U.S. DEPARTMENT OF
ENERGY

Electricity Delivery
& Energy Reliability

American Recovery and
Reinvestment Act of 2009

Use of IEC 61850-90-5 to Transmit Synchrophasor Information According to IEEE 37.118

NASPI Tutorial, October 16, 2012
August 2014 Update

NASPI Synchrophasor Technical Report

NASPI Synchrophasor Technical Report
NASPI IEC 61850-90-5 Tutorial
October 16, 2012
Summary and Update

Introduction and overview

This report offers an overview of the technical interoperability standards applicable to synchrophasor technology and substation automation, with a principal focus on IEC 61850, the substation automation standard. The IEC, International Electrotechnical Commission, is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies. Synchrophasor communications are addressed in IEC 61850-90-5[1], which was adopted in 2012. But it is important to understand the broader framework established in the suite of IEC 61850 standards to understand and use the synchrophasor-specific standard effectively.

The North American SynchroPhasor Initiative (NASPI) held a tutorial on IEC 61850 in October 2012. This report summarizes that workshop and explains briefly how this standard relates to other synchrophasor technical standards.

NASPI is a collaboration between the North American electric industry (utilities, grid operators, vendors and consultants), the U.S. Department of Energy, the Electric Power Research Institute, the North American Electric Reliability Corporation, and academics, to advance and accelerate the development and use of synchrophasor technology for grid reliability and efficiency. The material attached was produced for one of a series of NASPI technical workshops intended to educate and document the stakeholder community on the state of the art for key synchrophasor technology issues.

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[1] The formal title of Standard IEC 61850 is, "Power Utility Automation"; IEC 61850-90-5 is, "Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118".

<u>The Department of Energy and synchrophasor technology</u>

Synchrophasor technology was developed thanks to early research efforts by the U.S. Department of Energy and Bonneville Power Administration in the 1990s. With recognition that synchrophasor technology -- high-speed, wide-area, time-synchronized grid monitoring and sophisticated analysis -- could become a foundational element of grid modernization for transmission system, the Department continued and expanded its investment and industry partnership in the areas of synchrophasor measurement devices, communications, applications, measurements, and technical interoperability standards.

In 2009, the Department committed a total of $412 million of funds from the American Recovery & Reinvestment Act of 2009 to twelve Smart Grid Investment Grants and one Smart Grid Demonstration Project that implemented and tested synchrophasor technology using matching private funds. While some of the ARRA funds were spent on other transmission assets, in aggregate over $328 million of federal and matching private investment was spent on synchrophasor technology and related communications networks.

Additionally, DOE has funded significant technical assistance for NASPI and synchrophasor advancement through the National Laboratories and the National Institute for Standards & Technology, including funding to accelerate smart grid technical standards development -- including those for synchrophasor technology.

NASPI serves as a forum for information-sharing and problem-solving among the synchrophasor projects and stakeholders. Much of the work and insights reflected in this technical workshop were enabled by individuals and companies funded by DOE's on-going research and development projects and the ARRA investments. Thus it is appropriate to recognize the insights and work product documented in this workshop and technical report as one of many consequences and work products resulting from the federal Smart Grid investments. Therefore, the Department joins NASPI in re-releasing this material to the smart grid community to document additional impacts and value realized from the federal Smart Grid investments in synchrophasor technology.

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IEC 61850 and the NASPI tutorial

In November 2012, the North American SynchroPhasor Initiative held a tutorial led by expert members of the synchrophasor standards update group to explain the benefits of using IEC 61850 and some of the technical details behind the standard's structure and use. This document summarizes the presentations and comments made during that tutorial.

The expert presenters at this tutorial were:

- Vahid Madani (PG&E)
- Ron Farquharson (Enernex)
- Mark Adamiak (GE Energy)
- Ralph Mackiewicz (Sisco)
- Herbert Falk (Sisco)
- Christoph Brunner (**it**4power)
- Farnoosh Rahmatian (Quanta Technology)

The tutorial agenda and documents presented are posted at https://www.naspi.org/techworkshops and attached behind this summary. The full tutorial was videotaped and can be accessed at the same link.

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[2] The formal title of Standard IEC 61850 is, "Power Utility Automation"; IEC 61850-90-5 is, "Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118".

Synchrophasor technology and standards

Synchrophasor technology monitors electrical waves on the grid and synchronizes those measurements to a common time source. It characterizes grid conditions by calculating phasors (amplitude and phase) at a rate of 30 or 60 samples per second (1,800 samples per minute, compared to SCADA's 12 to 15 samples per minute). Phasor measurement units (PMUs)[3] measure or calculate frequency, voltage, current and phase angles, time-synchronized across the grid. These measurements, taken from diverse points across the grid, allow unprecedented visibility and better situational awareness of real-time grid conditions. Analysts can use synchrophasor data to analyze dynamic grid events and to improve static and dynamic models of grid assets such as generators.

Although synchrophasor concepts were developed in 1893, the first PMU was developed in 1988 and the first commercial PMU became available in 1992. The first technical standard developed to describe PMUs and guide synchrophasor measurements was IEEE 1344-1995.[4] It was superseded by IEEE C37.118-2005, which covered synchrophasor measurement, quantification and test specifications and defined PMU data transmission formats. IEEE, the Institute of Electrical and Electronics Engineers, is the world's largest professional association dedicated to advancing technological innovation and excellence for the benefit of humanity.

In 1995, the International Electrotechnical Commission began work on IEC 61850 as a standard for design of electrical substation automation systems and applications, to provide a single communication protocol for the interoperable storage, delivery, and exchange of diverse data across a substation. IEC 61850 (edition 1) became an International Standard in 2004. IEC 61850-90-5 is the standard that characterizes how the 61850 data protocols are applied to synchrophasor communications: it applies to communications from PMUs to Phasor Data Concentrators (PDCs) and Wide Area Monitoring, Protection and Control systems, and between control center applications.

In 2009, the IEC and IEEE created a joint task force to develop methodologies and agreements for coordinated updates to both standards. This effort yielded modifications and updates to both IEC 61850 and IEEE C37.118. The updated IEC 61850-90-5 standard was completed in October 2011 and published in May 2012.

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[3] The term PMU is used here to include a suite of devices that include PMU functionality and are used as PMUs, including digital relays upgraded to perform as PMUs, digital fault recorders, and FNET monitors.

[4] There are two relevant technical standards bodies for synchrophasor technology, the International Electrotechnical Commission (IEC) and the IEEE Power and Energy Society. The IEEE and IEC organizations have formal processes for cooperation and coordination, including the possibility that one organization adopts the other's adopted standard, and the possibility of joint development of new or revised standards. (See IEC and IEEE "Guide to IEC/IEEE Cooperation," retrieved June 14, 2014 at
http://standards.ieee.org/develop/intl/iec_ieee_coop.pdf.)

In December 2011, IEEE adopted modifications and updates to IEEE C37-118 to add more precision and extend the measurement from static to dynamic power system conditions:

- Synchrophasor Measurements -- IEEE Std. C37.118.1-2011 is the Standard for Synchrophasor Measurements for Power Systems; it defines the precise requirements for PMU steady-state and dynamic performance, including how various synchrophasor elements should be measured (including acceptable error ranges), computed and calculated (e.g., estimation algorithms and corrections). It defines a PMU as "a device that produces synchronized measurements of phasor (i.e., its amplitude and phase), frequency, ROCOF (Rate of Change of Frequency) from voltage and/or current signals based on a common time source that typically is the one provided by the Global Positioning system (GPS)."[5]
- Synchrophasor Data Transfer -- IEEE Std. C37.118.2-2011 is the Standard for SynchroPhasor Data Transfer for Power Systems; it covers communications standards for the formatting and delivery of synchrophasor data.

IEC 61850-90-5 and IEEE C37.118.1-2011 and 37.118.2-2011 differ in scope and content:

> While IEEE C37.118.1 is "the global standard for defining the measurement technology for synchrophasors, … IEEE C37.118.2 is the IEEE protocol to address current system requirements, enabling IEC TR 61850-90-5 to be the basis for a more scalable, and secure, protocol to meet NASPInet requirements. IEC TR 61850-90-5 has normative references to IEEE C37.118.1 as the method for measuring synchrophasors."[6]

IEC 61850-90-5 lays out a path for synchrophasor communications to migrate from the C37.118 architecture to the 61850 architecture, which supports faster sampling and data transmission rates and better cyber-security, and thus is better suited for system protection and control applications.[7]

Vahid Madani (PG&E) opened the tutorial with an overview of the tutorial objectives -- to understand the benefits of IEC 61850, its underlying technology, life cycle impact, how it integrates with other standards, installation examples, and deployment success factors. Madani noted that before IEC 61850 was available, several different communications protocols were used within electrical substations worldwide, and it was difficult and costly to make those protocols work together and integrate devices effectively. Thus the IEC standards community began working to develop a new communications protocol for data used within electric substations, to enable standardization, interoperability and ease of use for substation automation networks and

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[5] IEEE Standard C37.118.1-2011 has since been superseded by IEEE C37.118.1a-2014. This can be accessed through the IEEE at http://standards.ieee.org/findstds/standard/C37.118.1-2011.html.
[6] Falk, Herb, "IEC 61850-90-5 -- An Overview," PacWorld, December 2012.
[7] Ibid.

devices. Along the way, the IEC integrated the work of EPRI's Utility Communications Architecture (UCA) effort to produce the IEC 61850 architecture and protocols.

Ron Farquharson (EnerNex) reviewed the history of IEC 61850. It was originally intended to address substation automation, but has been expanded to address many of the automation systems used across the electric utility transmission and substation domains. It supports traditional protection and control functions, but is intended to enable new, advanced capabilities and integrate with enterprise applications that use the Common Information Model (an object-oriented information model of the power system that was adopted as part of IEC 61970). The standard uses object-oriented programming (a computational semantics approach for programming languages developed in the 1990s) with object models for different substation devices, to simplify and streamline power system component and communications design.

IEC 61850 is a multi-part standard covering a number of components; the organization of those components within the standard is laid out in Figure 1. As indicated within the figure, communications protocols relevant to synchrophasor measurements are contained in Part 9 of the standard (hence the naming suffix, 61850-90-5).

Figure 1 -- IEC 61850 Document Set
(Source -- Ron Farquharson, "Origin and History of IEC 61850," NASPI IEC 61850 Tutorial, October 16, 2012)
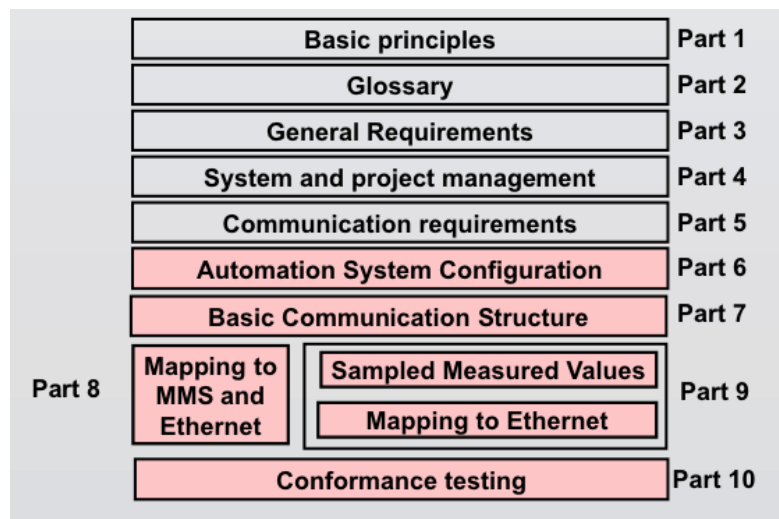
Farquharson itemized a number of benefits and impacts from the use of IEC 61850:

- Because it standardizes communications protocols and interfaces, it will make substation equipment interoperable and thus lower equipment acquisition and installation costs.

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- The availability of standard object models will lower substation engineering and design costs by enabling automated system engineering tools and processes and new substation designs.
- By enabling in-substation wire-less (no copper wires) communications, it will lower substation construction and commissioning costs by reducing or eliminating relay-to-relay wiring.
- It improves asset security because IEC 61850 incorporates the comprehensive IEC 62351 cyber-security standard.
- It can transmit waveform samples in real-time, enabling high-speed data services that can support real-time protection and control actions (e.g., tripping over the LAN).
- It enables the use of single measurements (e.g., CT and PT transducer signals) by many users or devices and applications (Multi-cast as well as Unicast), which enhances efficiency and redundancy and reduces equipment connection and wiring costs.
- Devices under 61850 have standard object naming conventions and are self-describing and discoverable by other 61850 devices and controllers, which reduces the cost and time required for design, specification, configuration, testing, commissioning and maintenance.
- IEC 61850 guidance for testing, verification and quality assurance of devices will expedite completion of compliance and certification processes, which will lower buyers' costs for requirements specifications and increase the availability of 61850-compliant equipment for transmission and distribution substation and field deployment.

Early experience with IEC 61850 by U.S. and other utilities indicates that using IEC 61850 for substation automation does in fact yield measurable engineering, operations and maintenance benefits due to the factors listed above.

Ralph Mackiewicz (Sisco) outlined the technical elements of IEC 61850. Mackiewicz stressed that the point of standards is to make diverse things work together in a cooperative and distributed fashion. Technical standards facilitate interoperability, defined as, "the ability of computer systems to exchange information with other systems and to cooperatively implement a useful process or function for the system owner or user," particularly through protocols that minimize differences at the interfaces between hardware devices. IEC 61850 (and similar standards) address both interoperability between devices and integration between applications, using protocols that span the power system with common specifications for data formats, meaning and behavior.

Mackiewicz reviewed the IEC 61850 object model (as illustrated in Figure 2) and explained the relationship between the CIM and 61850 information models and modeling tools. He stressed that 61850 and the model-driven approach dramatically improves the productivity of planning, design, device selection, engineering and configuration, implementation, wiring, testing and maintenance of automated power systems.

Figure 2 -- IEC 61850 Object Model
(Source: Ralph Mackiewicz & Herbert Falk, " Insight in IEC 61850 -- What is it?"
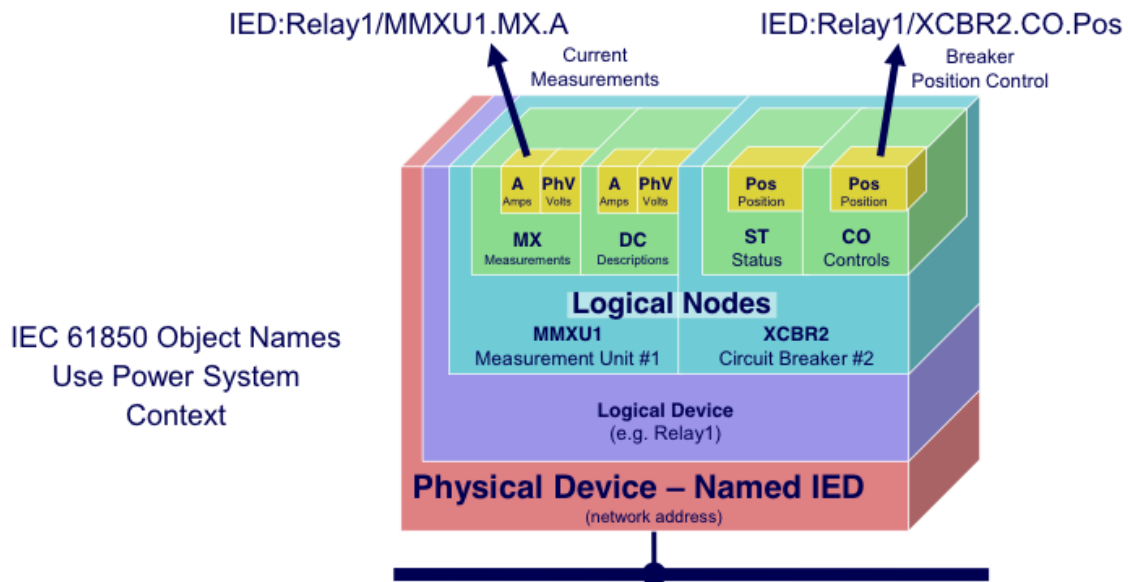NASPI IEC 61850 tutorial, October 16, 2012)

Figure 3 shows an object name consistent with the above format.

Figure 3 -- Anatomy of an IEC 61850-8-1 object name
(Source: Mark Adamiak & Drew Baigent (GE Dital Energy) and Ralph Mackiewicz (SISCO),
"IEC 61850 Communication Networks and Systems in Substations: An Overview for Users,"
Spring 2009, at http://www.gedigitalenergy.com/multilin/journals/issues/spring09/iec61850.pdf)
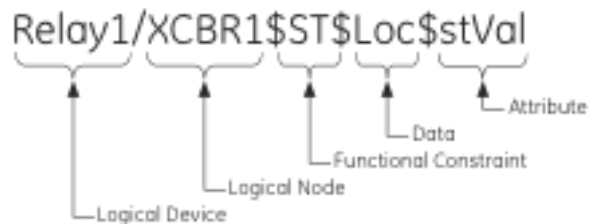
Herb Falk (Sisco) explained how IEC 61850 works within substations (Figure 4) and over networks (Figure 5) and reviewed various IEC 61850 profiles to show the ways that networks could be configured and data managed and routed under the 61850 architecture.
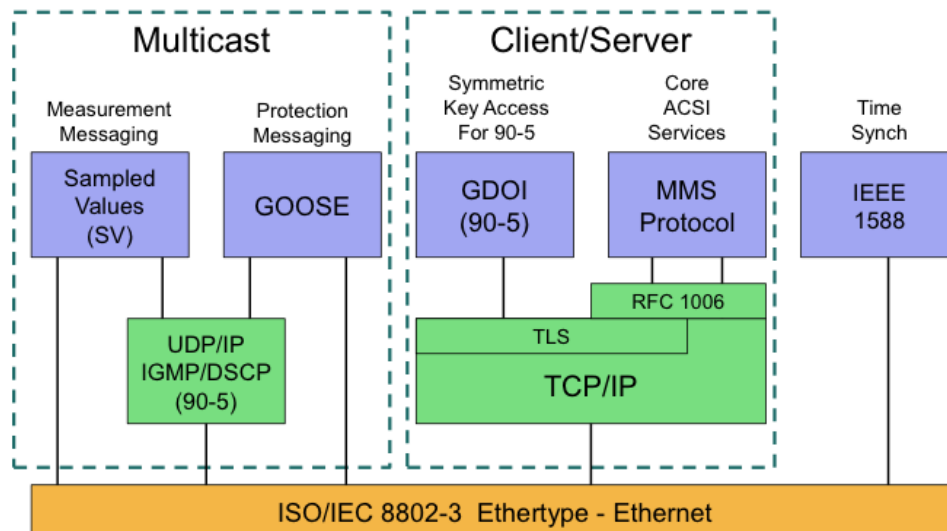
Figure 4 -- IEC 61850 Substation Architecture
(Source: Ralph Mackiewicz & Herbert Falk, " Insight in IEC 61850 -- What is it?"
NASPI IEC 61850 tutorial, p. 72, October 16, 2012)
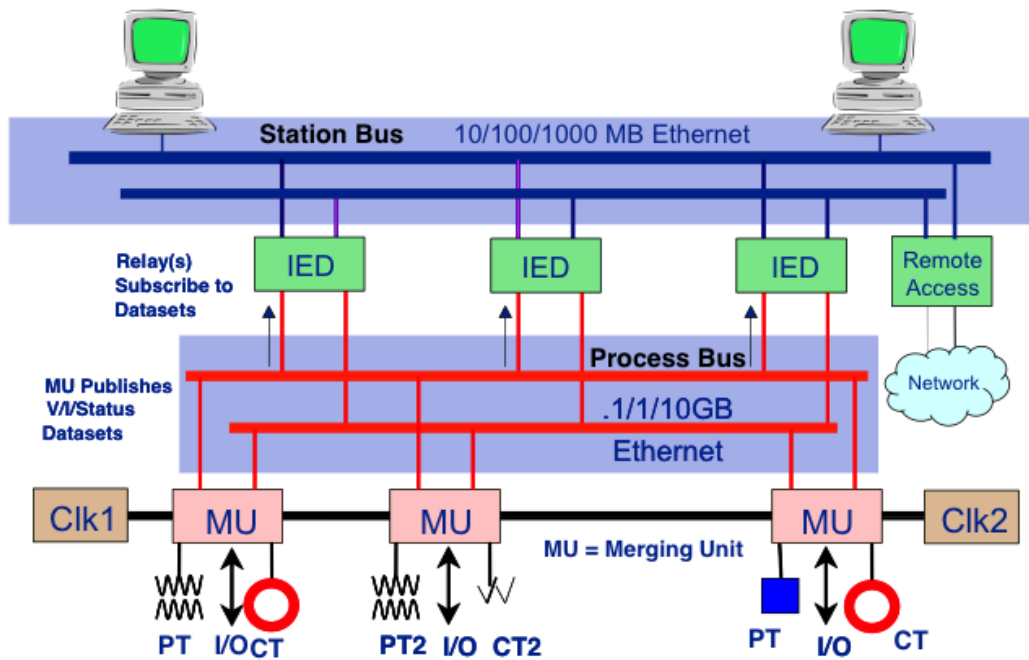

Figure 5 -- IEC 61850 Profiles
(Source -- Ralph Mackiewicz & Herbert Falk, "" Insight in IEC 61850 -- What is it?"
NASPI IEC 61850 tutorial, p. 64, October 16, 2012)

Falk also reviewed the communications elements contained within the various sections of IEC 61850, and explained the role of Logical Nodes -- the grouping of data and services relating to a specific power system function, with attributes defined by a Common Data Class. Power system objects such as breakers have data attributes such as control, configuration, measurement and reporting, and those data attributes have Functional Constraints specific to that piece of data. Falk reviewed many of the functional constraints and value options, and some of the logical nodes relevant for substation objects. (See Figure 6)

Figure 6 -- IEC 61850 Device Structure
(Source -- Ralph Mackiewicz & Herbert Falk, " Insight in IEC 61850 -- What is it?"
NASPI IEC 61850 tutorial, p. 75, October 16, 2012)
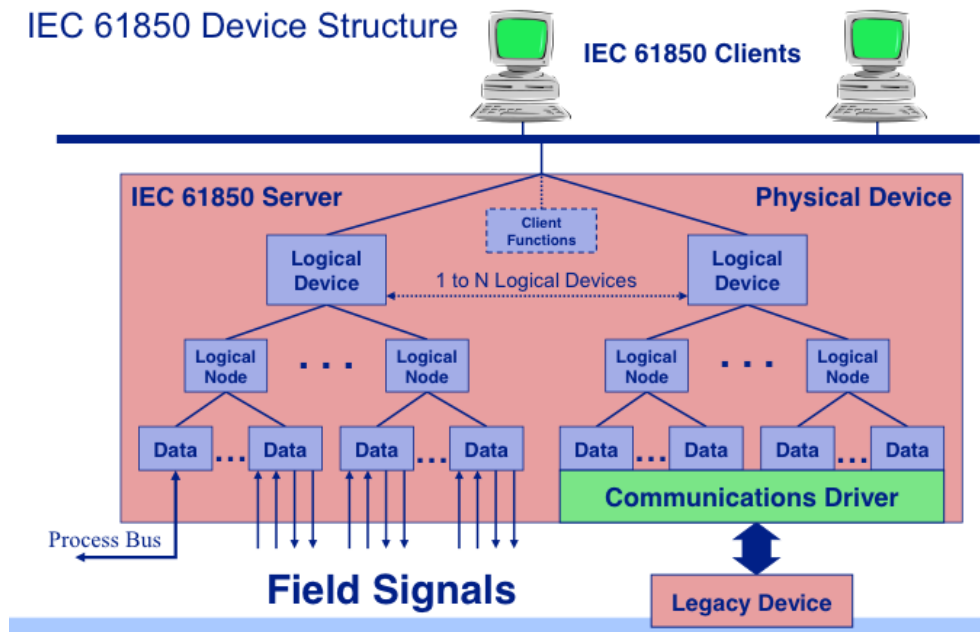
Falk explained the IEC 61850 Service Model, which offers several messaging options:

- GOOSE -- Generic Object Oriented Substation Events messages are event-based. They group data into a dataset and transmit it in Ethernet data packets within four milliseconds. GOOSE messages are multi-cast (sent on a publisher-subscriber basis from one source to numerous pre-authorized recipients) and are retransmitted for redundancy (until the next event occurs).
- GSSE -- Generic Substation State Events convey status data in a simpler format than GOOSE messages.
- SV -- Sampled Value (or Sampled Measured Value) messages contain PT and CT measurements that are streamed in real time.
- ACSI (Abstract Communications Service Interface).

Last, he reviewed Substation Configuration Language (SCL), an XML-based language that describes the substation automation system, switchyard, and Intelligent Electronic Devices (IEDs) and the relationships and configuration of IEDs within SCL.

Christoph Brunner (it4power) reviewed some of the early applications of IEC 61850 in substations. These include two substations in Switzerland in 2004, and substations in Bangalore and Australia. He also reviewed several ways that IEC 61850 has been used for specific applications, including under-frequency load shedding, reverse blocking, and other system protection schemes.

Brunner outlined the extensive amount of work and technical reports that the IEC Working Groups have undertaken to extend IEC 61850 to additional types of power system components (such as FACTS devices and gas turbines), communication relationships (as between substations and the control center), and into distribution automation and distributed energy resources. He closed with a review of communication redundancy options.

Mark Adamiak (GE Digital Energy) addressed GOOSE and SV messaging. He opened by comparing unicast messaging (sending one message to one subscriber) to multicast (sending one message to intended recipients) and broadcasting (sending one message to all recipients with no restrictions). The NASPInet vision anticipates that encrypted synchrophasor data will be shared through multicast with a secure publish-subscribe model. (Figure 7) To this end, an IEC committee recently approved a Technical Report on how to use IEC 61850 to transmit synchrophasor information according to IEEE C37.118, which goes far to integrate the two standards.

Figure 7 -- NASPInet architecture vision
(Source: Quanta Technology for U.S. Department of Energy, "Data Bus Technical Specifications for North American Synchrophasor Initiative", May 2009)
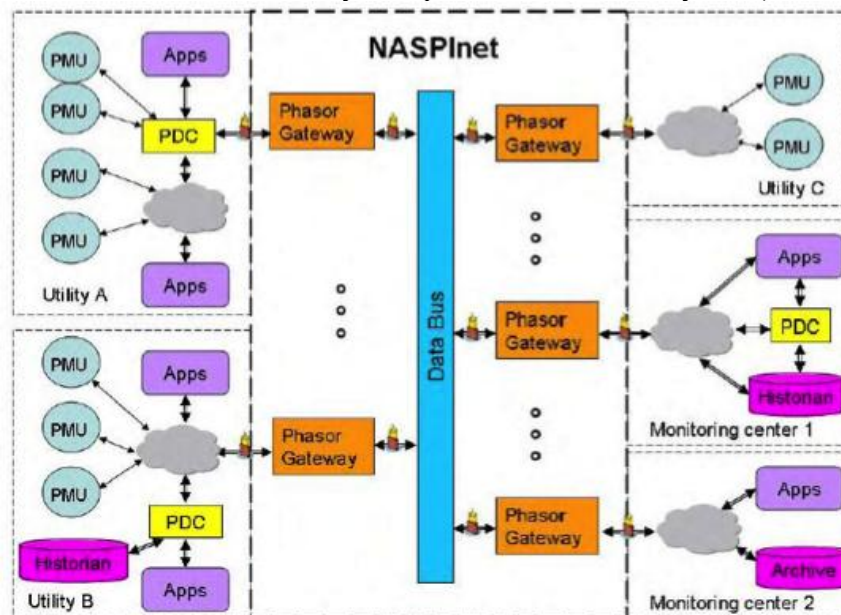
Adamiak reviewed the IEC 90-5 data model (Figure 8) to explain how IEC 61850-90-5 messages in the GOOSE and SV formats can be used for NASPInet data transfers. He offered detail on how these data packets could be structured and mapped, with appropriate security provisions for those messages.

Figure 8 -- IEC 90-5 Data Model
(Source: Mark Adamiak, "The New GOOSE & SV," NASPI IEC 61850 Tutorial, p. 13, October 16, 2012)
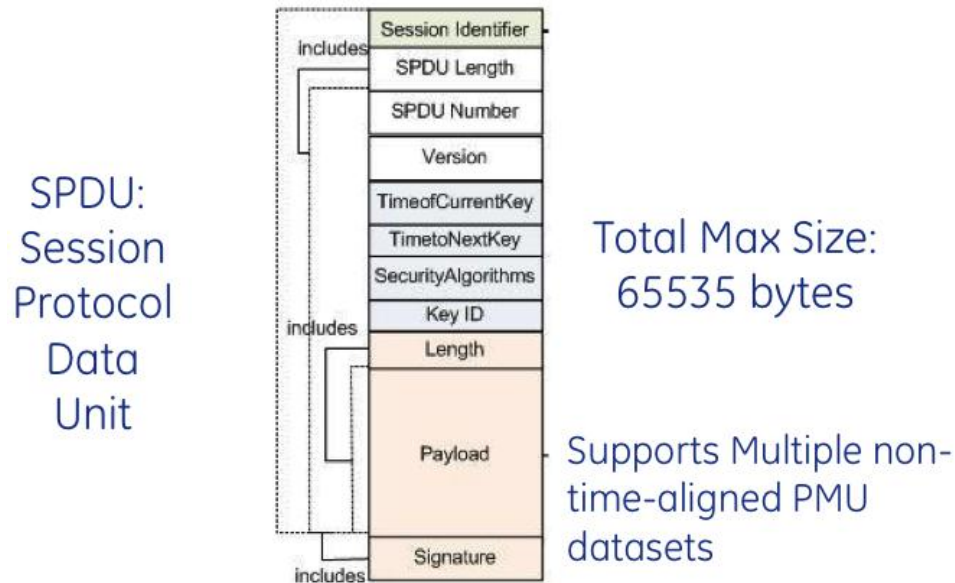
Mark Adamiak (GE Digital Energy) and Farnoosh Rahmatian (Quanta Technology) then discussed how IEEE 1588, the standard for Precision Time Protocol (PTP) over Ethernet, is being used for the time synchronization that makes grid measurements into valuable synchrophasors. IEEE 1588 applies to data synchronized in sub-microsecond time spans, and provides a messaging system to identify and guide master and slave clock performances and how the time synch calculations should be made and applied. (See Figure 9) Other related timing functions include GPS and IRIG-B.

Figure 9 -- Basic operation of the master and slave clocks and time stamping under IEEE 1588
(Source: Mark Adamiak and Farnoosh Rahmatian, "Brief Overview of IEEE 1588 Test Results -- Concept and Practical Examples and Lessons Learned," NASPI IEC 61850 Tutorial, p. 3, October 16, 2012)

As the synchrophasor message travels from the point of measurement and calculation and initial time-stamping at the PMU through PDCs, the communications network, and up to the application software that uses it, the message can experience latency and fluctuation. PG&E's synchrophasor project tested the effectiveness of the 1588, GPS and IRIG-B methods and the impact of these latency delays, using PG&E's Synchrophasor Proof of Concept facility. These tests revealed that clock performance varies in terms of accuracy and drift over time, and that delays in network communications can cause delays in the Transparent Clock.

Vahid Madani (PG&E) and Farnoosh Rahmatian (Quanta Technology) closed the tutorial with examples of interoperability issues and tests relating to IEC 61850. They explained that applicable technical standards and a compliance regime are necessary but not sufficient to achieve interoperability between devices -- true interoperability usually requires implementation agreements among device developers and manufacturers, plus testing to verify that true inter-operation has been achieved. Although there is a plan to develop certification for IEC 61850-compliant devices, such certification alone will not assure that 61850-conformant devices are interoperable.

Switching to design requirements for an IEC 61850 substation, Madani and Rahmatian discussed system design requirements and criteria, including the advantages of networked communications versus local control wiring for wide-area protection and control. They

pointed out that Ethernet controls and use of several emerging technologies can enhance system flexibility and accuracy, offer insights for asset maintenance and event analysis, and speed data access and process controls. But these require continuing adoption of substation automation (under IEC 61850 specifications), further development of industry tools and applications (as for maintenance and device performance tracking), conformance certification, extensive process changes for substation automation and protection design, and extensive training of engineers, vendors and practitioners on how to use IEC 61850 concepts, devices and networks effectively.

Madani and Rahmatian also offered recommendations for how to conduct interoperability testing for PMU to PDC communications, and a comparison of data transmission using C37.118 UDP versus IEC 61850 Unicast and Multicast. They advised that it is valuable to have a collaborative testing environment between vendors and users, and the importance of developing efficient configuration and testing tools.

* * *

Sources and references

Adamiak, Mark & Drew Baigent (GE Dital Energy) and Ralph Mackiewicz (SISCO), "IEC 61850 Communication Networks and Systems in Substations: An Overview for Users," Spring 2009, at http://www.gedigitalenergy.com/multilin/journals/issues/spring09/iec61850.pdf)

Apostolov, Alex, "IEC 61850-90-5", NASPI PSTT, February 2011

Brunner, Christophe, "Synchrophasor Data and IEC 61850", NASPI PSTT, February 2010

Falk, Herbert, "IEC 61850-90-5 -- An Overview," PacWorld, December 2012.

IEC Standard 61850-90-5, "Power Utility Automation"

IEC, "Communication networks and systems for power utility automation -- Part 90-5: Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118," IEC/TR 61850-90-5, Edition 1.0, May 2012.

IEEE Standard C37.118.1-2011, "Standard for SynchroPhasor Measurement for Power Systems,"

IEEE Standard C37.118.2-2011, "Standard for SynchroPhasor Data Transfer for Power Systems,"

Madani, Vahid & M. Adamiak, H. Falk, D. Baigent, "An Overview of the New IEC 61850 Synchrophasor Publish-Subscribe Profile, DistribuTech 2013, Smart Grid Communications Technology Panel.

Madani, Vahid, D. Novosel et. Al, "Interoperability of Synchrophasor Data Transport Using IEC 61850-90-5 and IEEE C37.118.2", PSTT / NASPI, June 5, 2012, Denver, CO.

Paolone, Mario, "Synchrophasor Fundamentals: from Computation to Implementation; Tutorial -- Synchrophasor Fundamentals and Applications: Leveraging the Investment," IEEE PES General Meeting, Vancouver, July 21-25, 2013.

North American SynchroPhasor Initiative
Tutorial on IEC 61850
Technical Interoperability Standard for
Synchrophasor Measurement & Data Communications
October 16, 2012
1:00 to 5:30 pm

Westin Buckhead Hotel
3391 Peachtree Road, NE
Atlanta Georgia 30326

The NASPI community has invested significant time and effort in the development of IEC technical interoperability standard 61850-90.5, the technical interoperability standard newly adopted by the International Electrotechnical Commission as part of the reference architecture for electric power systems. This tutorial will give attendees a clear and practical understanding of what this technical standard entails, how it be used for PMU measurements and data communications, why technical interoperability standards matter, and what comes next. The tutorial will be taught by two IEEE Fellows and associated experts who developed the new standard and are guiding the electric industry in its implementation.

There will be no registration fee for this tutorial. The meeting registration link is at http://www.nerc.net/meetingregistrations/Committee.aspx?meetingdate=10/16/2012&meetingtype=NASPI%20IEC.

NASPI has secured a block of rooms at the Westin Buckhead Hotel for the nights of October 15 through 18 for those who wish to attend this tutorial or the NASPI Work Group meeting, which will be held on October 17 and 18. The hotel reservation link is at https://www.starwoodmeeting.com/StarGroupsWeb/booking/reservation?id=1112307682&key=5AA40.

Tuesday, October 16, 2012		
12:30 - 1:00 pm	Registration and networking	
1:00 - 1:10 pm	Welcome, introductions, and logistics review	Alison Silverstein (NASPI)
1:10 - 1:20 pm	Tutorial objectives and a brief history of IEC 61850	Vahid Madani (PG&E) Ron Farquharson (Enernex)
1:20 - 1:35 pm	IEC 61850 benefits and overview of NIST standardization process	Mark Adamiak (GE Energy) Ron Farquharson (Enernex)

1:35 - 2:45 pm	Insight in IEC 61850 - What is it?	Ralph Mackiewicz (Sisco) Herb Falk (Sisco) Alex Apostolov (PAC World)
2:45 - 3:00 pm	Q& A Session	Damir Novosel (Quanta Technology)
3:00 - 3:15 pm	Break (refreshments and networking)	
3:15 - 3:50 pm	IEC 61850 Applications with real-life examples	Christophe Brunner (**it**4power) Vahid Madani (PG&E)
3:50 - 4:30 pm	IEC 61850-90-5, including interaction with IEEE 37.118	Mark Adamiak (GE Energy)
4:30 - 4:40 pm	Brief overview of IEEE 1588 test results – Concept and practical examples and lessons learned	Farnoosh Rahmatian (Quanta Technology) Mark Adamiak (GE Energy)
4:40 - 5:10 pm	Interoperability issues, tests, and practical examples (PMU, PDC, SuperPDC)	Vahid Madani (PG&E) Farnoosh Rahmatian (Quanta Technology)
5:10 - 5:25 pm	Q&A session	Damir Novosel (Quanta Technology)
5:25 pm	Adjourn	

NASPI Tutorial
on
IEC 61850 Introductions

Tuesday October 16, 2012

Vahid Madani
Pacific Gas and Electric Co.

Tutorial Objective

❖ Benefits and Impact of IEC 61850

❖ Understanding of technology behind IEC 61850

❖ Life cycle impact of IEC 61850

❖ Integration with other standards and interoperability

❖ Installation examples - North America and Internationally

❖ Key deployment success factors and deployment roadmaps

Tutorial Overview and Outline

- Tutorial objectives and brief history of IEC 61850 – **Madani / Farquharson**

- IEC 61850 benefits and overview of NIST standardization process – **Adamiak / Farquharson**

- Insight in IEC 61850 - What is it? – **Mackiewicz / Falk**
    a) What is IEC 61850 and Its Relationship to other IEC Standards
    b) Impact of IEC 61850 on the Engineering Processes of SCADA, Automation, Protection
    c) IEC 61850 Profiles
    d) IEC 61850 Modeling
        i. Device and Object Models
        ii. Service/Behavior Models
    e) Substation Configuration Language
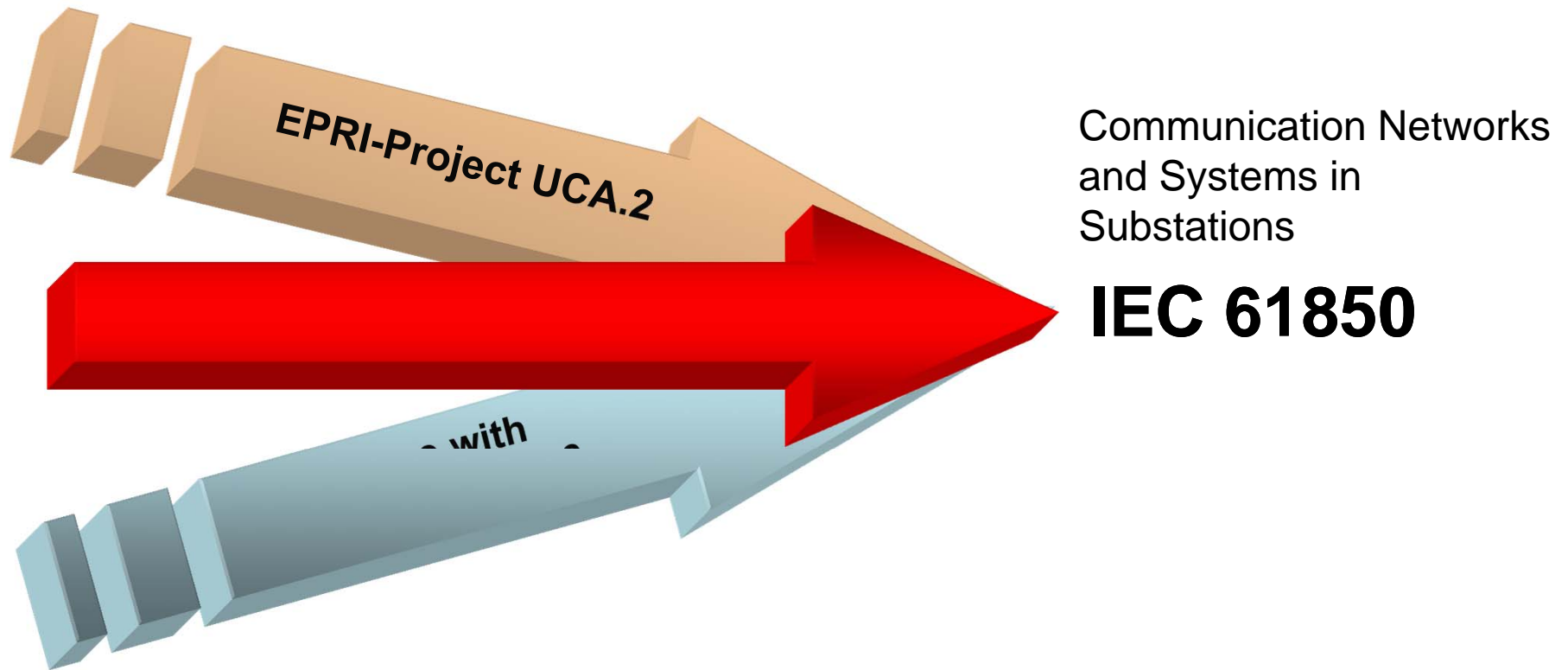
- Q & A Session – **Novosel**

Break - 15 Minutes

- IEC 61850 Applications with real-life examples, Recent Industry Activities **Brunner / Madani**

- IEC 61850-90-5, including interaction with IEEE 37.118 **M. Adamiak**

- Brief overview of IEEE 1588 test results – Concept and practical examples and lessons learned - **Rahmatian / Adamiak**

- Interoperability issues, tests, and practical examples - **Madani / Rahmatian**

- Q&A session – **Novosel**

Two clarification type qualification questions from each presenter immediately after the presentation
Additional questions will be deferred to the panel session.

Why IEC 61850?
Harmonization, Standardization, Ease of Use

Too Expen$ive & Complex

National Origin??

EPRI-Project UCA.2

Communication Networks and Systems in Substations

IEC 61850

with

• Necessity to simplify & standardize substation design, construction, commissioning, operation and maintenance

Driven By

• Utilities through UCA & IEC standard committees

IEC 61850 - Communication networks and systems in substations

Why it is real:

- Driven by Utilities to meet a need
- Finally see the "Promised LAN" (…and we don't anticipate taking 40 years to get there…)
- It works and is in the market (after many years)
- Fits and supports today's Power System Technical and business drivers – Makes a business case
- Networking dominates the utility landscape
- Time for paradigm Shift
  - ✓ If you are not on-board, you will be soon
  - ✓ Start Developing the foundations & standards for application in your company
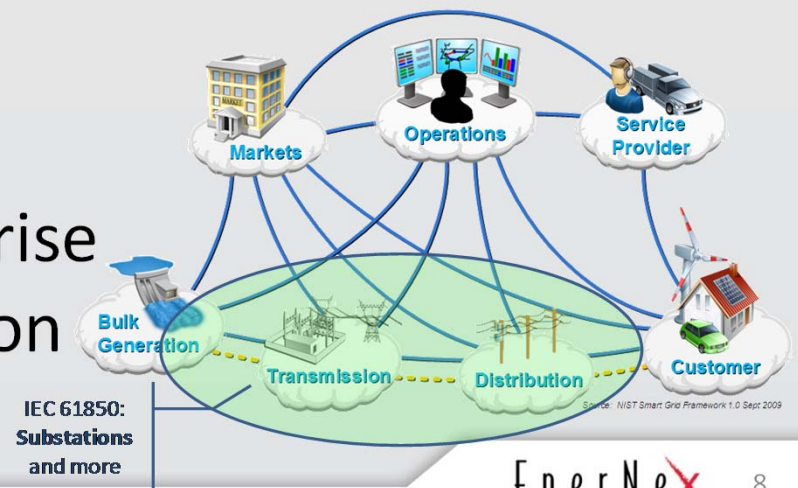   - » Timing is right
    - » Better get involved sooner
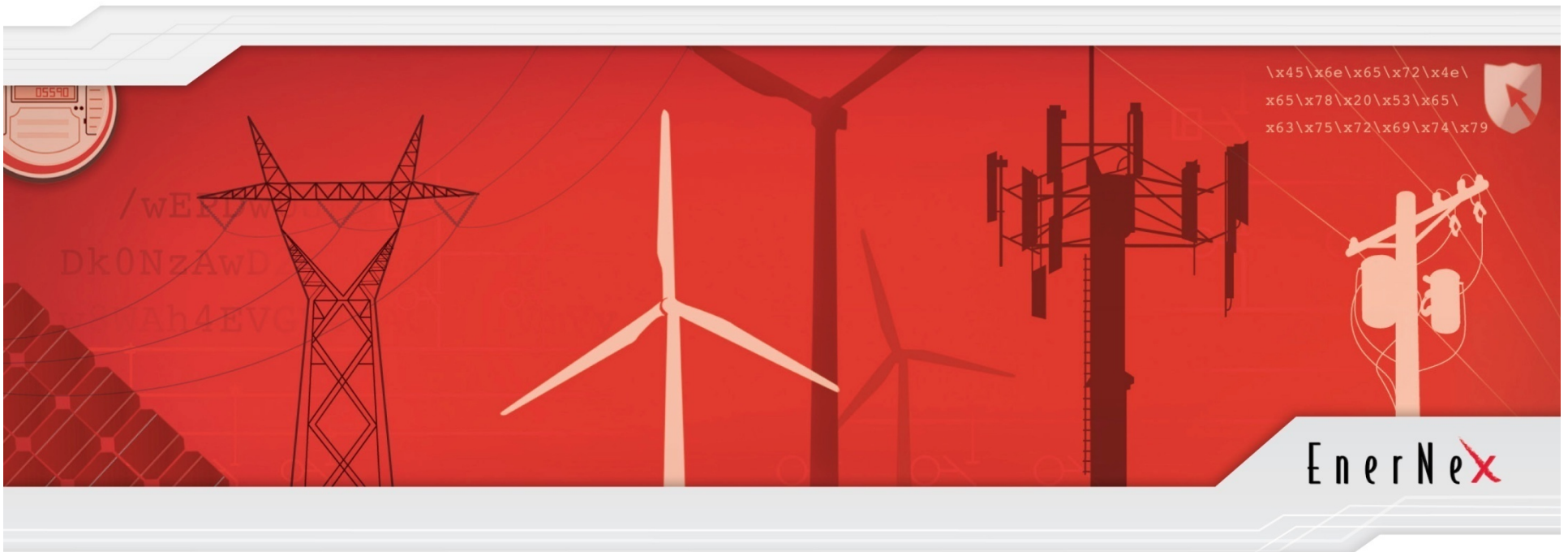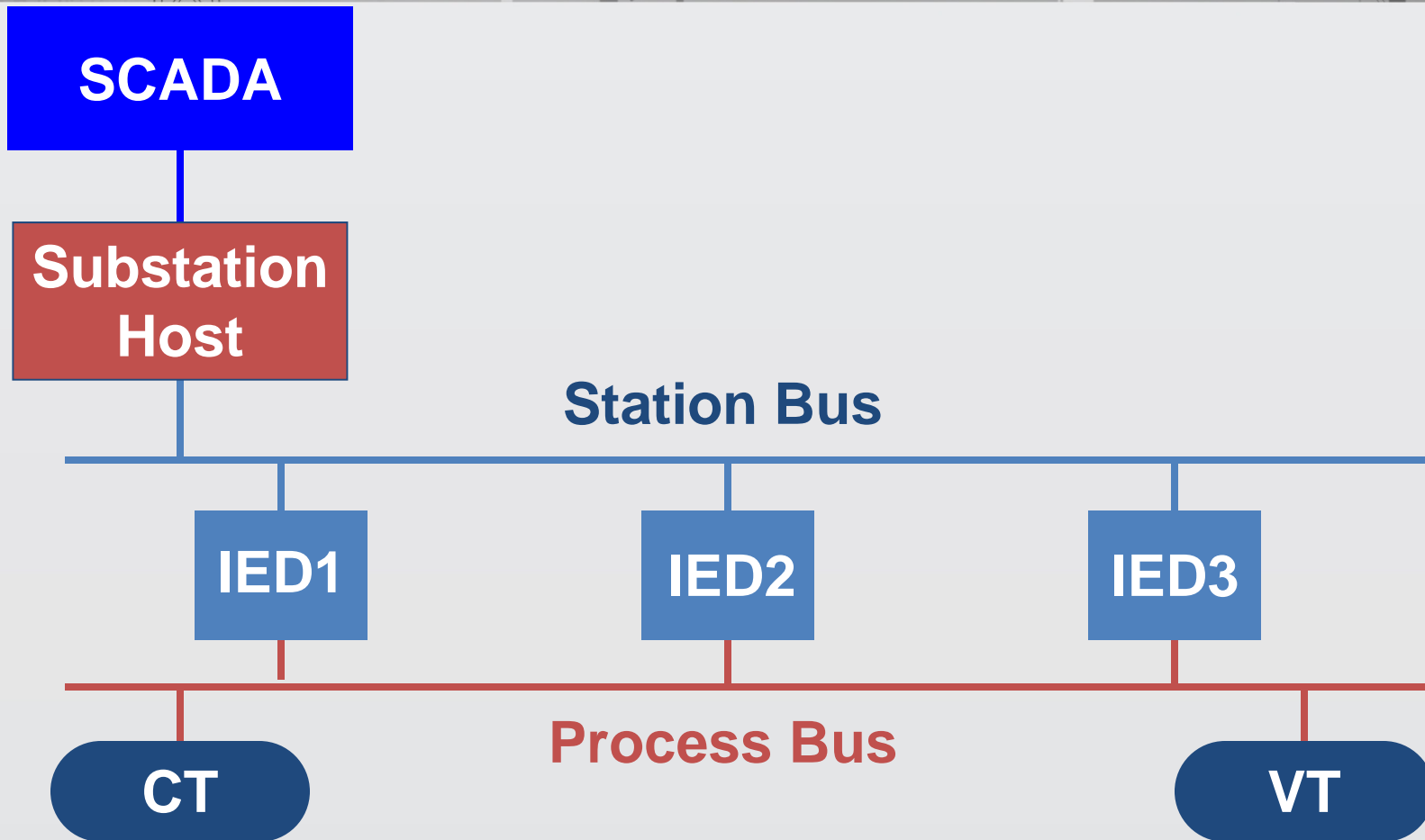
IEC 61850's role in the "Big Picture"

- ▶ Identified in the first batch of interoperability standards key to Smart Grid deployment by NIST

- ▶ Initial focus was substation automation (Edition 1)

- ▶ Scope is now expanded to address many of the automation systems utilized in the electric utility transmission and distribution domains

- ▶ Supports traditional protection and control functions while enabling new advanced capabilities

- ▶ Future integration with enterprise applications using CIM (Common Information Model)

IEC 61850: Substations and more

IEC 61850 Architecture

IEC61850 Interface Model

Control Center

Technical Services

Station Level

Fct A ↔ Fct B

Station Bus

Bay Level

Protection - Control

Protection - Control

Remote Protection

Process Bus

Process Level

Process Interface

Process Interface

HV Equipment
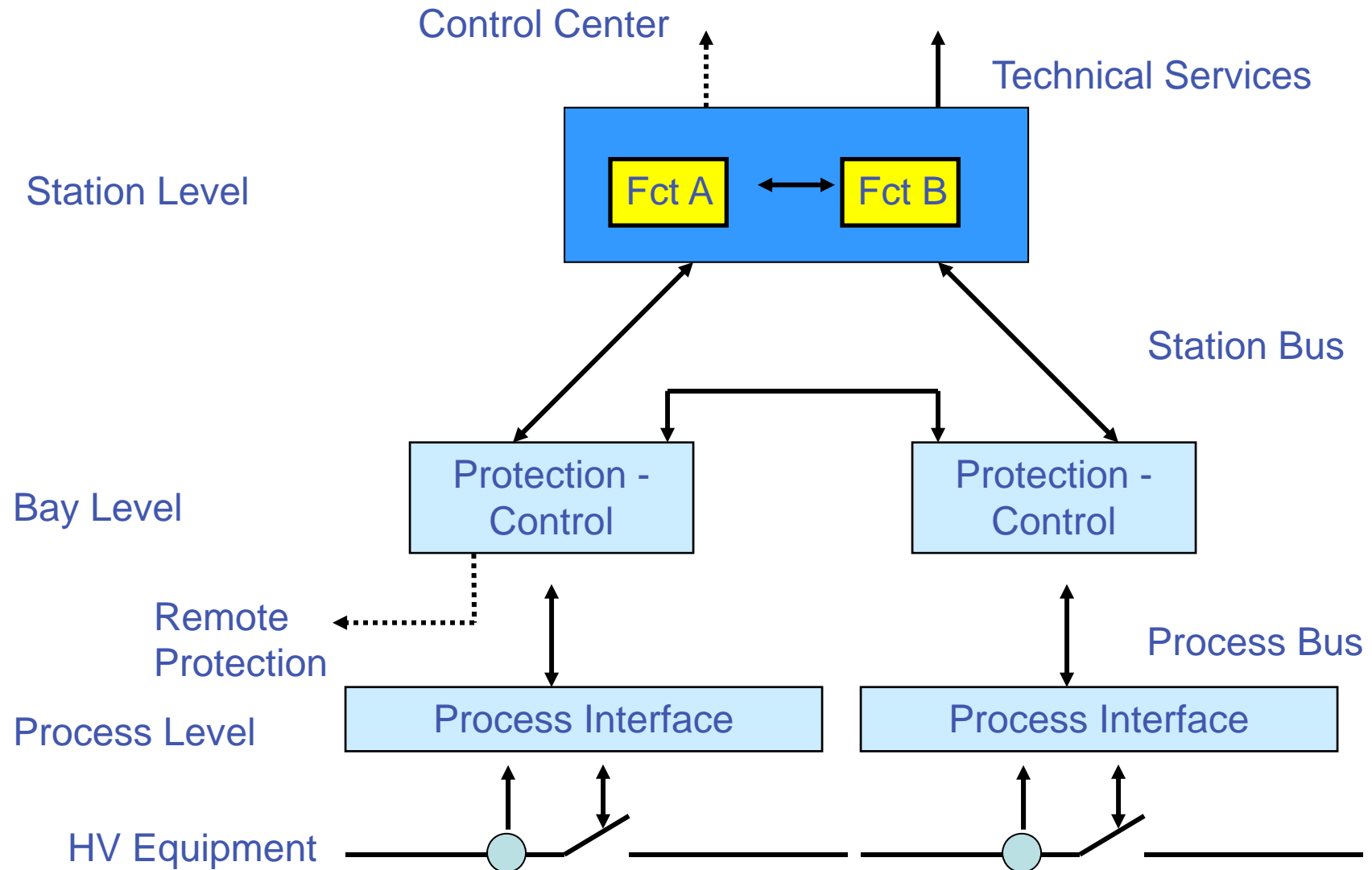
Document Set

|		
Basic principles		Part 1
Glossary		Part 2
General Requirements		Part 3
System and project management		Part 4
Communication requirements		Part 5
Automation System Configuration		Part 6
Basic Communication Structure		Part 7

Part 8	**Mapping to MMS and Ethernet**	**Sampled Measured Values**	Part 9
		Mapping to Ethernet	

Conformance testing	Part 10

EnerNex 11

# Object Modeling: Visualize a Substation
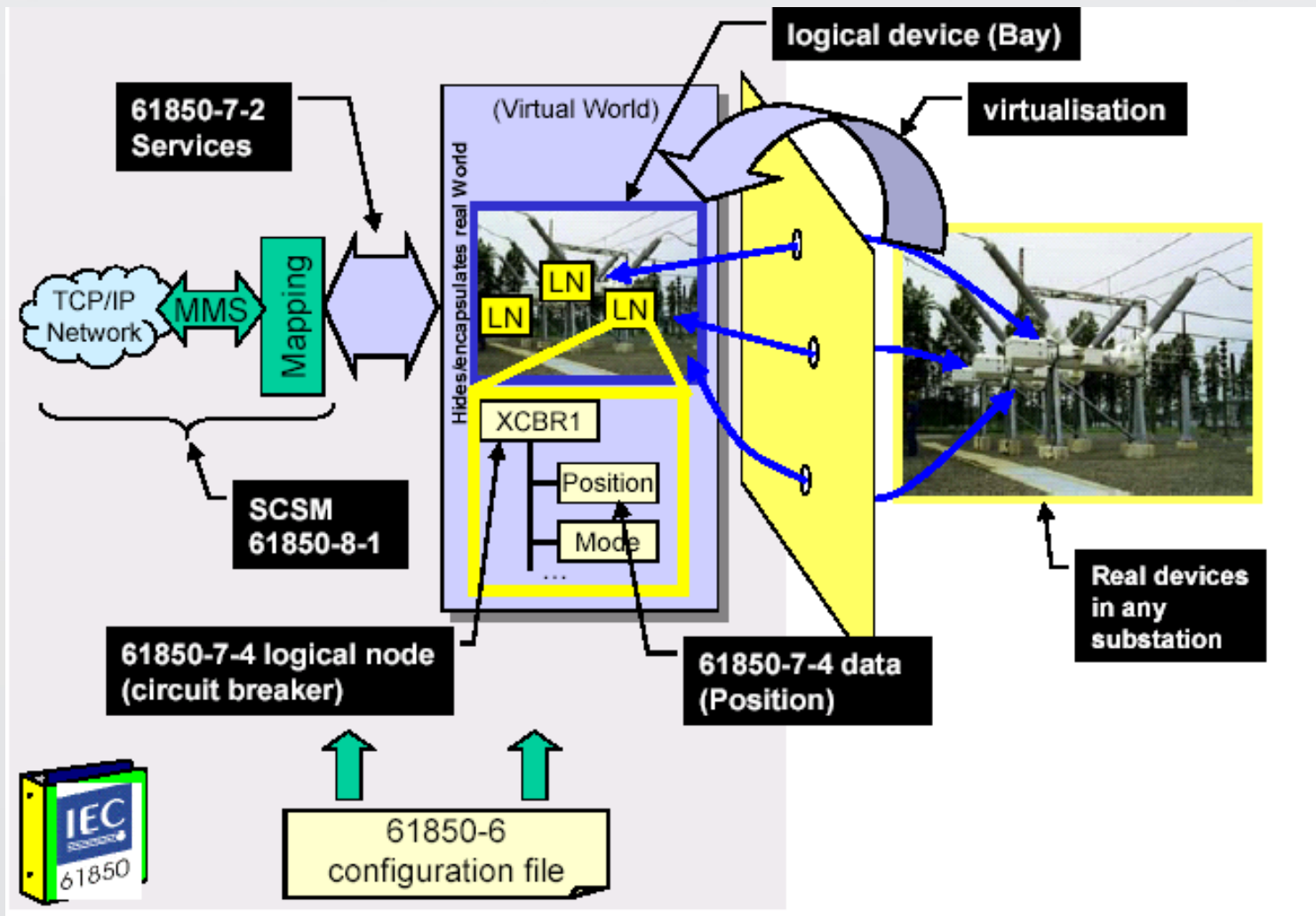
Origin and History - 1

- ▶ Sponsored by Electrical Power Research Institute (EPRI)
- ▶ Early work by GE, KEMA, others
- ▶ EPRI RP3599 became UCA 1.0 in 1990 - no TCP/IP
- ▶ Many pilot projects, no consensus
- ▶ American Electric Power initiative brought focus
- ▶ UCA 2.0 became an International Standard - IEEE TR-1550 (1999)
- ▶ UCA 2.0 became the core technology in IEC 61850 released as Edition 1 in 2003
- ▶ EPRI considered that UCA included the popular Inter-Control-Center Protocol (ICCP) a separate standard: Telecontrol Application Service Element (TASE.2), IEC 60870-6
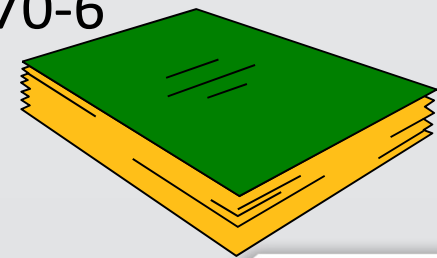
Origin and History - 2

▶ UCA International Users Group founded in 2003

▶ IEC 61850 Edition 2 – releases started in 2010

▶ New technical reports for synchrophasor data, condition monitoring, communications outside the substation (other stations, control centers etc)

▶ New standards for DER, hydro, wind, distribution automation, electric vehicle charging

▶ Standards for mapping to other protocols:

   – IEC 60870-5-104

   – IEEE 1815 – 2010 (DNP3) - pending

▶ Cyber security addressed by IEC 62351
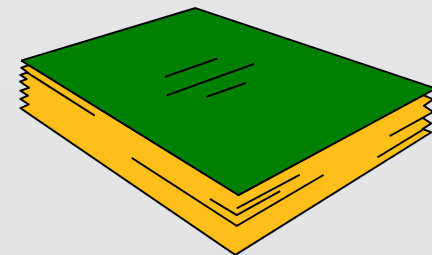
Origin and History - 3
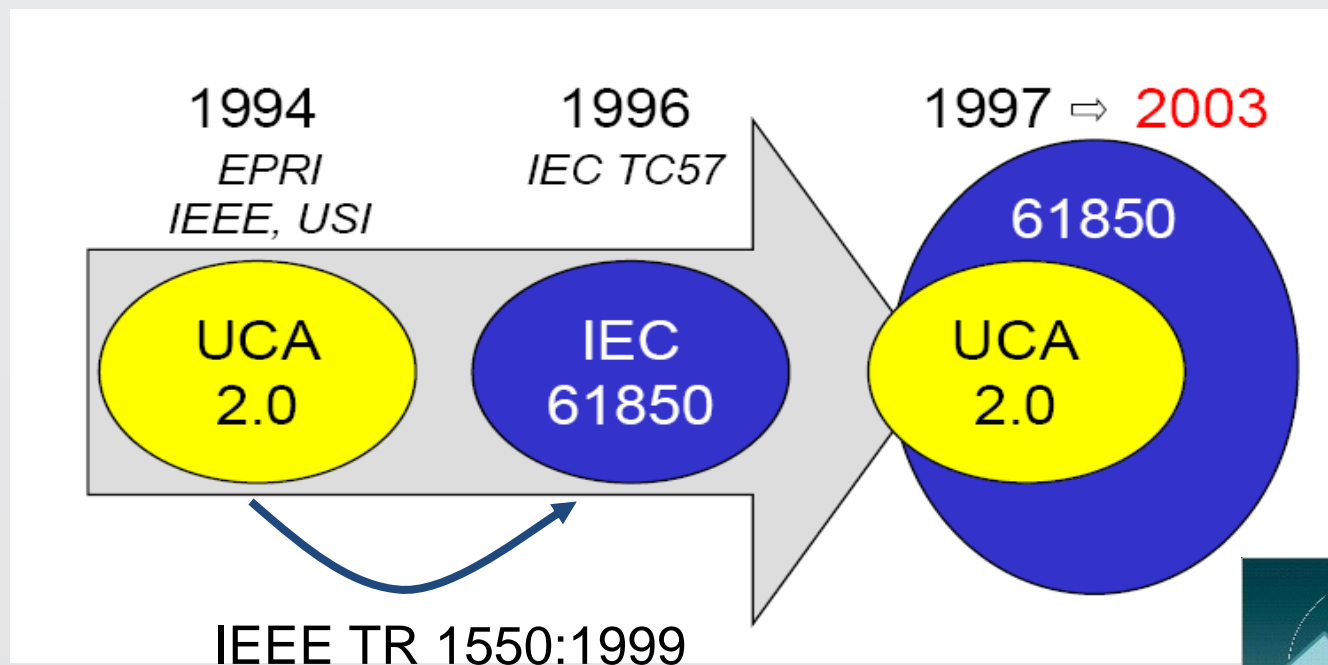
"UCA & 61850 for Dummies." – Douglas Proudfoot

Origin and History - 4
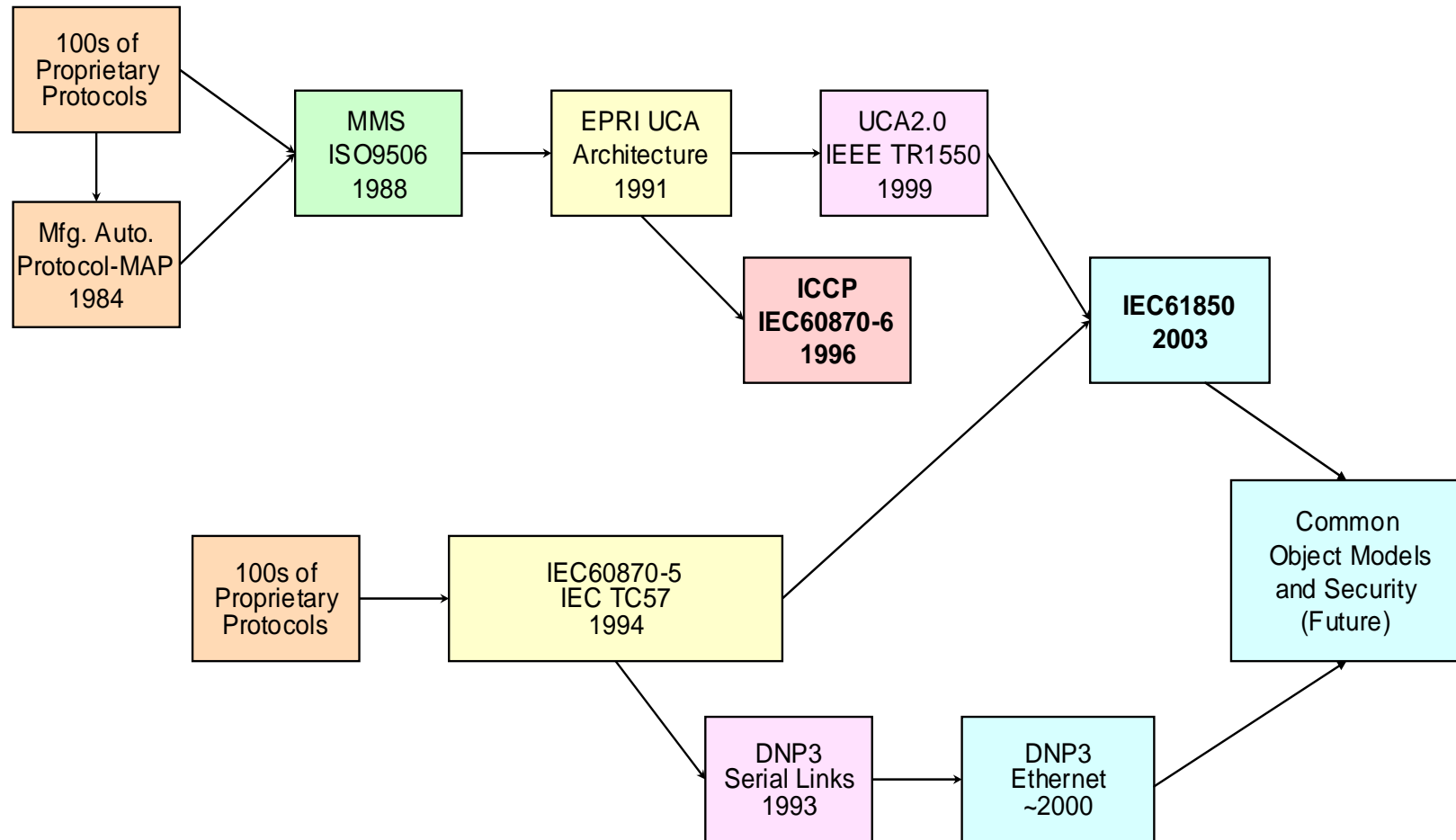
UCA International User's Group (UCAIug)

- Founded in 2003

- Key Committees:
  - Technical Oversight Committee
  - CIMug (CIM Sub Committee)
  - IEC61850ug (IEC61850 Sub Committee)
  - OSGug (Open Smart Grid Sub Committee)
  - Harmonization Sub Committee
  - Technical Publications Sub Committee
  - Testing Sub Committee

Rationale and Benefits for IEC 61850 and NIST Catalog of Standards

Ron Farquharson,
Principal Consultant, EnerNex
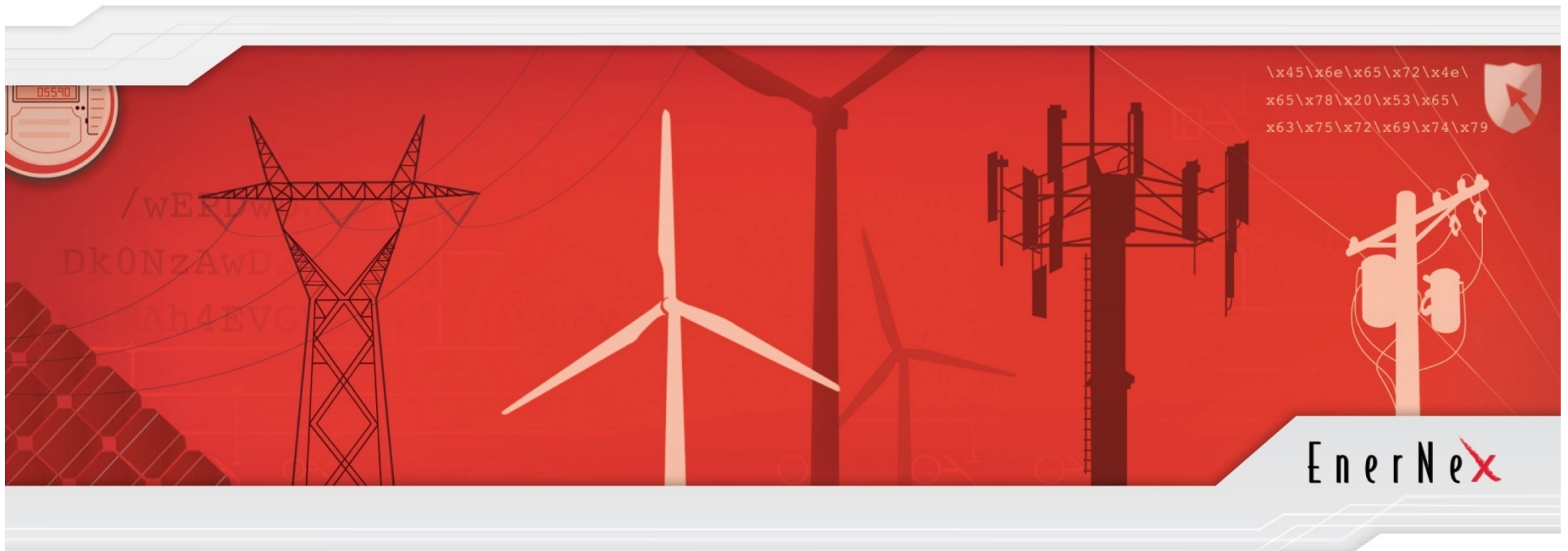
Example Benefits by Stakeholder

▶ **Utility Decision Maker**

- Lower capital costs

- Improved engineering efficiency

- Benefits of data modeling extend into the utility enterprise

▶ **Utility Engineer**

- New tools and options for designing systems to meet the evolving requirements of a smart grid world

- Process improvements

▶ **Regulator**

- High benefit-cost ratio (BCR)

▶ **Vendor**

- Narrower focus on product communication features - more focus on innovation, features, benefits, cost

So Why all the Excitement?

