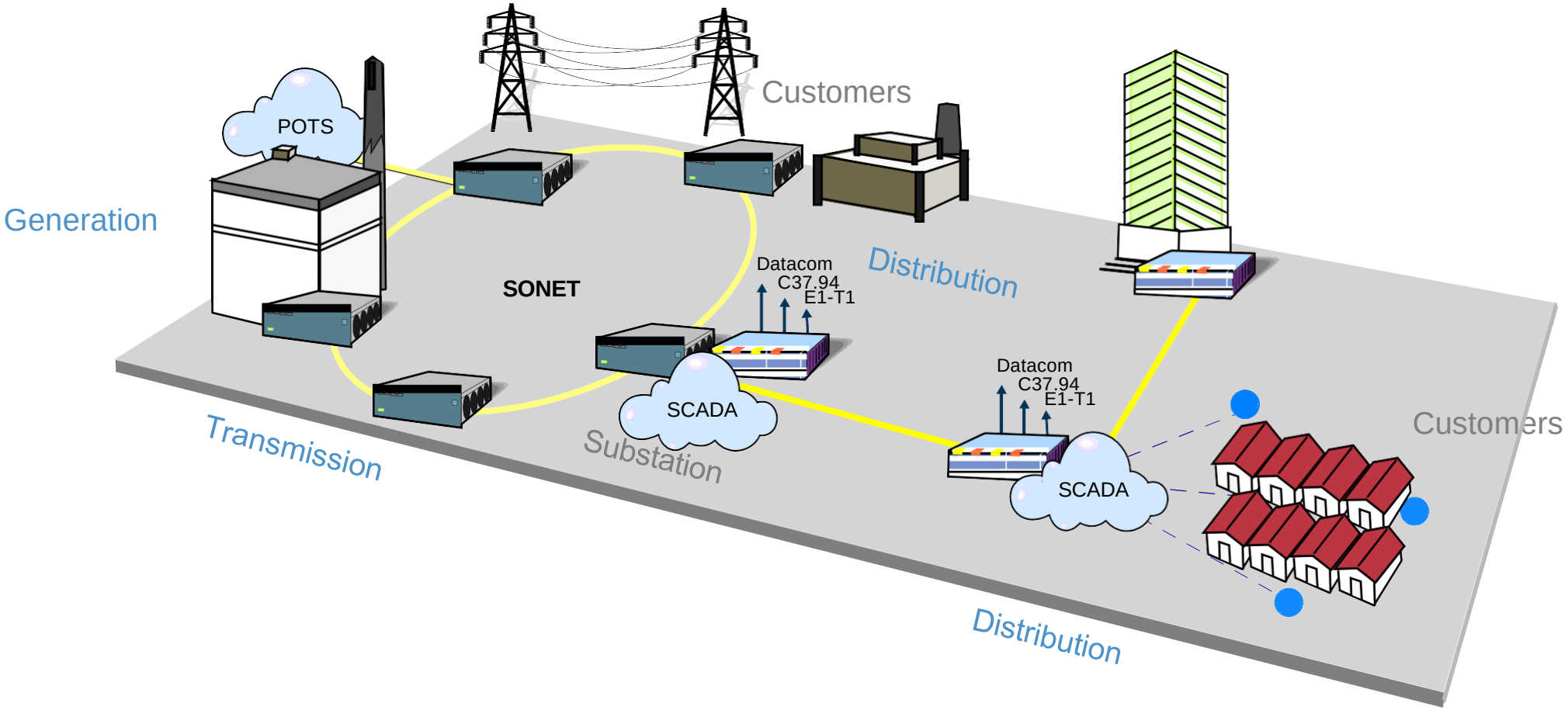
ALBEDO (2009 - today)

The Power Grid



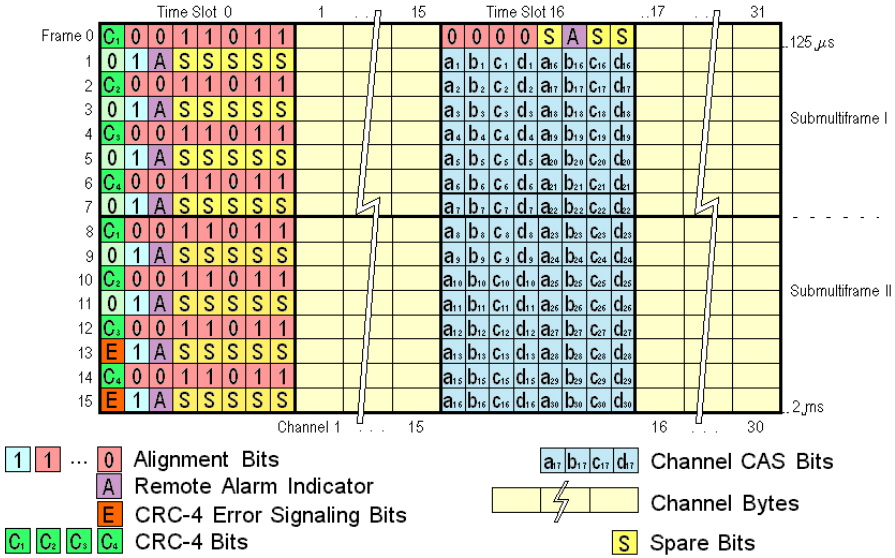
The basic architecture of electricity transmission and distribution changed very little during the first 100 years. However, in recent decades, the concept of **Smart Grid** emerged thanks to the massive use of digital technologies to increase efficiency, resilience and quality of the service.

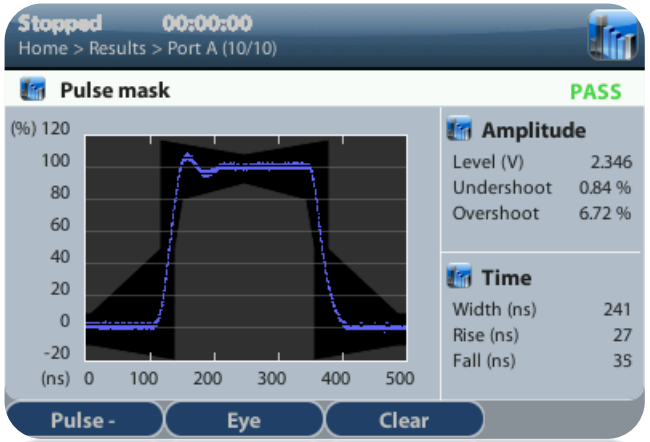
Network evolution: **SONET/SDH**



At the 80's SONET was the first network to be deployed and it was a satisfactory solution for common applications such as SCADA, Telephony and Tele-protection because it is a predictable, symmetric, low latency, and fault tolerance architecture.

Complete **E1 / T1 / G703 test**





Analysis / Generation

- E1 / T1: frame / unframed with / without CRC
- Overheads: display and edition
- CAS analysis
- Pulse Mask
- Channel map: Busy / Free, Drop / Insert of 64 kb/s

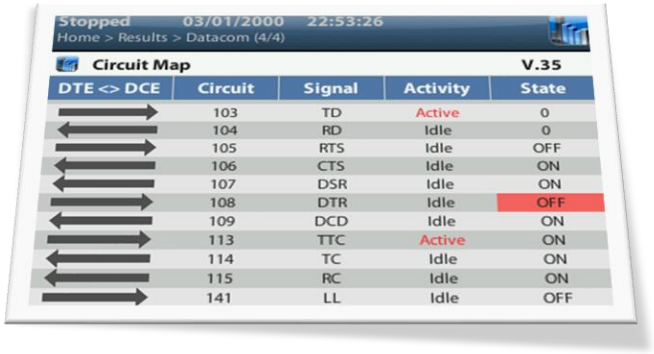
Measurements

- BER
- Line / Freq
- Errors / Alarms
- G.821, G.826, M.2100
- VF: tone generation / analysis
- Attenuation, Freq, Freq. deviation, Level, Peak codes
- E1 / T1 in sync

Analysis / Generation

- Jitter analysis: Peak to peak, RMS, hits, count (.1 at 100kHz)
- Wander: With mask (1µHz to 10Hz)
- Wander: 10 MHz, 2048 kHz, 1544 kHz, 1pps

Serial Communications tests



Based on hot pluggable modules

- V.24 / V.28, X.12 / V.11, X.21 / V.11, V.35, V.36 / RS-449, EIA-530 / A
- Data, Stop, Parity, inter word gap
- DTE / DCE emulation, Full duplex monitor

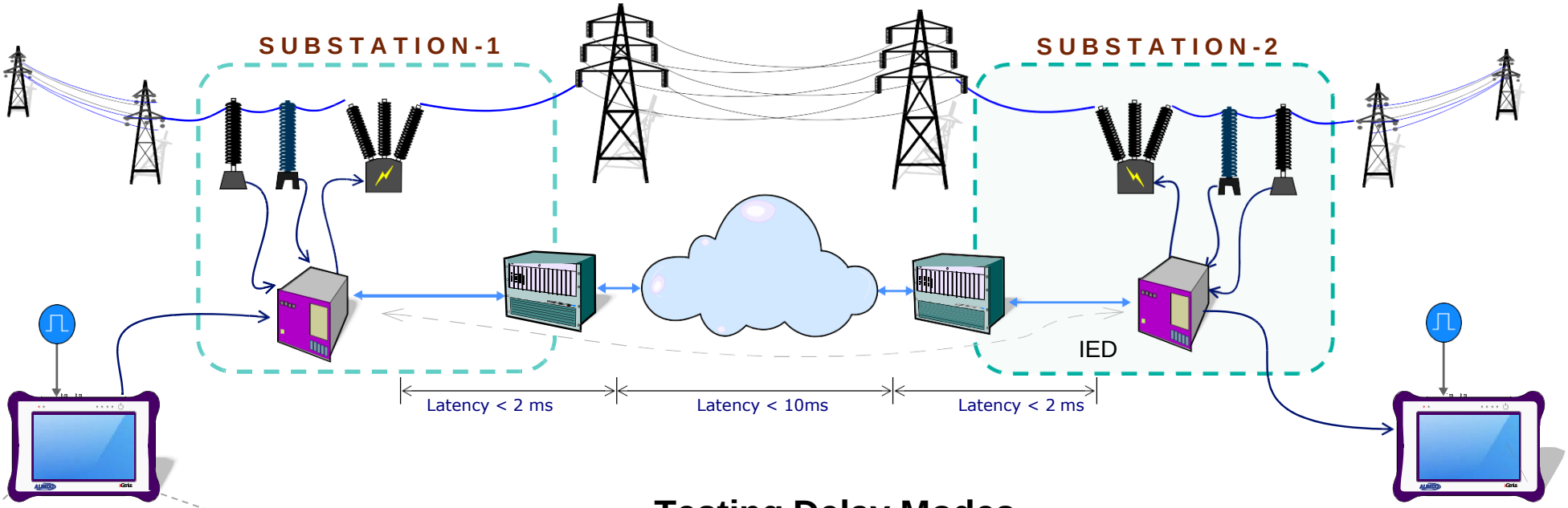
Inserting events

- Pattern: TSE, Slip, LSS, All 0, All 1
- Asynchronous interfaces: FRM, PRTY

Modes

- Anomalies: single, rate
- Defects: continuous
- V.24/V.28, X.12/V.11, X.21/V.11, V.35, V.36/RS-449, EIA-530/A

