

Power Grid Architectures



As result of the standardization process in the Power Grid a critical standard was released the IEC 61850 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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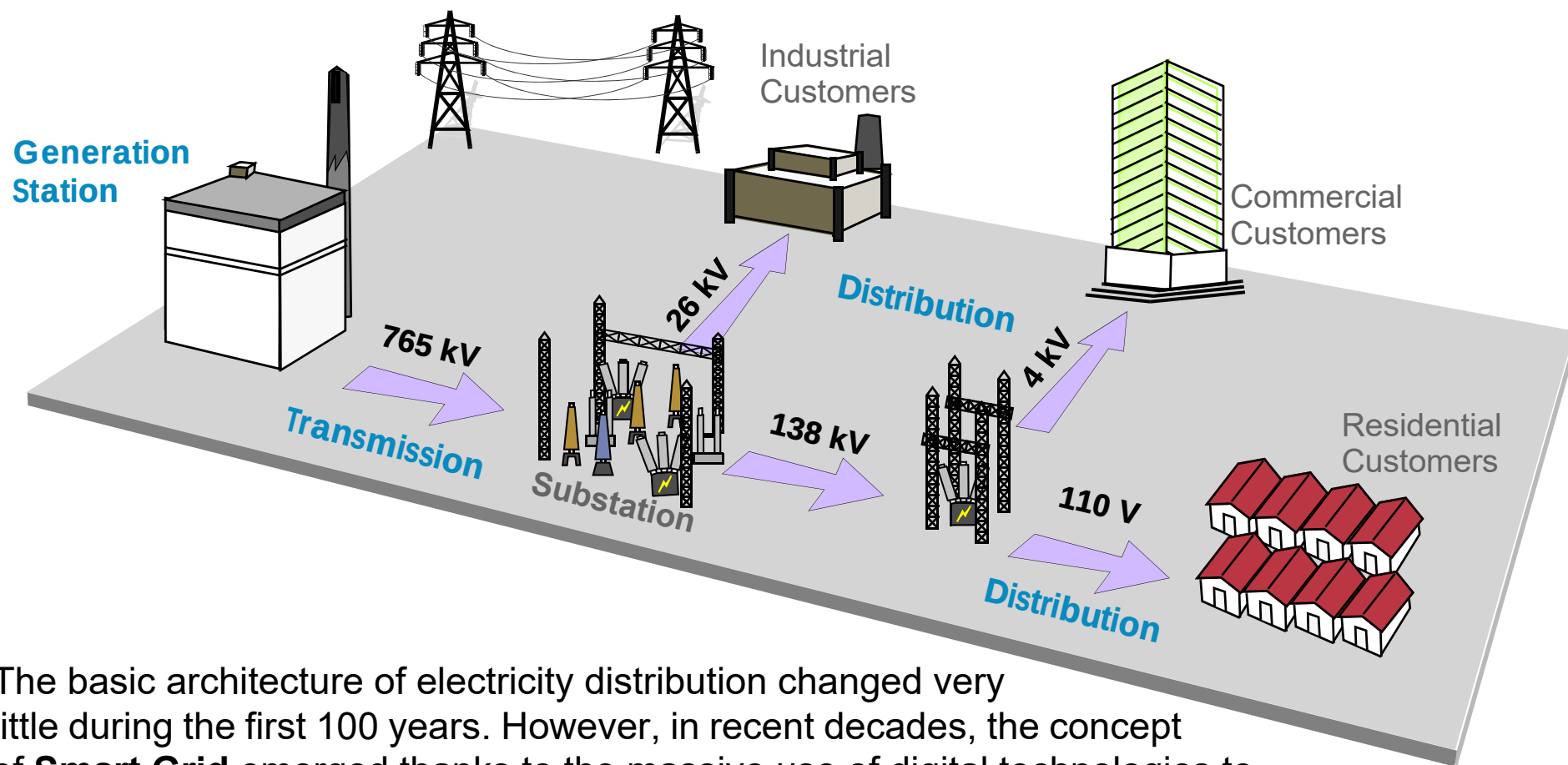




As result of the convergence process in the **Power Grid**, a new standard was released, the **IEC 61850**, that defines a set of Ethernet-based protocols.

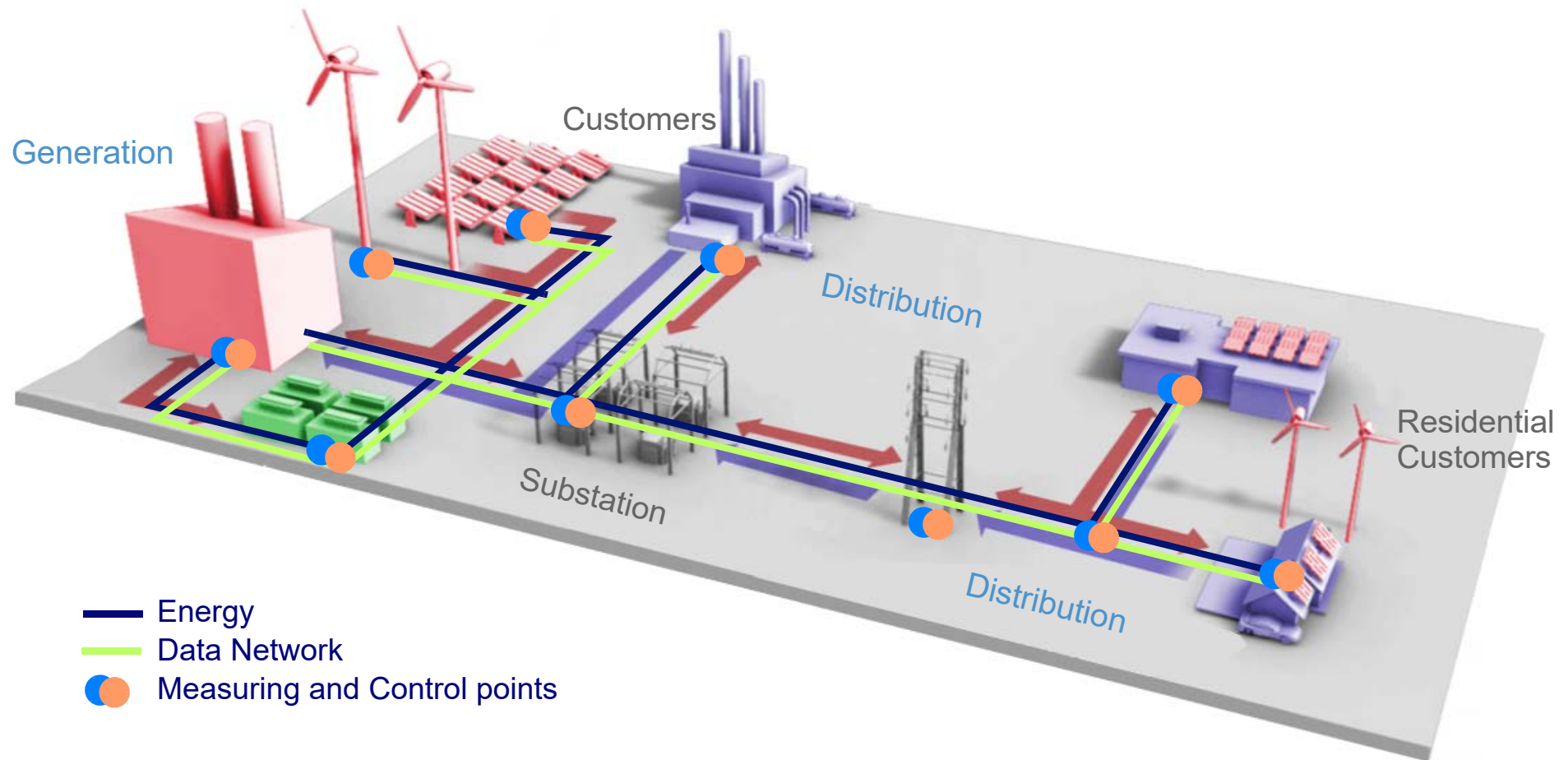
The IEC 61850 objective is to facilitate the interoperability (between devices and systems), ease of configuration (allocation of functions to devices), long term stability (layered, object-model based design), and reliability (lossless network architectures) to replace wire communications.

The Power Grid

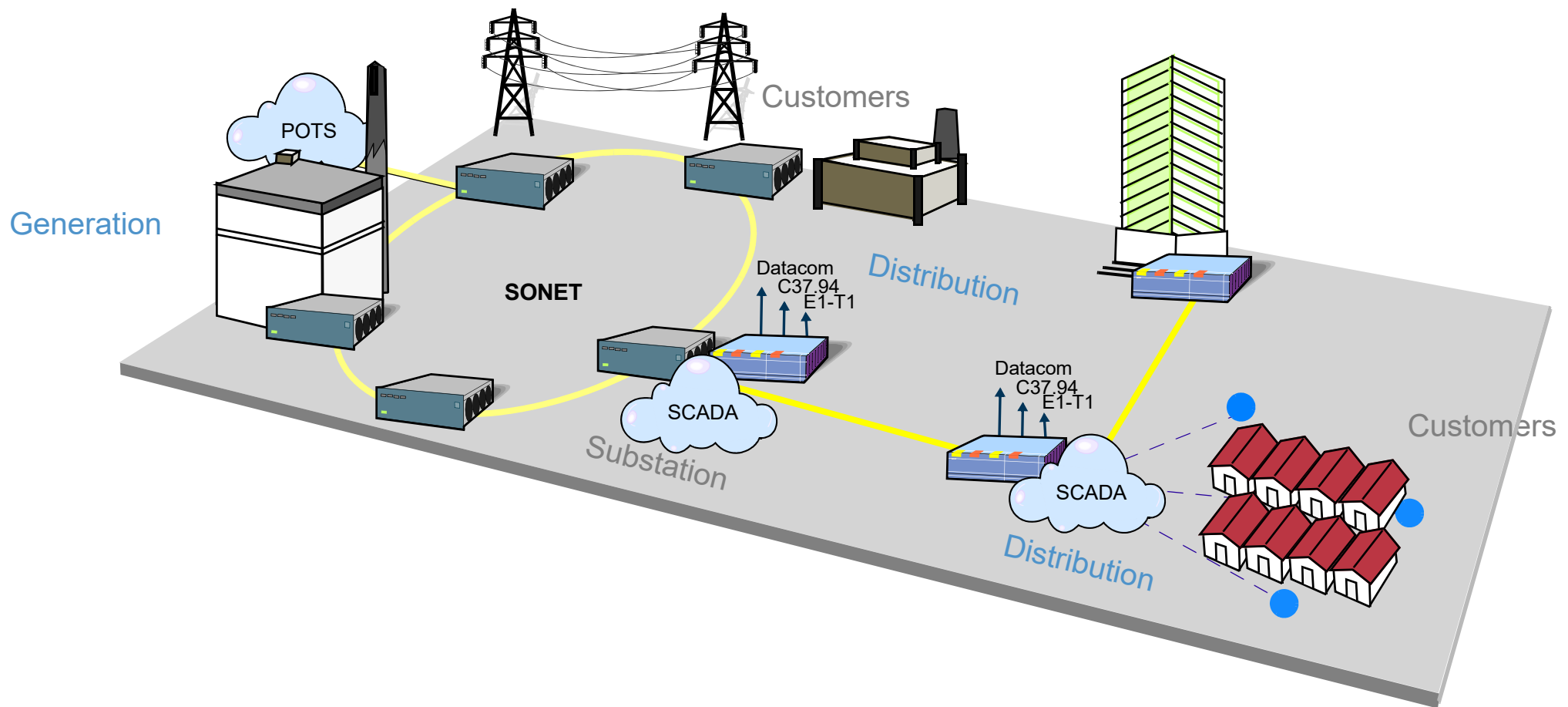


The basic architecture of electricity distribution changed very little during the first 100 years. However, in recent decades, the concept of **Smart Grid** emerged thanks to the massive use of digital technologies to increase efficiency, resilience and quality of the service.

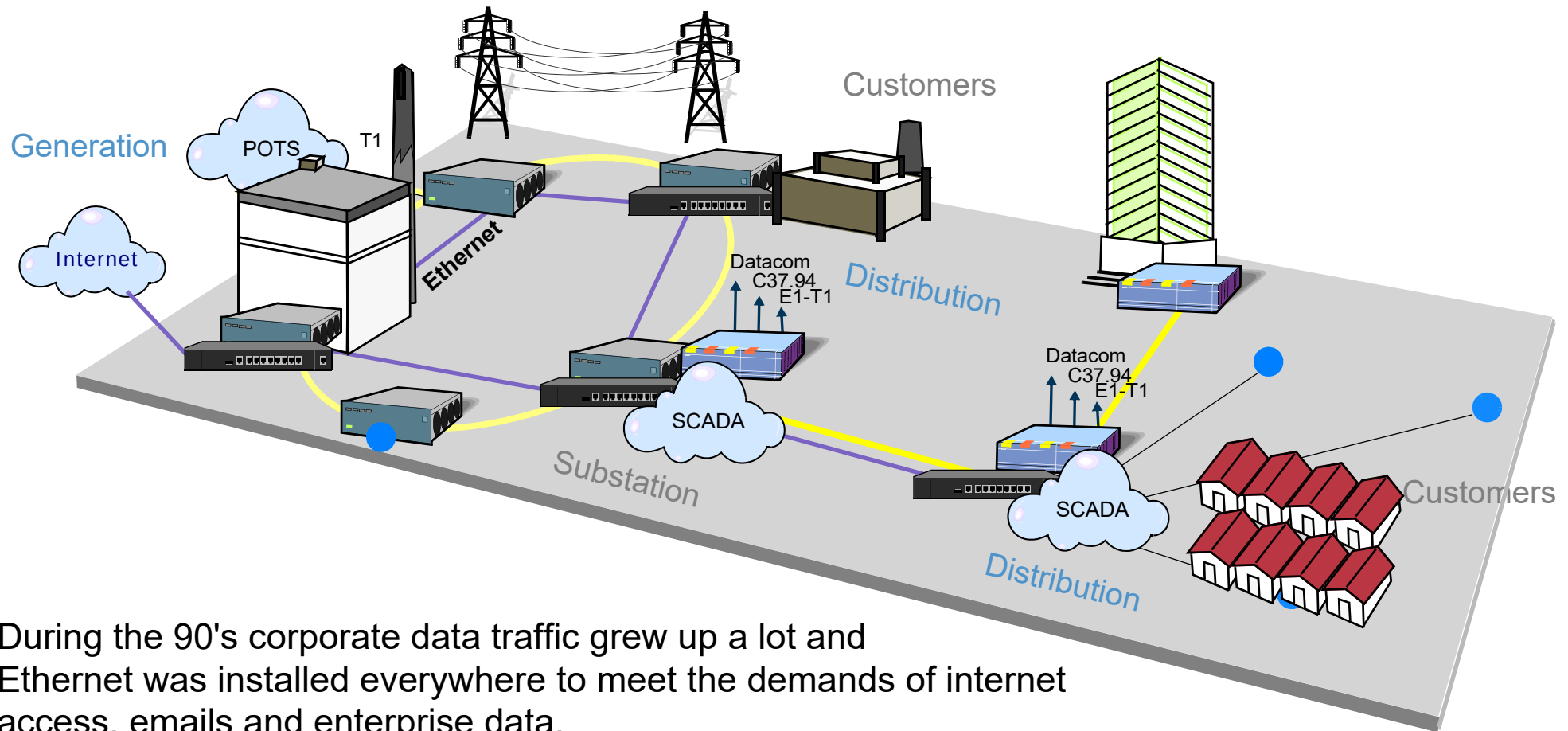
The new Smart Power Grid



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.