▶ **Part of a broad scope, world-wide electric power interoperability effort for devices & systems:**

- Industry consensus object models for power system devices

- Self-description and structured meta data

- Publish/subscribe services

- Fast data services for protection/control (eg tripping over LAN)

- Transmitting waveform (synchrophasor) samples in real-time

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So Why all the Excitement?

▶ **Part of a broad scope, world-wide electric power interoperability effort for devices & systems (cont'd):**

- ■ LAN-Based Time Synchronization

- ■ Cyber security (IEC 62351)

- ■ Substation Configuration Language

- ■ Support for automated system engineering tools and processes

- ■ Testing, verification, and quality assurance processes

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Fast Peer-to-Peer Communication

- ▶ Generic Object-Oriented Substation Event (GOOSE)
- ▶ Intended to replace relay-to-relay wiring
- ▶ Each device multi-casts (one to many) a selected set of data
- ▶ Assumes the message will not get through
- ▶ Retransmits immediately, exponential back-off
- ▶ Periodic retransmission

Sampled Values on the LAN

▶ Enables a single measurement and sharing with multiple devices and applications

▶ Separates sampling physically from:

– Measurement

– Metering

– Calculation

▶ More flexibility in measurement

– Any device may measure any circuit

▶ Used for synchrophasor measurement (TR 61850-90-5)

▶ Gigabit Ethernet will likely be required
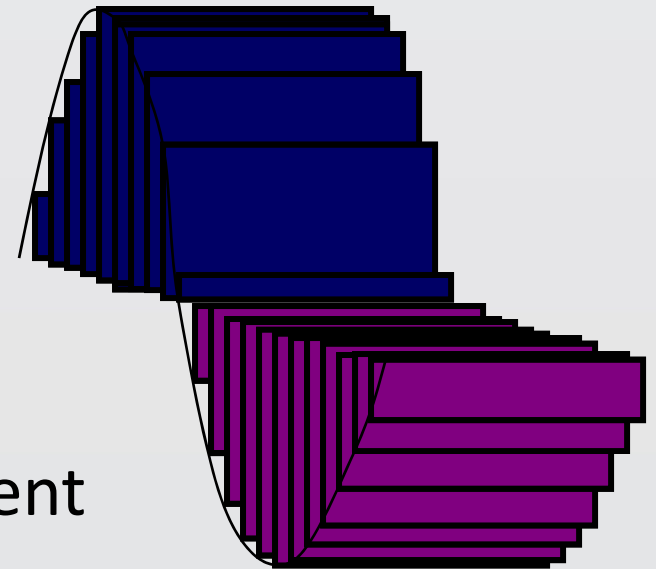
What are the Benefits of IEC 61850?

▶ GOOSE (high performance) messaging for inter-relay communications can reduce hard wiring and/or enable functions not possible with hard wires. Saves $$ in engineering, wiring and maintenance.

▶ Enhanced communications services enable self-describing devices and automatic object discovery. Saves $$ in configuration, testing, commissioning and maintenance.

▶ Sampled measured value messaging enables sharing of transducer (CT/PT) signals. Saves $$ by reducing equipment, wiring and connection costs

▶ Comprehensive cyber security solution (IEC 62351)

Contributions: Mark Adamiak, GE

EnerNex

What are the Benefits of IEC 61850?

▶ Standardized configuration file formats enables exchange of device configuration and auto-configuration capabilities. Supports a range of tools. Saves $$ in design, specification, configuration, testing, commissioning and maintenance.

▶ Industry standard object naming conventions with power system context eliminates device dependencies and tag mapping. Saves $$ in configuration, testing, commissioning and maintenance.

▶ Significant potential in process improvement!!

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Excerpts from a Recent Post by a Large and Respected IOU...... (edited)

- ▶ (They are in the process of adopting IEC 61850 for their next generation substation automation systems)
- ▶ Successful implementation of "IEC 61850" will result in measurable engineering, operations and maintenance benefits through cost reduction, reliability and safety.
- ▶ The primary benefits arise the use of an open system such as the IEC 61850 standard for substation communications and include:
  - ▶ Cost Savings due to process improvement
  - ▶ Enhanced Security
  - ▶ Configuration Management (auto-configuration)
  - ▶ Interoperability – including future integration with distribution automation and field area networks.

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PAP-13 SGIP Activities - 1

- IEEE Std C37.238-2011 – now in the Catalog of Standards
  - Full document set completed and posted on CoS TWiki
  - Successful reviews by the CSWG and SGAC
  - IEEE Std C37.238-2011 approved for Catalog of Standards – October 18, 2011
  - Moving forward:
    - T & D DEWG to address time synchronization compatibility issues that were identified as part of our PAP13 work.
    - Need to address (per the CSWG review) cyber security deficiencies with the existing IEEE 1588 standard.

PAP-13 SGIP Activities - 2

- IEC TR 61850-90-5 – now in the Catalog of Standards:

  - Full document set completed and posted on CoS TWiki

  - Successful reviews by the CSWG and SGAC

  - IEC TR 61850-90-5 approved for Catalog of Standards – September 14, 2012

  - Moving forward:

    - Technical Report means that the content is gradually adopted into the next editions of the various parts of IEC 61850.

    - A task group is developing an Implementation Guide to address (e.g.) mapping between IEEE C37.118.2 and IEC 61850.

    - IEEE PSRC meeting has formed a new Task Force to determine whether a formal IEEE standard should be developed for the Implementation Agreement

Contact Information

► Ron Farquharson

  – ron@enernex.com

► http://www.enernex.com/

The New GOOSE & SV

Mark Adamiak
GE Digital Energy

Functional Requirement: One message to multiple subscribers

Unicast solution – limited on connection

Definition of Terms: Broadcast

Router Duplicates Packet to ALL Locations

Multicast Solution:

One Message Only Sent to Intended Recipients

Multicast Addresses

Class D Address	Purpose
224.0.0.1	All hosts on a subnet
224.0.0.2	All routers on a subnet
224.0.0.4	All DVMRP routers
224.0.0.5	All MOSPF routers
224.0.0.9	Routing Information Protocol (RIP)-Version 2
224.0.1.1	Network Time Protocol (NTP)
224.0.1.2	SGI Dogfight
224.0.1.7	Audio news
224.0.1.11	IETF audio
224.0.1.12	IETF video
224.0.0.13	Protocol Independent Multicasting (PIM_1)

imagination at work

1 – CISCO Recommended

Gaps in C37.118

- No defined security
  - Requires an external solution
  - Multicast and associated security not defined
- Dataset Configuration tools are vendor specific
- No standard data names
- Limitations on dataset name length
- Lack of Negative response from the server
  - Some consider this a feature……

imagination at work

North American SynchroPhasor Initiative Network - NASPInet Vision

Mapping Synchrophasors into GOOSE

GOOSE/SV message

Router w/ UDP/IP

Routed GOOSE/SV

Requires Router configuration

GOOSE
- No IP Address
- No Transport
  - o UDP
  - o TCP

Bit Bucket

GOOSE after router

Communication NEEDS: Networked Publish/Subscribe Message

- Should be routable
  - Multicast to reach multiple subscribers
- Message should be authenticated
- Message should be able to be encrypted
- Should accommodate large message size
- Should manage the Authentication and Encryption key

Committee Approved Technical Report:

**IEC 61850:
COMMUNICATION NETWORKS AND SYSTEMS FOR
POWER UTILITY AUTOMATION –**

**Part 90-5: Use of IEC 61850 to transmit synchrophasor
information according to IEEE C37.118**

Mark's Proposed name for IEC 90-5:
Networked **O**bject **O**riented **S**ubstation **E**vent

The NOOSE !

But people got hung up on the idea... So we have:

- R-GOOSE (for Routed GOOSE)
    - For routing of Event Data

And

- R-SV (for Routed Sample Values)
    - For routing periodic data

IEC 90-5 Data Model

SPDU:
Session
Protocol
Data
Unit

Detail Format

Total Max Size:
65535 bytes

Supports Multiple non-time-aligned PMU datasets

IEC 61850 90-5 Networked GOOSE/SV

Potential Solution for NASPINet

Payload

- Consists of Multiple IEC 61850-9-2 Protocol Data Units (PDUs)

- PDU consists of:
  - Header

  - Dataset

  An Implementation Agreement is proposed to "agree" to the items in the Header and Dataset

imagination at work

Implementation Agreement: Header

- Multicast Sample Value ID – MSVID

  - \<name>-\<IDCode>-\<Class>
    - IDCode inherited from C37.118 (PMU or PDC)
    - Class = P, M, or N (for none)
    - All data in a given PDU shall be of the same Class

- RefrTim – Mandatory

  - Synchrophasor TimeStamp per C37.118
  - Same Time Stamp as in C37.118 (SoC+FoS+TQ)
  - TimeBase = 2^{24} = 16,777,216
  - TQ = C37.118 TQ

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Implementation Agreement Dataset inclusions

- STAT word
  - 16 bit Unsigned Integer
  - Semantics from C37.118
- Synchrophasors Frequency and ROCOF to be included
- Synchrophasors
- Analog Values

Reliable Transport through Repeat

APCI
(Application – Protocol Control Information)

ASDU's (Application – Service Data Unit)

Tag	Length	No. of ASDUs (UI16)	ASDU 1	ASDU 2	● ● ●	ASDU n

APDU (Application – Protocol Data Unit)

ASDU1 – Oldest data
ASDUn – Newest data
n is a user-settable parameter

Internet Protocol Priority via Differentiated Services byte

Bit #:	0	1	2	3	4	5	6	7
Value:	1	0	1	1	1	0	0	0
DSCP							ECN	

- DSCP - Differentiated Service Code Point
  - set for Expedited Forwarding (0x2E)
- ECN – Explicit Congestion Notification
  - Set by the routers if enabled
- Overall byte value: 0xB8

Mapping of C37.118 FoS to 61850

$$\text{FractionOfSecond\_61850} =$$

$$\frac{FractionOfSecond\_C37.118}{C37.118\_Time\_BASE} * 16{,}777{,}216 (2\string^24)$$

Unicast vs. Multicast

Point-to-Point
Multiple Streams

Multicast
One Output Stream

- Requires 3x Bandwidth in this example
  - 3X Infrastructure $$$
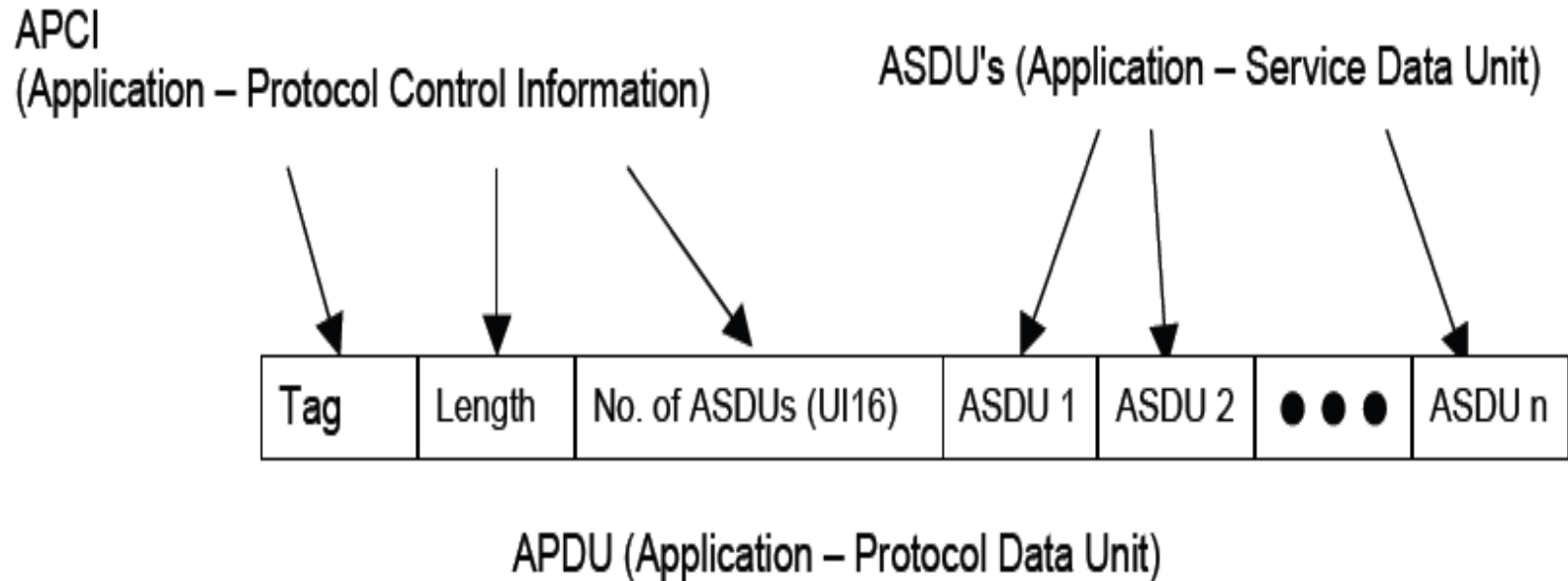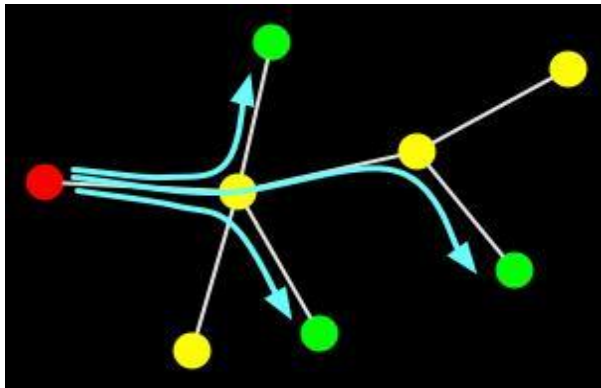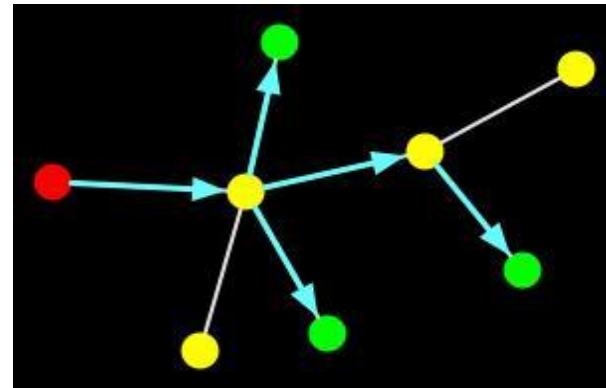
imagination at work

Multicast Path Establishment via Internet Gateway Management Protocol – IGMP
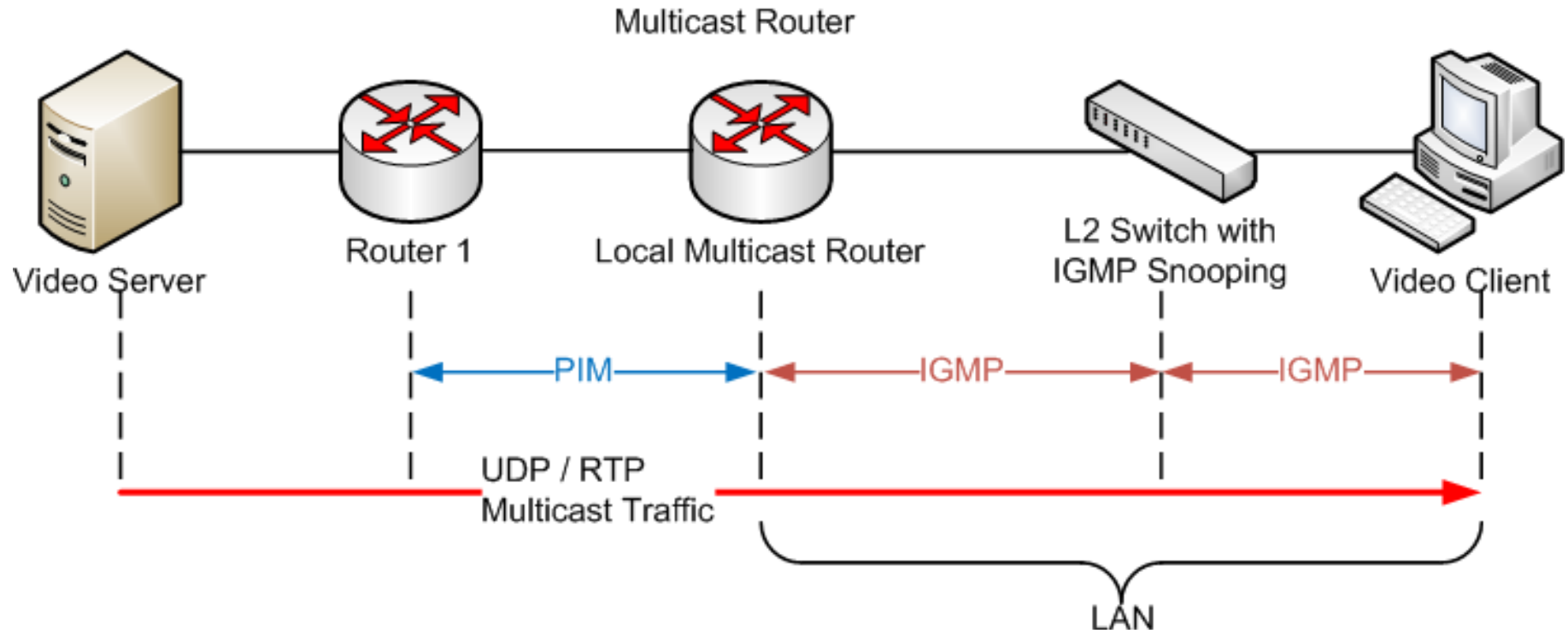
IGMP Packet Structure

bit offset	0–3	4	5–7	8–15	16–31
0	Type = 0x11			Max Resp Code	Checksum
32	Group Address				
64	Resv	S	QRV	QQIC	Number of Sources (N)
96	Source Address [1]				
128	Source Address [2]				
	. . .				
	Source Address [N]				

Group Address: This is the multicast address being queried when sending a Group-Specific or Group-and-Source-Specific Query. The field is zeroed when sending a General Query

Input LNs Required

M60MMXUnn
- Calc. Method:
  - "P" or "M" class
- Phase Voltages
- Phase Currents
- Frequency
- Rate of Change of Frequency - (HzRte)
- SmpRate

P120MSQInn
- Calc Method
  - "P" or "M" class
- Sequence Voltages
- Sequence Currents

- LNs Identified as a C37.118 Calculation Type "P" or "M"
- Report rate included in the LN
- Nominal Frequency added to LPHD

Mapping of C37.118 STN and IDCode

- STN and IDCode mapped into "d"escription field of the Label CDC (LPL) of LLN0
- Mapped as:
  - <STN>-<IDCode>
- SmpRate added as a DO in LLN0

PMU to PDC Mapping
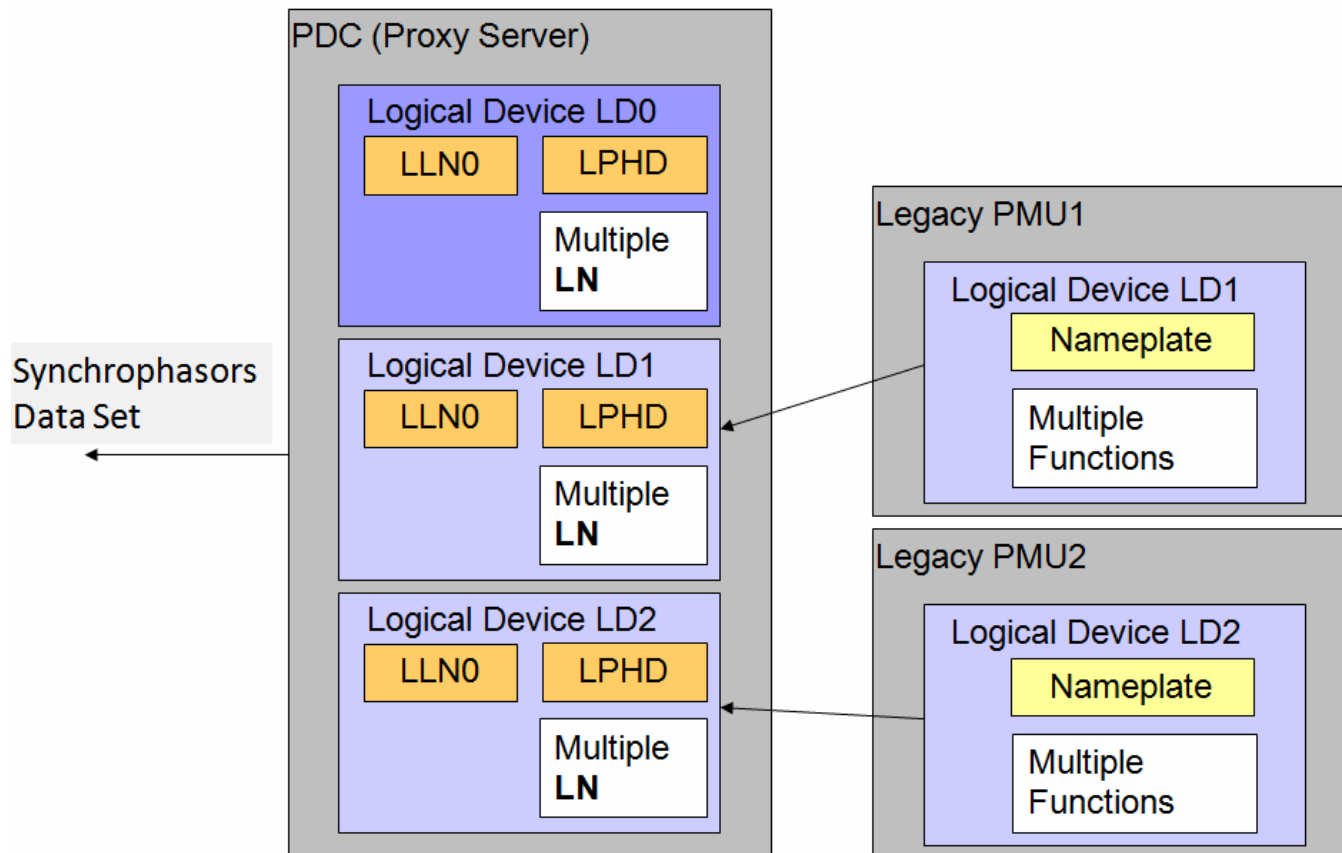
Implementation Agreement

C37.118.2 to 90-5 Data Mapping Proposal:

PMU1 STAT Word (C37.118 Type Bitstring)

PMU1 Data

PMU2 STAT Word

PMU2 Data

....

PMUn STAT Word

PMUn Data

PMU Data Organization

- STAT word (16 bit Unsigned Integer) – Semantics from C37.118.2

- Synchrophasors – Float 32 / Polar Format

- Frequency – Float 32

- Rate of Change of Frequency – Float 32

- Analogs – Float 32

- C37.118.2 Binary Status (16 bit Bitstring)

Standardized Dataset Configuration

- Uses the IEC 61850 XML Configuration language
  - SCL Extensions added for the 16 bit – bit strings used in C37.118
    - There is now a C37.118 "Data Type"
- Dataset members can be published via standard registration services

Security Definition in 90-5

- Defines a Secure Hash Algorithm - SHA2 Hash code for message authentication / integrity

- Defines AES as the encryption algorithm

- Identifies / Extends a Key management system
  - RFC 3547 The Group Domain of Interpretation
  - The publisher manages the keys to all subscribers
  - Same key for Hash and Encryption

Security Options as defined in 90-5:

Table 9 – Allowed values for MAC signature value calculations

Enumerate value	HMAC algorithm	Number of bits	Designation	Mandatory (m), Optional (o)
0	None	None	MAC-None	c1
1	SHA-256	80	HMAC-SHA256-80	m
2	SHA-256	128	HMAC-SHA256-128	m
3	SHA-256	256	HMAC-SHA256-256	m
4	AES-GMAC	64	AES-GMAC-64	m
5	AES-GMAC	128	AES-GMAC-128	m
c1 – Shall only be used when encryption is also in use.				

One-way Compression
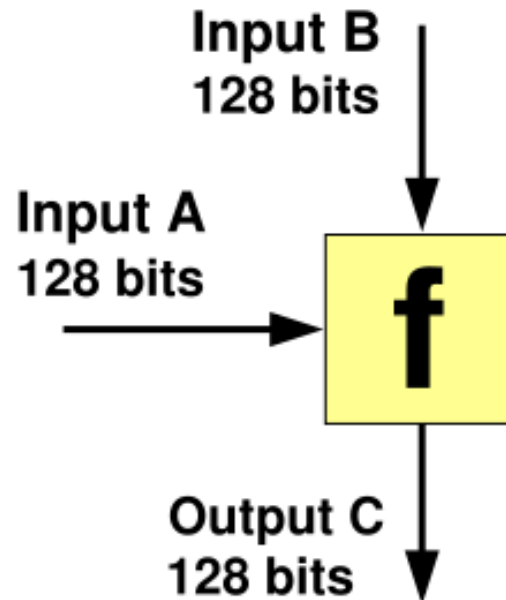
- Input values typically cannot be re-produced

Hash Function Concept

- Processes an arbitrary-length message into a fixed-length output

- Typical implementation breaks the message into N blocks and operates on each block in sequence
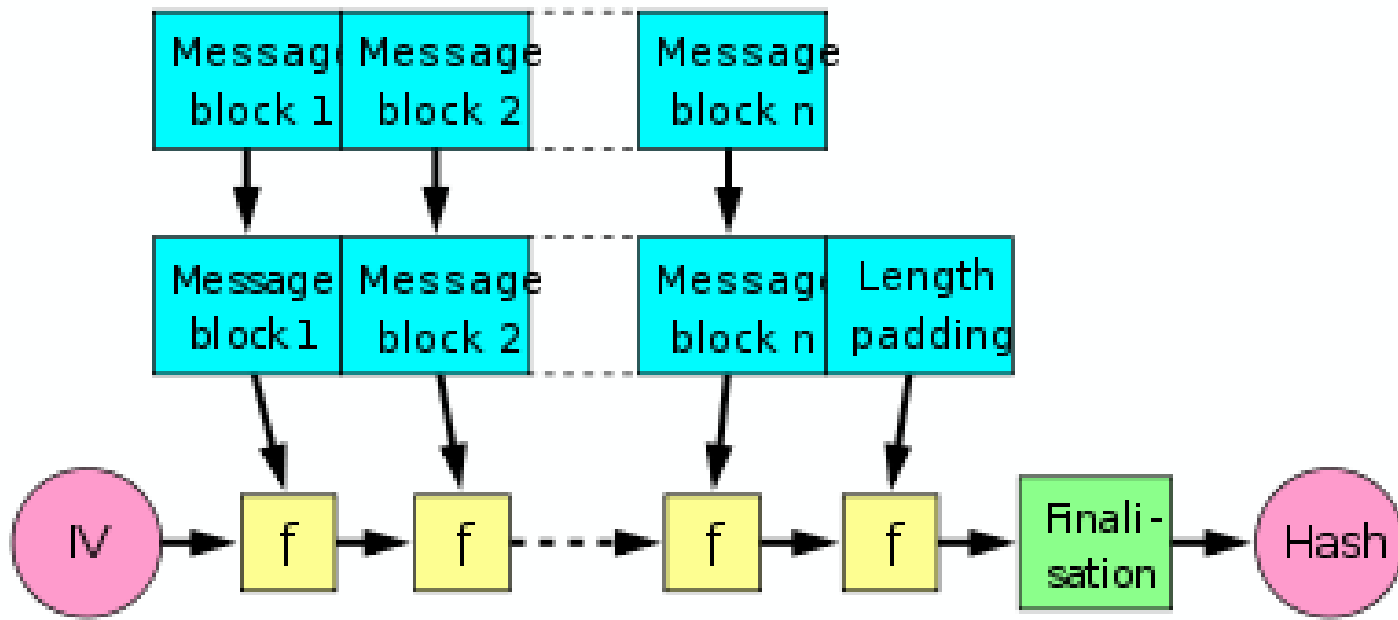
Cryptographic Hash Concept
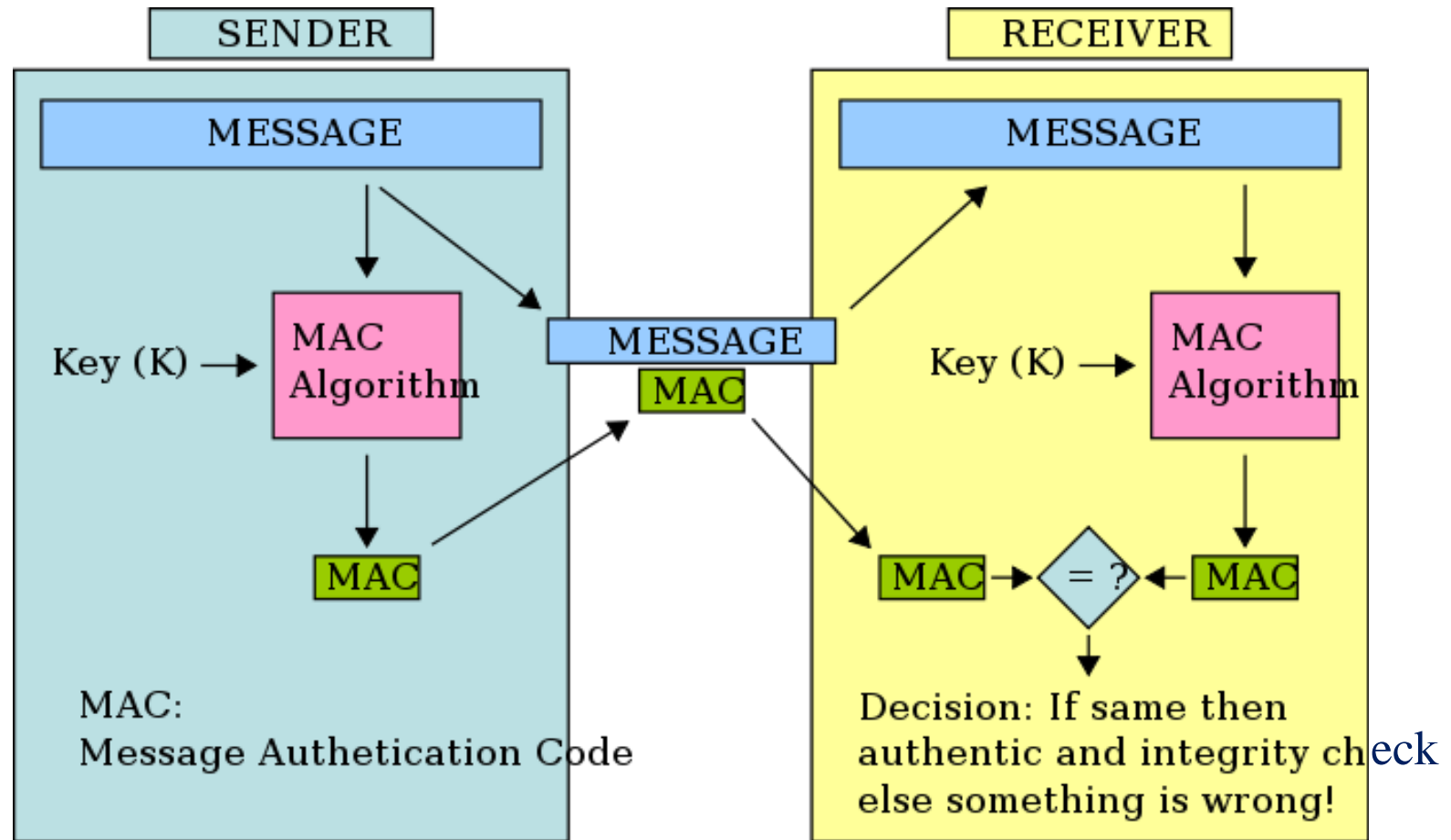
Also known as a Hash based Message Authentication Code – **HMAC**
Also called a Message Integrity Code **- MIC**

Example of Hash Outputs from SHA-1*

Input		Digest
Fox	cryptographic hash function	DFCD 3454 BBEA 788A 751A 696C 24D9 7009 CA99 2D17
The red fox jumps over the blue dog	cryptographic hash function	0086 46BB FB7D CBE2 823C ACC7 6CD1 90B1 EE6E 3ABC
The red fox jumps ouer the blue dog	cryptographic hash function	8FD8 7558 7851 4F32 D1C6 76B1 79A9 0DA4 AEFE 4819
The red fox jumps oevr the blue dog	cryptographic hash function	FCD3 7FDB 5AF2 C6FF 915F D401 C0A9 7D9A 46AF FB45
The red fox jumps oer the blue dog	cryptographic hash function	8ACA D682 D588 4C75 4BF4 1799 7D88 BCF8 92B9 6A6C

* SHA-1 now deprecated due to vulnerabilities

Cryptography Basics
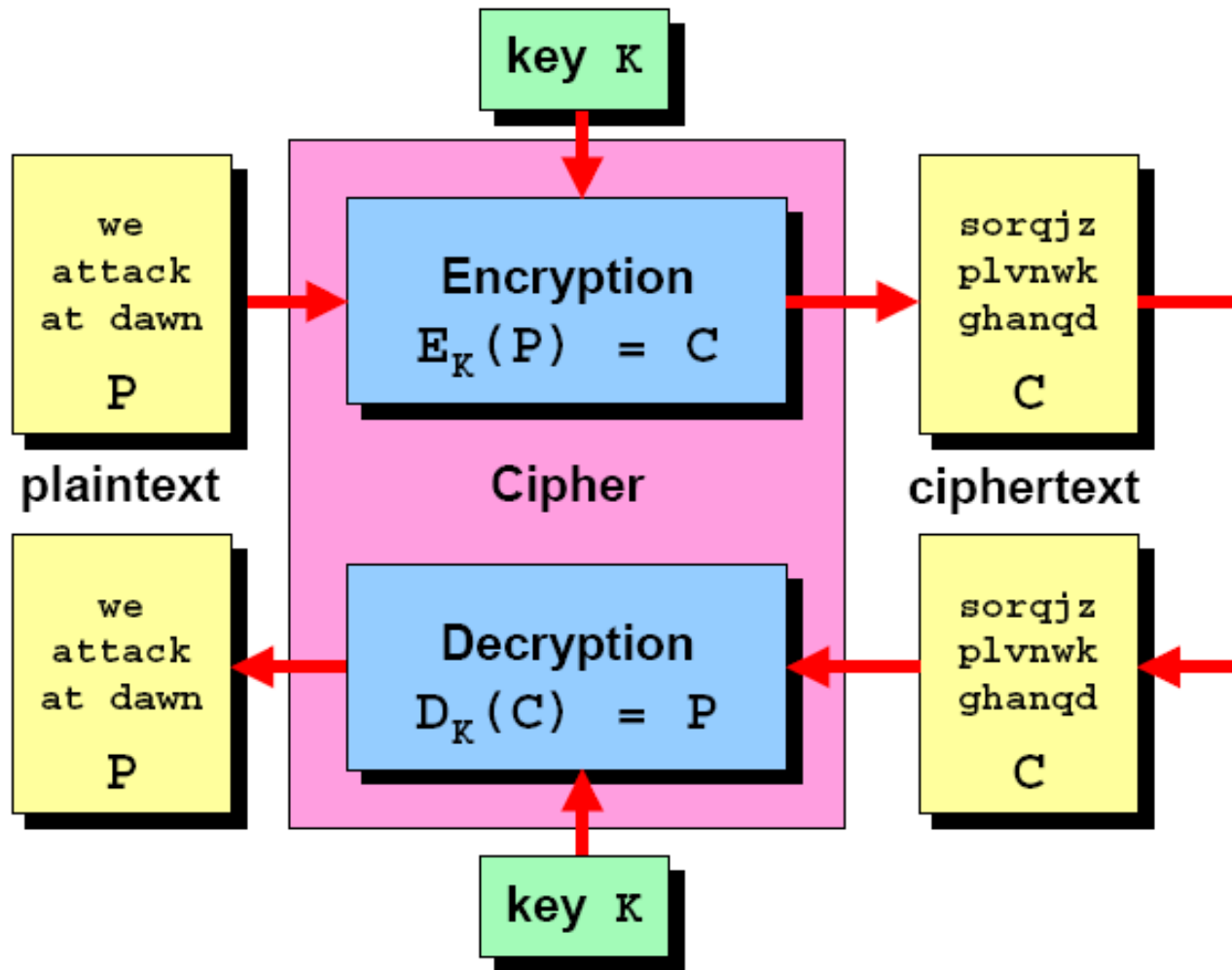
Block Cypher Concept
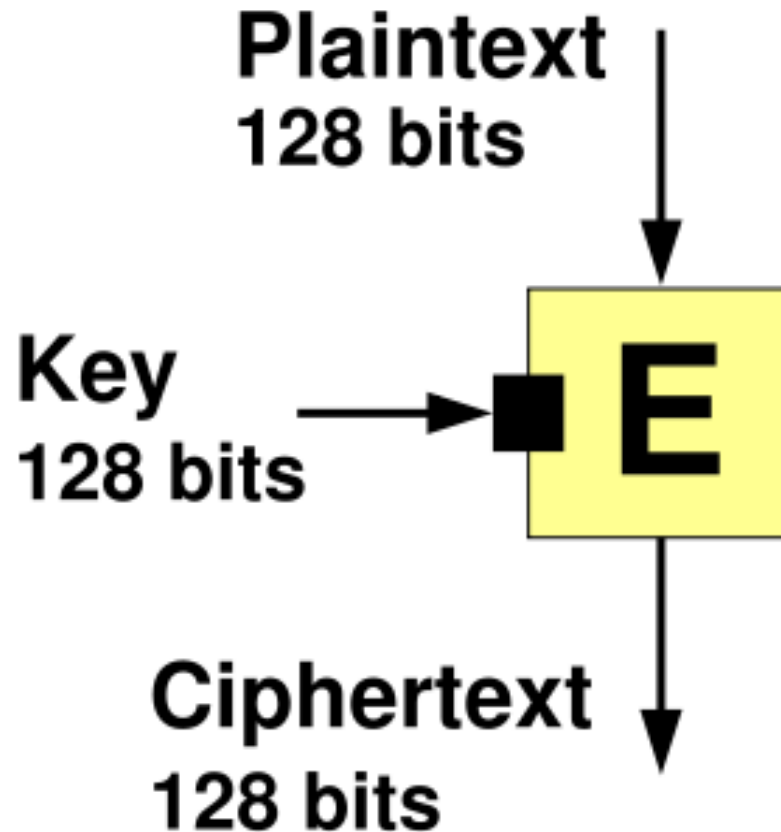
AES Works on 128 Bit blocks of data

Packet Encryption via:
Advanced Encryption Standard (AES)

AES Encryption Package

the Advanced Encryption Standard (AES) **encryption package** , also known as Rijndael, is a block cipher adopted as an encryption standard by the US government. The National Institute of Standards and Technology (NIST) established the new Advanced Encryption Standard (AES) specification on May 26, 2002.

The AES **encryption package** is a cryptographic algorithm that can be used to protect electronic data. Specifically, AES is an iterative, symmetric-key block cipher that can use keys of 128, 192, and 256 bits, and encrypts and decrypts data in blocks of 128 bits (16 bytes).

AES is the successor to the older Data Encryption Standard (DES). DES was approved as a Federal standard in 1977 and remained viable until 1998 when a combination of advances in hardware, software, and cryptanalysis theory allowed a DES-encrypted message to be decrypted in 56 hours. Since that time numerous other successful attacks on DES-encrypted data have been made and DES is now considered past its useful lifetime.

The AES algorithm is based on permutations and substitutions. Permutations are rearrangements of data, and substitutions replace one unit of data with another. AES performs permutations and substitutions using several different techniques.

The AES **encryption package** will certainly become a de facto standard for encrypting all forms of electronic information, replacing DES. AES-encrypted data is unbreakable in the sense that no known cryptanalysis attack can decrypt the AES cipher text without using a brute-force search through all possible 256-bit keys.

AES Step 1 – Substitute Bytes
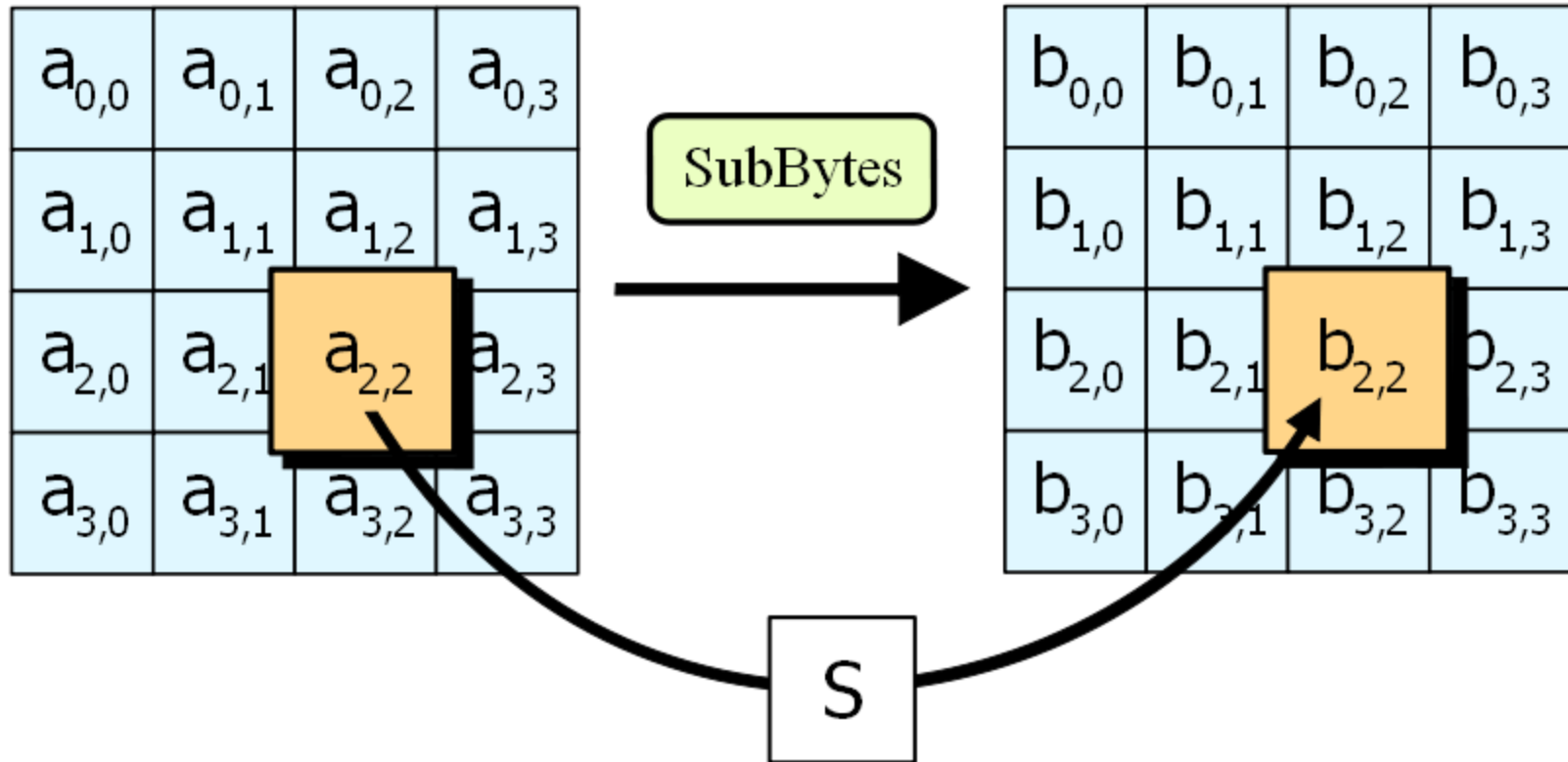
In the SubBytes step, each byte in the state is replaced with its entry in a fixed 8-bit lookup table, S; $b_{ij} = S(a_{ij})$.

AES – Step 2 – Shift Rows
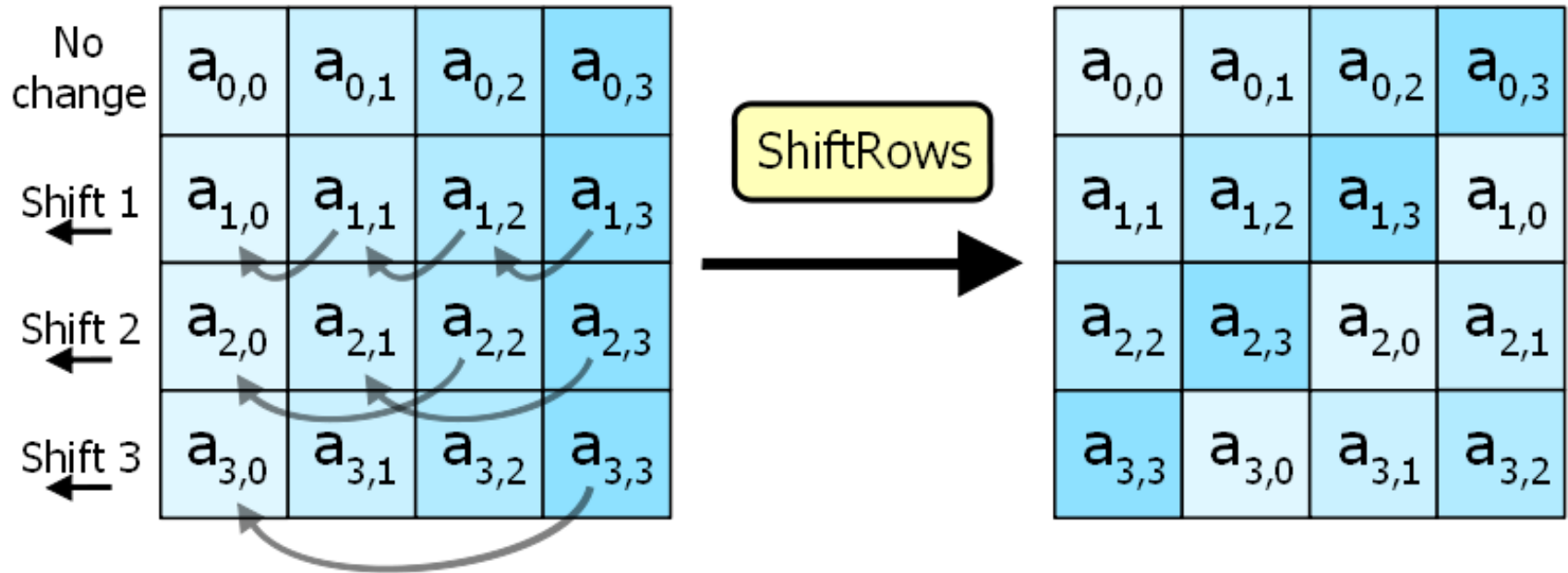
In the ShiftRows step, bytes in each row of the state are shifted cyclically to the left. The number of places each byte is shifted differs for each row.

AES – Step 3 – Mix Columns
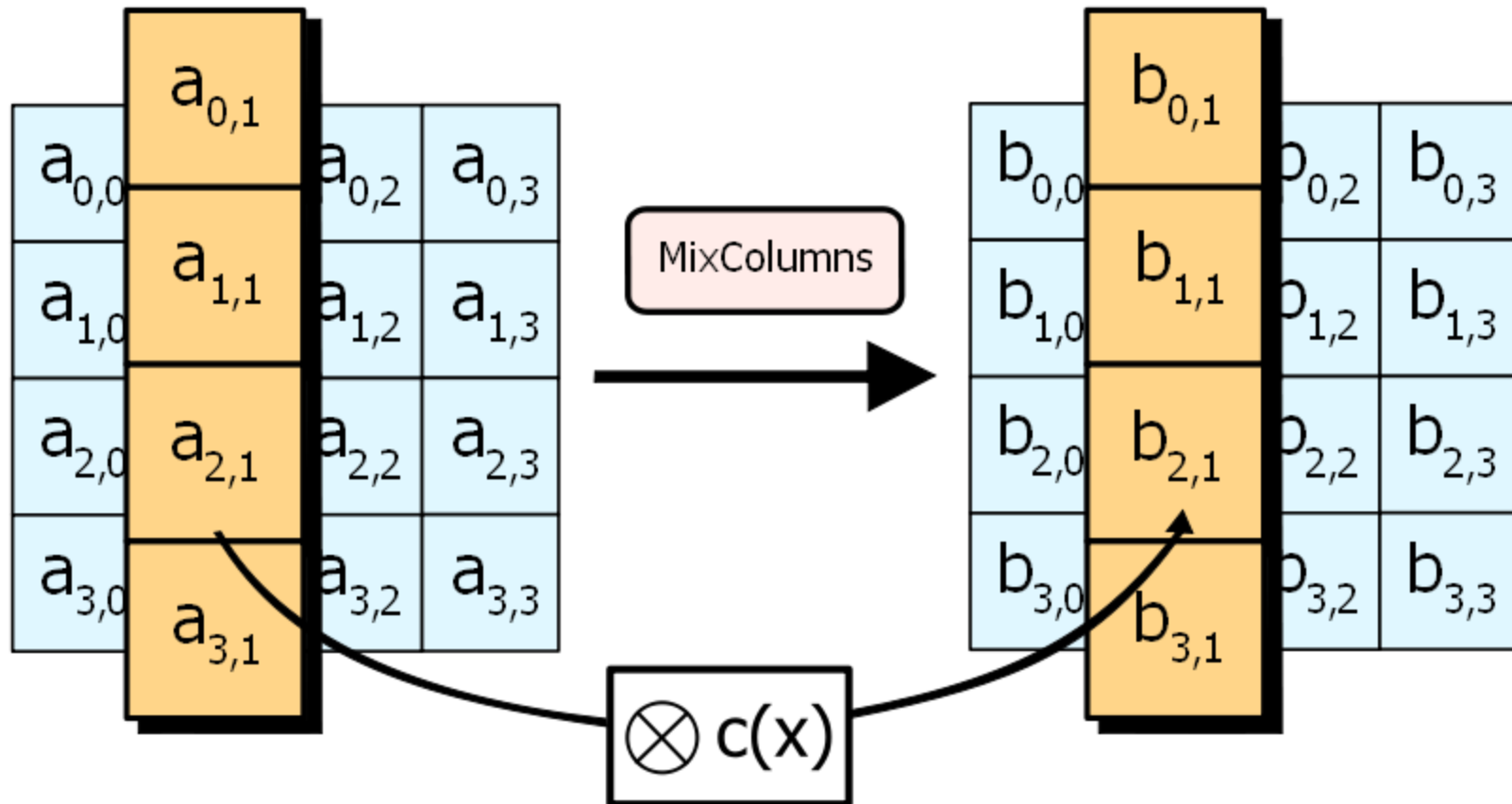
In the MixColumns step, each column of the state is multiplied with a fixed polynomial c(x).

imagination at work

AES – Step 4 – Add round Key
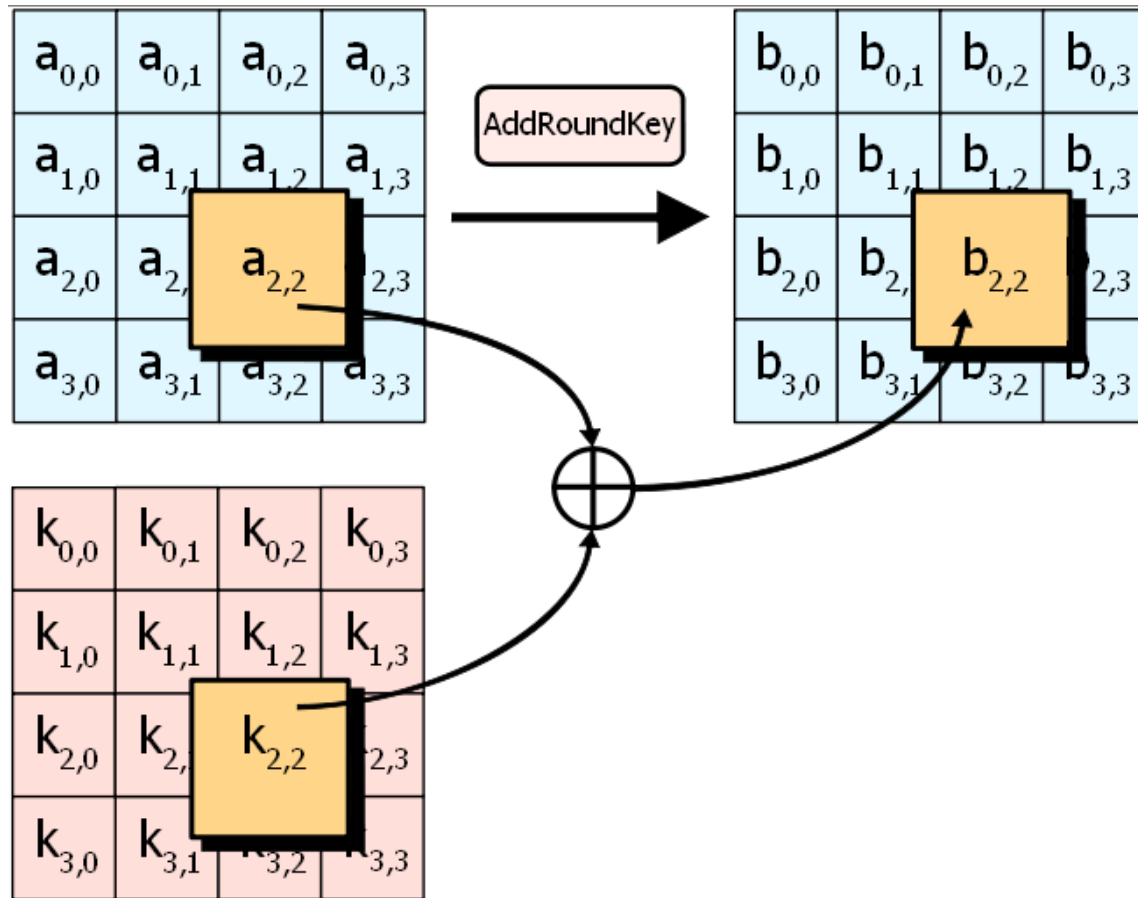
In the AddRoundKey step, each byte of the state is combined with a byte of the round subkey using the XOR operation ($\oplus$).

Group Domain of Interpretation - GDOI
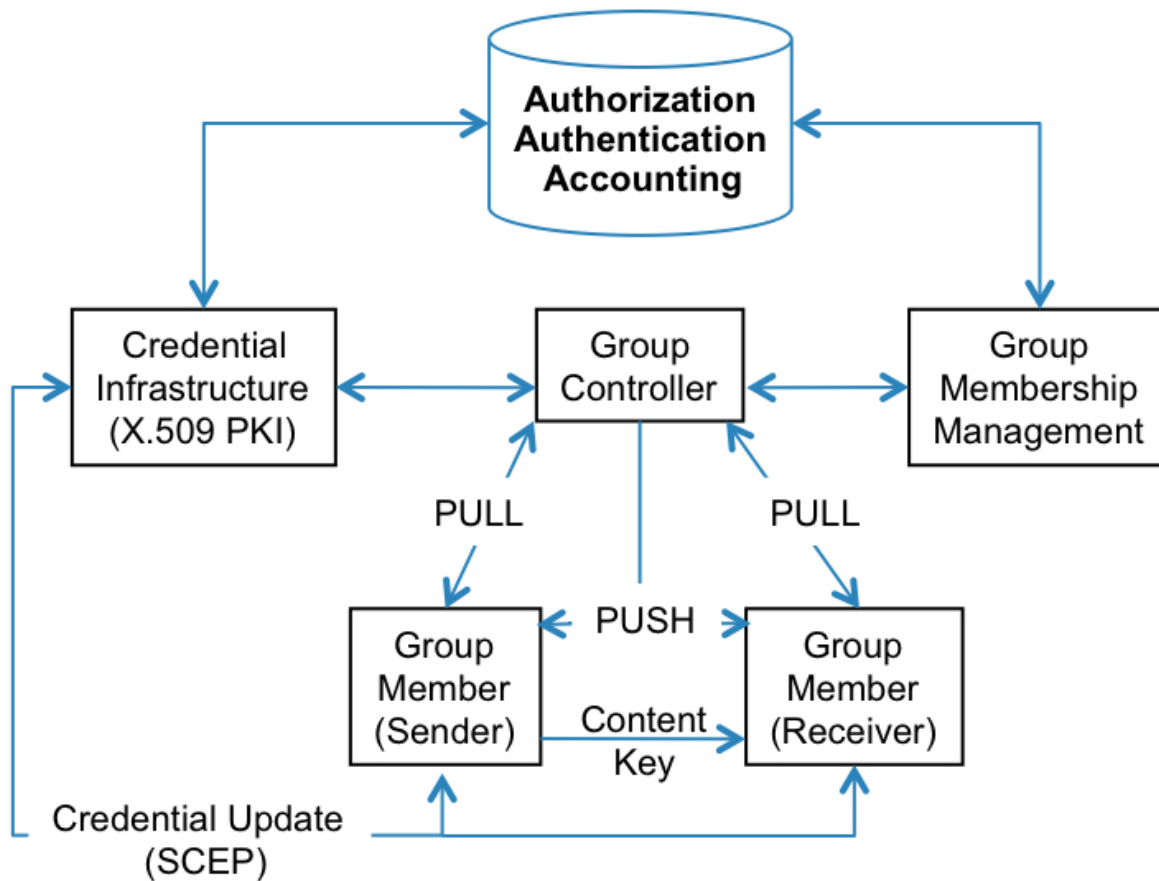
- Publishers act as Controllers
- Receiving Group Members "Pull" new keys
- Centralized Authorization Management

Publisher-based Key Management
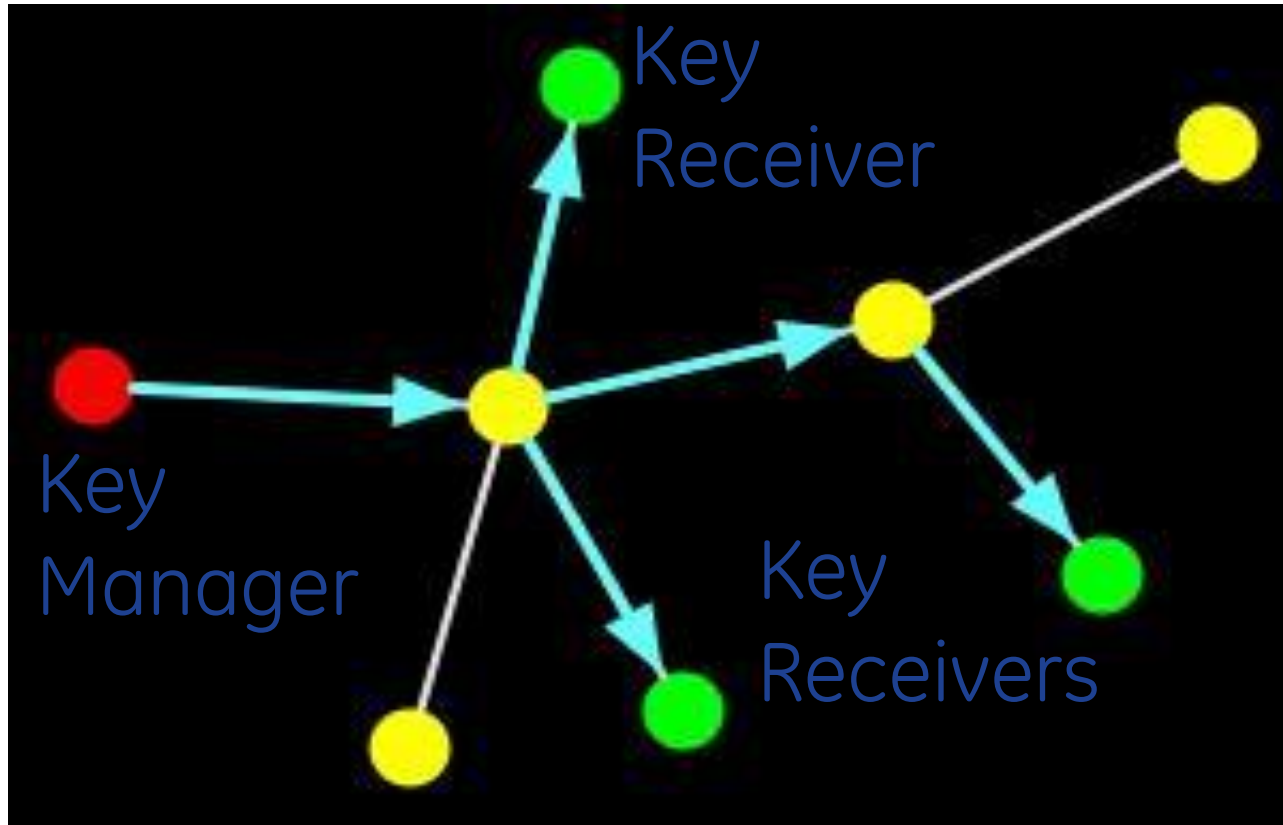
Keys are dynamically managed
Changed when a Subscriber is removed

Insight in IEC 61850

What is it?

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6605 19½ Mile Road
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Email: ralph@sisconet.com – herb@sisconet.com

Topics

- IEC 61850 and Its Relationship to other IEC Standards

- Impact of IEC 61850 on the Engineering Processes of SCADA, Automation, and Protection

- IEC 61850 Profiles and use of networks

- IEC 61850 Modeling
  - Device and Object Models
  - Service/Behavior Models

- Substation Configuration Language

IEC 61850 and Other Key IEC Standards

What is it with all these "models"?

Definitions:

Interoperability and Integration

The ability of computer systems to exchange information with other systems and to cooperatively implement a useful process or function for the system owner/user.

Interoperability and Integration

- Easy to Achieve:

Nearly anything is possible with enough money and development effort

A Better Way

- Interoperability and Integration without having to program it all yourself:

  - Where applications and devices are inherently capable of interoperating with other systems and performing integrated application functions in a cooperative and distributed manner.

- This is only possible if there are standards to enable it.

  - This work is progressing.