Latency analysis for all interfaces



Testing Delay Modes

- Bidirectional Delay (Round Trip Delay)
- One way delay with GNSS or ToD help

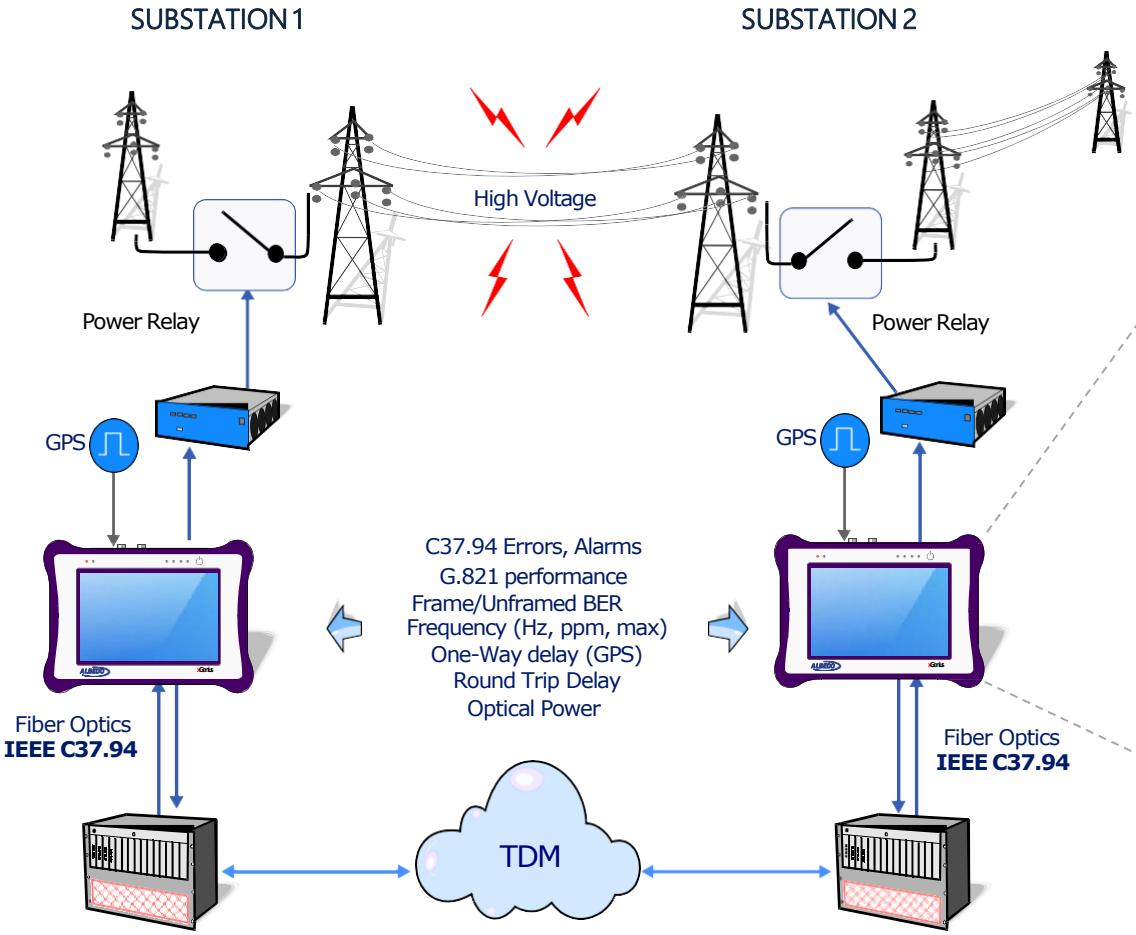
Latency results

- Bidirectional Delay or Round Trip Delay (RTD)
- One Way Delay Forward and Reverse Path
- Asymmetry with min. / max records
- Patch cord delay compensation
- PASS / FAIL indication

Objectives

- Bidirectional Delay or Round Trip Delay (RTD)

Verification of **C37. 94** for teleprotection



C37.94 Testing **Operation modes**

- Endpoint emulation
- Intrusive pass-through
- Monitoring
- Loopback

Delay statistics

	Current	Average	Range	Std. dev.
Offset (theta)	0.278 µs	0.278 µs	0.003 µs	0.000 µs
Delay (delta)	0.954 µs	0.954 µs	0.000 µs	0.000 µs
Delay (forward)	0.697 µs	0.697 µs	0.002 µs	0.000 µs
Delay (return)	0.140 µs	0.140 µs	0.005 µs	0.001 µs
Asymmetry	0.557 µs	0.557 µs	0.000 µs	0.001 µs
Jitter (psi)	0.278 µs			

What to **measure/emulate/verify**

- Performance: BERT, G.821
- Analysis / generation: of events
- Optical power & frequency measurement
- Asymmetry: One-way / round-trip delay,
- Jitter and wander analysis

Objectives

C37.94 activation, verification & troubleshooting

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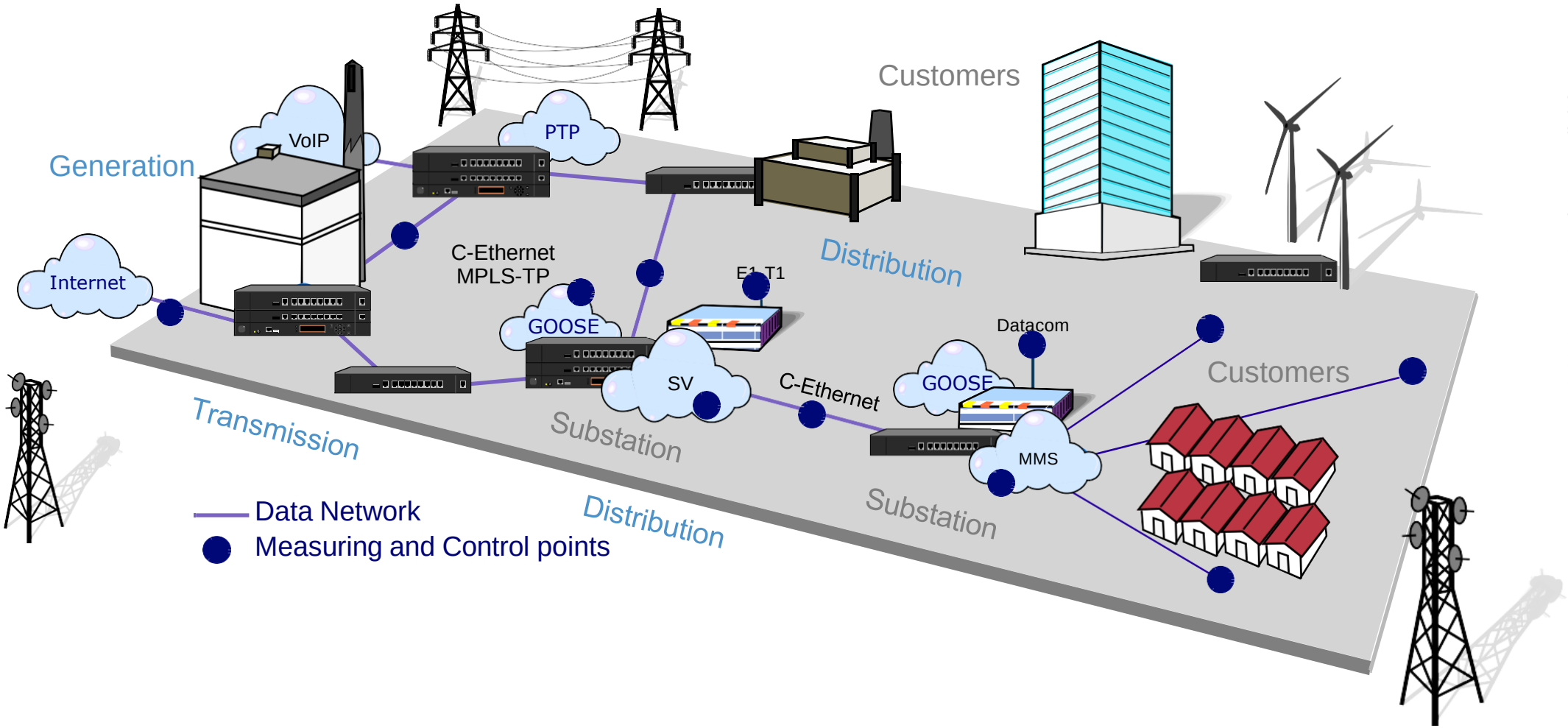
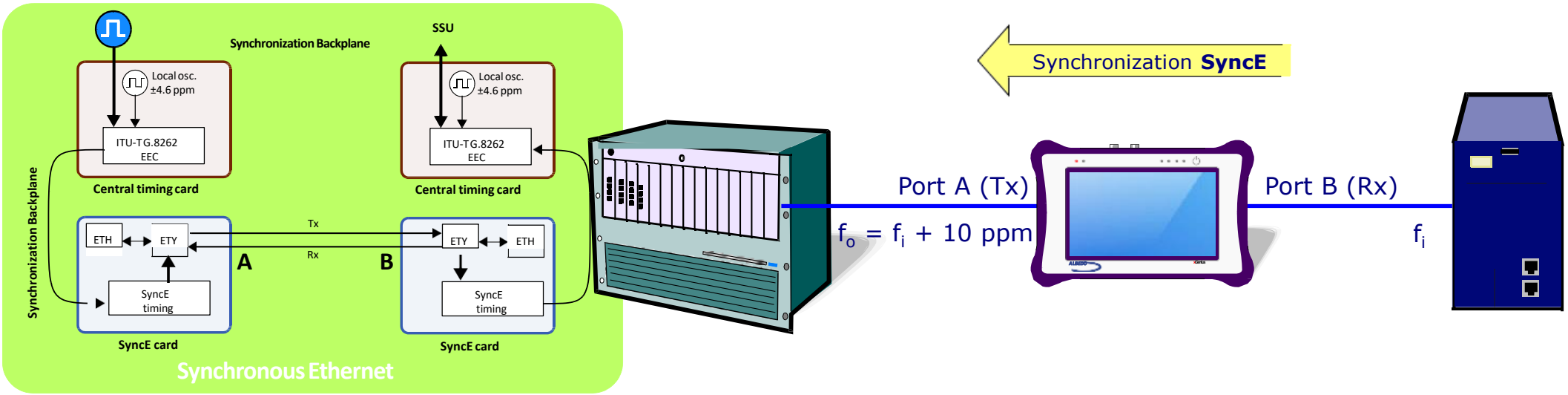
Power Grid based on **Ethernet**



Smart Grid require a **Telecom Data Network** to communicate all the elements of the Power System, including Generation plants, Substations and Customers in order to increase the efficiency, resilience and quality of the power grid, while allowing advanced management.

Verify **Synchronous Ethernet** (SyncE)



Testers have a set of tests to ensure SyncE

Quality tests

- Synchronism according to ITU-T G8261, G8262, G8264 standards
- Check Line Frequency (MHz), offset (ppm), drift (ppm / s)
- Analysis / Generation of ESMC and SSM messages
- SSM counter & speed