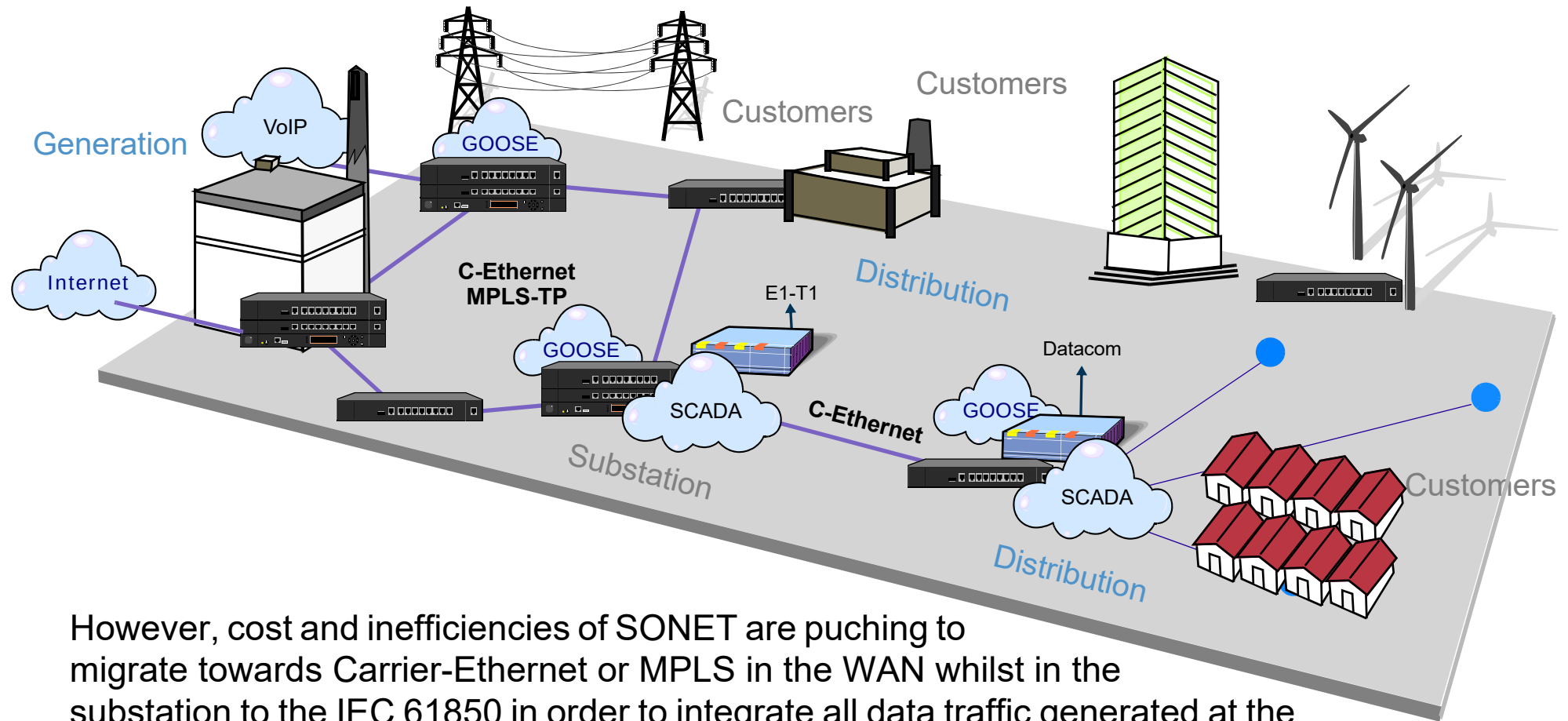
At the 80's SONET was the first network to be deployed and it was a satisfactory solution for common applications such as SCADA, Telephony and Tele-protection because it is a predictable, symmetric, low latency, and fault tolerance architecture.



During the 90's corporate data traffic grew up a lot and Ethernet was installed everywhere to meet the demands of internet access, emails and enterprise data.

For many years, both networks were operational and interconnected:

- SONET to carry services such as T1/E1, Datacom (RS232), C37.94 and SCADA
- Ethernet to transport enterprise information such Internet, email, corporate files and new services



However, cost and inefficiencies of SONET are pushing to migrate towards Carrier-Ethernet or MPLS in the WAN whilst in the substation to the IEC 61850 in order to integrate all data traffic generated at the power grid under the Ethernet umbrella:

- IEC 61850: GOOSE, SV, MMS, PTP and SNTP protocols
- Carrier-Ethernet, MPLS and MPLS-TP to communicate substations
- Circuit Emulation to support legacy T1/E1, Datacom (RS232), C37.94

What is a Substation?

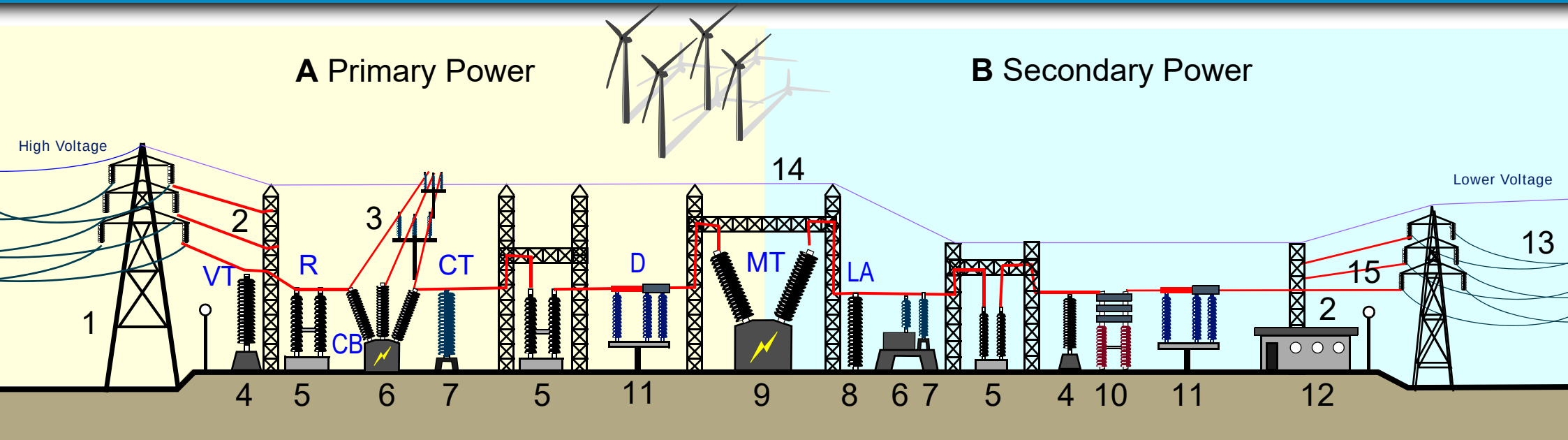


Located in between Generation and Consumers Substations manage key functions:

1. **Transforms:** Converting High to Lower Voltages
2. **Distribution:** Splitting power lines for sending the energy to the consumers
3. **Operation:** Configuring and supervising the electric system to the correct values
4. **Protection:** Detecting events and Isolating power elements and lines when faults occur
5. **Interconnection:** Linking circuits of varying voltages and different lines at the same voltage

Components & Systems in a Substation

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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 going to Industrial and residential consumers.

Main Transformer installed in between. **Disconnecter** (D) isolates physically and visually the lines while **Lightning arrester** (LA) protects the power grid from electric storms. **Current** (CT) and **Voltage Transformers** (VT) are measuring devices to provide information to **Relays** (R) that process the inputs in real time. If a fault is detected (i.e. Current or Voltage changes, or a short-cut) then the Relay indicates the **Circuit Breaker** (CB) to close the line and disconnect the faulty section. **Capacitors** help to correct phase shifts and to improve the power factor.

IED (Intelligent End Device)

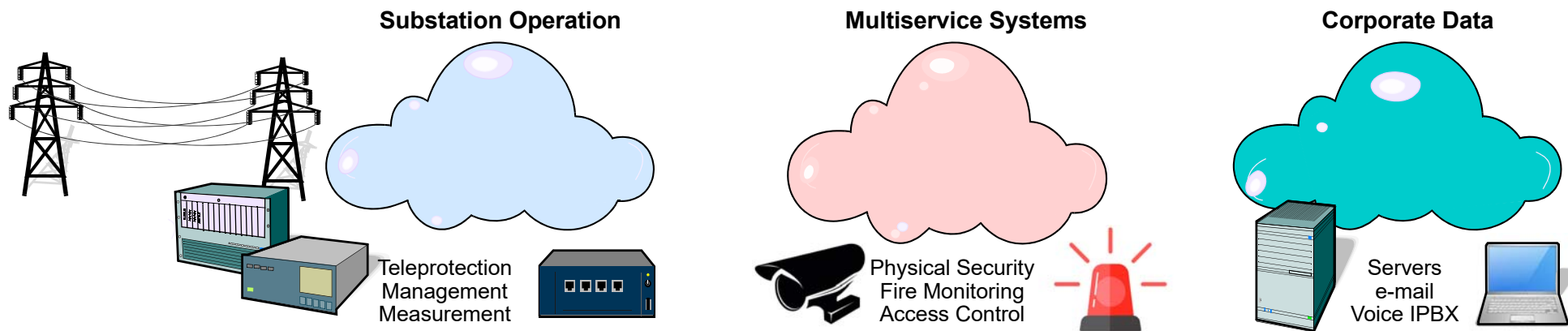


IEDs are a key element in the substation and the result of the evolution of relays and other devices now equipped with microprocessor and advanced communications. There are several types of IED:

- **Protection Relays:** to protect lines, generators, motor, transformers, or feeders.
- **Bay Controllers:** to manage voltage regulators, logics in circuit breakers, event recording, etc.
- **Metering Devices:** to data acquisition and storage from primary level including Voltage (V), Current (A), frequency (Hz), Power (MW), Energy (kWh), Harmonics (H), Temp (C), Tripping (t), etc.

IED can take decisions thanks to its capability to obtain and process information from the power grid. For instance in case of an event or a fault IEDs can automatically command circuit breakers to open or close for protection, IED can also reconfigure the network and provide service restoration in milliseconds.

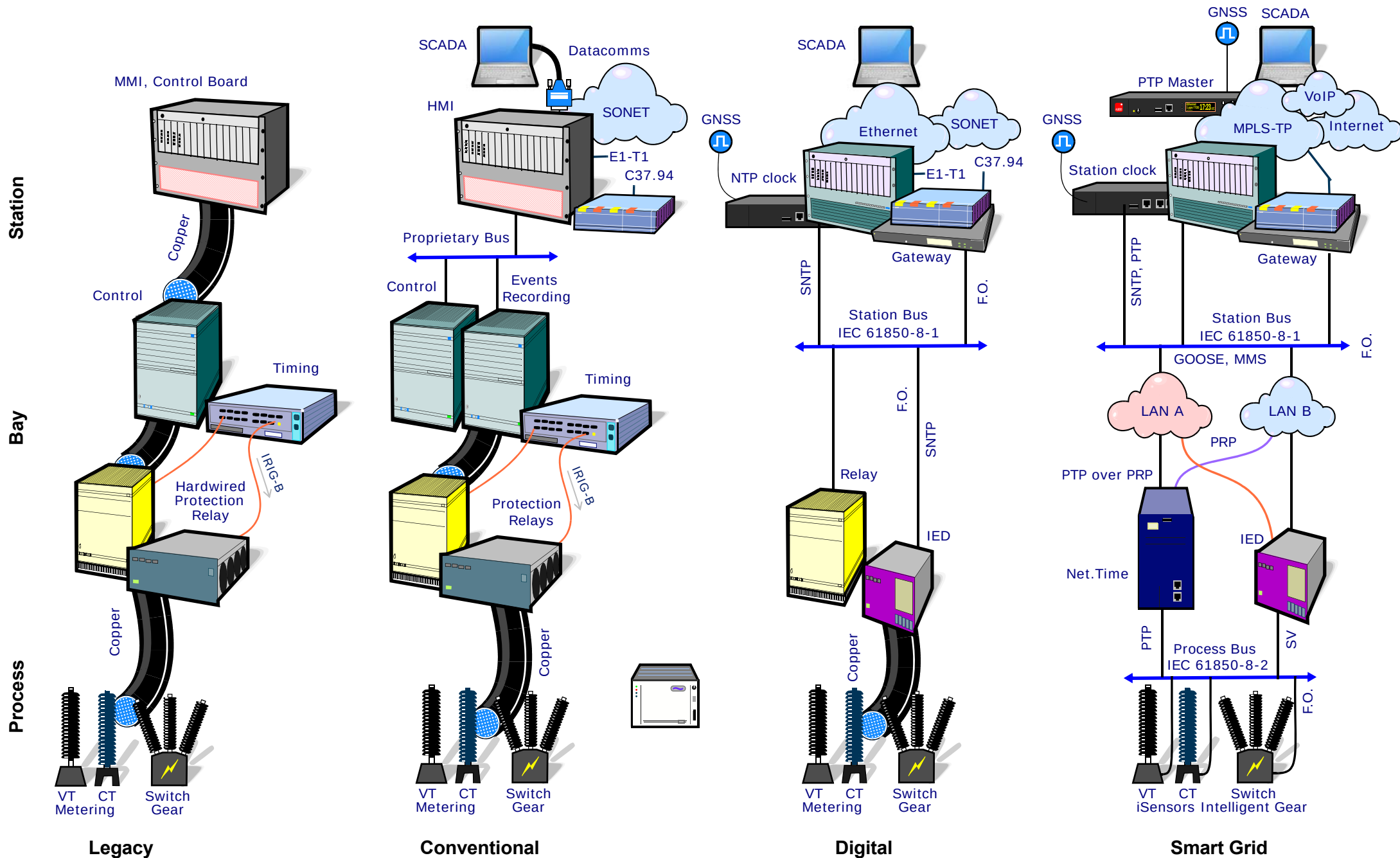
Modern IEDs support IEC 61850 communication standards in order to assure vendor interoperability by means of universal protocols and data structures.



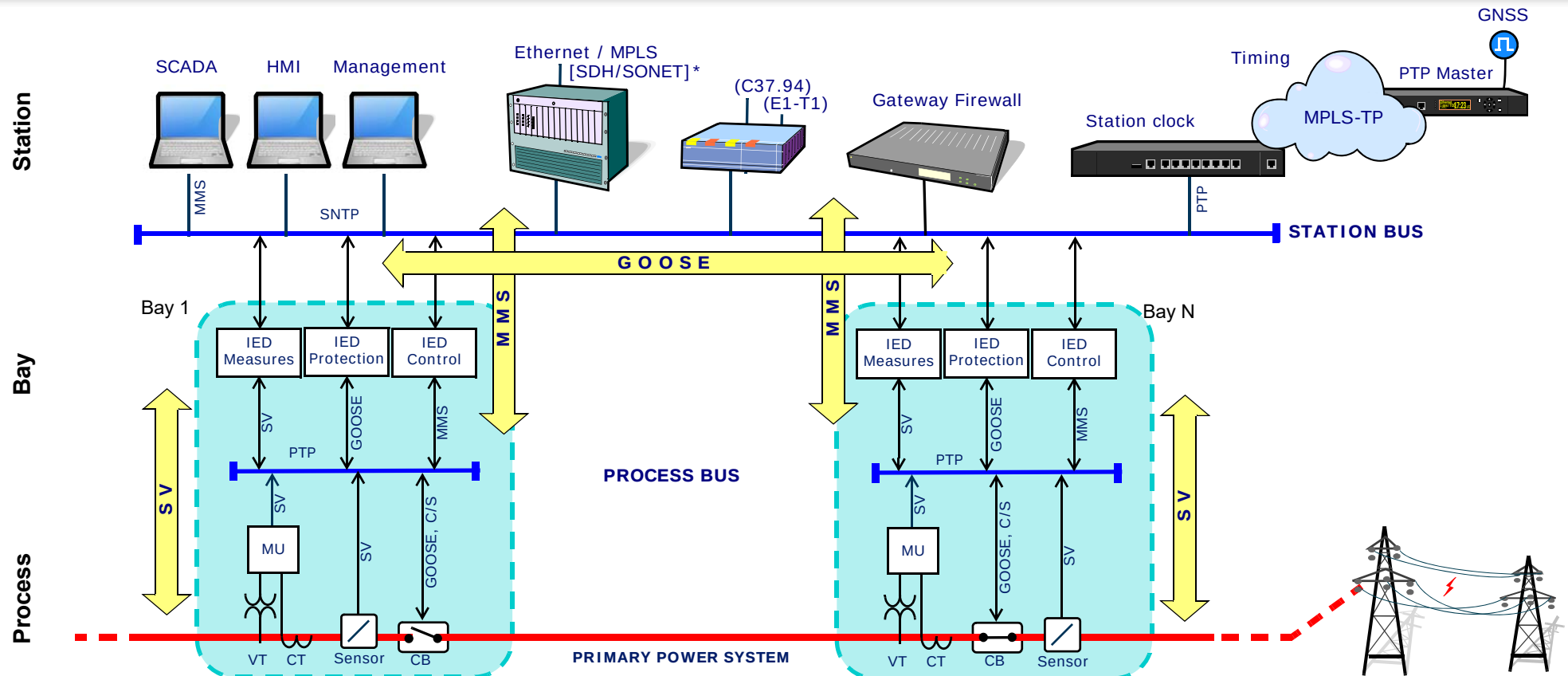
Communication infrastructures of a substation have three separate and differentiated networks:

- **Operation:** includes grid management and protection. It is deployed in the zone where critical utility monitoring and controlling infrastructure reside. It contains station and process buses as defined by IEC 61850 and other protocols such as C37.94, SCADA, Serial Datacom, E1/T1. Data have strict requirements for Latency, Symmetry and Redundancy.
- **Corporate:** for data traffic, LAN, email (no critic, no time sensitive) Ethernet connectivity (Wi-Fi), voice services, and general Ethernet connectivity for employees to access email, and Internet
- **Multi-service:** includes physical security components like Ethernet-connected badge readers, video surveillance cameras, local authentication, authorization, and accounting, and logging applications.

