Substation Communications Design - Legacy to IEC 61850

Part 2/3: Practical Application

Tim Wallaert
Chris Jenkins

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Your Utility Customer Tells You

"We're doing our first IEC 61850 substation and we want you to design the communication infrastructure to support it"

What Do You Do Now?

A. Take the job

B. Panic

C. Try to talk them out of it

D. Tell them you know how to design them a great communication infrastructure for IEC 61850 (with help from presentations such as this!)

E. All of the above

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Topics Covered in this Presentation (and Why)

- Why the utility is implementing IEC 61850…
  (so you know what they hope to get out of it!)
- IEC 61850 Overview…
  (so you can speak their language)
- Environmental Conditions…
  (so you can understand why the environmental requirements are important in selecting a switch)
- Communication Requirements…
  (so you can design a solution that will work)
- Network Architectures…
  (so you can select the right one for the job)

What is IEC 61850?

- IEC 61850 is…
  - A standard for communication networks and systems for power utility automation
  - Defines an application-focused architecture
  - Defines environmental conditions
  - Translates all information into data models based on standard naming convention
  - Efficient engineering process of an application and integration of devices from multiple vendors
  - Much more than just a communication protocol

- IEC 61850 is NOT…
  - A guarantee of interoperability among different vendors

Why Does the Utility Care?

Project Stage	IEC 61850 Feature	Utility Benefit
Design	Substation Configuration Language (SCL)	Eliminates procurement ambiguity – get accurate quotes
Install	Data available to all devices on LAN	Reduces wiring costs (no more point to point wiring)
Startup	Reduced manual configuration of devices	Lower commissioning costs
Operate	Data available to other substations	Wide area protection schemes are now possible
Maintain	Device status data	Prevent unplanned downtime
Upgrade	Same naming convention in similar devices	New devices added without costly rework

Bottom line: Utilities can do more with their substation automation for less

Topics

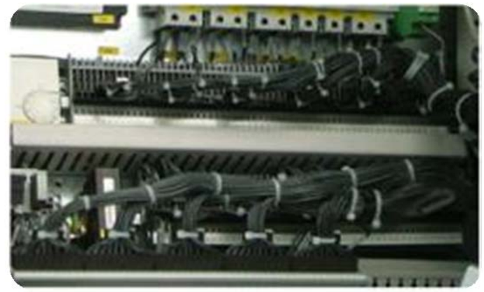
- IEC 61850
- Environmental Conditions
- Communication Requirements
- Network Architecture

Historical Substation Protocols

- Vendor-based
  - Alstom Courier
  - ABB SPA
  - Siemens Profibus
  - Schneider Modbus

- Standard
  - DNP3 (mostly North America)
  - IEC 60870 (mostly Europe)

- Problem
  - Proprietary structures
  - Different functionality
  - No interoperability



Distributed
Network
Protocol

IEC 61850 and UCA2

International Electro Technical Commission

"The IEC is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies — collectively known as electro technology"

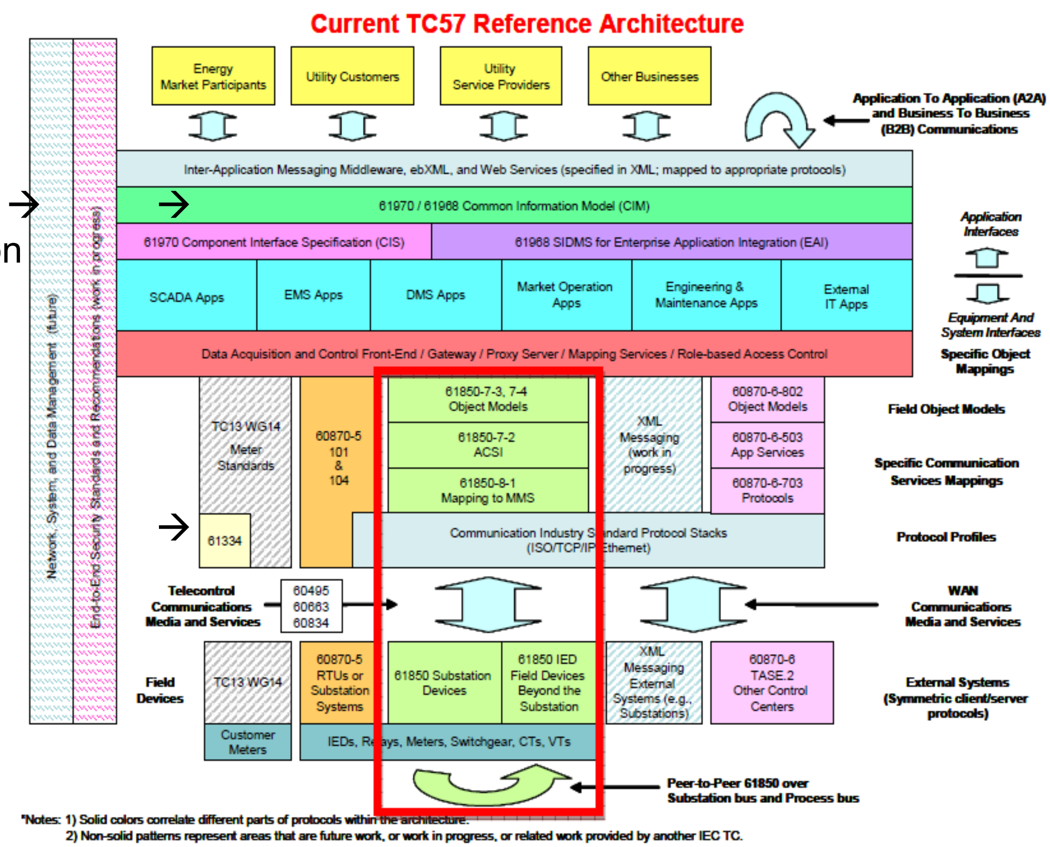
IEC TC 57
IEC TECHNICAL COMMITTEE

IEC 61850: COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION

IEC TC57 System Reference Architecture

61970/968
Application
communication →

62351
Security →



Power Utility control system reference architecture from IEC TC 57
Source: IEC61850-1

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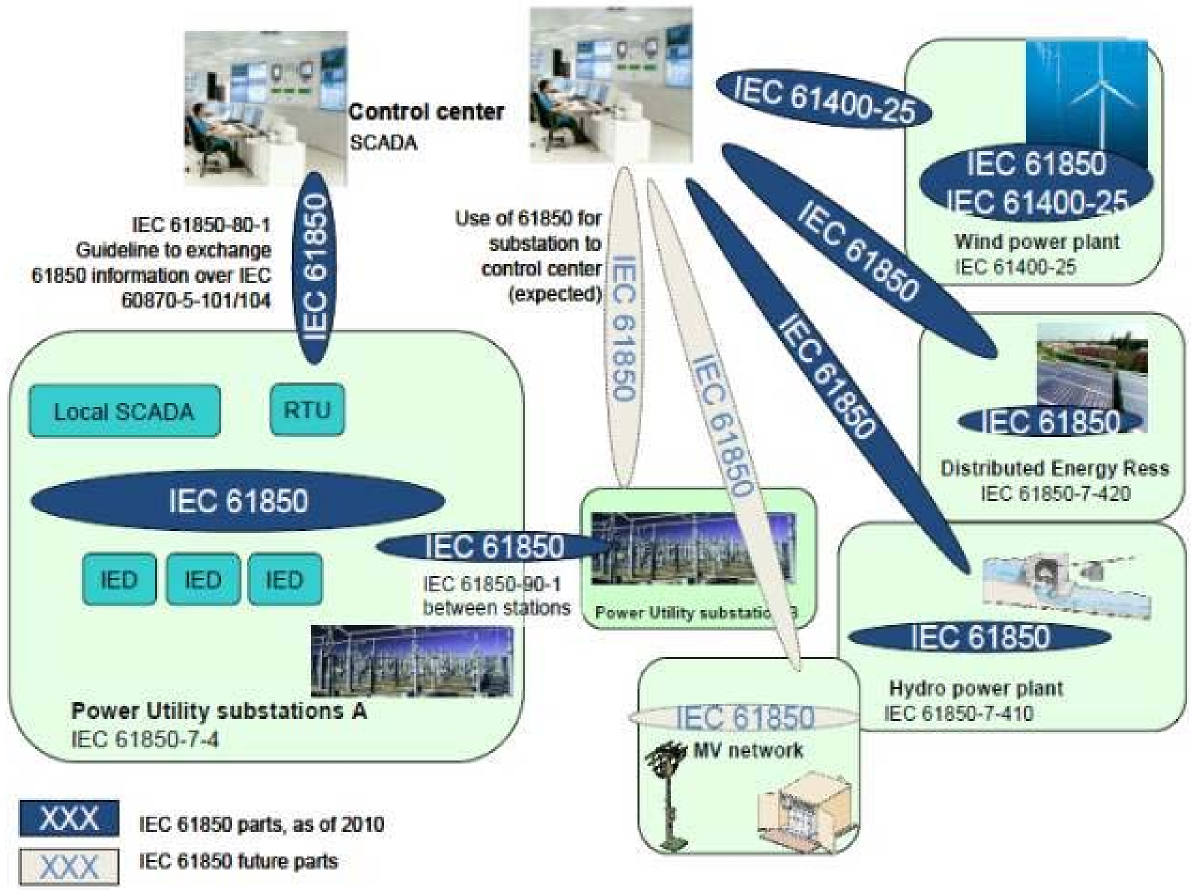
What is IEC 61850?