- This is the goal of the IEC TC57 standards

6

Standards are Needed

- Standards enable independent developers to reduce the uniqueness of their solutions at the interface points

- Traditionally, this meant the protocols to the devices

- But, this did not address the **integration** dilemma for applications (not devices) that did not use "protocols" as the interface

- Existing protocols provided **interoperability** but little **integration**

- A new level of standardization is needed

- **This is what the IEC TC 57 Standards are about.**

Strategic Vision for Integration and Interoperability

- Abstract Modeling
  - **Object and Information Models**
  - Abstract Service and Interface Models
  - Self Description and Discovery
  - Technology Independent Design

- Security
  - Applying mainstream standards to TC57 standards
  - Power system specific applications and recommendations
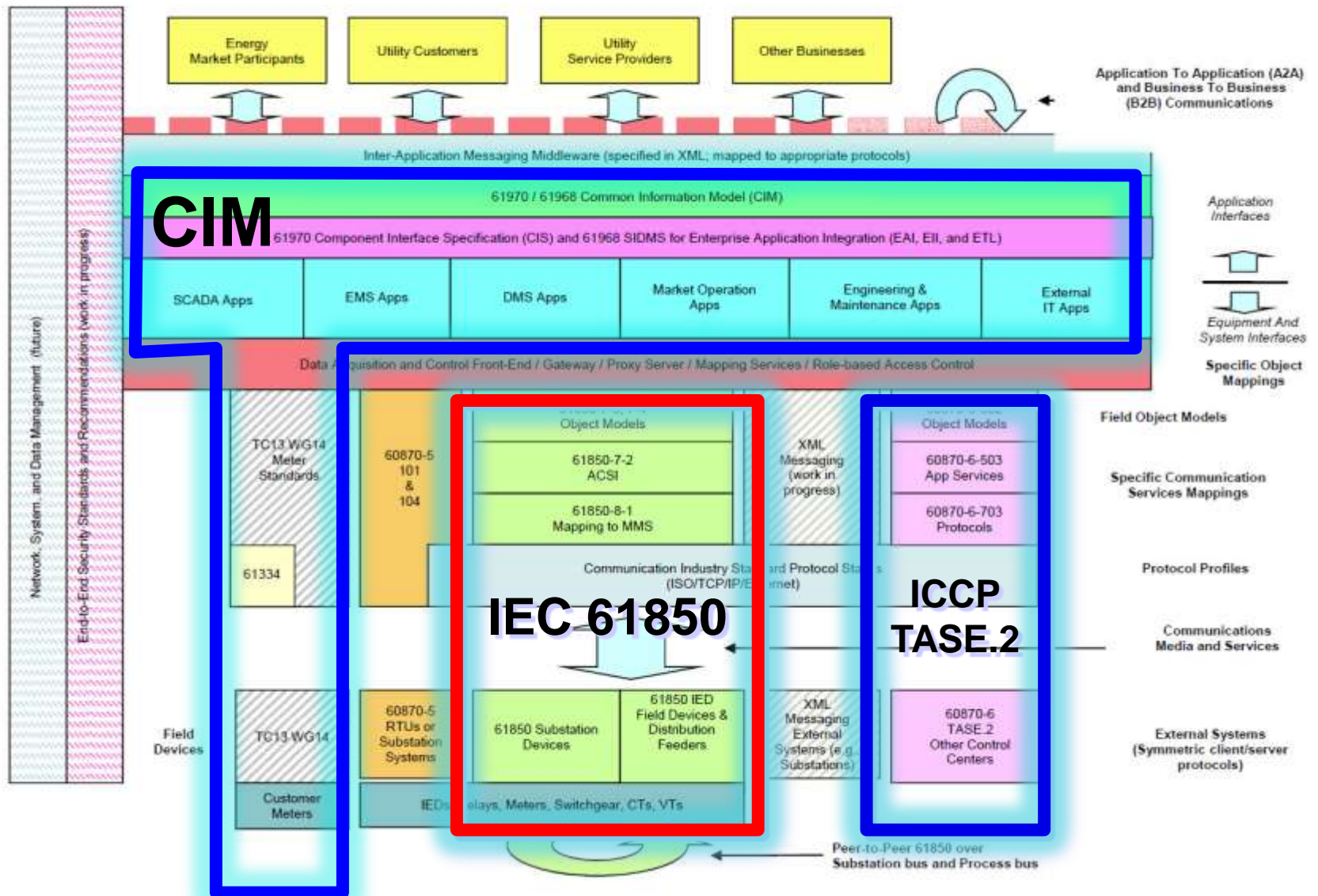
IEC TC 57 Technical Committees

- **WG 3** – Telecontrol Protocols
  - **IEC 60870-5-7** – Security for IEC 60870-5 protocols.
- **WG 10** - Power system IED communication and associated data models
  - **IEC 61850** – Communications for power system automation
- **WG 13** - Energy management system application program interface (EMS - API)
  - **IEC 61970** – Common Information Model (CIM) and Generic Interface Definition (GID)
- **WG 14** - System interfaces for distribution management (SIDM)
  - **IEC 61968** – CIM for distribution and model driven messaging
- **WG 15** - Data and communication security
  - **IEC 62351** – Communications Security
- **WG 16** - Deregulated energy market communications
  - **IEC 62325** – CIM for energy markets
- **WG 17** - Communications Systems for Distributed Energy Resources (DER)
  - **IEC 61850-7-420** – IEC 61850 for DER applications
  - **IEC 61850-8-2** – Web service mapping for IEC 61850
- **WG 18** - Hydroelectric power plants - Communication for monitoring and control
  - **IEC 61850-7-410** – IEC 61850 for Hydropower applications
- **WG 19** - Interoperability within TC 57 in the long term
  - **IEC 62445** – Use of IEC 61850 between control centers and substations
  - IEC 61850-CIM harmonization, ICCP-TASE.2 update, naming and design rules for CIM, quality codes.
- **WG 9 and WG 20** – Power line carrier systems for DMS (9) and planning for same (20)
  - **IEC 60495, 60663, 62488** – Power line carrier systems
- **WG 21** - Interoperability within TC 57 in the long term
  - **IEC 62746** – Interfaces and protocol for systems connected to the Smart Grid
- **JWG 16** – DLMS/COSEM – metering protocols (TC13)
- **JWG 25** – Windpower systems (TC 88)

Traditional Protocol Standards

- Specified how you arrange bytes on the wire in order to transfer bytes of data between a device and an application

- **Good News: It worked!** Device communications costs were lowered.

- Bad News: No standard for data representation or how devices should look and behave to network applications.

  - Some Interoperability but not Integration

Typical Legacy Protocol Data Model
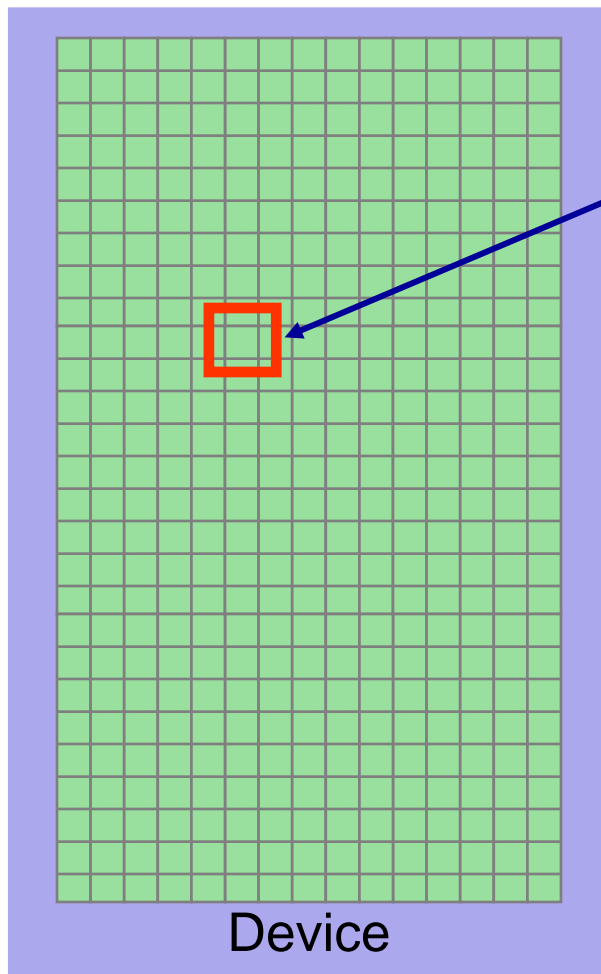
It is in:
Object #6,
Variation #2,
Index #27

That's intuitive?

I need the Phase A voltage for the 345KV primary feeder

NO POWER SYSTEM CONTEXT FOR DATA ACCESS

Device

Behavior Modeling

- Assume Index #25 is always used to store breaker status.
    - Does 1 mean open or closed?
    - Can I write this object to operate the breaker?
    - Where is the select?
    - Is it selected?

- **Even if every device used Index #25 to hold breaker status this still isn't enough to provide integration.**

A New Approach Needed

- For protocols to provide interoperability at the system level they need to:

    - Specify the bytes/format of the data on the wire

    - Specify the meaning of data

    - Specify the behavior of the data

IEC 61850: New Approach

- IEC 61850 is a new and innovative approach to substation automation:
  - Standardized Device and Object Modeling
    - Logical Devices, Logical Nodes, Common Data Classes, etc.
    - Extensions unique to specific applications (Hydro, Distributed Energy Resources (DER), Wind power, etc.)
  - Standardized Service/Behavior Modeling
  - Standardized XML for Systems and Device Configuration
  - Standardized Communications Protocols for Specific Use Cases:
    - Station Level Monitoring and Control (substation SCADA) (TCP/IP)
    - Protection and Control – GOOSE over Ethernet
    - Sampled Values – Process Bus over Ethernet
  - Standardized Conformance Test Cases

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Legacy Object Mapping

- Legacy data objects must be mapped to power system for each different device, application, and vendor.

Power System Functions

Measurements	Phase A Voltage
	Phase B Voltage
	Phase C Voltage

Controls	Local/Remote Status
	Breaker Position
	Blocked Open

Protection	Activate Phase A
	Activate Phase B
	Activate Phase C

Legacy Device

- R400040
- R400041
- R400042
- R400043
- R400044
- R400045
- R400046
- R400047
- R400048
- R400049
- R40004A
- R40004B

All Cost…No Value
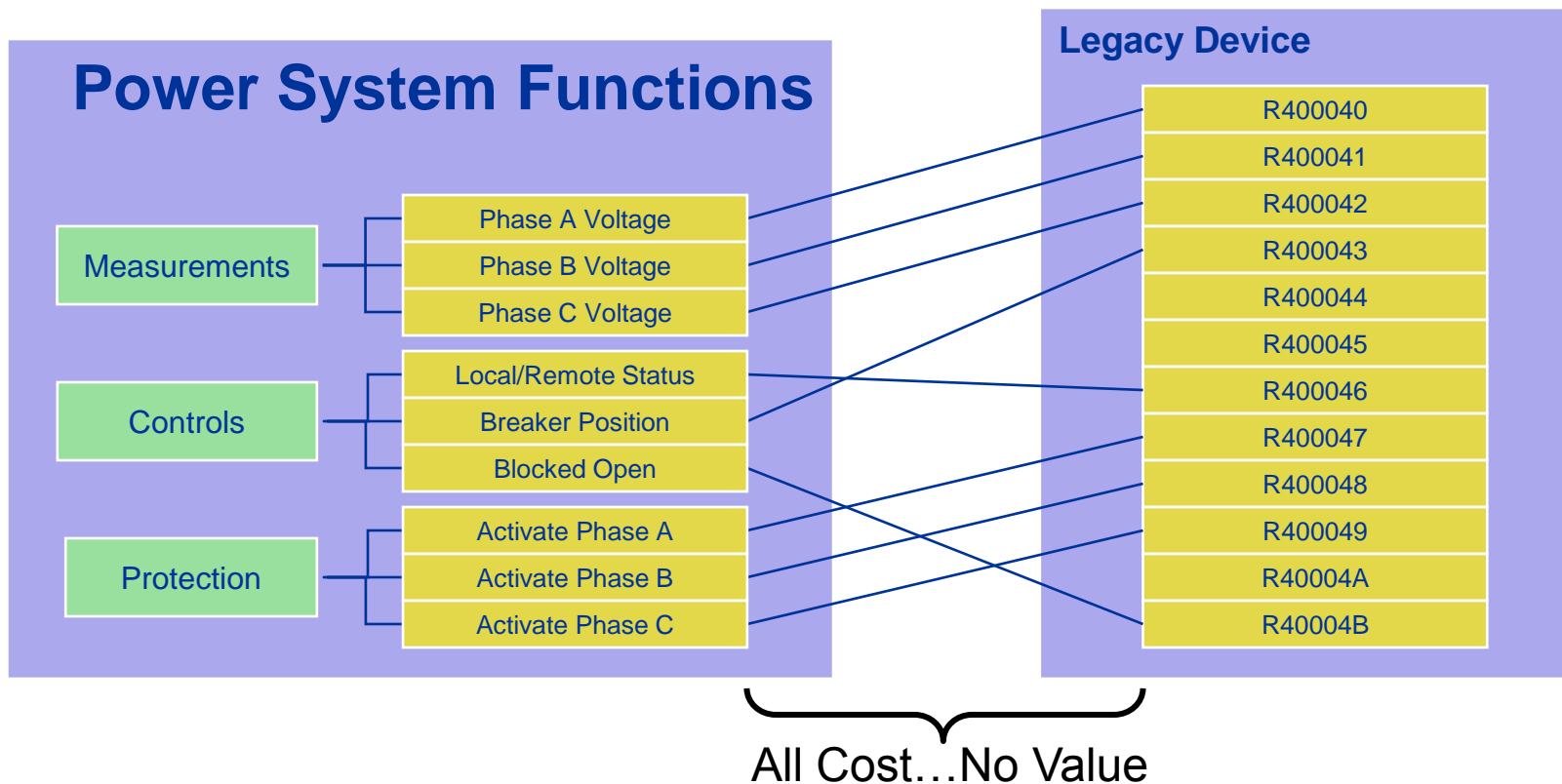
IEC61850 Object Model

IED:Relay1/MMXU1.MX.A

IED:Relay1/XCBR2.CO.Pos

Current Measurements

Breaker Position Control
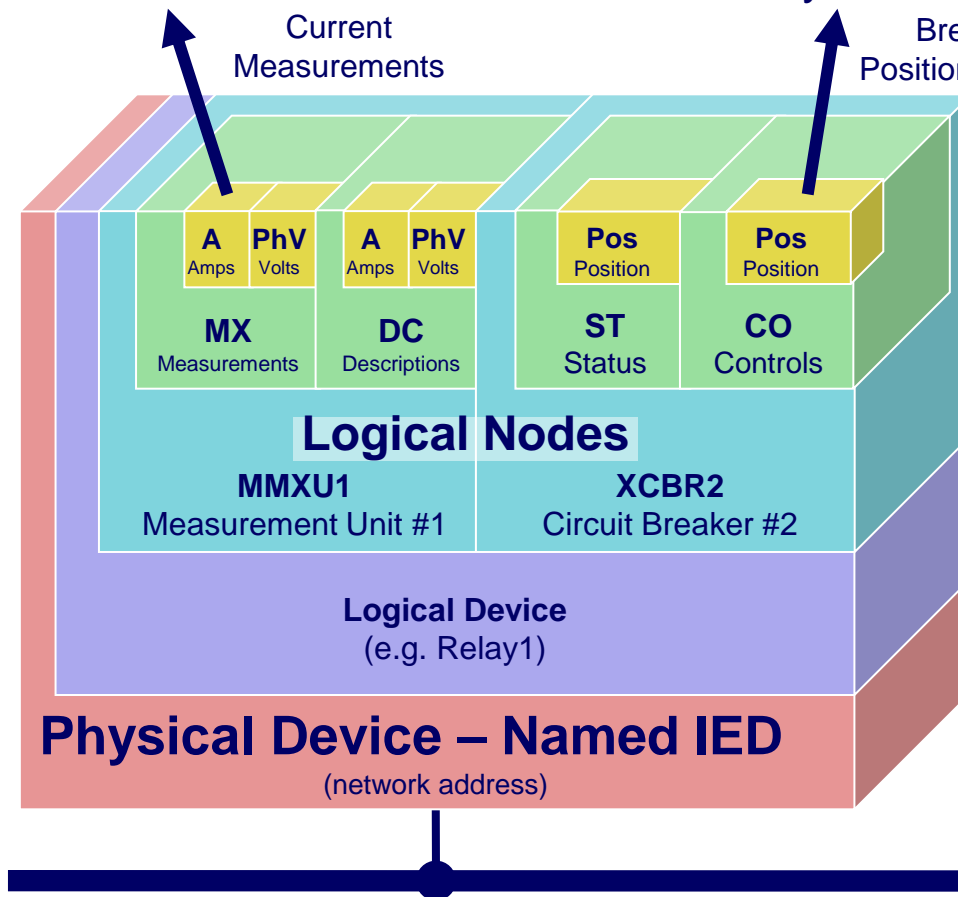
IEC 61850 Object Names Use Power System Context

| A Amps | PhV Volts | A Amps | PhV Volts | Pos Position | Pos Position |

| MX Measurements | DC Descriptions | ST Status | CO Controls |

Logical Nodes

| **MMXU1** Measurement Unit #1 | **XCBR2** Circuit Breaker #2 |

Logical Device (e.g. Relay1)

Physical Device – Named IED (network address)

IEC 61850 Object Mapping

- **NO MANUAL MAPPING NEEDED**: IEC61850 objects already portray the power system context.
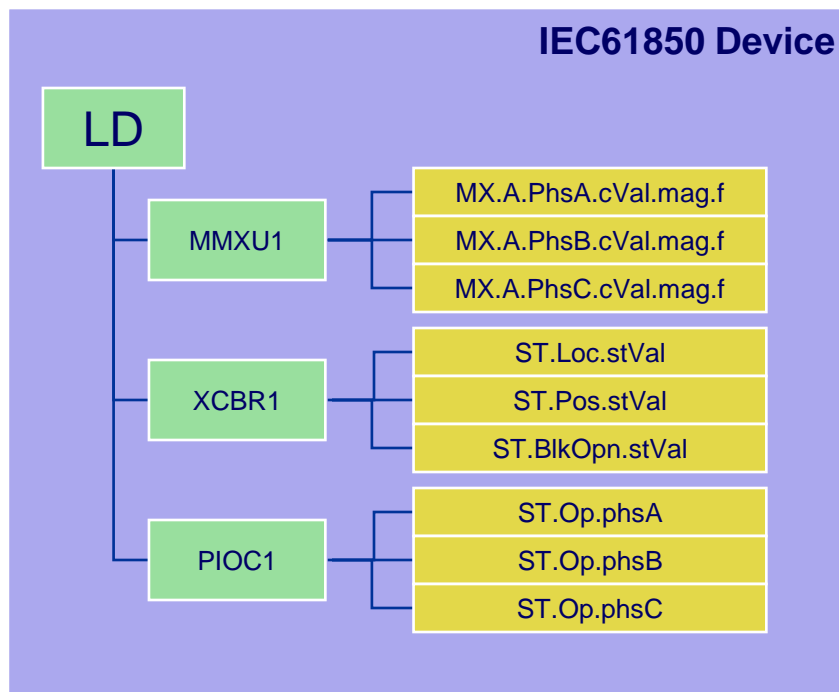
IEC61850 Models Independent of Function and Brand
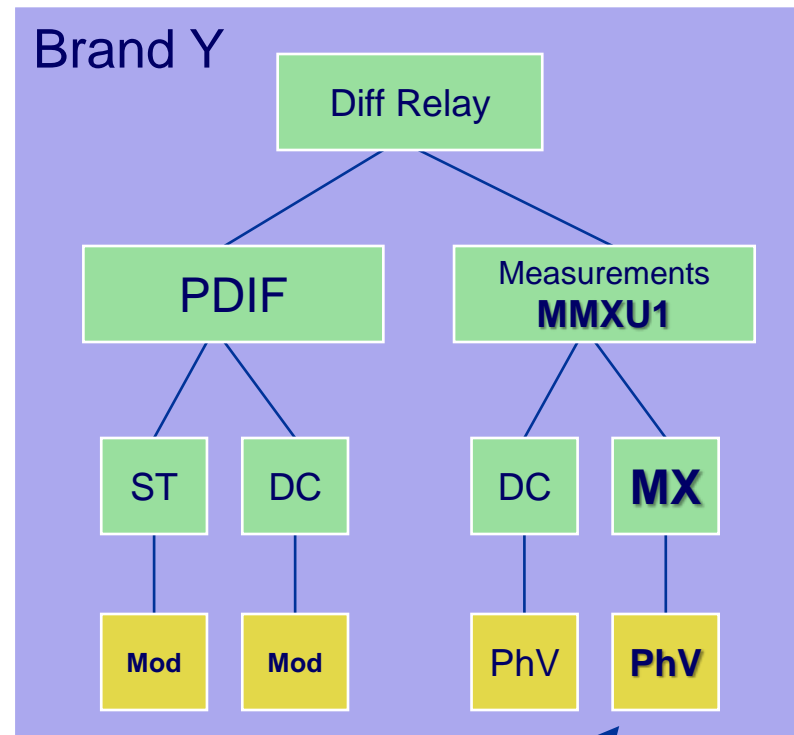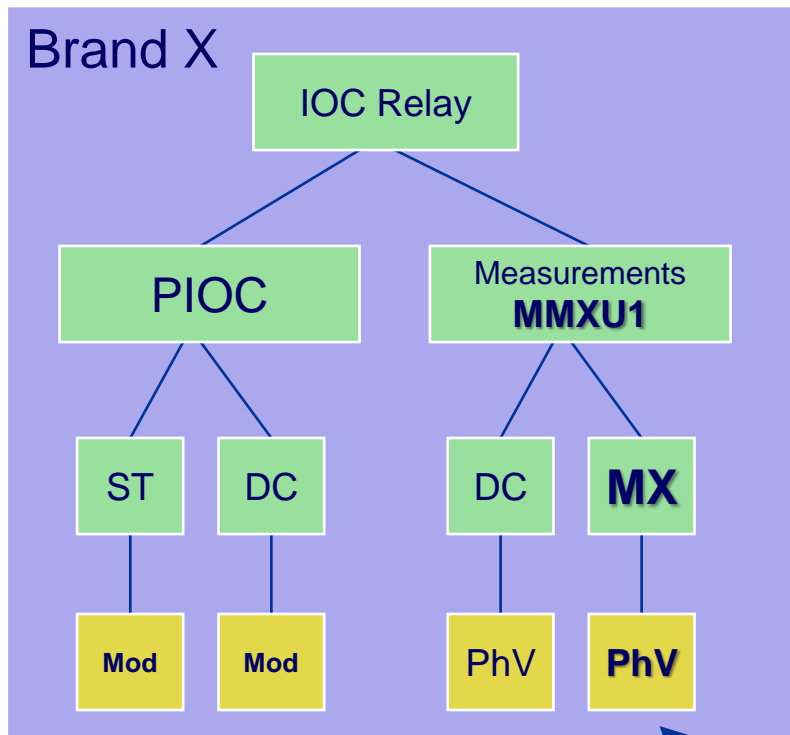
MMXU1.MX.PhV
IEC61850 Name for Phase-to-Ground Voltage Measurements

IEC61850 – Layered Standard

Device Object Models - IEC61850-7-3, 7-4

Device Model	Data Objects	Data Types	Naming Conventions

Abstract Service Model - IEC61850-7-2

Associate	Reporting	Self-Description	Control	Data Set	Logs

Mapping to MMS Protocol - IEC61850-8-1

Initiate	InfoReport.	GetNameList	Write	VariableList	Journals

TCP/IP

Ethernet
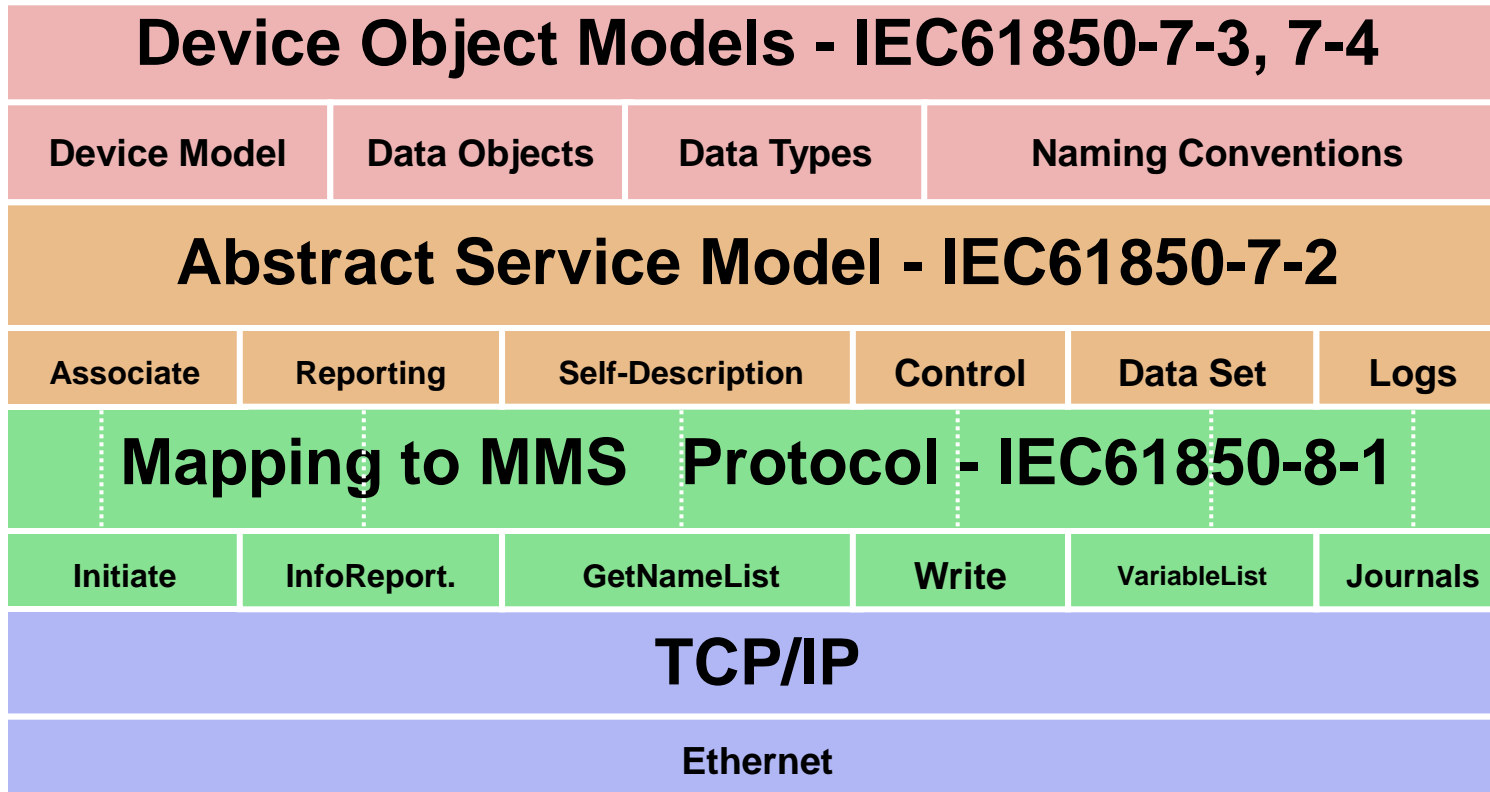
Benefits of Abstraction and Layering

- Abstract models are independent of the protocol and can be used outside of protocol applications (SCADA tag naming convention)

- Enables definition beyond just the bytes on the wire to incorporate naming and behavior

- Each layer can be optimized independently

- Enables protocols to be separated from application functions to enable use of existing standards (Ethernet, TCP/IP, etc.)

- Enables use of the abstract concepts to other protocols/systems in the future as technology changes.

Other Mappings Possible

Abstract

Device Object Models - IEC61850-7-3, 7-4			
Device Model	Data Objects	Data Types	Naming Conventions

Abstract Service Model - IEC61850-7-2					
Associate	Reporting	Self-Description	Control	Data Set	Logs

Real

Mapping to Web Services – IEC 61850-8-2

Web Services – http/SOAP??

TCP / IP protocol stack
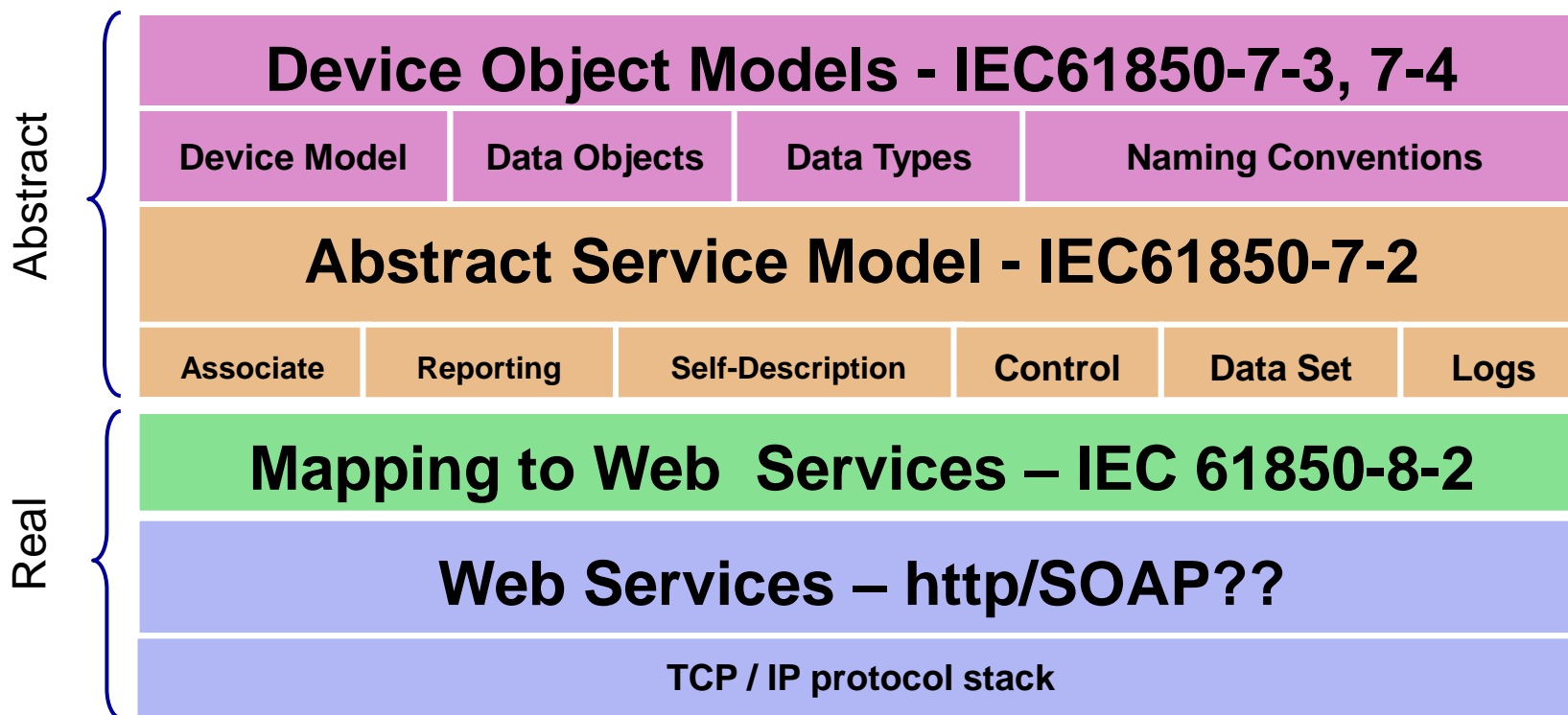
What is ICCP?

The Intercontrol Center Communications Protocol (ICCP) is an international standard (IEC60870-6 TASE.2) for the real-time exchange of SCADA data between control centers and external organizations like other utilities, power pools, and power plants.

Suggested Applicability

External Links Only

ICCP
Bilateral
Configuration

Strictly Controlled Access

Power Plants

Power Plants

Control Center

ISO/RTO/ Power Pool

Neighbor Utility

Secured Open Access

Substation — Substation — Substation — Substation

IEC61850 – Automated Configuration

Power System Automation & Protection Internal to Company

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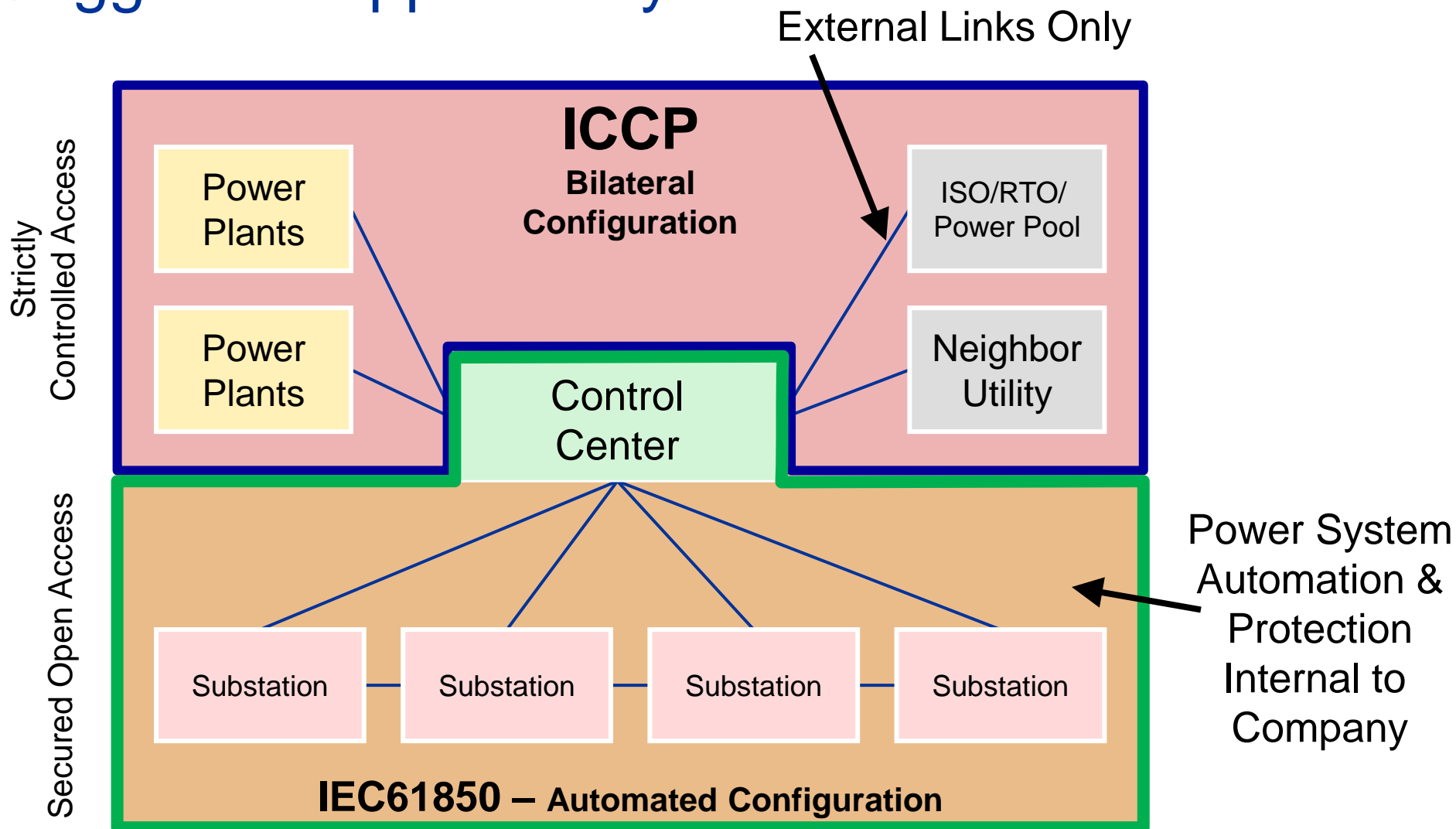
Common Information Model (CIM) is an object-oriented information model of the power system
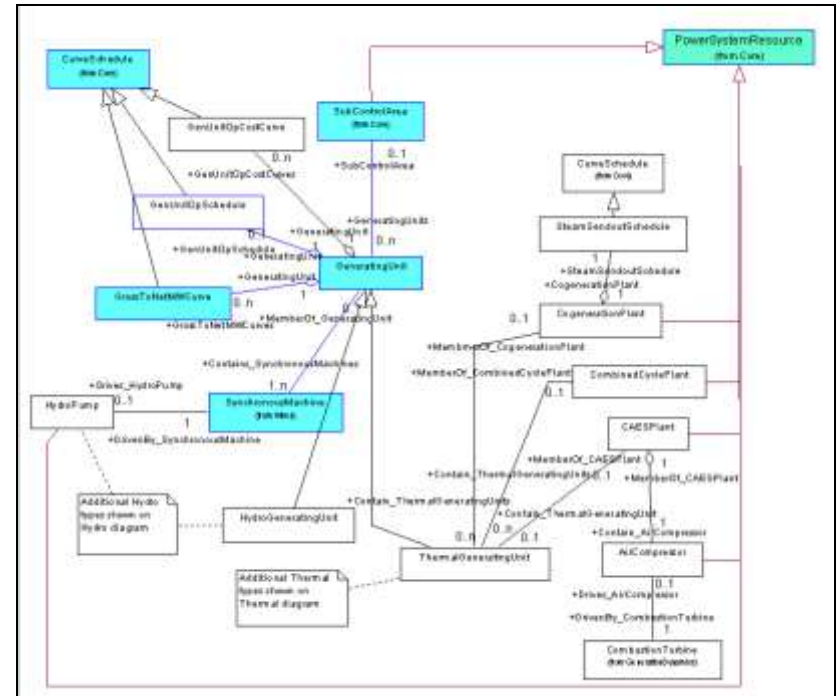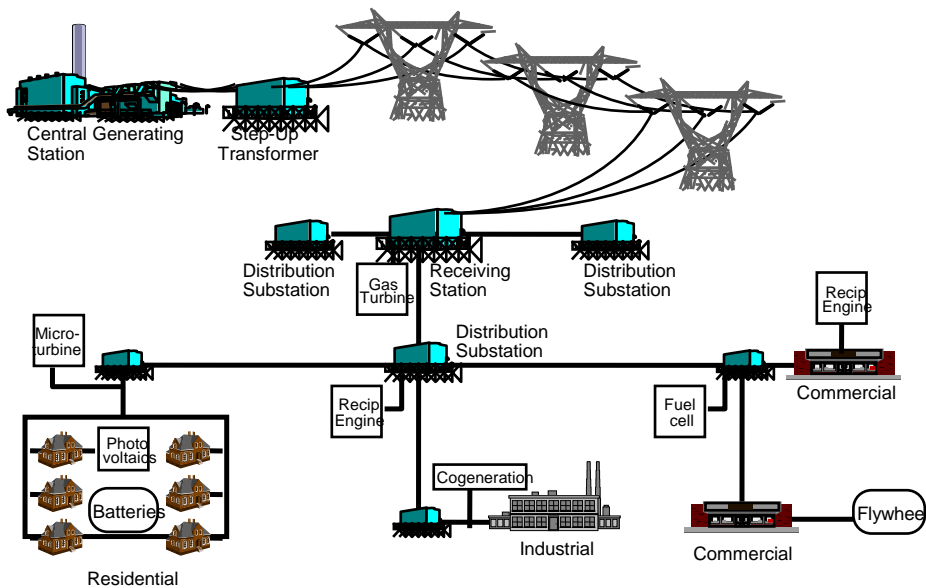
UML – Unified Modeling Language

CIM Packages

IEC 61970 from IEC TC57 WG13

- Core
- SCADA
- Load
- Protection
- Outage
- Wires
- Generation
- Measurements
- Domain
- Topology

IEC 61968 from IEC TC57 WG14

- Assets (metering)
- Documen-tation
- Consumer
- Core2
- ERP
- OAG

IEC 62325 from IEC TC57 WG16

- Financial
- Energy Scheduling
- Reservation
- Market Operations

Distribution
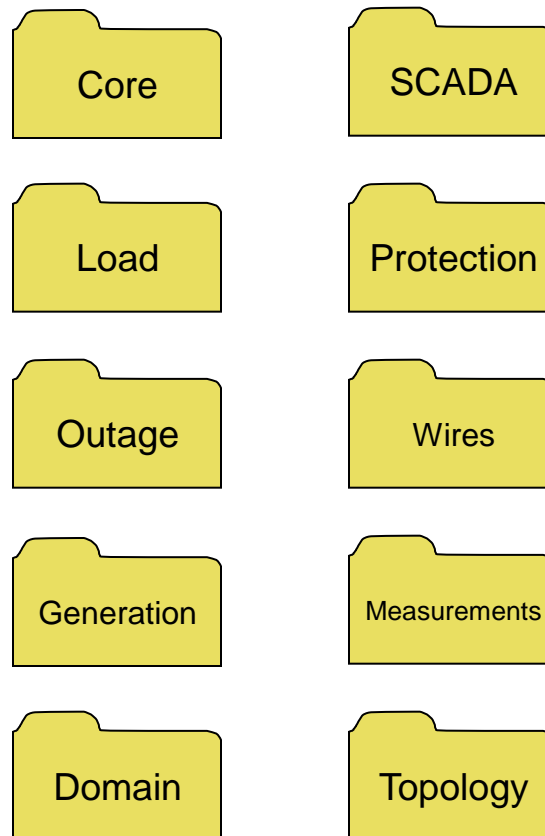
EMS, Transmission & Planning
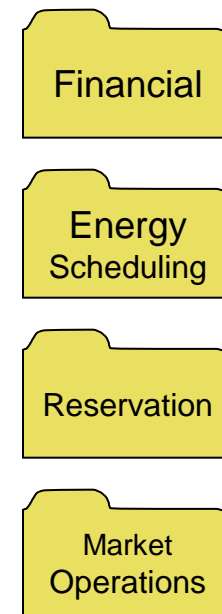
Markets (Euro & NA)

The Legacy Data Model Has Always Worked

Applications use Tags
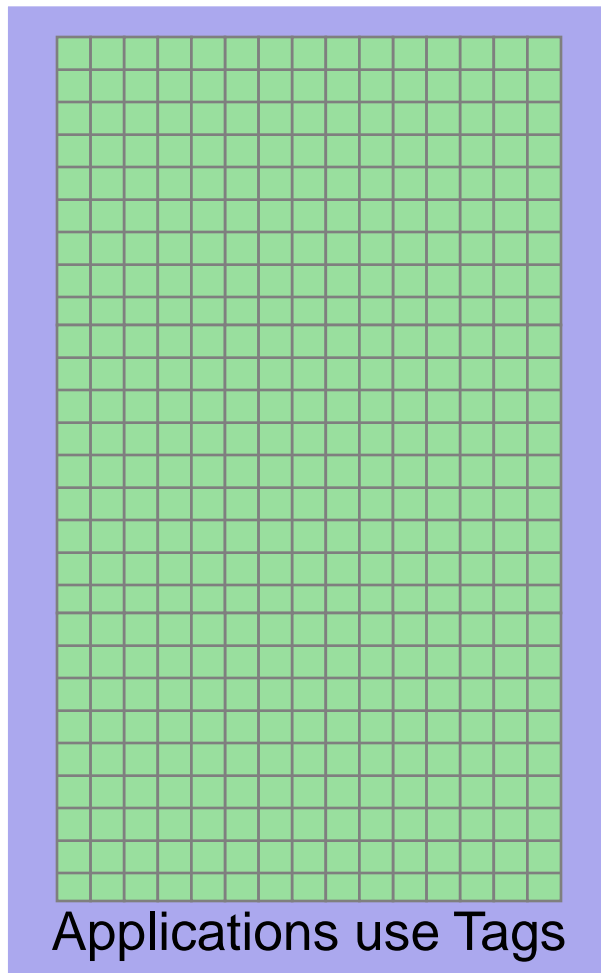
Why do I want the "complexity" of the CIM and all this modeling stuff? Tags are simple!

The Problem to be Solved?

A "one-off" point to point link will always be cheaper if the cost to integrate in the future is ignored.

Actual Business Process From a Real Company

Legend box:
Mainframe apps - **Blue**
PC/NT apps - **Green**
Unix apps - **Yellow**
3rd party interface - **Orange**
Lines: Colors have no special meaning. They are to help make the diagram easier to read.
For More Information: See the database containing information about each application: *Application V4.mdb*

Application boxes (labels):

Vendor Setup
Budget Analysis Tool
Vendor Maintenance
Printer Maintenance
Printer PO
Print Costing
Process Servers (Imaging)
Insertions Orders
Invoice App
General Maintenance
Broadcast Filter
AIS Calendar
AIS Reports
Due Dates
Stores & Mrkts
Smart Plus
Smart Plus Launcher
P16 - Tally Sheet
Stock Options
L02-Resource Scheduling (Campbell)
Resumix
Cobra
CTS
ACH
Prodigy
Banks - ACH and Pos to Pay
Plan Administrators (401K, PCS, Life, Unicare, Solomon Smith Barney)
E02-Employee Purchase
Scorecard - HR
P09 Bonus/HR
ASIS
I35 - CEI
Rebate Transfer
ELT PowerSuite
Store Monitor
Texlon 3.5
U16-Texlon
CopyWriter's Workspace
Merch Mngr Approval Batch Forcasting Ad Measurement AIMS Admin
Ad Launcher
PSP
In-Home Repair
Warranty Billing System
Star Repair
Data Warehouse (Interfaces to and from the Data Warehouse are not displayed on this diagram)

M03 - Millennuim 3.0
M02 - Millennium
P15 EES Employee Change Notice
P14 On-line New Hire Entry
P09 - P17 Cyborg
POS
S08 - Vertex Sales Tax
Intercept
V03- Mkt Reactions
S03-Polling
V04-Sign System
V01-Price Management System
I18 SKU Rep
Sign System
G02 - General Ledger
AIMS
AIMS Reporting
C02 - Capital Projects
F06 - Fixed Assets
Optika
SiteSeer
Connect 3
Connect 3 PDF Transfe
Connect 3 Reports

S20-Sales Polling
E13 E3 Interface
S07 - Cell Phones
D01 Post Load Billing
A04 - Cust Refund Chks
AAS
Frick Co
CTO2.Bestbuy.com
U18 - CTO
B01 - Stock Status
Spec Source SKU Tracking
NPD, SoundScan
Spec Source
I05 Inventory Info
A05 - AP
Equifax
P01-Employee Masterfile

S01 - Sales Corrections
I12 Entertainment Software
E01-EDI
I04 Home Deliveries
I09 Cycle Counts
K02 Customer Repair Tracking
I55 SKU Information
I07 Purchase Order
B02 Merchandise Analysis
NARM
I14 Count Corrections
EDI Coordinator
US Bank Recon File
S05 - House Charges
Cellular Rollover
ICMS Credit
Cash Receipts/Credit
Cash Over/ Short

Mesa Data
NEW Soundscan NPD Group AIG Warranty Guard
Roadshow
Sterling VAN Mailbox (Value)
Depository Banks
UAR - Universal Account Reconcilliation
I06 - Customer Order
I13- Auto Replenishment
I17 Customer Perceived In-Stock
I15 Hand Scan Apps
I06 Warehouse Management
S04 - Sales Posting
Fringe PO
I03 Return to Vendor
S06 - Credit App
S09 - Digital Satellite System
L01-Promo Analysis
V02-Price Marketing Support
Washington, RGIS, Ntl Bus Systems
S11 - ISP Tracking
I02 - Transfers
X92-X96 Host to AS400 Communication
I11 Price Testing
Supplier Compliance
I10 Cycle Physical Inventory
S02 - Layaways
I01 PO Receiving
L60 MDF Coop
SKU Performance
SKU Selection Tool
I35 Early Warning System
Arthur Planning
Ad Expense
Store Scorecard
Store Budget Reporting
BMP - Bus performance Mngt
Valley Media
Journal Entry Tool Kit
S05 - Vertex Sales Tax

INVENTORY CONTROL APPS - PC
DPI/CPI
Code Alarm
Debit Receivings
Devo Sales
Display Inventory
In Home
Junkouts
Merchandise Withdrawl
Promo Credits
RTV Accrual
Shrink
AP Research - Inv Cntrl
AP Research-Addi Rpts
Book to Perpetual Inventory
Close Out Reporting
Computer Intelligence Data
Count Corrections
Cross Ref for VCB Dnlds
Damage Write Off
Debit Receivings
DFI Vendor Database
Display Inventory Reconcil
Display Inventory Reporting

INVENTORY CONTROL APPS - PC
IC Batching
Inventory Adj/Count Correct
Inventory Control Reports
Inventory Levels
Inventory Roll
Merchandise Withdrawl
Open Receivings
PI Count Results
PI Time Results from Inv
Price Protection
Sales Flash Reporting
Shrink Reporting
SKU Gross Margin
SKU Shrink Level Detail
USM
VCB Downloads

ACCTS REC APPS - PC
990COR
Bad Debt
Benefical Fees
Benefical Recconcil
JEAXF
JEBFA
JEBKA
JEDVA
JESOA
JEVSA
JEVSF
NSF
TeleCredit Fees

OTHER APPS - PC
AP - Collections/Credit
TM - Credit Card DB

Misc Accounting/Finance Apps - PC/NT
COBA (Corp office Budget Assistant)
PCBS(Profit Center Budget System)
Merchandising Budget

Prepared by Michelle Mills

Scale The Legacy Data Model Up to the Smart Grid

Utility

If it takes 15 seconds to configure a tag, it would take 26 man-years to configure 2M meters!

CIM versus IEC 61850: What they define

CIM

- Detailed Power System Topology
- Asset Model
- Consumer and load models
- Financial
- Scheduling and transactions
- Market operations
- Work management
- SCADA and Measurements
- GIS – Location
- Business Messaging (WG14)
- Interface Services (GID)

IEC 61850

- Power System Topology Model
- Device Configuration Description
- Device Models
- Service Models
  - Reporting
  - Controls
  - Protection
- Performance/Requirements
- Object and Data Naming Conventions
- Protocols

CIM versus IEC 61850: What they define

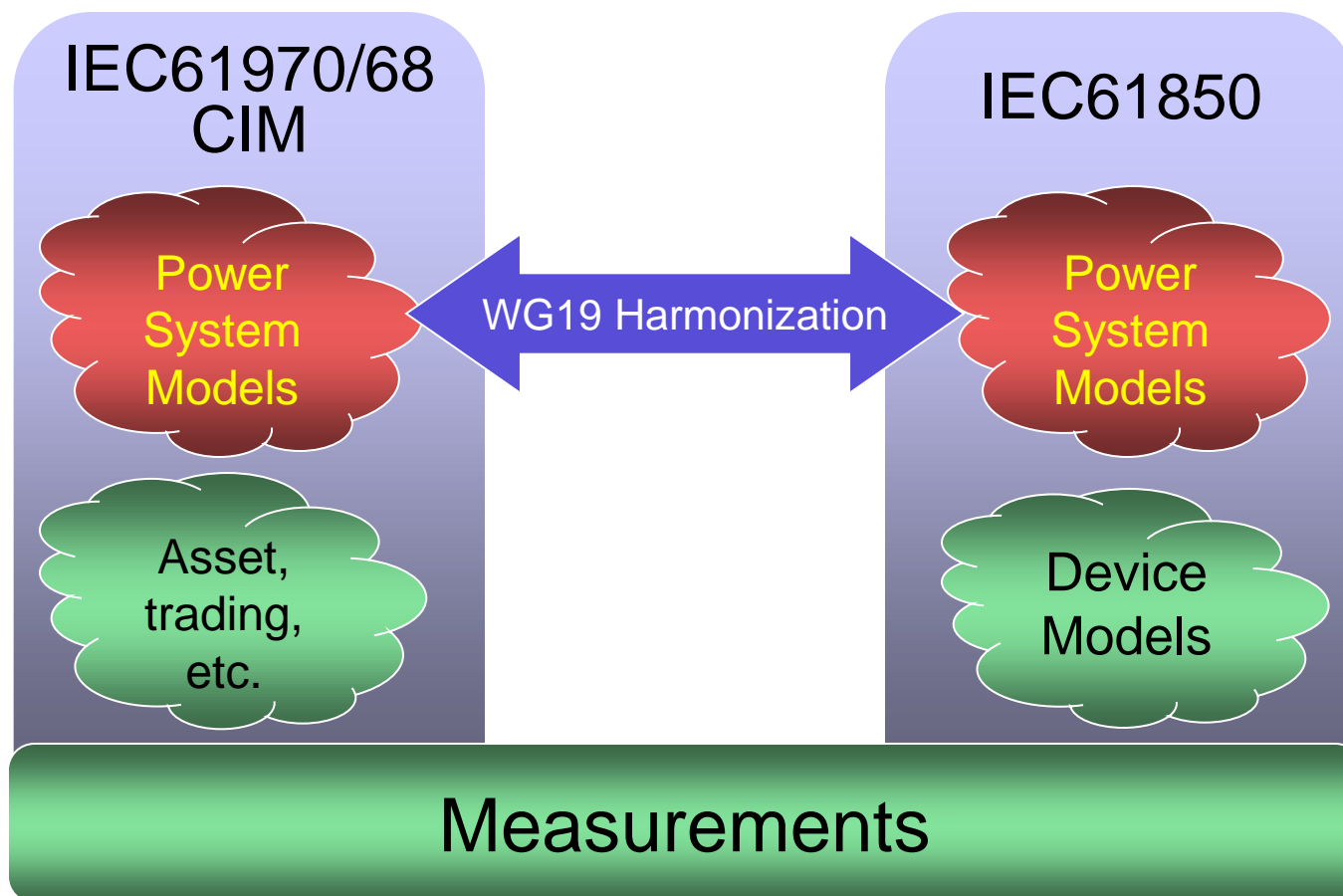| CIM	IEC 61850

CIM

- Detailed Power System Topology
- Asset Model
- Consumer and load models
- Financial
- Scheduling and transactions
- Market operations
- Work management
- SCADA and Measurements
- GIS – Location
- Business Messaging (WG14)
- Interface Services (GID)
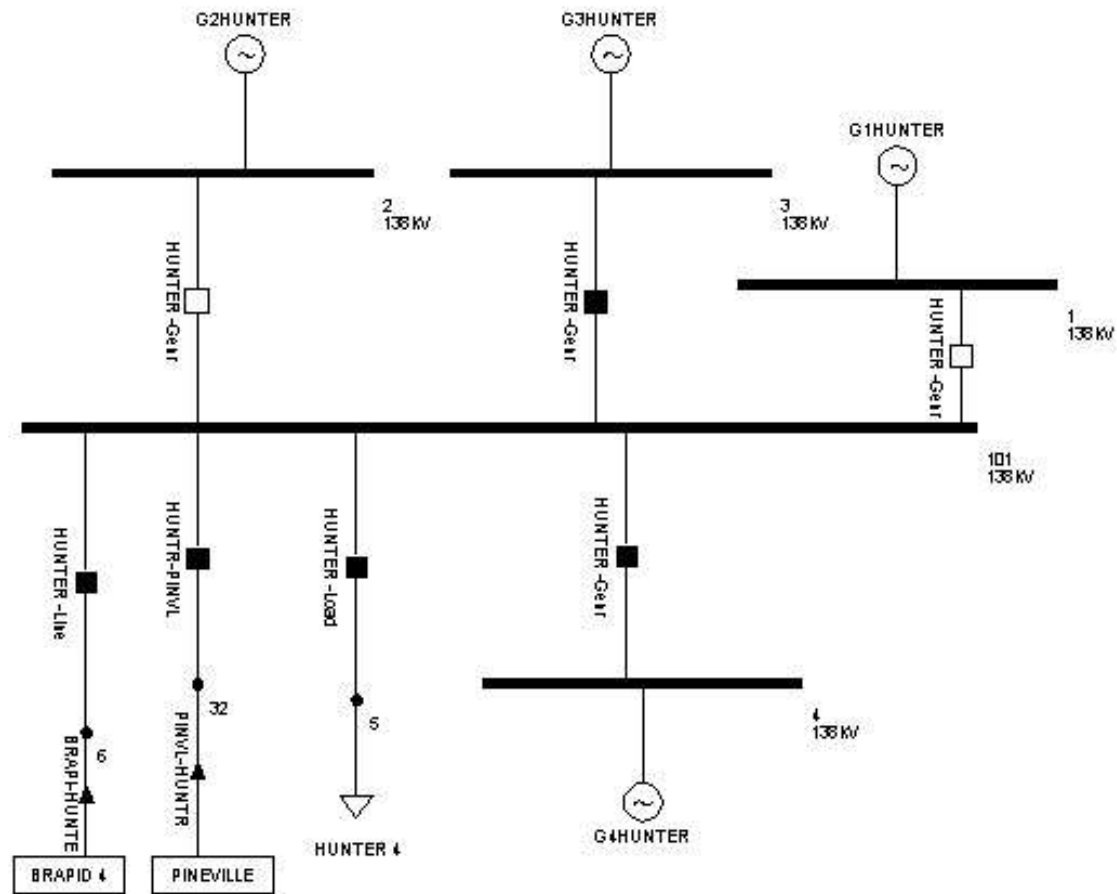
IEC 61850

- Power System Topology Model
- Device Configuration Description
- Device Models
- Service Models
  - Reporting
  - Controls
  - Protection
- Performance/Requirements
- Object and Data Naming Conventions
- Protocols

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CIM Asset-Power System Models & IEC 61850 Device Models

CIM Based Modeling Tool

IEC 61850 Based Modeling Tool (SCL)
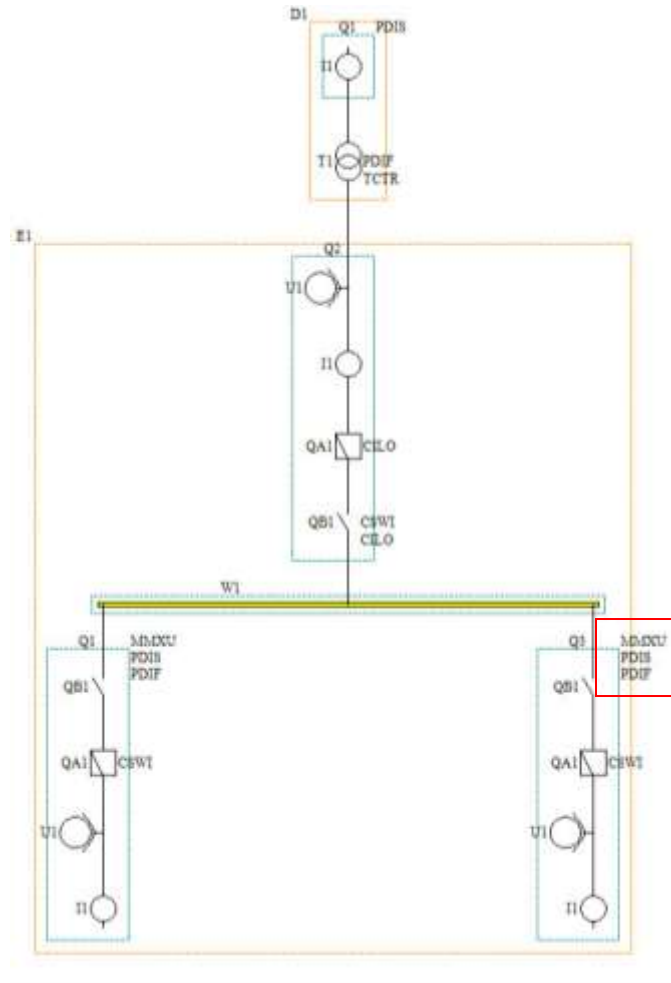
Logical Node Designators

Two Different Purposes – Two Solutions are OK, BUT
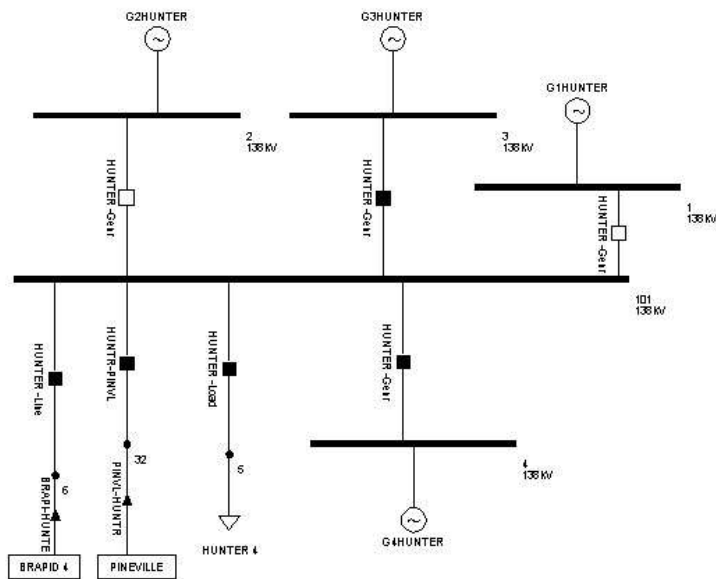
- Detailed system wide description
- Model exchange for high-level systems
- Power flow, state estimation, etc.
- Market operations
- Planning and system design
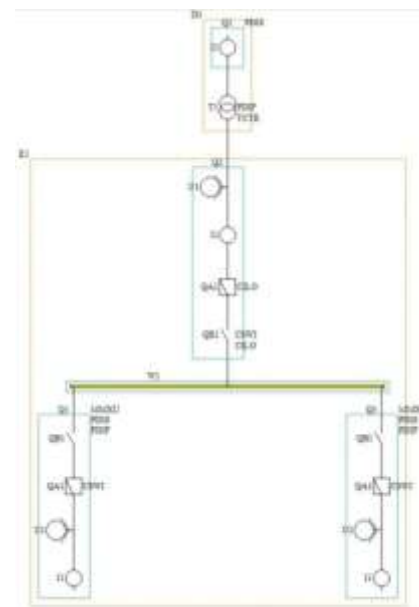
- Substation design and modeling
- Device configuration management
- Protection and device control
- SCADA, protection, & control data exchange

CIM and IEC 61850 Difference in Topology
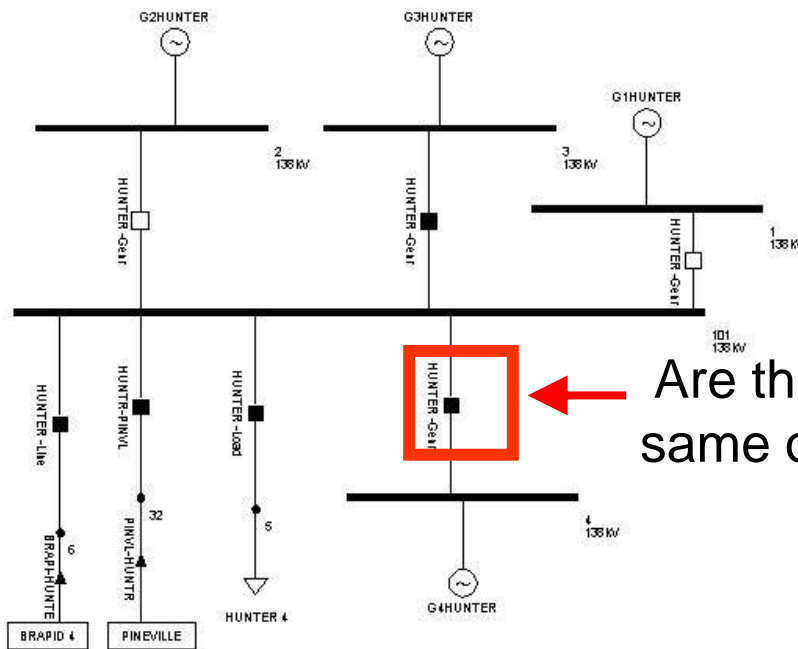
IEC 61970-301 EMS Diagram

Are these the same objects?
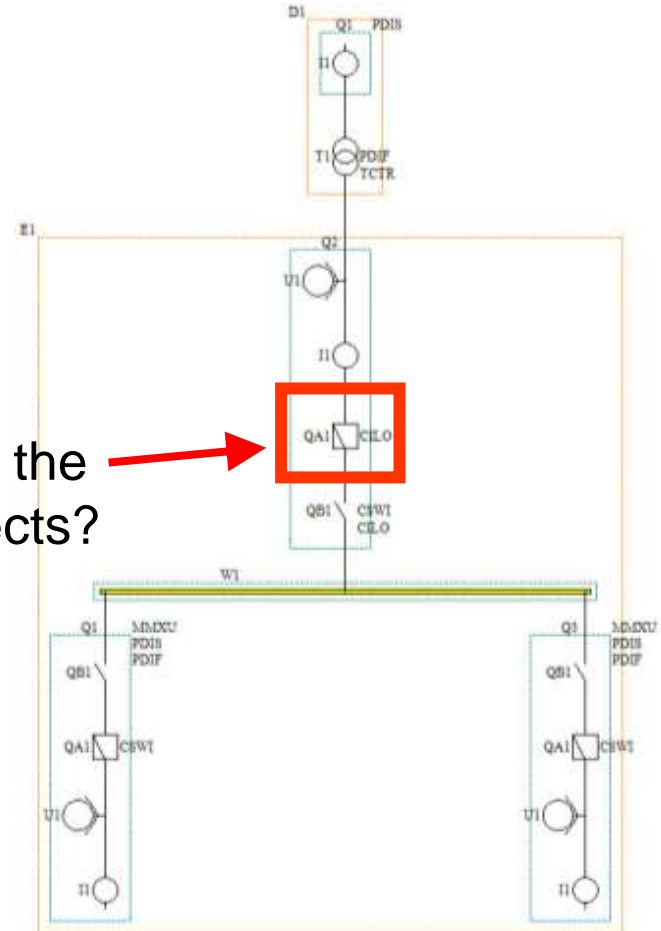
IEC 61850-6 SCL Diagram

Simplified Planning Process

New Subdivision &
Shopping Mall

↓

Studies on
Existing
Systems

↓

Design New
Systems

↓

Studies on New
Systems

↓

Finalize New Design
Submit Prints, specs
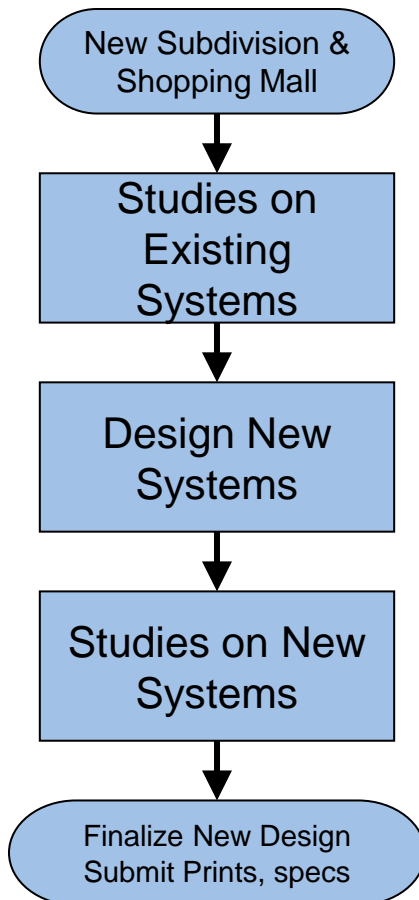
- Well defined processes and tools for designing new power system extensions, simulating their impact, defining new contingencies, etc.