Substation Evolution

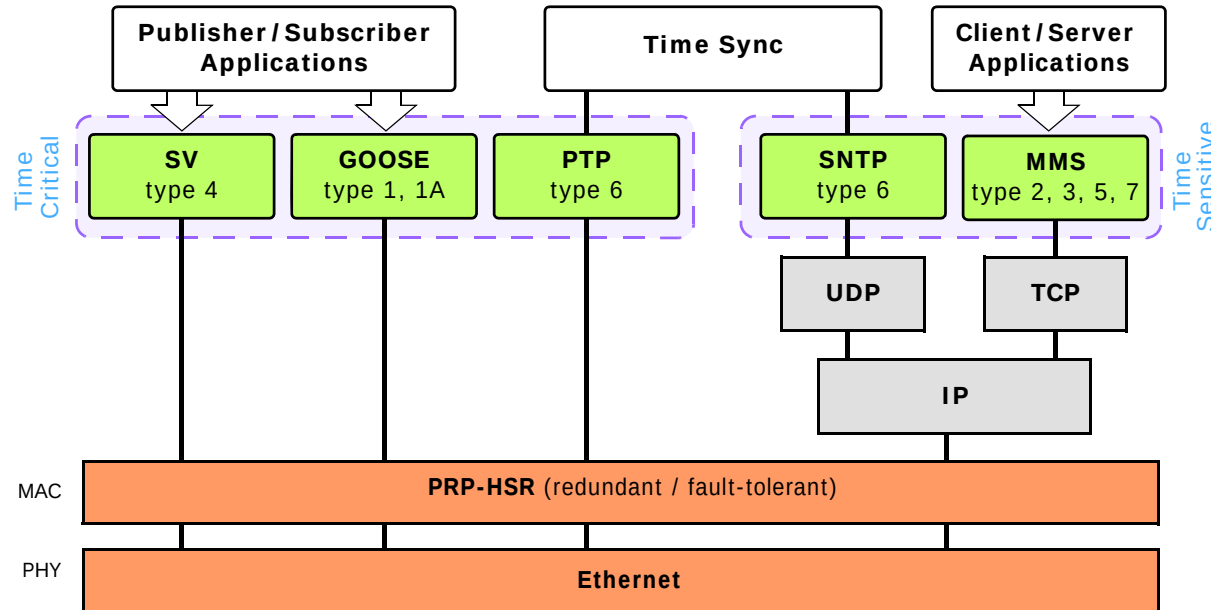


Smart Grid Substation in detail



The **Station bus** provides connectivity to individual bays, distributed controllers, gateways, management and human machine interfaces (HMIs). It may connect up to hundreds of Intelligent End Device (IEDs), often segmented physically or logically depending on their application.

Process bus, connects process equipment such as Current (CTs) and Voltage Transformers (VTs), Sensors, or Circuit Breakers to IED transporting data (such as voltage, current, status...) and operation commands (i.e. open/close circuit). The connection can be direct or by means of Merging Units (MU) that transform the analog measurements to digital data.



The IEC 61850 is a set of standards and technical reports for 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.

- **Ethernet-based Protocols:** Sampled Values (SV), Generic Object Oriented Substation Event (GOOSE), and Manufacturing Message Specification (MMS) that transport data and commands.
- **Time Synchronization:** Precision Time Protocol (PTP) and Simple Network Time Protocol (SNTP) that align in time the complete grid.
- **Lossless Architectures:** Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR) that build a fault-tolerant network to a single point of failure.
- **Substation Configuration Language** (SCL) specified by IEC 61850 for the configuration of substation includes representation of modeled data to have a complete interoperability

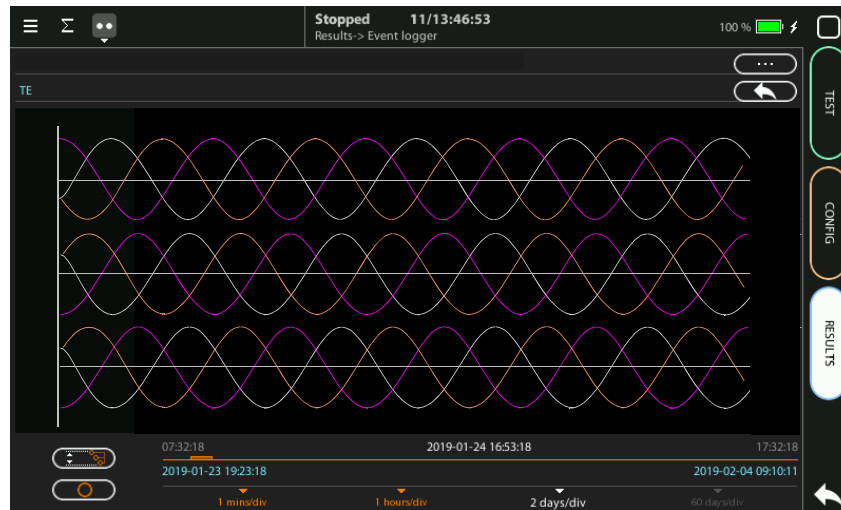
Substations are the building blocks for electric power grids. Substation automation refers to using data from intelligent electronic devices to enable stability, increase efficiency and maintain the system integrity. To make it possible a new standard was released, the IEC-61850 that facilitates the intensive use of ICT technologies and guarantees the interoperability between vendors, appliances and processes. The IEC-61850 defines a set of protocols and network architectures to synchronize, measure, exchange data, command and protect the grid.

Protocol	Layer	Message	BWidth	Delay	Priority	Bus	Model	Application
GOOSE	L2 - Multicast	1. Trip	Low	< 3 ms	High	Process	Publisher	Protection
GOOSE	L2 - Multicast	1A. Other	Low	< 200 ms	High	Process	Publisher	Protection
MMS	L3 - IP/TCP	2. Medium Speed	Low	< 100 ms	Medium Low	Process & Station	Client/Server	SCADA
MMS	L3 - IP/TCP	3. Low Speed	Low	< 500 ms	Medium Low	Process & Station	Client/Server	SCADA
SV	L2 - Multicast	4. Raw Data	High	< 208.3 ms	High	Process	Publisher	Process Bus
MMS	IP/TCP/FTP	5. File Transfer	Medium	< 1000 ms	Low	Process & Station	Client/Server	Management
PTP	L2 - PTP	6. Timing	Low	< 3 ms	Medium High	Process & Station	Unidirectional	Synchrophasors, IED
MMS	L3 - IP	7. Command	Low		Medium Low	Station	Client/Server	SCADA

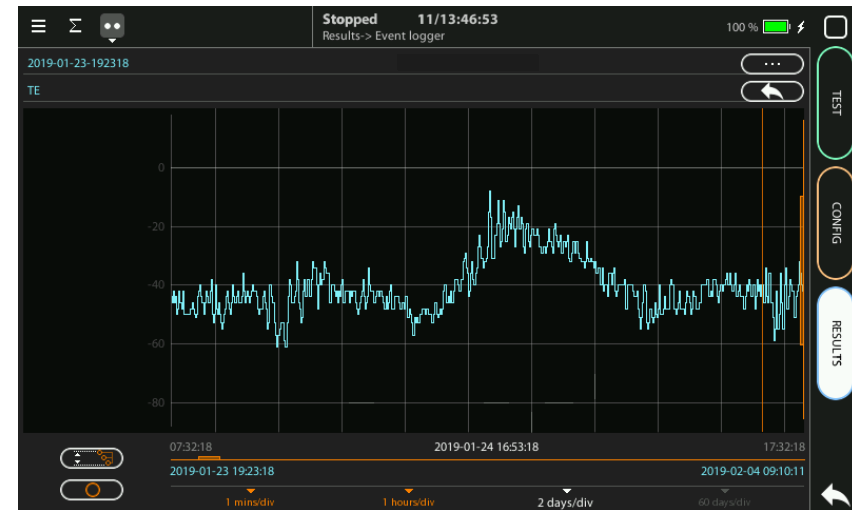
Power grid elements use IEC 61850-7-2 defines a basic set of services to exchange data, send commands and measure values that permit **the configuration, supervision, protection and control** the wide-area electrical network. Appliances such as IEDs of different vendors can now communicate each other with the help of common **protocol stacks** and **data structures**.

SV (Sampled Values)

Voltage SV represented at Control Station



Phase Time Error extracted from captured SV

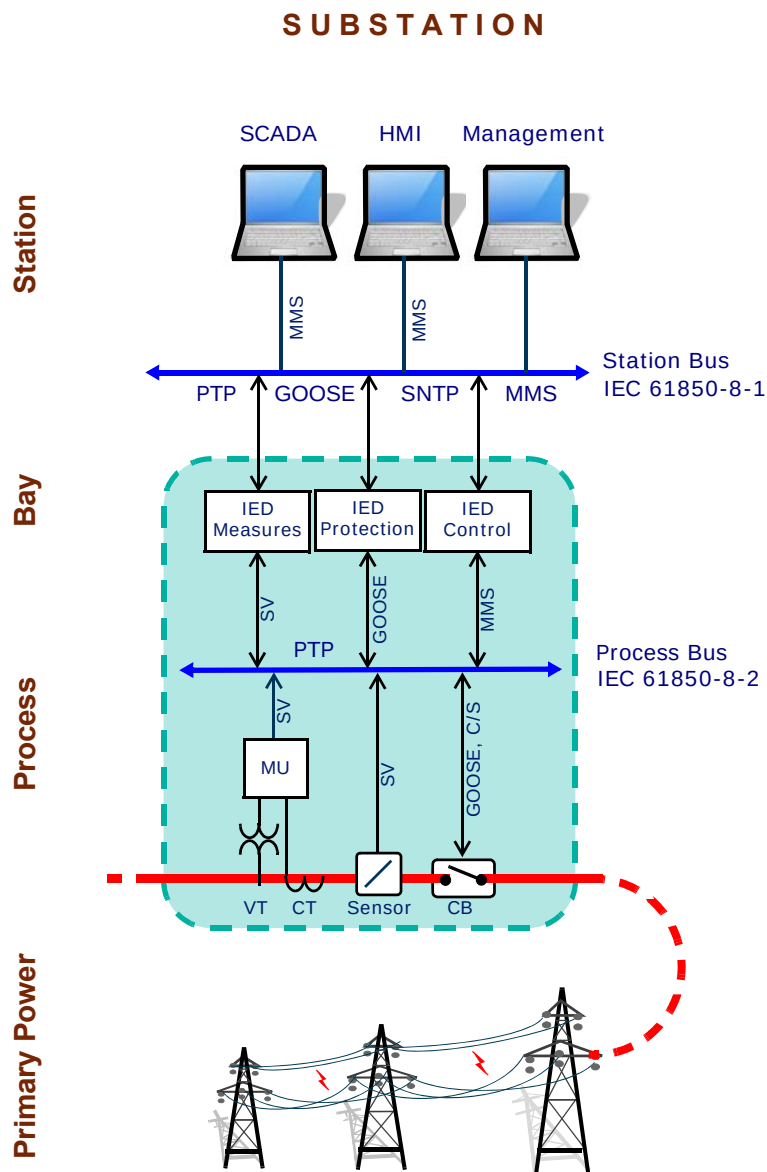


SV is used to transmit high speed streams of **values measured** by conventional or non-conventional current and voltage transformers:

- **Publisher/subscriber model**, for time critical transmitting unacknowledged data to subscribers
- SV is mapped **directly to Ethernet** to provide real-time communication
- Data is sent in multi-cast Ethernet frames to the **process bus**
- The **Merging Units (MU)** converts analog to digital data before sending to the network
- SV simplifies substations using the process bus not need for specific wiring to make connections
- Used to send data about the Transformers deployed in the substations
- Transmission of Sampled Values from instrumental transformers: high amount of data to be sent in real-time and loss of data shall be detected

GOOSE (Generic Object Oriented Substation Event)

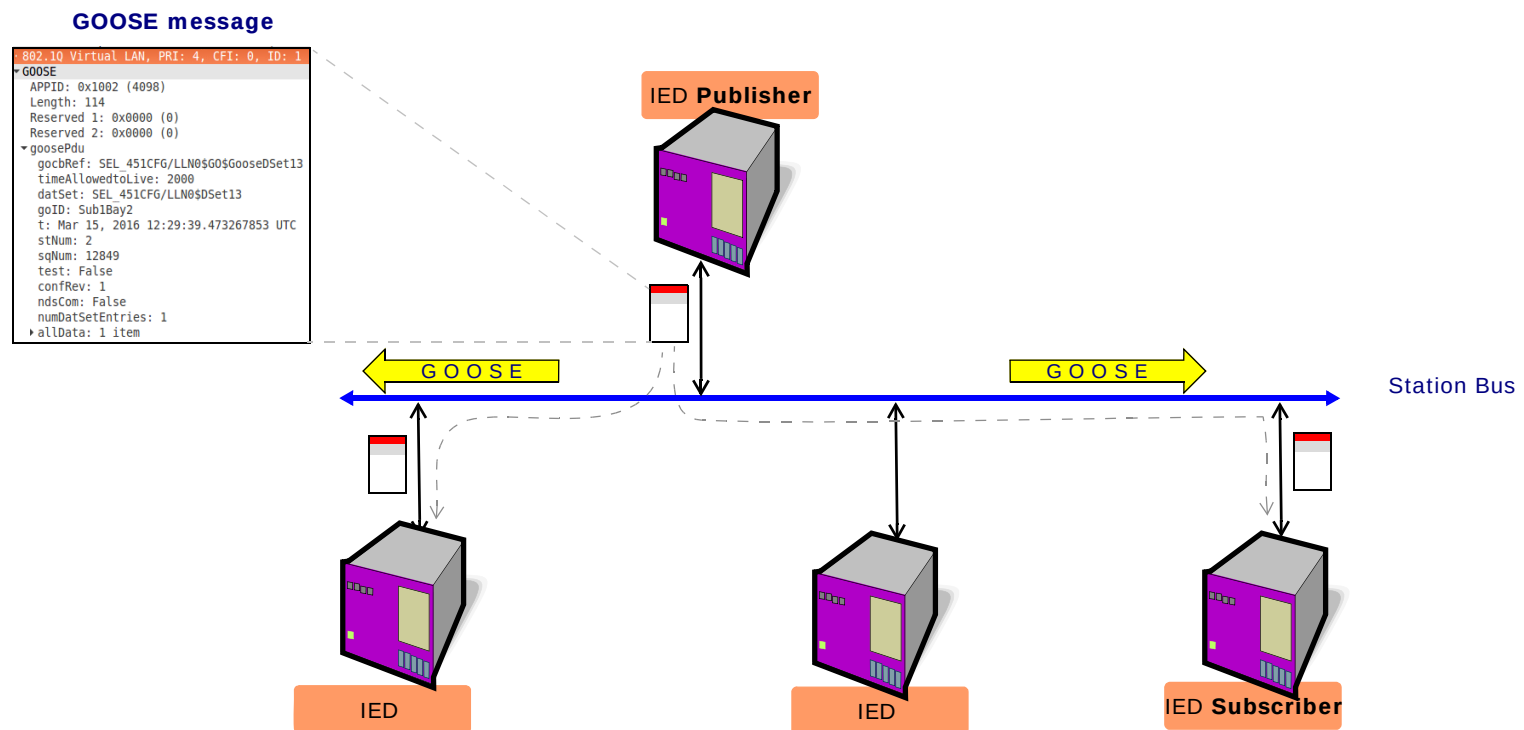
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GOOSE is a messaging system used by IEDs and mission-critical applications to tell about substation substation events, such as commands, alarms, indications and measurements:

- Applications e.g. tripping of switchgear, starting of disturbance recorder, providing position indication for interlocking, and tele-protection.
- **L2 protocol**, GOOSE works in real-time ethernet context and used for fast / reliable distribution of data.
- **Publisher/Subscriber** method is used: *one* IED sends a message that can be read by *N* receivers. The reaction of each receiver depends on its functionality and configuration. For instance a message tells position of the Circuit Breaker (Open, Close, Intermediate)
- **No ACK** mechanism but messages are repeated cyclically during certain time, even if there are no changes. The idea to keep connected as a polling.
- **Simplifies wiring**, while the adoption of **fiber optic** unifies traffic reducing dramatically metallic cables.
- GOOSE is vendor **inter-operable** and **scalable**.