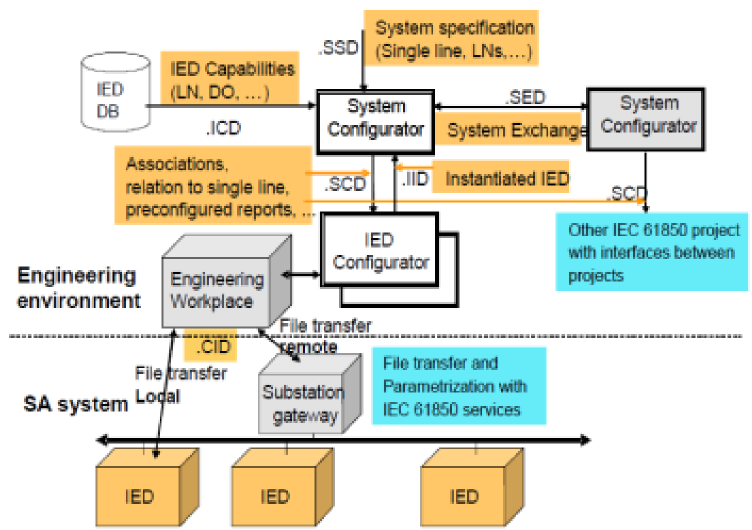
Scope of application of IEC 61850
Source: IEC61850-1

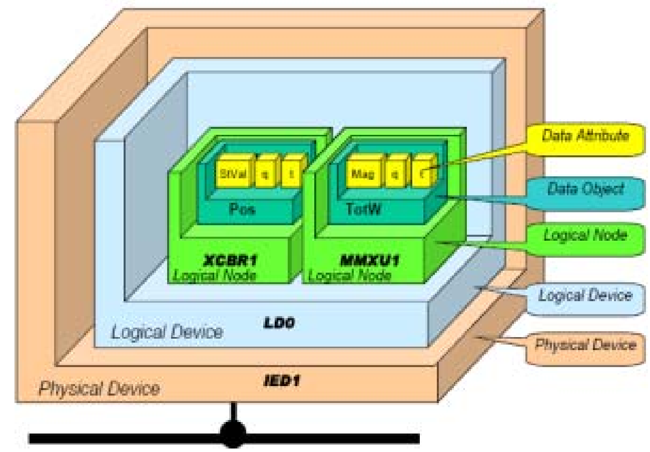
Modeling

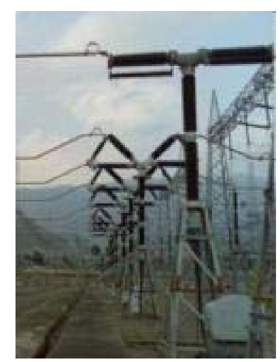
Basic Idea:

Complete description of a technical system
(e.g. Substation) based on an object-oriented model

→ Not new, but in this dimension and kind of application very innovative

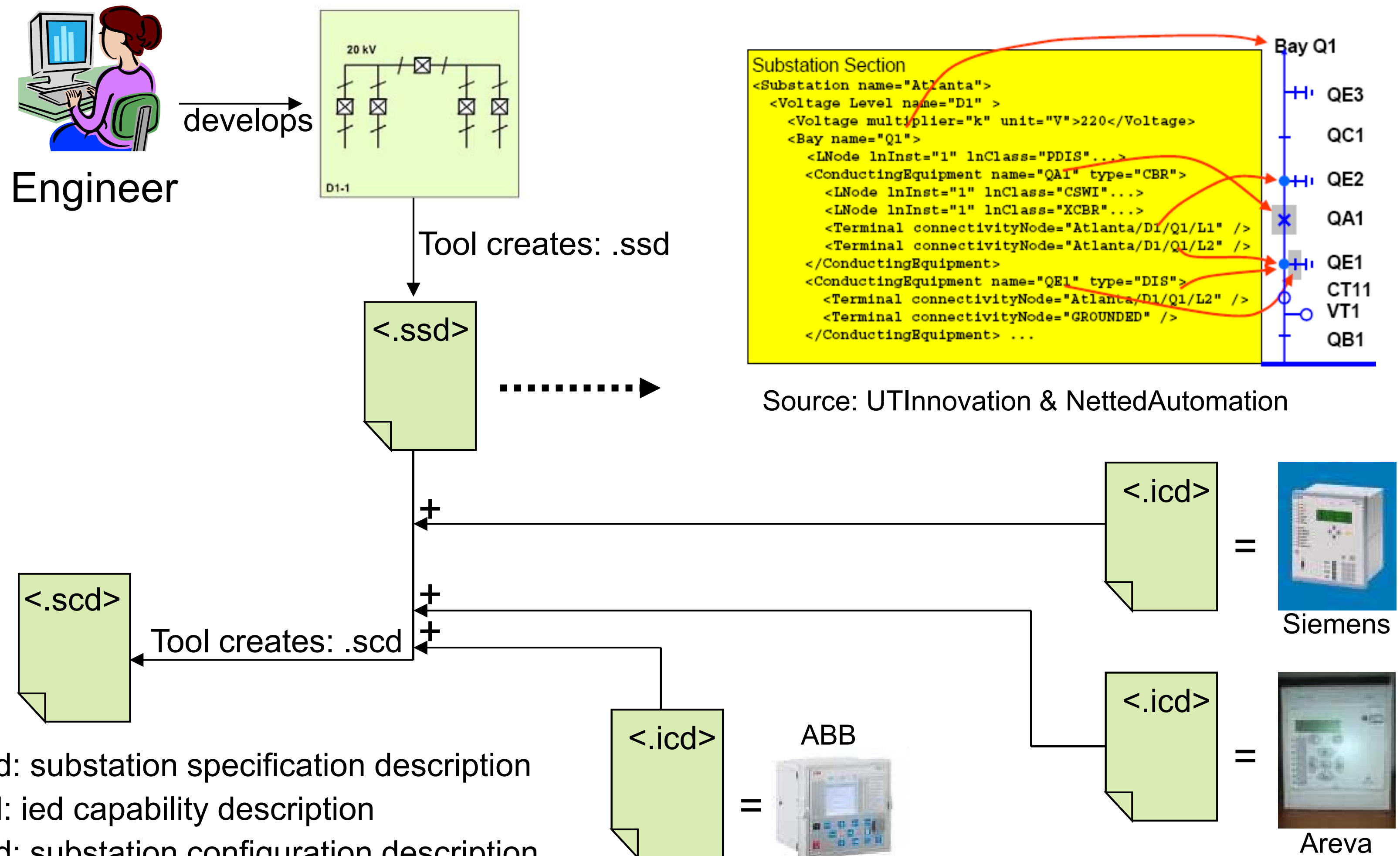






Reference model for information flow in the configuration process
Source: IEC61850-6:2010

The Substation Configuration Language



ssd: substation specification description
icd: ied capability description
scd: substation configuration description

The Standard IEC 61850 - Edition 1

→ International standard since 2003

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	**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
Configuration Part 6: Configuration Language for electrical Substation IED's	**Abstract Comm. Services** Basic Communication Structure for Substations and Feeder Equipment Part 7-2: Abstract Communication Services (ACSI) Part 7-1: Principles and Models
Testing Part 10: Conform. Testing	**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

IEC TC 57
IEC TECHNICAL COMMITTEE

MMS: Manufacturing Massaging Specification

The Standard IEC 61850 - Edition 2

IEC 61850 ongoing work in IEC TC57

→ Extensions of the existing standards (Edition 2)

→ Addresses additional topics:

- → part 7-410 Hydroelectric power plants - Communication for monitoring and control
- → part 7-420 Communications systems for distributed energy resources (DER)
- → part 80-1 Guideline to exchange information from a CDC based data model using IEC 60870-5-101/104
- → part 90-1 Using IEC 61850 for the communication between substations
- → part 90-2 Using IEC 61850 for the communication between substations and control centres
- → part 90-3 Condition Monitoring
- ~~→ part 90-4 Communication Network Engineering Guideline~~
- → part 90-5 Use of IEC 61850 to transmit synchrophasor information

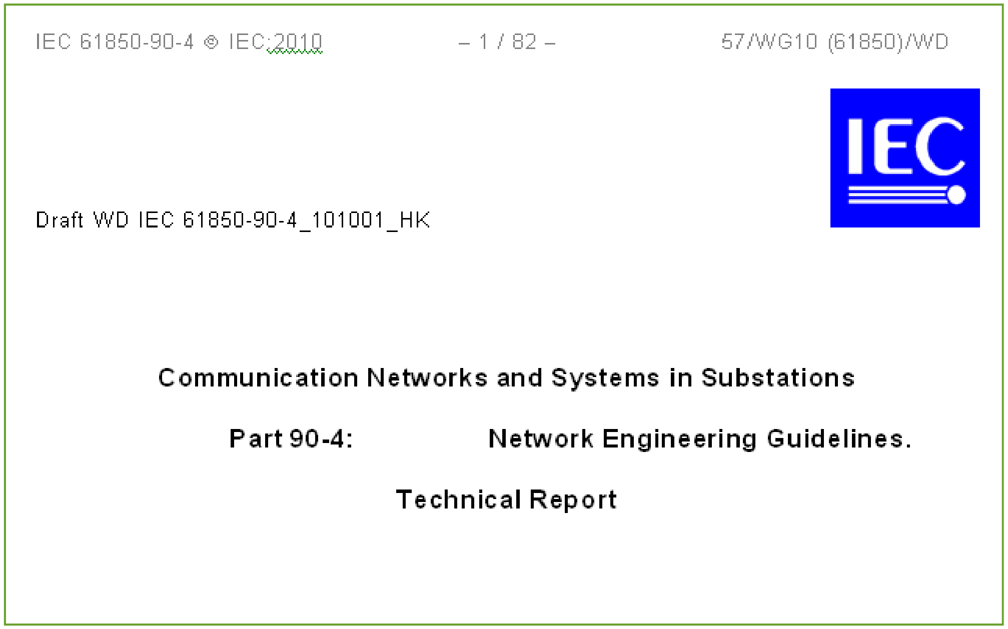
→ Target: approval in 2012 - 2013

IEC 61400-25: Communications for monitoring and control of wind power plants

→ based on IEC 61850

Hirschmann Is an Active Contributor IEC 61840

Communication Network Engineering Guideline


IEC 61850-90-4 © IEC:2010 – 1 / 82 – 57/WG10 (61850)/WD

Draft WD IEC 61850-90-4_101001_HK

Communication Networks and Systems in Substations

Part 90-4: Network Engineering Guidelines.