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Moving Design to Operations

- CIM has improved the ability to move models from planning to operations (and vice-a-versa) in a multi-vendor environment.
  - To be expected through use of standards.
  - Eventually enable wide exchange of planning models like ENTSO-E

- EMS and planning already use a set of tools that have been harmonized to enable the flow of information between them.

Moving Design to Substations
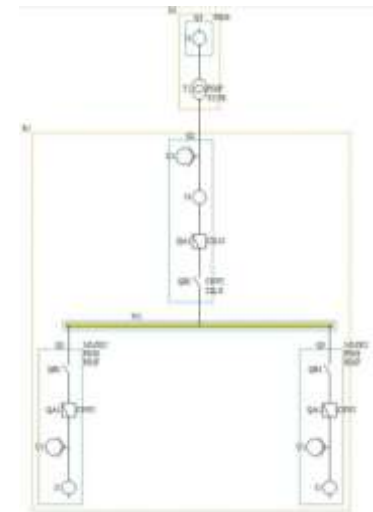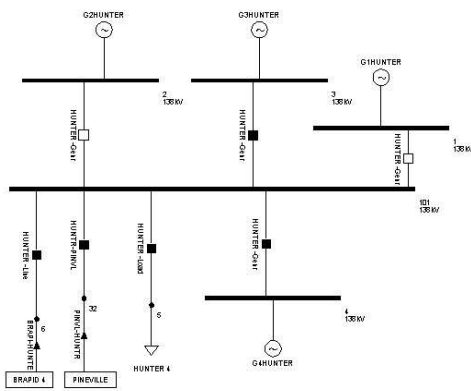
Substation engineers use a completely different set of tools supporting a completely different set of standards to define the substation automation and protection systems.

It's About Productivity

- The effort and knowledge put into the planning and operations models that isn't embodied in the one-line diagrams is lost and has to be transferred manually into the substation design through the engineering process duplicating previous effort.

- If the tools used a common set of standards the flow of information can be automated enabling topology, SCADA, protection, communications, settings, etc. to be preserved and leveraged through the engineering process.

The Engineering Process of IEC 61850-4

Beyond the protocol to dramatically improve the effectiveness of designing, building and testing power automation systems.

Why is IEC 61850 Different?

If adapted fully from engineering to operations, IEC 61850 (and the model-driven) approach is a new process for power system automation and engineering that is designed to dramatically improve the productivity of engineering, implementation, and maintenance of power automation systems.

The IEC 61850-4 Engineering Process

It starts with a power system design
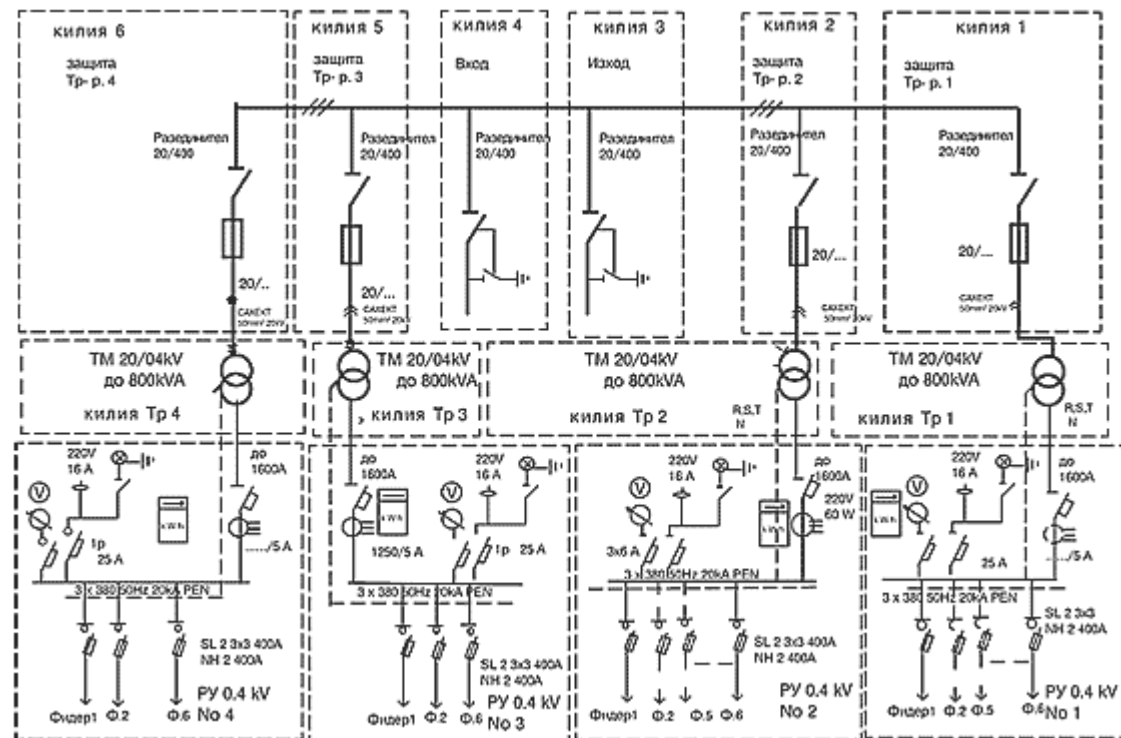
The IEC 61850-4 Engineering Process

The automation and protection functions are defined
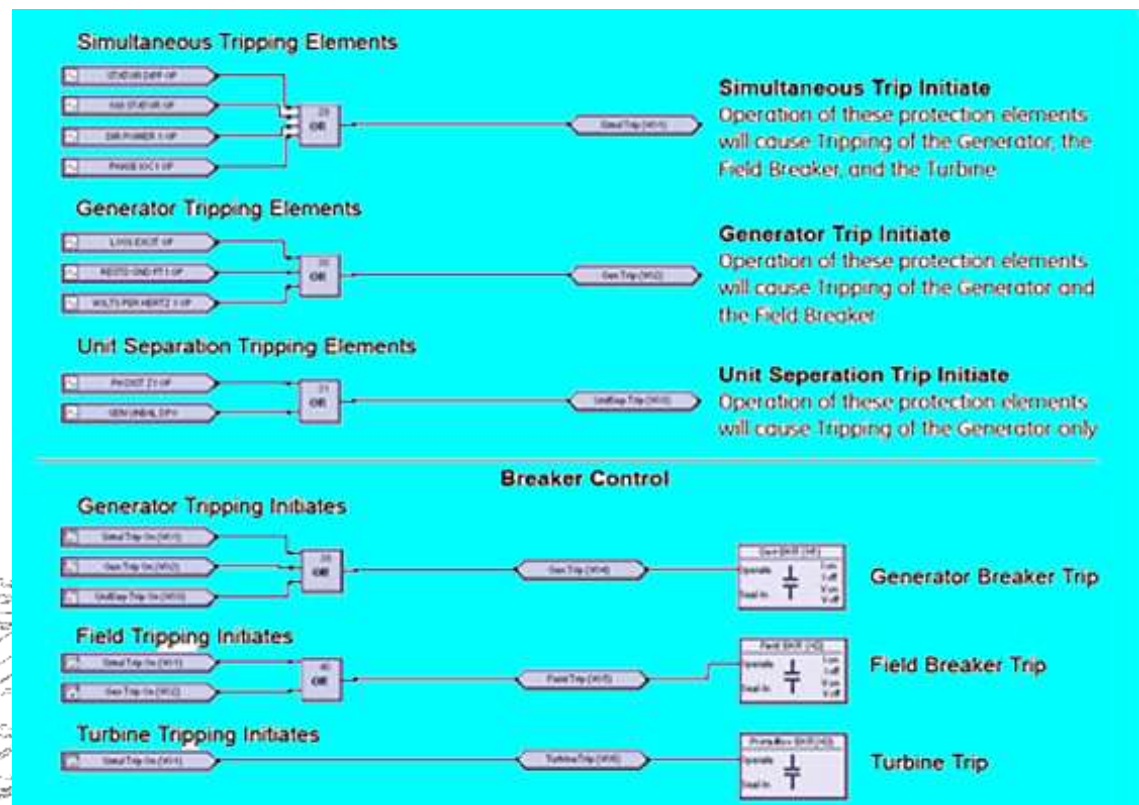
The IEC 61850-4 Engineering Process

IEDs are selected and configuration and programming is defined
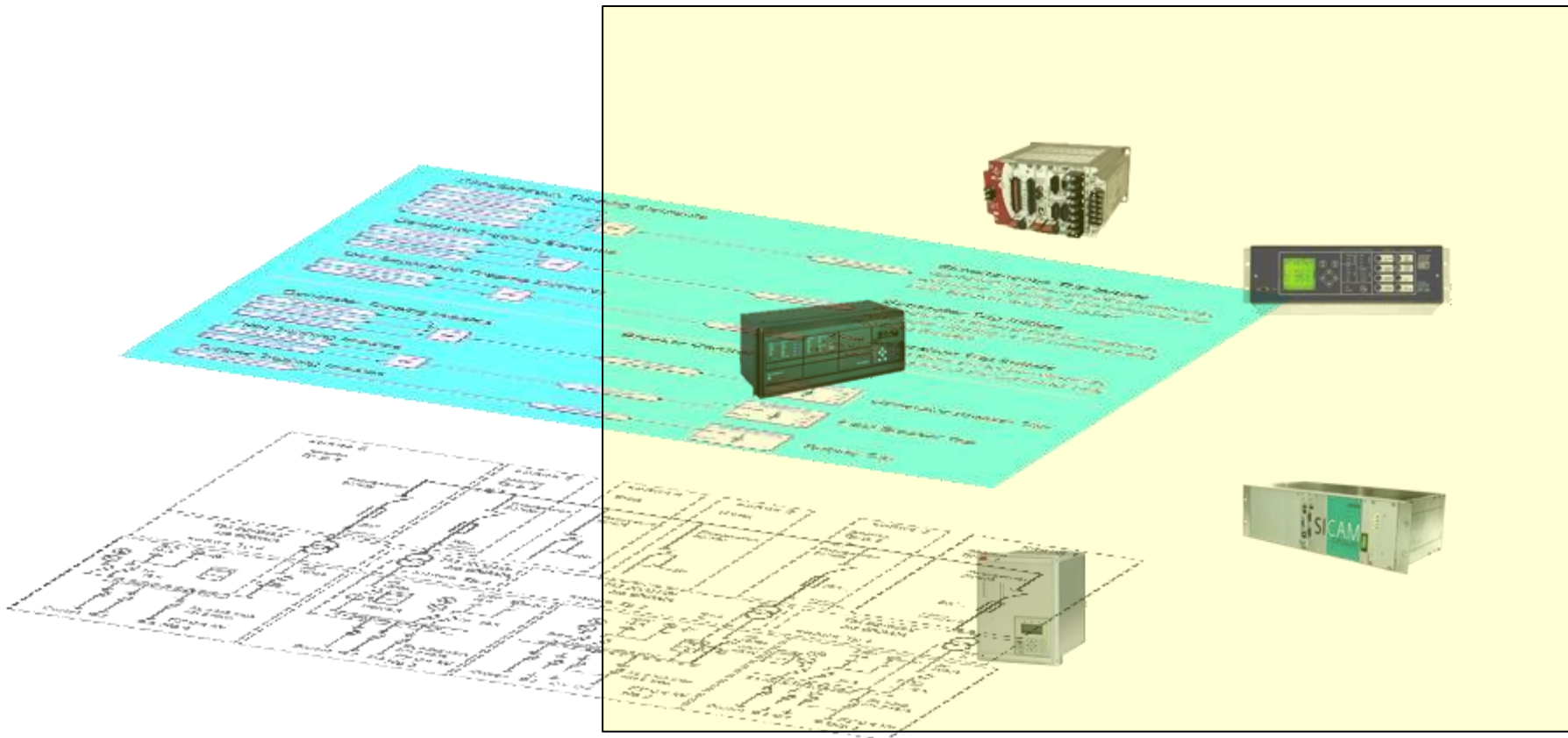
The IEC 61850-4 Engineering Process

The IEDs are tied together via the network to integrate the power system automation and protection functions
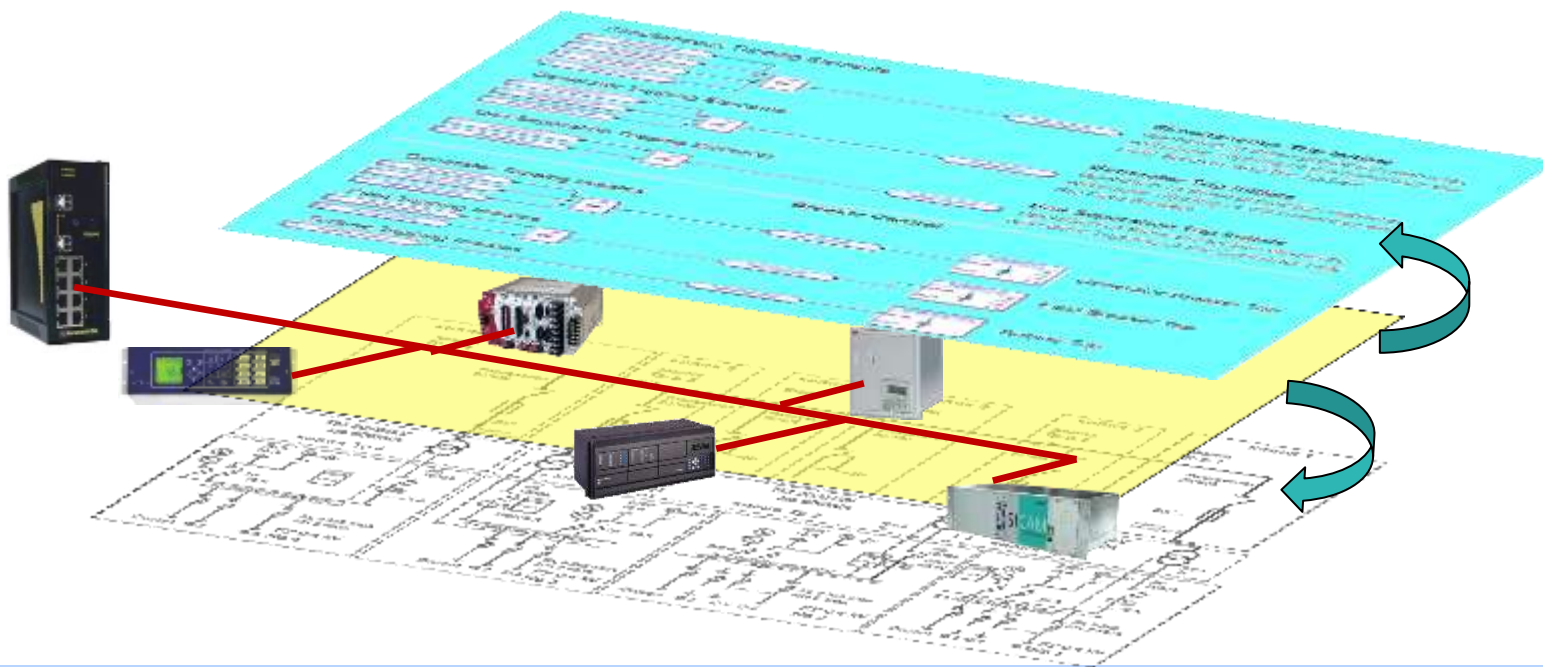
The IEC 61850-4 Engineering Process

Monitoring and visualization enables control of the power system
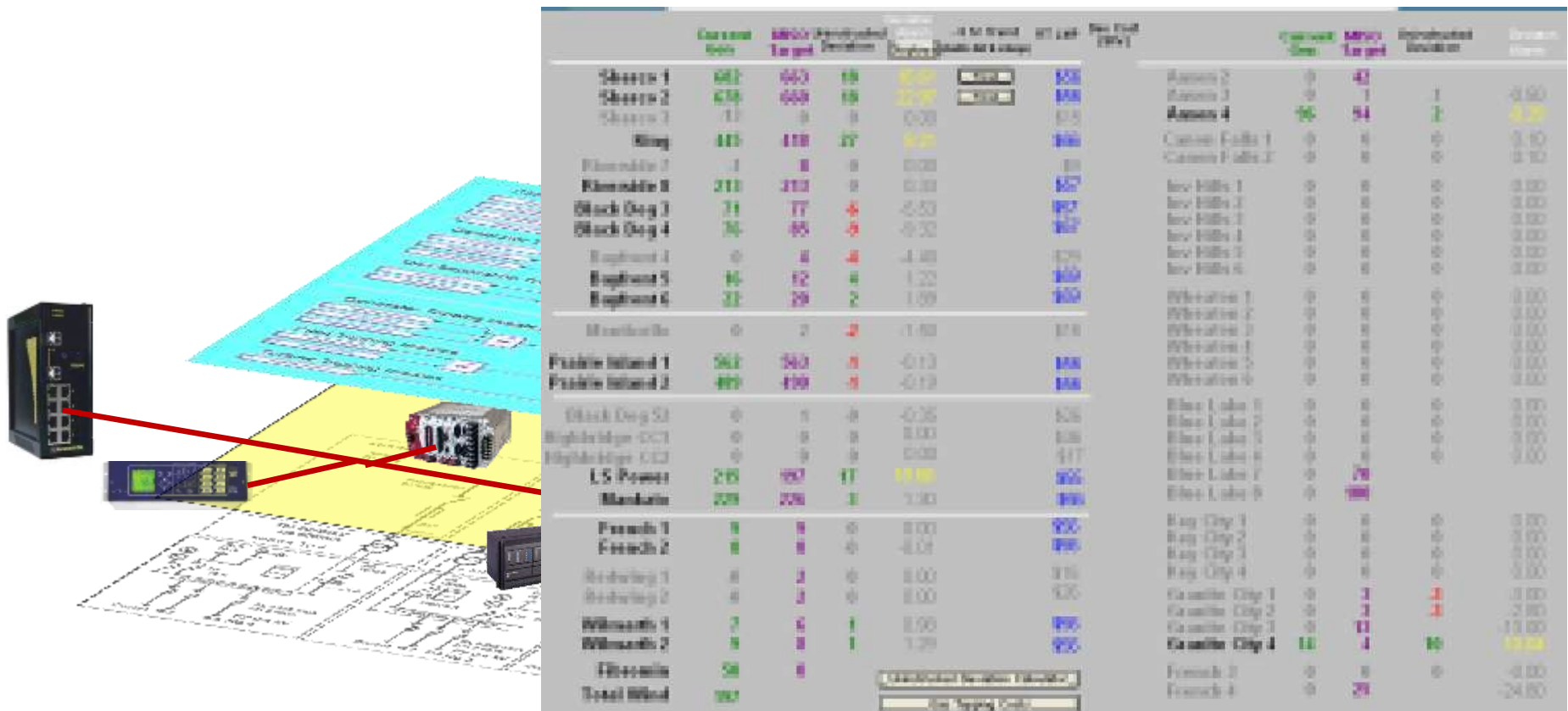
The IEC 61850-4 Engineering Process

The IEC 61850 addresses all aspects of the engineering process that need to be successfully planned, designed, and deployed.
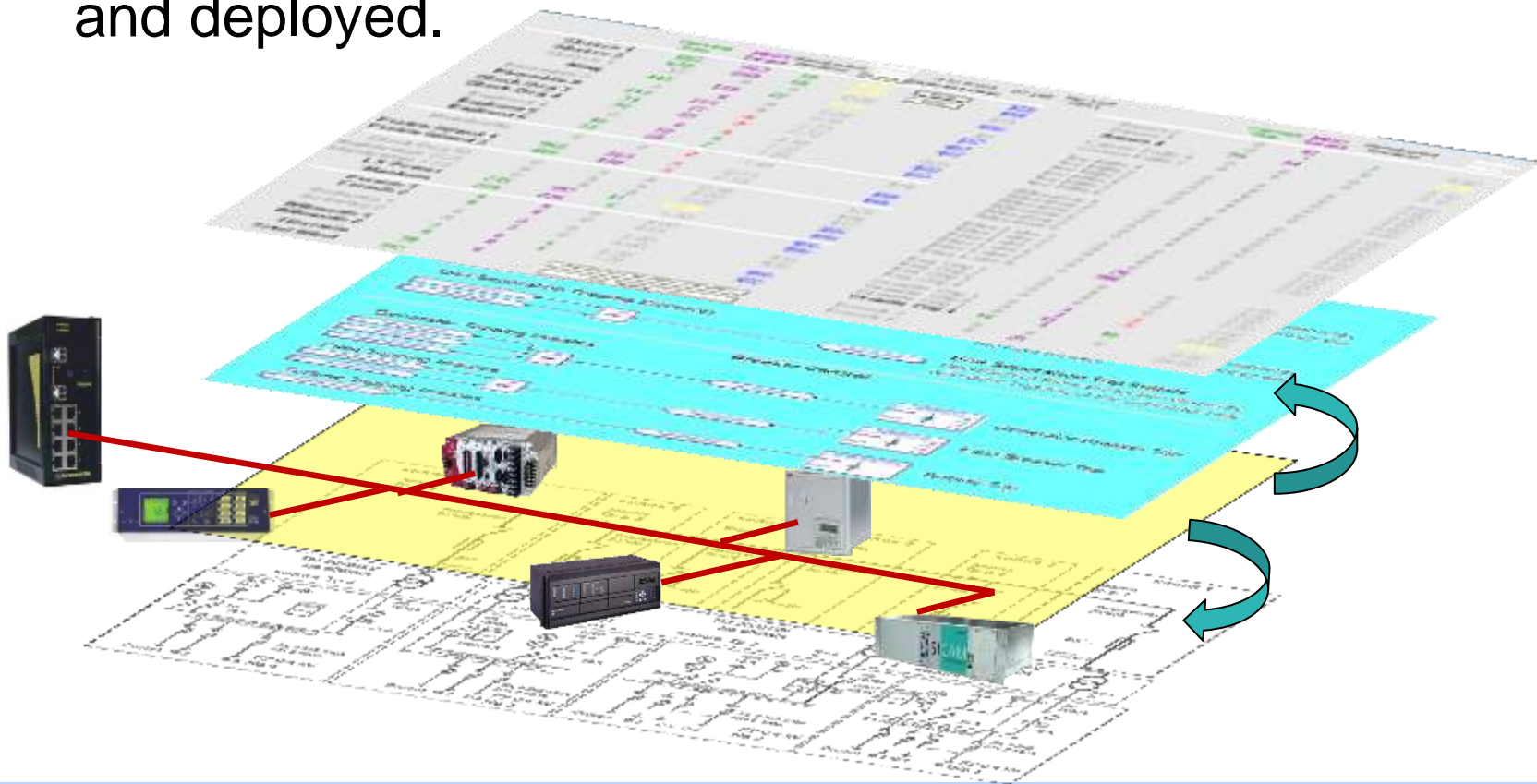
61850 Impacted by all areas of "construction"

The set of utility processes must lead to appropriate:

Power System Resource Selection
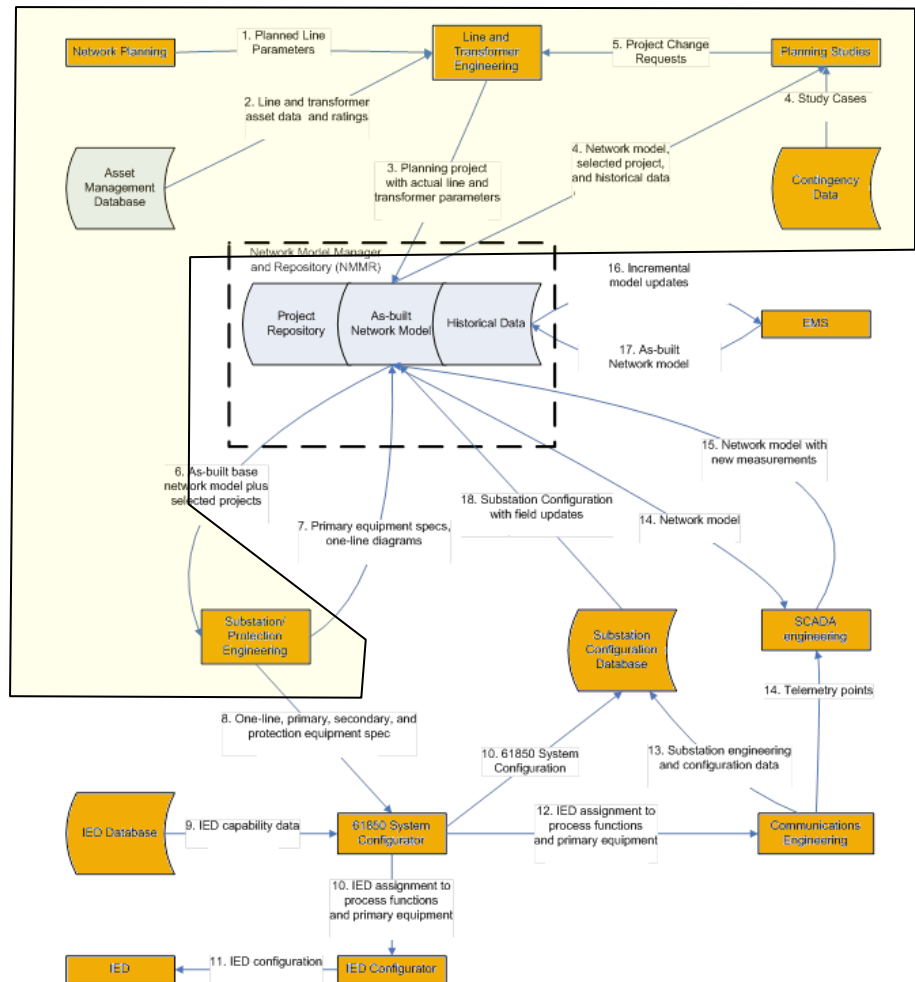
61850 Impacted by all areas of "construction"

The set of utility processes must lead to appropriate:

Power System Resource Selection

Power System Topology Design
  Generates One-lines
  Rating Information
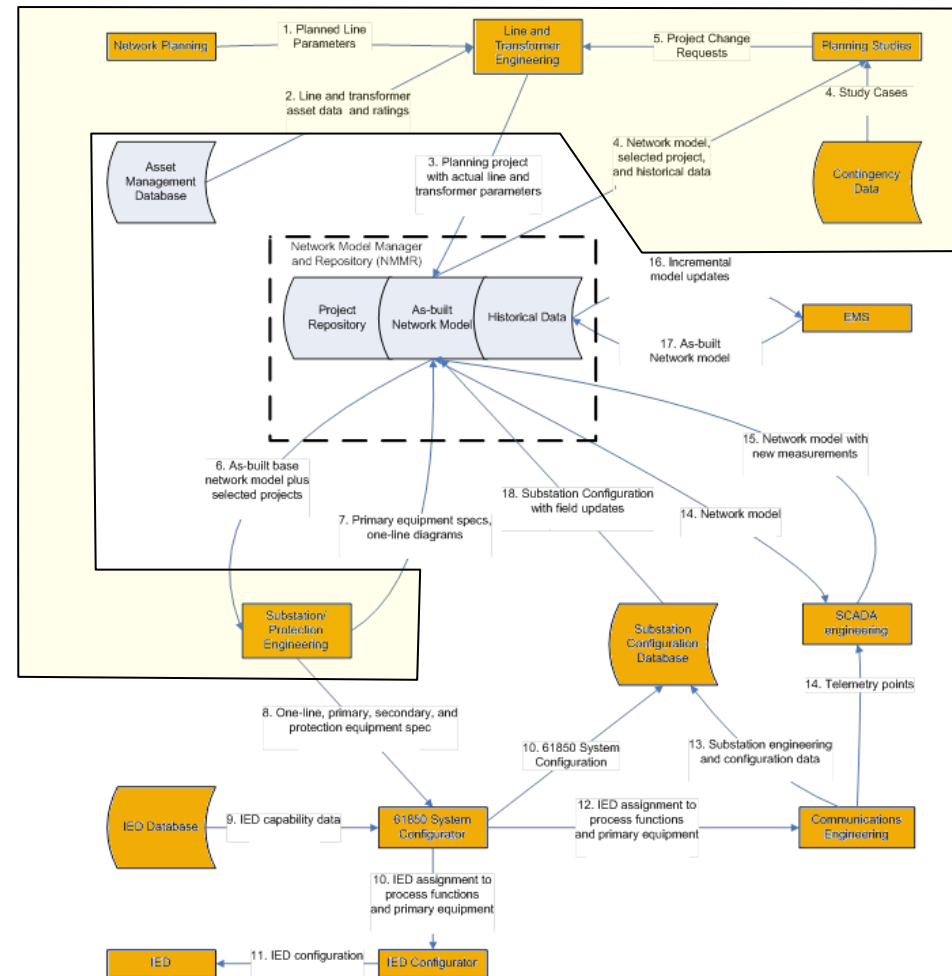
61850 Impacted by all areas of "construction"

The set of utility processes must lead to appropriate:

Power System Resource Selection

Power System Topology Design

IED Selection

Automation and Protection Logic

61850 Impacted by all areas of "construction"

The set of utility processes must lead to appropriate:

Power System Resource Selection

Power System Topology Design
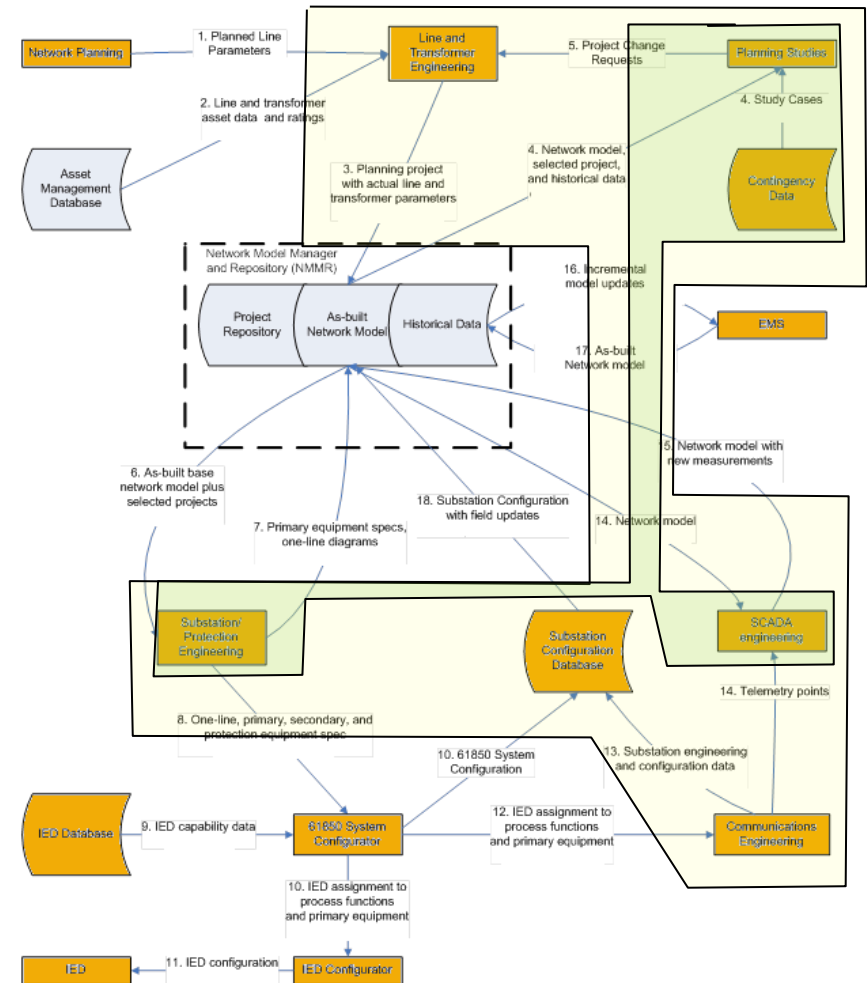
IED Selection

Substation design and wiring

61850 Impacted by all areas of "construction"

The set of utility processes must lead to appropriate:

Power System Resource Selection

Power System Topology Design

IED Selection

Substation design and wiring
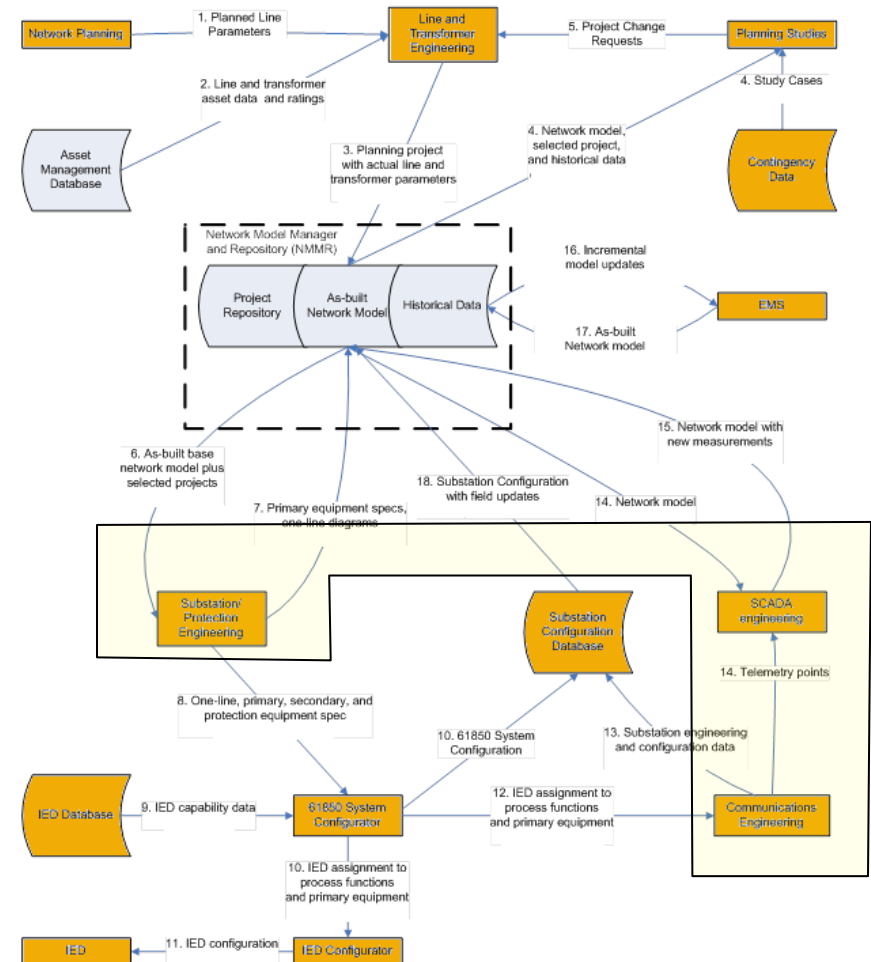
Communications

61850 Impacted by all areas of "construction"

The set of utility processes must lead to appropriate:

Power System Resource Selection

Power System Topology Design

IED Selection

Substation design and wiring

Communications

Parameterization of IEDs

Domain of 61850 Substation Configuration Files (SCL) and IEC 61850-6 processes
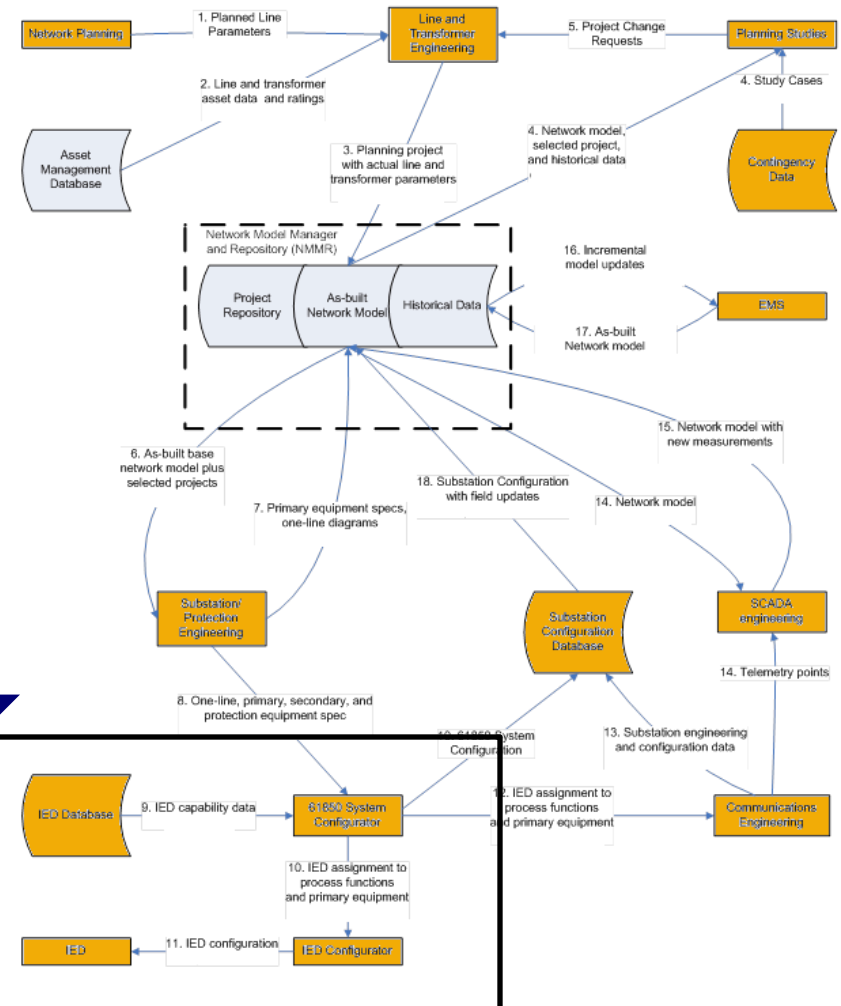
SCL facilitates specification

System Specification Description (SSD)

IED Specifications

System Specification Description' (SSD)

Requirements
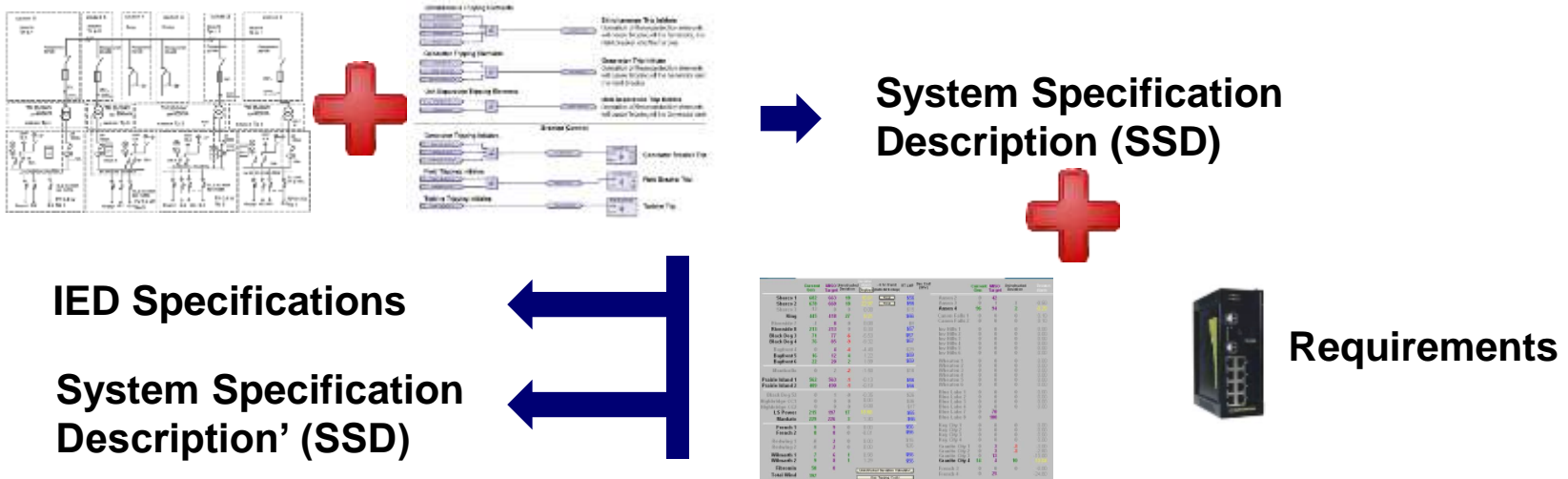
SCL facilitates design and engineering

System Specification Description (SSD)

IED Selection

Specifics

System Configuration Description (SCD)

Knowledge

Detailed

Vendor tooling

Parameterization

Configured Device
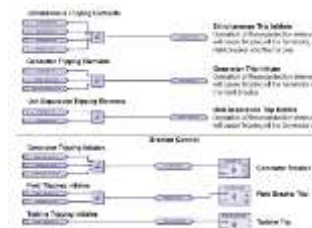
SCL facilitates validation

← Original System Configuration Description (SCD) file

← Substation specific System Configuration Description (SCD) file

Configured Device → **Vendor Specific Tooling** → **Configured IED Description (CID) file** → **Substation Configuration Tool**
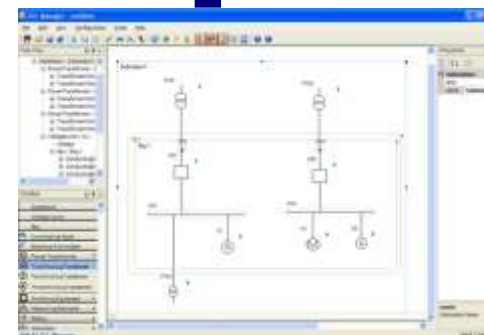
SCL facilitates testing

Partial SAT

System Configuration Description (SCD) file
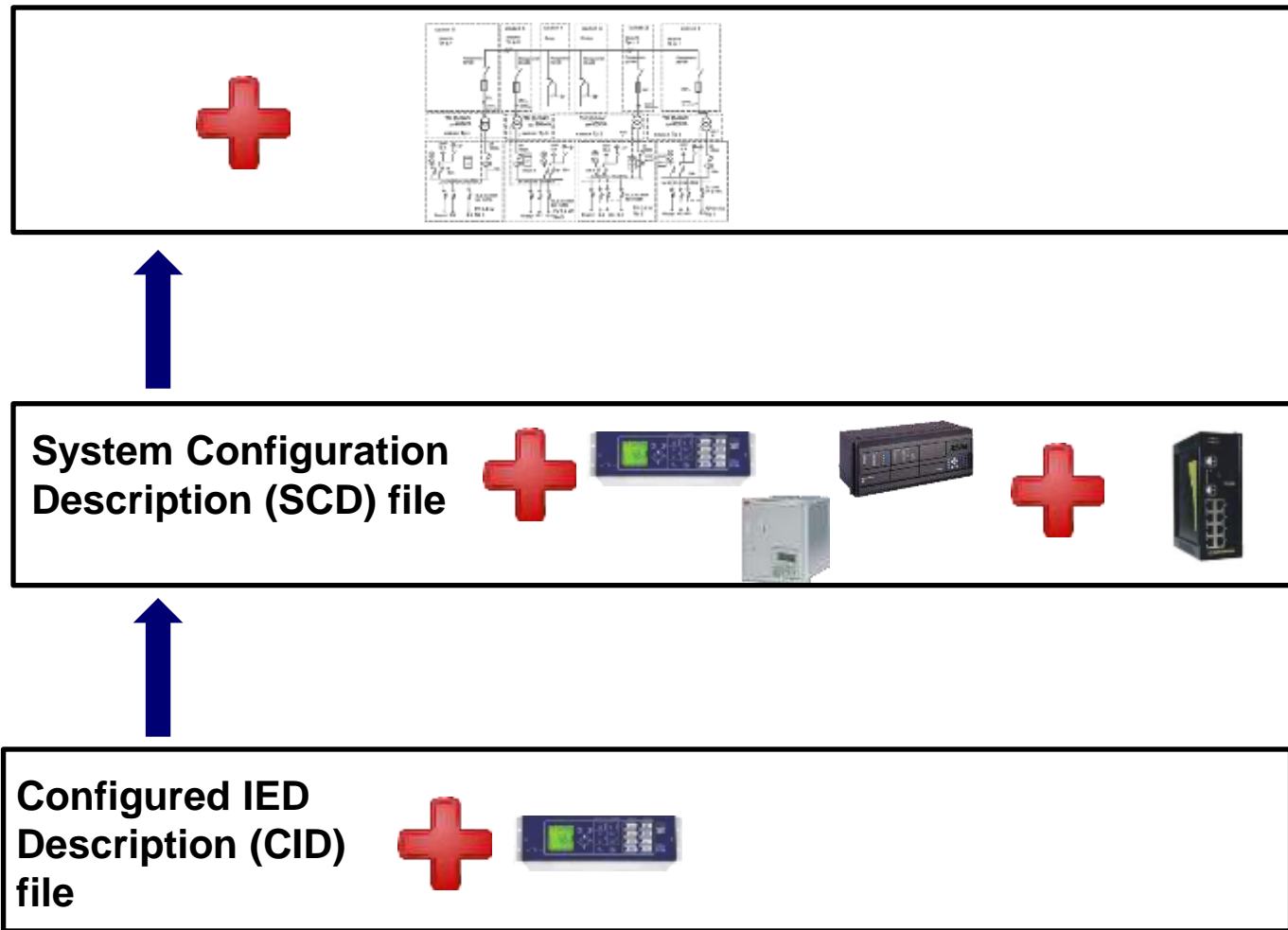
Communication testing
Partial FAT

Configured IED Description (CID) file

Partial Unit Testing

Systems Integration Specialists Company, Inc.

IEC 61850 Profiles

How IEC 61850 Works Over Networks.

Some Terms

- Network Access Methods:

  - Master Slave – a master controls slave access to the network (e.g. DNP3)

  - Peer-to-peer – any entity may send data to any other peer entity on the network without having to coordinate with a master (TCP/IP-Ethernet).

- Client-Server – defines roles between 2 peers that communicate directly with just each other on a network.

- Multicast – A server with data publishes data to the network which delivers the data to subscribing clients without requiring knowledge of the clients to the publishing server.

IEC 61850 Client/Server Communications
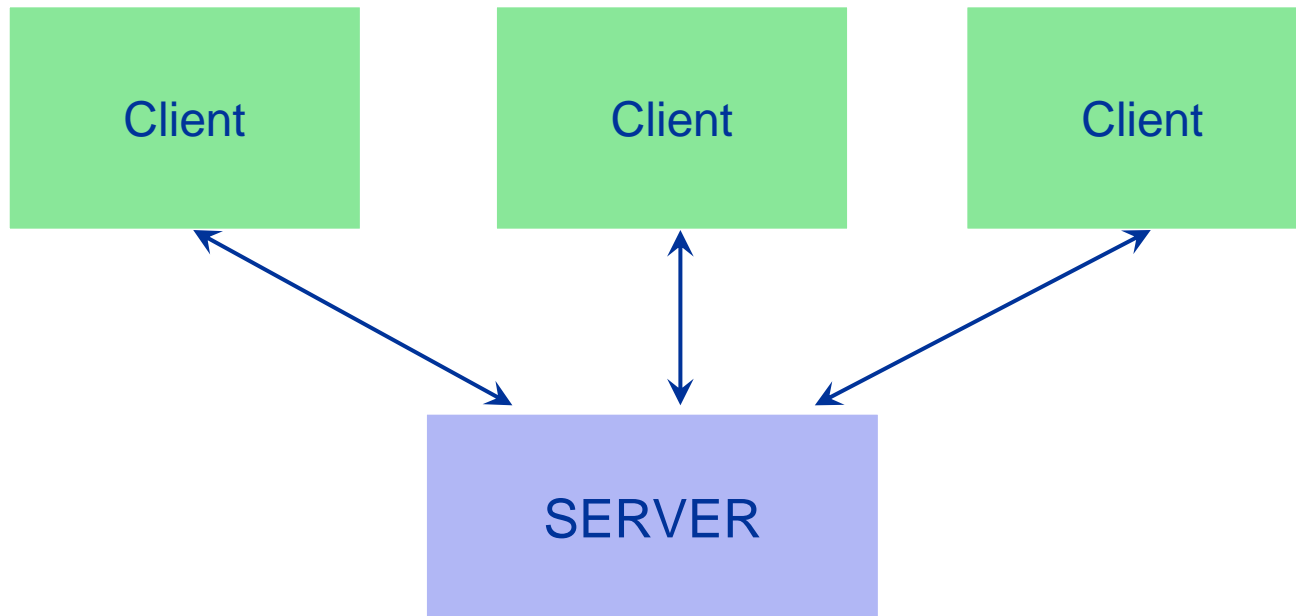
Peer – to – Peer communications. Either entity may initiate communications to the other entity.

Multi-Cast Application Association
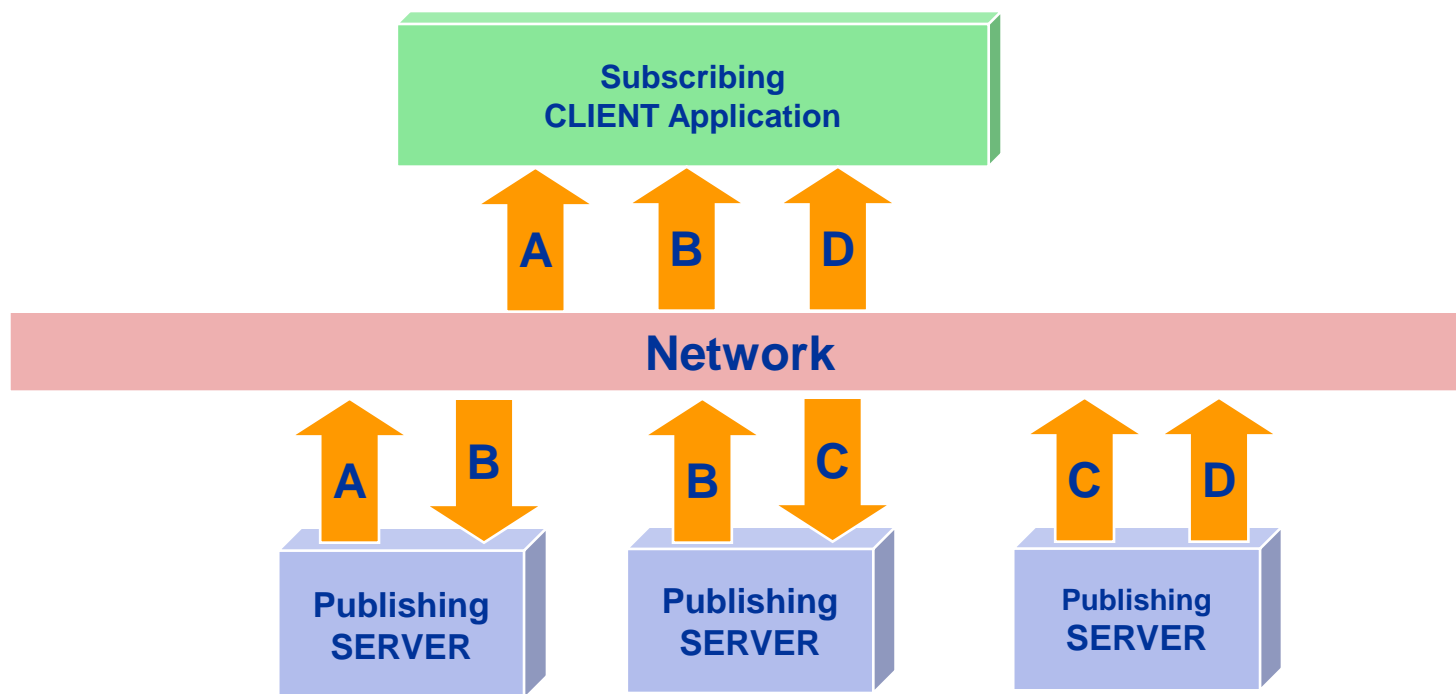
Service: send Data (unconfirmed)

IEC 61850 Profiles
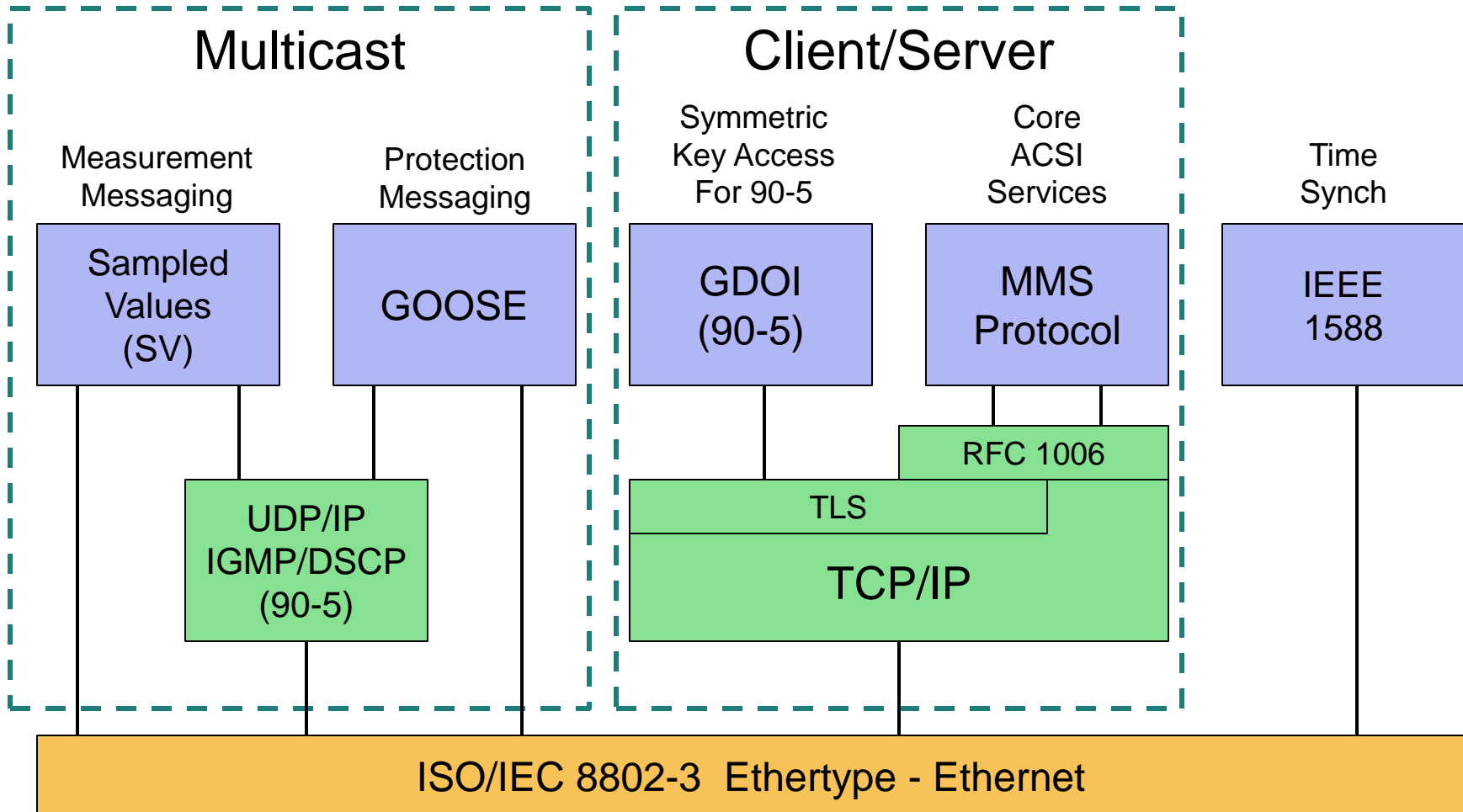
Redundant Port Implementations

Redundant Port: 2 independent Ethernet ports with 2 different addresses

MAC – 1
IP Addr - 1

Ethernet1
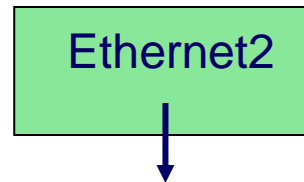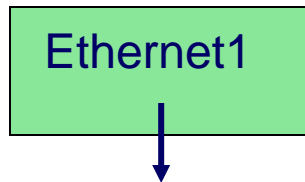
Ethernet2

MAC – 2
IP Addr - 2

Redundant Media: 1 Ethernet port with switched media

MAC – 1
IP Addr - 1
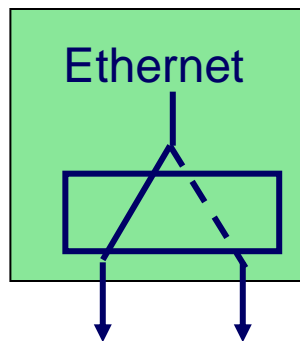
Ethernet

Switches on loss of Ethernet link pulses

Primary   **Back-Up**

Redundant Media is Common - Easy to Configure for Redundancy

Redundant Network Configuration
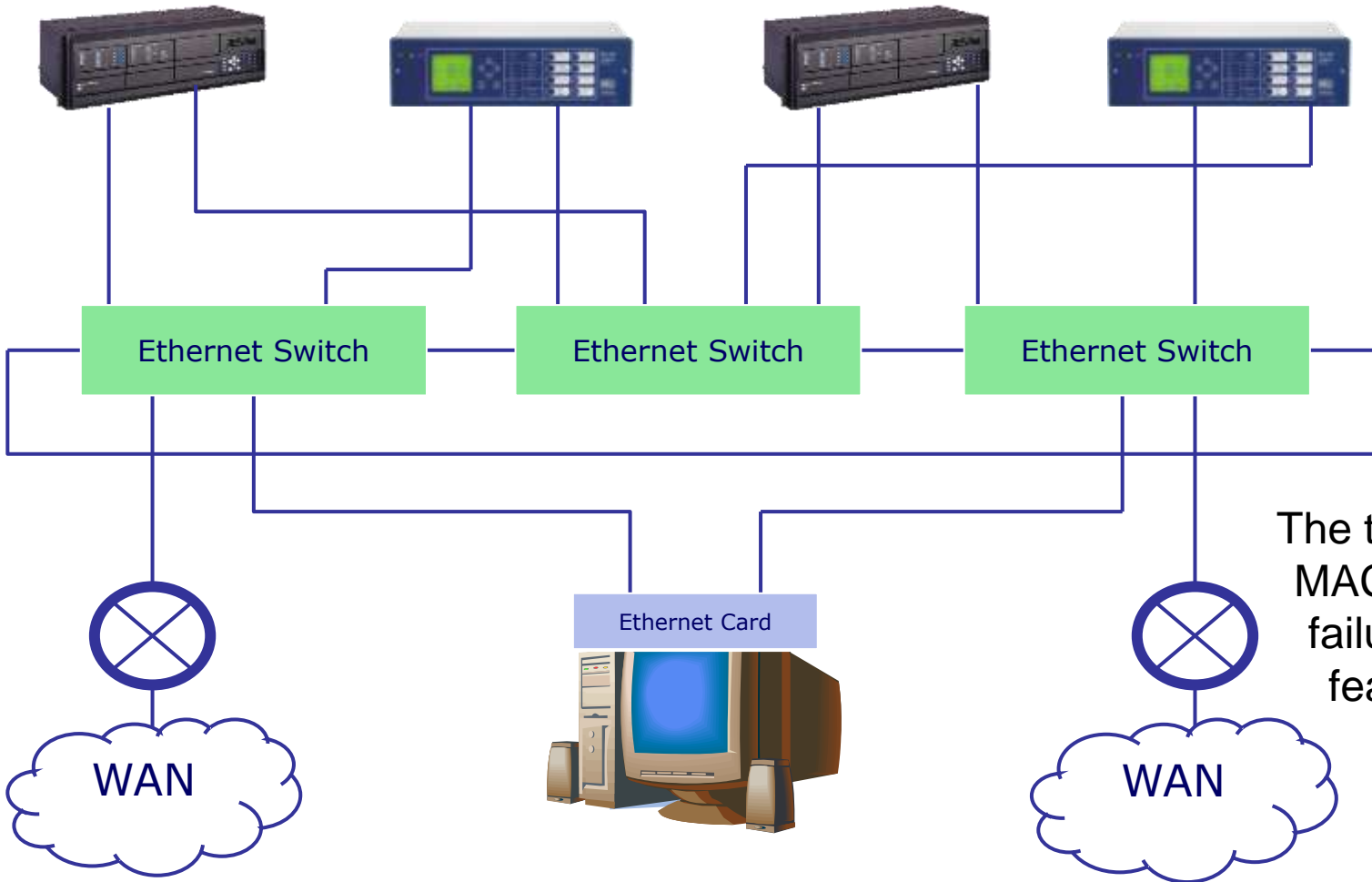
The time to rebuild MAC tables after failure is critical feature of the switches

Ethernet Switch   Ethernet Switch   Ethernet Switch

WAN   Ethernet Card   WAN

Rapid Spanning Tree Protocol (RSTP) enables network rebuild after MAC failure/change

Emerging Approach – Embedded Switching
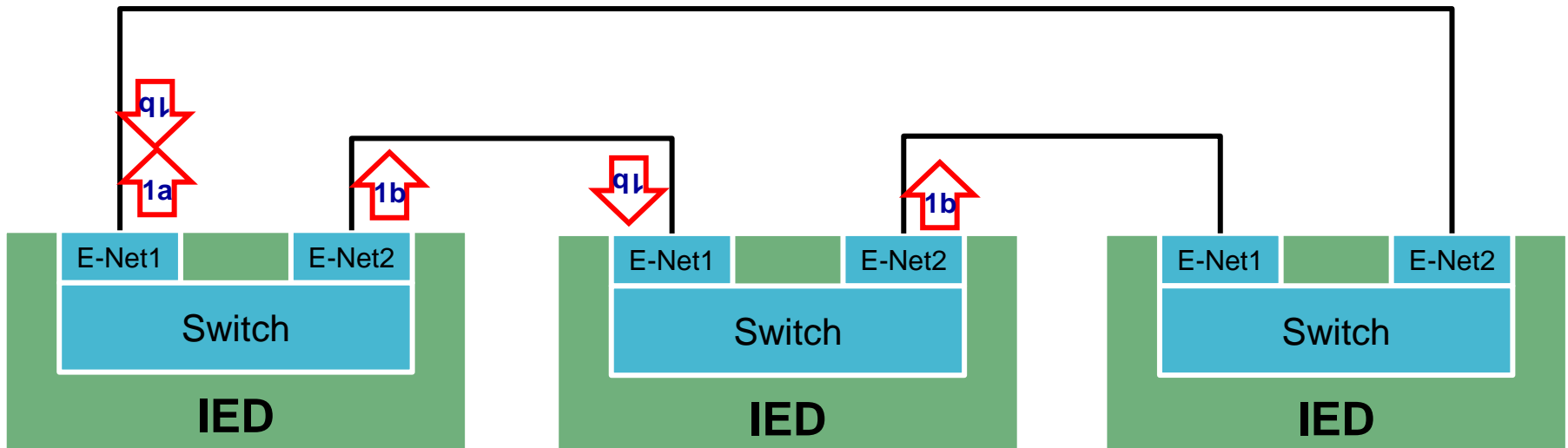
HSR – High-Speed Redundancy Ethernet uses this kind of approach
to avoid the delay of rebuilding the MAC tables on a failure

Emerging Approach –
Parallel Redundancy Protocol (PRP)