Wander analysis

- SyncE TIE, MTIE and TDEV measurement
- SyncE Wander generation

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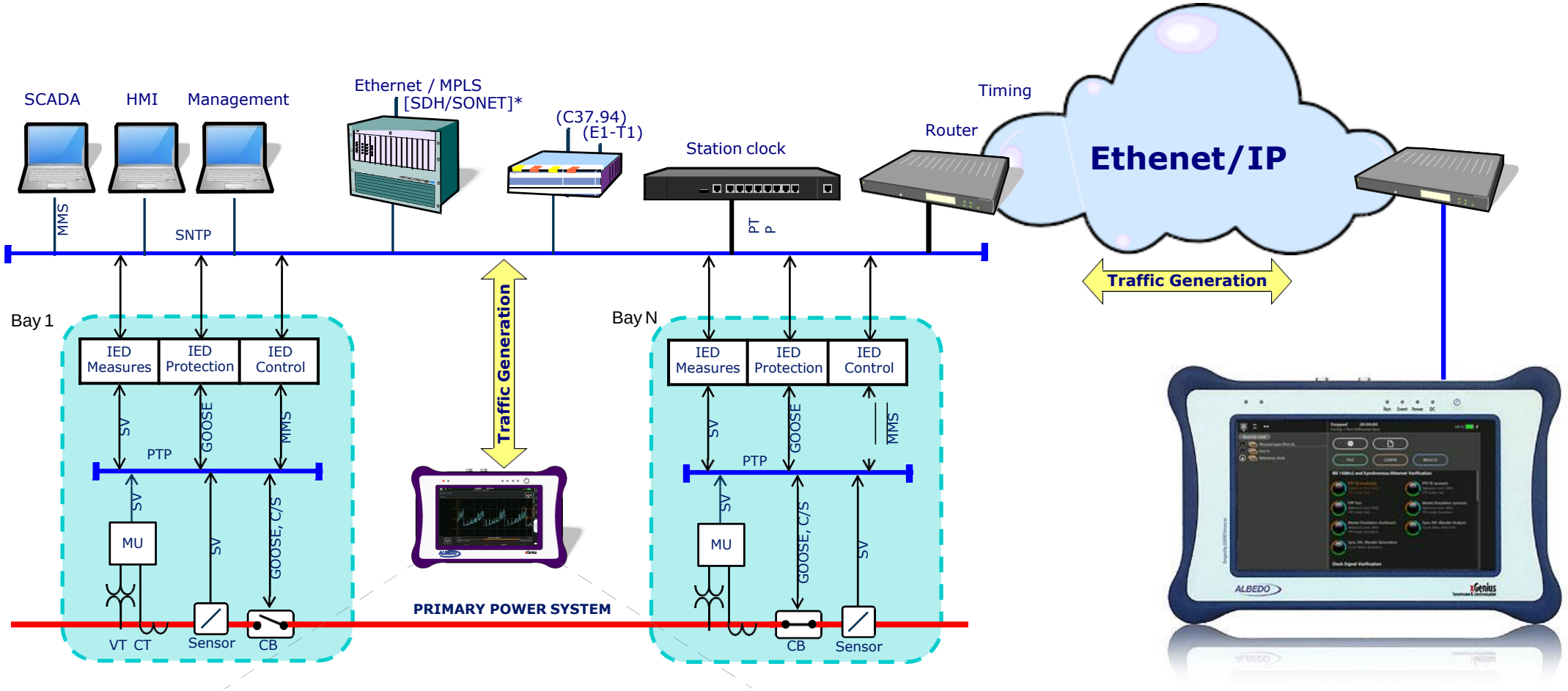
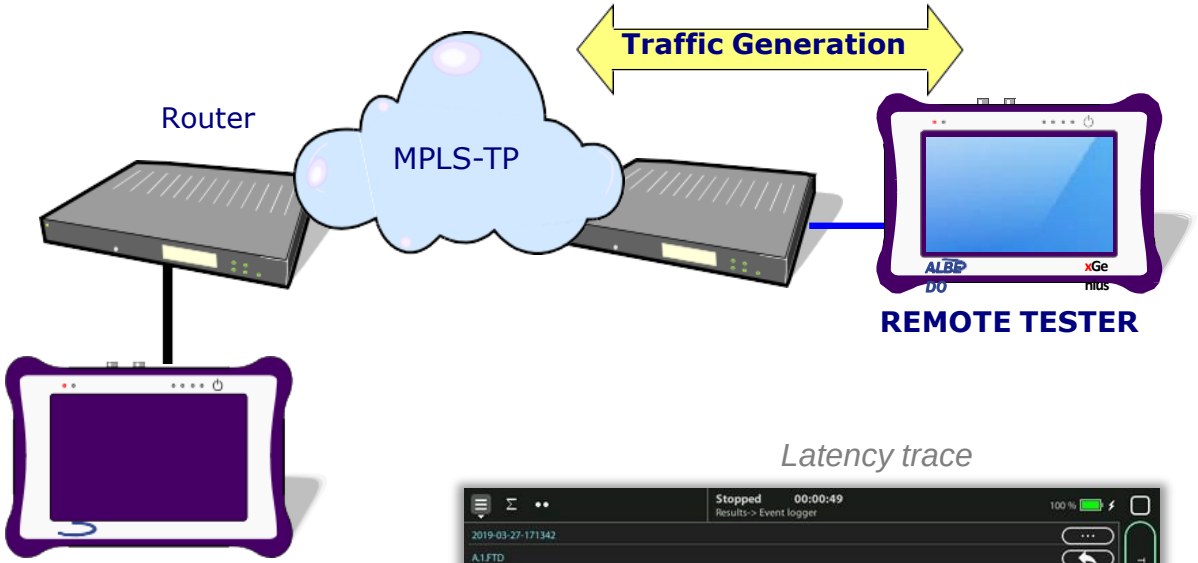
Hands-on: check network **Capacity** & **Quality**



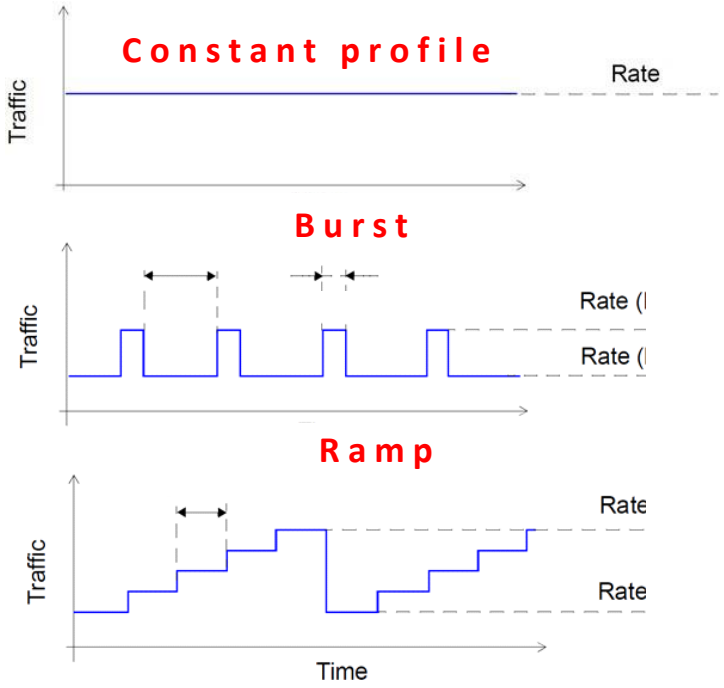
Objectives

- Check Eth/TCP/IP: RFC2544, RFC6349, Y1568
- Detect congestion points and error causes

Wan Network **Capacity RFC 2544**



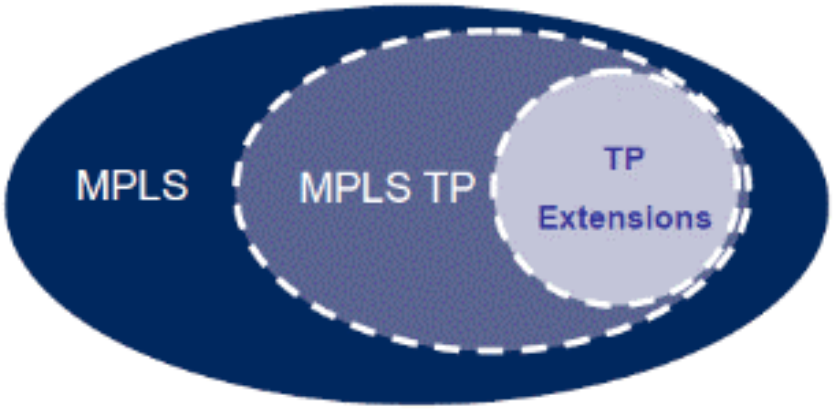
Latency trace



Objectives

- Detect congestion points and error causes

MPLS-TP is a subset of MPLS



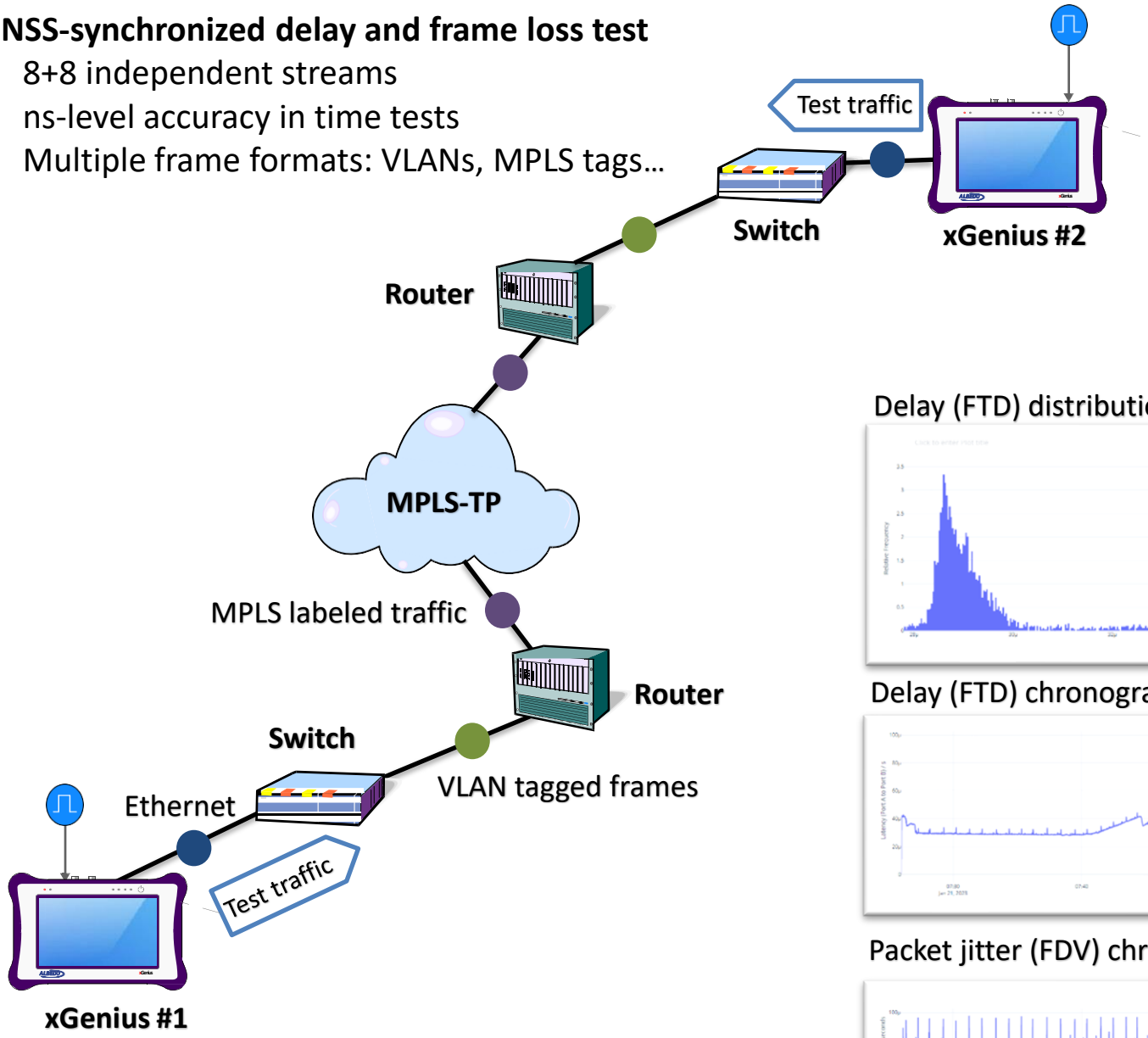
MPLS Features

- IP Endpoint mode: MPLS generation + analysis
- Through mode: MPLS analysis

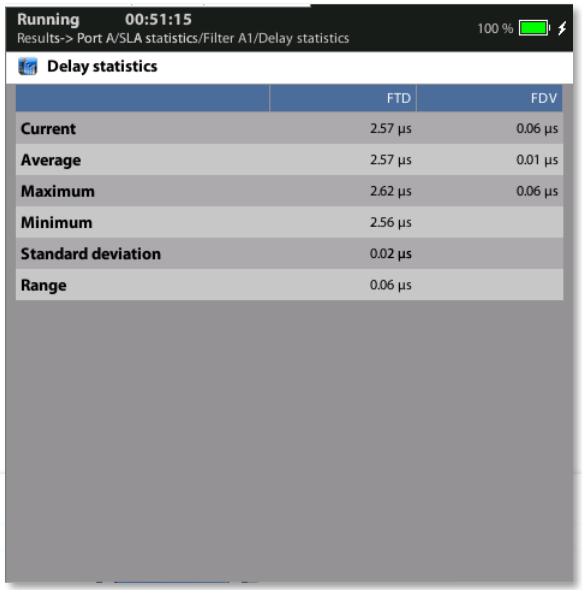
QoS Analysis by **MPLS test**

GNSS-synchronized delay and frame loss test

- 8+8 independent streams
- ns-level accuracy in time tests
- Multiple frame formats: VLANs, MPLS tags…