Technical Report

IEC TC 57

IEC TECHNICAL COMMITTEE

Provides definitions and specifications for the Ethernet network architecture of IEC 61850 based systems.

Network Engineering Guideline

CONTENTS

Network Engineering Guideline

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IEC 61850 Traffic Classes
MMS, GOOSE, SV
Station Bus and Process Bus

Network Engineering Guideline

CONTENTS

Criteria to be considered when planning a substation network

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Network Engineering Guideline

CONTENTS

Introduction to Ethernet specific aspects
(cabling, physical layer, filtering, QoS, VLANs, redundancy)

Network Engineering Guideline

CONTENTS

Reference Topologies for station bus and process bus
(star, ring, bus, mesh, …)

Network Engineering Guideline

CONTENTS

IP addressing schemes

Network Engineering Guideline

CONTENTS

Latency and delay aspects

Network Engineering Guideline

CONTENTS

Traffic management
(multicast control, segmentation, VLAN management)

Network Engineering Guideline

CONTENTS

Time synchronization
(use of NTP, PPS, IRIG-B, PTP)

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Network Engineering Guideline

CONTENTS

Network management
(use of SNMP, 61850 services)

Network Engineering Guideline

CONTENTS

Testing the communication network

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Network Engineering Guideline

CONTENTS

Case studies:
IEC 61850 project examples

Hirschmann Contributes to Many Standards

Hirschmann is actively working in many standardization organizations:

- Member of **DKE K 952** (German national committee „Netzleittechnik“)
- Member of **IEC TC57 WG10** (Power system IED communication and associated data models)
- Member of **IEC SC65C WG 15** (High Availability Automation Networks)
- Member of **IEEE1588** (Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems)
- Contributing to **IEEE PSRC H7** (IEEE 1588 Profile for Protection Applications)
- Working in **IEEE802.1** (LAN/MAN Standards Committee)

Contents

- IEC 61850
- Environmental Conditions ✓
- Communication Requirements
- Network Architecture

Substation Environmental Conditions

- Electric fields
- Magnetic fields
- Electrostatic discharge
- High energy power surges
- Ground potential rise during ground faults
- Temperature & humidity
- Vibration
- Condensation

Some More Examples

RFI Immunity Requirements

- IEC 61850-3 Communications Systems and Networks in Substations (Section 5.7)
- IEEE 1613 - IEEE Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations

EMI for Substations

- IEC 61850-3 Communications Networks and Systems in Substations – Part 3: General Requirements.

- *General immunity standard:*
  - *IEC 61000-4-x* *series basic immunity standard*
  - *IEC 61000-6-2/-4* *for industrial devices*
  - *IEC 61000-6-5* *special enhancements for substations*

EMI Immunity Requirements

IEC 61850-3 — Communications Networks and Systems in Substations – Part 3: General Requirements

↑

IEC 61000-6-5 — Immunity for Power Station and Substation Environments

↑

IEC 61000-6-2/-4 — for industrial devices

↑

IEC 61000-4-x Series — Basic Immunity Standards

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Climatic Requirements – IEC 61850

1. Class A: air-conditioned locations
2. Class B: heated or cooled enclosed conditions
3. Class C: sheltered locations
4. Class D: outdoor locations

Class C Operating Temperature Ranges:

1. Class C1: -5 to +45°C
2. Class C2: -25 to +55°C
3. Class C3: -40 to +70°C
4. Class Cx: Special (defined by manufacturer)

What about the network equipment?

- No “standard” substation switch
- The network should not be the weakest link
- Switches must pass the same EMI tests as the IEDs

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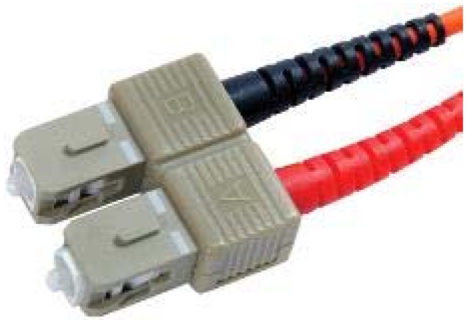
Transmission Media

Fibre

- Immunity to electrical interference
- Avoidance of ground loops
- Large bandwidth
- Extended distances



- **Copper**
  - Control room cabinets
  - Links to IEDs

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- ✓ **IEC 61850**
- ✓ **Environmental Conditions**
- **Communication Requirements**
- **Network Architecture**

Logical communication substation

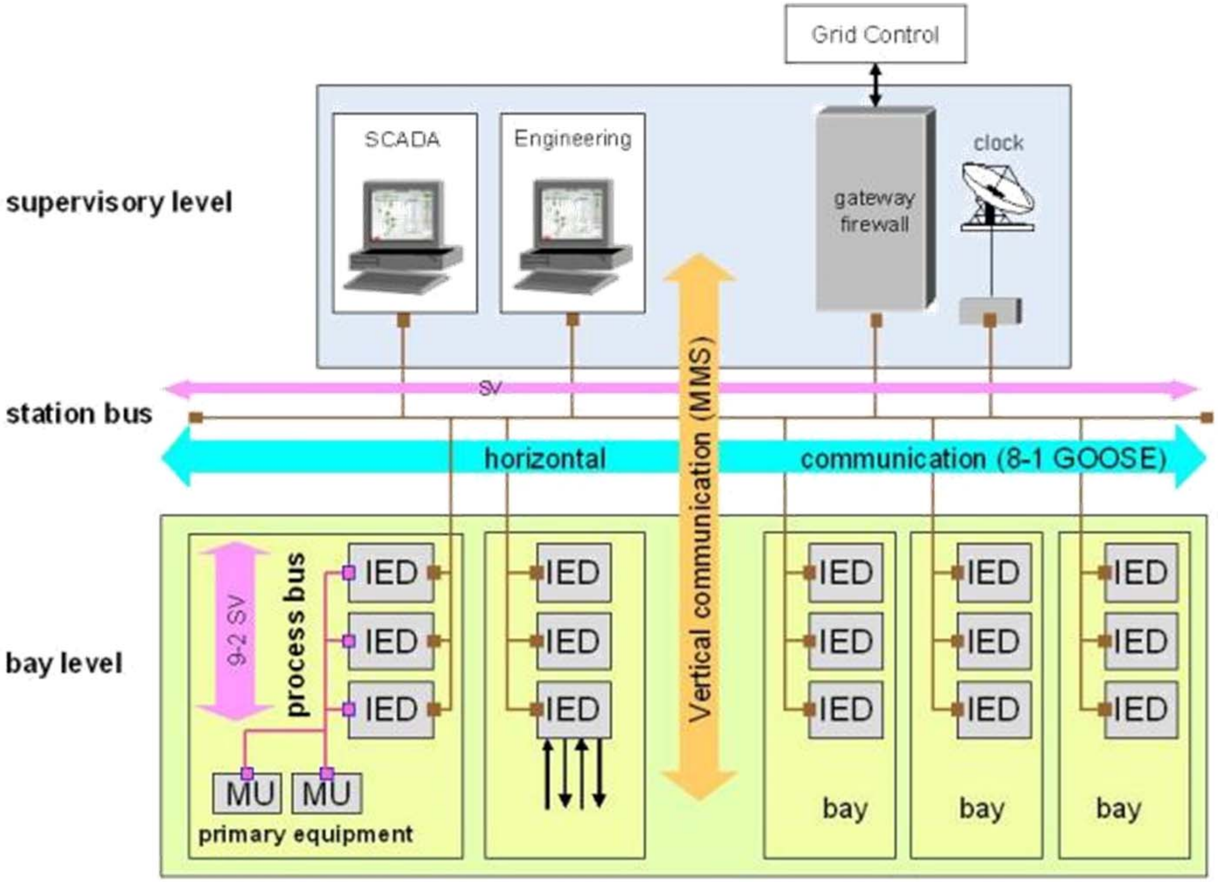


Figure 8 – Station Bus, Process Bus and traffic example

Source: Working Draft IEC TR 61850-90-4

Logical communication substation

- **Vertical**
  - Bay to Substation level
  - Control and monitoring
  - Client / Server
  - →**Low priority**

- **Horizontal**
  - Time critical data between IEDs
  - Automation
  - → **High priority**