Send to both

LAN A

LAN B

PDU

PRP Header

PRP Cache

PDU

First PRP frame in
is delivered

68
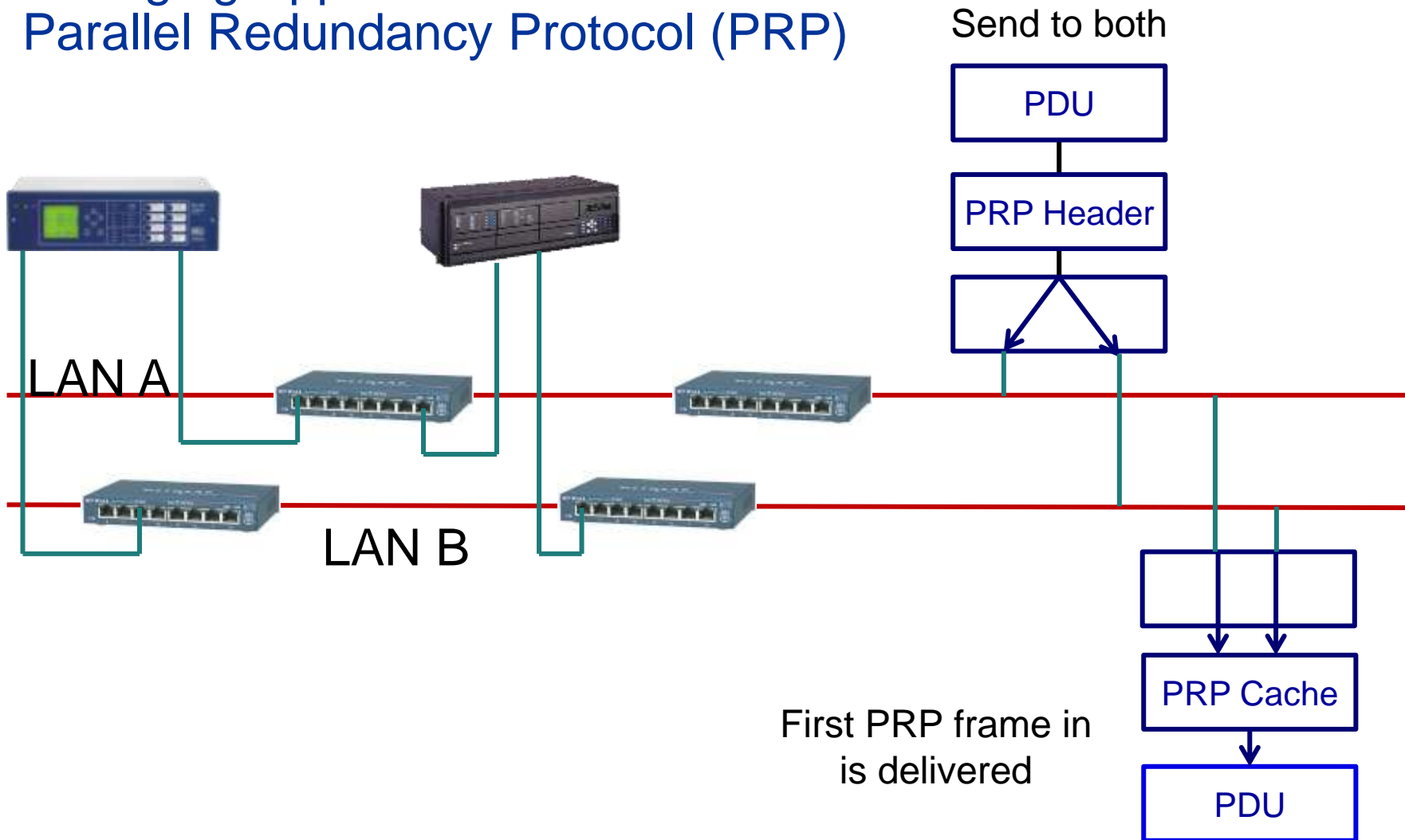
VLANs

- VLANs: Are logical groupings of nodes that reside in a common broadcast domain
  - Virtual because the VLAN is artificially created and the nodes need not be physically located on the same switch or even reside in the same building, but
    - Nodes that are members behave like they are connected together by one layer 2 bridge or switch
    - A router is required to communicate between the two VLANs
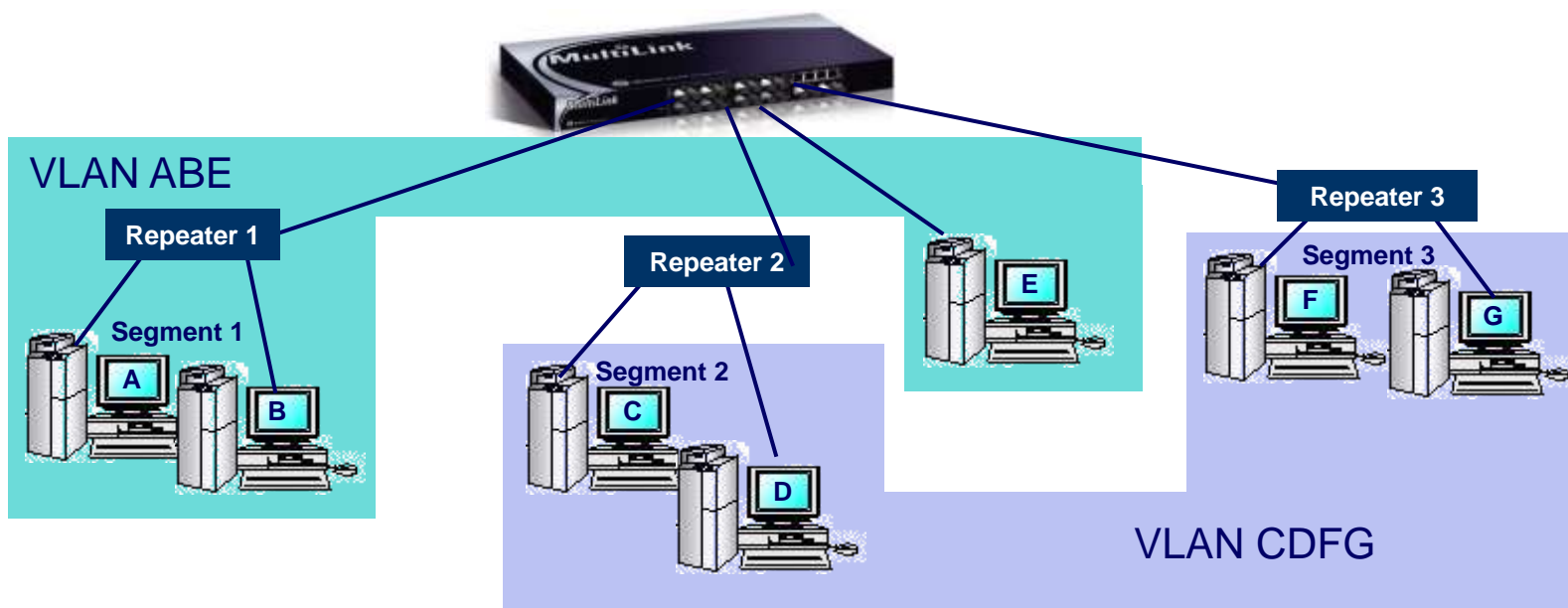
Ethernet Priority

- Ethernet 802.1q provides a priority setting
- "High" priority messages are moved to the priority queue
- Specified in IEC GOOSE and Implemented in GE Multilink Switch
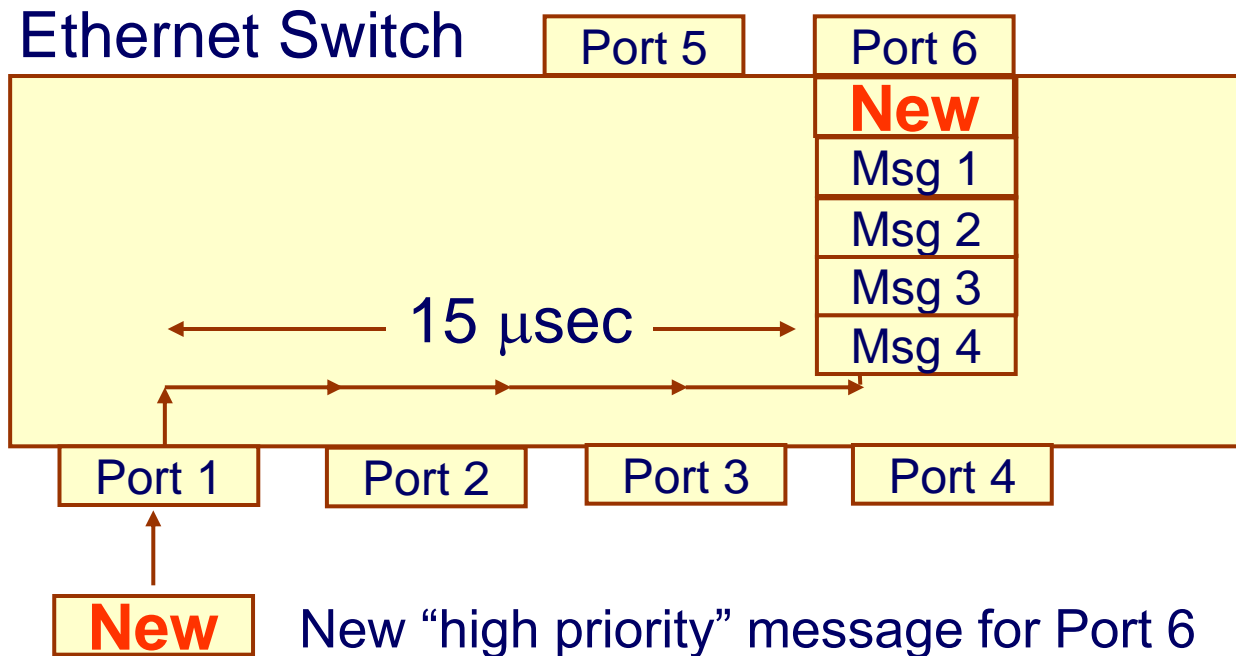
Ethernet Switch

Port 5	Port 6
	New
	Msg 1
	Msg 2
	Msg 3
	Msg 4

$15\ \mu\text{sec}$

Port 1	Port 2	Port 3	Port 4

New   New "high priority" message for Port 6

Courtesy of GE Digital Energy

IEC 61850 Models

IEC61850 Substation Architecture

Station Bus 10/100/1000 MB Ethernet

IED **IED** **IED** Remote Access

Relay(s) Subscribe to Datasets

Process Bus

MU Publishes V/I/Status Datasets

.1/1/10GB

Ethernet

Network

Clk1 **MU** **MU** **MU** Clk2

MU = Merging Unit

PT I/O CT PT2 I/O CT2 PT I/O CT
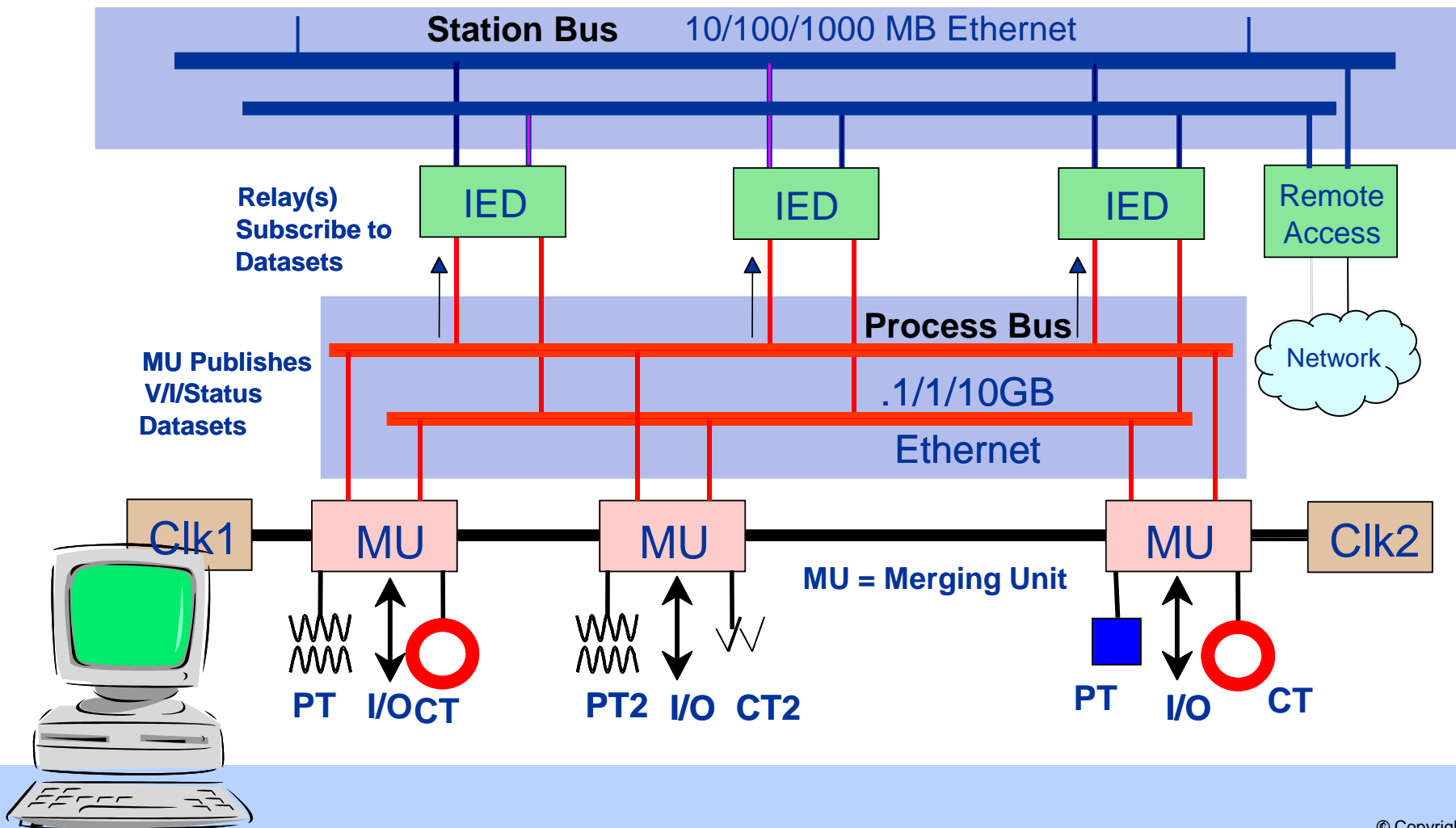
IEC61850 – Communications Parts

- Part 6: Substation Configuration Language (**SCL**)

- Part 7-2: Abstract Communications Service Interface (**ACSI**) and base types

- Part 7-3: Common Data Classes (**CDC**)

- Part 7-4: Logical Nodes (**LN**)

- Part 7-4XX: Other LNs and CDCs

- Part 8-1: Specific Communications Service Mappings (**SCSM**) - MMS & Ethernet

- Part 9-2: SCSM - Sampled Values over Ethernet

- Part 10: Conformance Testing

IEC 61850 Virtual Model
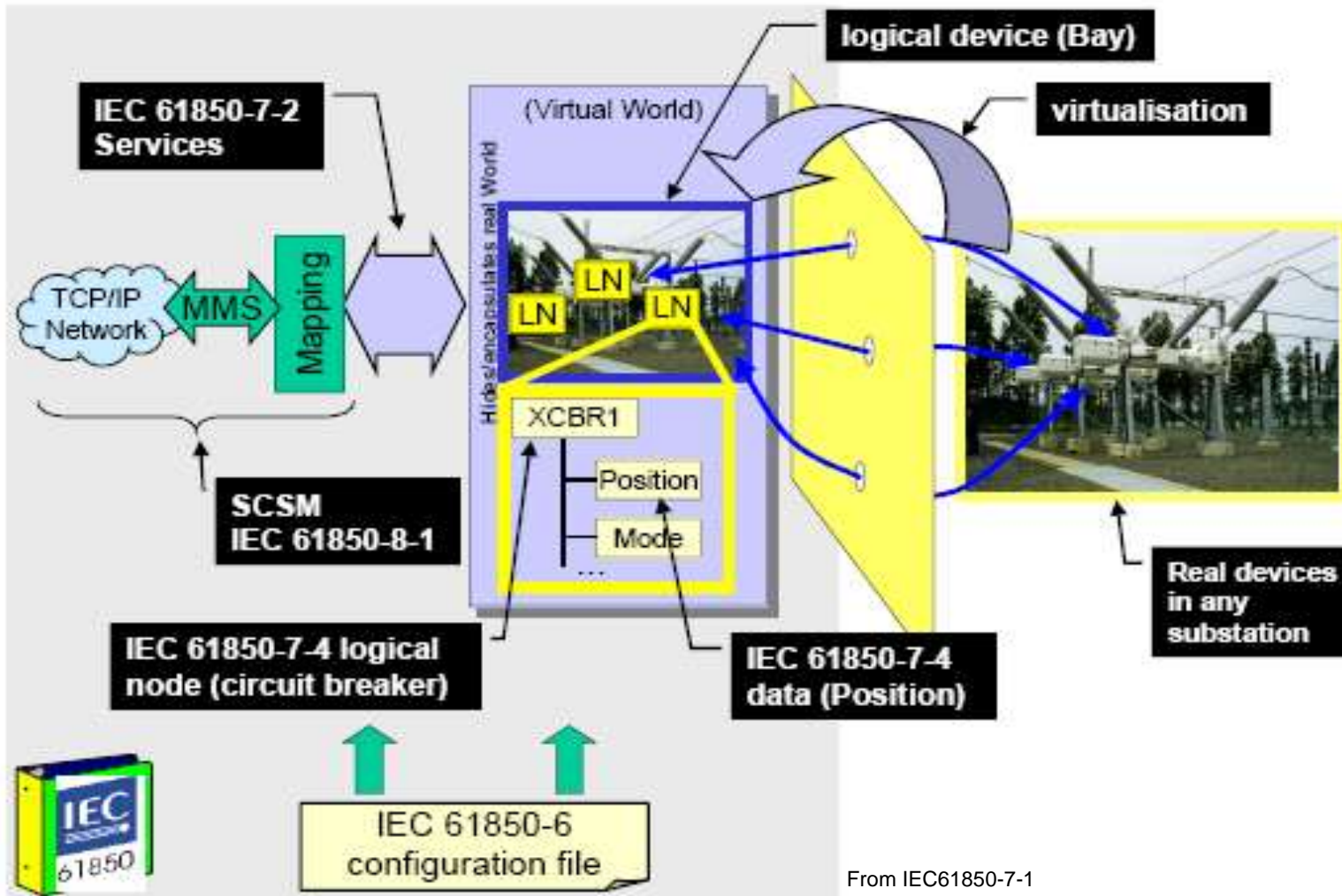
From IEC61850-7-1

IEC 61850 Device Structure
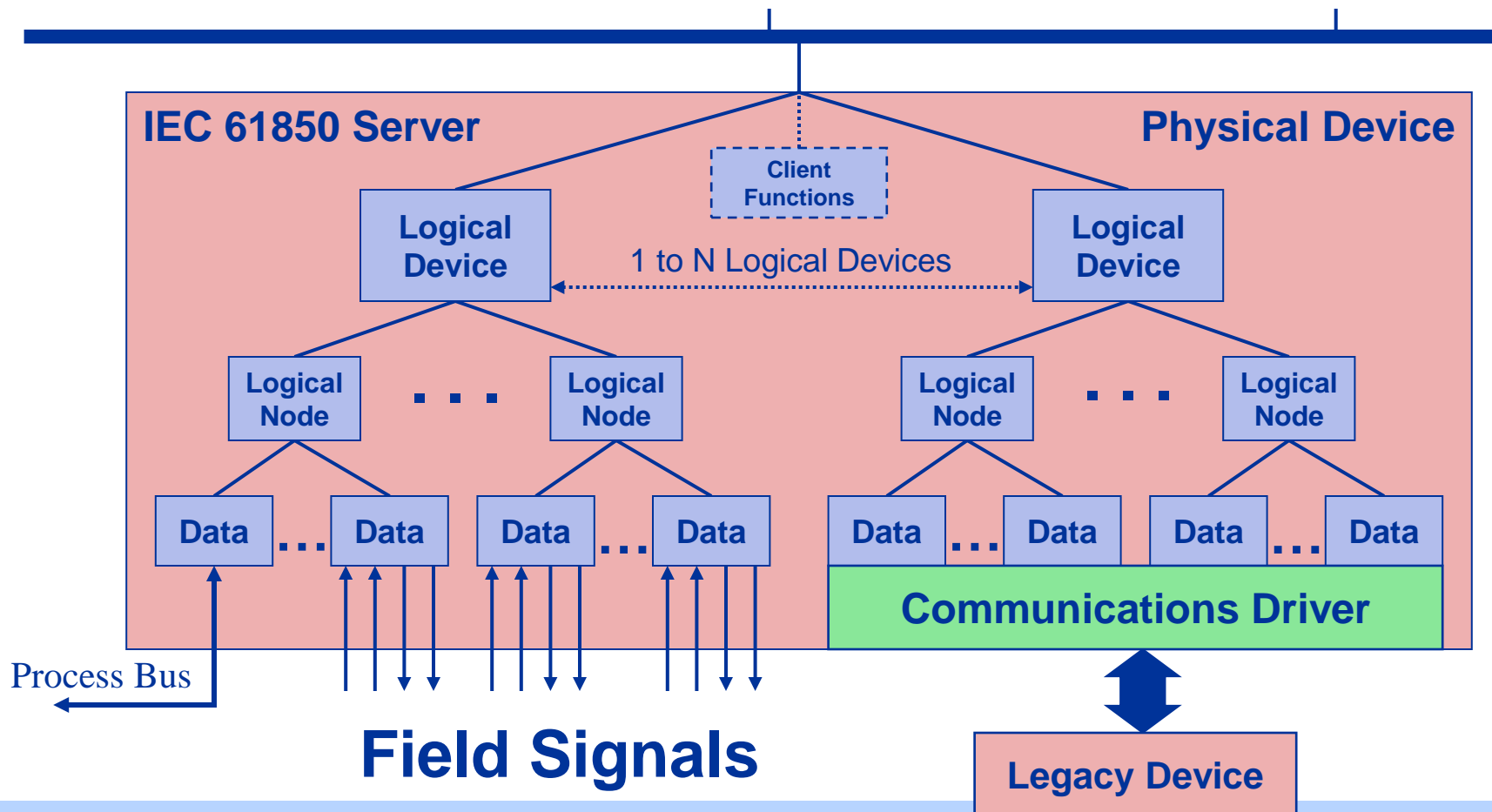
Logical Node

- A named grouping of data and associated services that is logically related to some power system function.

- Consists of one or more attributes each of a type defined by a Common Data Class (CDC)

Examples of Logical Nodes

Breaker

Breaker

Breaker

Current Transformer

Voltage Transformer

Switch Controller
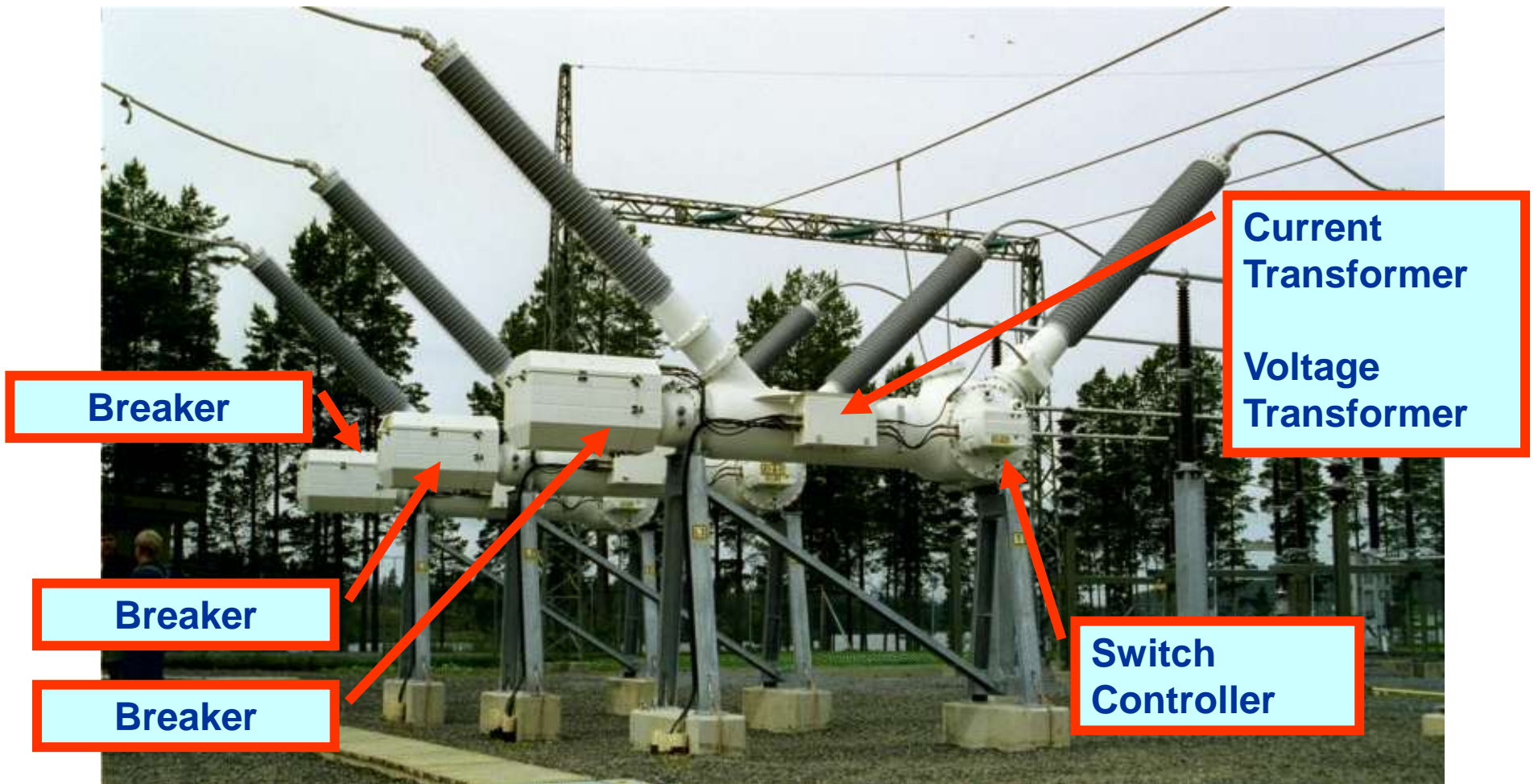
Common Data Classes (CDC)

- Defines structure for common types that are used to describe DATA objects.

- CDC are complex objects built on predefined simple base types organized into functional constraints (FC)

- Examples:
    - Single point status (SPS) – on/off
    - Double point status (DPS) – on/off/transient
    - Double point controllable (DPC) – state can be changed via controls

Common Data Classes - Status

Name	Description
SPS	Single Point Status
DPS	Double Point Status
INS	Integer Status
ENS	Enumerated Status
ACT	Protection Activation
ACD	Directional Protection Activation Info.
SEC	Security Violation Counting
BCR	Binary Counter Reading
HST	Histogram
VSS	Visible String Status

Common Data Classes - Measurands

Name	Description
MV	Measured Value
CMV	Complex Measured Value
SAV	Sampled Value
WYE	Phase to ground measured values for 3-phase system
DEL	Phase to phase measured values for 3-phase system
SEQ	Sequence
HMV	Harmonic value
HWYE	Harmonic value for WYE
HDEL	Harmonic value for DEL

Common Data Classes - Controls

Name	Description
SPC	Controllable Single Point
DPC	Controllable Double Point
INC	Controllable Integer Status
ENC	Controllable Enumerated Status
BSC	Binary Controlled Step Position Info.
ISC	Integer Controlled Step Position Info.
APC	Controllable Analogue Process Value
BAC	Binary Controlled Analog Process Value

Common Data Classes – Settings and Descriptions

Name	Description
SPG	Single Point Setting
ING	Integer Status Setting
ENG	Enumerated Status Setting
ORG	Object Reference Setting
TSG	Time Setting Group
CUG	Currency Setting Group
VSG	Visible String Setting
ASG	Analogue Setting
CURVE	Setting Curve
CSG	Curve Shape Setting
DPL	Device Name Plate
LPL	Logical Node Name Plate
CSD	Curve Shape Description

Single Point Status (SPS)

SPS class						
Data Attribute name	**Type**	**FC**	**TrgOp**	**Value/Value range**		**M/O/C**
DataName	Inherited from GenDataObject Class or from GenSubDataObject Class (see IEC 61850-7-2)					
DataAttribute						
			status			
stVal	BOOLEAN	ST	dchg	TRUE | FALSE		M
q	Quality	ST	qchg			M
t	TimeStamp	ST				M
			substitution and blocked			
subEna	BOOLEAN	SV				PICS_SUBST
subVal	BOOLEAN	SV		TRUE | FALSE		PICS_SUBST
subQ	Quality	SV				PICS_SUBST
subID	VISIBLE STRING64	SV				PICS_SUBST
blkEna	BOOLEAN	BL				O
			configuration, description and extension			
d	VISIBLE STRING255	DC		Text		O
dU	UNICODE STRING255	DC				O
cdcNs	VISIBLE STRING255	EX				AC_DLNDA_M
cdcName	VISIBLE STRING255	EX				AC_DLNDA_M
dataNs	VISIBLE STRING255	EX				AC_DLN_M

Attribute Name   Type   Functional Constraint   Trigger Options   Range of Values   Mandatory/ Optional

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Functional Constraints

- There are many data attributes in an object like a breaker that have related use:
  - Control, configuration, measurement, reporting, etc.

- Functional Constraints (FC) is a property of a data attribute that characterizes the specific use of the attribute.

- Useful to functionally organize data attributes to provide structure and context.

Mandatory/Optional Parameters

- Specifies whether a data attribute is mandatory (M) or optional (O) and under what conditions.
  - PICS_XXXX: Specifies an ACSI service model (e.g. SUBST = Substitution) that if supported then it is mandatory.
  - AC_xxx specifies if the name space differs from that specified for higher-level objects (e.g. private extensions

Double Point Status (DPS)

DPS class					
Data Attribute name	**Type**	**FC**	**TrgOp**	**Value/Value range**	**M/O/C**
DataName	Inherited from GenDataObject Class or from GenSubDataObject Class (see IEC 61850-7-2)				
DataAttribute					
			status		
stVal	CODED ENUM	ST	dchg	intermediate-state | off | on | bad-state	M
q	Quality	ST	qchg		M
t	TimeStamp	ST			M
			substitution and blocked		
subEna	BOOLEAN	SV			PICS_SUBST
subVal	CODED ENUM	SV		intermediate-state | off | on | bad-state	PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
blkEna	BOOLEAN	BL			O
			configuration, description and extension		
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

2-bit pair in DPS versus boolean in SPS

Controllable Double Point – DPC

DPC class					
Attribute Name	**Attribute Type**	**FC**	**TrgOp**	**Value/Value Range**	**M/O/C**
DataName	Inherited from Data Class (see IEC 61850-7-2)				
DataAttribute					*From IEC61850-7-3*
control and status					
ctlVal	BOOLEAN	CO		off (FALSE) | on (TRUE)	AC_CO_M
operTm	TimeStamp	CO			AC_CO_O
origin	Originator	CO, ST			AC_CO_O
ctlNum	INT8U	CO, ST		0..255	AC_CO_O
stVal	CODED ENUM	ST	dchg	intermediate-state | off | on | bad-state	M
q	Quality	ST	qchg		M
t	TimeStamp	ST			M
stSeld	BOOLEAN	ST	dchg		AC_CO_O
substitution					
subEna	BOOLEAN	SV			PICS_SUBST
subVal	CODED ENUM	SV		intermediate-state | off | on | bad-state	PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
configuration, description and extension					
pulseConfig	PulseConfig	CF			AC_CO_O
ctlModel	CtlModels	CF			M
sboTimeout	INT32U	CF			AC_CO_O
sboClass	SboClasses	CF			AC_CO_O
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

Mandatory if control is supported

Optional if control is supported

Direct or SBO

Control Model (ctlModel)

- 0: Status only. No control allowed.

- 1: Direct control with normal security

- 2: SBO control with normal security

- 3: Direct control with enhanced security

- 4: SBO control with enhanced security

Logical Node Name Plate - LPL

LPL class					
Data attribute name	**Type**	**FC**	**TrgOp**	**Value/Value range**	**M/O/C**
DataName	Inherited from GenDataObject Class or from GenSubDataObject Class (see IEC 61850-7-2)				
DataAttribute					
	configuration, description and extension				
vendor	VISIBLE STRING255	DC			M
swRev	VISIBLE STRING255	DC			M
d	VISIBLE STRING255	DC			O
dU	UNICODE STRING255	DC			O
configRev	VISIBLE STRING255	DC			AC_LN0_M
paramRev	INT32	ST	dchg		O
valRev	INT32	ST	dchg		O
ldNs	VISIBLE STRING255	EX		shall be included in **LLN0** only; for example "IEC 61850-7-4:2003"	AC_LN0_EX
lnNs	VISIBLE STRING255	EX			AC_DLD_M
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

Configuration Revision Parameters
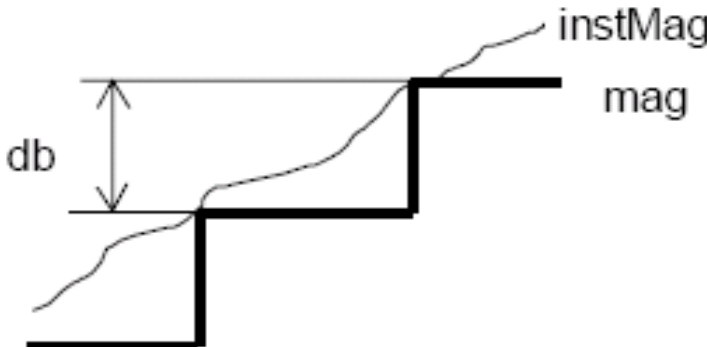
- configRev – Changed whenever at least on semantic aspect of the data has changed within the Logical Device (LD) within which this LLN0 is contained. Left to the "user" (vendor) for other LNs.
  - New LNs
  - New attributes.

- paramRev – Changed when the value of any editable setting (SE) or setpoint (SP) parameter is changed.
  - If changed via communications or local HMI the value is increased by 1.
  - If changed via SCL import the value is increased by 10,000.

- valRev – changed when the value of any configuration (CF) parameter is changed.
  - If changed via communications or local HMI the value is increased by 1.
  - If changed via SCL import the value is increased by 10,000.

Measured Value - MV

MV class

Data attribute name	Type	FC	TrgOp	Value/Value range	M/O/C
DataName	Inherited from GenDataObject Class or from GenSubDataObject Class (see IEC 61850-7-2)				
DataAttribute					
			measured attributes		
instMag	AnalogueValue	MX			O
mag	AnalogueValue	MX	dchg, dupd		M
range	ENUMERATED	MX	dchg	normal|high|low|high-high|low-low	O
q	Quality	MX	qchg		M
t	TimeStamp	MX			M
			substitution and blocked		
subEna	BOOLEAN	SV			PICS_SUBST
subMag	AnalogueValue	SV			PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
blkEna	BOOLEAN	BL			O
			configuration, description and extension		
units	Unit	CF	dchg	see Annex A	O
db	INT32U	CF	dchg	0 … 100 000	O
zeroDb	INT32U	CF	dchg	0 … 100 000	O
sVC	ScaledValueConfig	CF	dchg		AC_SCAV
rangeC	RangeConfig	CF	dchg		GC_CON_range
smpRate	INT32U	CF	dchg		O
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

instMag v.s. mag

Deadbanded value. Shall be based on a dead band calculation from instMag as illustrated below. The value of mag shall be updated to the current value of instMag when the value has changed according the configuration parameter db.

NOTE 7 The figure above is an example. There may be other algorithms providing a comparable result; for example as an alternate solution, the dead band calculation may use the integral of the change of instMag. The algorithm used is a local issue.

NOTE 8 This value mag is typically used to create reports for analogue values. Such a report sent "by exception" is not comparable to the transfer of sampled measured values as supported by the CDC SAV.

- Use mag in datasets to trigger a report when data changes
- Use instMag in datasets for reporting data without triggering a report

Trigger Option (TrgOp)

Specifies the conditions under which reporting on the data attribute can be triggered.

	data-change	BOOLEAN
	quality-change	BOOLEAN
	data-update	BOOLEAN
	integrity	BOOLEAN
	general-interrogation	BOOLEAN

Sampled Values (SAV)

SAV class					
Data attribute name	**Type**	**FC**	**TrgOp**	**Value/Value range**	**M/O/C**
DataName	Inherited from GenDataObject Class or from GenSubDataObject Class (see IEC 61850-7-2)				
DataAttribute					
measured attributes					
instMag	AnalogueValue	MX			M
q	Quality	MX	qchg		M
t	TimeStamp	MX			O
configuration, description and extension					
units	Unit	CF	dchg	see Annex A	O
sVC	ScaledValueConfig	CF	dchg		AC_SCAV
min	AnalogueValue	CF	dchg		O
max	AnalogueValue	CF	dchg		O
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

WYE Connected Measurements (WYE)

WYE class					
Data attribute name	**Type**	**FC**	**TrgOp**	**Value/Value range**	**M/O/C**
DataName	Inherited from GenDataObject Class or from GenSubDataObject Class (see IEC 61850-7-2)				
SubDataObject					
phsA	CMV				GC_1
phsB	CMV				GC_1
phsC	CMV				GC_1
neut	CMV				GC_1
net	CMV				GC_1
res	CMV				GC_1
DataAttribute					
configuration, description and extension					
angRef	ENUMERATED	CF	dchg	Va | Vb | Vc | Aa | Ab | Ac | Vab | Vbc | Vca | Vother | Aother Synchrophasor	O
phsToNeut	BOOLEAN	CF	dchg	DEFAULT = FALSE	O
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

Complex Measured Value (CMV)

Vector =
mag
&
ang

DataAttribute					
measured attributes					
instCVal	Vector	MX			O
cVal	Vector	MX	dchg, dupd		M
range	ENUMERATED	MX	dchg	normal|high|low|high-high|low-low	O
rangeAng	ENUMERATED	MX	dchg	normal|high|low|high-high|low-low	O
q	Quality	MX	qchg		M
t	TimeStamp	MX			M
substitution and blocked					
subEna	BOOLEAN	SV			PICS_SUBST
subCVal	Vector	SV			PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
blkEna	BOOLEAN	BL			O
configuration, description and extension					
units	Unit	CF	dchg	see Annex A	O
db	INT32U	CF	dchg	0 … 100 000	O
dbAng	INT32U	CF	dchg	0 … 100 000	O
zeroDb	INT32U	CF	dchg	0 … 100 000	O
rangeC	RangeConfig	CF	dchg		GC_CON_range
rangeAngC	RangeConfig	CF	dchg		GC_CON_rangeAng
magSVC	ScaledValueConfig	CF	dchg		AC_SCAV
angSVC	ScaledValueConfig	CF	dchg		AC_SCAV
angRef	ENUMERATED	CF	dchg	V | A | other Synchrophasor	O
smpRate	INT32U	CF	dchg		O
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

Vector

Vector Type Definition			From IEC61850-7-3
Attribute Name	**Attribute Type**	**Value/Value Range**	**M/O/C**
mag	AnalogueValue		M
ang	AnalogueValue		O

The Standards Based Integration Company

Systems Integration Specialists Company, Inc.

Logical Nodes

Abstract Representation of a Power System Function

Logical Nodes
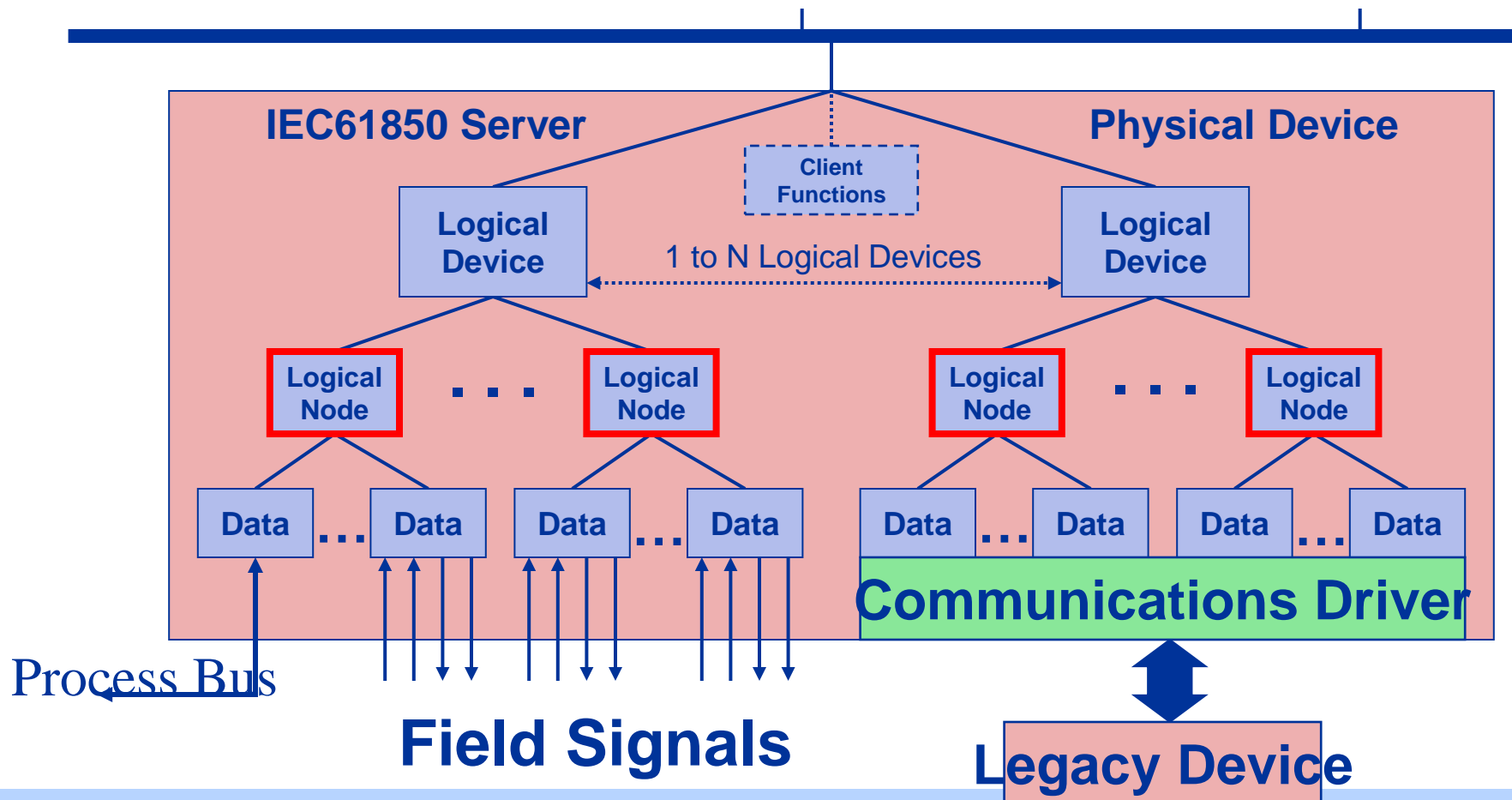
System Logical Nodes "L"

Name	Description
LPHD	Physical Device
LLNO	Common Logical Node MANDATORY
LCCH	Physical Communications Channel Supervision
LGOS	GOOSE Subscription
LTIM	Time Management
LTMS	Time Master Supervision
LTRK	Service Tracking

Automatic Control Logical Nodes "A"

Name	Description
ANCR	Neutral Current Regulator
ARCO	Reactive Power Control
ARIS	Resistor Control
ATCC	Automatic Tap Changer controller
AVCO	Voltage Control

Supervisory Control Logical Nodes "C"

Name	Description
CALH	Alarm Handling
CCGR	Cooling Group Control
CILO	Interlocking
CPOW	Point-on-wave switching
CSWI	Switch Controller
CSYN	Synchronizer Controller

Functional Block Logical Nodes "F"

Name	Description
FCNT	Counter
FCSD	Curve Shape Description
FFIL	Generic Filter
FLIM	Control Function Output Limitation
FPID	PID Regulator
FRMP	Ramp Function
FSPT	Set-Point Control Function
FXOT	Action at Over Threshold
FXUT	Action at Under Threshold

Generic Function Logical Nodes "G"

Name	Description
GAPC	Generic Automatic Process Control
GGIO	Generic Process I/O
GLOG	Generic Log
GSAL	Generic Security Application

Use only when there is no other power system related LN that can represent the data.

Interfacing and Archiving Logical Nodes "I"

Name	Description
IARC	Archiving
IHMI	Human Machine Interface
ITCI	Telecontrol Interface
ITMI	Telemonitoring Interface
ISAF	Safety Alarm Function
ITPC	Teleprotection Communications Interface

Mechanical and Non-Electrical Logical Nodes "K"

Name	Description
KFAN	Fan
KFIL	Filter
KPMP	Pump
KTNK	Tank
KVLV	Valve Control

Metering and Measurement Logical Nodes "M"

Name	Description
MHAI	Harmonics or interharmonics
MHAN	Non phase related harmonics or interharmonics
MMTR	Metering
MMXN	Non phase related measurements
MMXU	Measurements
MSQI	Sequence and Imbalance
~~MSTA~~	~~Metering Statistics~~
MENV	Environmental Information
MFLK	Flicker Measurement
MHYD	Hydrological Information
MMDS	DC Measurement
MMET	Metrological Information

Protection Logical Nodes "P"

Name	Description
PDIF	Differential
PDIR	Direction
PDIS	Distance
PDOP	Directional overpower
PDUP	Directional underpower
PFRC	Rate of change of frequency
PHAR	Harmonic restraint
PHIZ	Ground detector
PIOC	Instantaneous overcurrent
PMRI	Motor restart inhibition
PMSS	Motor starting time supervision
POPF	Over power factor
PPAM	Phase angle measuring

Protection Logical Nodes (cont'd)

Name	Description
PSCH	Protection scheme
PSDE	Sensitive directional earth fault
PTEF	Transient earth fault
PTOC	Time over current
PTOF	Over frequency
PTOV	Over voltage
PTRC	Protection trip conditioning
PTTR	Thermal overload
PTUC	Under current
PTUV	Under voltage
PVOC	Voltage controlled time over current
PVPH	Volts per Hz
PZSU	Zero speed or under speed

Protection Logical Nodes (cont'd)

Name	Description
PRTR	Rotor Protection
PTHF	Thyristor Protection
PUPF	Underpower Factor Protection

Power Quality Events Logical Nodes "Q"

Name	Description
QFVR	Frequency Variation
QITR	Current Transient
QIUB	Current Unbalance Variation
QVTR	Voltage Transient
QVUB	Voltage Unbalance Variation
QVVR	Voltage Variation

Protection Related Logical Nodes "R"

Name	Description
RDRE	Disturbance recorder function
RADR	Disturbance recorder channel analogue
RBDR	Disturbance recorder channel binary
RDRS	Disturbance record handling
RBRF	Breaker failure
RDIR	Directional element
RFLO	Fault locator
RPSB	Power swing detection/blocking
RREC	Auto reclosing
RSYN	Synchronism-check or synchronising
RMXU	Differential Measurements

Sensors and Monitoring Logical Nodes "S"

Name	Description
SARC	Monitoring and diagnostics for arcs
SIMG	Insulation medium supervision
SIML	Insulation medium supervision (liquid)
SPDC	Monitoring and diag. for partial discharges
SCBR	Circuit Breaker Supervision
SLTC	Tap Changer Supervision
SOPM	Supervision of Operating Mechanism
SPTR	Power Transformer Supervision
SSWI	Circuit Switch Supervision
STMP	Temperature Supervision
SVBR	Vibration Supervision

Instrument Transformer Logical Nodes "T"

Name	Description
TCTR	Current transformer
TVTR	Voltage transformer
TANG	Angle
TAXD	Axial Displacement
TDST	Distance
TFLW	Liquid Flow
TFRQ	Frequency
TGSN	Generic Sensor
THUM	Humidity
TLVL	LMedia Level

Instrument Transformer Logical Nodes (cont'd)

Name	Description
TMGF	Magnetic Field
TMVM	Movement Sensor
TPOS	Position Indicator
TPRS	Pressure Sensor
TRTN	Rotation Transmitter
TSND	Sound Pressure Sensor
TTMP	Temperature Sensor
TTNS	Mechanical Tension/stress
TVBR	Virbration Sensor
TWPH	Water Acidity

Switchgear Logical Nodes "X"

Name	Description
XCBR	Circuit Breaker
XSWI	Circuit Switch

Power Transformer Logical Nodes "Y"

Name	Description
YEFN	Earth fault neutralizer
YLTC	Tap changer
YPSH	Power shunt
YPTR	Power transformer

Other Power System Equipment Logical Nodes "Z"

Name	Description
ZAXN	Auxiliary network
ZBAT	Battery
ZBSH	Bushing
ZCAB	Power cable
ZCAP	Capacitor Bank
ZCON	Converter
ZGEN	Generator
ZGIL	Gas insulated line
ZLIN	Power overhead line
ZMOT	Motor
ZREA	Reactor
ZRRC	Rotating reactive component
ZSAR	Surge arrestor
ZTCF	Thyristor controlled frequency converter
ZTCR	Thyristor controlled reactive component
ZRES	Resistor
ZSCR	Semiconductor Controlled Rectifier
ZSMC	Synchronous Machine

Logical Node Names

- Example for Circuit Breaker:

ddd XCBR01

Logical Node Instance #

Logical Node Name per
IEC 61850-7-4 (circuit breaker)

Optional Application Specific Prefix
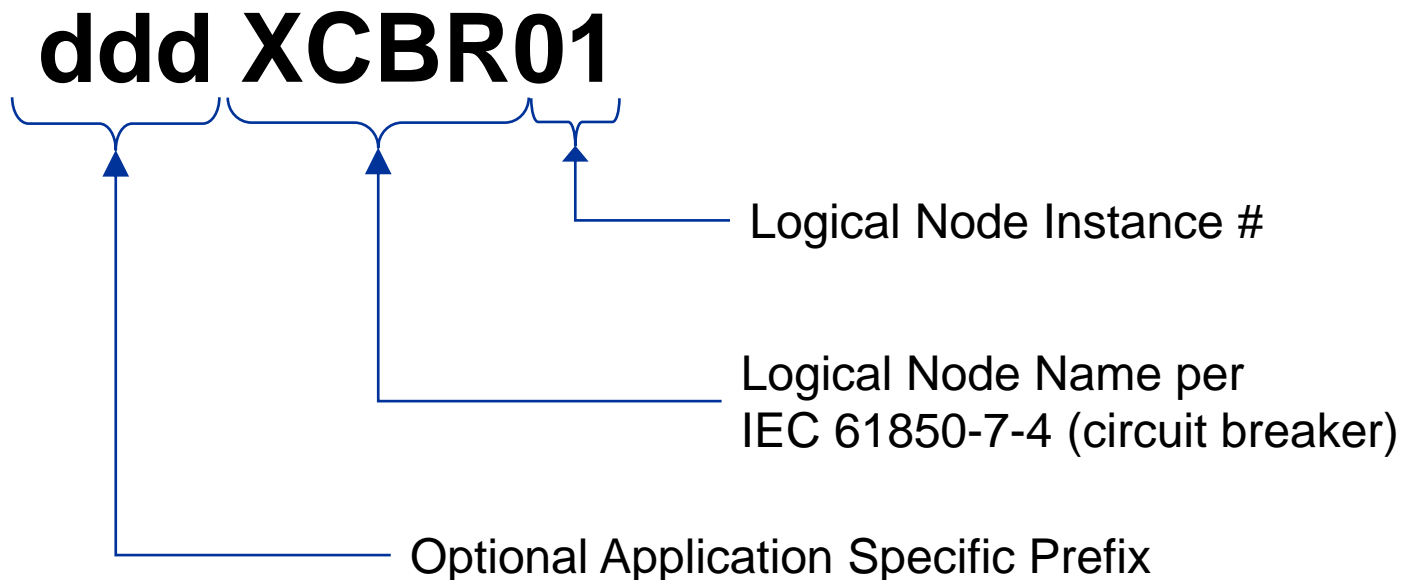
prefix digits + instance digits ≤ 7 (Ed. 1)
prefix digits + instance digits ≤ 12 (Ed. 2)

Logical Node Classes

LN

LPHD

Common LN

LLN0

Domain Specific LNs (i.e. XCBR)

Inherited Relationships

An IEC 61850 device must contain LPHD, LLN0, and 1 or more domain specific logical nodes.
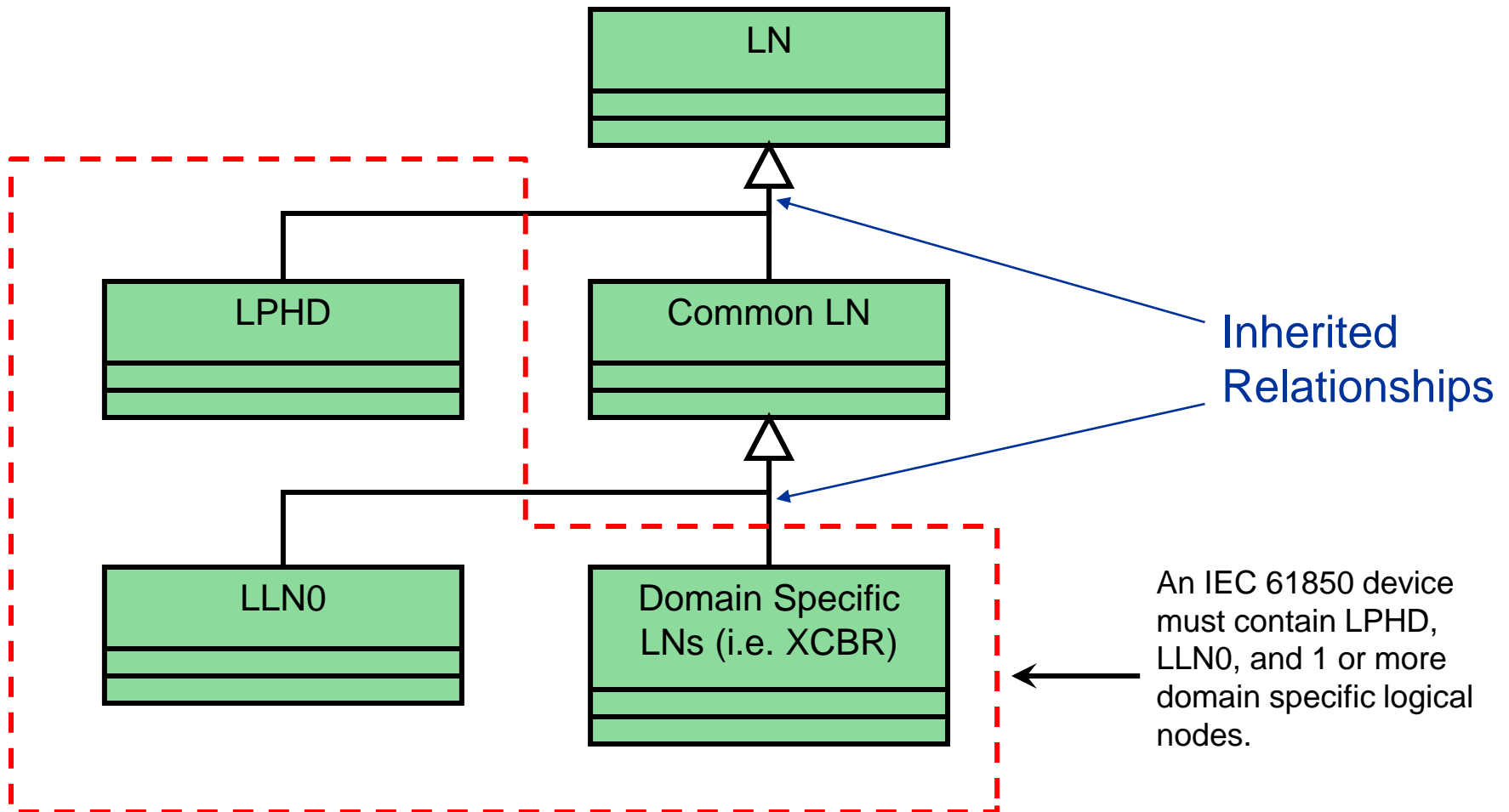
Physical Device - LPHD

LPHD class					
Data object name	**Common data class**	**Explanation**		**T**	**M/O/ C**
Data objects					
Status information					
PhyNam	DPL	Physical device name plate			M
PhyHealth	ENS	Physical device health			M
OutOv	SPS	Output communications buffer overflow			O
Proxy	SPS	Indicates if this LN is a proxy			M
InOv	SPS	Input communications buffer overflow			O
NumPwrUp	INS	Number of Power ups			O
WrmStr	INS	Number of Warm Starts			O
WacTrg	INS	Number of watchdog device resets detected			O
PwrUp	SPS	Power Up detected			O
PwrDn	SPS	Power Down detected			O
PwrSupAlm	SPS	External power supply alarm			O
Controls					
RsStat	SPC	Reset device statistics		T	O
Sim	SPC	Receive simulated GOOSE or simulated SV			O

Data Object Names

Common Data Class

Description

Mandatory/Optional/Conditional

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Common Logical Node Class

Common Logical Node class				
Attribute Name	**Attr. Type**	**Explanation**	**T**	**M/O**
LNName		Shall be inherited from Logical-Node Class (see IEC 61850-7-2)		
Data				From IEC61850-7-4
Mandatory Logical Node Information (Shall be inherited by ALL LN but LPHD)				
Mod	INC	Mode		M
Beh	INS	Behaviour		M
Health	INS	Health		M
NamPlt	LPL	Name plate		M
Optional Logical Node Information				
Loc	SPS	Local operation		O
EEHealth	INS	External equipment health		O
EEName	DPL	External equipment name plate		O
OpCntRs	INC	Operation counter resetable		O
OpCnt	INS	Operation counter		O
OpTmh	INS	Operation time		O

ALL other logical nodes contain these attributes even though they are not listed in the other logical node description tables.

Common Logical Node – LLN0

(Logical Node Zero)

LLNO class					
Data object name	**Common data class**	**Explanation**		**T**	**M/O/C**
Data objects					
Status information					
LocKey	SPS	Local operation for complete logical device			O
LocSta	SPC	Switching authority at station level			O
Loc	SPS	Local Control Behavior			O
OpTmh	INS	Operation time			O
Controls					
Diag	SPC	Run Diagnostics			O
LEDRs	SPC	LED reset		T	O
Settings					
MltLev	SPG	Select mode of authority for local control (True – control from multiple levels above the selected one is allowed, False – no other control level above allowed)			O

The Mode (Mod) and Local/Remote status of this logical node affects all LNs in that Logical Device

Logical Node Description – XCBR

XCBR class				
Data object name	**Common data class**	**Explanation**	**T**	**M/O/C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22.		
Data objects				
LocKey	SPS	Local or remote key (local means without substation automation communication, hardwired direct control)		O
LocSta	SPC	Switching authority at station level		O
Loc	**SPS**	Local Control Behavior		M
EEHealth	ENS	External equipment health		O
EEName	DPL	External equipment name plate		O
OpCnt	INS	Operation counter		M
Controls				
Pos	DPC	Switch position		M
BlkOpn	SPC	Block opening		M
BlkCls	SPC	Block closing		M
ChaMotEna	SPC	Charger motor enabled		O
Metered values				
SumSwARs	BCR	Sum of Switched Amperes, resetable		O
Status information				
CBOpCap	INS	Circuit breaker operating capability		O
POWCap	INS	Point On Wave switching capability		O
MaxOpCap	INS	Circuit breaker operating capability when fully charged		O
Dsc	SPS	Discrepancy		O
Settings				
CBTmms	ING	Closing Time of breaker		O

Data Object Names

Common Data Class

Description

Mandatory/Optional/Conditional

Single Point Status (SPS) CDC
(e.g. loc)

SPS class					
Attribute Name	**Attribute Type**	**FC**	**TrgOp**	**Value/Value Range**	**M/O/C**
DataName	Inherited from Data Class (see IEC 61850-7-2)				
DataAttribute					From IEC61850-7-3
			status		
stVal	BOOLEAN	**ST**	dchg	TRUE | FALSE	M
q	Quality	ST	qchg		M
t	TimeStamp	ST			M
			substitution		
subEna	BOOLEAN	SV			PICS_SUBST
subVal	BOOLEAN	SV		TRUE | FALSE	PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
			configuration, description and extension		
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

Data Attribute Names

Functional Constraint

Object Name for Local/Remote Attribute of XCBR1

XCBR1.ST.Loc.stVal

Attribute

Data

Functional Constraint

Logical Node
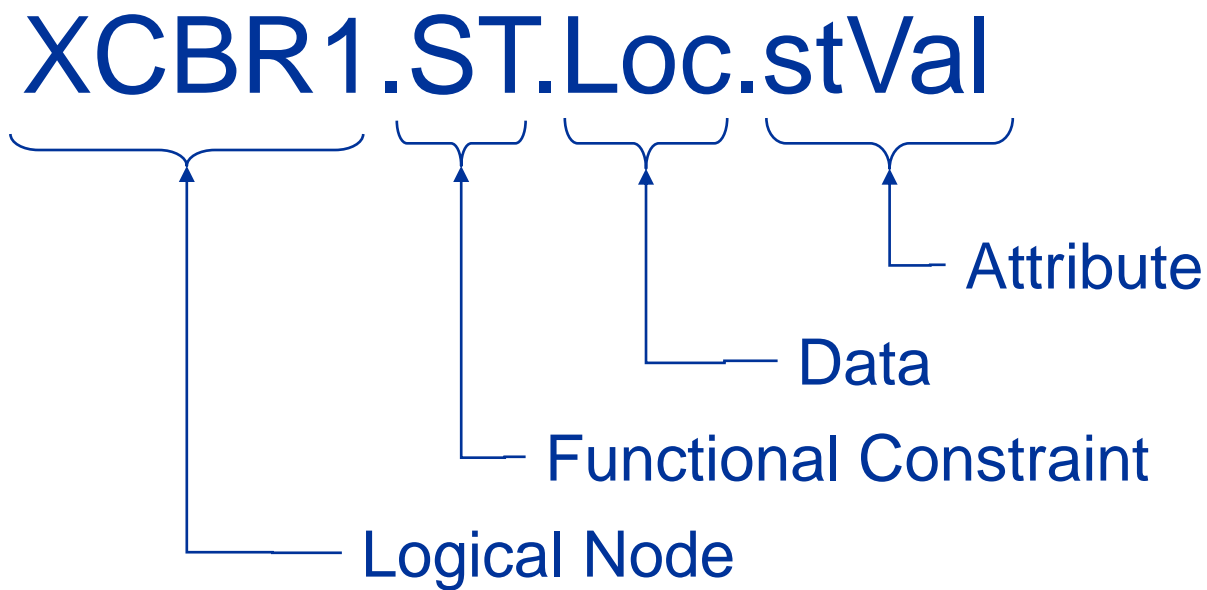
Mapping of Names via 8-1

- Section 8-1 maps the IEC61850 LN and Data Object Names to MMS (ISO9506)

- MMS allows only numbers, letters, "$", and "_" in object names.

- Resulting MMS Object Name:

XCBR1STLoc$stVal

Object Name for Breaker Position Attribute of XCBR1

XCBR1.ST.**Pos**.stVal

Attribute

Data

Functional Constraint

Logical Node

Measurement Unit (MMXU)

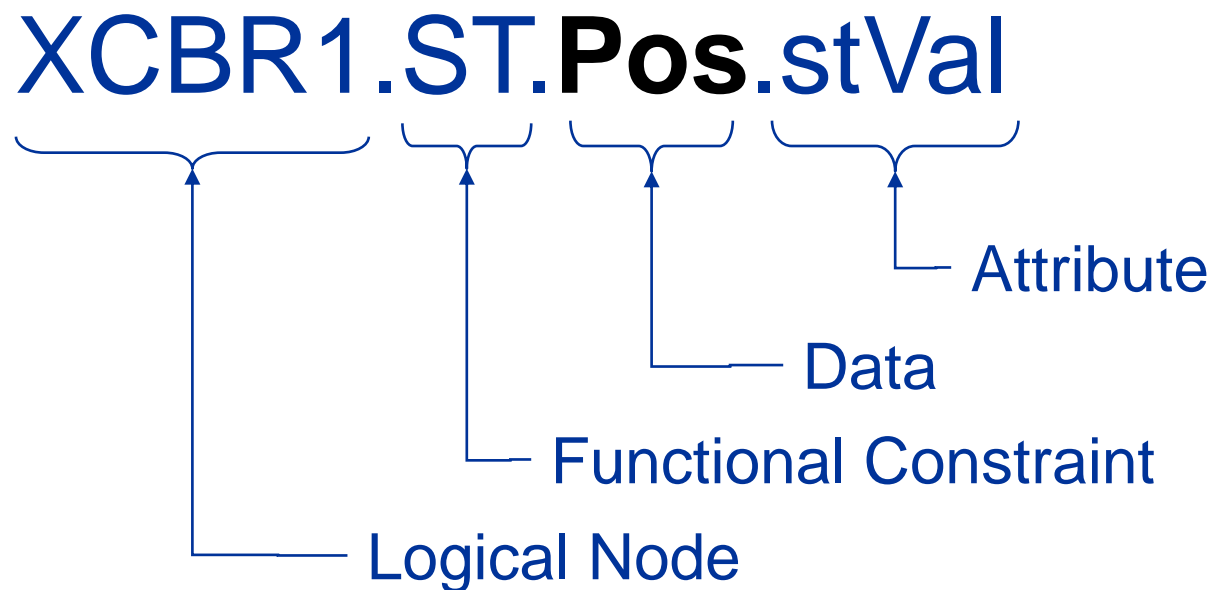| MMXU class					
Data object name	**Common data class**	**Explanation**		**T**	**M/O/ C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22.			
Data objects					
EEHealth	INS	External Equipment Health (external sensor)			O
Measured values					
TotW	MV	Total Active Power (Total P)			O
TotVAr	MV	Total Reactive Power (Total Q)			O
TotVA	MV	Total Apparent Power (Total S)			O
TotPF	MV	Average Power factor (Total PF)			O
Hz	MV	Frequency			O
PPV	DEL	Phase to phase voltages (VL1VL2, ...)			O
PNV	WYE	Phase to neutral voltage			O
PhV	WYE	Phase to ground voltages (VL1ER, ...)			O
A	WYE	Phase currents (IL1, IL2, IL3)			O
W	WYE	Phase active power (P)			O
VAr	WYE	Phase reactive power (Q)			O
VA	WYE	Phase apparent power (S)			O
PF	WYE	Phase power factor			O
Z	WYE	Phase Impedance			O

Object Name for Phase A to Ground Angle Measurement

MMXU1.MX.PhV.PhsA.cVal.ang.f

Data

Functional Constraint (measurements)

Logical Node
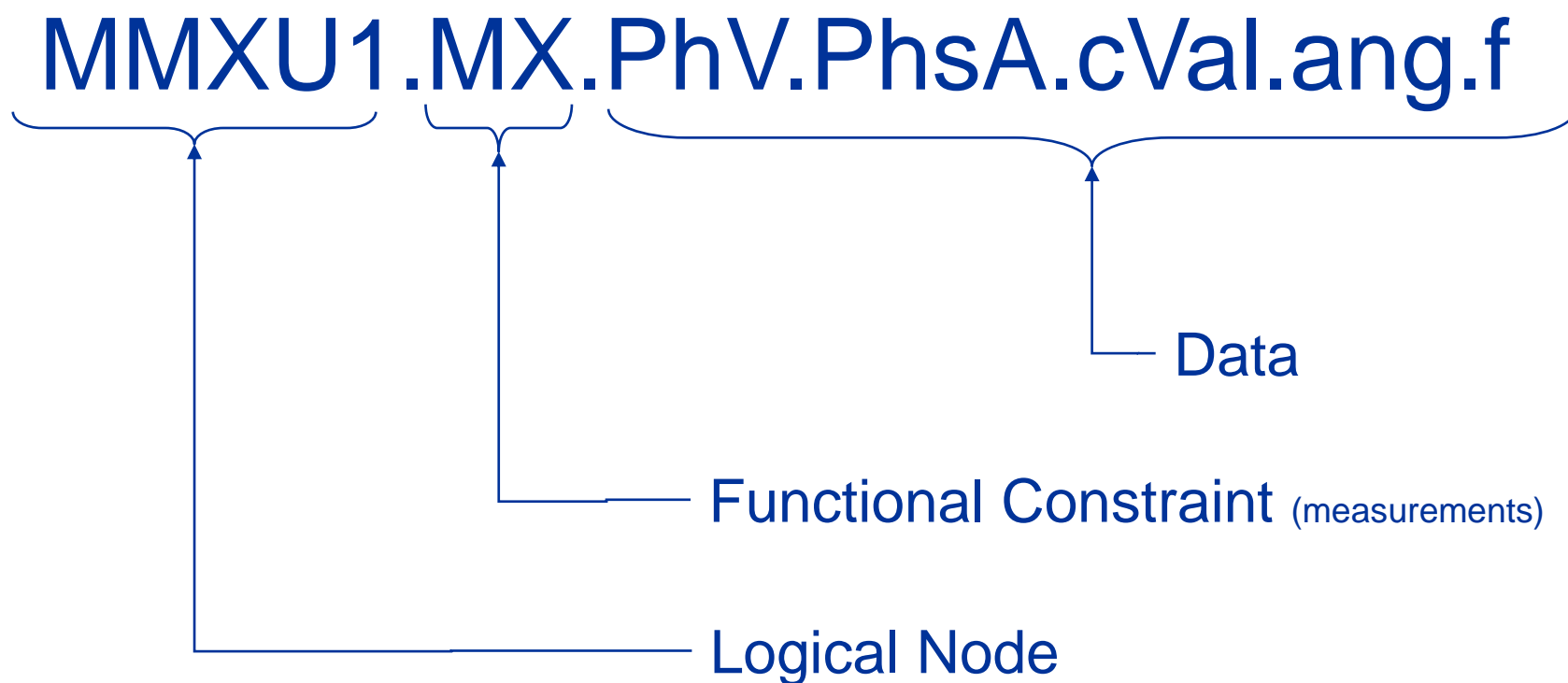
GOOSE Subscription – LGOS

LGOS class					
Data object name	**Common data class**	**Explanation**	**T**	**M/O/ C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22		
Data objects				
Status information				
SbsNdsCom	SPS	Subscription needs commissioning		O
SbsSt	SPS	Status of the subscription (True = active, False=not active)		O
SbsSim	SPS	Subscription wih simulation		O
LastStNum	INS	Last state number received		O
ConfRevNum	INS	Expected Configuration revision number		O
Settings				
GoCBRef	ORG	Reference to the subscribed GOOSE control block		O

ACSI

Abstract Communications Service Interface

The IEC 61850 Service Model

ACSI
Abstract Communications Service Interface

- Defines a set of Objects

- Defines a set of Services to manipulate and access those objects

- Defines a base set of data types for describing objects

ACSI Objects and MMS Mapping

ACSI Object Class	MMS Object
SERVER class	Virtual Manufacturing Device (VMD)
LOGICAL DEVICE class	Domain
LOGICAL NODE class	Named Variable
DATA class	Named Variable
DATA-SET class	Named Variable List
SETTING-GROUP-CONTROL-BLOCK class	Named Variable
REPORT-CONTROL-BLOCK class	Named Variable
LOG class	Journal
LOG-CONTROL-BLOCK class	Named Variable
GOOSE-CONTROL-BLOCK class	Named Variable
GSSE-CONTROL-BLOCK class	Named Variable
CONTROL class	Named Variable
Files	Files

Some ACSI Services

Enable Self Describing Devices

ACSI Services	MMS Services
LogicalDeviceDirectory	GetNameList
GetAllDataValues	Read
GetDataValues	Read
SetDataValues	Write
GetDataDirectory	GetVariableAccessAttributes
GetDataDefinition	GetVariableAccessAttributes
GetDataSetValues	Read
SetDataSetValues	Write
CreateDataSet	CreateNamedVariableList
DeleteDataSet	DeleteNamedVariableList
GetDataSetDirectory	GetVariableAccessAttributes
Report (Buffered and Unbuffered)	InformationReport
GetBRCBValues/GetURCBValues	Read
SetBRCBValues/SetURCBValues	Write
GetLCBValues	Read
SetLCBValues	Write
QueryLogByTime	ReadJournal
QueryLogAfter	ReadJournal
GetLogStatusValues	GetJournalStatus
Select	Read/Write
SelectWithValue	Read/Write
Cancel	Write
Operate	Write
Command-Termination	Write

Reporting

- Unbuffered Reporting allows clients to receive data from the server without polling but, if the network connection is lost between the client and server, data is lost.