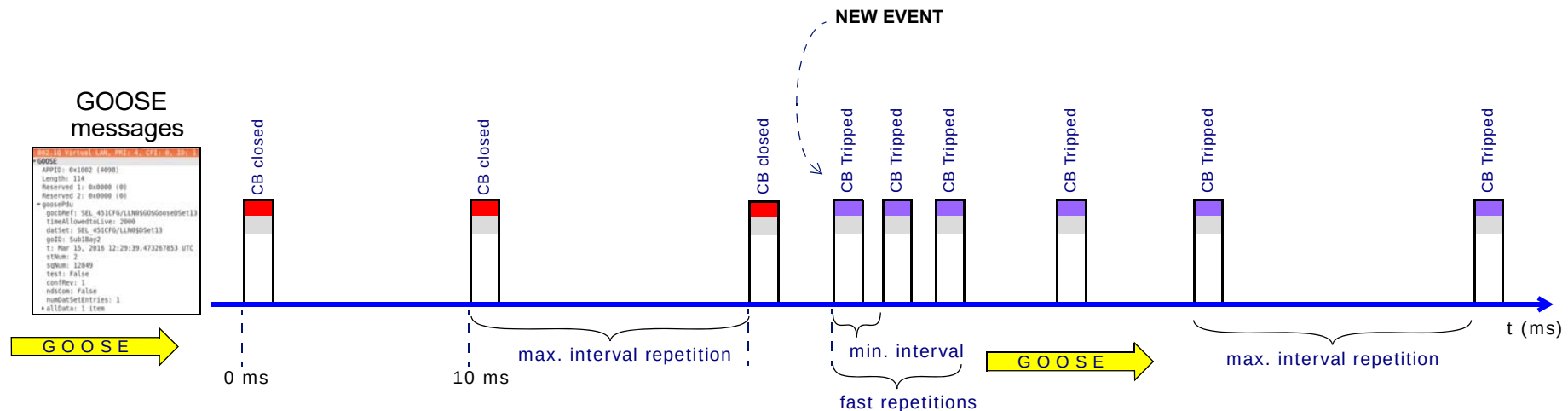
- GOOSE is mapped **directly to Ethernet** to provide real-time communication
- Point-to-Multipoint connection or Multicast-Application-Association (MCAA)
- This method provides efficient interchange of information between IED
- Tripping of Circuit Breakers: short information that needs to be sent without loss within msec



- The Publisher IED transmits a message that only the subscribers receive. The reaction of each receiver depends on its configuration and functionality

Repetition mechanism

Since the GOOSE messages replace hard-wired signals used for protection and control applications IEC 61850 introduces mechanisms that ensure the delivery of the required information.



- DataSet values are coded as GOOSE messages and published
- At the beginning of a new message the repetition interval is very short just a few milliseconds
- Then the interval time increases until it reaches a value of a few seconds
- Max time interval (IEC 61850-8-1): **100ms < max interval < 60s**
- When any **DataAttribute** value changes Publisher transmits a new message
- The repetition mechanism allows continuous monitoring of the communications interface - something that is not possible in conventional hardwired systems.

Messages are a collection of values as members of a **Dataset**:

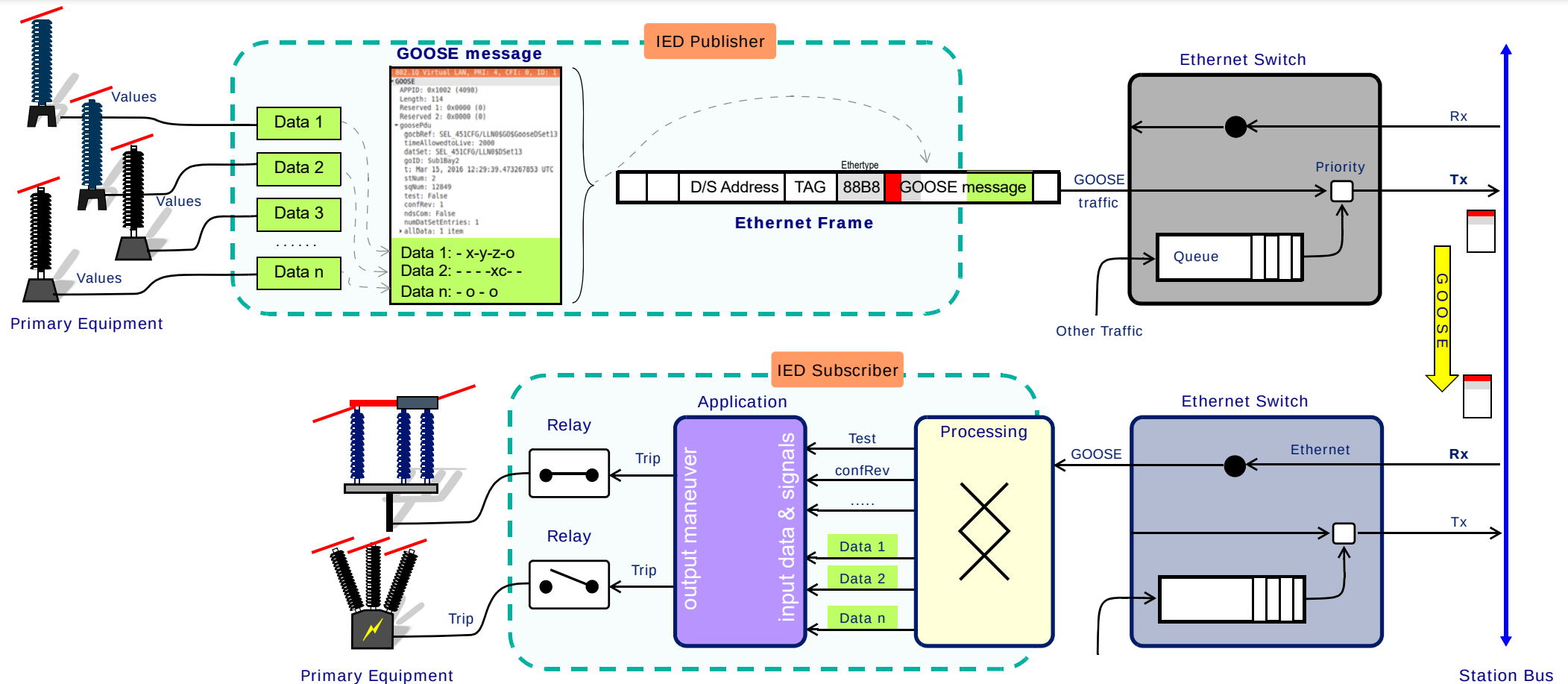
```
802.1Q Virtual LAN, PRI: 4, CFI: 0, ID: 1
▼ GOOSE
  APPID: 0x1002 (4098)
  Length: 114
  Reserved 1: 0x0000 (0)
  Reserved 2: 0x0000 (0)
  ▼ goosePdu
    gocbRef: SEL_451CFG/LLN0$G0$GooseDSet13
    timeAllowedtoLive: 2000
    datSet: SEL_451CFG/LLN0$DSet13
    goID: Sub1Bay2
    t: Mar 15, 2016 12:29:39.473267853 UTC
    stNum: 2
    sqNum: 12849
    test: False
    confRev: 1
    ndsCom: False
    numDatSetEntries: 1
    ▶ allData: 1 item
```

- **gocbRef** address of the information
- **timeAllowedtoLive** max time to the next retransmission
- **datSet** description of the information contents
- **goID** identifier of the message
- **t** actual time
- **stNum** State number is a message counter
- **sqNum** sequence number of repetitions
- **test** tells if the message is just a test not a true value
- **confRev** compatibility verification
- **ndsCom** tells about the configuration
- **numDataSetEntries** number of DataSet entries
- **allData** data of the GOOSE message

NOTES:

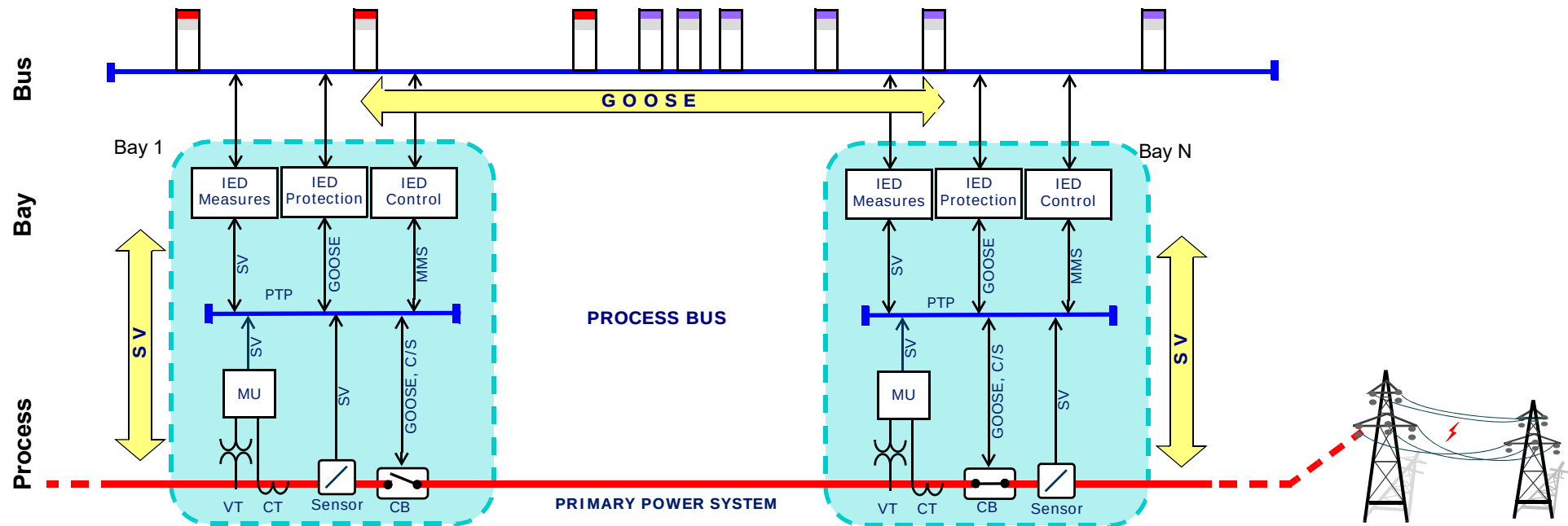
- 1.. if **timeAllowedtoLive** is greater subscribers can assume a communications failure
- 2.. **StNum + SqNum** can be used to detect intrusion (cybersecurity without encryption)
- 3.. if **test = true** indicates that the message is used only for test and simulations

Publisher & Subscriber



1. The IED publisher writes the values in a transmission buffer and multicast it over the substation local area network to the different subscribers sends the message without requirements and confirmation.
2. The prioritization of GOOSE over other traffic, requires switches supporting Priority in TAG field.
3. The Subscriber receives then process the messages. The reaction of IED Subscriber will depend on its configuration and functionality.

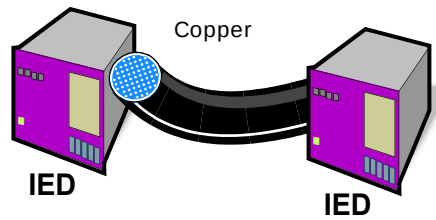
Heartbeat



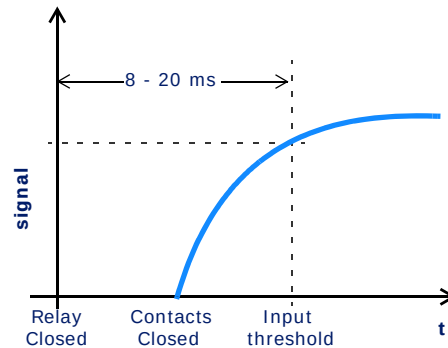
During normal operating conditions IED broadcast and retransmits GOOSE messages cyclically, this is the **heartbeat** of the substation. The health of the GOOSE messages are monitored closely to assure on-time delivery. A missing message is an indication for the **Subscribers** that the communication from the **Publisher** has become disturbed.

GOOSE messages are repeated to account for possible lost datagrams due to congestion or failure scenarios. IEC 61850 architecture prioritizes GOOSE and SV traffic to grantee high-speed avoiding degradations of layer 3 traffic which is used for normal Ethernet LAN traffic.

GOOSE vs. Hardwired



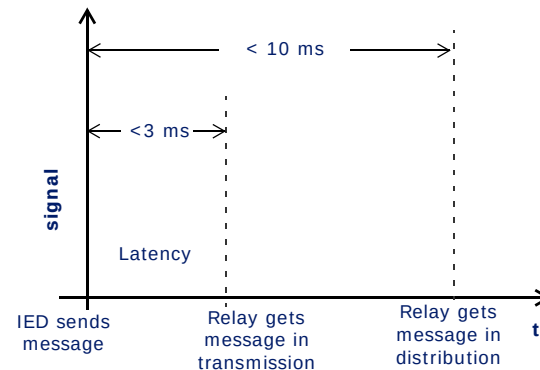
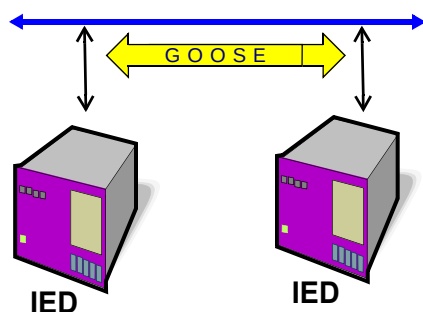
Hardwired Performance



The performance of hardwired solutions is based on relays that in the worst scenario the IED transfer time can be 3/4 of cycle (15ms) that is improved with GOOSE alternative below to 3 ms.

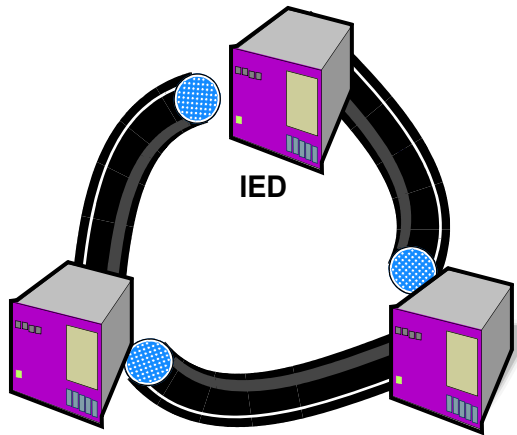
When a GOOSE message is generated by IED (IEC 61850 server), it uses a layer 2 multi-cast transmission to send the event on the network. The receiving devices, known as a subscriber, subscribe to the multicast address of the message to be able to quickly filter the information and execute the needed task(s).