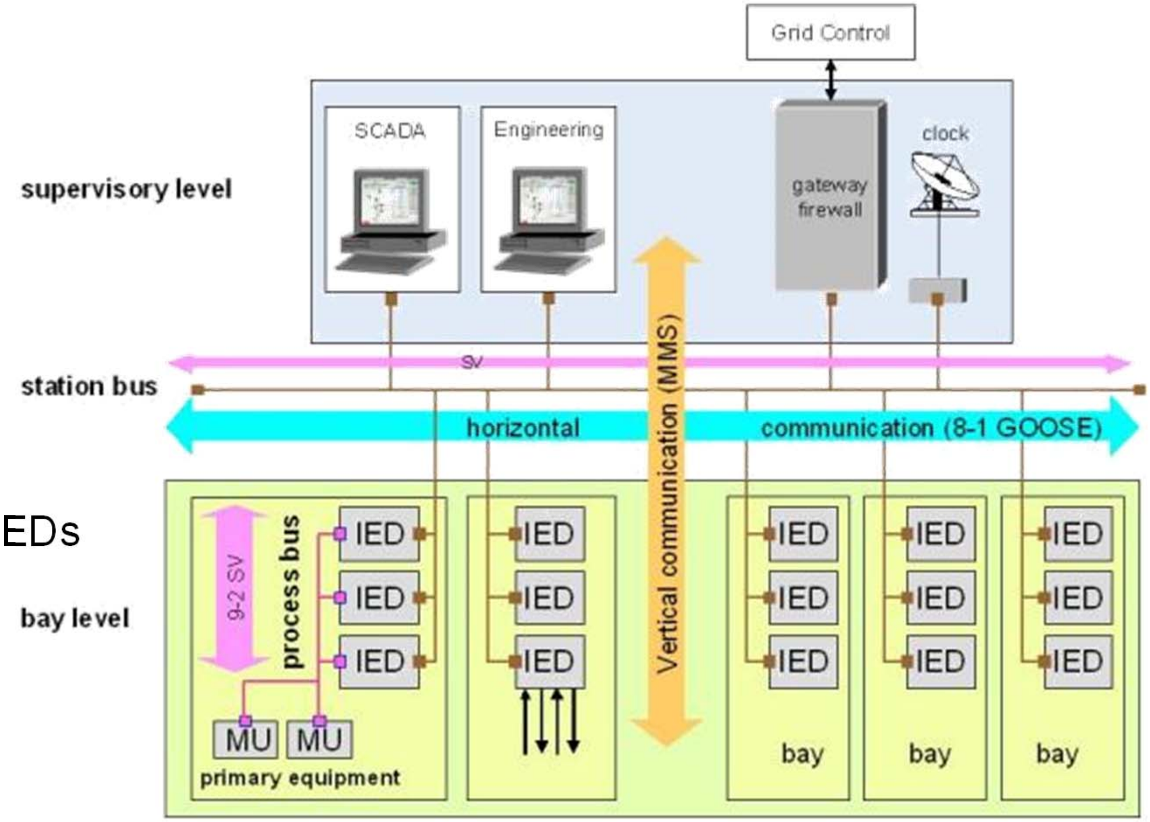
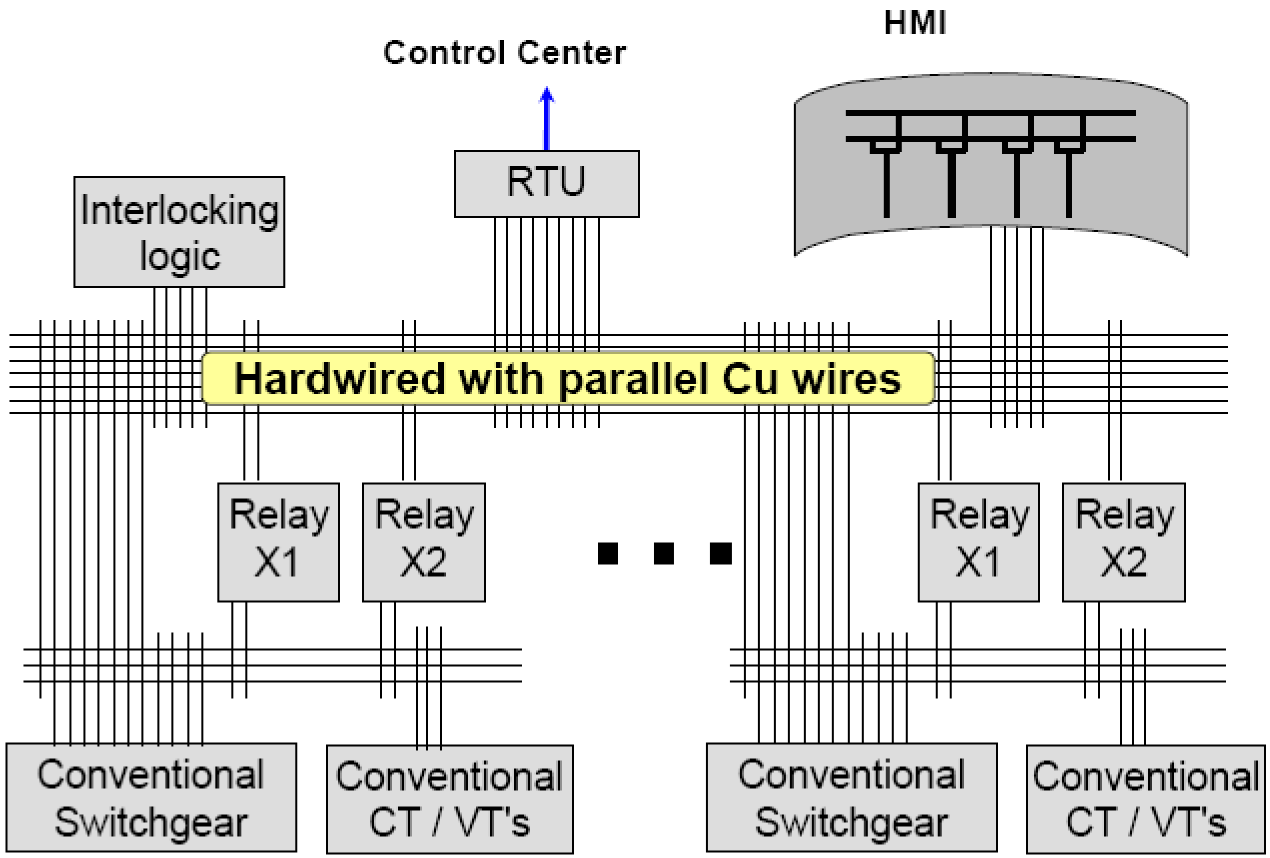


Figure 8 – Station Bus, Process Bus and traffic example

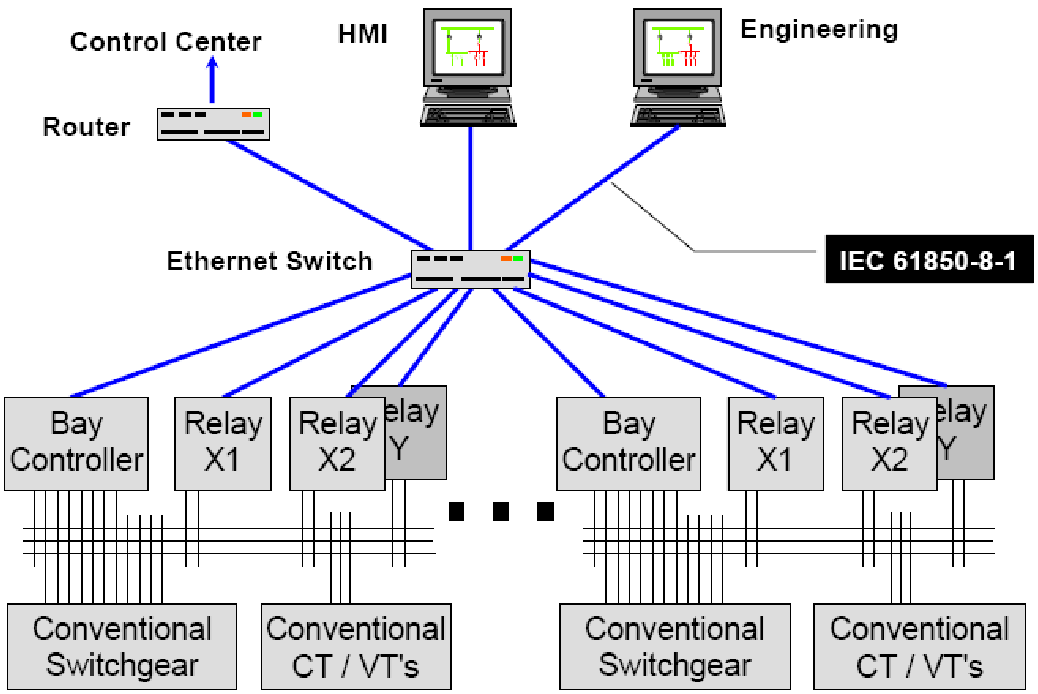
Communication- conventional cabling (yesterday)



Source: UT Innovation, Netted Automation

Communication - Station bus LAN
Process bus conventional (today)

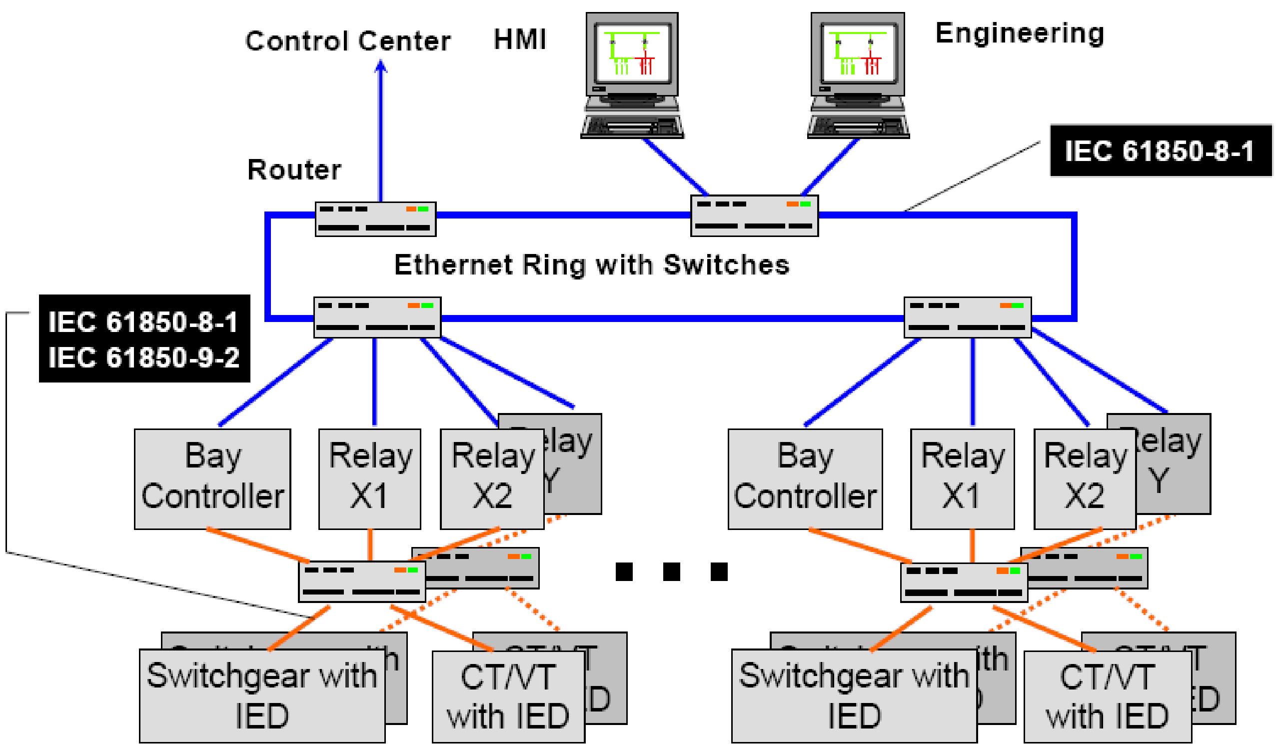
Substation – Station bus LAN / Process level conventional (today)