- Buffered reporting enables the server to retain data if connections are lost enabling the client to retrieve ALL the data.
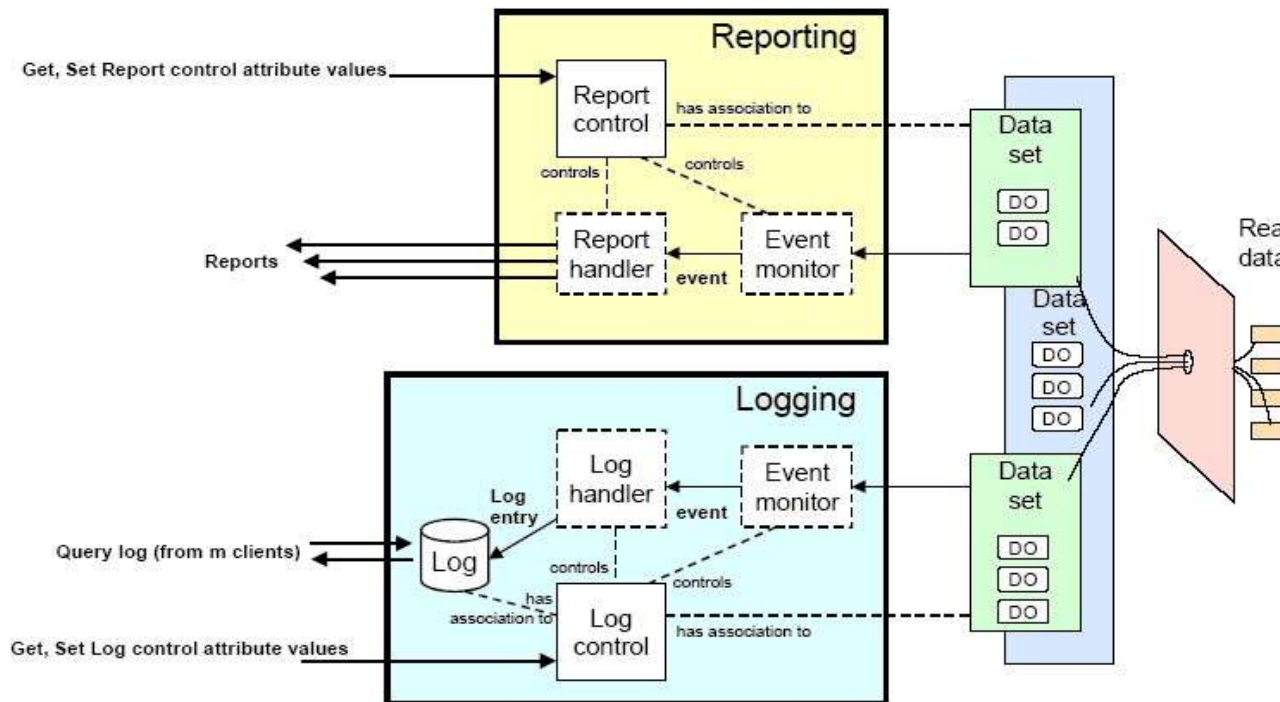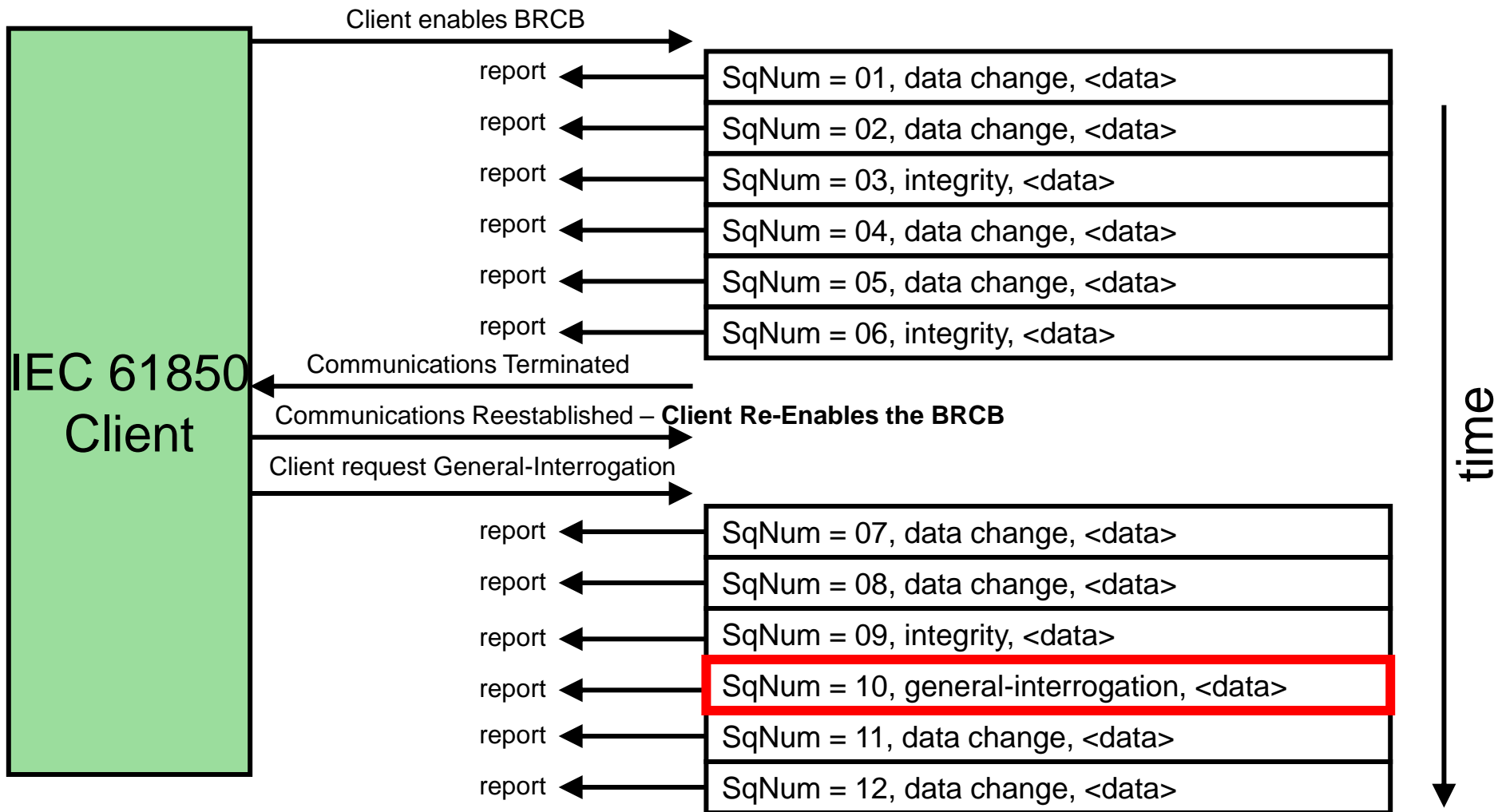
Buffered Report Tracking Service – BST

BTS Class						
Attribute name	**Attribute type**	**FC**	**TrgOp**	**r/w**	**Value/value range**	**M/O/C**
Shall inherit all the data attributes of the **CST CDC**						
Specific to the BTS						
rptID	VISIBLE STRING129	SR		r	Service parameter ReportIdentifier is mapped to rptID	M
rptEna	BOOLEAN	SR		r	Service parameter ReportEnable is mapped to rptEna	M
datSet	ObjectReference	SR		r	Service parameter DatSetReference is mapped to datSet	M
confRev	INT32U	SR		r	Service parameter ConfigurationRevision is mapped to confRev	M
optFlds	PACKED_LIST	SR		r	Service parameter OptionalFields is mapped to optFlds	M
bufTm	INT32U	SR		r	Service parameter BufferTime is mapped to bufTm	M
sqNum	INT32U	SR		r	Attribute SqNum of BRCB is mapped to sqNum	M
trgOps	TriggerConditions	SR		r	Service parameter TriggerOptionsEnabled is mapped to trgOps	M
intgPd	INT32U	SR		r	Service parameter IntegrityPeriod is mapped to intgPd	M
gi	BOOLEAN	SR		r	Service parameter GeneralInterrogation is mapped to go	M
purgeBuf	BOOLEAN	SR		r	Service parameter PurgeBuf is mapped to purgeBuf	M
entryID	EntryID	SR		r	Service parameter EntryIdentifier is mapped to entryID	M
timeOfEntry	EntryTime	SR		r	Service parameter TimeOfEntry is mapped to timeOfEntry	M
resvTms	INT16	SR		r	Service parameter ReserveTimeSecond is mapped to resvTms	O

Buffered Reporting with GI Example

Client enables BRCB

report — SqNum = 01, data change, <data>
report — SqNum = 02, data change, <data>
report — SqNum = 03, integrity, <data>
report — SqNum = 04, data change, <data>
report — SqNum = 05, data change, <data>
report — SqNum = 06, integrity, <data>

Communications Terminated

Communications Reestablished – **Client Re-Enables the BRCB**

Client request General-Interrogation

report — SqNum = 07, data change, <data>
report — SqNum = 08, data change, <data>
report — SqNum = 09, integrity, <data>
report — SqNum = 10, general-interrogation, <data>
report — SqNum = 11, data change, <data>
report — SqNum = 12, data change, <data>

IEC 61850 Client

time

SqNum = 10 flags when the GI was issued by the client to identify data that was reported while disconnected.

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Using Modeling to Control Reports

- Requirements:
  - Desire to receive average readings of current measurements on all 3 phases of a feeder and the actual voltage measurement on one phase every 10 minutes.
  - Any under or over voltage or current conditions should be reported immediately.

- Use MSTA for average current measurements

- Use MMXU for actual voltage measurement and range alarms

- Careful selection of attributes (instMag versus mag) and range alarms enable these complex requirements to be handled via client interaction with server.
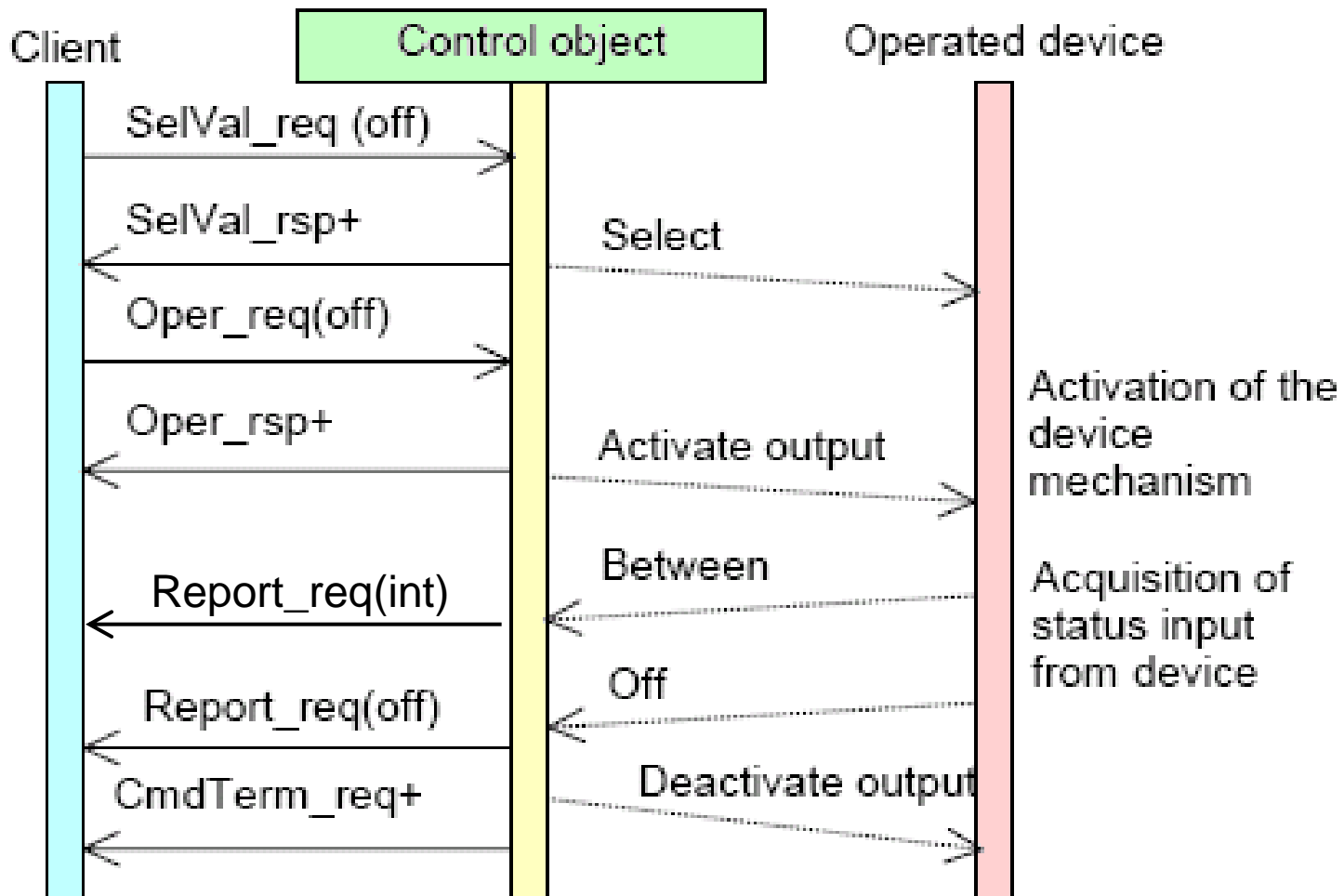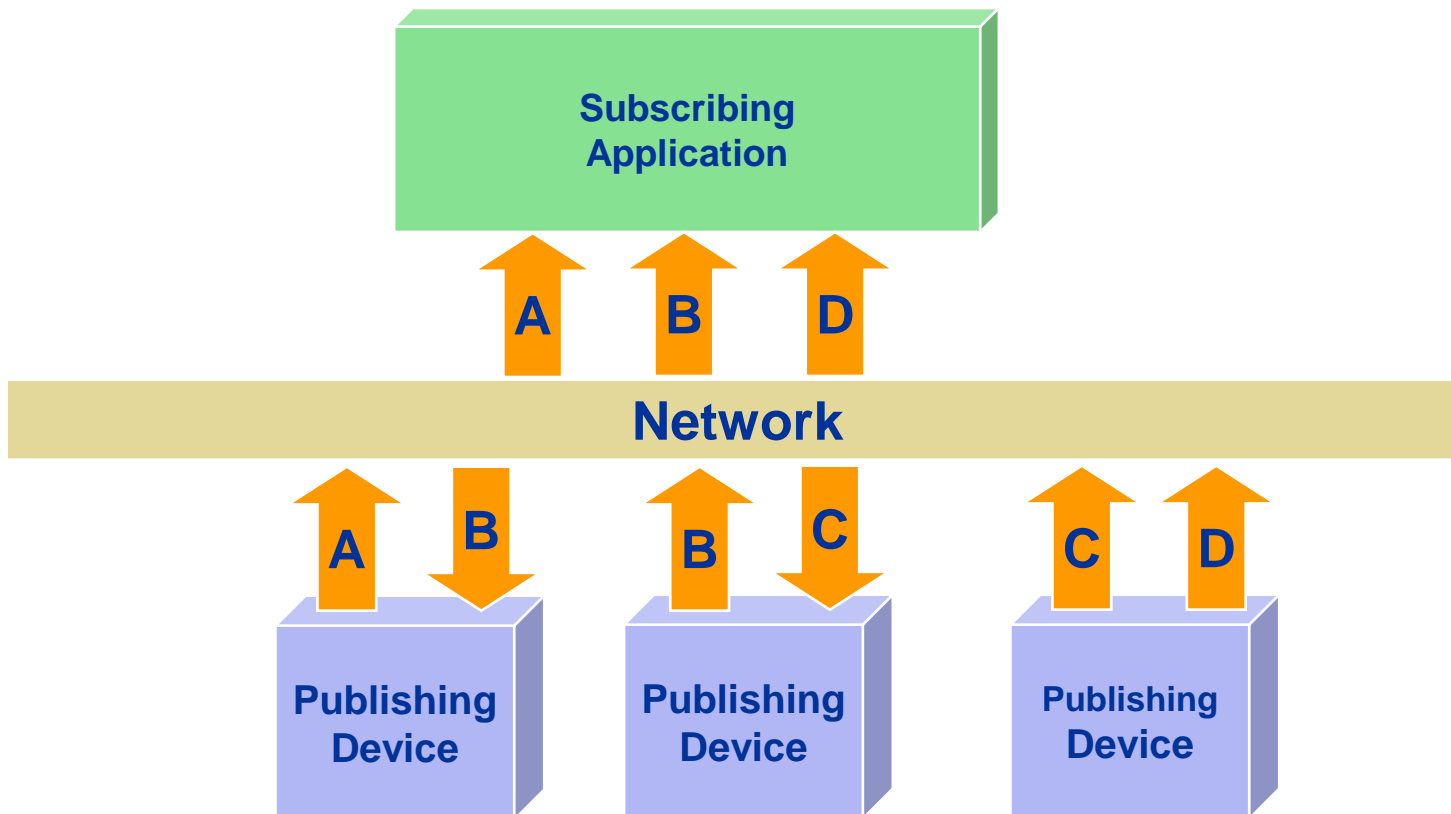
General Control Model
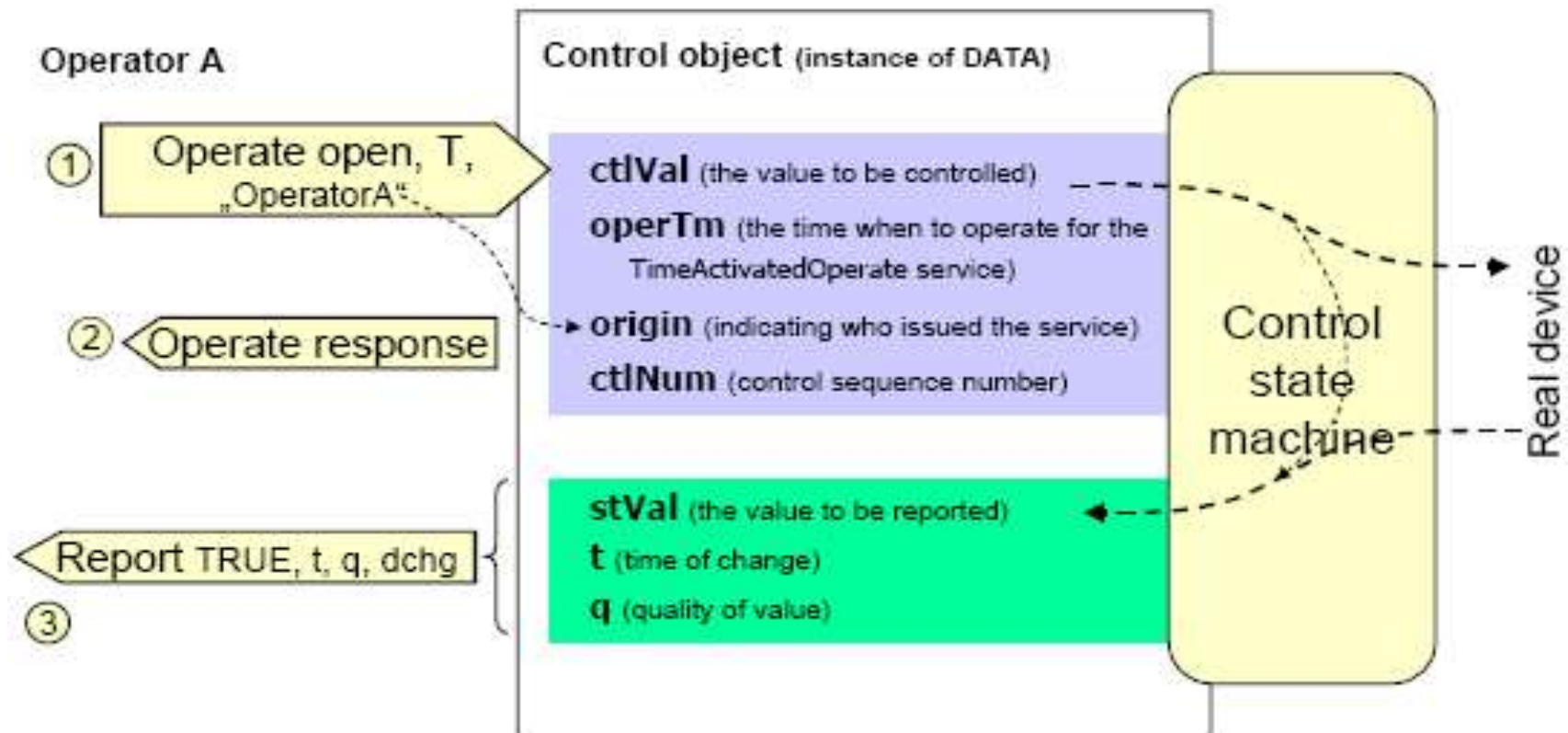
Direct Control with Normal Security
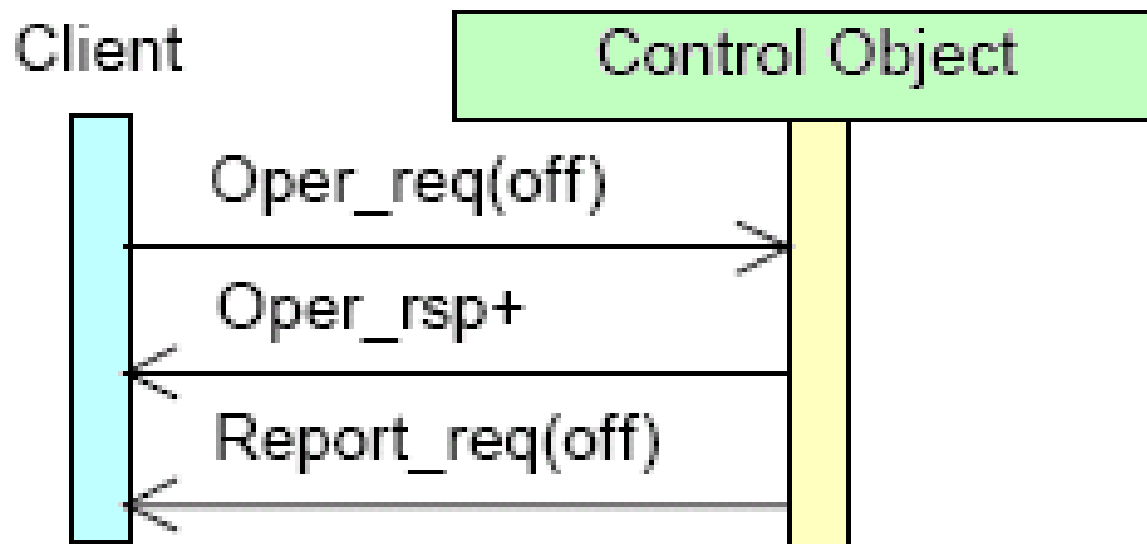
SBO Control with Enhanced Security
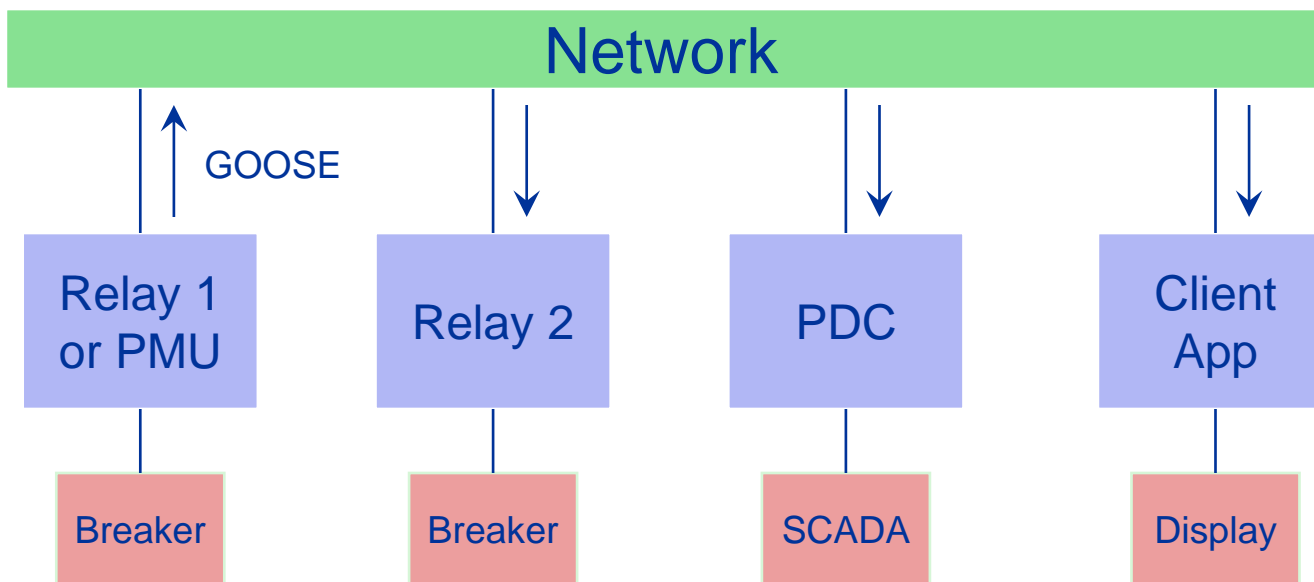
GOOSE Messaging

Applications "subscribe" by listening for data **sent** to a given multi-cast **destination** address

IEC61850 Network Architecture

GOOSE - Generic Object Oriented Substation Event (sends data sets)

GOOSE Message

Name	Type
gocbRef	GOOSE Control Block
timeAllowedtoLive	How long to wait for next message (ms)
datSet	The name of the data set being sent
goID	ID of the sending GOOSE application (gocbRef)
T	Time of state change
stNum	State Number
sqNum	Sequence Number
Simulation	Simulated Data (true/false)
confRev	Configuration Revision of the GOOSE Control Block (dataset config)
ndsCom	Needs Commissioning (true/false)
numDatSetEntries	Number of data set entries in the message
Data	The data values of the data set in sequence.

Binary encoding of above data

Ethernet Multicast Address Using 802.3 Ethertype or 90-5 for IP Multicast

GOOSE is reliable multicast

Each line below represents a GOOSE message

State = 1, Seq = 0

State = 2, Seq = 0

State = 1, Seq = 6

Event at t=0

Time increases until
steady state of ~1/min is reached

State change occurs

t
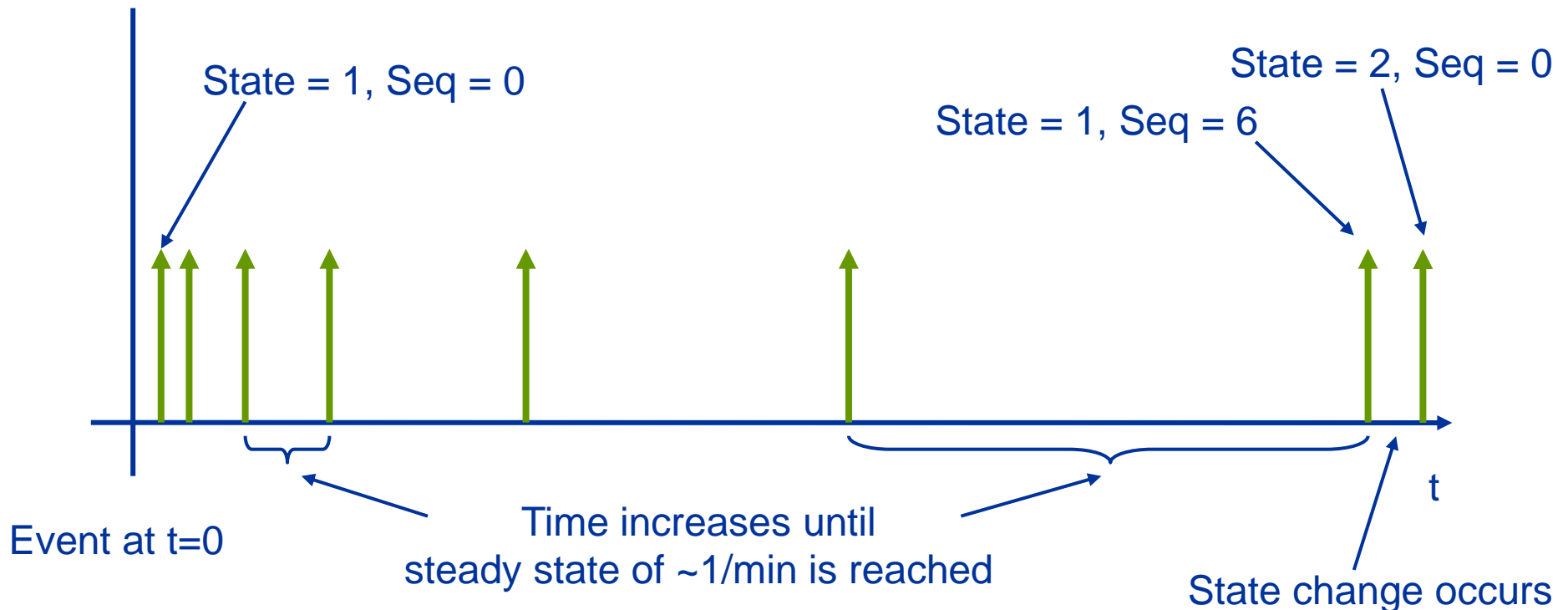
Sampled Value Messaging

- Unlike GOOSE Messaging, which is event based, SV messaging is stream based

  - Each message contains one or more samples of data taken at a specified sample rate

  - Messages are sent constantly at a sufficient rate to communicate all the samples.

Sampled Value Message

Name	Type
MsvCBRef	Multicast Sampled Value Control Block
DatSet	The name of the data set being sent
MsvID	System wide unique ID of the sending application
SmpCnt	The number of samples in the message
RefrTm	Time of the first sample
ConfRev	Configuration Revision of the MSV Control Block (dataset config)
SmpSynch	Samples are time are time synchronized (true/false)
SmpRate	Sample Rate
SmpMod	Sample Mode: samples/period, samples/second, seconds/sample
Simulation	Simulated data (true/false)
Sample [1..n]	The sequence of samples (one data set per sample)

Binary encoding of above data

Ethernet Multicast Address Using 802.3 Ethertype or 90-5 for IP Multicast

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Substation Configuration Language

SCL
IEC 61850-6

SCL – Substation Configuration Language
IEC61850-6

- Description language for communication in electrical substations related to the IEDs.

- XML based language that allows a formal description of

  - Substation automation system and the switchyard and the relation between them
  - IED configuration
  - Support for private extensions

Basic Substation Config. Language (SCL) File Types

- **SSD**: System Specification Description.
  - XML description of the entire system

- **SCD**: Substation Configuration Description.
  - XML description of a single substation.

- **CID**: Configured IED Description.
  - XML configuration for a specific IED.

- **ICD**: IED Capability Description.
  - Description of what is supported by an IED (required for servers).

How SCL Files Work Together

ICD versus CID Files

ICD File = What an IED is capable of

CID = Configuration for a specific IED

Substation specific configuration information
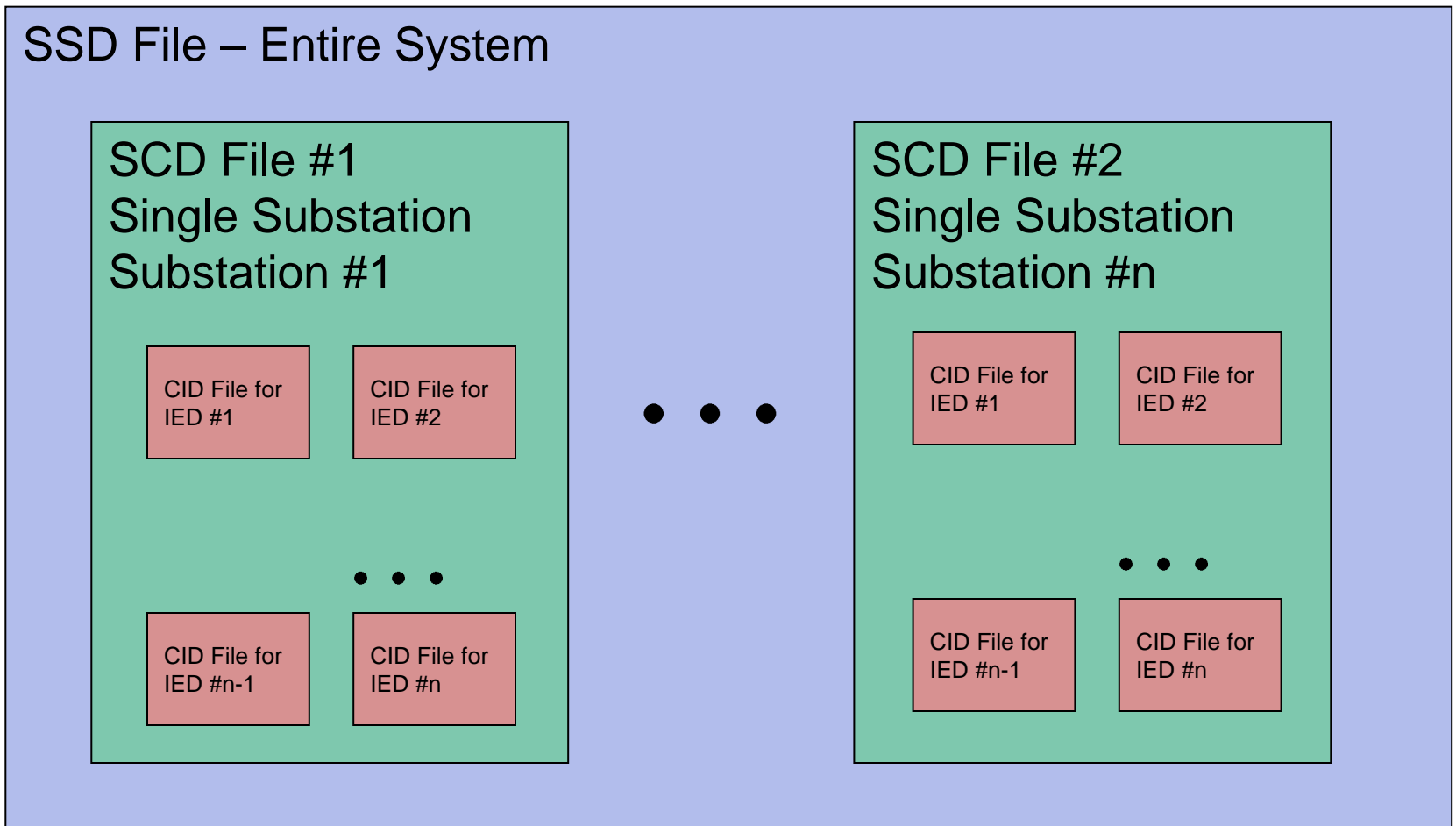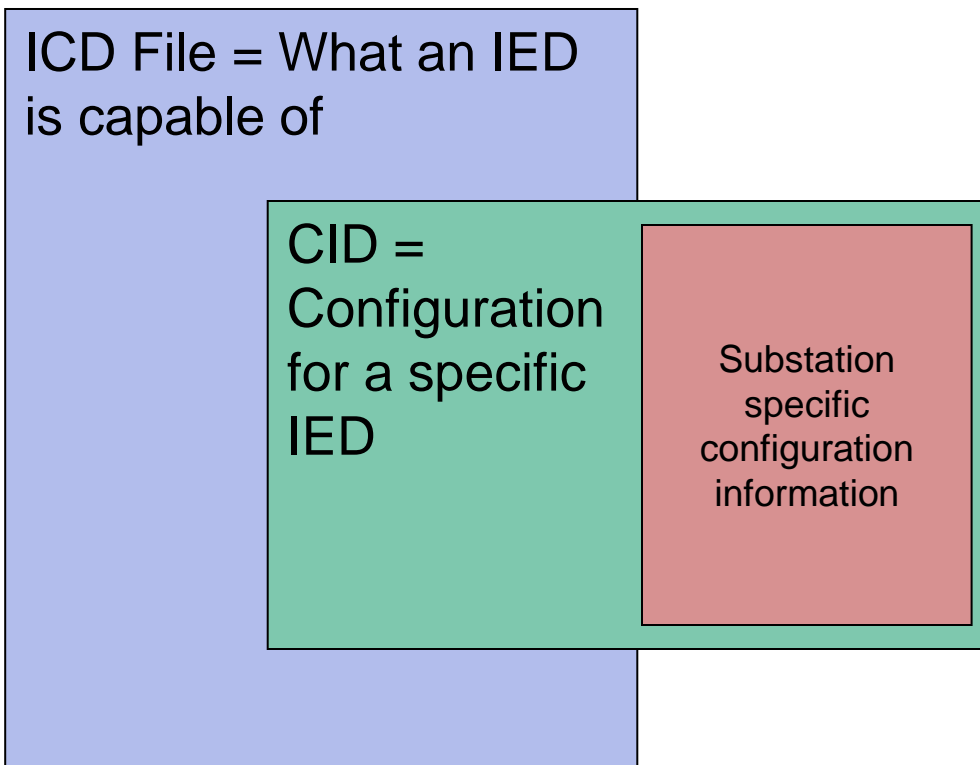
- CID File = Subset of ICD File Actually Used + Substation Specific Configuration Info.

- Subset:
  - Not all logical nodes, control blocks, I/O, etc. supported by the device are used in a system.

- Substation Configuration Info:
  - Report control block presets
  - Static values for location, and other descriptions.

ICD – IED Capability Description
CID – Configured IED Description

SCL Driven Naming
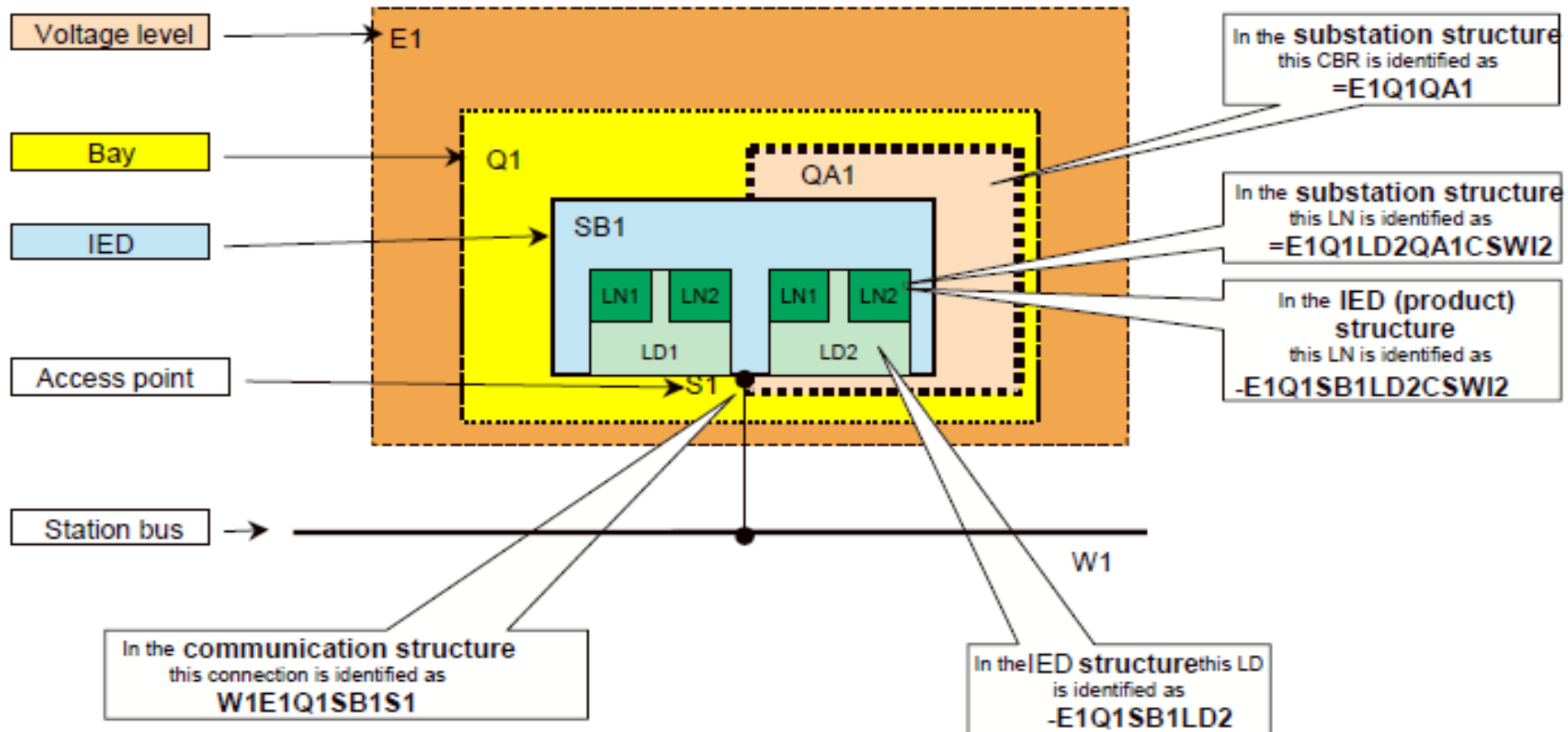
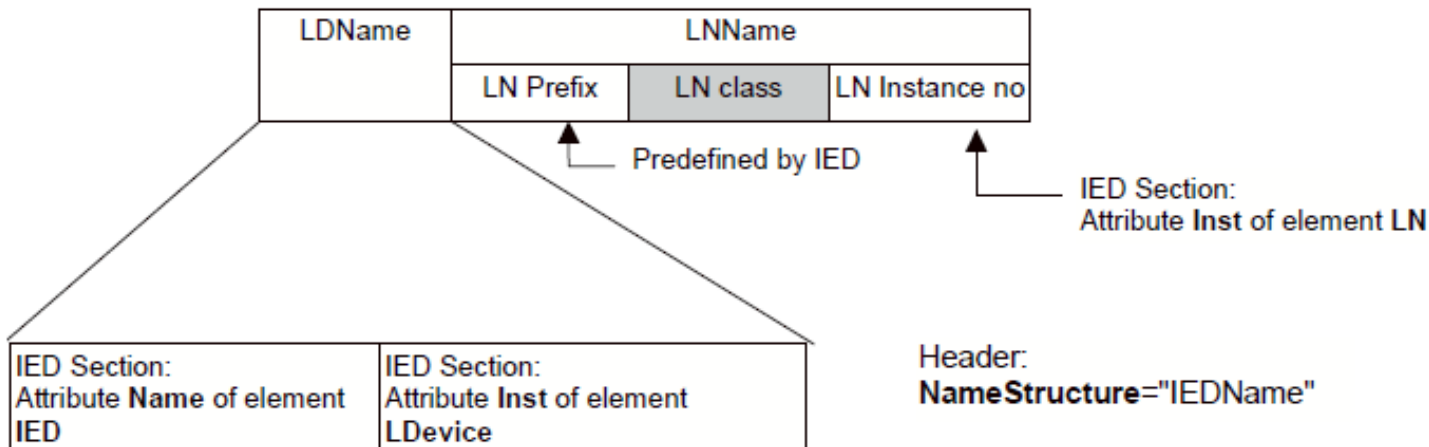# Logical Device and LN Naming = IEDName