GOOSE Performance

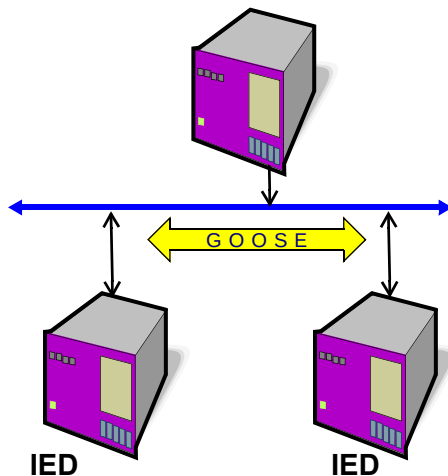


The requirements for a GOOSE message are stringent - no more than 4 ms to elapse from the time an event occurs to the time the message is received protection and control applications

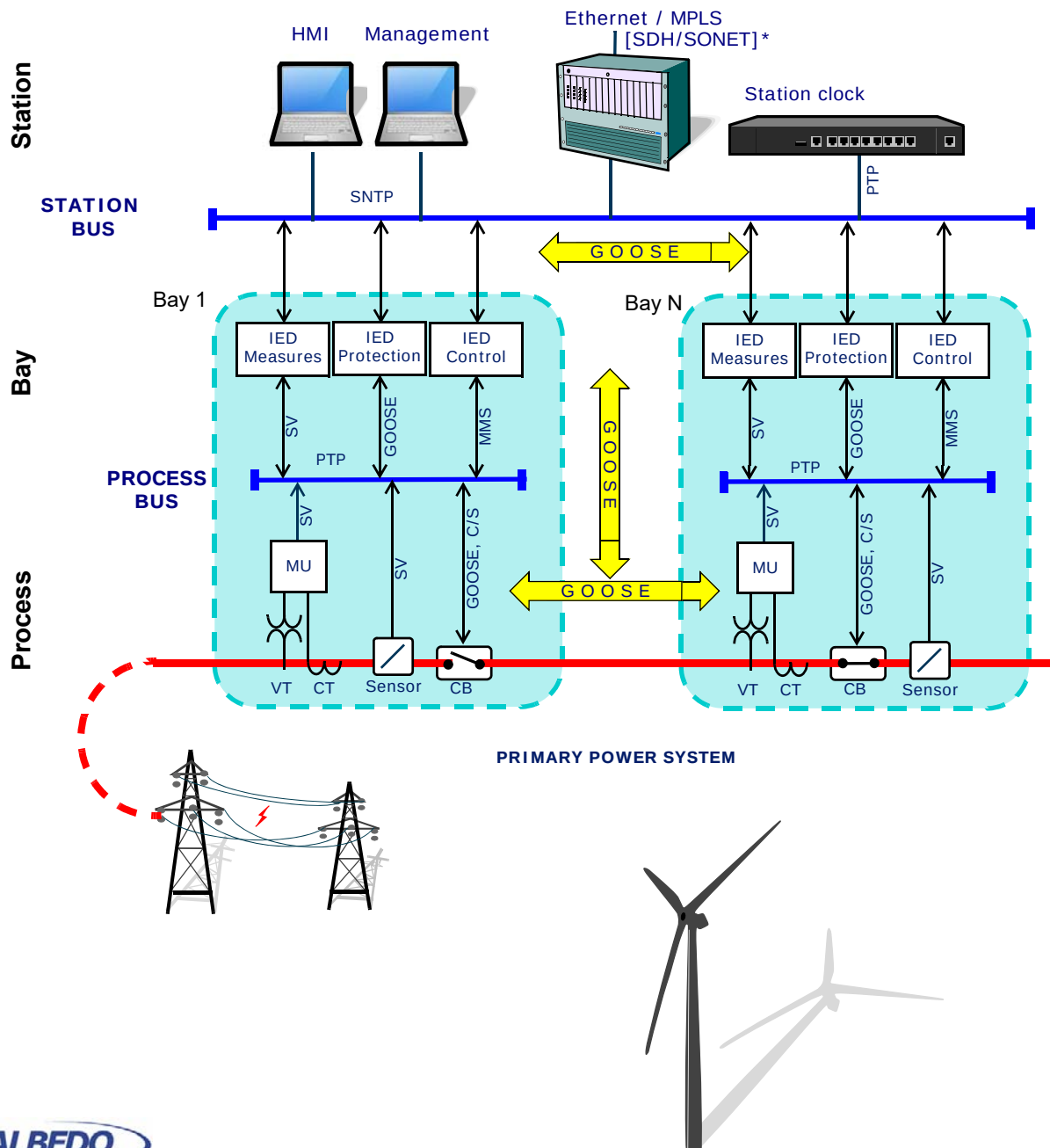
Binary outputs are hardwired



Relays communicating via GOOSE



1. **Installation Costs:** due to the replacement of thousands individual control copper cables with a limited number of fiber optic cables from the terminal blocks to the relay terminals with a single pair of fiber.
2. **Testing cost:** It makes easier the testing of all hardwired interfaces vs. Ethernet GOOSE messages.
3. **Flexibility:** using GOOSE messages and virtual signals of the SCL configuration language can be achieved without the need for physical presence in the substation.
4. **Multipoint:** a single message can reach multiple subscribers then simplifies the interconnection particularly when several IED are involved for instance in a protection operation.
5. **Interoperability** the use of standard improves the reliability on the subscription of both IEDs on each side of several manufacturers.
6. **Reduced Maintenance** hard wired connections cannot be monitored then verification of all interfaces between individual components of the protection and control system is expensive.
7. **Remote Testing** verification of IED require its testing before putting it back in operation. In the typical cases this requires sending a testing crew to the substation to perform the testing - a time consuming and expensive process. The use of protection systems in a digital substation environment allows the testing to be performed remotely, however the use of both sampled values and GOOSE messages is required for the end-to-end testing.

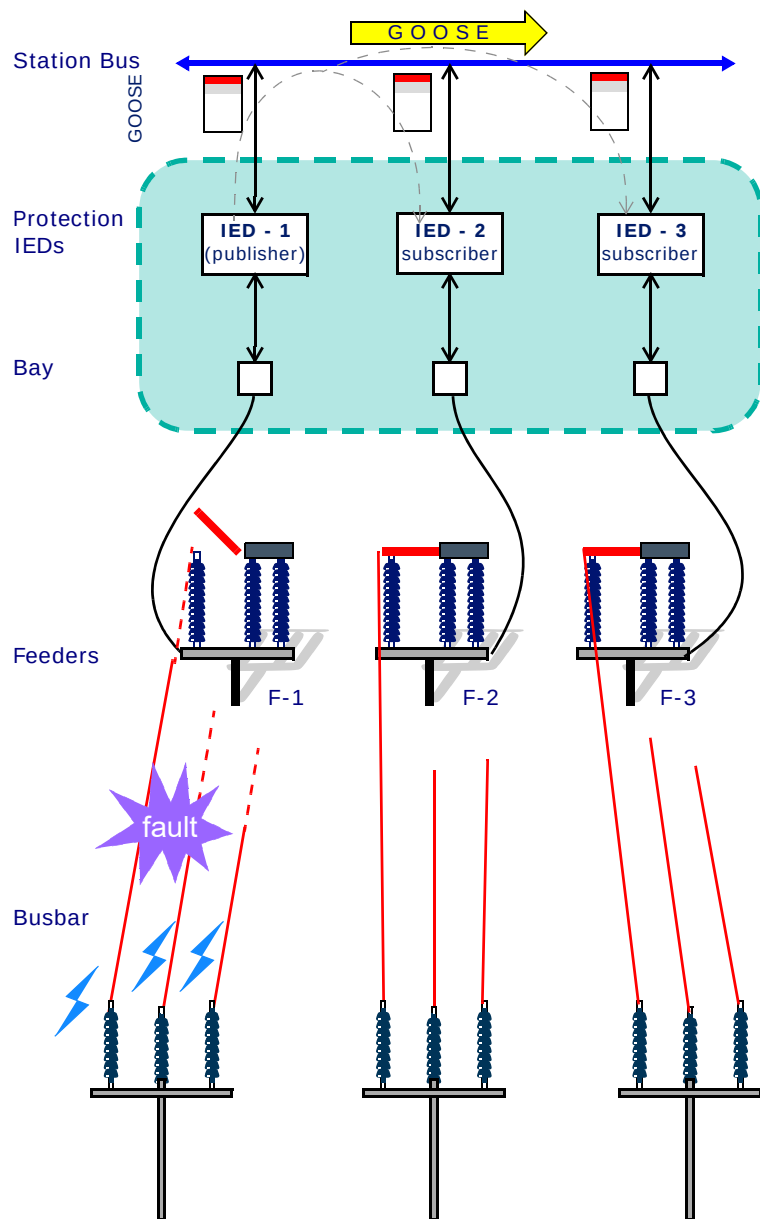


GOOSE most often applications is used for protection, control and automation of electric systems.

GOOSE messages subscribed by an IED can be used for internal data processing (eg, blocking logic) or to maneuver an output to the application (eg, trip order). The management and processing of GOOSE messages received are not part of the standard:

- Tripping of switchgear
- Sympathetic Trip Logic
- Starting of disturbance recorder
- Providing position indication
- Protection applications
- Remote Testing
- Load Shedding

Sample 1: Sympathetic Trip Logic



SUBSTATION

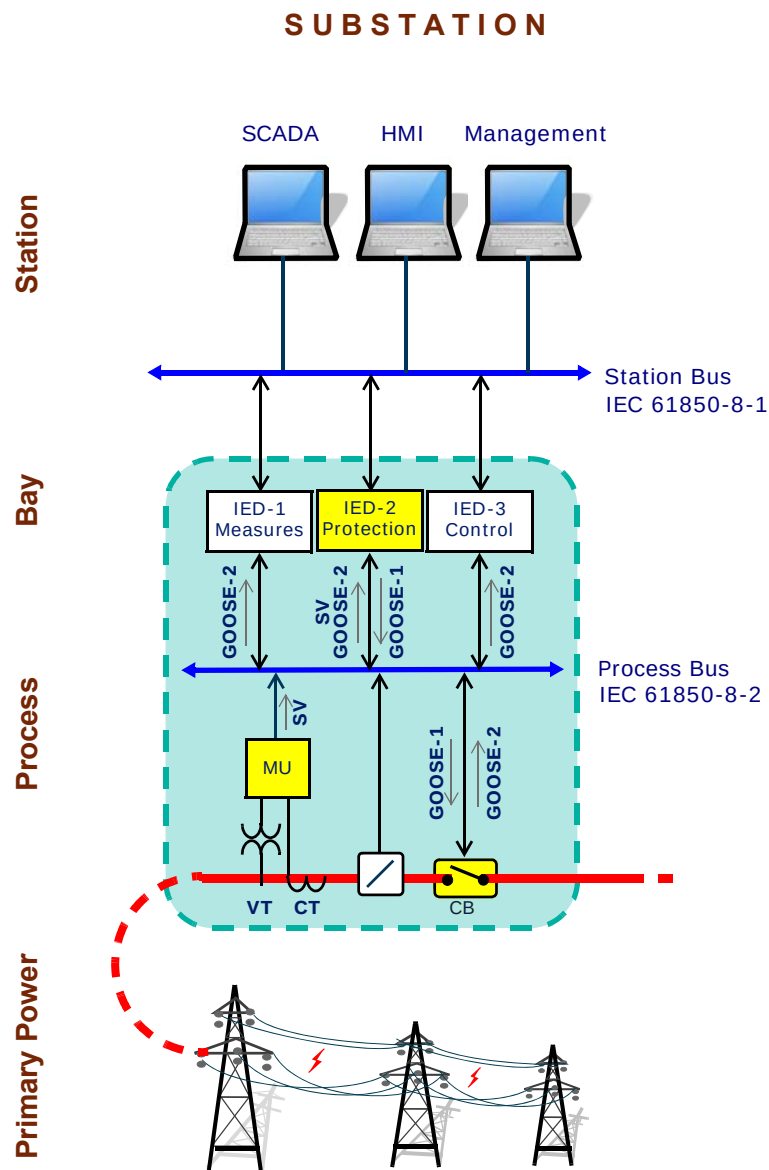
A fault causes a voltage drop on a feeder and, after the clearing of the fault, results in an inrush condition (a sudden arrival of energy) which may lead to a undesired operation of protection on the healthy feeders.

The IED-1 that protects Feeder-1, detects a fault and sends a GOOSE message to inform about an inrush condition will occur as a result of the voltage recovery after fixing the fault. Then the other IEDs protecting Feeder-2 and Feeder-3 adapt its settings expecting the coming inrush. They have two options:

1. Block the sensitive overcurrent setting
2. Reduce the sensitivity by increasing the pickup setting for the duration of the inrush

The benefit of using GOOSE messages is that doesn't need large number of wires between the inputs and outputs of all feeder IEDs, only need to publish/subscribe to messages from the adjacent IEDs.

Sample 2: SV & GOOSE



A **Merging Unit (MU)** accepts multiple analogue current and voltage samples coming from the VT and CT current and voltage transformers which are connected directly to the power line.

MU act as an analogue-to-digital-converter converting the samples into digital format and encapsulating them along with meta-data to put these measurements in context as SV packets, and sends them over the Process Bus to IED-2 that extracts the samples and measures to detect evidence of a fault.

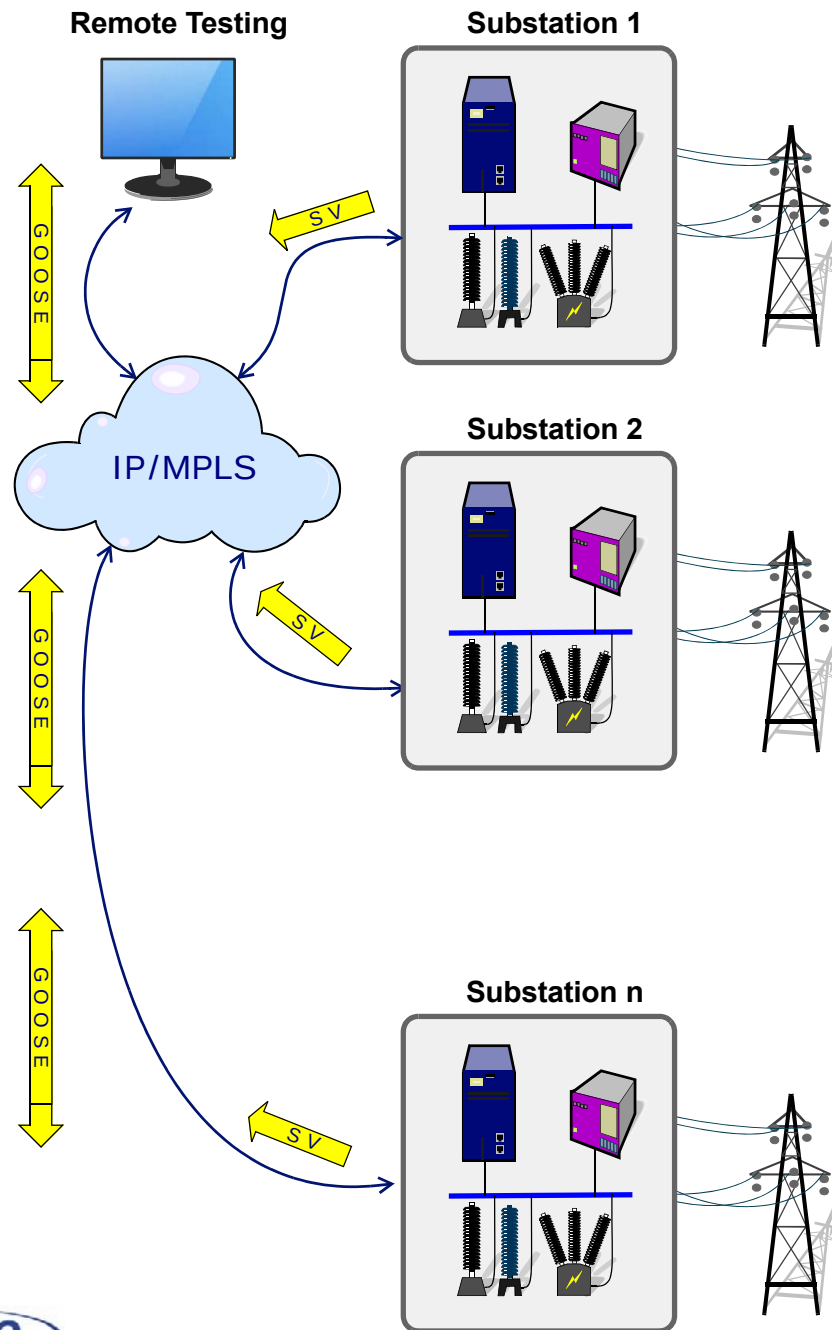
If the outcome of the examination is positive, it issues a Trip order encapsulated as **GOOSE message-1** to the **Circuit Breaker (CB)** which then trips the appropriate switchgear and isolates the fault.