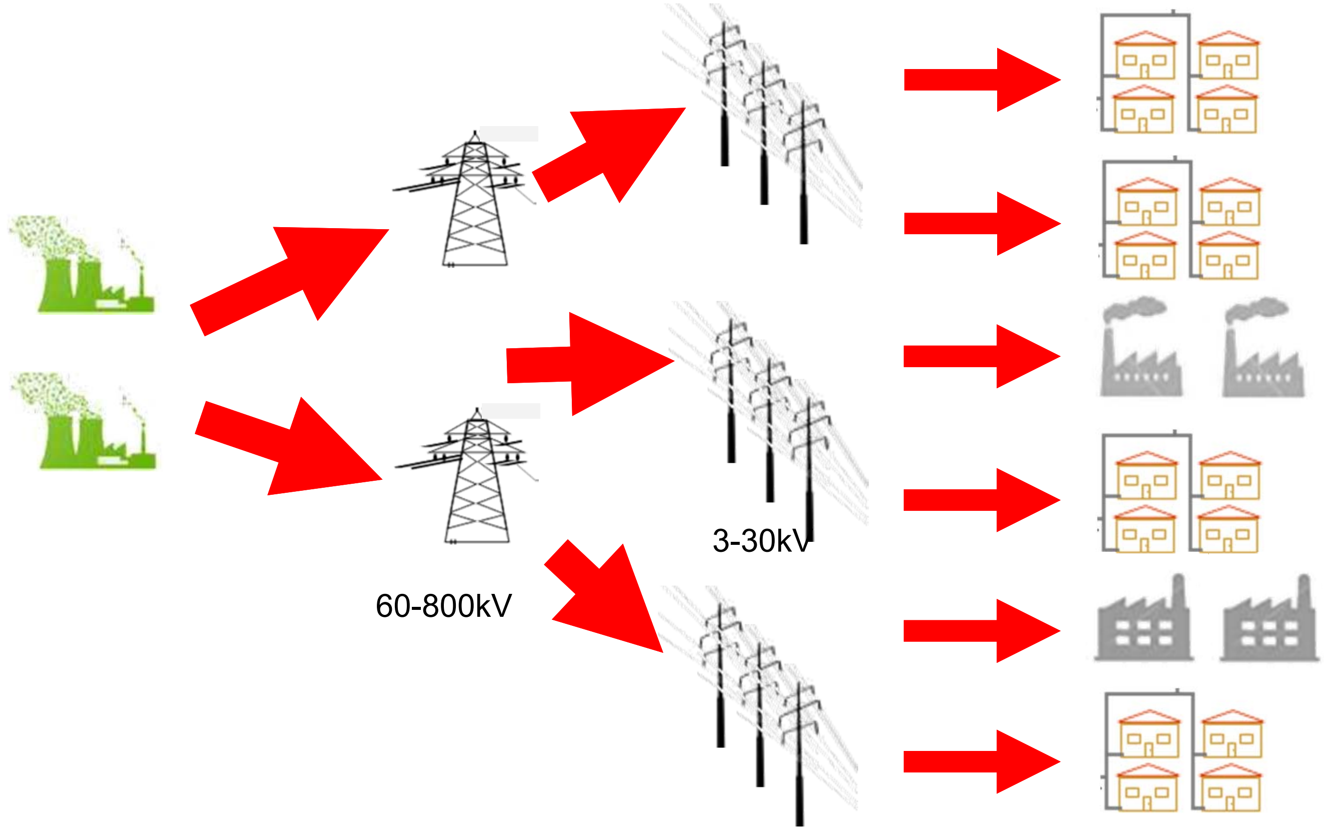
Source: UT Innovation, Netted Automation

Communication- Station and Process LAN (future)

Substation – Station and Process LAN (tomorrow)

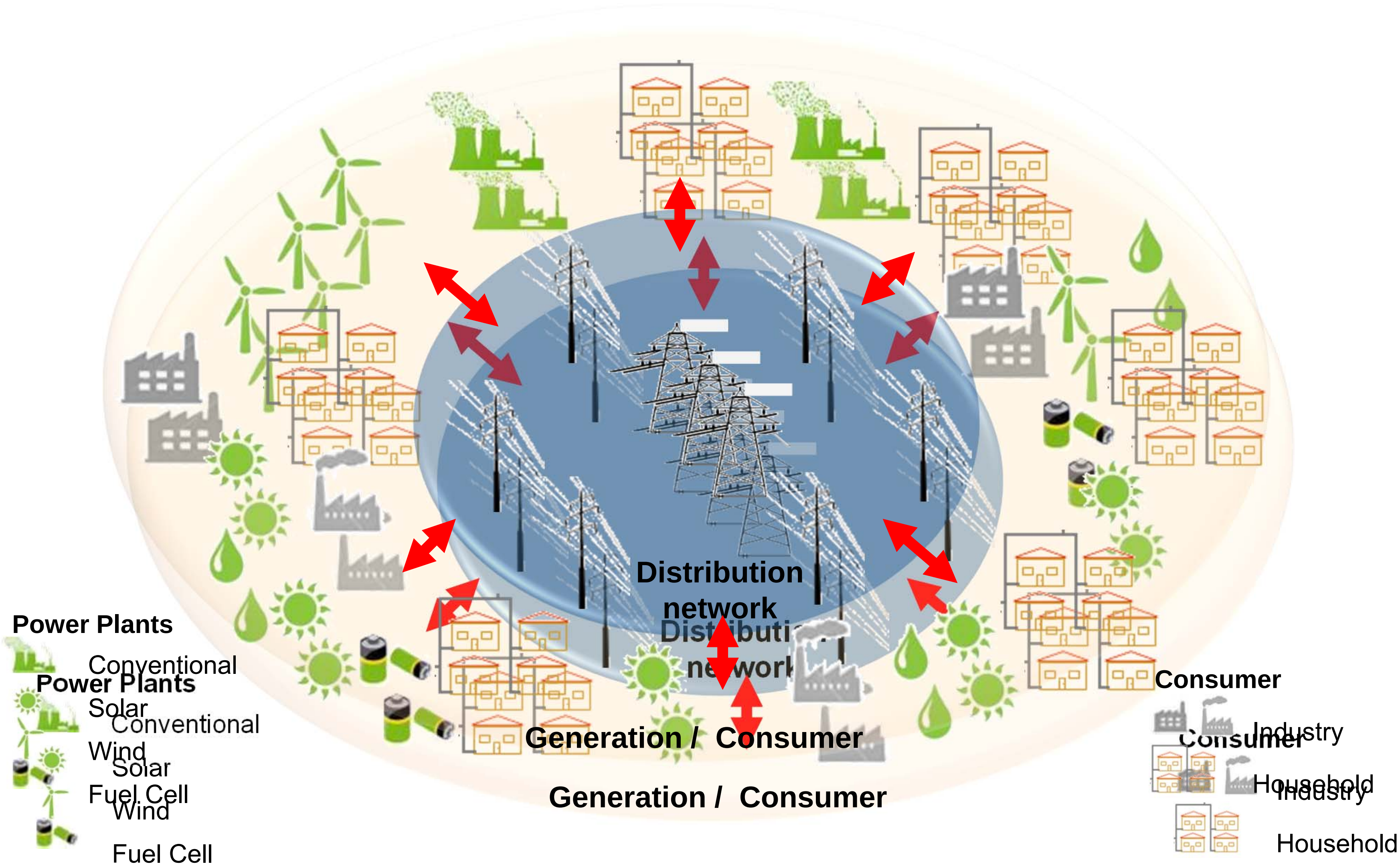


Power Distribution - In the Past



Power Generation ------------ **T&D Network** --------------- **Consumer**

Power Distribution - In the Future (present)



Decentralized Power Generation and Smart Grid

- Decentralized power generation is increasing strongly
  - ➔ Photovoltaic
  - ➔ Wind energy
  - ➔ Combined heat and power
  - ➔ Fuel cells
  - ➔ Biomass
  - ➔ Hydro power

Source: EWE AG

- Strong fluctuations of produced energy results in need of
  Decentralize **E**nergy **M**anagement **S**ystem
  to balance supply and demand in real time
  = SMART GRID

→ **IT and communication are necessary**

IEC 61850 Communication

Management

- MMS: monitoring device information
- MMS: Reports

„Fast Event

- Ethernet: IEC 61850 GOOSE

Sensor data

- Ethernet: Sampled Values

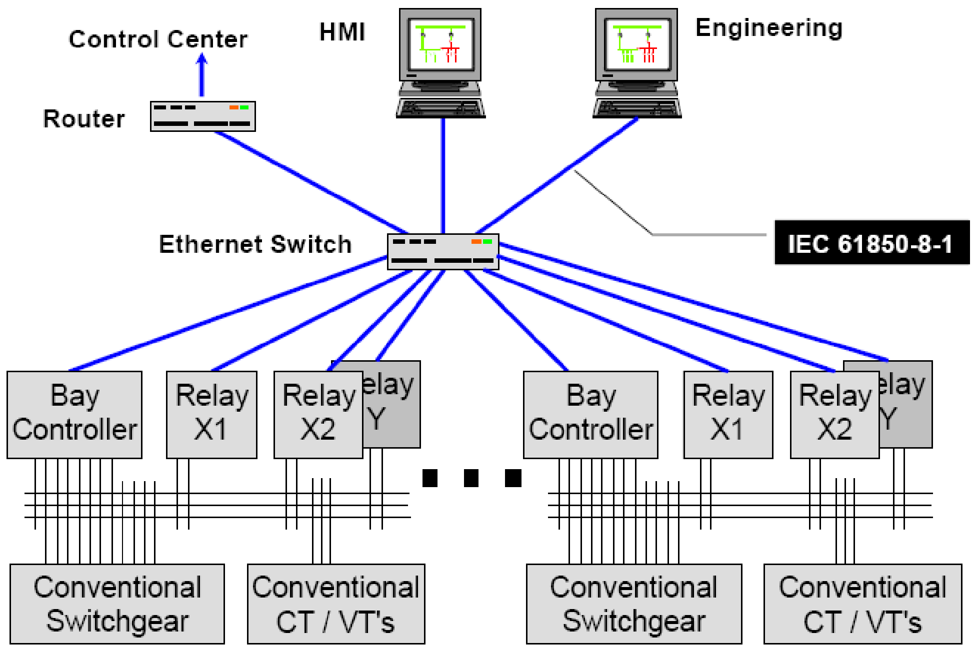
MMS = Manufacturing Messaging Specification