Example of SCL

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<SCL xmlns="http://www.iec.ch/61850/2003/SCL" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.iec.ch/61850/2003/SCL SCL.xsd">
<Header id="SISCO_DEMO_IED" version="1" revision="2" toolID="WordPad" nameStructure="IEDName"/>
  <Communication>
            <SubNetwork name="StationBus1" type="8-MMS">
                        <Text/>
                        <BitRate unit="b/s">100</BitRate>
                        <ConnectedAP iedName="SISCO_IED_" apName="AXS4MMS_IED">
                                    <Address>
                                                <P type="IP">192.168.0.194</P>
                                                <P type="IP-SUBNET">255.255.255.0</P>
                                                <P type="OSI-TSEL">0001</P>
                                                <P type="OSI-SSEL">0001</P>
                                                <P type="OSI-PSEL">00000010</P>
                                    </Address>
                                    <GSE ldInst="CTRL" cbName="ControlDataSet1">
                                                <Address>
                                                            <P type="MAC-Address">01-0C-CD-01-F1-04</P>
                                                            <P type="APPID">0000</P>
                                                            <P type="VLAN-ID">1</P>
                                                            <P type="VLAN-PRIORITY">4</P>
                                                </Address>
                                    </GSE>
```

SCL Applications

- For users to specify IED requirements.

- For vendors to specify IED capabilities.

- Configure IEC61850 clients w/o IEDs.

- Extract IED configuration from power system design tools.

- Export IED configuration to power system design tools and other applications.

Questions - Discussion

Systems Integration Specialists Company, Inc.

Thank You

Ralph Mackiewicz
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Fax: +1-586-254-0053
Email: ralph@sisconet.com

Applications and Industry Activities

Christoph Brunner
Switzerland

it4*power*

The Contents of IEC 61850, Edition 1

System Aspects

Part 1: Introduction and Overview

Part 2: Glossary

Part 3: General Requirements

Part 4: System and Project Management

Part 5: Comm Requirements for Functions and Device Models

Configuration

Part 6: Configuration Language for electrical Substation IED's

Testing

Part 10: Conform. Testing

Data Models

Basic Communication Structure for Substations and Feeder Equipment

Part 7-4: Compatible Logical Node Classes and Data Classes

Part 7-3: Common Data Classes

Abstract Comm. Services

Basic Communication Structure for Substations and Feeder Equipment

Part 7-2: Abstract Communication Services (ACSI)

Part 7-1: Principles and Models

Mapping to real Comm. Networks (SCSM)

Part 8-1: Mapping to MMS and ISO/IEC 8802-3

Part 9-1: Sampled Values over Serial Unidirectional Multidrop Point-to-Point link

Part 9-2: Sampled Values over ISO/IEC 8802-3

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Who should know what from IEC61850?

	Part 1	Part 5	Part 7-1	Part 7-2	Part 7-3	Part 7-4	Part 6	Part 8-1, 9-x
	Introduction	Requirements	Principles	ACSI	CDC	LN	SCL	mapping to MMS
UTILITY								
Manager	important		partly important					
Engineer	important	important	important	partly important	important	important	partly important	
VENDOR								
Application E.	important	important	important	partly important	important	important	important	partly important
Communication E.	important	important	important	important			partly important	important
Product Manager	important	important	partly important	partly important	partly important	important	partly important	
Marketing	important	important	partly important	partly important	partly important	partly important	partly important	
CONSULTANT								
Application E.	important	important	important		important	important	partly important	
Communication E.	important		important	important			partly important	important
others	important	important	important					

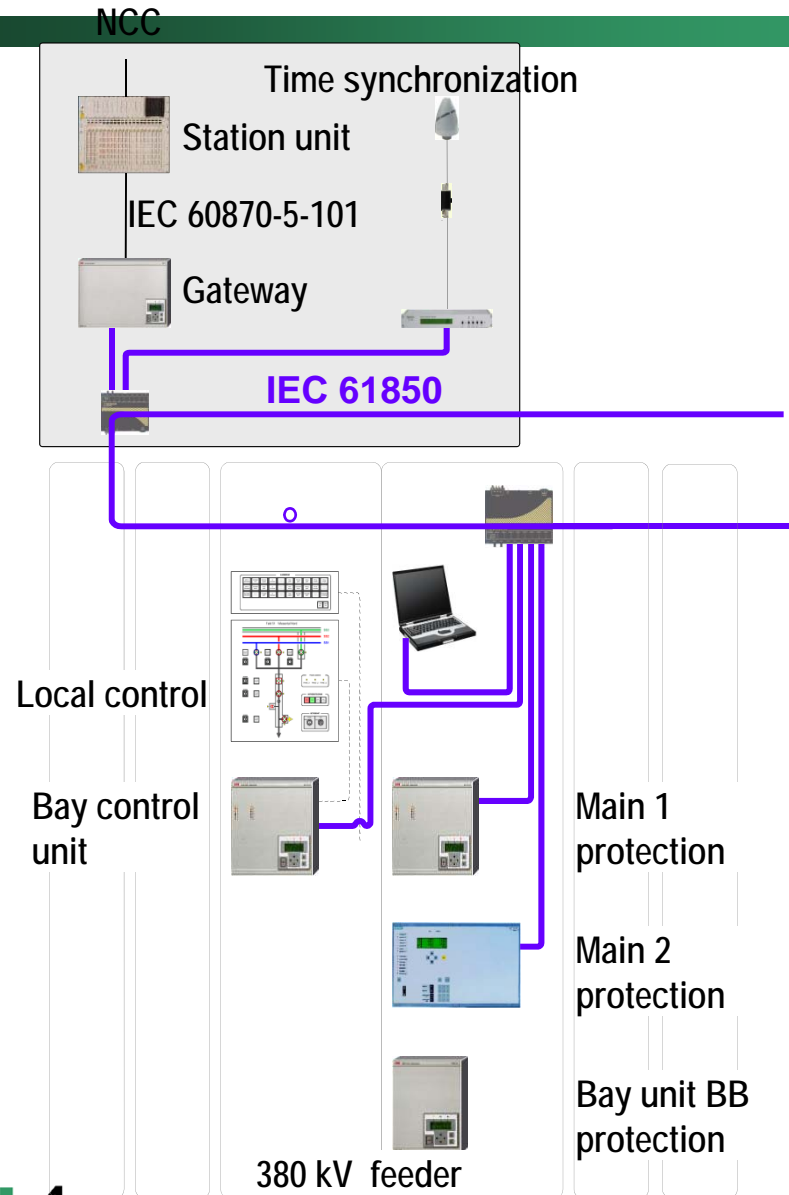|	
important	(red)
partly important	(yellow)
minor importance	(white)

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Content

- Project Examples
- Application Examples
- Industry Activities

Winznauschachen (Switzerland)

- **In operation since 11/2004**
- **16 kV Distribution**
- **9 Bays**
- **Comprising Substation Controller, Relays, Engineering according to part 6**

Laufenburg (Switzerland)

NCC

Time synchronization

Station unit

IEC 60870-5-101

Gateway

IEC 61850

Local control

Bay control unit
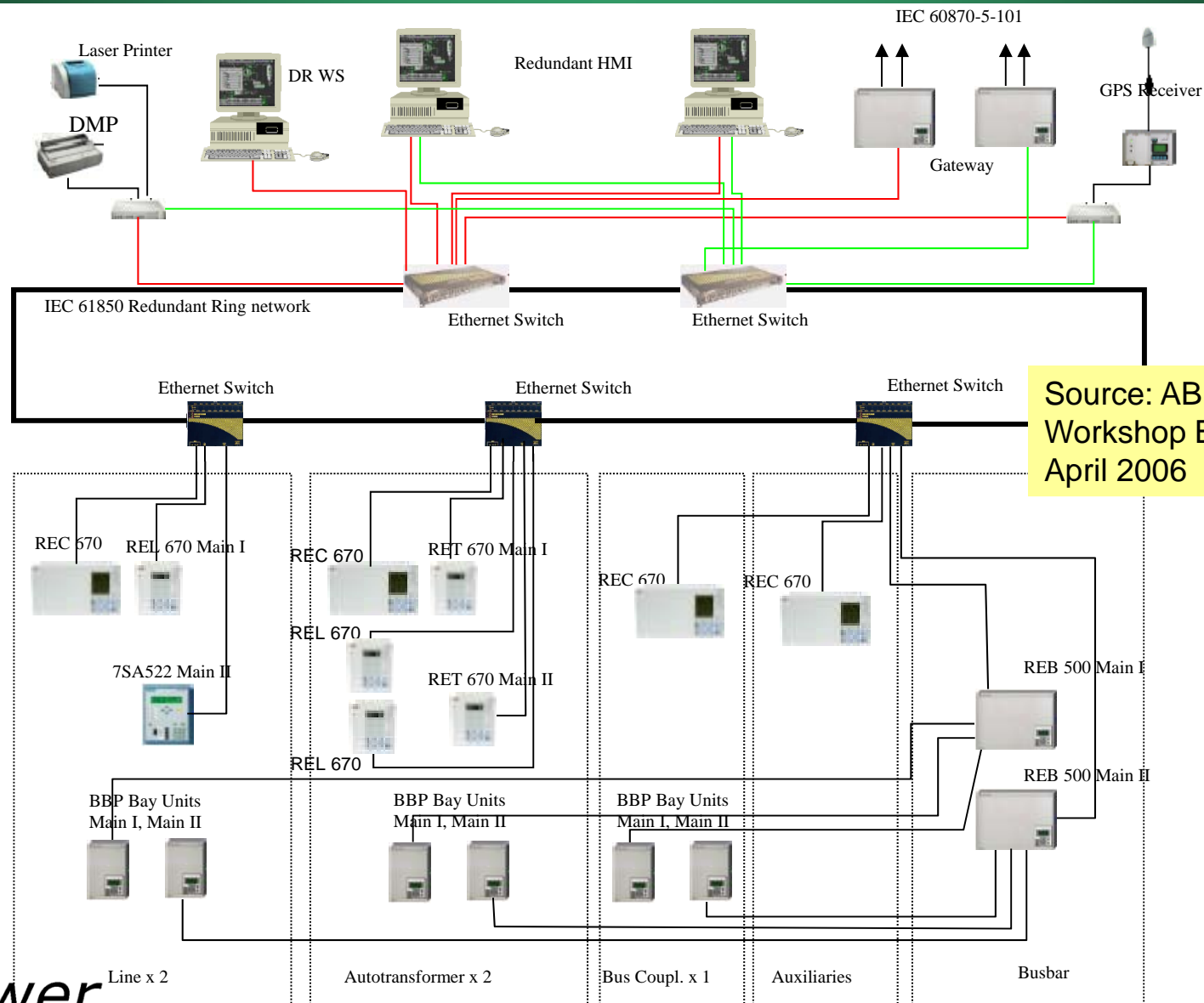
Main 1 protection

Main 2 protection

Bay unit BB protection

380 kV feeder

- First bay in operation since 12/2004
- 380 kV transmission substation
- Main 2 protection from different supplier
- Retrofit
  - Stepwise retrofit of 7 bays
  - Integration of the existing station control system

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PGCIL Maharanibagh 400 kV S/S

IEC 60870-5-101

Laser Printer

DR WS

Redundant HMI

GPS Receiver

DMP

Gateway

IEC 61850 Redundant Ring network

Ethernet Switch

Ethernet Switch

Ethernet Switch

Ethernet Switch

Ethernet Switch

Source: ABB at CPRI
Workshop Bangalore,
April 2006

REC 670   REL 670 Main I

REC 670   RET 670 Main I

REC 670   REC 670

REL 670

7SA522 Main II

RET 670 Main II

REB 500 Main I

REL 670

REB 500 Main II

BBP Bay Units
Main I, Main II

BBP Bay Units
Main I, Main II

BBP Bay Units
Main I, Main II

Line x 2

Autotransformer x 2

Bus Coupl. x 1

Auxiliaries

Busbar

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CB 2012-09-21

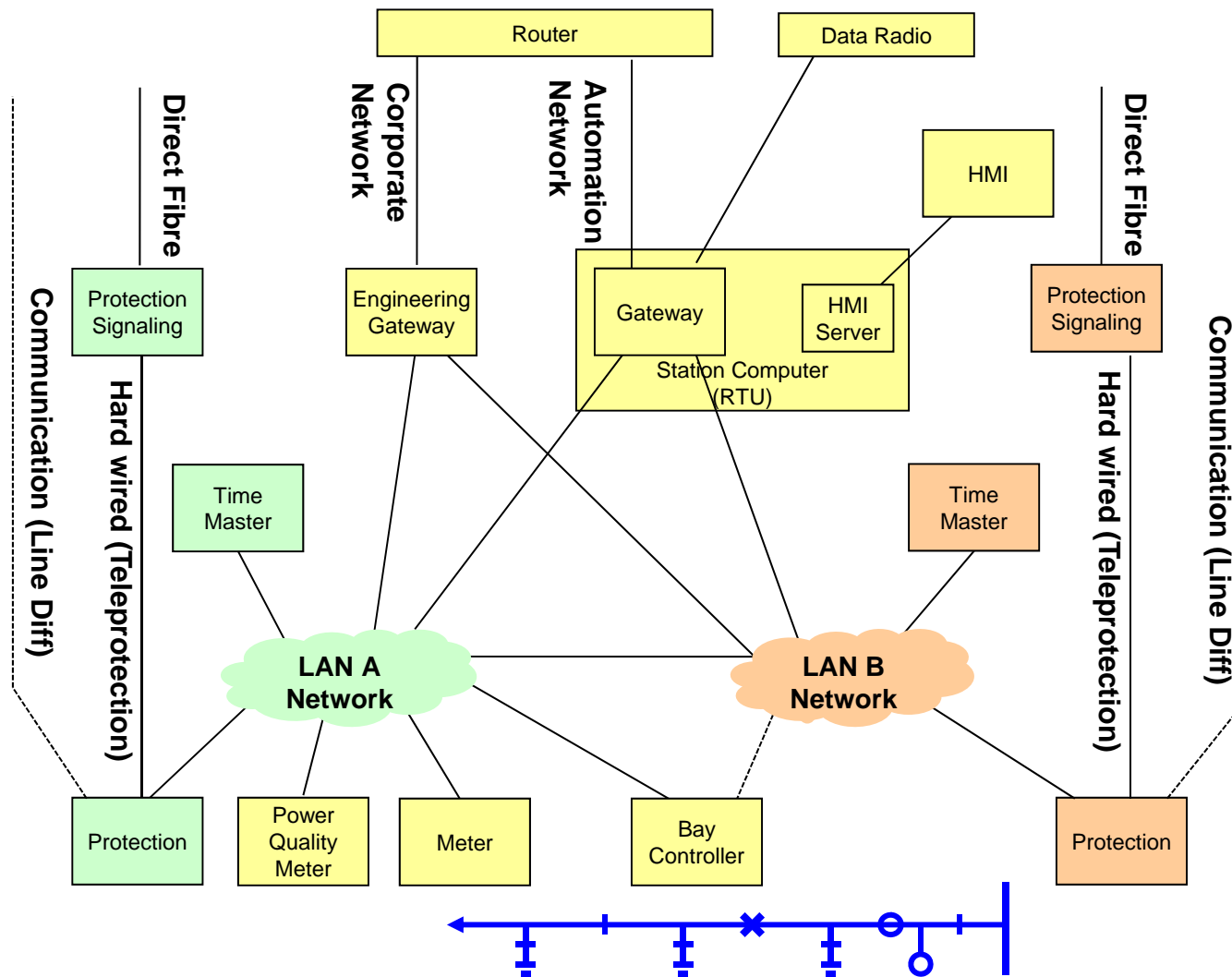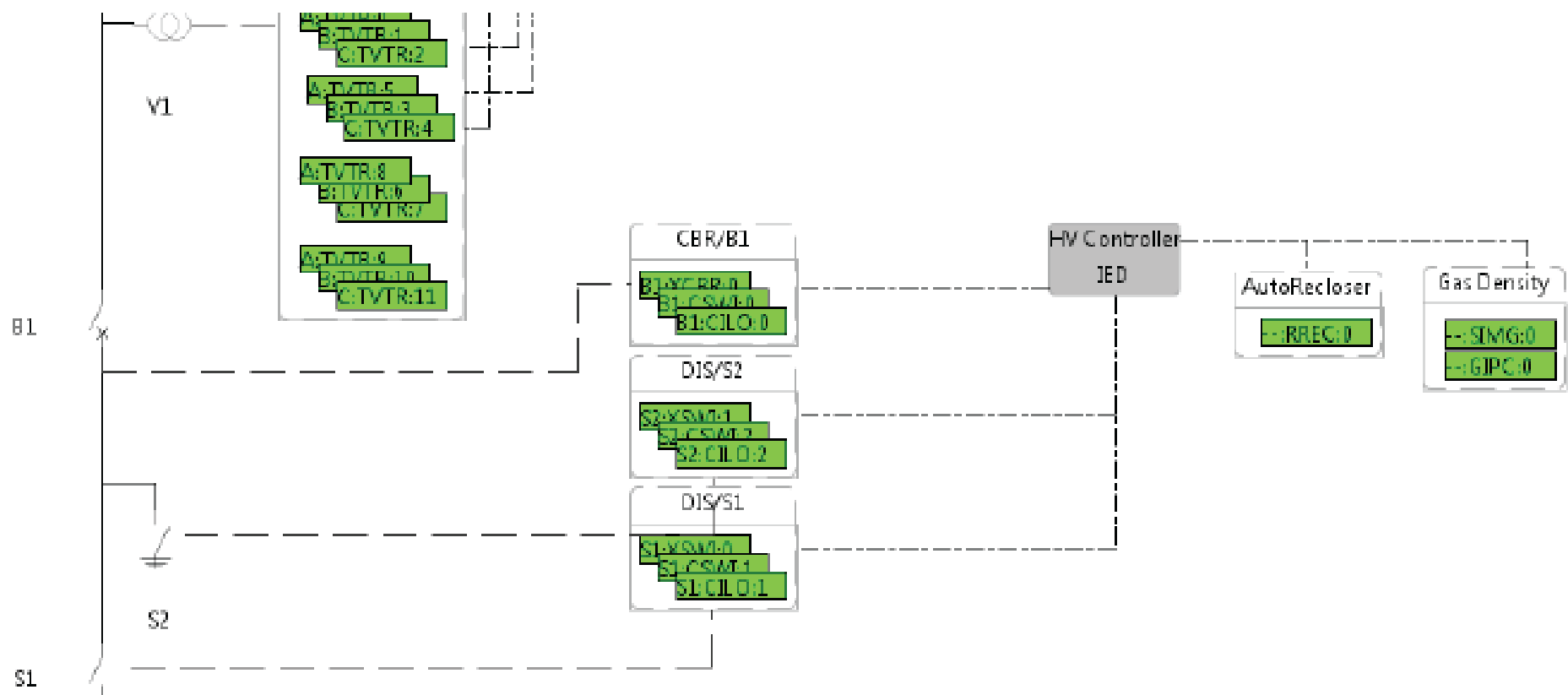# Case study: Integral Energy (Australia)

- Issued Functional Specification for IEC 61850 based SAS
- Fully duplicated main 1 / main 2 protection scheme
- No physical wires between IEDs in different bays

Integral Energy - Architecture
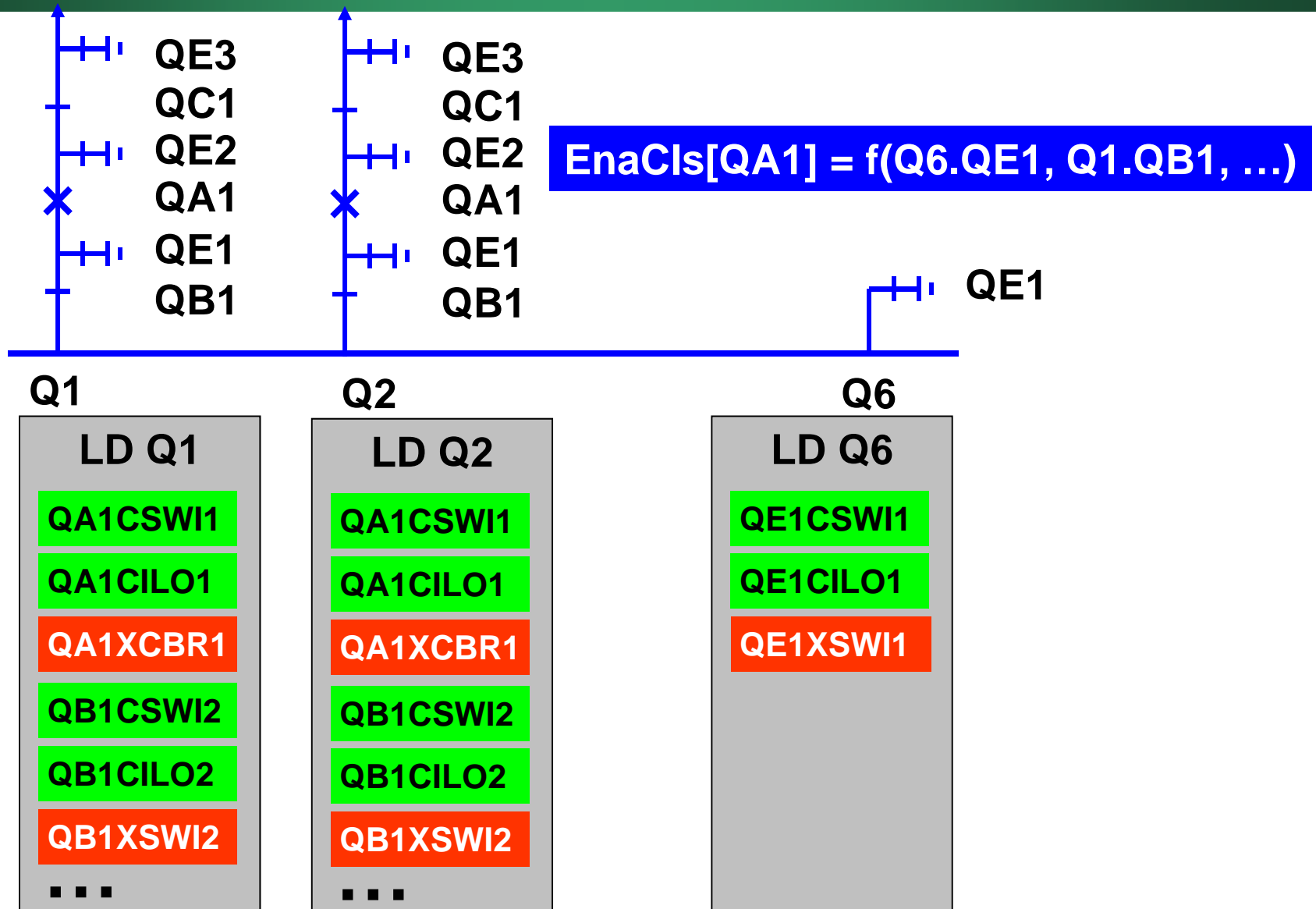
Integral Energy – Extract specification
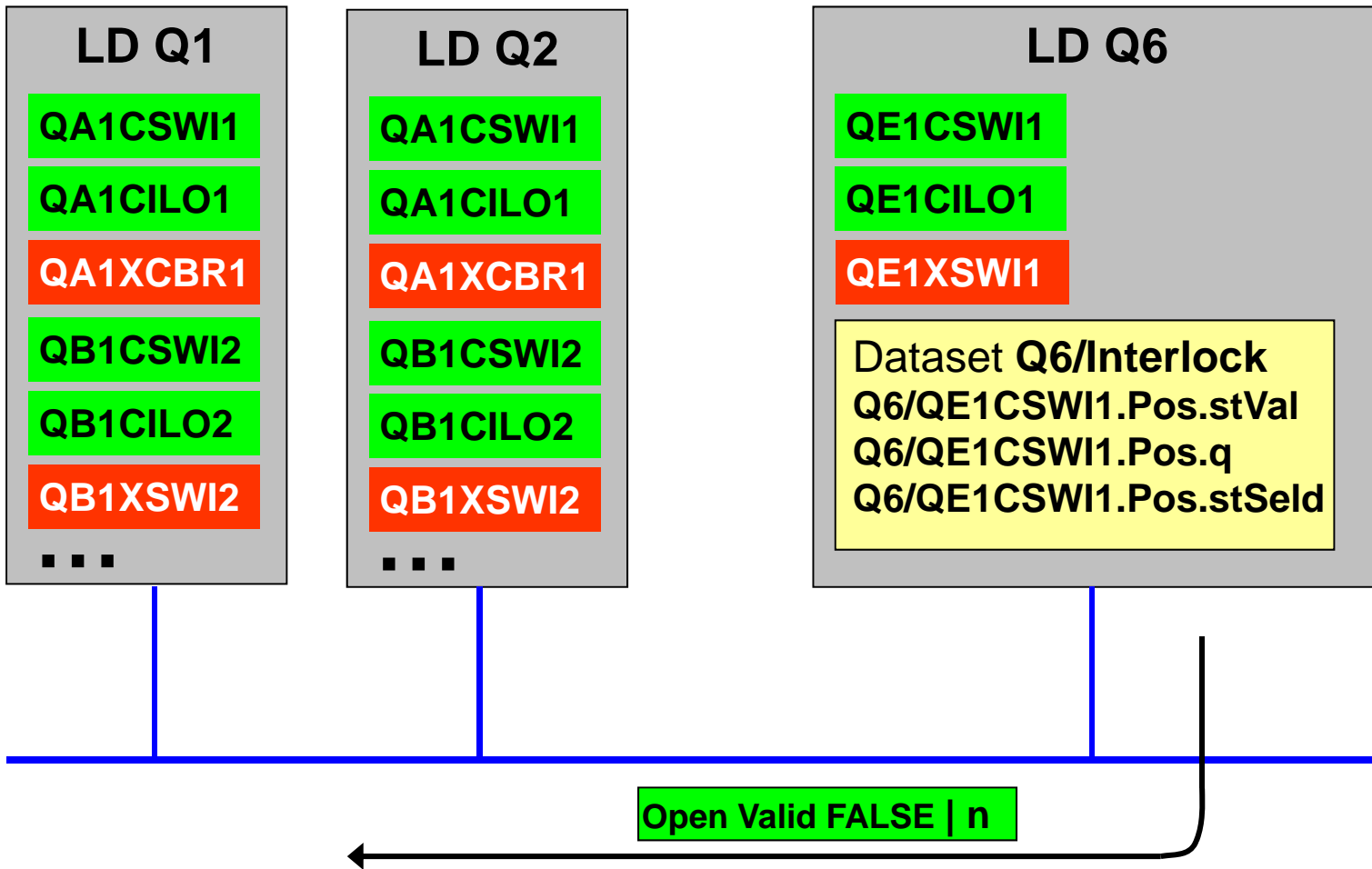
Content

- Project Examples
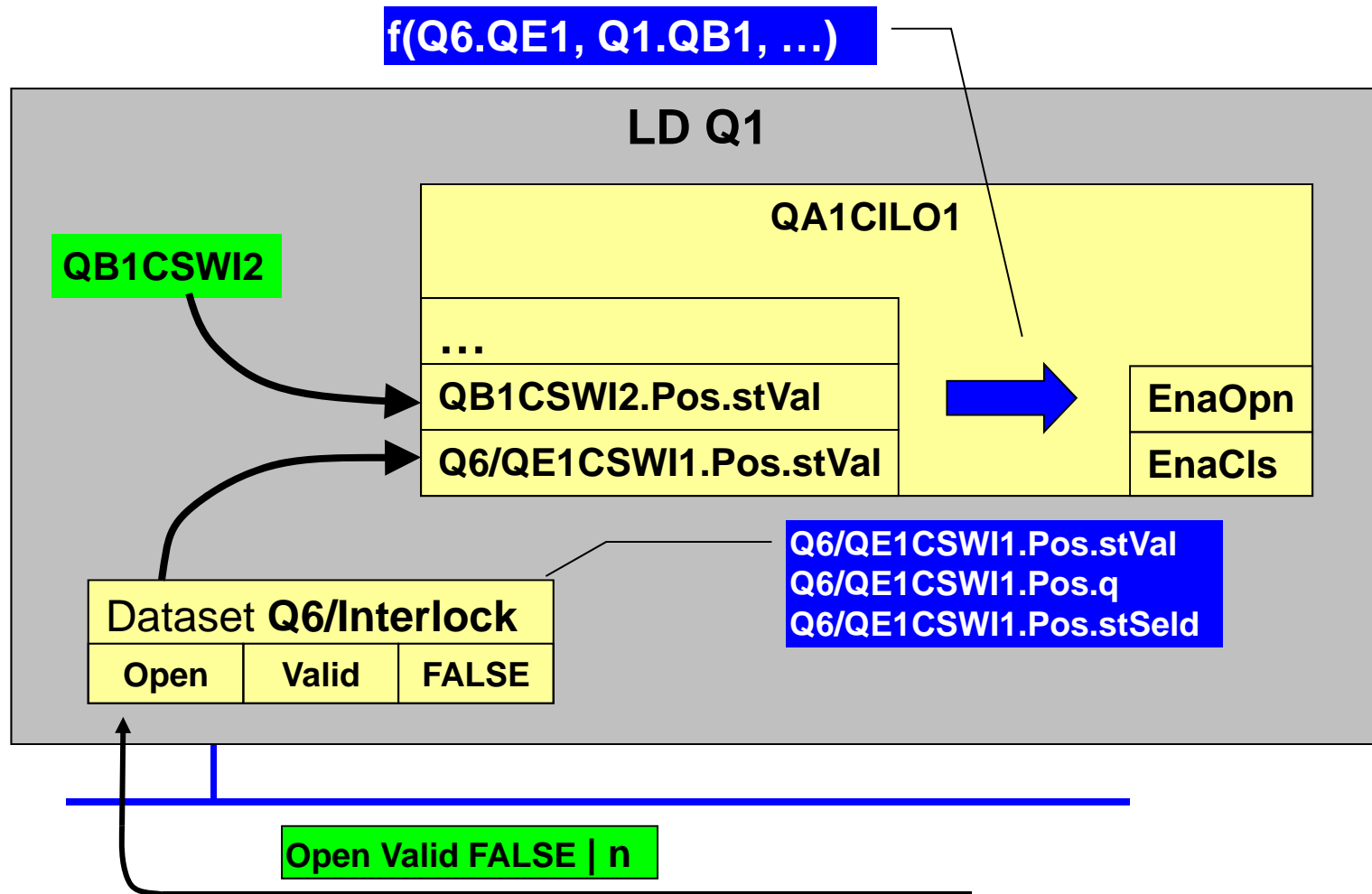- **Application Examples**
- Industry Activities

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Interlocking (1)

EnaCIs[QA1] = f(Q6.QE1, Q1.QB1, …)

QE3
QC1
QE2
QA1
QE1
QB1

QE3
QC1
QE2
QA1
QE1
QB1

QE1

Q1

Q2

Q6

LD Q1

QA1CSWI1
QA1CILO1
QA1XCBR1
QB1CSWI2
QB1CILO2
QB1XSWI2
...

LD Q2

QA1CSWI1
QA1CILO1
QA1XCBR1
QB1CSWI2
QB1CILO2
QB1XSWI2
...

LD Q6

QE1CSWI1
QE1CILO1
QE1XSWI1

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Interlocking (2)

LD Q1
- QA1CSWI1
- QA1CILO1
- QA1XCBR1
- QB1CSWI2
- QB1CILO2
- QB1XSWI2
- . . .

LD Q2
- QA1CSWI1
- QA1CILO1
- QA1XCBR1
- QB1CSWI2
- QB1CILO2
- QB1XSWI2
- . . .

LD Q6
- QE1CSWI1
- QE1CILO1
- QE1XSWI1

Dataset **Q6/Interlock**
Q6/QE1CSWI1.Pos.stVal
Q6/QE1CSWI1.Pos.q
Q6/QE1CSWI1.Pos.stSeld

Open Valid FALSE | n

EnaCls[QA1] = f(Q6.QE1, Q1.QB1, …)

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Interlocking (3)

f(Q6.QE1, Q1.QB1, …)

LD Q1

QB1CSWI2

QA1CILO1

…

QB1CSWI2.Pos.stVal

Q6/QE1CSWI1.Pos.stVal

EnaOpn

EnaCls

Q6/QE1CSWI1.Pos.stVal
Q6/QE1CSWI1.Pos.q
Q6/QE1CSWI1.Pos.stSeld

Dataset **Q6/Interlock**

Open	Valid	FALSE

Open Valid FALSE | n

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Underfrequency Load Shedding

PTUF1

PTUF2

PTUF2.Op

PTUF1.Op

PTRC

PTRC

Feeder to trip on stage 2

Feeder to trip on stage 1
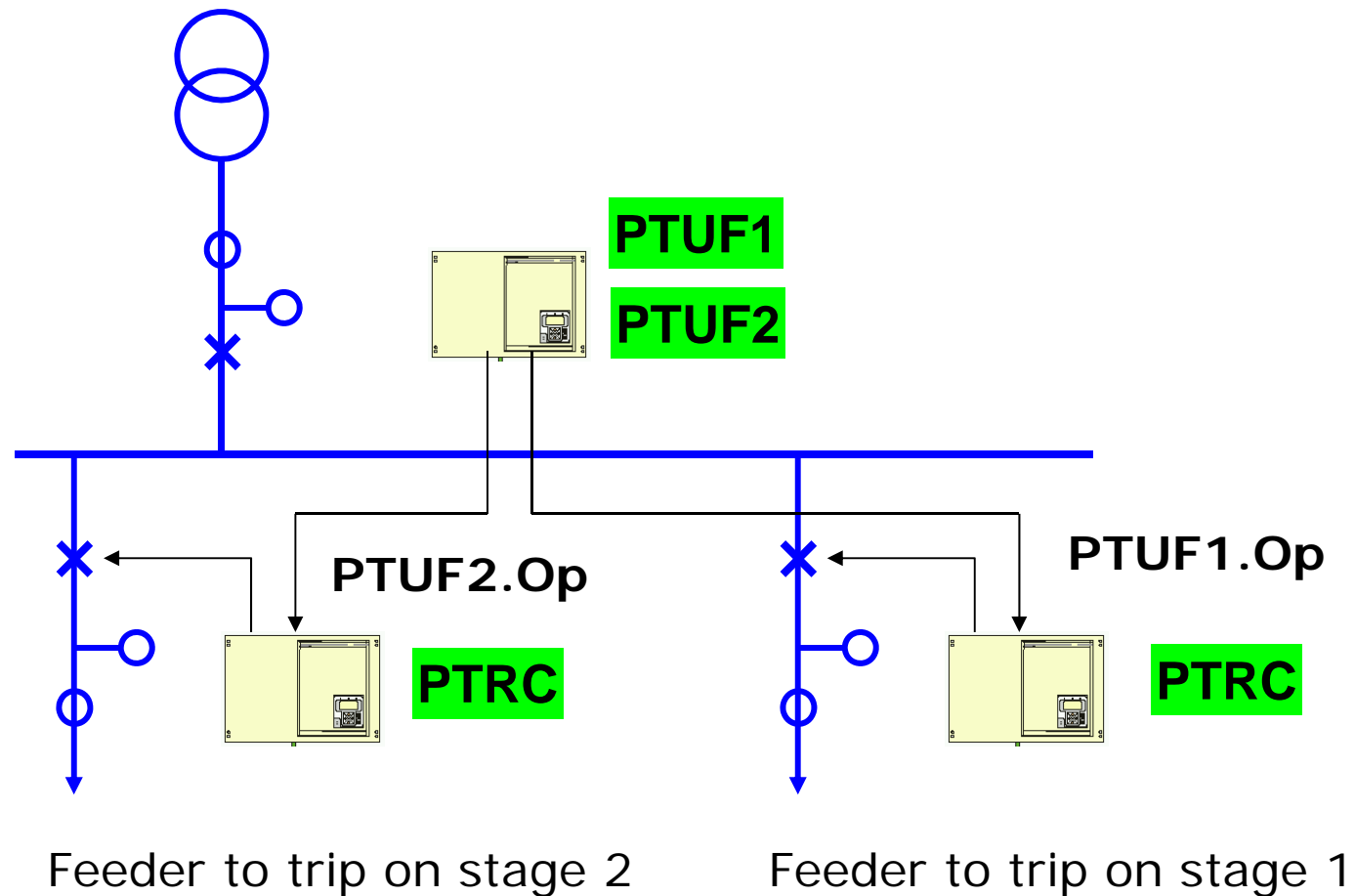
Reverse blocking

GOOSE Message
- PDIS.Str
- PTRC.Op

Trigger Breaker Failure

Control HV
Transformer Protection Main 2

Trigger Breaker Failure

PDIF

PDIS

PTRC

Control LV
Transformer Protection Main 1
Busbar Protection 16 kV BB

Trigger Breaker Failure
Reverse blocking

PDIS

PTRC

Feeder Control
Feeder Protection

Feeder Control
Feeder Protection

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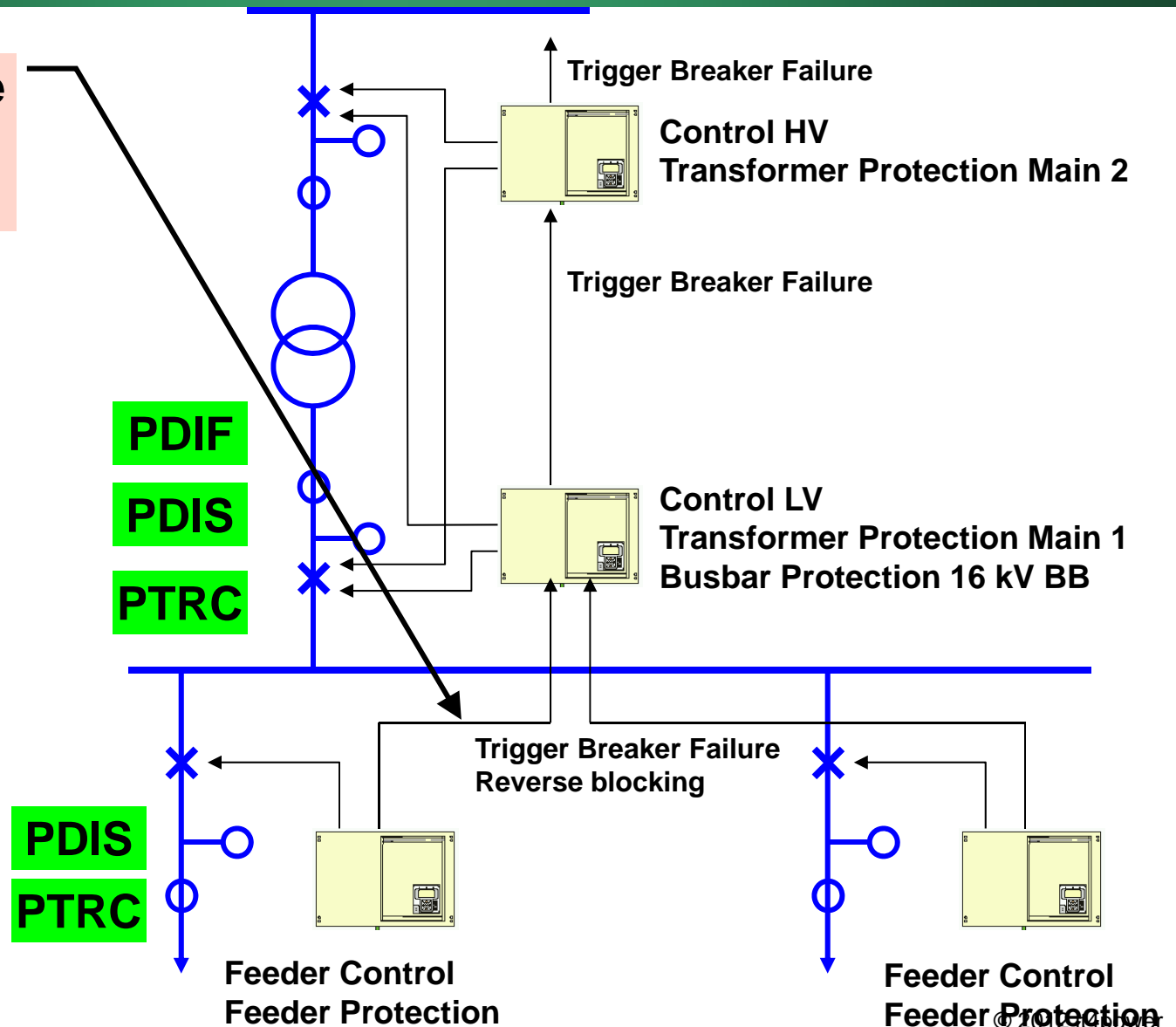
PUTT scheme – Gateway approach

Gateway approach

it4power
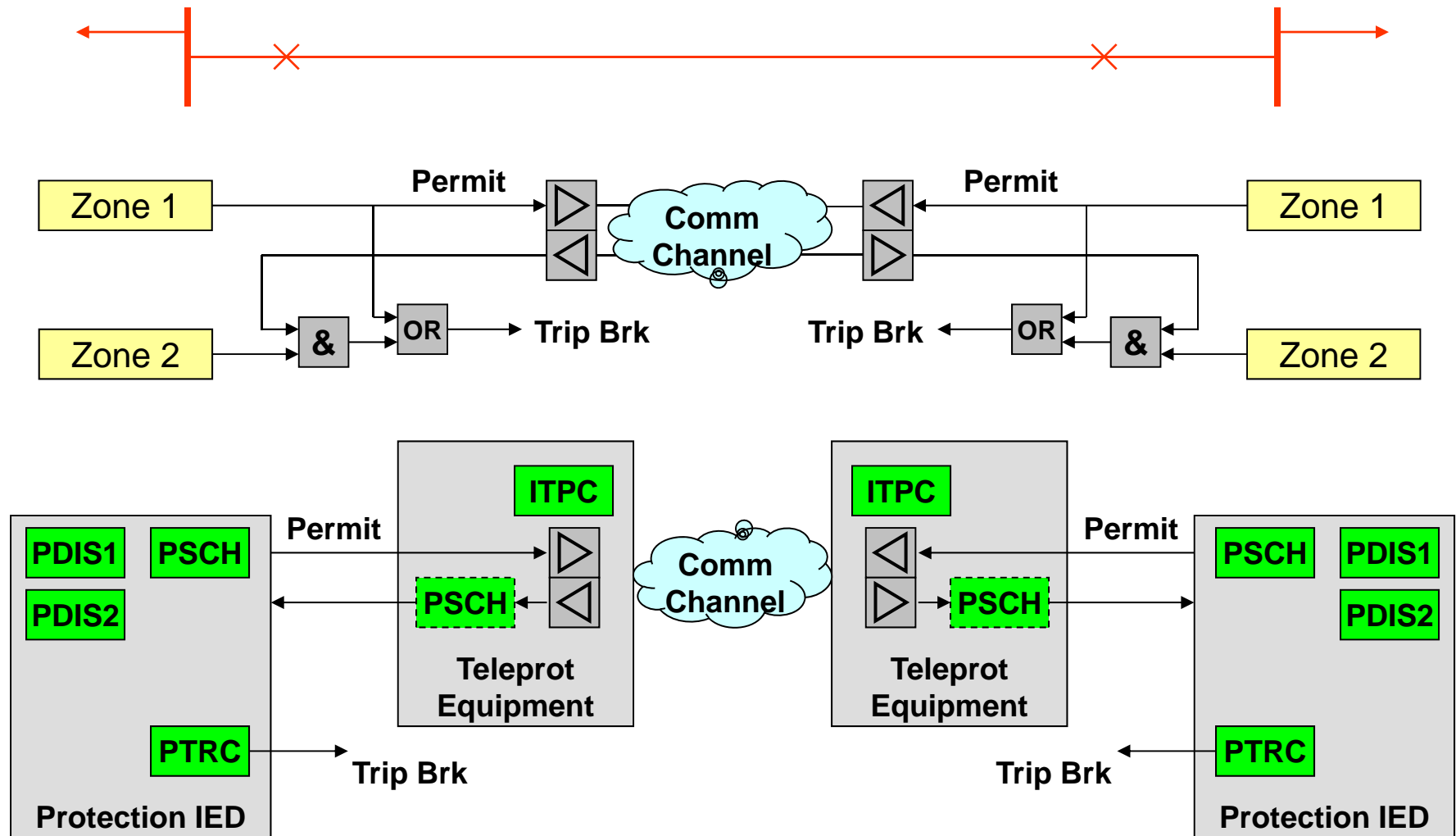
PUTT scheme – Tunneling approach
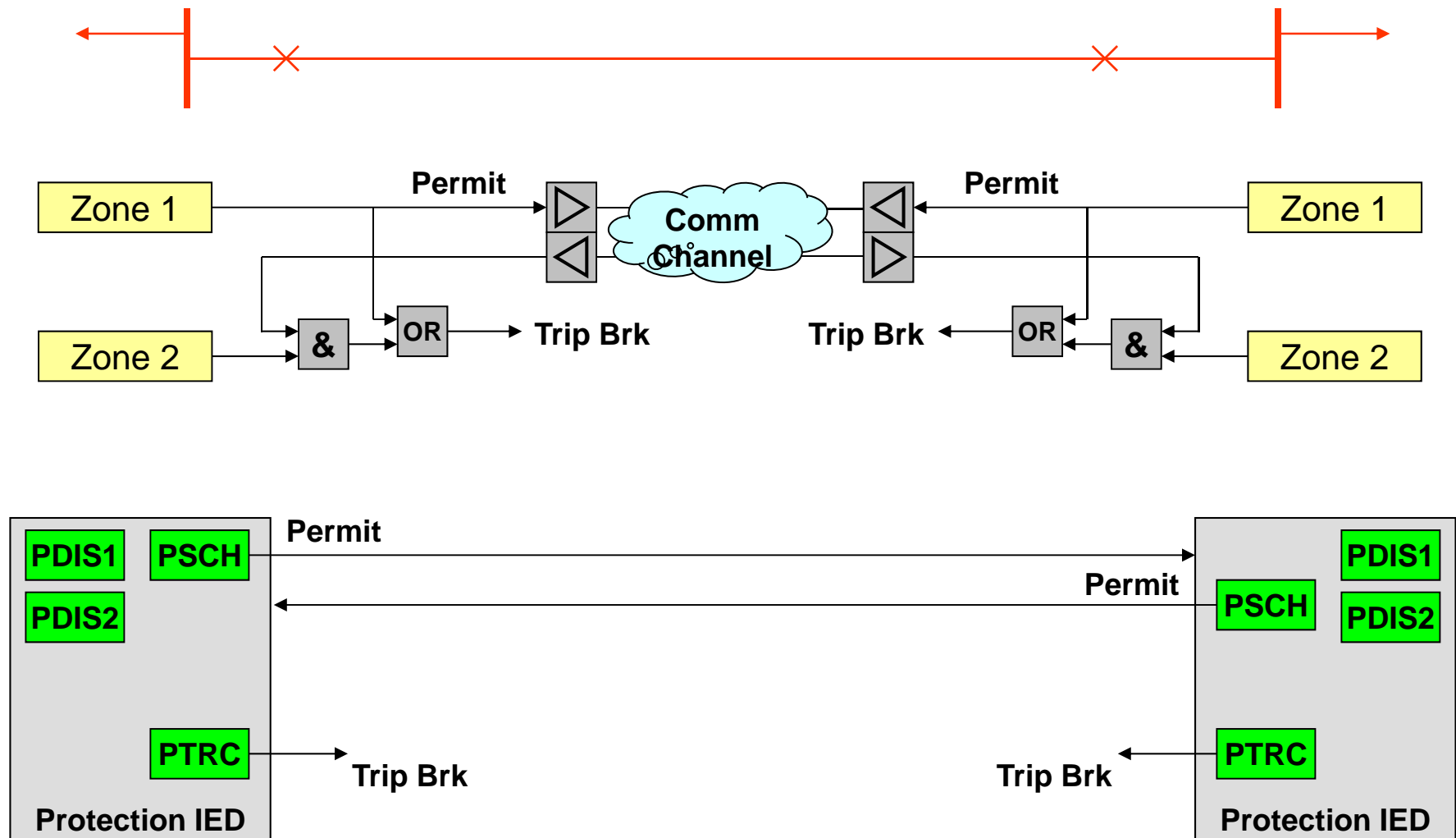
Tunneling approach

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Content

- Project Examples
- Application Examples
- **Industry Activities**

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Published documents beyond Ed 1

- IEC 61850-7-410 – Hydroelectric power plants – Communication for monitoring and control
- IEC 61850-7-420 – Communications Systems for Distributed Energy Resources (DER)
- IEC 61850-80-1 – Guideline to exchange information from a CDC based data model using IEC 60870-5-101 / -104

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New technical reports published

- IEC 61850-90-1: Using IEC 61850 for communication between substations (published)
- IEC 61850-90-5: Using IEC 61850 to transmit synchrophasor information according to IEEE C37.118

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WG10 ongoing work (1)

- IEC 61850-90-2: Using IEC 61850 for communication between substations and control center
- IEC 61850-90-3: Using IEC 61850 for condition monitoring
- IEC 61850-90-4: Network engineering guidelines (LAN in substations)
- IEC 61850-90-11: Methodologies for modeling of logics for IEC 61850 based applications
- IEC 61850-90-12: Network engineering guidelines for WAN
- IEC 61850-90-14: Using IEC 61850 for FACTS data modeling

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WG10 ongoing work (2)

- **IEC 61850-7-5**: Use of logical nodes to model applications – generic principles
- **IEC 61850-7-500**: Use of logical nodes to model applications in substations
  - Explain, how to use the concepts of IEC 61850 to model the applications of a substation automation system
- **IEC 61850-100-1**: Methodologies for testing of functions in IEC 61850 based systems
- System management
- Alarm handling
- Preparation of UML model for IEC 61850

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WG17 ongoing work

- IEC 61850-90-6: Using IEC 61850 for distribution automation
- IEC 61850-90-7: IEC 61850 object models for photovoltaic, storage and other DER inverters
- IEC 61850-90-8: IEC 61850 object models for electrical vehicles
- IEC 61850-90-9: IEC 61850 object models for electrical energy storage systems
- IEC 61850-90-10: Modeling of schedules in IEC 61850
- IEC 61850-90-15: Hierarchical DER system model
- IEC 61850-8-2: Mapping on Web Services

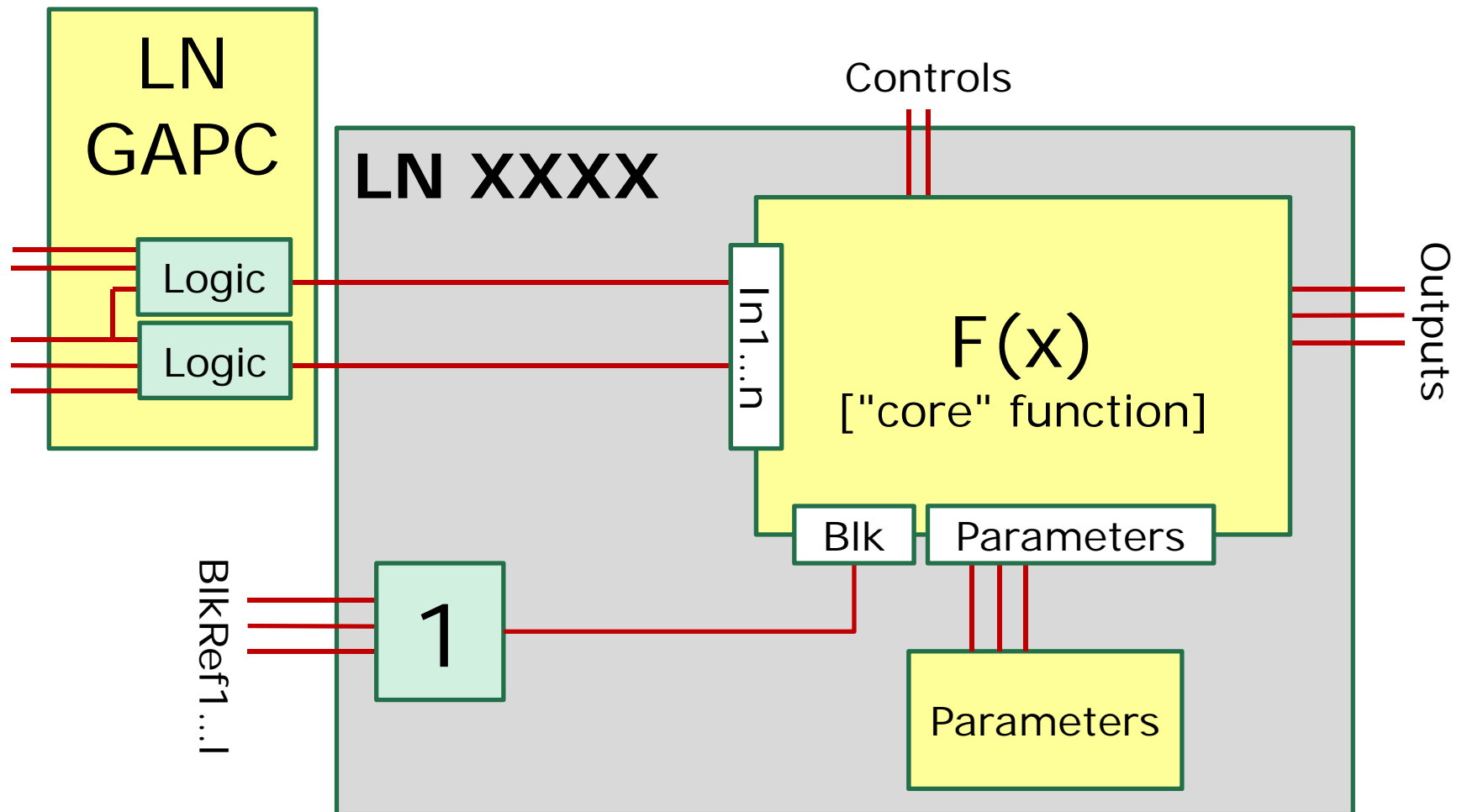**it4power**

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CB 2012-09-21

WG18 ongoing work

- IEC 61850-7-510: Hydro Power plants – Modeling concepts and guidelines
- Communication network structure in hydro power plants
- IEC 61850-90-13: Extensions to include models for steam and gas turbines
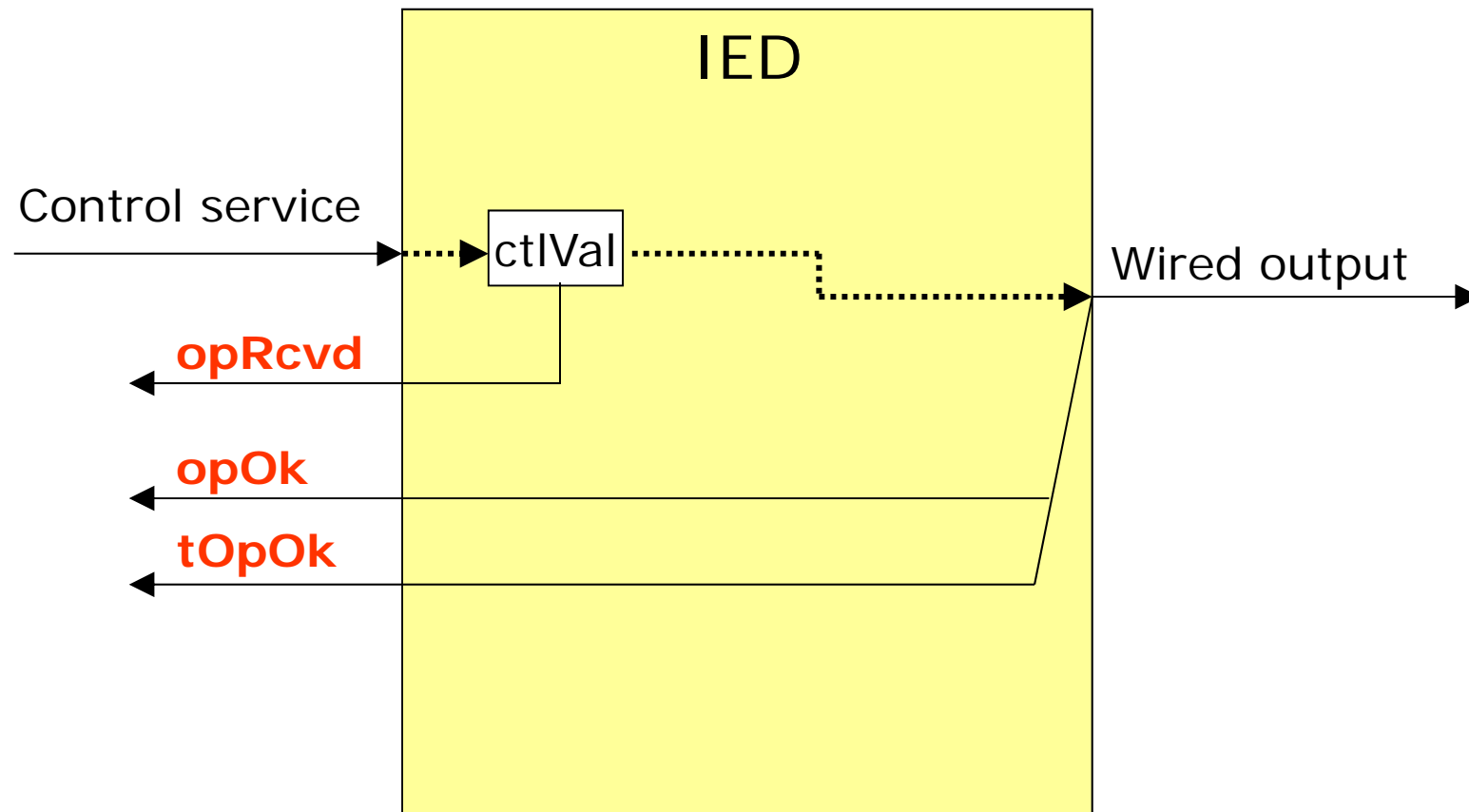- Interoperability test for hydro equipment based on IEC 61850

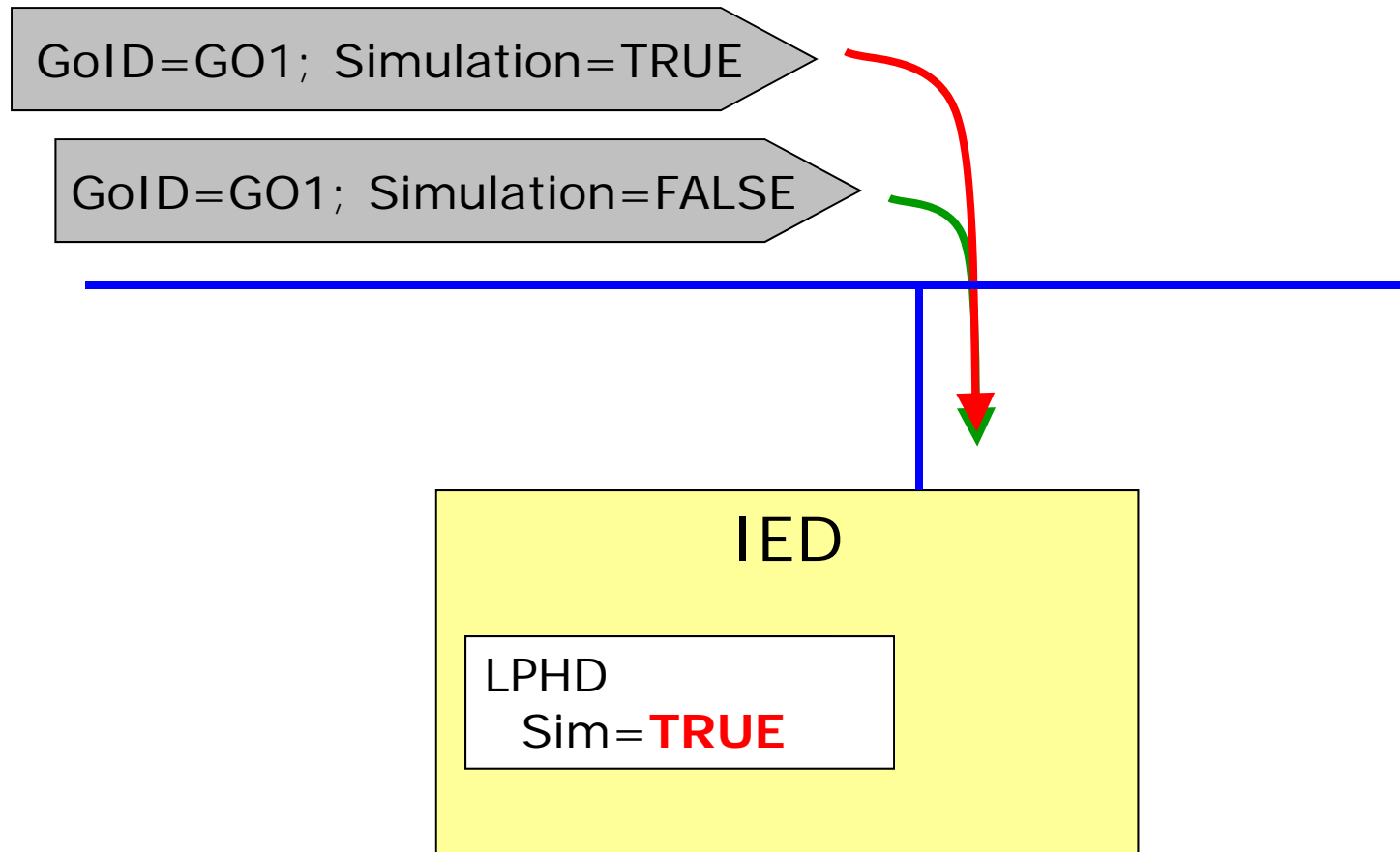**it4power**

Logic modeling - Functional view of a LN
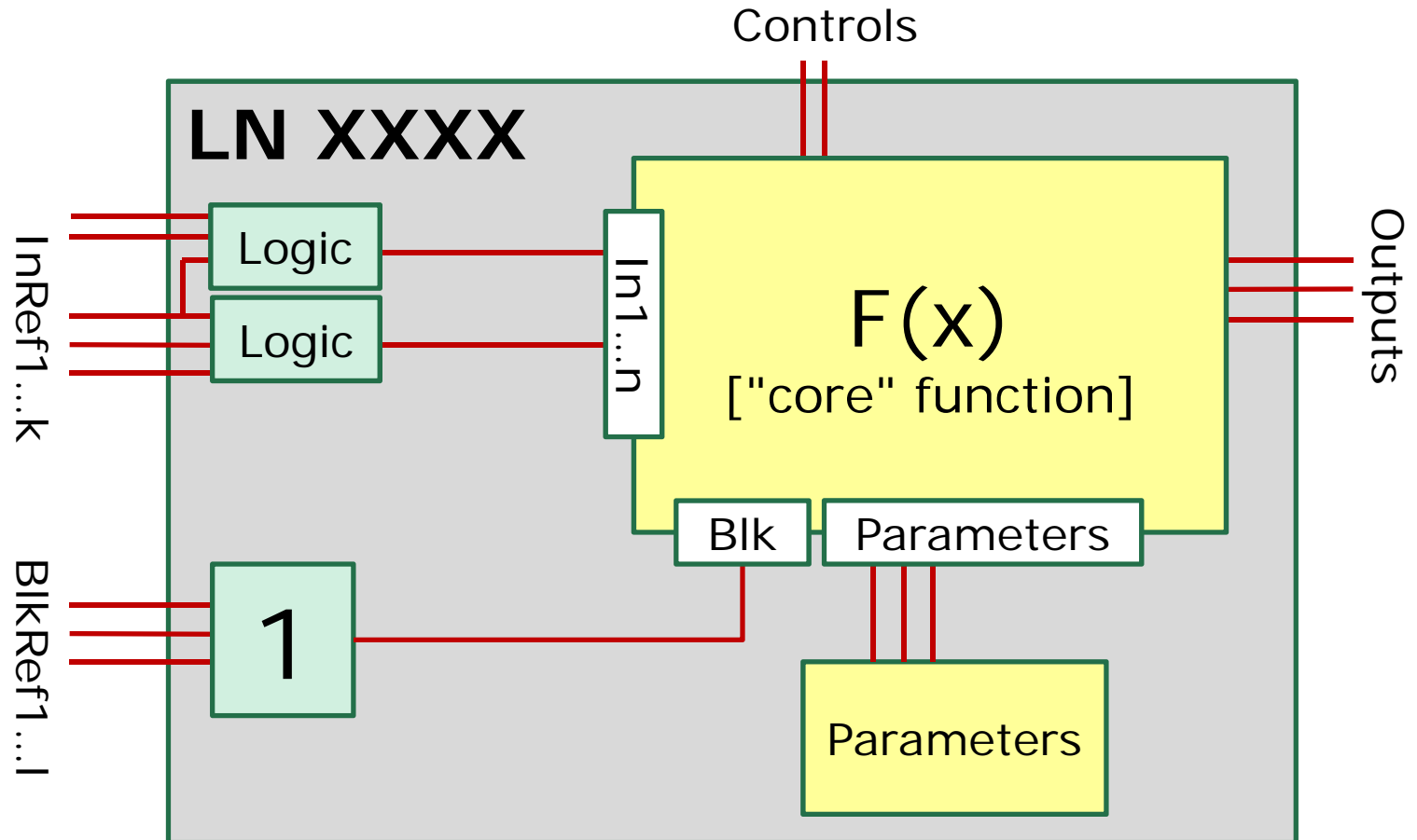
Logic modeling - Functional view of a LN
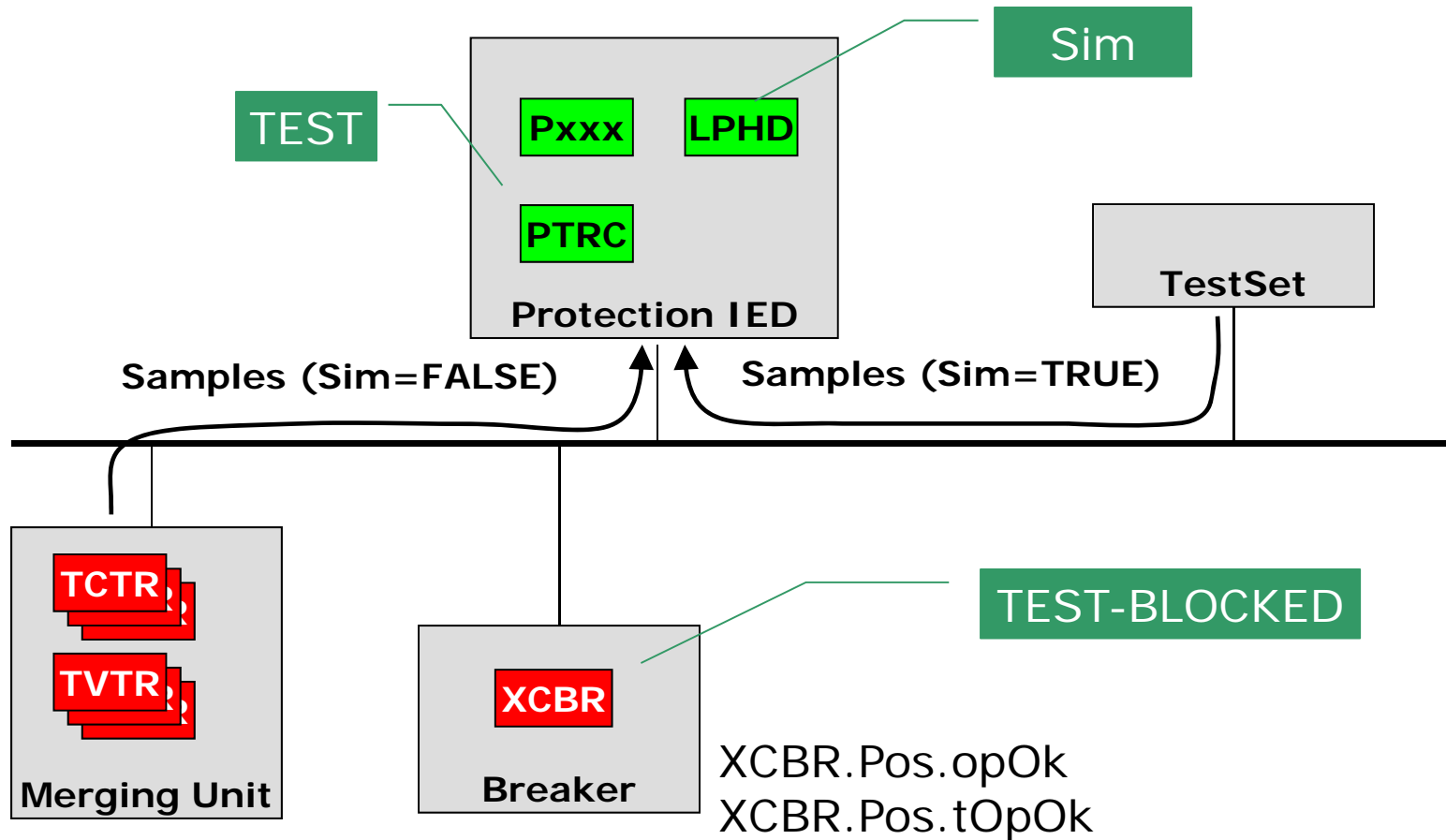
Testing - Mirroring control information
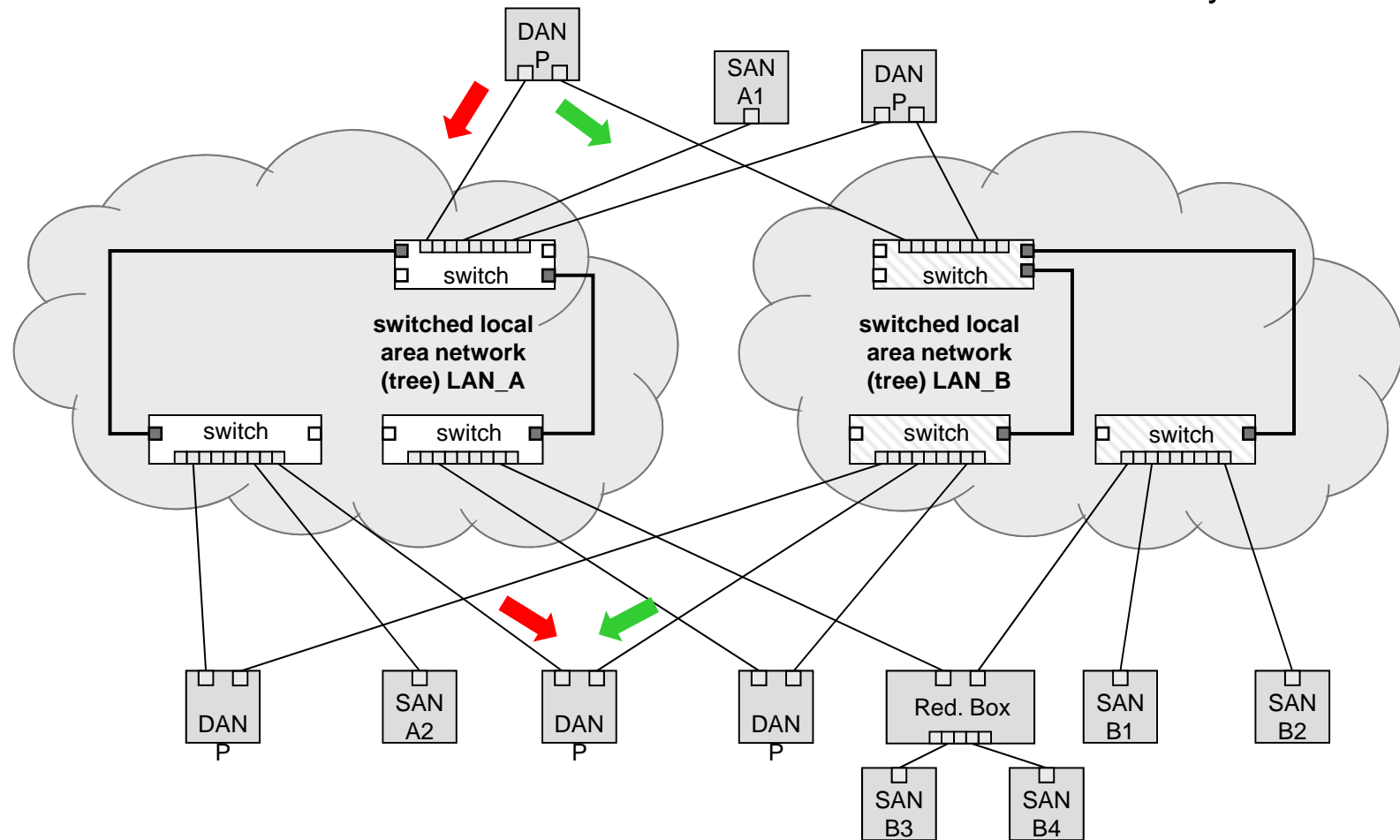
Testing - Simulation of messages

GoID=GO1; Simulation=TRUE

GoID=GO1; Simulation=FALSE

IED

LPHD
Sim=**TRUE**

Isolation and test

Sim

TEST

Pxxx   LPHD

PTRC

Protection IED

TestSet

Samples (Sim=FALSE)   **Samples (Sim=TRUE)**

TCTR

TVTR

Merging Unit

XCBR

Breaker

TEST-BLOCKED

XCBR.Pos.opOk
XCBR.Pos.tOpOk

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Parallel Redundancy Protocol (PRP)

SAN = singly attached nodes
DAN = doubly attached nodes

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High Availability Seamless Ring (HSR)

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Communication network redundancy

Fig 2. Network Topology of PRP/HSR Interoperability Demonstration and Generic IEC 61850 Demonstration at UCAIug CIGRÉ 2012 Booth

Demo CIGRE 2012

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2 it4power
012-09-21
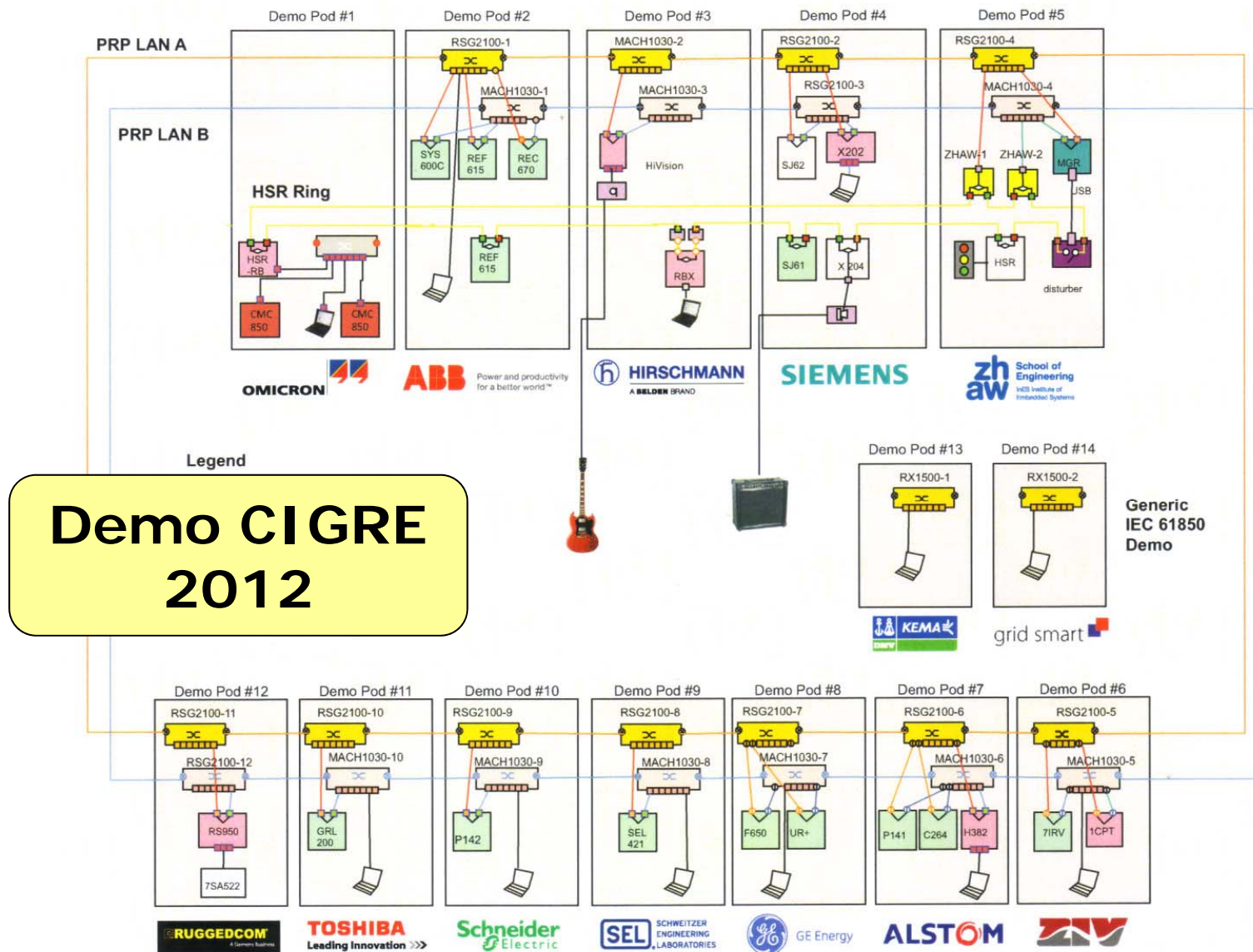
Conclusions

- **IEC 61850 today**
  - Interoperability for communication of information in several domains of the power utility automation
  - Framework to facilitate engineering
- **IEC 61850 tomorrow**
  - Improved engineering interoperability to design distributed automation function like protection and control schemes
  - New features supporting the challenges of a Smart Grid communication backbone

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Brief Overview of IEEE 1588 Test Results – Concept and Practical Examples and Lessons Learned

Mark Adamiak / Farnoosh Rahmatian

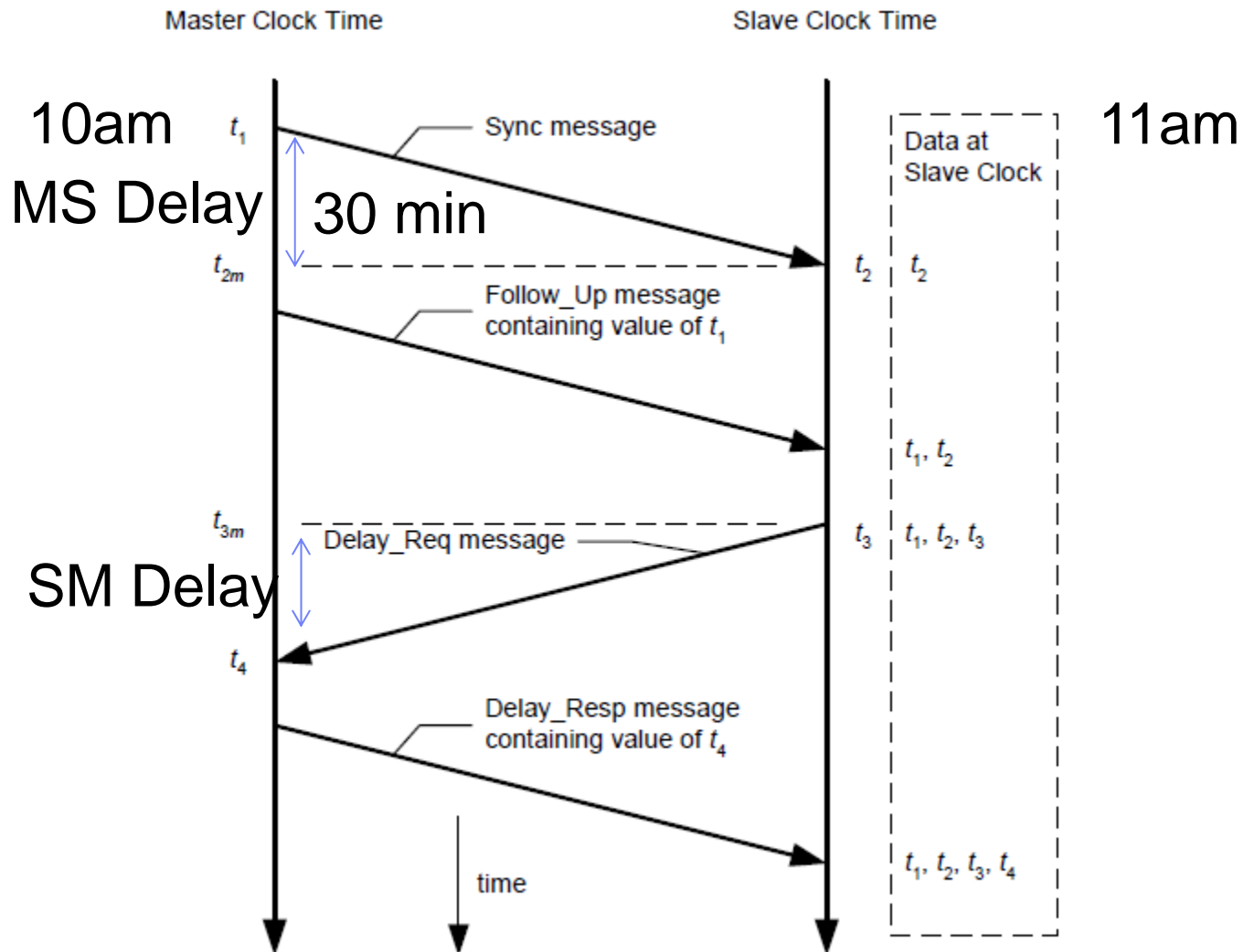NASPI Meeting, October 16, 2012, Atlanta, GA

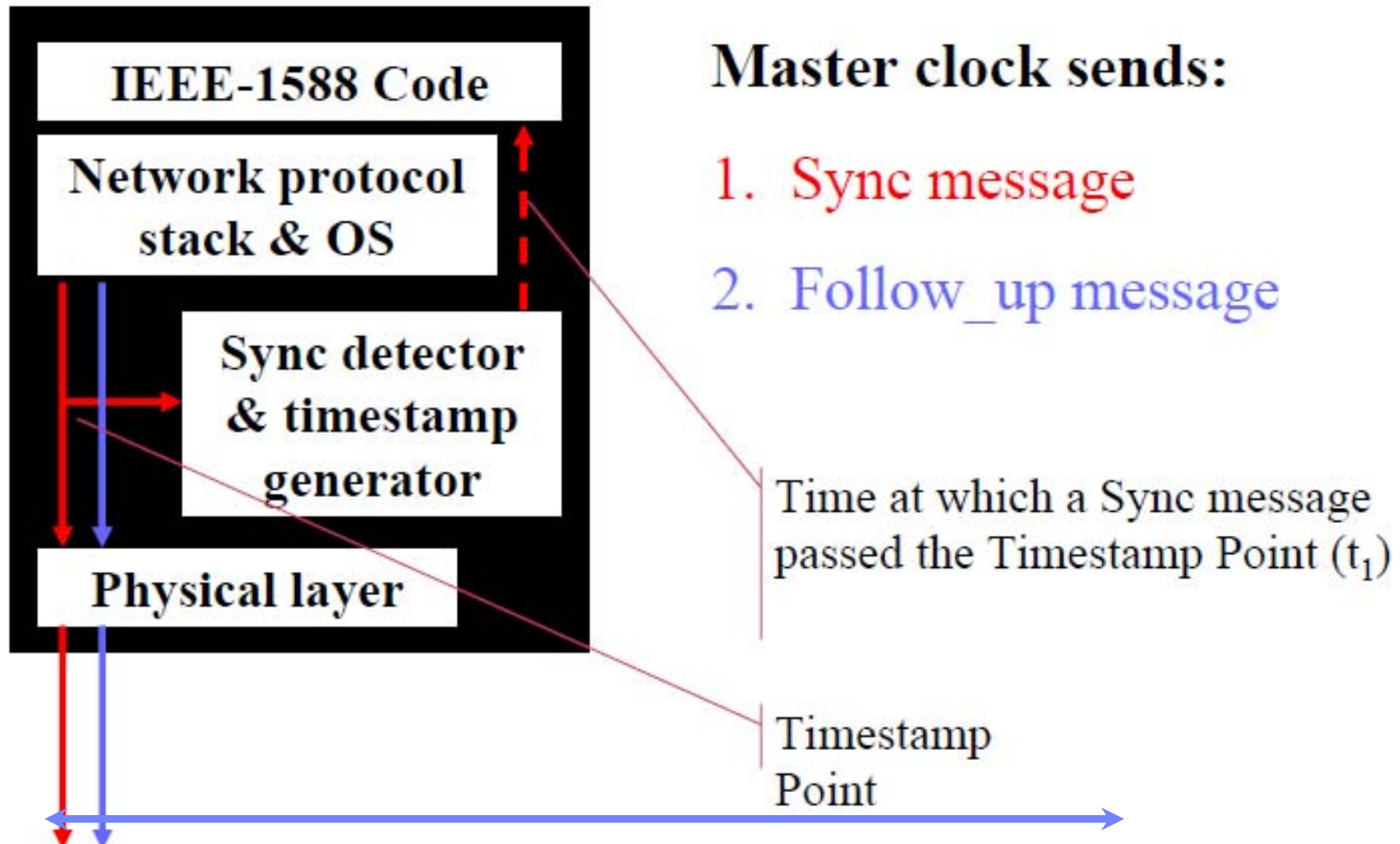# IEEE 1588 – Precision Time Protocol (PTP) over Ethernet

- Capable of sub-microsecond time sync

- Provides a messaging system to identify the various clock performances

- Operates through messages in the Ethernet data frame

2

1588 Basic Operation (1-step, 2-step)

3

Synchronization Details (clauses 6 & 7)

Master clock sends:

1. Sync message

2. Follow_up message

IEEE-1588 Code

Network protocol stack & OS

Sync detector & timestamp generator

Physical layer

Time at which a Sync message passed the Timestamp Point (t_1)

Timestamp Point

4

Synchronization Details (continued)
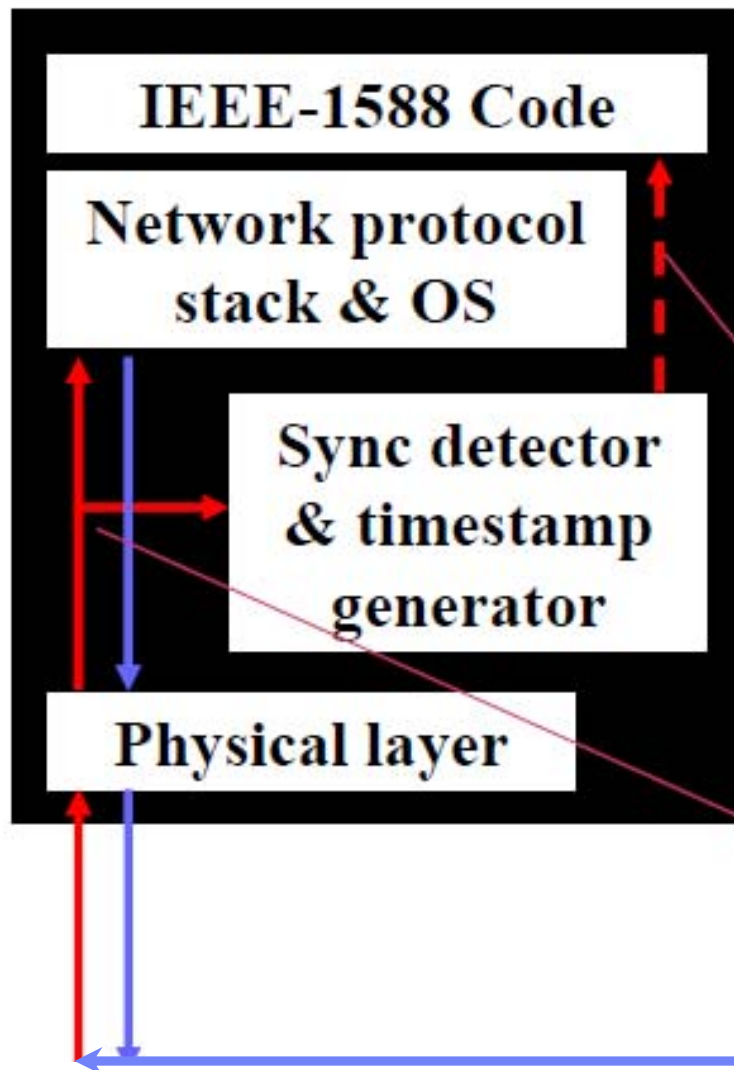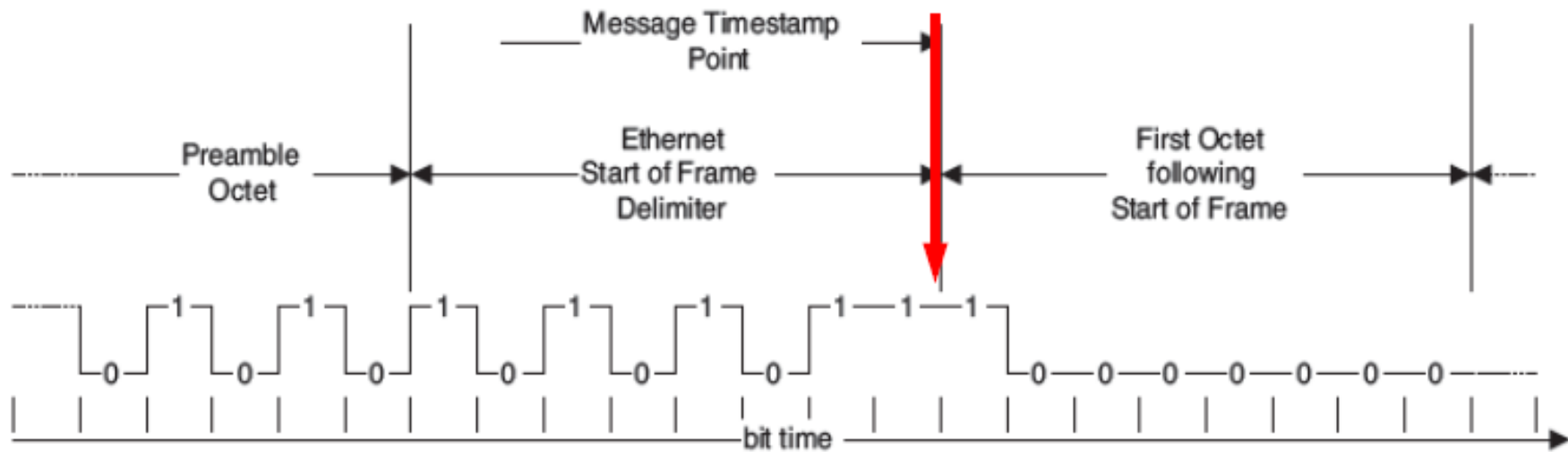

Master clock receives:

- Delay_Req message

Master clock sends:

- Delay_Resp message

Time at which a Delay_Req message passed the Timestamp Point (t_4)

Timestamp Point

5

Ethernet Message Time Stamping

Hardware-based Time Stamp is applied based on the Rising Edge
of the First Bit after the Start of Frame Delimiter

6

Time Sync Calculations

MS_difference = offset + MS_delay = t2-t1
   = 11:30 – 10:00 = 90 min

SM_difference = -offset + SM_delay = t4-t3
   = 11:30 – 10:30 = -30 min

Assuming that MS_delay=SM_delay then:

Offset and Delay Calculations

Offset = (MS_difference – SM_difference)/2
         = (90 – (-30)) / 2   = 60 Min

One_Way_Delay = (MS_Difference + SM_difference)/2
         = (90 + (-30)) / 2   = 30 min

7
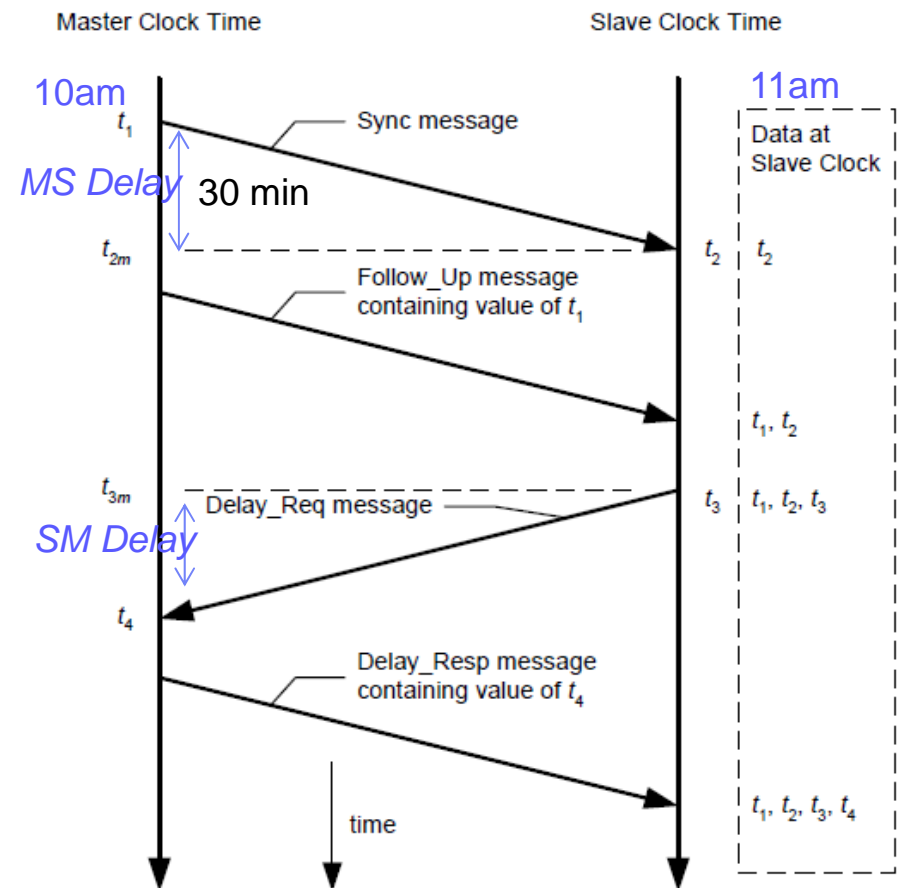
Announce Message:

- Clock ID
- Grand Master Clock Accuracy
- Grand Master Variance
- Origin Time Stamp (Sec and nsec)
- UTC Offset
- Grand Master Time Source (e.g. – GPS)

8

Included in the Sync Message:

- Message ID (e.g. – Sync, Follow-up, delay request
- PTP Version Number
- Message Length (2 bytes)
- Subdomain Number (1 byte)
- PTP Flags (16)
- Correction (nsec)
- Clock Identity (8 bytes)
- Source Port (2 bytes)
- Origin Time Stamp (Seconds & Nanoseconds)

Timing Latency & Fluctuation

Application layer

Network protocol stack

Physical layer

msecs of delay and fluctuation

< 100 nsecs of delay and fluctuation

Application layer

Network protocol stack

Physical layer

Repeater, Switch, or Router

Repeaters & Switches: fluctuations ~100ns to usec
Routers:fluctuations ~ms
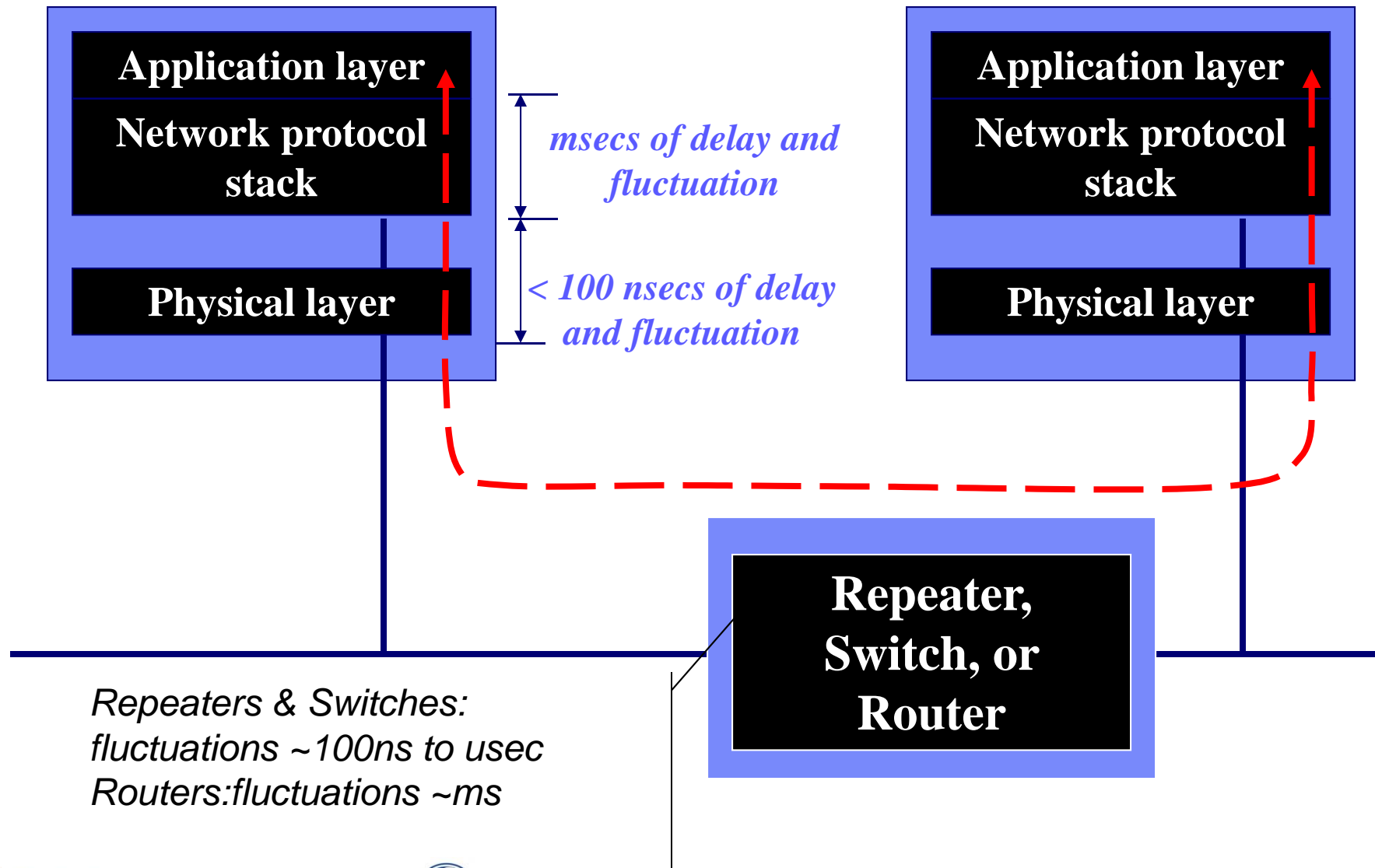
PG&E Synchrophasor Project – Proof of Concept Architecture

C37.118 is used for interim testing while harmonization with IEC 61850 is demonstrated
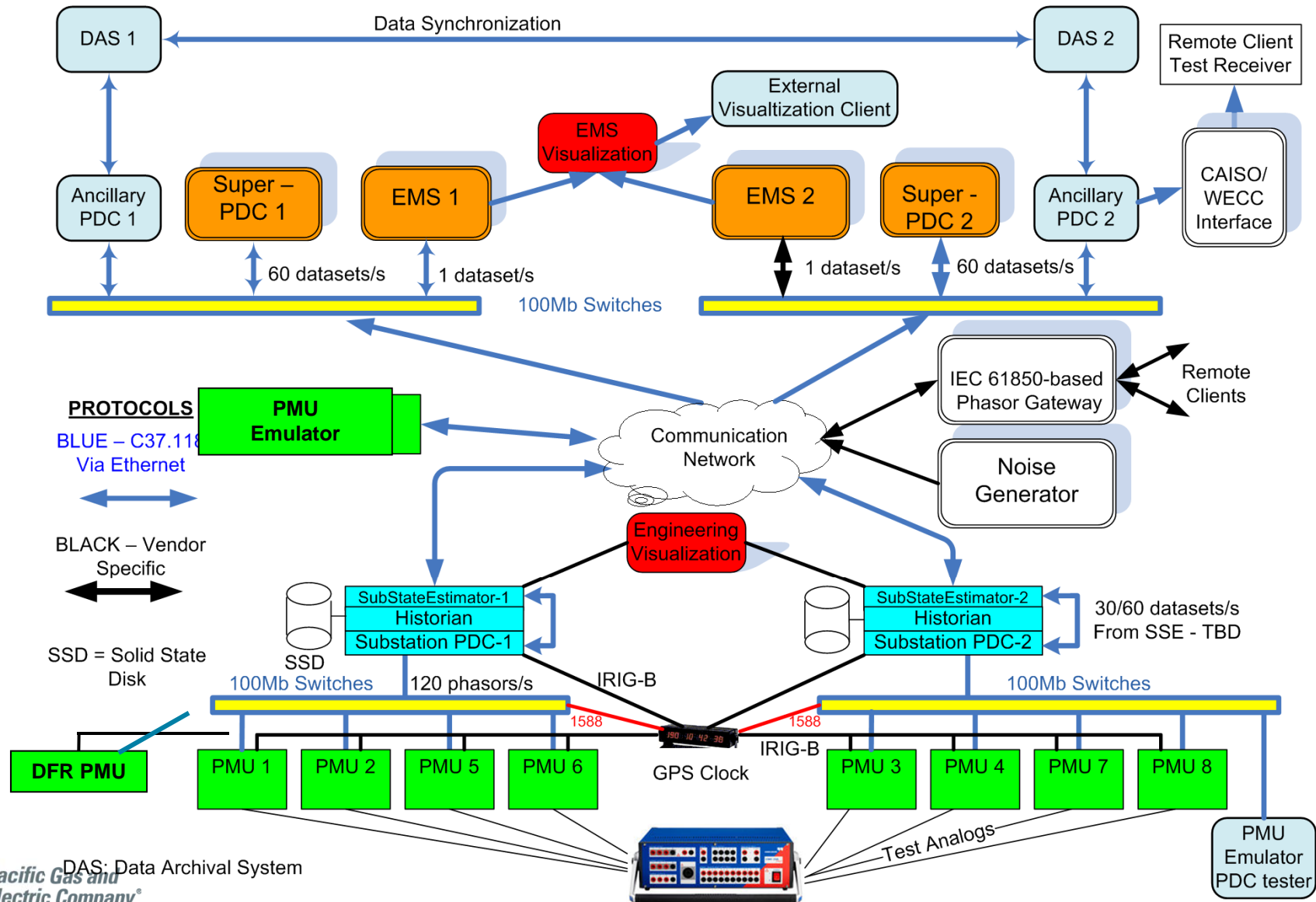
Observations – Timing functions (GPS, IRIG-B, and IEEE 1588)
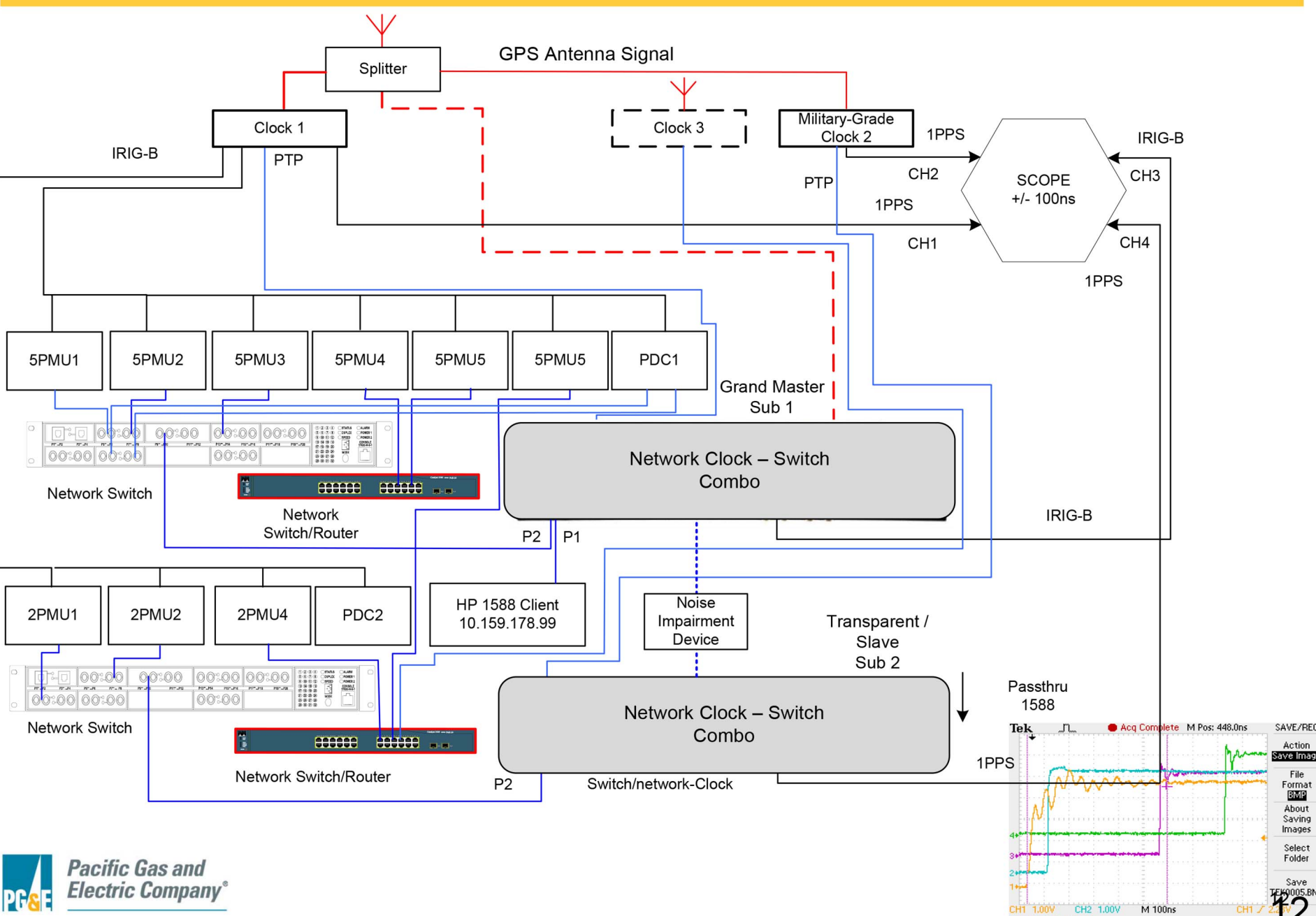
Noise Impairment Tests

- Noise Injection / IP Packet interference

PMU to Sub PDC - Standard Configuration

PMU to Sub PDC – Signal Impairment Configuration
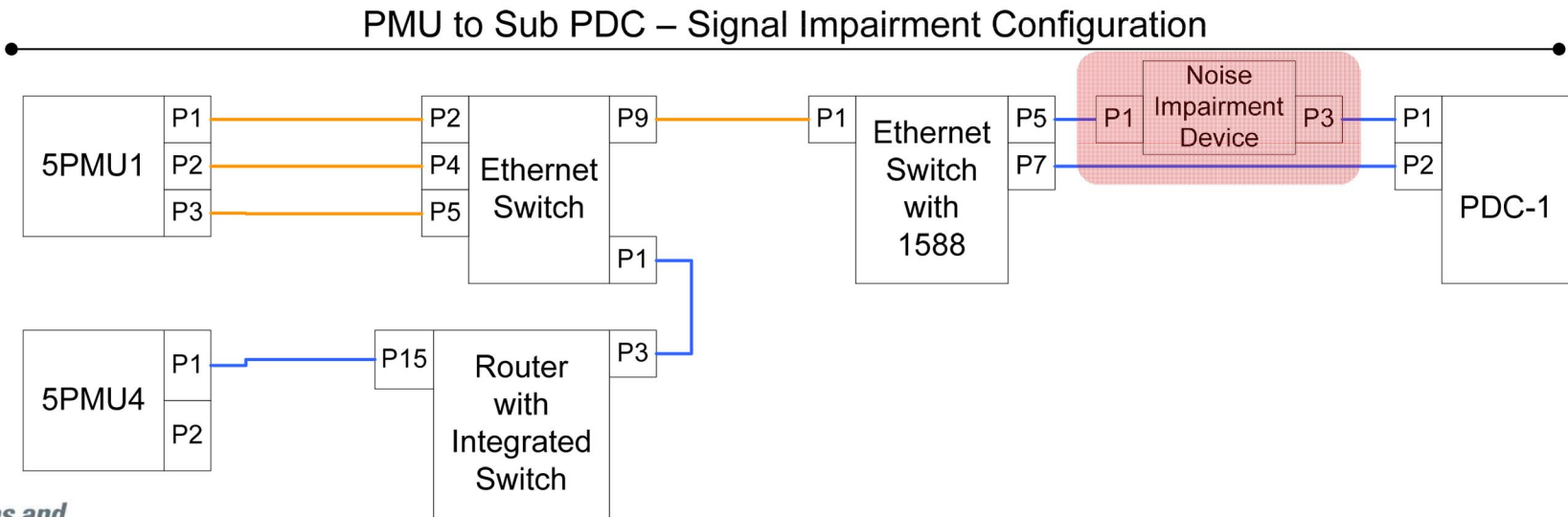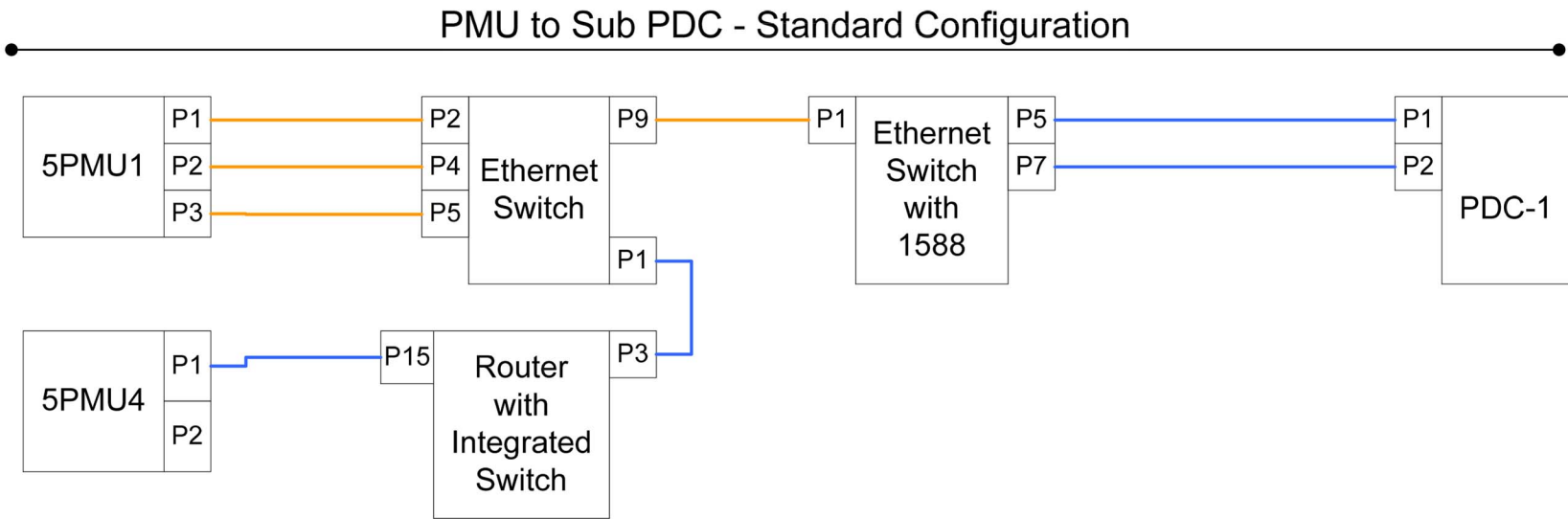
Observations – Timing functions (GPS, IRIG-B, and IEEE 1588)

Before calibration (-0.25 μs)

Reference (MIL) clock
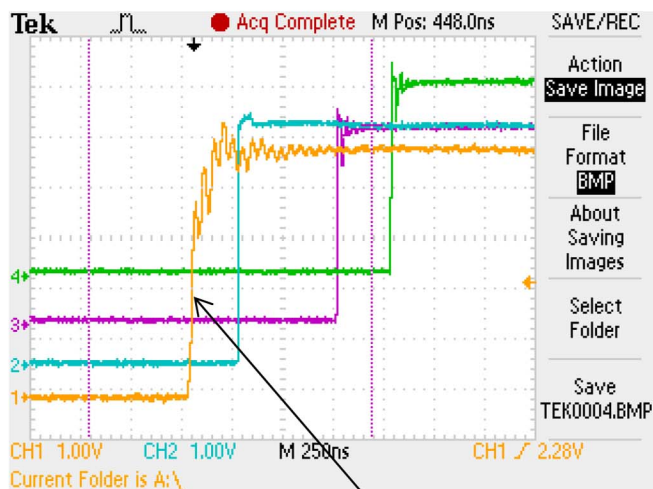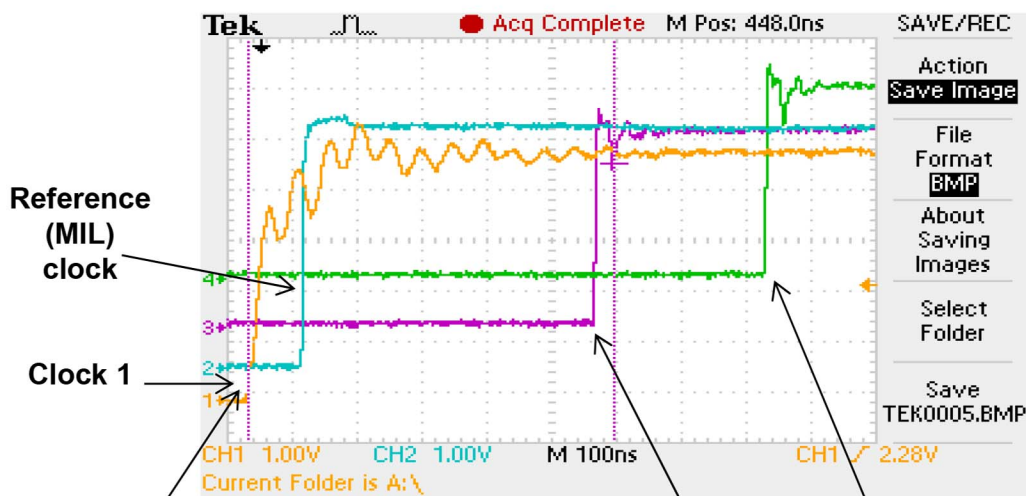
Clock 1

After calibration (0.1μs)
Compensating for GPS
Antenna cable length

Grandmaster   Transparent-Clock
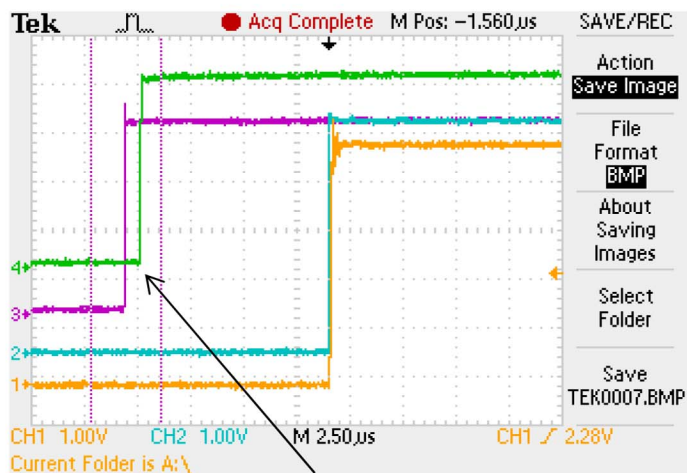
~15 minutes after GPS Antenna removal
from Grandmaster(10 μs)
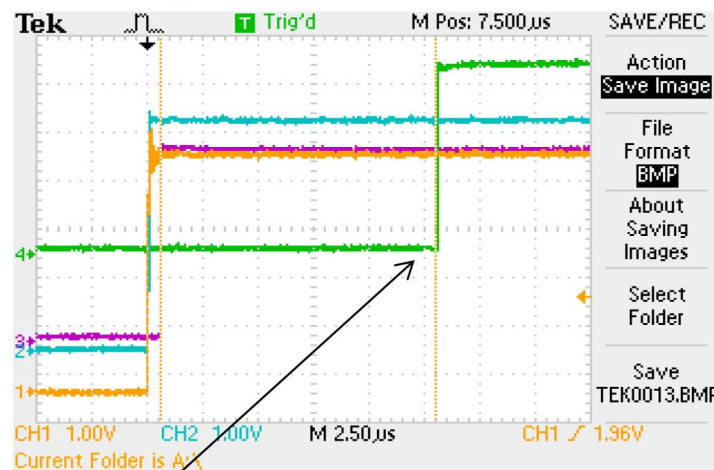
10 μs delay injected in 1588 path
between grandmaster and transparent clock

Observations – Timing functions (GPS, IRIG-B, and IEEE 1588)

- Several GPS-synchronized clocks providing timing accuracy better than 1 us (mostly on the order of 0.1 us)

- Some clocks did not update time-quality bits in IRIG-B timing data after loss of GPS input. Similarly, for IEEE 1588 PTP.

- In the absence of GPS input, clock drifts on the order of 10^{-7} to 10^{-9} were observed from different clocks.

  - Typical commercial products

    - 10^{-9} is a drift of 4 us in about an hour
    - 10^{-7} is a drift of 26 us in about 4 minutes (Bad Time)
      - Synchrophasor permissible TVE of 1% ~ 26.5 us

- Other 1588 PTP (precision time protocol) test results

  - Typical accuracy of 0.1 to 0.5 us has been observed.

  - Any delay in network communication can translate to delay in Transparent Clock when not compensated.

  - Some Slave clocks assume transmission delay is the same in both directions (usually OK, but not always)

Pacific Gas and Electric Company®
PG&E

Tests – Summary of the Findings

- Several GPS-synchronized clocks providing timing accuracy better than 1 us (mostly on the order of 0.1 us)

- Some clocks did not update time-quality bits in IRIG-B timing data after loss of GPS input. Similarly, for IEEE 1588 PTP.

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  - Some slave clocks assume transmission delay is the same in both directions (usually OK, but not always)