Afterwards, CB advises other IED of the action by issuing a **GOOSE message-2**. The exchange of time-critical messages described above is based on the publisher/subscriber messaging model in which one or more IED subscribe to the publisher stating that they want to be notified of a particular event (in this case, to act as sinks for SV or GOOSE packets).



A virtual private LAN service (VPLS) has been configured to transport the Ethernet-layer SV and GOOSE data over the (emulated) wide-area IP/MPLS network. An “e-pipe” service would also be suitable for this application. It is also possible to encapsulate SV and GOOSE packets within routable layer-3 IP packets (IEC 61850-90-5) this is not necessary for a pure IP/MPLS network (which also has the benefit of constant latency due to the deterministic label-switched paths and packet prioritisation).

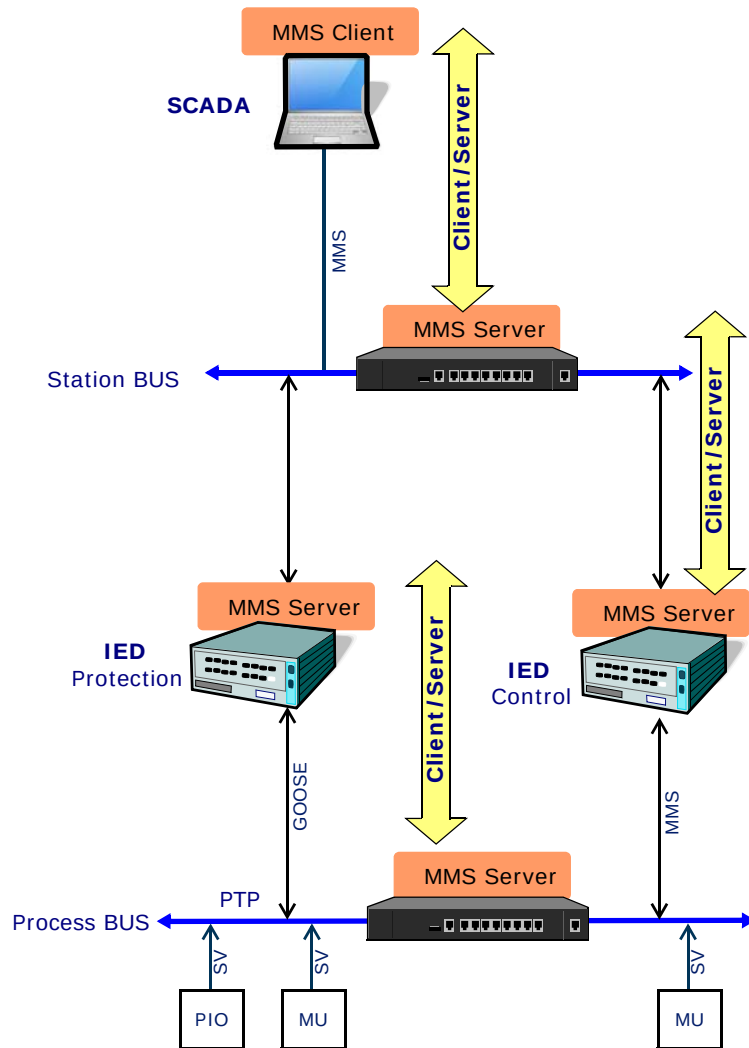
Sample 3: Remote Testing



Since IEC 61850 Edition 2 – the **Simulation bit** in the GOOSE message and the different modes of the tested function elements play a critical role in the verification of Utility systems including the ability to **remotely test** a subset of functions and their elements while keeping the rest of the **system in service**.

Simulation is a parameter that indicates that the GOOSE message is used for test purposes (if TRUE) in this case values of the message have been issued just for simulation and shall not be used for operational purposes. The GOOSE subscriber will report the value of the simulated message to its application instead depending on the setting of the receiving IED.

Maintenance testing in cases such as IED mal-operation require its testing before putting it back in operation. In the past it required sending a testing crew to the substation to perform the testing which is an expensive process. The use of **protection systems** allows the testing to be performed remotely in this case SV and GOOSE is required for the end-to-end testing.



MMS is used by the applications to **transfer data** between substation levels, communicating IEDs and SCADA systems to move the information such as device status, obtain reports, data acquisition in order to monitor and get control.

MMS uses **Client-Server method** to interchange no-critical information. The communication is done through a direct connection by means of commands and messages covering large geographical areas.

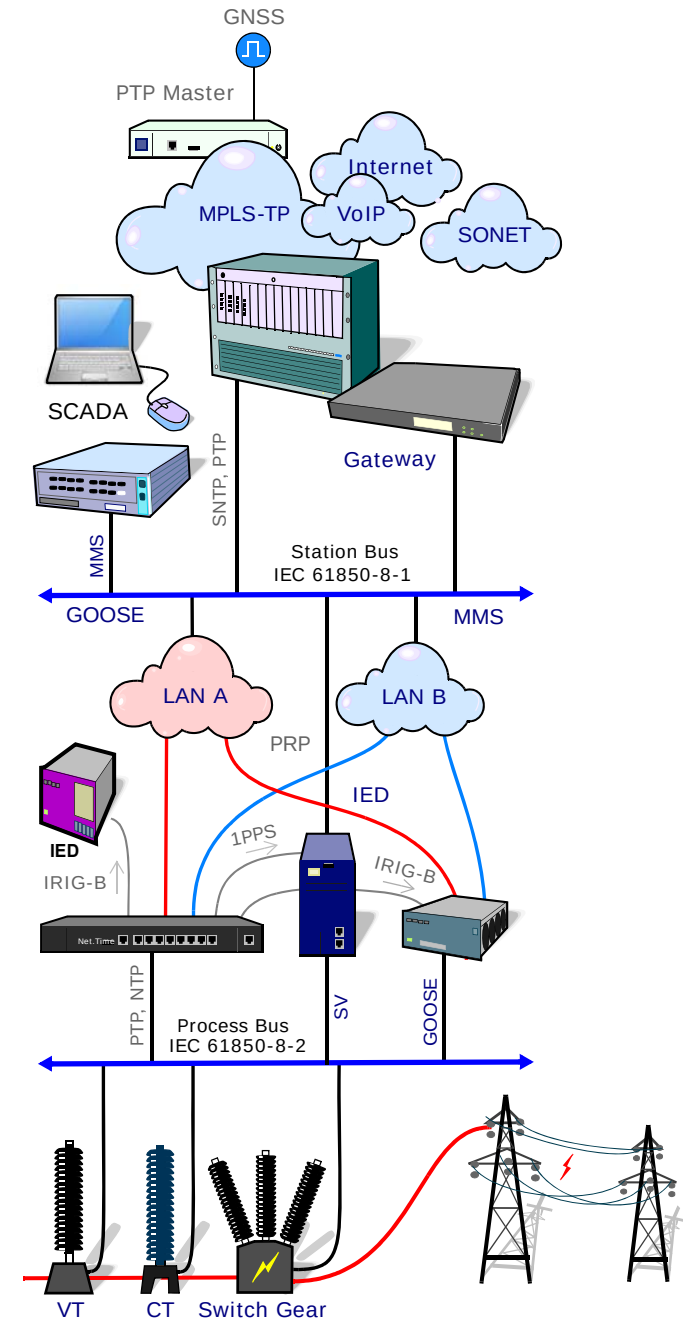
An IED acts as a **MMS server** and then transmits data the local station control system is then a connected client. The information contained in the "data set" of the IED (i.e. values of actions, triggers, position feedback, etc.) is transferred in a report to the **MMS client** in this case the SCADA system whenever a trigger condition is met for example a data change.

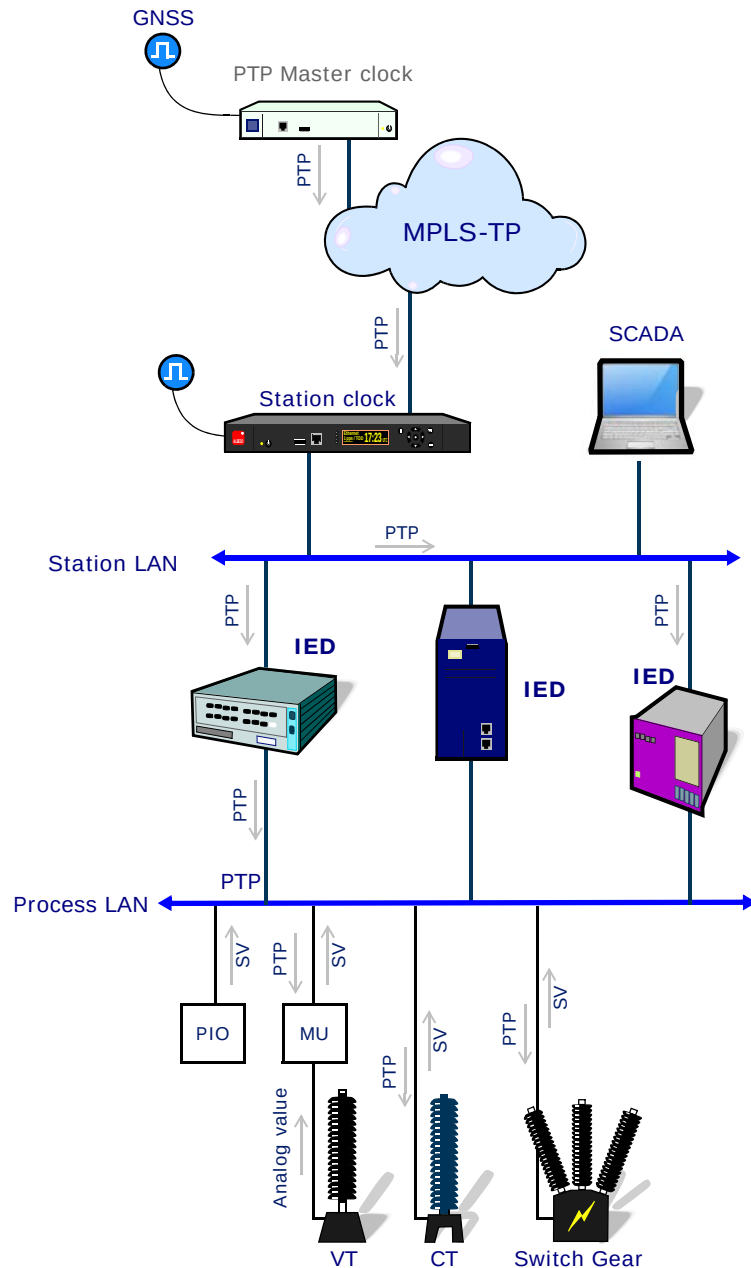
The communication with SCADA is based on TCP / IP.

Time synchronization helps to achieve accurate control and precise analysis when, where and why any fault have occurred to generate the correct response. The following applications require time synchronization:

- IEC 61850 protocols like SV, GOOSE and MMS
- Real-time data acquisition from IEDs, RTUs and MUs
- Management applications such as SCADA
- Protection process and devices Relays, Switchgears
- Events recording for fault and performance analysis

SNTP (a simplified version of NTP) which can provide a milisecs range of precision, is good enough for the station bus to synchronize SCADA and Ethernet switches but is not for the Process Bus with GOOSE and SV messages and devices that require an accuracy of microsecs. For these high demanding applications there are only two options GPS/GNSS or PTP.





IEDs require accurate synchronization, unfortunately SNTP does not satisfy the needs of all applications.

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.

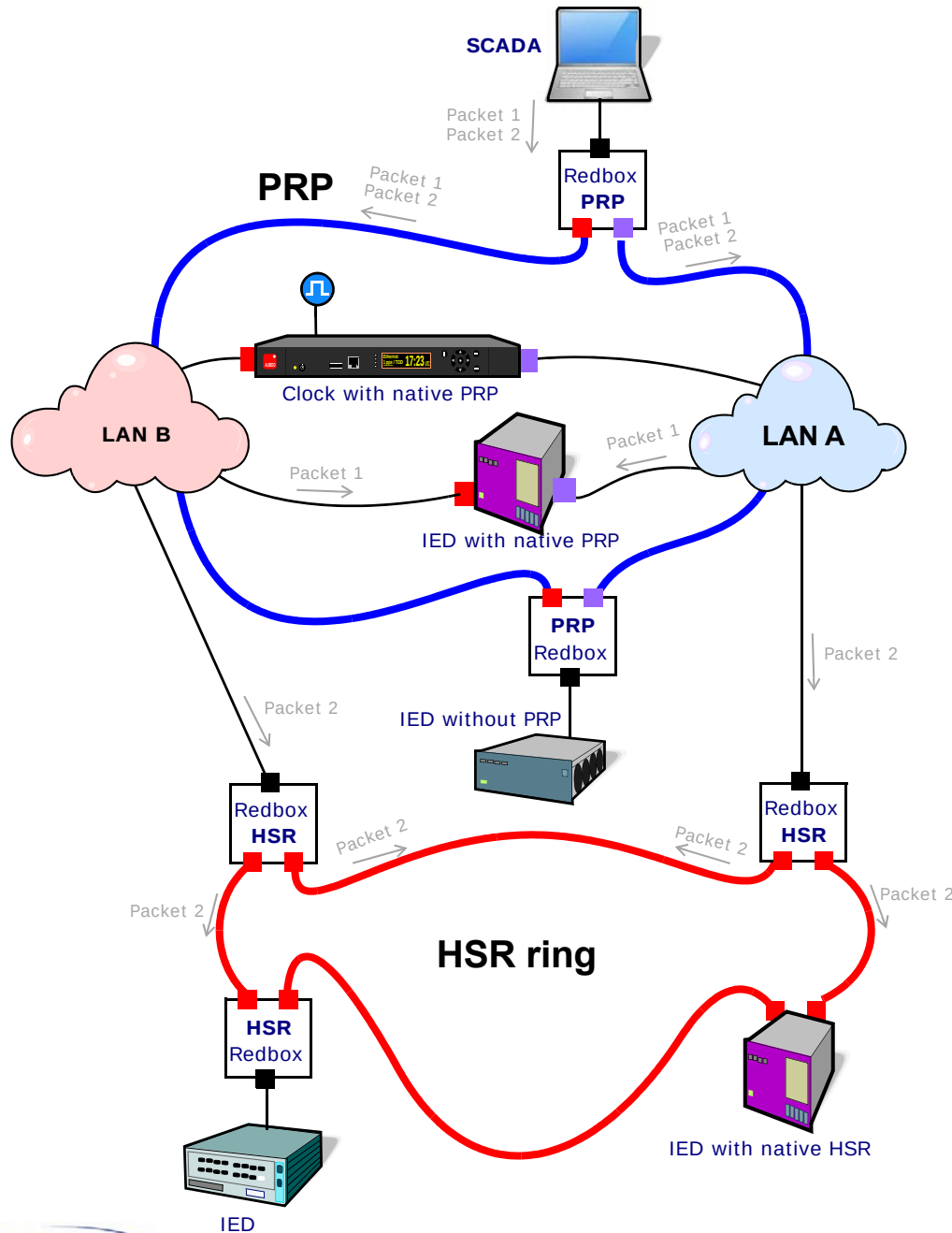
Application	Accuracy	Timing
PMU	1 μ s	Absolute
Protection	1 μ s	Relative
SV	1 μ s	Relative
SCADA	1 ms	Absolute

Phasor Measurement Units (PMU) are not part of the IEC 61580 but the C37.1188 standard. PMUs are deployed across the grid for analyzing the quality of the power service by measuring magnitudes such as phase angle, line voltage and current waveforms in real-time. Values are collected at 30 to 120 samples/s, time-stamped with UTC and sent to data servers. Information is processed comparing many different points to know the situation, to load balance and to prevent faults. Synchrophasors have indeed timing needs due to high-frequency reporting, the wide geographic distribution and the large number of PMUs.



(*) Problems are produced by interferences and installation faults cause significant concerns about the reliability of satellite timing. Common issues include storms, satellite decommissioning, poor antenna installations, receiver failures, terrestrial or spacial interferences, and malicious spoofing that may send false timing to receivers that in some extreme cases, this could cause operational problems for the electric grid.