GOOSE = Generic Object Oriented Substation Event

IEC 61850 Communication → today

Sampled Values and GOOSE: High MAC Multicast traffic

Today: GOOSE Multicasts on Station level approx. 10-20 devices
→ network uncritical



Source: UTInnovation & NettedAutomation

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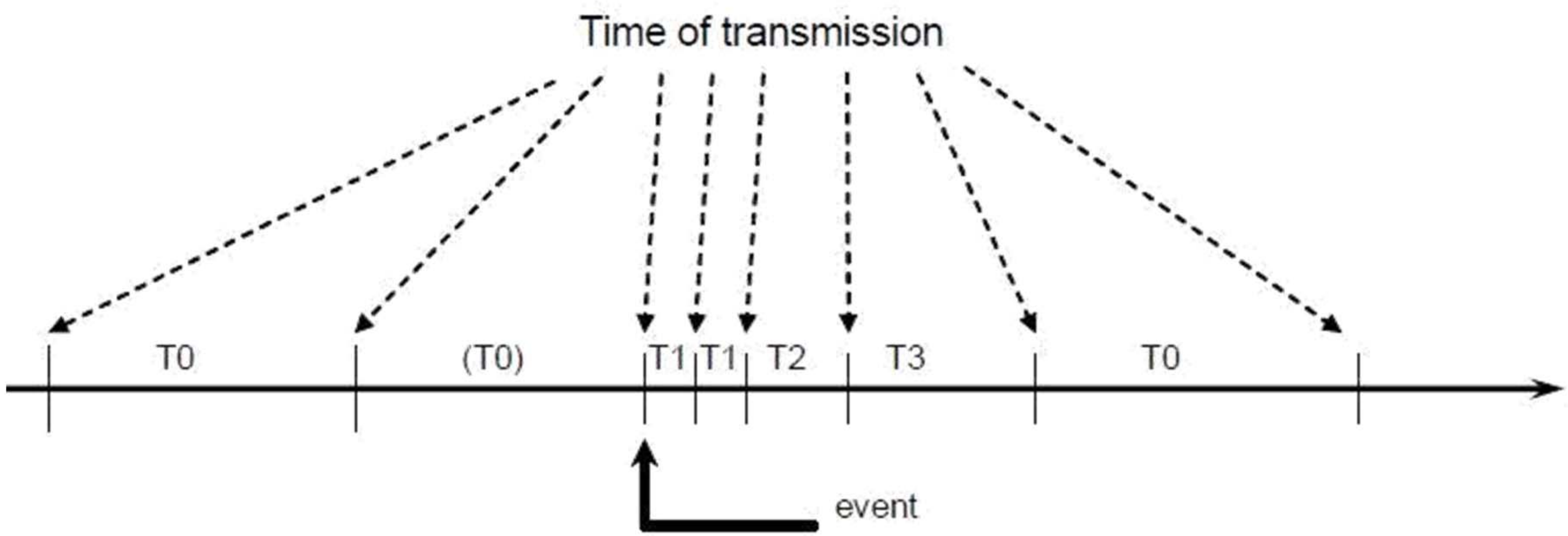
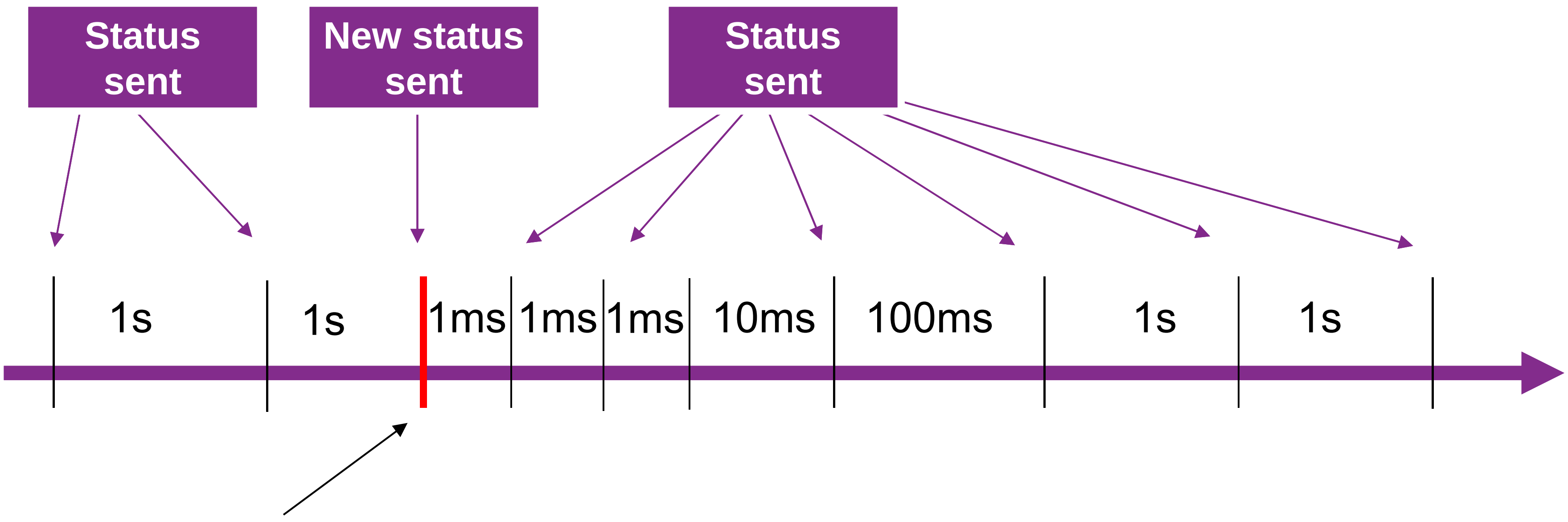
Adaptive GOOSE Transmission Time



T0	retransmission in stable conditions (no event for a long time).
(T0)	retransmission in stable conditions may be shortened by an event.
T1	shortest retransmission time after the event.
T2, T3	retransmission times until achieving the stable conditions time.

IEC 142/04

Adaptive GOOSE Transmission Time



Settings application specific

Shortest GOOSE transmission time 1ms (triple-GOOSE)

Timing requirement 12ms:

application	→ application
event	→ reaction
lightning strike	→ open protection relay

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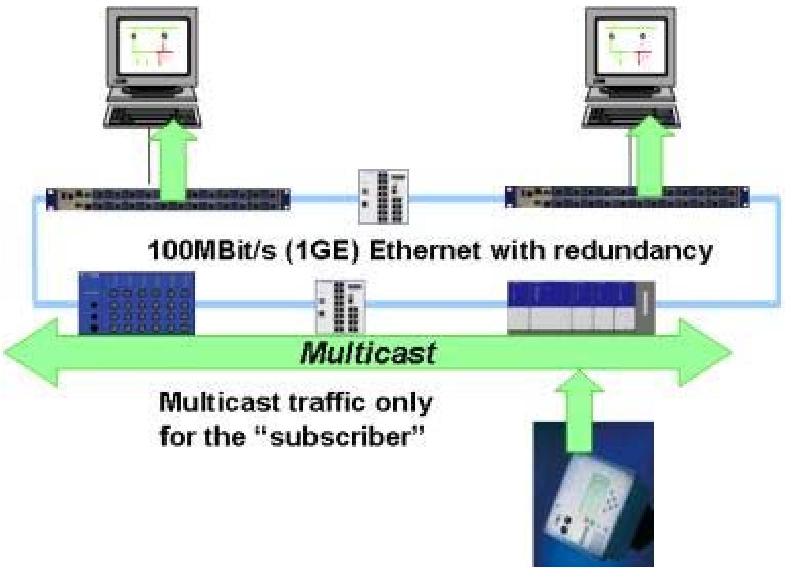
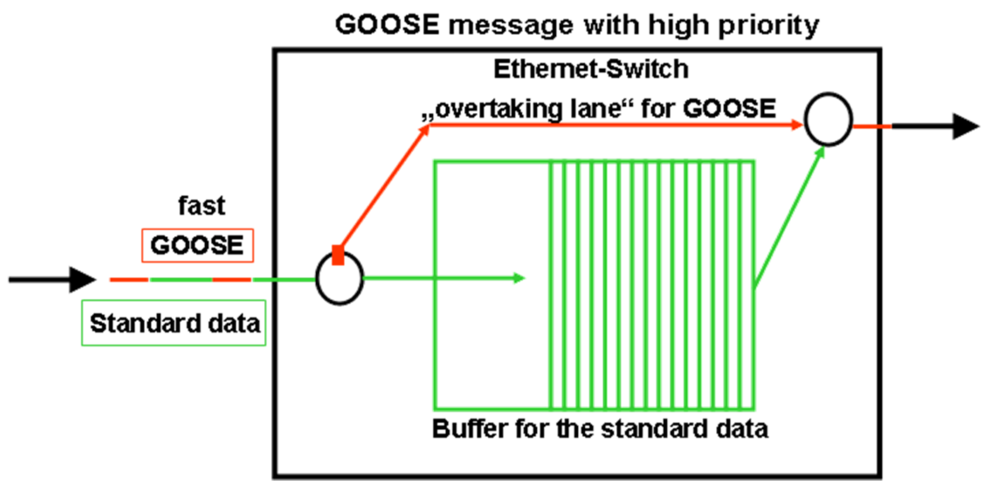
GOOSE protocol
Fast and efficient communication