16

IEC61850 Levels of Time Synchronization

LN – STIM identified to set time and provide time synchronization in a substation

Class	Accuracy	Function/phase error
T1	$\pm$ 1 ms	Event timing
T2	$\pm$ 0.1 ms	Zero Crossing / Sync Check
T3	$\pm$ 25 μs	32' at 60Hz / 27' at 50 Hz
T4	$\pm$ 4 μs	5' at 60Hz / 4' at 50 Hz
T5	$\pm$ 1 μs	1' - Synchrophasors
T6	$\pm$ 0.1 μs	Available, but not defined yet

C37.118 4 Bit Time Quality Indicator Code

BINARY	HEX	VALUE (worst case accuracy)
1111	F	Fault--Clock failure, time not reliable
1011	B	10 seconds
1010	A	1 second
1001	9	100 milliseconds (time within 0.1 sec)
1000	8	10 milliseconds (time within 0.01 sec)
0111	7	1 millisecond (time within 0.001 sec)
0110	6	100 microseconds (time within 10^{-4}sec)
0101	5	10 microseconds (time within 10^{-5}sec)
0100	4	1 microsecond (time within 10^{-6} sec)
0011	3	100 nanoseconds (time within 10^{-7} sec)
0010	2	10 nanoseconds (time within 10^{-8} sec)
0001	1	1 nanosecond (time within 10^{-9} sec)
0000	0	Normal operation, clock locked

Interoperability Issues, Tests, and Practical Examples (PMU, PDC, SuperPDC)

Vahid Madani / Farnoosh Rahmatian

NASPI Meeting, October 16, 2012, Atlanta, GA

Pacific Gas and Electric Company®

QUANTA TECHNOLOGY

Interoperability Considerations

- Standards
  - Having standard(s) is required but not sufficient for interoperability.
  - Standard compliance doesn't guarantee interoperability
- Implementation Agreements
  - Clear Implementation Agreement(s) among various device developers and manufacturers are usually required to achieve interoperability
- Testing
  - Both standards and implementation agreements are subject to interpretation and may include options, choices, or configurations.
  - Only actual testing can verify interoperability between various devices/systems.
  - Testing often identifies the need (or desire) for improvements and enhancements, as well as feedback for improving standards and implementation agreements.
- Life-cycle management
  - Life-cycle management, asset utilization, and revision control are all considerations affected by interoperability
  - Device interoperability needs to support system life-cycle management and asset utilization (long-term system deployment roadmap to be supported)

2

IEC 61850 Certification

- ❖ Benefits of conformance test before implementation?
  - ➢ Resolves interpretation differences
  - ➢ Early identification of non-conformances
  - ➢ Exact functionality of the protocol is identified
  - ➢ Multi-vendor solutions will have interoperability issues
  - ➢ New offerings will have bugs
  - ➢ Most manufacturers have missing pieces
- ❖ Conformance Test
  - ➢ Does implementation conform to the standard?
  - ➢ What is the behavior in error situations?
- ❖ Interoperability Test
  - ➢ Do the communication services provided by one device interoperate with other devices?
- ❖ Involves UCA-IUG Documents
  - ➢ QA Program
  - ➢ Accreditation program
  - ➢ Approved Test Procedures

- ❖ Requiring a Certified Product from a Vendor Means:
  - ➢ Vendor makes the investment as appraisal costs
  - ➢ Cost is spread over all sold licenses of the product
  - ➢ Early discovery of problems avoids dealing with unexpected behaviors during installation and over project life cycle
  - ➢ Vendor and User save dollars and time in Operation & Maintenance

IEC 61850 Certification does not address….

- Interoperability Test
  - ✓ Does not cover application interoperability
  - ✓ Burden is on the User – Include in your Spec.
- Stress and Performance Test
  - ✓ Identifies boundary limits for the device
  - ✓ Establishes whether the device meets the performance requirements for the application
- Reliability, Redundancy, Failure Modes and Contingencies

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Example – Hybrid GOOSE and Serial Communication
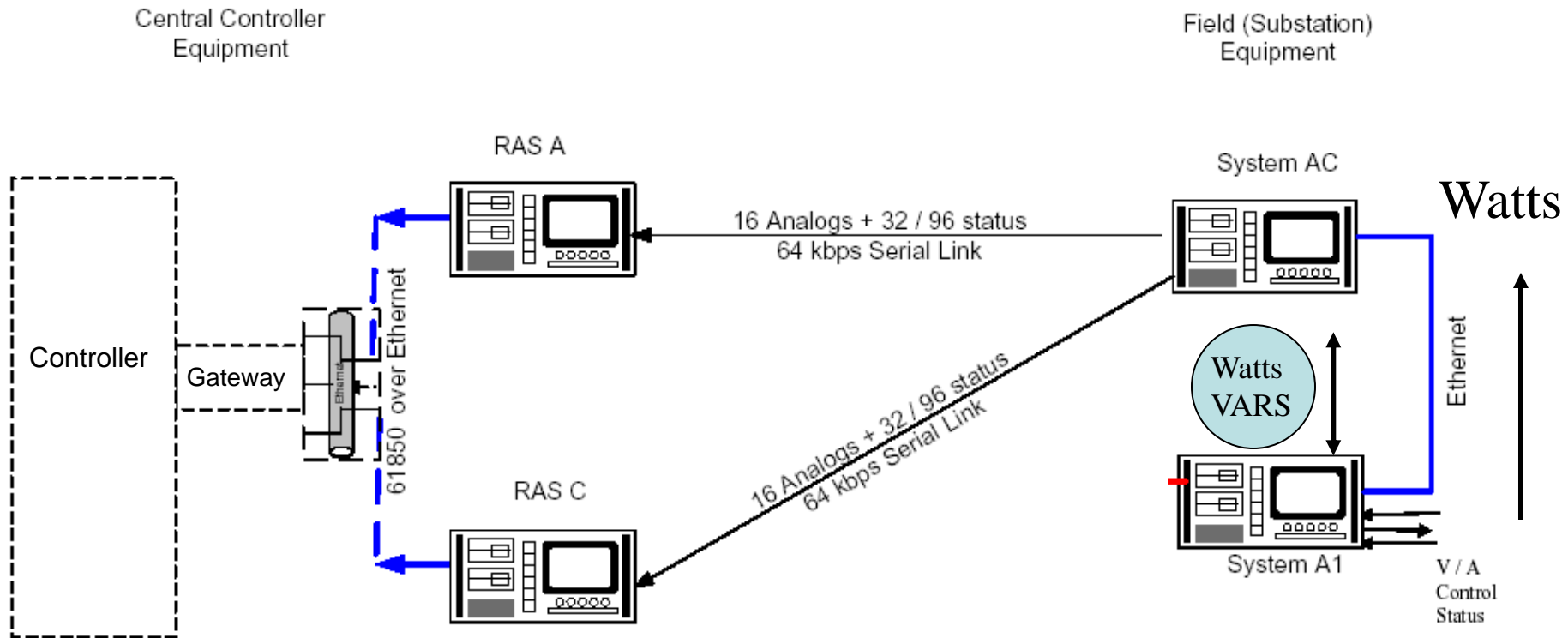
Use of high speed serial links (Up to T1 level) and Interface with GOOSE Messaging

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Benefits

- ❖ Replacement of wires with communication
  - ➢ Costs
  - ➢ Improved flexibility
  - ➢ Reduced commissioning time
  - ➢ Improved monitoring
  - ➢ Ease of use with optical sensor technology
  - ➢ Prevents mixing DC circuits
  - ➢ Ease of applications when I/Os are limited
- ❖ Besides SCADA Data
  - ➢ Superior Asset Management means
  - ➢ Condition monitoring of primary equipment
  - ➢ Power Quality Information
- ❖ Self description and configuration language
  - ➢ Verify the configuration of the system
  - ➢ Automatically create test patterns
- ❖ Ease of Applications with Synchronized phasors
  - ➢ Data sharing over large geographical grids
    - ✓ Neighboring systems (subject to Cyber security)
  - ➢ Phasor Data Concentrators (PDC)

- ❖ When implemented properly…
- ❖ **Self monitoring capability**
  - ➢ Constant real-time status of control point communications, with alarming by IEDs for failure anywhere from the source IED intelligence to the implementing IED.
- ❖ **Fits with "overlapping** zones of monitoring" approach to having a maintenance program.
  - ➢ Critical for Protection
  - ➢ Vital for System Integrity Protection Schemes (SIPS) and Wide-area Remedial Actions Schemes (RAS)
- ❖ **Better than** many or most existing schemes in this way
- ❖ **Timing and loss rate** monitoring can be programmed

Design Requirements/Criteria

Example – typical for the overall system

1. High availability/reliability (>99.995)

2. Automatic self diagnostics

3. Easy to maintain

4. Throughput time < 25 ms

   ➢ Hierarchical structure

   ➢ Detection, transmission, central processing, and execution

5. Full Redundancy (no single point of failure)

6. Controllers-Triple Modular Redundant- (2 out of three voting scheme)

7. Compliance with regulations

Messaged versus Hardwired

- Advantages:
  - Replace local control wiring with network communications
  - No need for periodic testing (devices communicate continuously)
  - Minimizes hardware installation
  - Saves space
  - Provides almost endless expansion capabilities
  - No need to update wiring diagrams
  - No contacts, debounce filtering, not prone to noise

- Drawbacks:
  - Signal Propagation delay – May be variable
  - Need robust setting tracking mechanism (version control)

Example - Wide-Area Protection and Control

GPS Clock

Controller-B

OPC

OPC

Host Computer   IEC 61850

SOE
OSC

Alternate

Status & Actions

Controller-A

OPC

OPC

Host Computer   IEC 61850

SOE
OSC

Primary

Status & Actions

Controller Sites

Tele-Protection and SCADA Network

Substation

MMXU/GGIO
Report over
TCP/IP Ethernet

GPS Clock

Watts

us

V/A ⟶

Status ⟶

Watts, VAR, Freq., Temperature,
Thermal, Phasor, Angle

Control

Transducer (Temperature)

Hub

Example
Wide-Area Protection and control

Controller

_ED _RS

Modbus A Master | Modbus B Master | Modbus C Master
N1 N2 N3 | N1 N2 N3 | N1 N2 N3

_ED _RS

Modbua A Slave | Modbus B Slave | Modbus C Slave
N1 | N1 | N1

_EQ
_LL
_OC
_Comm
_Test

Goose Digital Data
Critical status
from B SMP's

Modbus TCP Data

_MW
_MV
_FQ
_CF
_LA
_EF
_Comm
_Test

Configurable Goose/DNP3
Analog Data
Non critical data from B SMP's

Data To B SMP's (Non critical data, future TT)

Modbus TCP Data

SMP CP
Analogs

_Comm
_Test

SMP AP
Digitals

_Comm
_Test

Goose Digital Data
Critical status to B
Controller

61860 Report – Analog
and Optionally -- Digital
Data

_MW
_MV
_FQ

Goose Digital Data
Critical status

_EQ
_LL
_OC

Server running SISCO AX-S4 MMS
(61850) and OPC

61850 Client/Server
Non-Critical / Diagnostic
status

_CF
_LA
_EF

IED

_EQ
_CF
_LA
_EF
_LL
_OC
_MW
_MV
_FQ

LEGEND:
EQ ---Equipment Unavailable
CF ---Channel Fail
LA ---Local Mode
EF ---Ethernet Fail
LL ---Line Loss
OC--- Outage Confirmation
MW--- Megawatts
MV---Megavars
FQ---Frequency
Comm ---Communication Fail
Test ---Goose test bit
ED ---RTP Modbus Error Detection
RS ---RTP Modbus Register Status
N1 ---Modbus Node 1
N2 ---Modbus Node 2
N3---Modbus Node 3

Benefits of using New Emerging Technologies

- Condition based maintenance (reduction of human errors)
- Performance statistics
- Tools for Clearance analysis and tracking
- Database historian can be leveraged to provide maintenance and testing reports.
- Flexibility in Engineering, Design, and Asset Utilization
- Access operational and non-operational data for many business purposes
- Sequence of Events (SOE) Records-Oscillography
- Trending data
- Help in system restoration
- Automated reports/charts generation
- Ability to record and playback actual events

Why focus on Ethernet control?

❖ Deployment of advancing IT technology elsewhere in the enterprise – Can we leverage the investment?

❖ Industrial activity

  ➢ Ethernet LANs for control used in process control

  ➢ Modbus RTU on TCP

  ➢ Ethernet IP – DeviceNet in Ethernet format.

  ➢ Lots of low-cost hardware is breaking down old focus on "non-deterministic" network – not as bad as feared!

  ➢ Sub-microsecond accuracy time sync over Ethernet (IEEE 1588)

❖ Substation LANs

  ➢ DNP3 over TCP; Modbus TCP

  ➢ UCA and IEC 61850 emerging (more later)

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Example: RING or Breaker and Half Bus Messaging
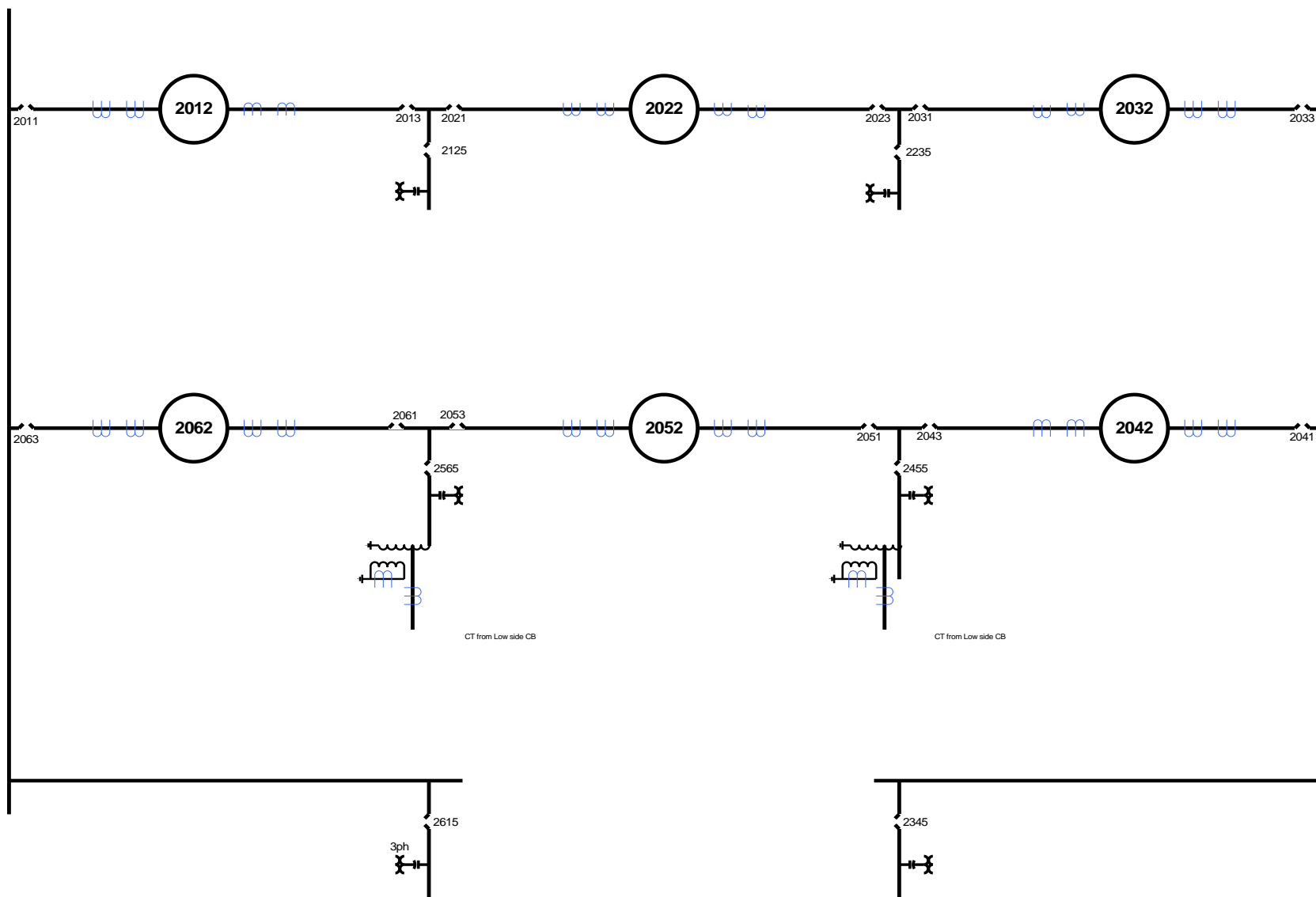
What is Needed? - Tools

Device / Output	REMOTE I/O--RING BUS DEVICE:	CB-2012 1	Set A Line -1 2	CB-2022 3	Set A - XFMR 4	CB - 2032 5	Set A Line 3 6
1.1	BFT BLOCK AUTO (86BF)	RO:1		RI:3			
1.3	BFT TO DTT	RO:3	RI:2				
1.2	HS 1ONLY INTLK TO LEFT	RO:2					
1.4	HS 1ONLY INTLK TO RIGHT	RO:4		RI:4			
1.5	CBM CONTROL	RO:5		RI:6			
1.7	CBM LT13 TO LEFT	RO:7					
1.8	CBM LT14 TO RIGHT	RO:8	RI:9	RI:9			
1.12	52A 20n2	RO:12		RI:11			
2.8	STUB BUS STAT	RI:5	RO:8	RI:10			
2.15	REMOTE BLK CLOSE	RI:15	RO:15	RI:16			
3.1	BFT BLOCK AUTO (86BF)	RI:1		RO:1		RI:3	
3.3	BFT TO DTT		RI:1	RO:3			
3.2	HS 1ONLY INTLK TO LEFT	RI:2		RO:2			
3.4	HS 1ONLY INTLK TO RIGHT			RO:4		RI:4	
3.5	CBM CONTROL	RI:7		RO:5		RI:6	
3.7	CBM LT13 TO LEFT	RI:8	RI:8	RO:7			
3.8	CBM LT14 TO RIGHT			RO:8	RI:9	RI:9	
3.12	52A 20n2	RI:12		RO:12		RI:11	

What is needed?

- ❖ Adequate training of engineers and practitioners
- ❖ Adoption to existing substation automation concepts and changes in the specification and design process
- ❖ Conformance Certification of Devices to IEC 61850
- ❖ The protection engineers need to prepare for the changed specification and design process
- ❖ Tools Industry Participation is Key:
  - ➢ Application Development
  - ➢ Ddocumentation of engineering desig – Substitues for Wiring and Schematics
  - ➢ Mapping
  - ➢ Performance Tracking
  - ➢ IP Address Standards and Management - Over Project Life Cycle
    - ✓ Ease of expansions
  - ➢ Configuration and testing
  - ➢ Troubleshooting
  - ➢ Maintenance
- ❖ Basic understanding of
  - ➢ The engineering approach with the use of the configuration language
  - ➢ The concepts of the object models and the basic communication services
  - ➢ The Ethernet technology with switches and priority tagging

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What is Needed: Process Change

❖ Roll out for substation automation and Protection interlocking

❖ Top down process for specification and design

❖ Specification shall concentrate on

➢ Functionality and data to be communicated

➢ Performance and availability requirements

❖ Role of system integrator

➢ Roles need to be properly defined

➢ Responsible for performance and behavior of the overall system

➢ Cooperation between user and manufacturer is important

Summary Conclusion

- ❖ Balancing Wire vs. Messaging
  - ➢ Know your application
  - ➢ Minimize logic variations between bus configurations
- ❖ Challenges and Opportunities - Bottom line:
  - ➢ Requires Teamwork with IT, Automation, and SCADA / EMS groups
  - ➢ Requires Acceptance by Management and Operators
  - ➢ Automating the system to meet the challenges of 21st century & reliable energy delivery
  - ➢ Real-time system prognosis and adaptive protection and controls
  - ➢ Reduce Down time
  - ➢ Easily adaptable to advancing technology – Ease of upgrade
  - ➢ Saving time & Smart Investment - $$$
  - ➢ Tools – User input is needed

- ❖ Real benefits
  - ➢ Innovative protection & control integration and automation solutions
- ❖ Internal Challenges and solutions
  - ➢ Internal:
    - ✓ Develop a migration path
    - ✓ Widespread rollout vs. spot upgrade
    - ✓ Standards, Training, Management Leadership support, In-house tools
    - ✓ When opportunity knocks, follow the blue print
  - ➢ Externals:
    - ✓ Industry collaborations for well defined standards
    - ✓ Work with vendors to develop features, enhance capability, tools, training

IEC 61850 – Process Level Mappings

- ❖ Get rid of most switchyard wiring.

- ❖ Streams of sampled values of voltages and currents multiplexed on few Ethernet fibers.

- ❖ Status and samples come from switchyard; control and time signals goes out into the yard

- ❖ Wiring losses and burdens are cut.

- ❖ EMI is eliminated.

- ❖ New signals can be added without new wiring to control house.

Interoperability Test – PMU to PDC Communications

- Synchrophasor data transport using IEC 61850-90-5 – streaming data:
  - PMU to Substation PDC
  - Substation PDC to Super PDC
  - PMU to Super PDC
  - Comparison with IEEE C37.118 UDP
- Communicating configuration data
- Mixed protocol – a PDC receiving IEC61850-90-5 and transmitting in IEEE C37.118.2-2011 UDP
- Impact of timing signals (e.g., IEEE 1588 v2 with power profile C37.238-2011)
- Layered testing
  - Can the receiving device parse the received data (protocol)
  - Is the received data correctly understood / interpreted (format)
  - Is the received data correct or corrupted – and consequences (data quality)
    - E.g., misunderstood time-stamp – and what will happen to the data (lost or saved or flagged)

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QUANTA TECHNOLOGY

Examples: Comparison of Data Transmission using C37.118 UDP and IEC 61850-90-5 Unicast and Multicast

Set-up at PG&E Proof of Concept (POC) Test facility:

- Two PMUs, labeled 5PMU1 and 5PMU6 see the same voltage and current information
  - 5PMU1 – transmits using C37.118 through a substation PDC to a SuperPDC (SPDC)
  - 5PMU6 – transmits using 61850-90-5 directly to the SPDC
- 1 ASDU / Frame – One-to-one relationship between frame and data units
  - Data unit is same as message size, i.e., 4300 bytes
  - Reminder: ASDU – Application Service Data Units
  - Can also set up to include multiple data units (ASDU) per frame - To allow repeated data to protect against loss of data (address missing data). Not shown in this presentation.
- PMUs are streaming P Class data at 120 records (frames) per seconds
- Interval of tests is 10 second (1200 records / seconds)

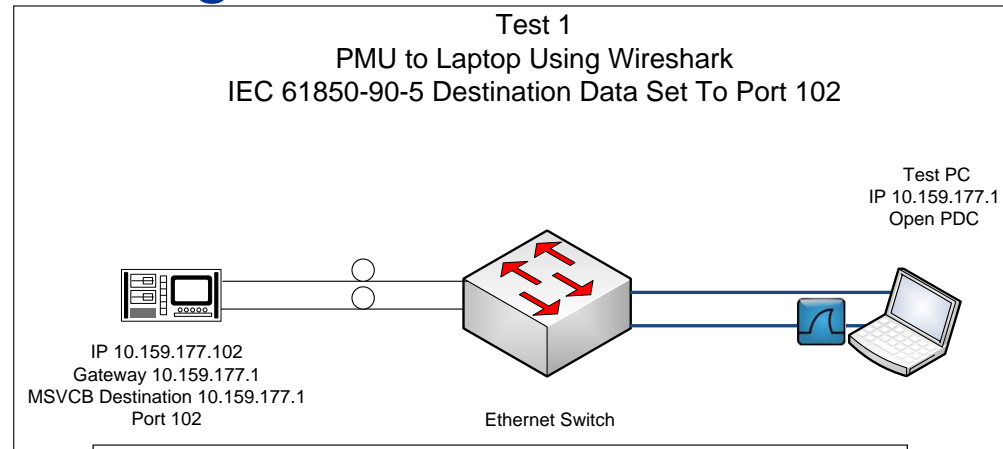Pacific Gas and Electric Company®

QUANTA TECHNOLOGY

Test Setup Progression – Using IEC 61850-90-5

Test 1 – Test Messages Transmitted By
  PMU to OpenPDC
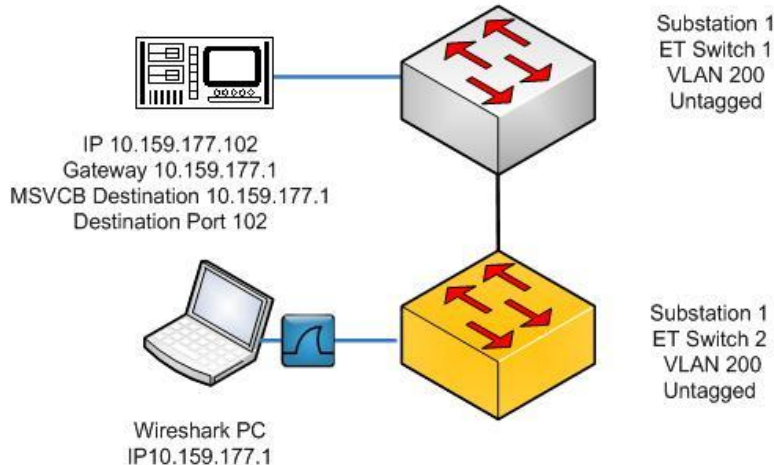**Test 4** – Test On Isolated POC Lab
  Ethernet Switches With VLAN
Test 5 – Test On Single Subnet With
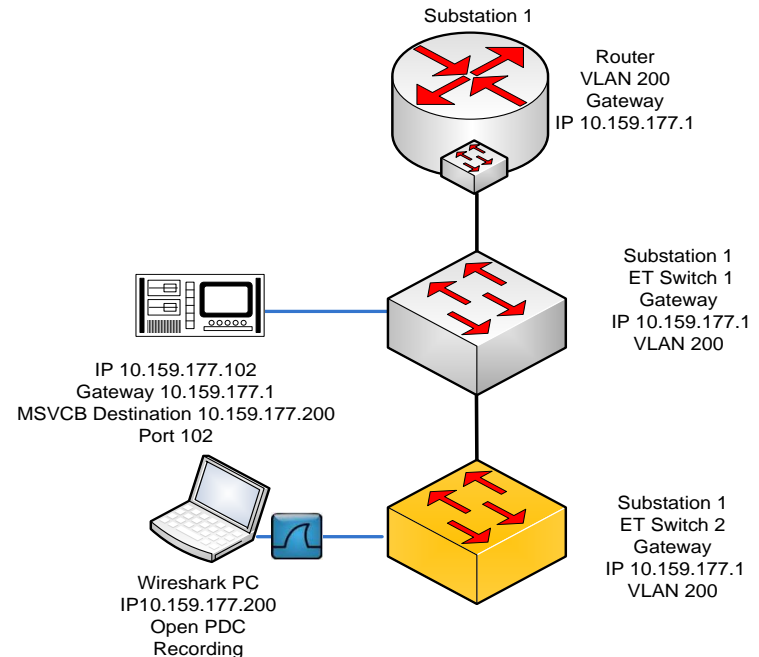 Router Connected
…

Test 1
PMU to Laptop Using Wireshark
IEC 61850-90-5 Destination Data Set To Port 102

Test PC
IP 10.159.177.1
Open PDC

IP 10.159.177.102
Gateway 10.159.177.1
MSVCB Destination 10.159.177.1
Port 102

Ethernet Switch

Test 4
Connect 2PMU6 to Ethernet Switch 1
Connected Wireshark PC to Substation 1 Ethenet Switch 2
IEC 61850-90-5 Destination Data Set To Port 102

IP 10.159.177.102
Gateway 10.159.177.1
MSVCB Destination 10.159.177.1
Destination Port 102

Substation 1
ET Switch 1
VLAN 200
Untagged

Substation 1
ET Switch 2
VLAN 200
Untagged

Wireshark PC
IP10.159.177.1

Test 5
Connect 2PMU6 to Ethernet Switch 1
Connected Wireshark PC to Substation 1 Ethernet Switch 2
IEC 61850-90-5 Destination Data Set To Port 102

Substation 1

Router
VLAN 200
Gateway
IP 10.159.177.1

Substation 1
ET Switch 1
Gateway
IP 10.159.177.1
VLAN 200

IP 10.159.177.102
Gateway 10.159.177.1
MSVCB Destination 10.159.177.200
Port 102

Substation 1
ET Switch 2
Gateway
IP 10.159.177.1
VLAN 200

Wireshark PC
IP10.159.177.200
Open PDC
Recording

TECHNOLOGY

Test Setup Progression

- Unicast and Multicast between PMUs and Test PC
- IEC 61850-90-5 Destination Data Set To Port 102
- **5PMU1** – transmits using C37.118 through a substation PDC to a SuperPDC (SPDC)
- **5PMU6** – transmits using 61850-90-5 directly to the SPDC

Test 13 - Unicast and Multicast To SPDC Through Firewall
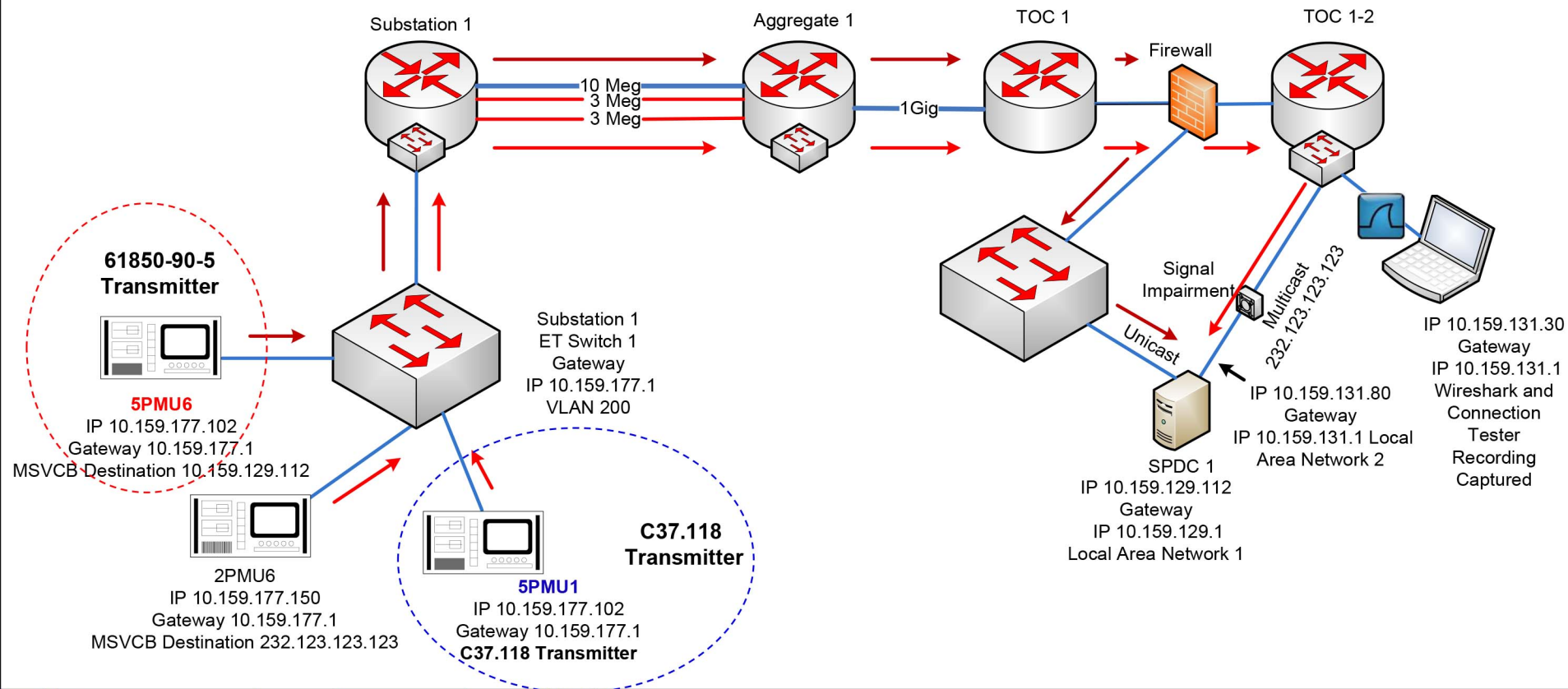
Multicast Between Field and Central Location

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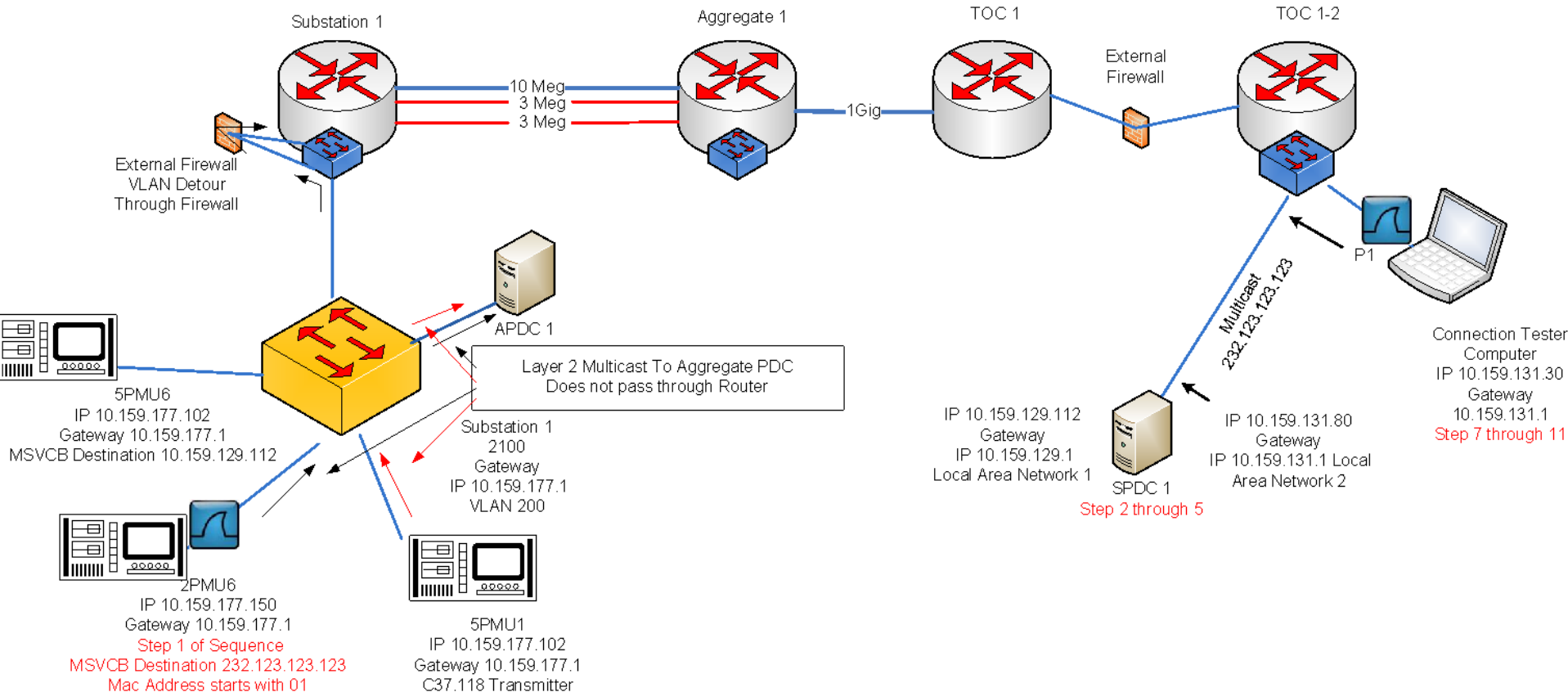
Interoperability Tests – Summary of the Findings

- A collaborative testing environment is a significant asset
- Various interpretations of standards and implementation agreements
  - Quality and status flags – limited implementation in some cases
- Different challenges for streamed data (e.g., synchrophasor measurements) and one-time data (e.g., status, control, config data)
- Unicast and multicast implementations
  - Varying support levels for routers, switches, and firewalls within the data path
- Impact of security features on interoperability and testing
  - Access to devices for configuration
  - IGMP 3.0 support
- Awareness of other system factors such as operating systems or communications stacks settings and limitations.
  - Example, UDP and TCP buffer sizes.
- Tools, tools, tools …
  - The need for efficient configuration and testing tools to accelerate and streamline interoperability (and other) tests.