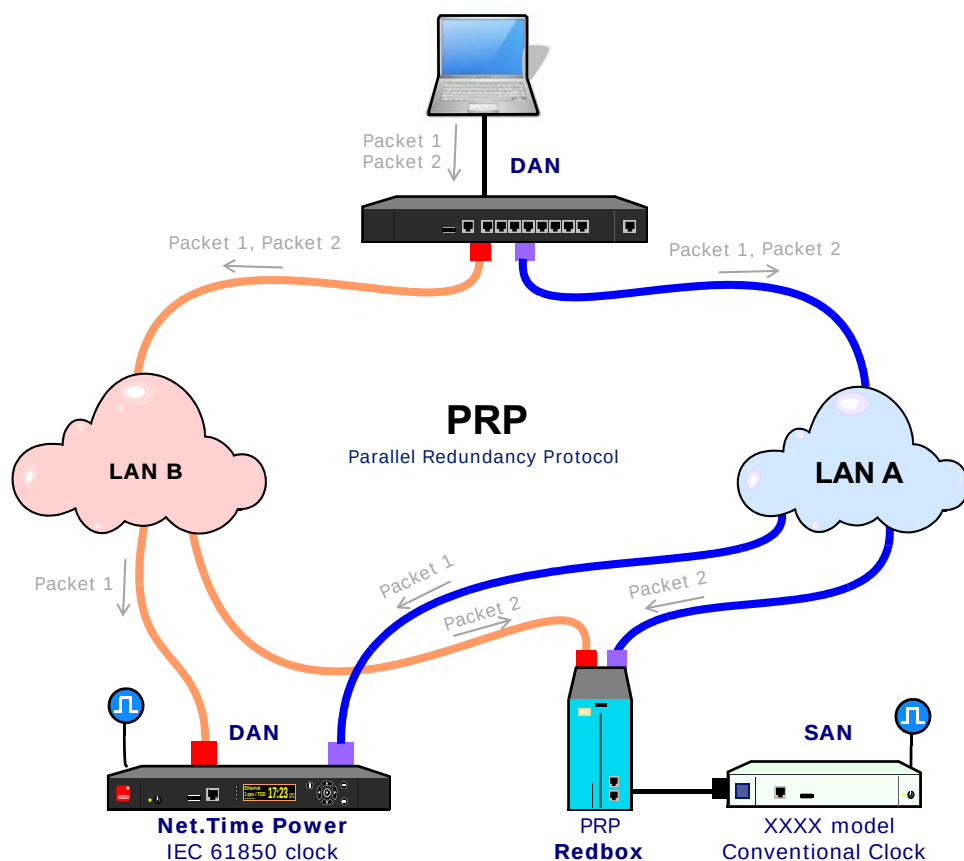
PRP - HSR network redundancy



Network redundancy is crucial for maintaining **high network availability**, and many redundancy technologies can provide millisecond-level recovery. However, some mission-critical and time-sensitive applications **cannot tolerate** even a **millisecond** of network interruption without severely affecting operations or jeopardizing the safety of on-site personnel.

Parallel Redundancy Protocol (**PRP**) and High-availability Seamless Redundancy (**HSR**) provide **seamless failover** from a single point of failure. PRP realizes active network redundancy by packet duplication over two independent networks that operate in parallel, whereas HSR is designed primarily for ring topologies.

Based on these two seamless redundancy protocols, a redundancy box (**Redbox**) can quickly activate non-HSR or non-PRP devices connected to HSR or PRP networks with zero switch-over time.



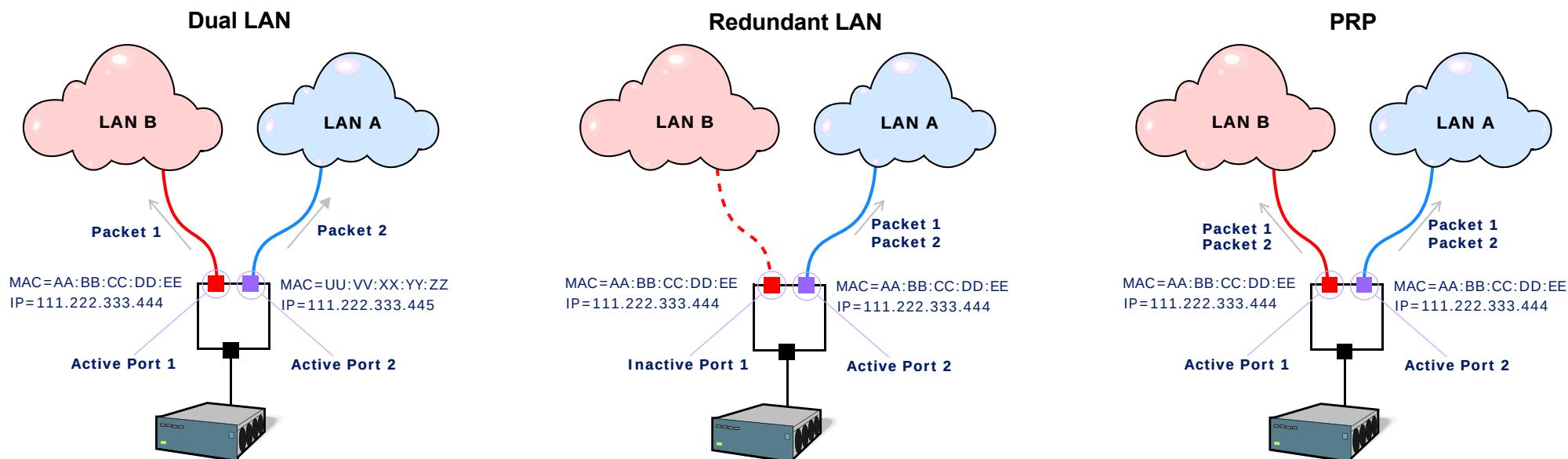
PRP is based on the use of two independent networks. The sender **must send each packet twice** (to LAN A and LAN B) through two separate ports.

The latency of both networks should be similar, if they were very disparate packets would always arrive first through the same network and wait for the second.

We can find two types of devices:

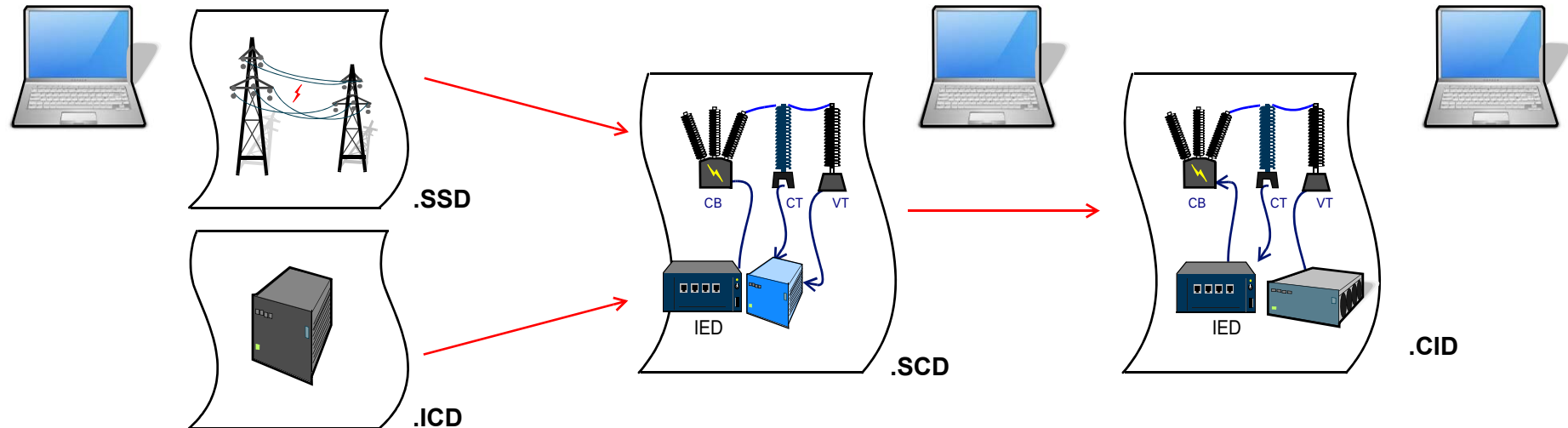
- **DAN** (Double Attached Node) if has PRP support is integrated, then can be attached directly
- **SAN** (Single Attached Node) conventional device without PRP support then a Redundancy Box (redbox) is required to be connected.

PRP is encapsulated in IP/MAC then it can use conventional networks so LAN A and LAN B can transport any traffic, PRP and non-PRP, and this a nice advantage compared with HSR.



PRP is based on the use of two independent networks: LAN A & LAN B

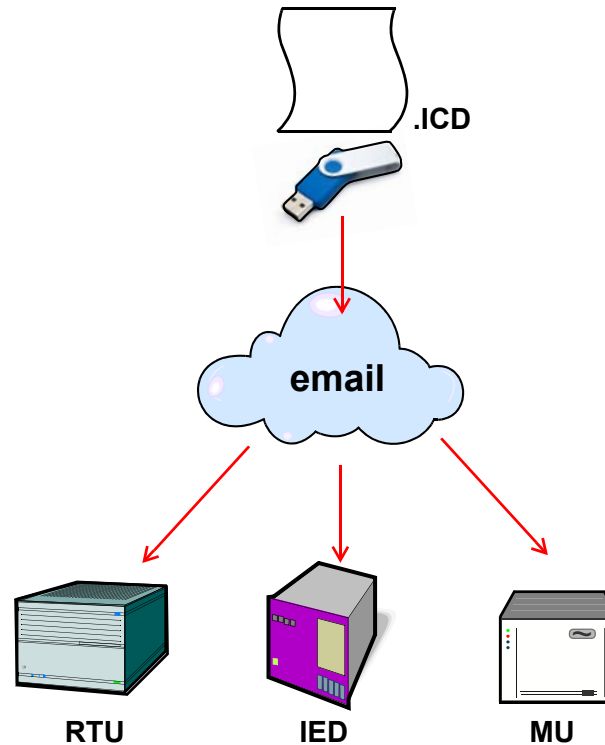
- Exactly the same frame (MAC & IP) is sent twice through two networks
- Latency in each LAN should be similar but not equal (if were very different we would always get the frame through the same network)
- PRP is encapsulated in MAC frames, then it is transparent, then PRP and no-PRP devices can communicate each other.



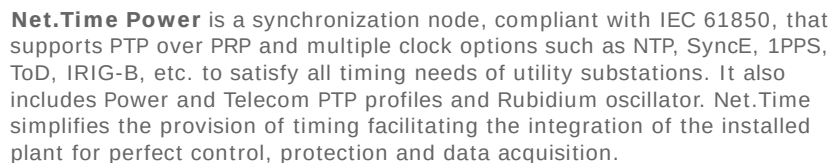
The **Substation Configuration Language** (SCL) specified by IEC 61850 for the configuration of substation includes representation of modeled data to have a complete interoperability:

- **Logical Node:** the smallest part of a function that can exchange data. For instance a XCBR has a the data structure called POS that tell its position (closed, open, intermediate). It has several attributes that belong to a function class. The all manufactures must implement this function.
- **Logical Device:** group of logical nodes. For instance we can group PIOC (instantaneous current) with PIOTC (Time Current) and the a logical IED groups several logical devices.
- **ECL language:** the SSD substation description.
- **ICD capabilities** description of the substation as the addition of all IED.
- **SCD:** Substation Configuration Description is the combination of the SSD and ICD defining also all the relations between IED.
- **CID:** individual configuration of each IED that can be transfer to individual IED.

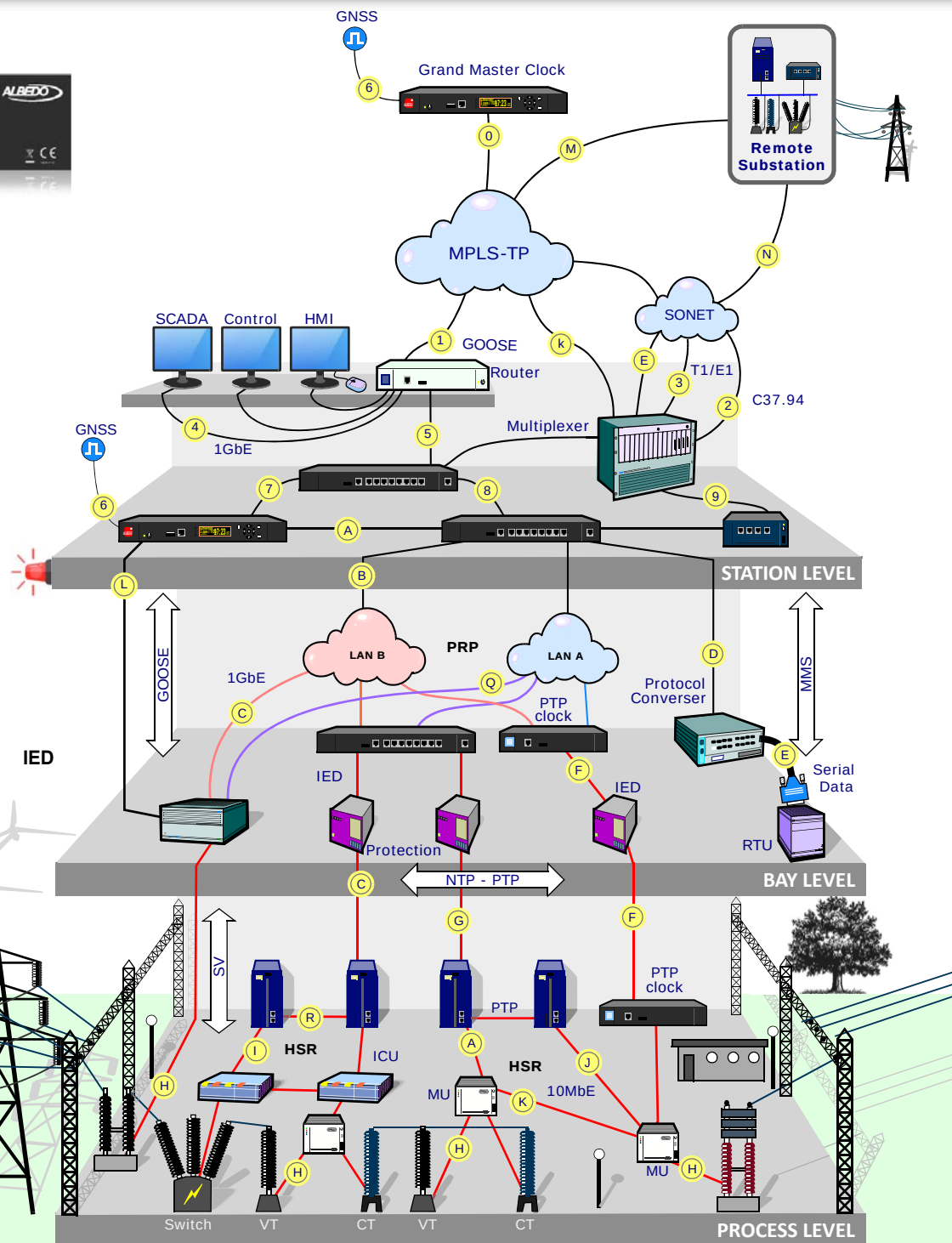
SCL allows to perform the IEC 61850 engineering using standard tools topics include importing and exporting SCL file formats, the IED modification capabilities described in the standard and the communication and data flow configuration.



- SCL is the basis for the success of Plug & Play to simulate configurations
- SCL provides a common object and description
- SCL allows configurations set up and distribution via e-mail



Zeus provides deep insights to design, install, maintain, troubleshoot and engineer communications infrastructures of the Smart Grid. The unit is able to test Ethernet/IP, PTP, GbE, IRIG-B, T1/E1, G703, C37.94 and GOOSE, SV and MMS protocols. One-way-delay tests, assisted by GPS, is possible at all interfaces. Zeus has a set of programmable filters to capture live data traffic at wire-speed. You can now analyze GOOSE, SV, MMS and other protocols to decode and save them in PCAP format or calculate propagation delay from local or remote substations.