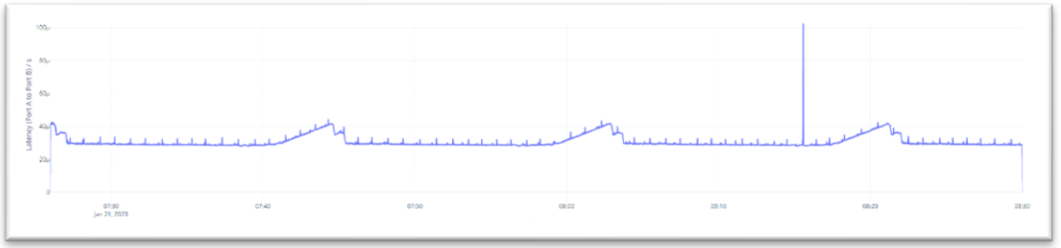


Delay & jitter statistics

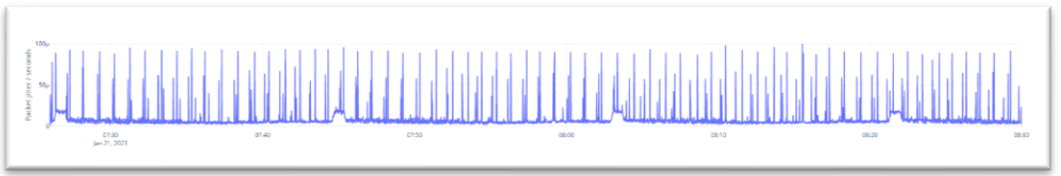


Delay (FTD) distribution

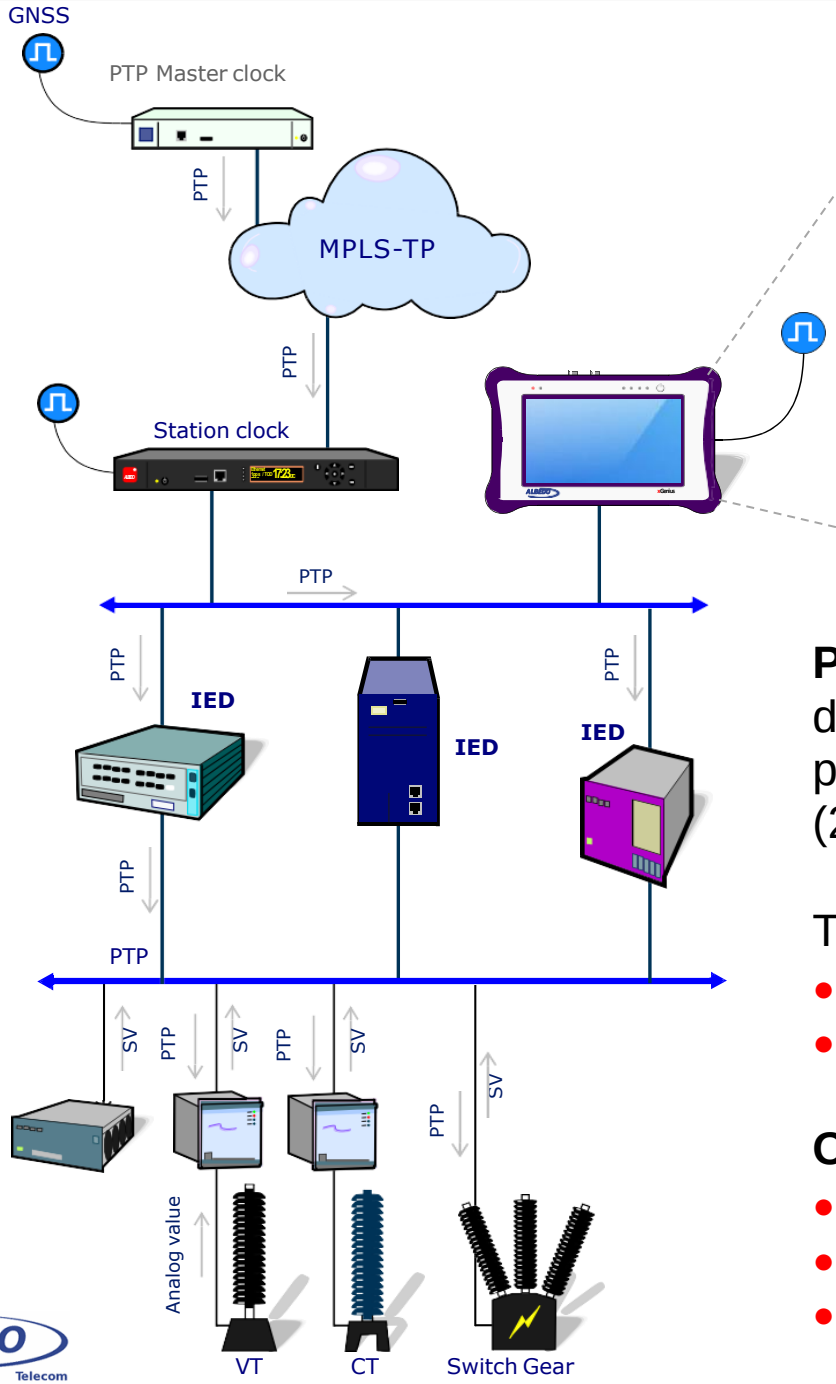
Delay (FTD) chronograph

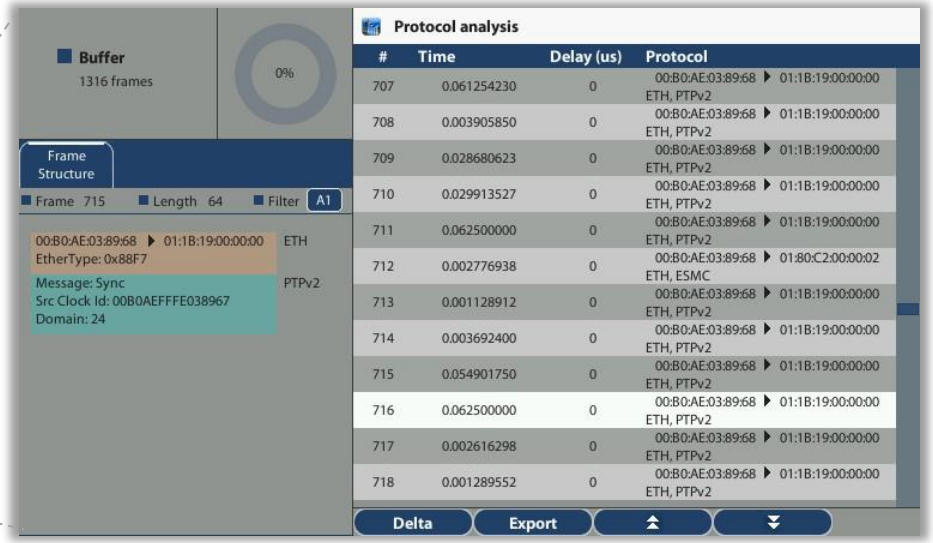


Packet jitter (FDV) chronograph



PTP testing (WAN & Substation)





Precision Time Protocol (IEEE 1588) with **Power Profile** defined in IEEE C37.238 address the requirements of the power industry in terms of accuracy, continuous operation (24/7) and deterministic failure behavior.

Testing PTP with xGenius / Zeus

- Master / Slave: emulation modes
- Frequency & Phase testing

Objectives

- Migration to PTP protocol from NTP or IRIG-B
- Check accuracy, holdover, GNSS, PPS and identify faults
- Facilitate interconnection of time sources and GPS back up

PTP **Wander** & **Time Error** analysis

Tests between PTP master to client clocks

- Time Error (TE) Test
- Bidirectional TE and max | TE |
- Low frequency TE, cTE + dLTE
- High frequency TE
- Delay asymmetry
- Delay between Master PTP and customers

Metrics of Wander

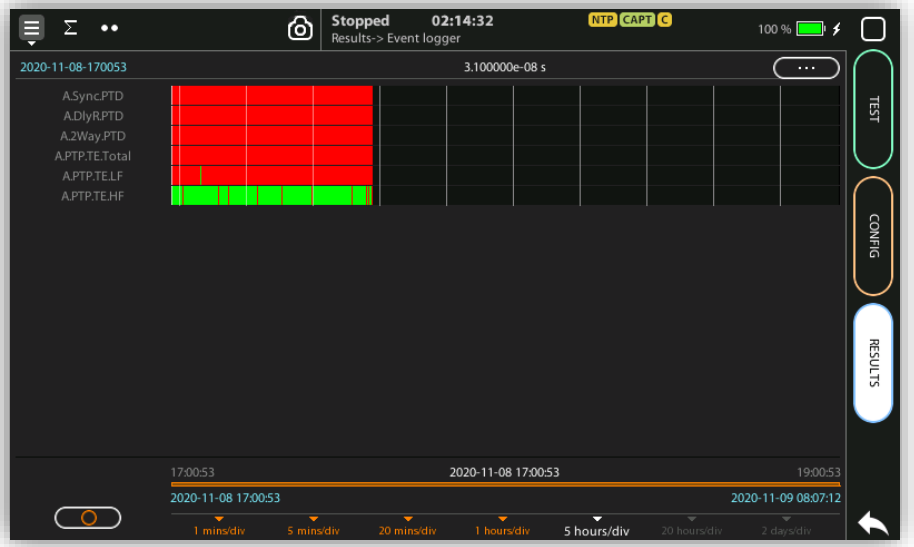
- TIE
- MTIE
- TDEV
- Tables and Graphs

Objectives

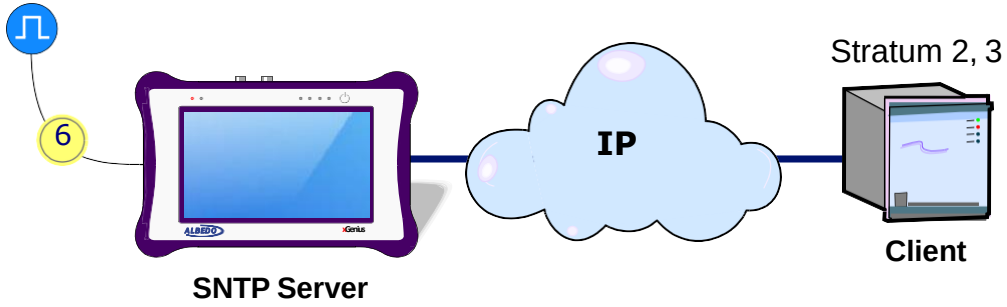
- Monitor the PTP clock
- Determine if Time Error is in range
- Verify the holdover and recovery times

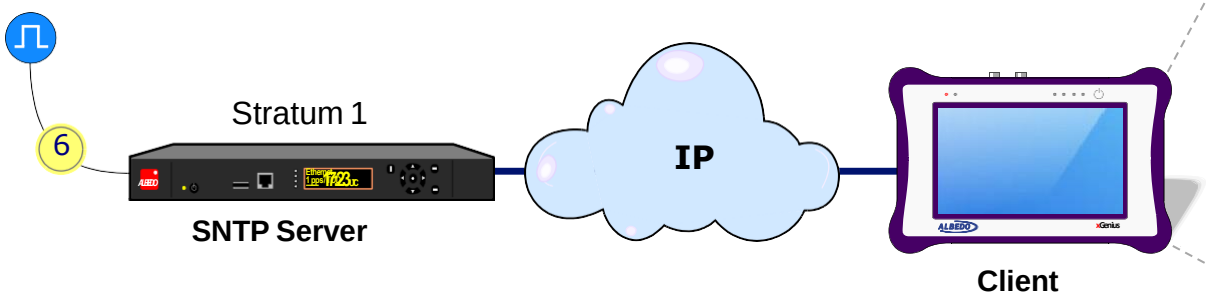
Built in TE chronograph

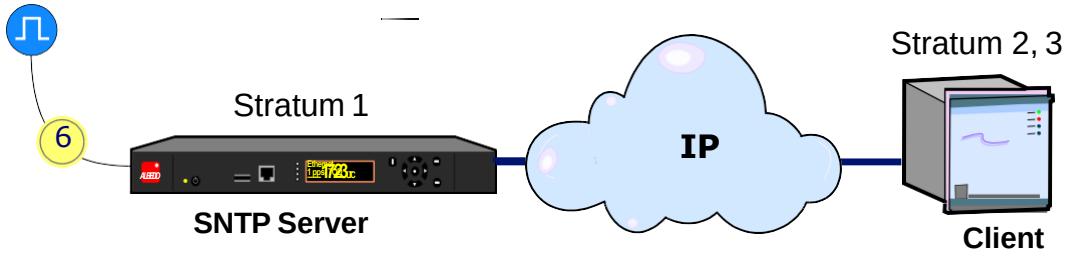
TE analysis (PASS/FAIL)



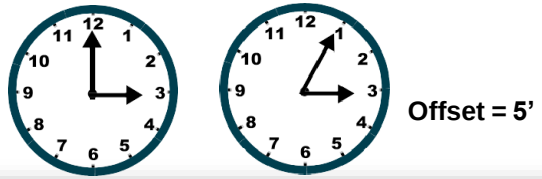
NTP testing (WAN & Substation)







Offset: difference between clocks



Zeus / xGenius testing features

- NTPv3 / v4 server and client emulation
- Traffic filtering, classification, analysis
- NTP delay and asymmetry
- Statistics of Time Error (TE)

Objectives

- Monitor the NTP clock
- Analyze time error tolerances
- Verify the holdover and recovery times