- Prioritization
- multicast

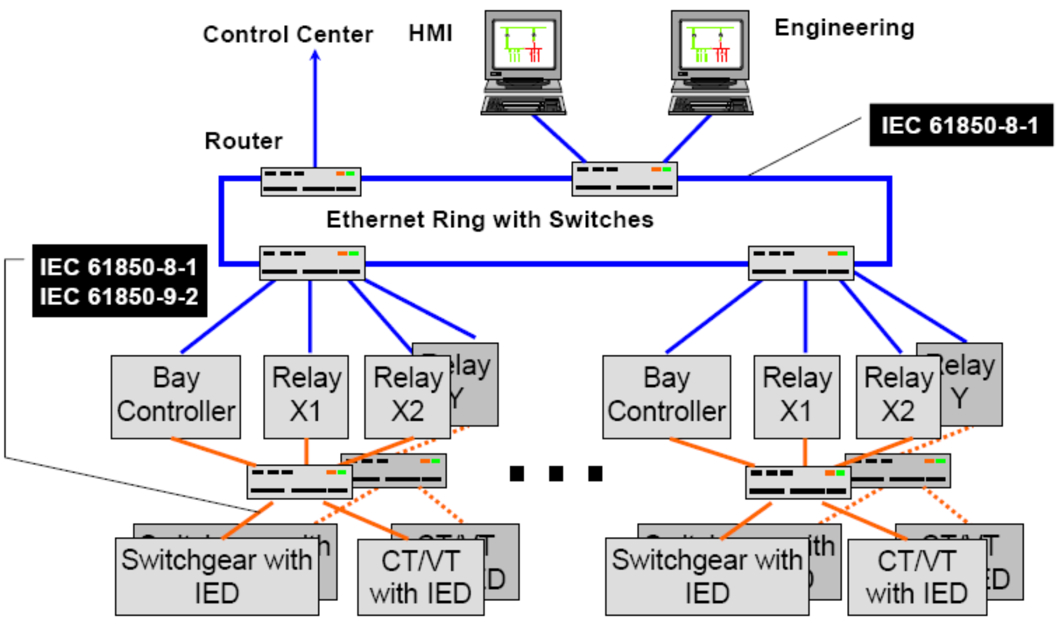




GOOSE (Generic **O**bject **O**riented **S**ubstation **E**vent)

IEC 61850 Communication → future

Future: Sampled Values and GOOSE communication via Ethernet network
→ new technology necessary



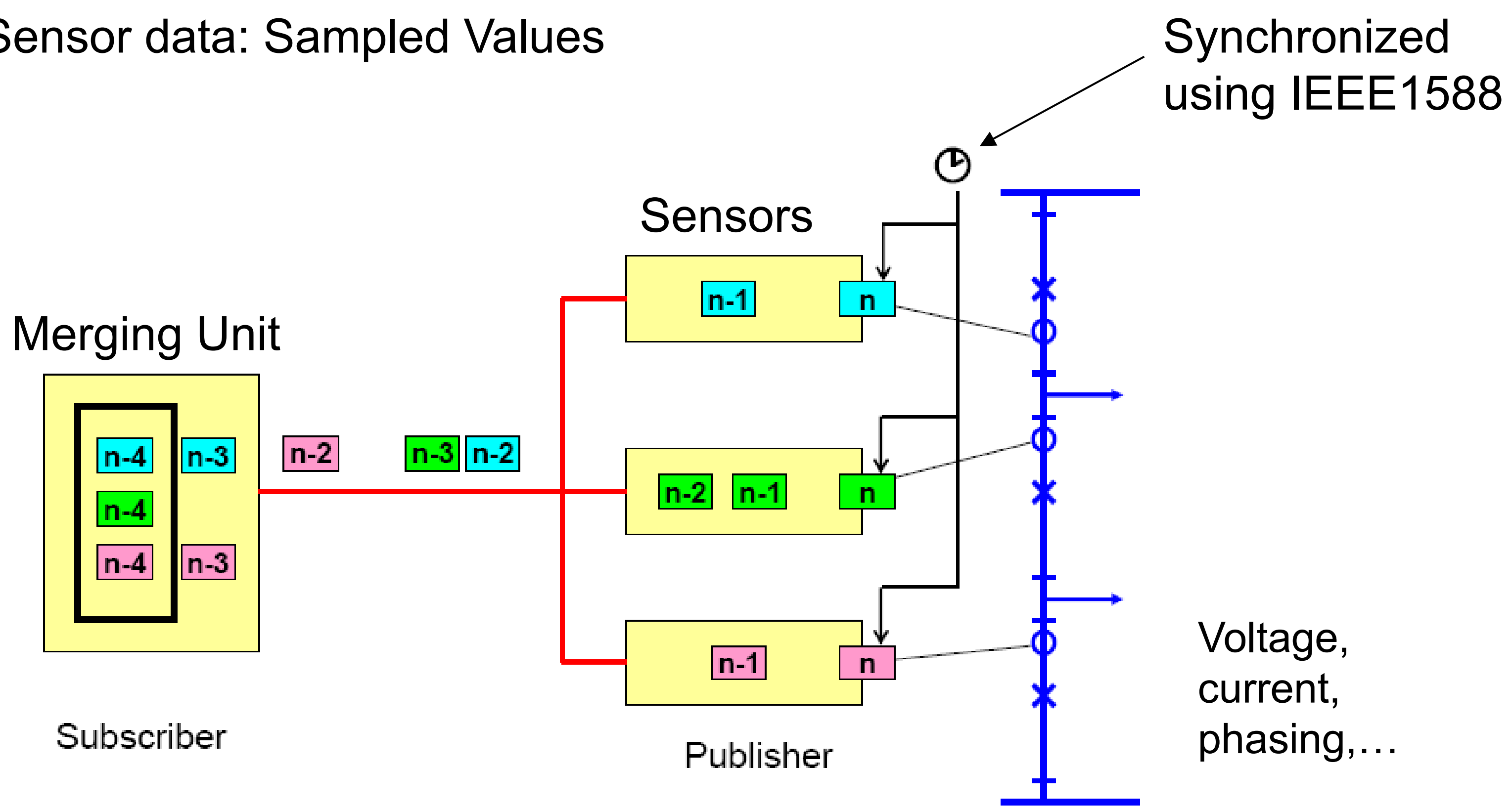
Source: UTInnovation & NettedAutomation

need for intelligent Multicast control (MMRP) to handle SV and GOOSE

→ Working group (61850-90-4)

IEC 61850 Communication

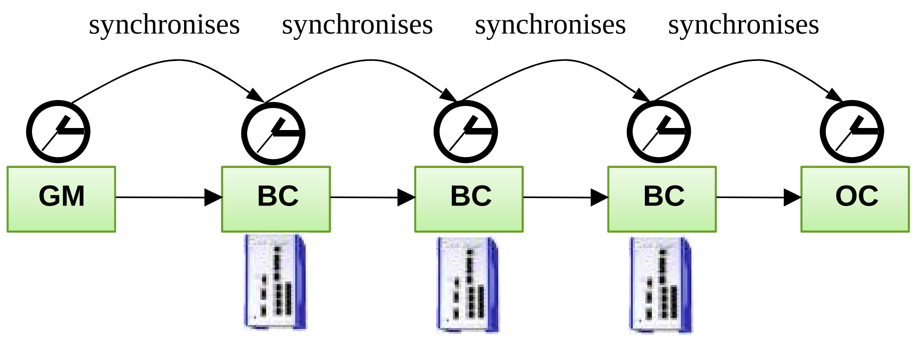
Sensor data: Sampled Values



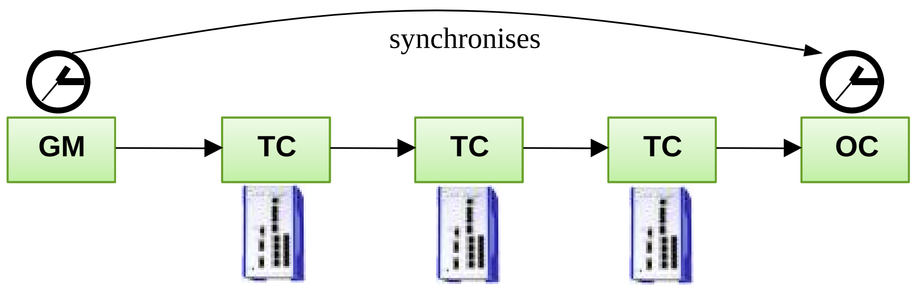
Source: UTInnovation & NettedAutomation

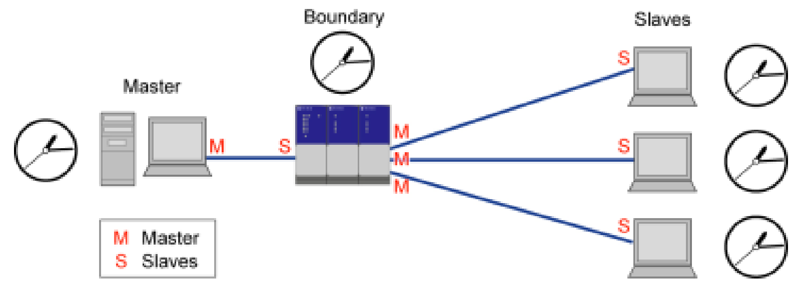
IEC 61850 Communication – IEEE1588 Time Synchronization

cascaded boundary clocks



cascaded transparent clocks





BC: point to point synchronization, cascading of control loops

TC: corrects only residence time, transparent for end devices (Grandmaster, Master, Ordinary Clock)

A TC causes less jitter in highly cascaded networks

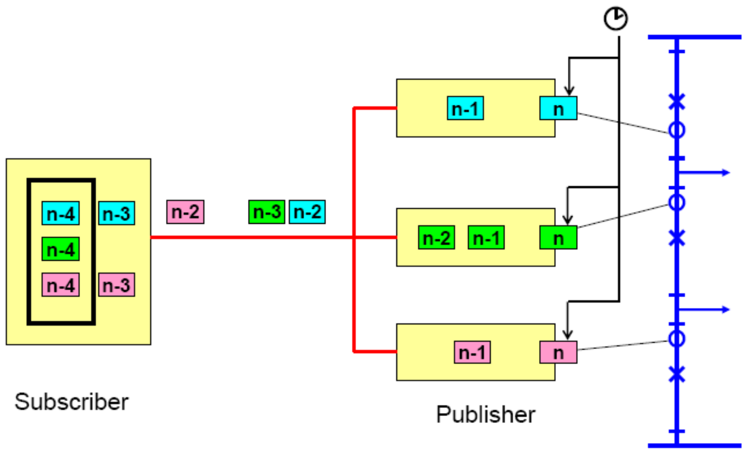
IEC 61850 Communication

Sensor data: Sampled Values

Each sensor data packet should reach the destination! (at least each second)

→ Special requirements for the redundancy
No data loss because of recovery times!