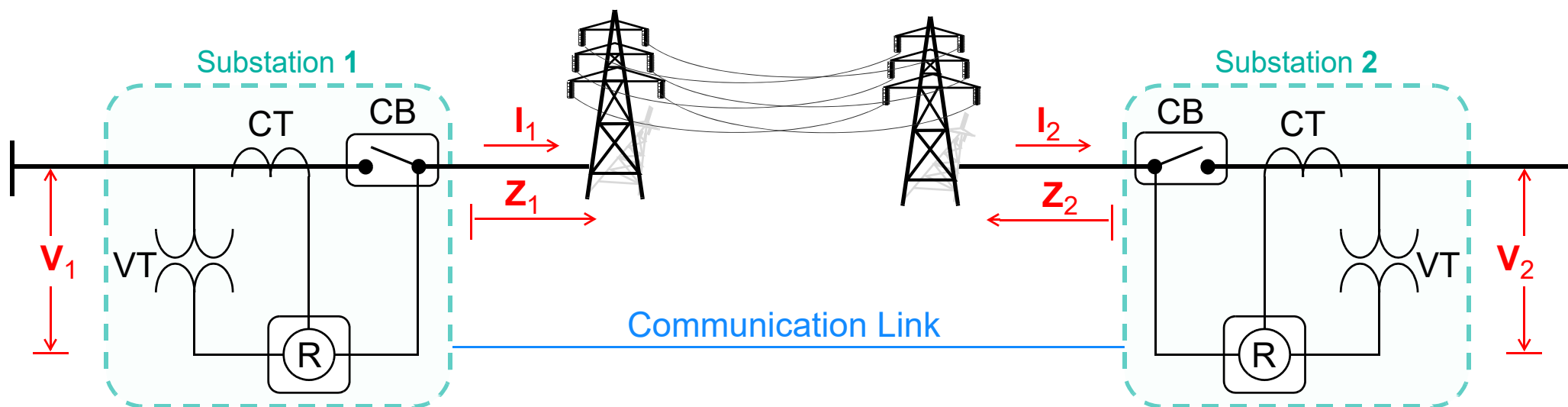




A secure and uninterrupted supply of electricity is only possible with the help of comprehensive protection and control functions which ensure the reliable operation of the power system. Protection schemes have the objective of keeping the Power System **stable and isolated** from natural events (storms, earthquakes, animals, winds), equipment failure, mis-operation... that may damage power grid elements:

- Power Generators
- Transformers in Plants and Substations
- Capacitors
- Power Lines (transmission & distribution)

Each component has its **particular way of protection** (fuse, differential, relay, disconnection...)



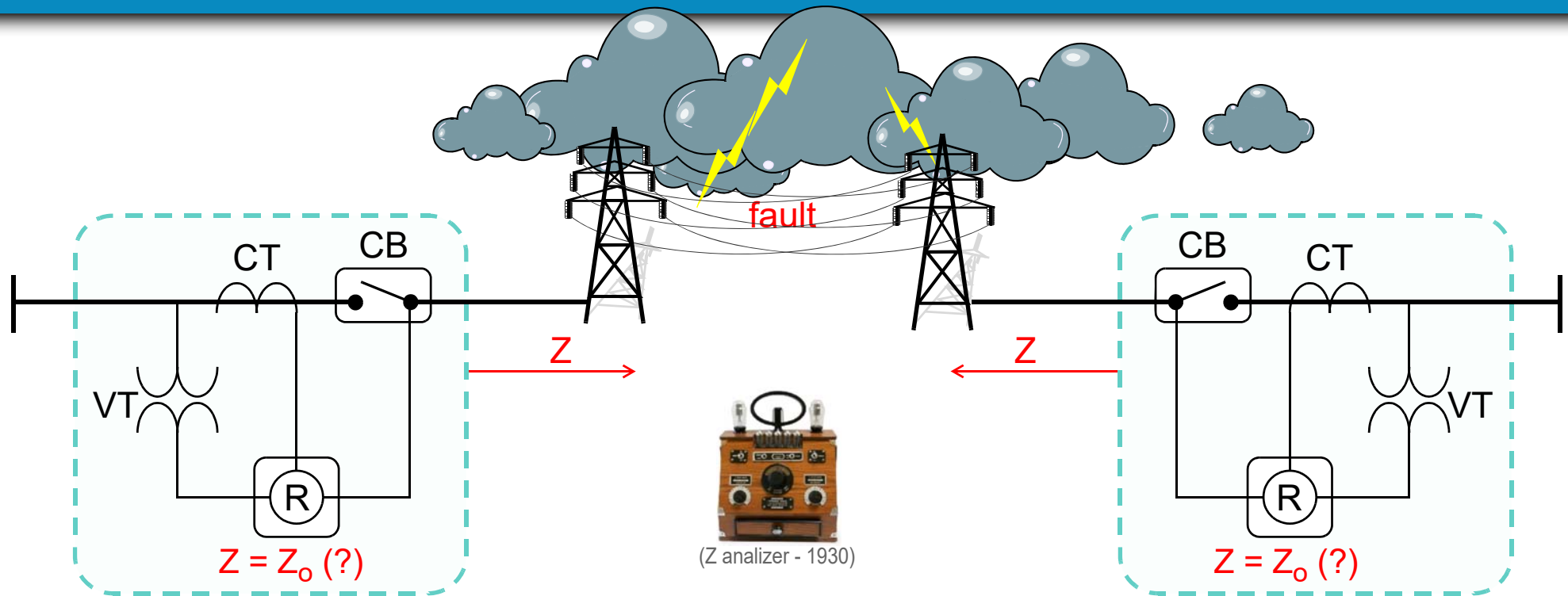
There are several line Protection schemes based on the measurement of electric values:

1. Stand-alone schemes:

- **Overcurrent:** Relay responds to overcurrent condition read on CTs indicates tripping to CB
- **Directional Overcurrent:** Relay responds to overcurrent condition in the forward direction only
- **Impedance:** Relay responds to Z_i changes measured at CT and VT

2. With communication link between Switchgears:

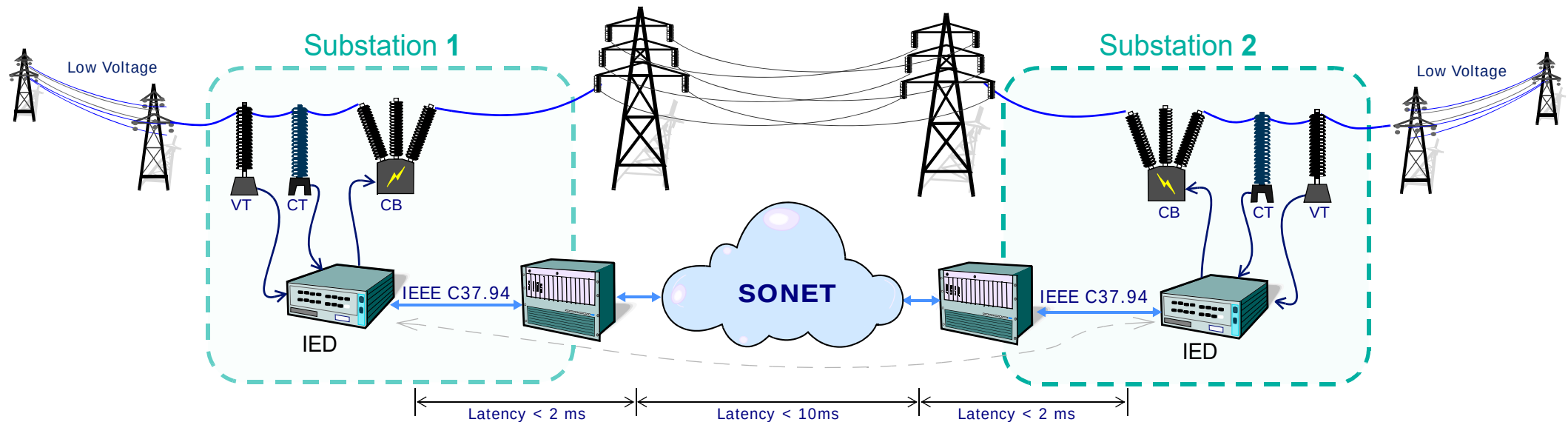
- **DCB** (Directional Comparison Blocking): CB tripping is allowed unless a block signal is received
- **POTT** (Permissive Overreaching Transfer Trip): CB tripping is allowed only if a signal is received
- **Line Current Differential:** current at I_1 is compared with the going I_2



Impedance $Z = V / I$ that is obtained measuring Voltage (V) at VT and Current (I) at CT.

Z_0 is the initial set up of the line, then protection responds when actual $Z \neq Z_0$ assuming then that there is a fault and the relay signals to the circuit breaker (CB) to cut the line and isolating the fault.

Incoming lines have a circuit breaker used as a protection device to interrupt fault currents automatically, and may be used to switch loads on/off, or to cut off a line when power is flowing in the 'wrong' direction. When a large fault current flows through the circuit breaker, this is detected through CT/VT transformers



Tele-protection: protection schemes aided by tele-communications

Tele-protection relays on communicate between substations to isolate faults of the electrical plant. The reliability of the links is critical and must be resilient to the effects encountered in high voltage areas such as high frequency induction and ground potential rise.

The IEEE C37.94 is a TDM standard defines a Nx64 Kbps ($N = 1 \dots 12$) multi-mode optical fiber interface between tele-protection and digital multiplexer equipment, for distances of up to 2km. Allowing protection relays with C37.94 compliant interfaces to be directly connected to the unit.

GOOSE is nextgen teleprotection

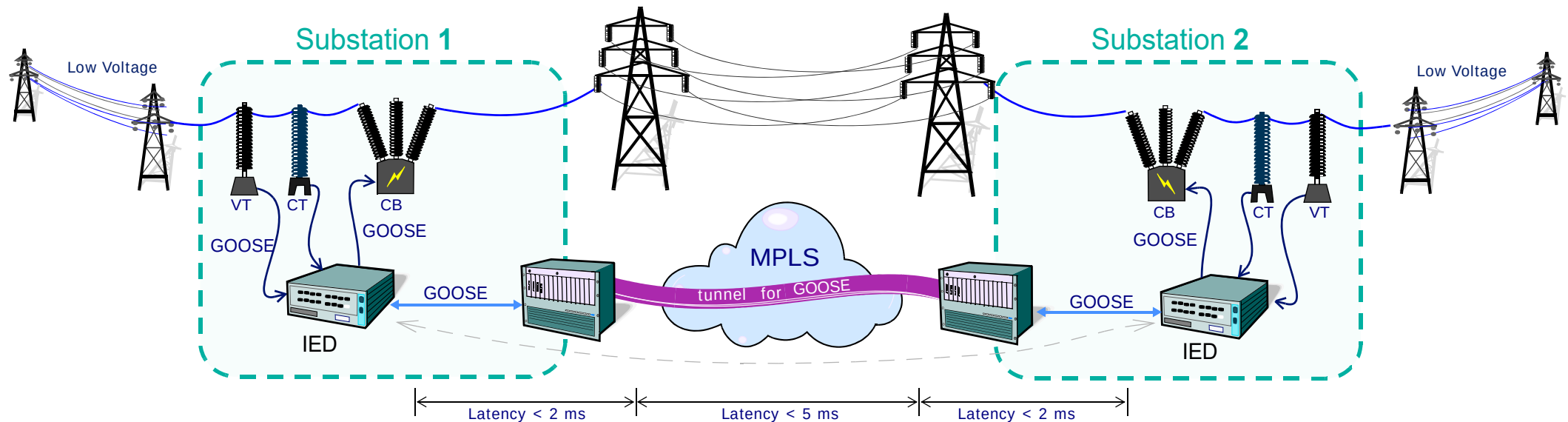


Table IV: Comparison of protocol trip times and bandwidth

	IEEE C37.94	IEC 61850 SV and GOOSE
Fault occurs (ms)	0.0	0.0
Trip message sent (ms)	<i>n/a</i>	23.4
Circuit breaker tripped (ms)	28.4	24.9
Backup intertrip (ms)	39.5	24.9
Bandwidth used (Mbps)	0.5	5.4

GOOSE is a Layer 2 protocol (not routable) used by IEDs send messages inside the substation LANs, nevertheless using MLPS it can be extended to remote substations and Tele-protection. MPLS facilitates GOOSE traffic through the WAN extending the LAN thus IEDs can exchange information with remote devices at remote substations:

- MPLS means good performance particularly on latencies that are critical for GOOSE
- GOOSE/MPLS architecture it is very scalable and inter-connectable with devices from different vendors.

AAA: Authentication, Authorization, and Accounting
ACL: Access Control List
AP: Access Point
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
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
DMZ: Demilitarized Zone
DCS: distributed control systems
DSC: Differentiated Services Code Point
ESP: Electronic Security Perimeter
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
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 against voltage surge
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, current...) 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 overcurrent Protection
PLC: Programmable Logic Controller
PMU: Phasor Measurement Unit
Process Bus: Connects primary measurement and control equipment to the IEDs.
PRP: Parallel Redundancy Protocol
PT: Potential Transformer, gives the reference voltage to the Relay for Over-voltage or Under-voltage Protection.
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
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
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 used for passing measured samples from sensor units, like CTs, VTs or digital I/O sharing between IED devices. Los Sampled Values (SV) se utilizan para transmitir valores instantáneos como corrientes y tensiones primarias y se publican en la red de la subestación y están disponibles para que cualquier dispositivo que pueda utilizarlos.
Switchgear is the combination of switches, fuses or CB to control, protect and isolate electrical equipment.
TLV: Type, Length, Value
UCA IuG: Utility Communications Architecture International Users Group
VDAN: Virtual Dual Attached Node

Symbols

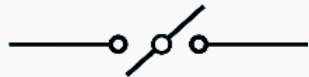
Busbars



Single-break isolating-switch



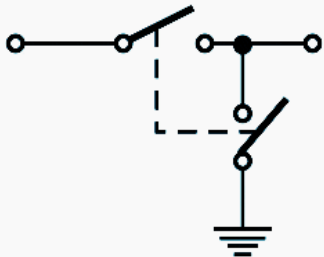
Double-break isolating-switch



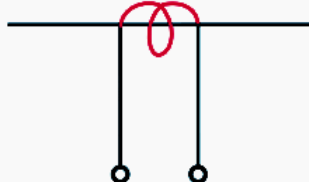
On-load isolating switch



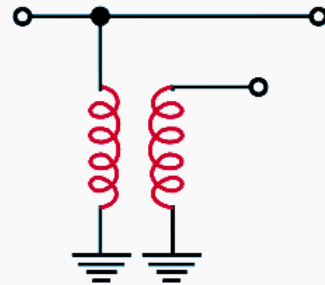
Isolating switch with earth blade



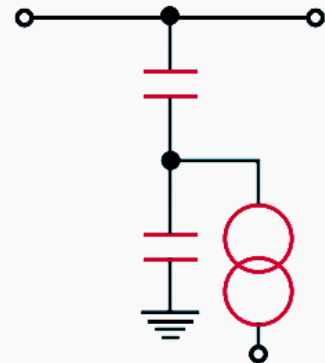
Current transformer (CT)



Potential (voltage) transformer (PT or VT)



Capacitive voltage transformer (CVT)



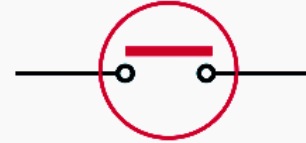
Oil circuit breaker



Air circuit breaker with overcurrent tripping device



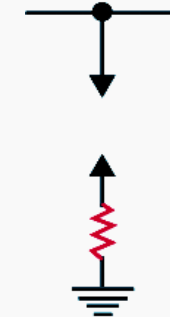
Air-blast circuit breaker



Lightning arrester (active cap)



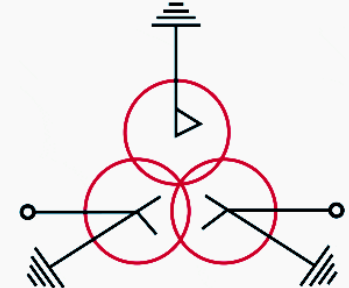
Lightning arrester (valve type)



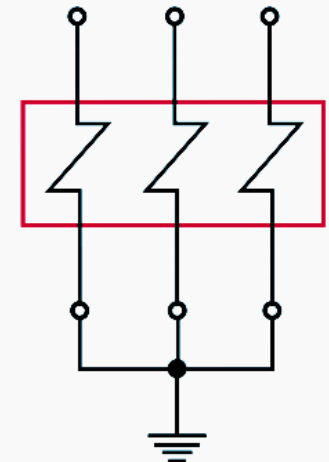
Arcing horn



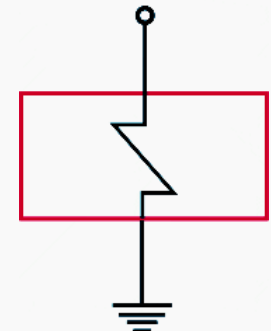
Three-phase transformer



Overcurrent relay



Earth fault relay



That's all



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