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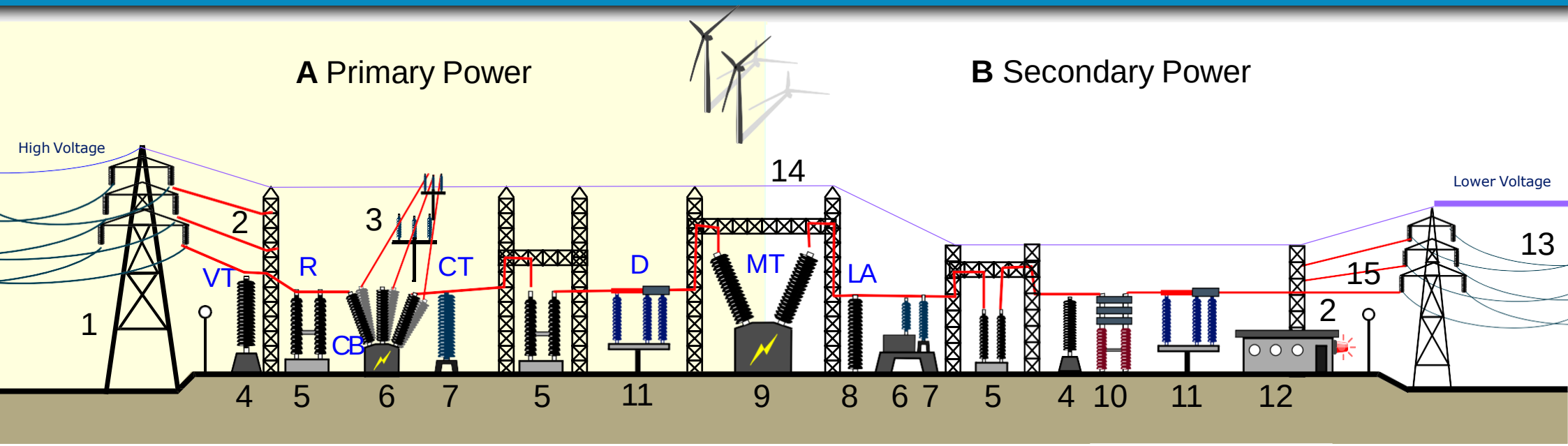
Substations and IEC-61850

As result of the convergence process in the **Power Grid,** a new standard was released, the **IEC 61850**, that defines a set of Ethernet-based protocols.

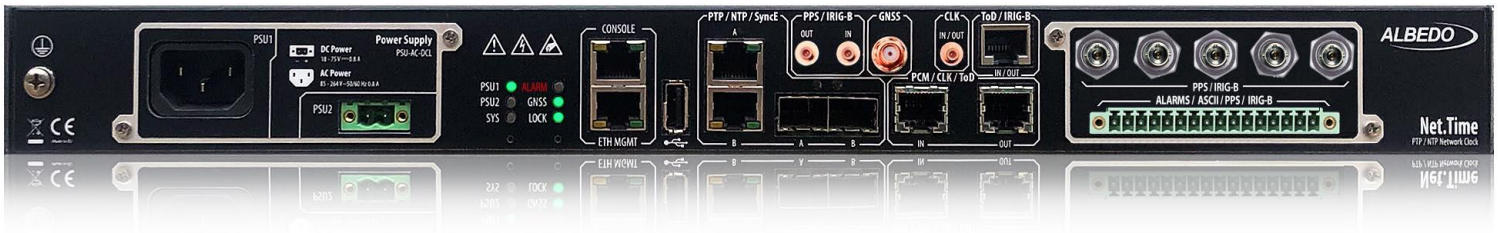
The IEC 61850 objective is to facilitate the interoperability (between devices and systems), ease of configuration (allocation of functions to devices), long term stability (layered, object-model based design), and reliability (lossless network architectures) to replace wire communications.

Components & Systems in a **Substation**

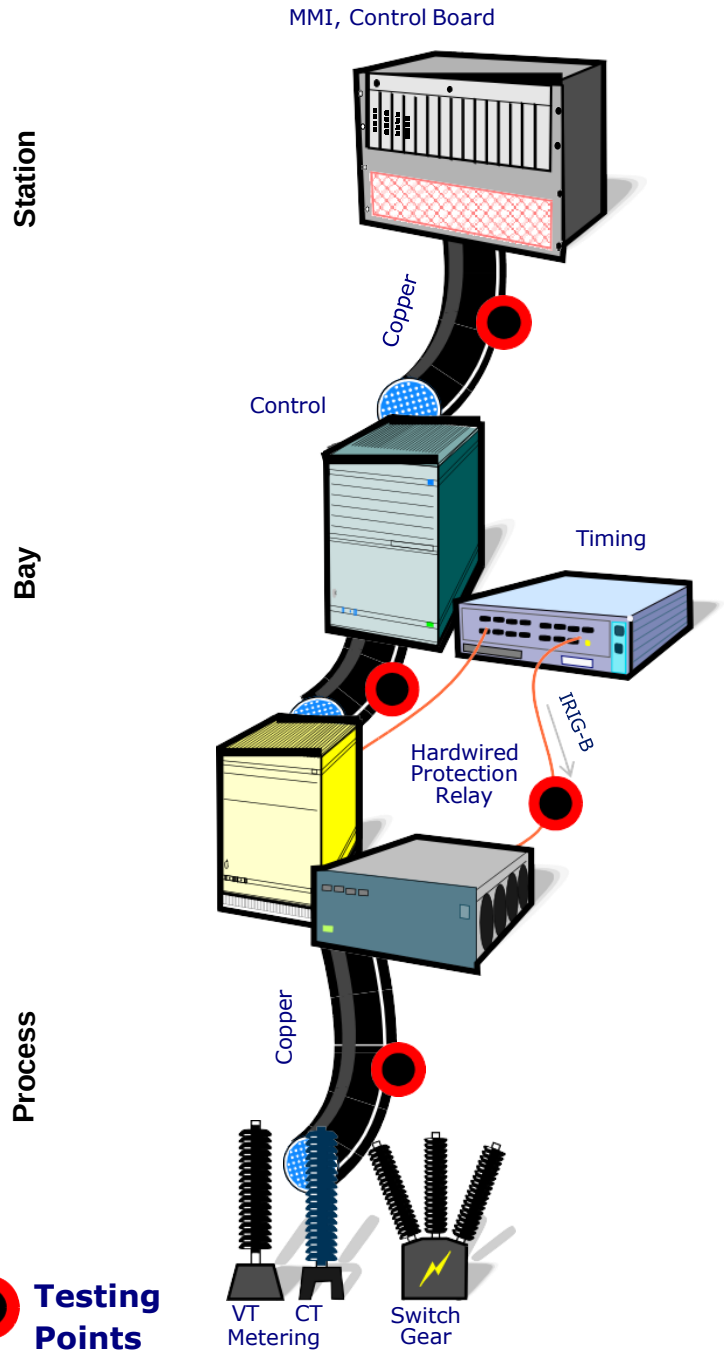


1.Primary Power (PP), 2.Feeder, 3. Busbar, 4.Voltage Transformer (VT), 5.Relay (R), 6.Circuit Breaker (CB), 7.Current Transformer (CT), 8.Lightning Arrester (LA), 9.Main Transformer (MT), 10. Capacitors (C), 11.Disconnector, 12.Control Shelter, 13.Secondary Lines, 14. Ground, 15. Overhead Lines

The **Primary Power** manages the high voltages lines coming from Generation while the secondary the lower voltages distributed to Industrial and residential consumers.



1 – **Legacy** Substations



What to Test

1. Serial communication: RS-232, RS-422, V.35, V.36
2. IRIG-B: timing accuracy
3. E1/T1: voice [and timing]

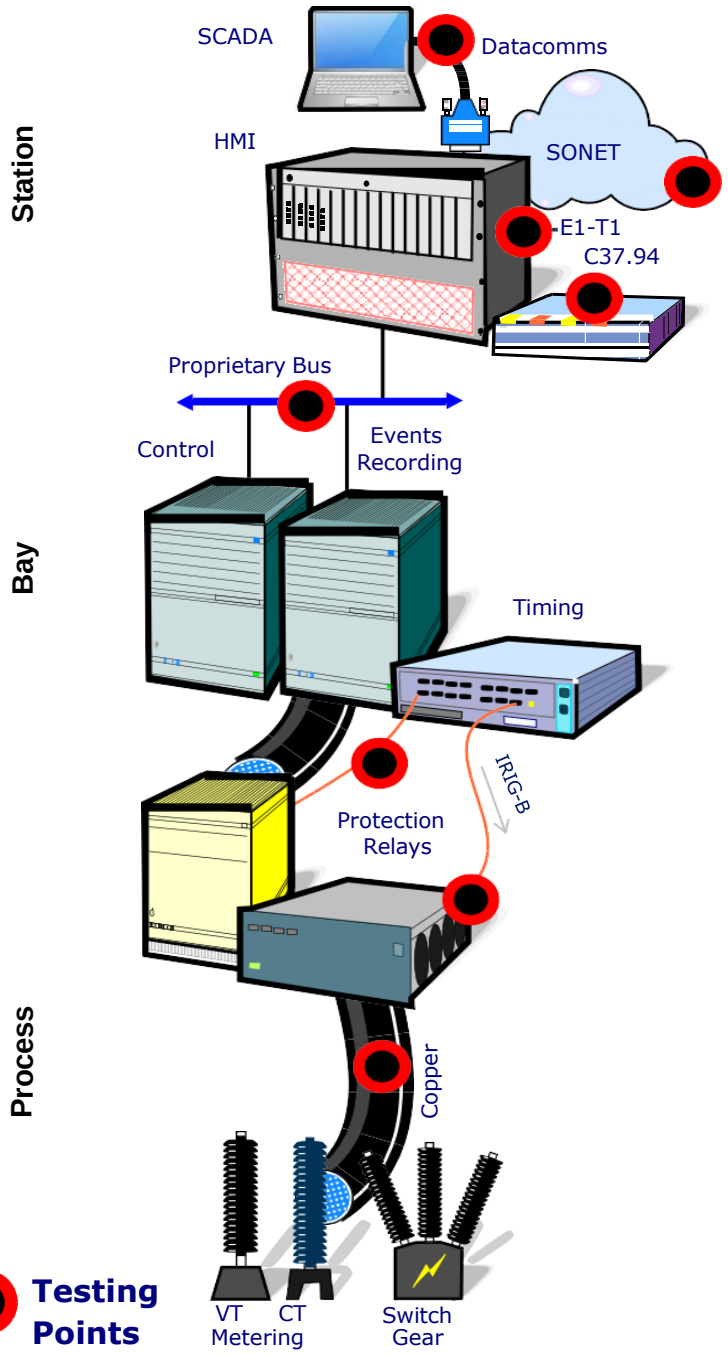
Objectives

Installation & maintenance of:

- Serial communications
- Timing quality
- Voice circuits

Serial Data Communication cables and interfaces

2 – **Convencional** Substations

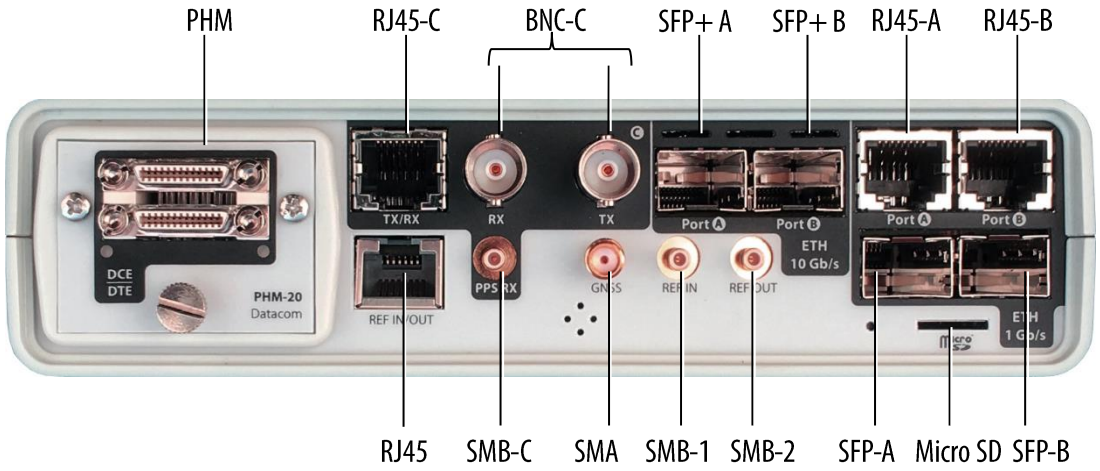


What to Test

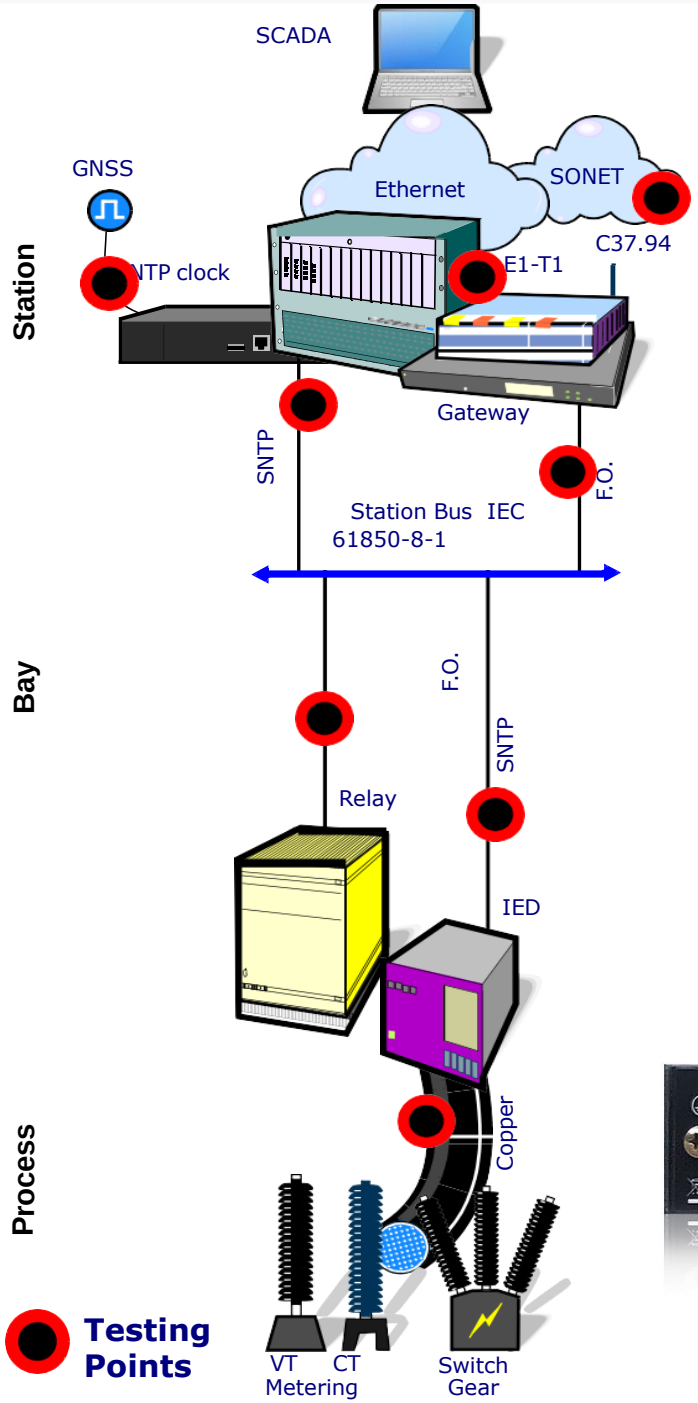
1. Serial communication data: RS-232, RS-422, V.35, V.36
2. IRIG-B: timing
3. E1 / T1: pulse, voice, data
4. C37.94: one-way / two-way delays, event emulations
5. Teleprotection: One-way delay
6. Ethernet capacity/quality: RFC 2544, eSAM, etc.

Objectives

- Check and adjust teleprotection based on C37.94
- Check the quality of the Ethernet network



xGenius testing interfaces



What to Test

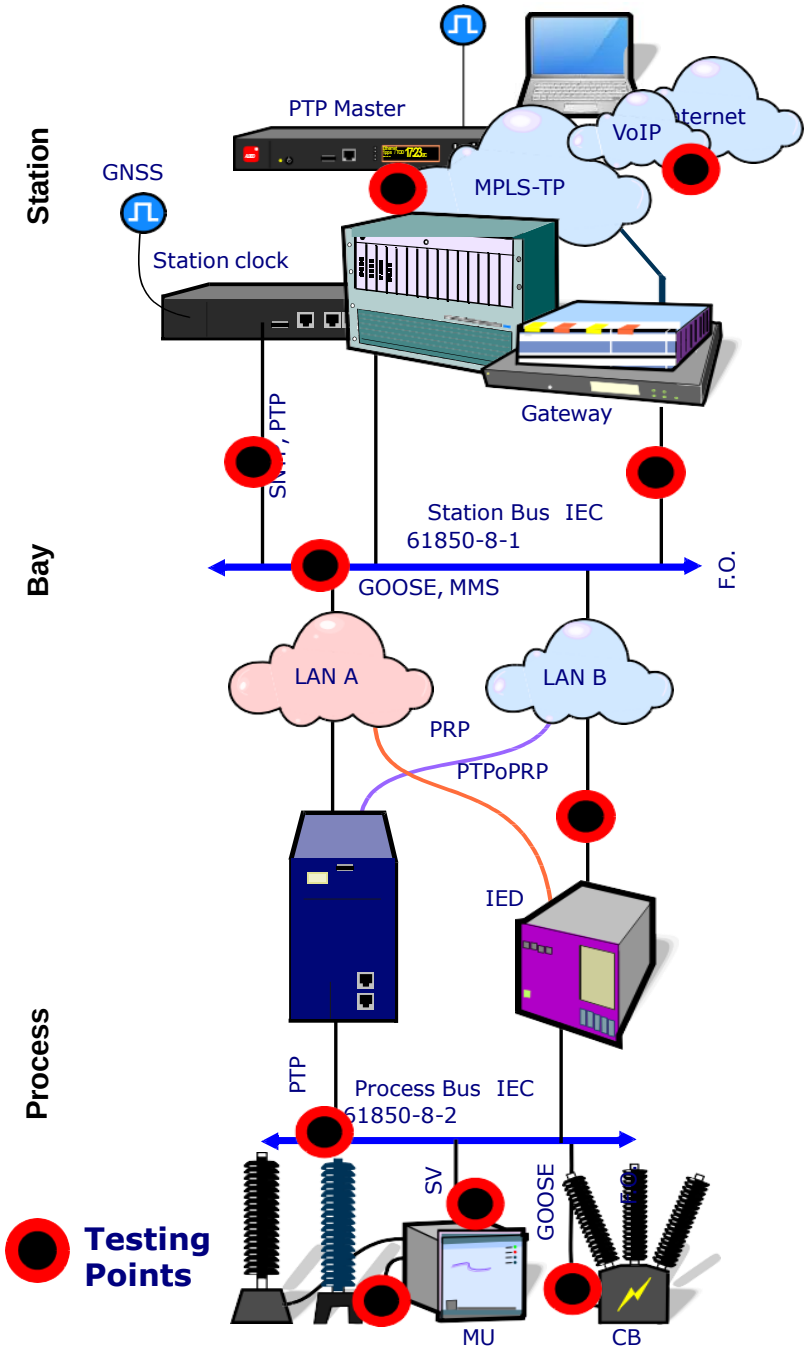
1. Serial communication data: RS-232, RS-422, V.35, V.36
2. IRIG-B: timing
3. E1 / T1: pulse, voice, data
4. Ethernet: RFC 2544, eSAM, etc.
5. IP: ping, trace route
6. Fiber Optic: Power, OTDR
7. NTP: message, delays, jitter, TE
8. Teleprotection: C37.94, One-way delay, Quality

Objectives

- Check the teleprotection times C37.94
- Check and adjust IRIG-B and NTP synchronisms
- Check the quality of the Ethernet network
- Install and maintain fiber optics

Net.Time φ PTP/NTP clock

4 – Test in **IEC-61850** Substations



What to Test

1. Serial communication data: RS-232, RS-422, V.35, V.36
2. IRIG-B: time
3. E1 / T1: pulse, voice, data
4. C37.94: delays, event emulations
5. Teleprotection: Unilateral delay
6. Ethernet: RFC 2544, eSAM, etc.
7. IP: ping, tracking route
8. MPLS-TP
9. Fiber Optic: Power, OTDR
10. NTP: message, delays, jitter, TE
11. PTP: Wander, PPS, TE
12. GOOSE: analysis / capture / decoding
13. SV: analysis / capture / decoding
14. MMS: analysis / capture / decoding
15. Master / slave clock emulation
16. IEC-61850: delay of protocols

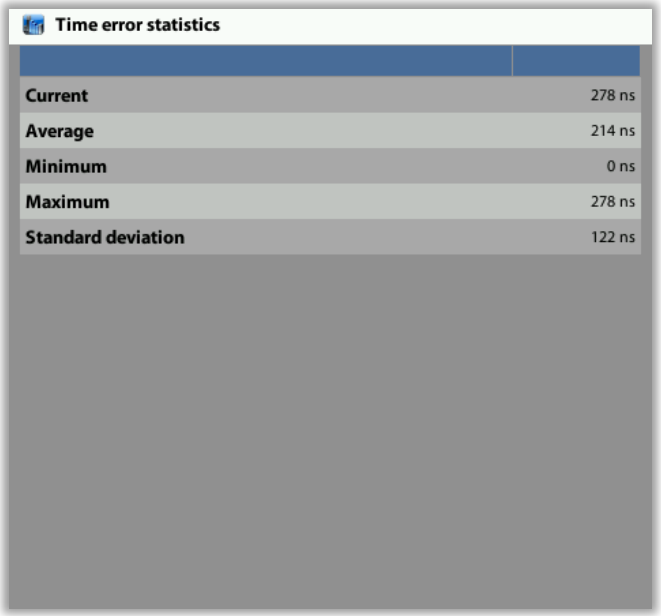
Objectives

- Guarantee the interconnection between different manufacturers
- Interconnection of new and old PTP-NTP-IRIG-B synchronism
- Install and develop new protocols like GOOSE

Assure the **Delay** for each protocol & application

Type	Message	Protocol	Layer	BWidth	Delay	Priority	Bus	Model	Application
1A	Trip	GOOSE	L2 - Multicast	Low	< 3 to 10ms	High	Process	Publisher	Protection
1B	Other	GOOSE	L2 - Multicast	Low	< 20 to 100ms	High	Process	Publisher	Control
2	Med Speed	MMS	L3 - IP/TCP	Low	< 100 ms	Medium Low	Process & Station	Client/Server	Data collection
3	Low Speed	MMS	L3 - IP/TCP	Low	< 500 ms	Medium Low	Process & Station	Client/Server	Data collection
4	Raw Data	SV	L2 - Multicast	High	< 3 to 10ms	High	Process	Publisher	Analysis, Protection
5	File Transfer	MMS	IP/TCP/FTP	Medium	< 1000 ms	Low	Process & Station	Client/Server	Management, Data
6	Timing	PTP	L2 - PTP	Low	Protection < 0,1 to 3ms Transformers ±1 to ±25us	Medium High	Process & Station	Unidirectional	Timing, IED, Synchrophasors
7	Command	MMS	L3 - IP	Low	< 500 ms	Medium Low	Station	Client/Server	Cconfiguration

IEC-61850 protocols to synchronize, configure, manage, control, protect, measure and data collection.



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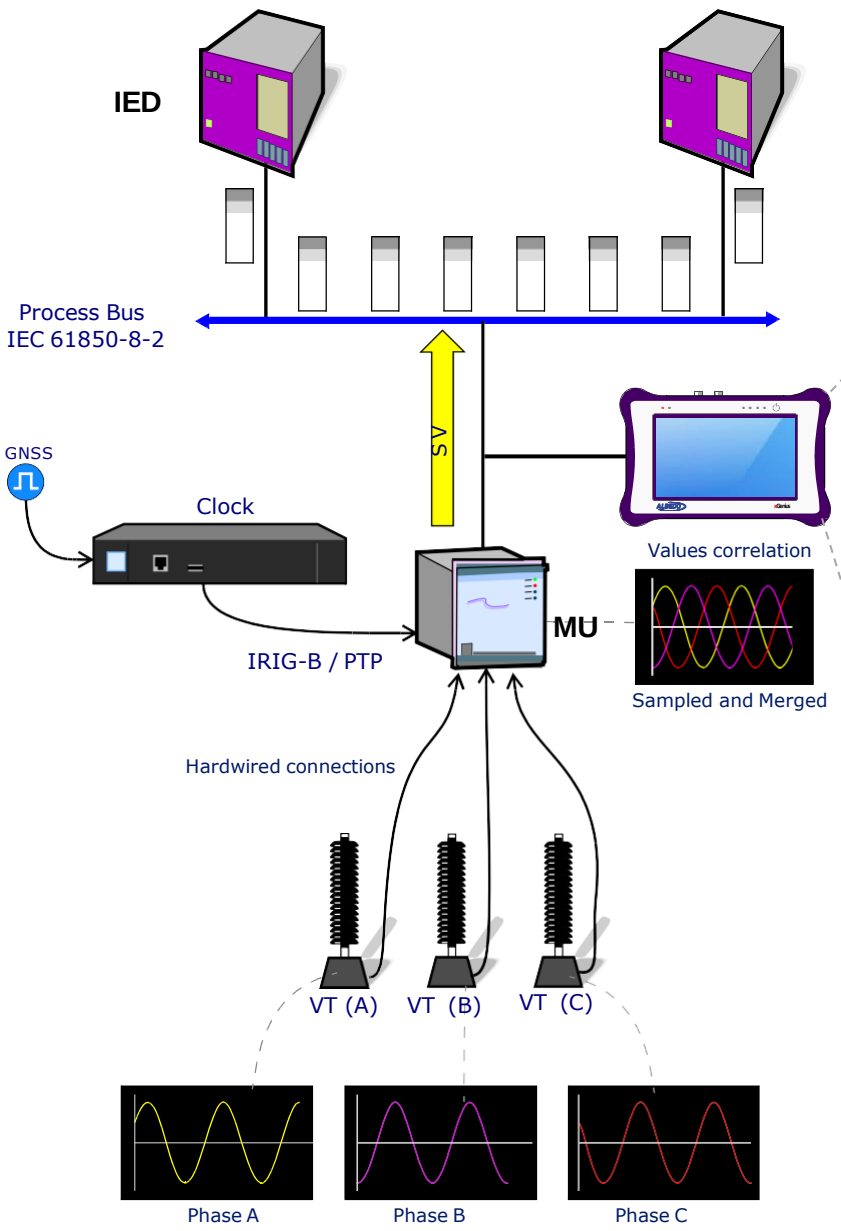
Capture & analysis of **SV packets**



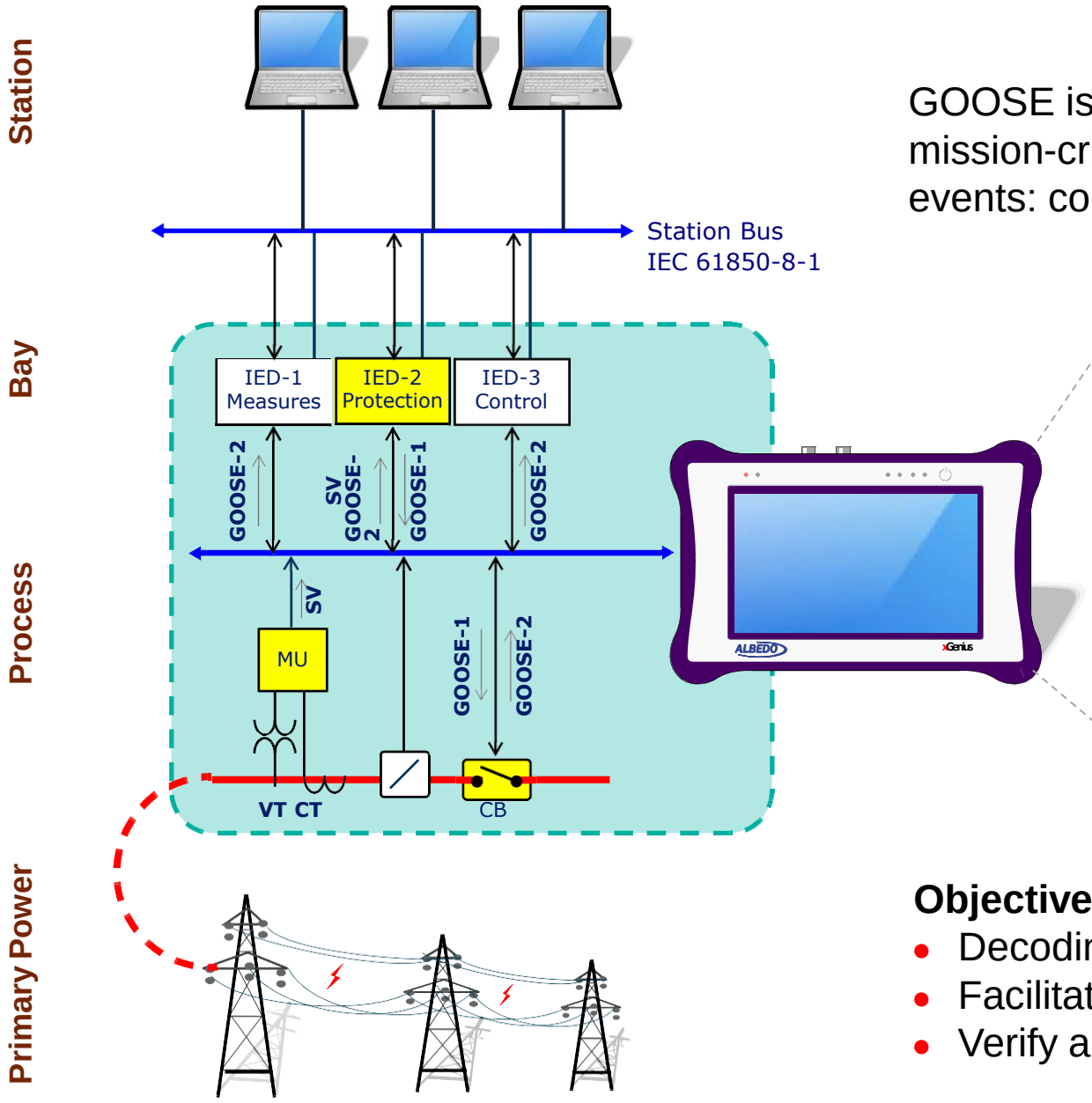
A **Merging Unit** (MU) digitalizes the analog measurements provided by current and voltage transformers (CT / VT) transmits the information using the Sampled Values (SV) protocol at a predefined bit rate.

State	Finished
Status	Idle
Packets stored	130
First capture at	05/12/2019 15:31:37
Last capture at	05/12/2019 15:31:37
Usage (%)	0

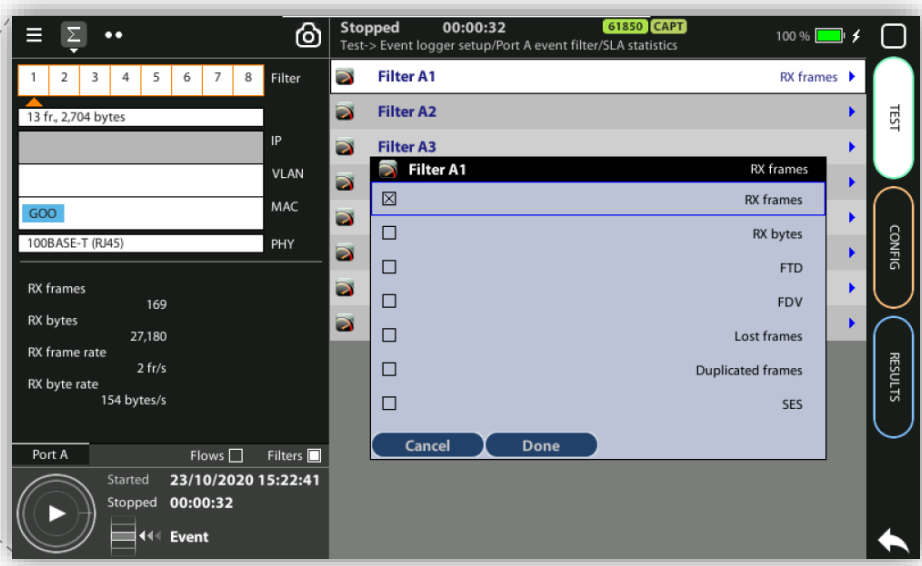
Objectives

- Detect SV transmission faults
- Facilitate interconnection between manufacturers
- Verify and adjust the latency of SV samples

Capture & Analysis of **GOOSE packets**



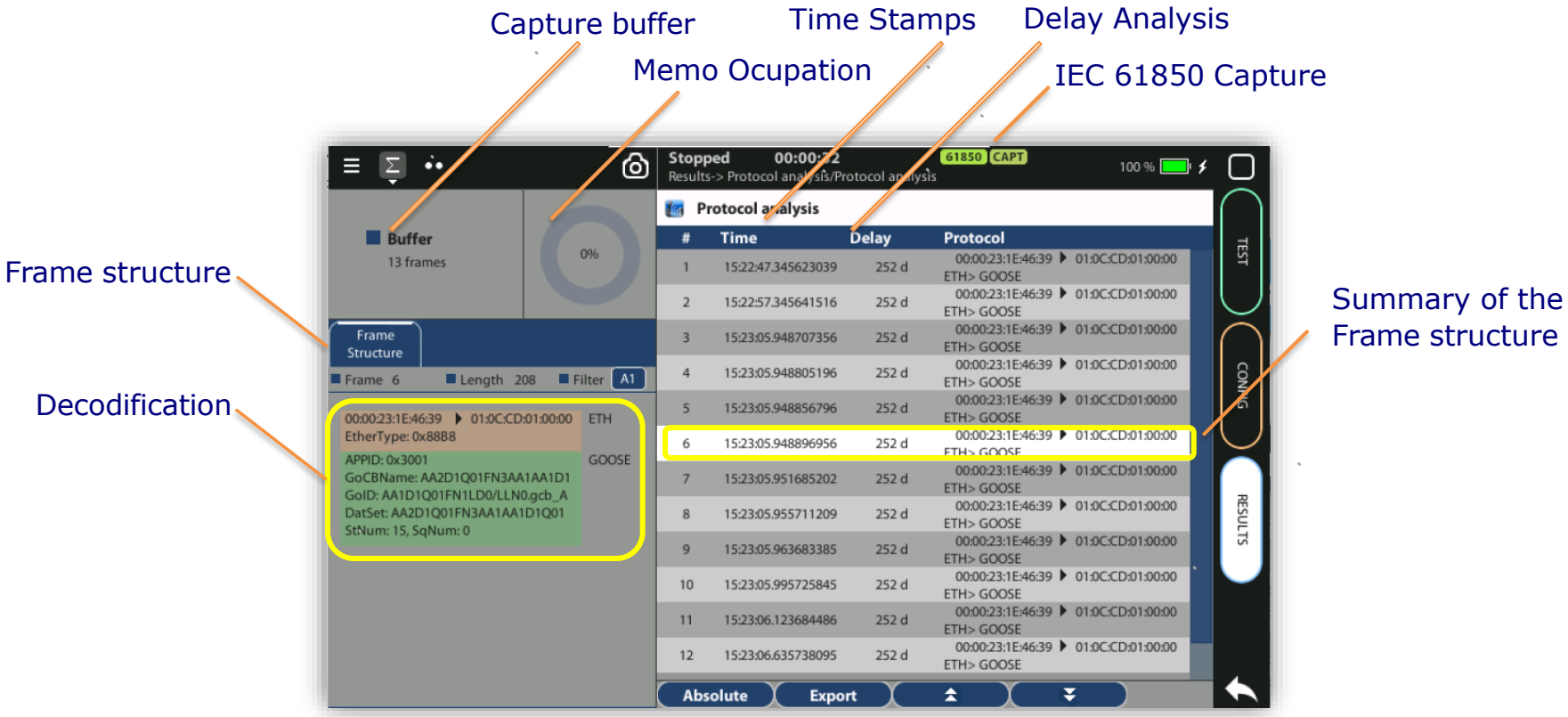
GOOSE is a messaging system used by IEDs and mission-critical applications to tell about substation events: commands, alarms, indications, measurements



Objectives

- Decoding of faults in GOOSE protocol
- Facilitate interconnection between manufacturers
- Verify and adjust the latency of GOOSE packets

Generic protocol **Capture&Decoding**



Supports **DNS, DHCP, GOOSE, SV, NTP, PTP** protocols

- Captures in pass-through and end-point modes
- High resolution hardware time stamp
- Synchronized captures (GNSS, IRIG-B, 1PPS / ToD)
- Package-by-package delay analysis
- Export to PCAP and PCAPng

IRIG-B used as time reference for testing

IRIG - Xabc

Rate
- A: 1000 PPS
- > **IRIG-B: 100 PPS** <
- D: 1 PPM
- E: 10 PPS
- G: 10000 PPS
- H: 1 PPS

Coding
- 0: BCD, CF, SBS
- 1: BCD, CF
- 2: BCD
- 3: BCD, SBS
- 4, 5, 6, 7: others

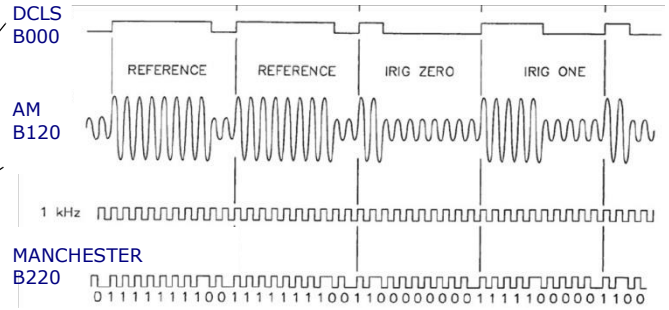
Carrier
- 0: No carrier (DCLS)
- 1: 100 Hz
- 2: 1 kHz
- 3: 10 kHz
- 4: 100 kHz
- 5: 1 MHz

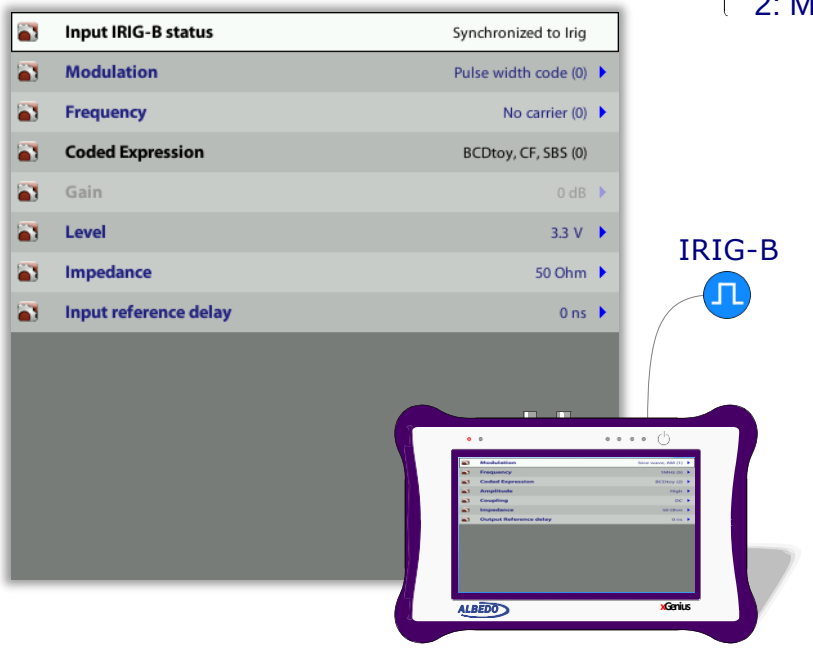
Modulation
- 0: Unmodulated DCLS
- 1: AM (Amplitude Modulated)
- 2: Manchester Modulated

BCD
0000 = 0
0001 = 1
0010 = 2
0011 = 3
0100 = 4
0101 = 5
0110 = 6
0111 = 7
1000 = 8
1001 = 9

BCD - Binary Coded Decimal, coding of time (HH,MM,SS,DDD)
SBS - Straight Binary Second of day (0....86400)
CF - Control Functions depending on the user application

IRIG SAMPLES: B000, B120, B220





IRIG-B sends a timing signal every second at 100 pulse/sec rate therefore the 100 is the number of bits of each frame. IRIG-B info includes Year, Day, Hour, Min, Sec.

- AM modulated clock reference input and output
- Unmodulated (DCLS) i/o over RS-422 / RS-485 or TTL
- Manchester encoded IRIG-B input and output

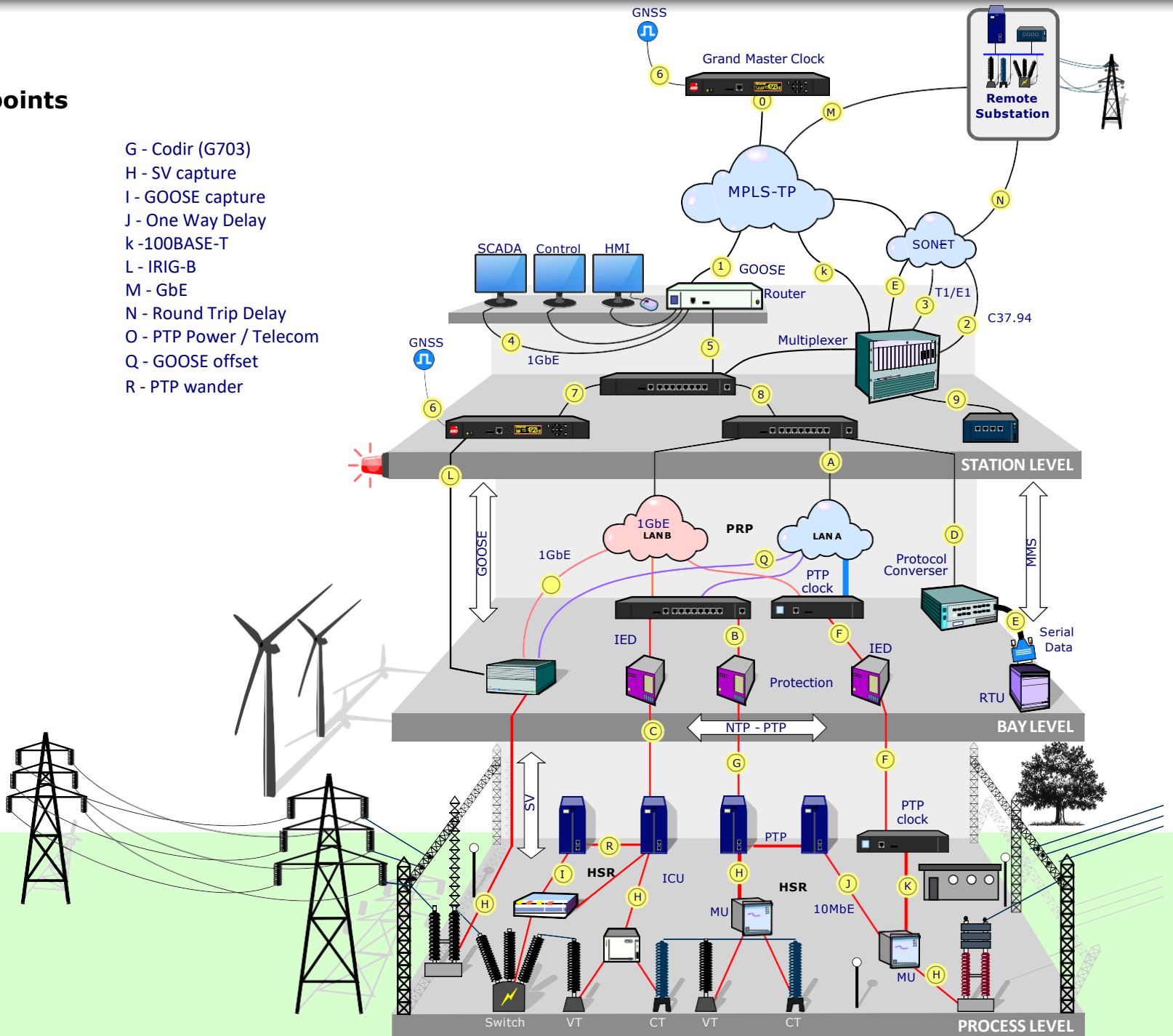
Test & Measurement

- Analysis of the received IRIG-B structure

Substation at the **Power Grid**

Key points

1 - GOOSE delay
2 - C37.94
3 - E1/T1
4 - GbE
5 - MMS
6 - GNSS
7 - 1PPS
8 - Eth/IP
9 - MPLS
A - PTP
B - NTP
C - GOOSE
D - PTP wander
E - RS-232
F - SyncE
G - Codir (G703)
H - SV capture
I - GOOSE capture
J - One Way Delay
k -100BASE-T
L - IRIG-B
M - GbE
N - Round Trip Delay
O - PTP Power / Telecom
Q - GOOSE offset
R - PTP wander



ALBEDO Telecom

Glossary

AAA: Authentication, Authorization, and Accounting
ACL: Access Control List
AP: Access Point
Busbar: Metallic strip or bar, typically housed inside switchgear, panel boards, and busway enclosures for local high current power distribution **C37.94**: TDM interface devoted for teleprotection
CB: Circuit Breaker designed to close or open electrical circuit under normal or abnormal conditions. It operates on relays command.
CBWFQ: Class-Based Weighted Fair Queuing
CG: Connected Grid
CID: Individual configuration of each IED
CIP: Critical Infrastructure Protection
CLI: Command-Line Interface
CorpSS: Corporate Substation
CT: Current Transformer, used for measurement of current, if too high to apply directly to measuring instruments, a CT produces a proportional current which can be measured and recorded, CT are used in metering and protective relays
DAN: Doubly Attached Nodes implementing HSR or PRP
DAU: Data Acquisition Unit
Disconnector: isolates physically and visually the lines
DMZ: Demilitarized Zone
DCB: Directional Comparison Blocking
DCS: distributed control systems
DSC: Differentiated Services Code Point
ESP: Electronic Security Perimeter
Feeder: Transmits power to the distribution points
GM: Grandmaster
GNSS: Global Navigation Satellite System
GOOSE: Generic Object-Oriented Substation Events is a control model defined as per IEC 61850 which provides a fast and reliable mechanism of transferring event data over entire electrical substation networks. When implemented, this model ensures the same event message is received by multiple physical devices using multicast or broadcast services
HMI: Human Machine Interface
PTP: Precision Time Protocol
RedBox: Redundancy Box
Relay: is automatic device which senses an abnormal condition of electrical circuit and closes its contacts and complete the circuit breaker trip.
REP: Resilient Ethernet Protocol
RCT: Redundancy Control Trailer
RTU: Remote Terminal Unit
SA: Substation Automation
SAN: Singly-Attached Node
Secondary Lines: lower voltage side at the substation
SCADA: Supervisory Control And Data Acquisition, transmits and receives data from events of controls, measuring, safety and monitoring. Power system elements can be controlled remotely over. Remote switching, telemetering of grids showing voltage, current, power, direction, consumption in kWh, synchronization.
SCD: Substation Configuration Description **SCL**: Substation Configuration Language **SNTP:** Simple Network Time Protocol
Station Bus: Connects the entire substation and helps provide connectivity between central management and individual bays
STP: Spanning Tree Protocol
SV: Sampled Values, is a method to read instantaneous values such as currents, voltages, impedances, etc. from CTs, VTs or digital I/O and then transmitted to make them are available for those IED subscribed.
Switchgear: combination of switches, fuses or CB to control, protect and isolate electrical equipment
SyncE: Synchronous Ethernet
TLV: Type, Length, Value
VT: Voltage Transformer (see CT)Potential Transformer, gives the reference voltage to the Relay for Over-voltage or Under-voltage Protection
UCA IuG: Utility Communications Architecture International Users Group
VDAN: Virtual D
HQoS: Hierarchical Quality of Service
HSR: High-Availability Seamless Redundancy
IA: Industrial Automation
ICS: Industrial control systems
ICU: Intelligent Control Unit
IEC: International Electrotechnical Commission
IEC 61850: Standard defining communication protocols for intelligent electronic devices at electrical substations
IED: Intelligent End Device, microprocessor-based controllers of power system equipment, such as circuit breakers, transformers and capacitor banks to enable advanced power automation.
IRIG: Inter-Range Instrumentation Group
ISE: Identity Services Engine
L3VPN: Layer 3 Virtual Private Network
LA: Lightning Arrester protects the power grid from electric storms
MQC: Modular QoS Command-Line Interface
MMS: Manufacturing Message Specification, messaging system for exchanging real-time data and supervisory control information. Allows client such as SCADA, an OPC server or a gateway to access all IED objects **MPLS**: Multi-protocol Label Switching
MU: Merging Unit connected to the process bus converts analog data(ie. volts, currect...) into digital information
NERC: North American Electric Reliability Corporation
NIST: National Institute of Standards and Technology
NMS: Network Management System
OAM: Operations and Maintenance
PCP: Priority Code Point
PIOC: Instantaneous overcorrent Protection
PLC: Programmable Logic Controller
PMU: Phasor Measurement Unit
POTT: Permissive Overreaching Transfer Trip
PP: Primary Power
Process Bus: Connects primary units and control equipment to the IEDs
PRP: Parallel Redundancy Protocol
PRTC: Primary Reference Clock
PT: see VT
T-GM: Grand Master PTP
T-BC: Boundary Clock
T-TSC: Slave Clock

That' all

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