→ No recovery time is acceptable
RSTP, MRP or any other available technology does not fulfill the requirements.
…up to now



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- ✓ **IEC 61850**
- ✓ **Environmental Conditions**
- ✓ **Communication Requirements**
- **Network Architecture**

Network topologies

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Network topologies

The standard describes several topologies:

“These reference topologies were chosen based on common practice in substation automation systems ranging from small distribution systems to large multi-voltage level substations. They are representative of the various networking issues described in this document.
There is no ‘best’ network topology and no ‘best’ redundancy protocol.
They all have strengths and weaknesses and the correct choice for a given application depends on many factors.”
Source: IEC61850 Network Engineering Guideline

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Included in the Guideline are

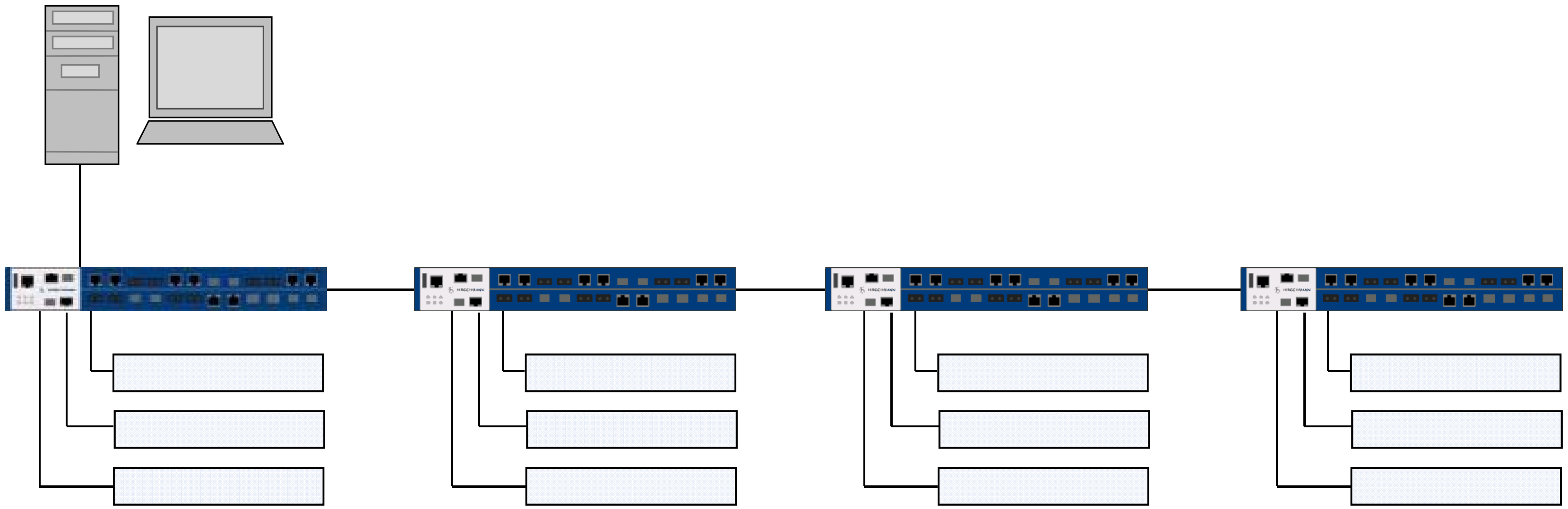
Topologies:

Star, Ring / Multi-Ring and double networks.
There is no clear recommendation but a trend to ring structures.

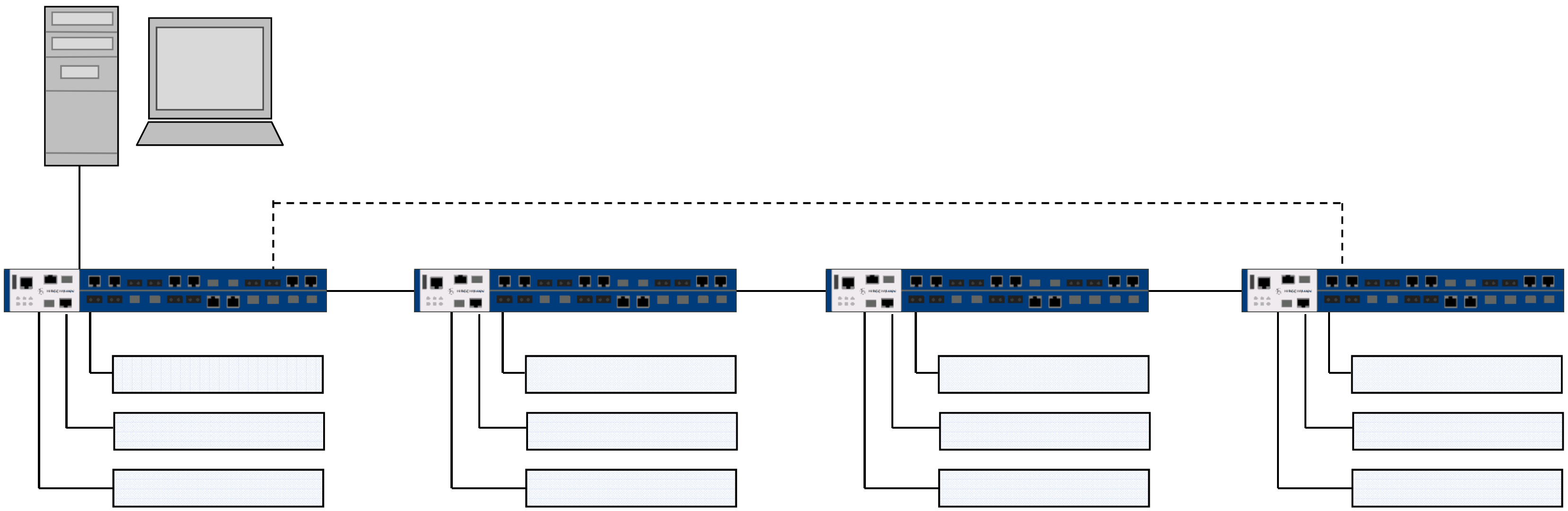
Redundancy technologies:

RSTP – IEC 62439-1
PRP
HSR

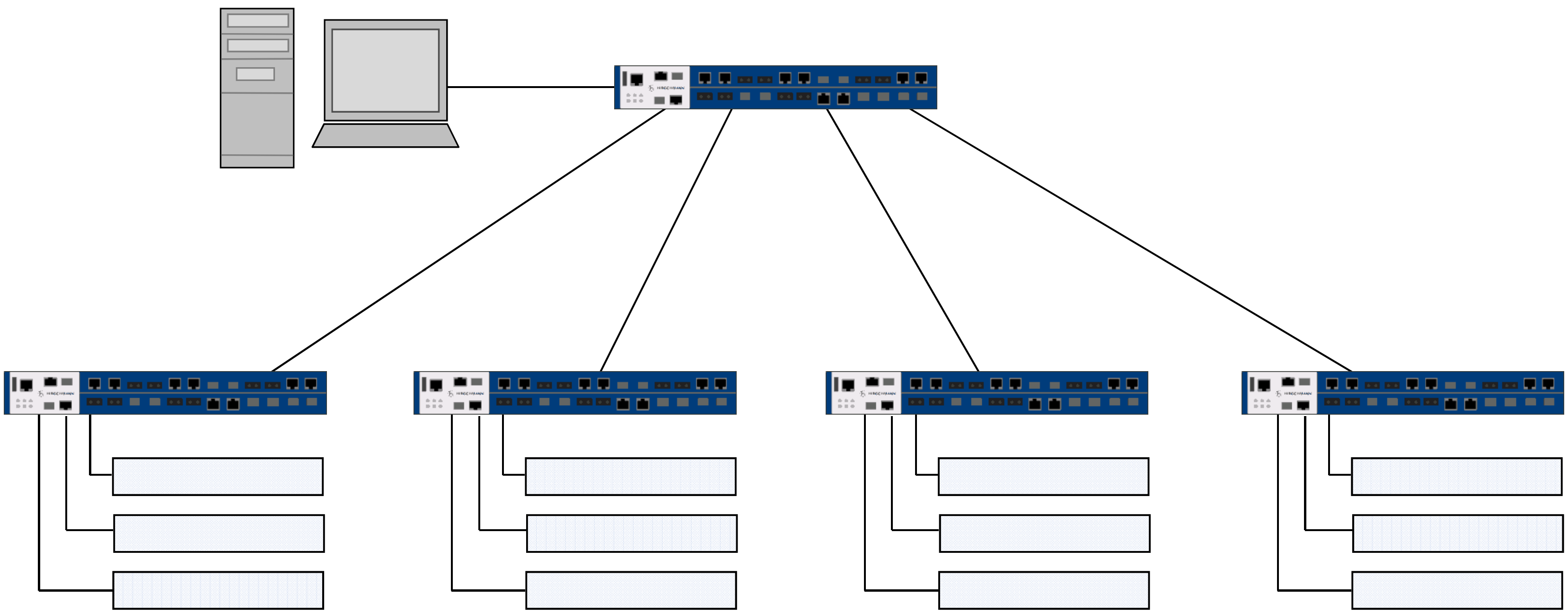
Cascade Architecture



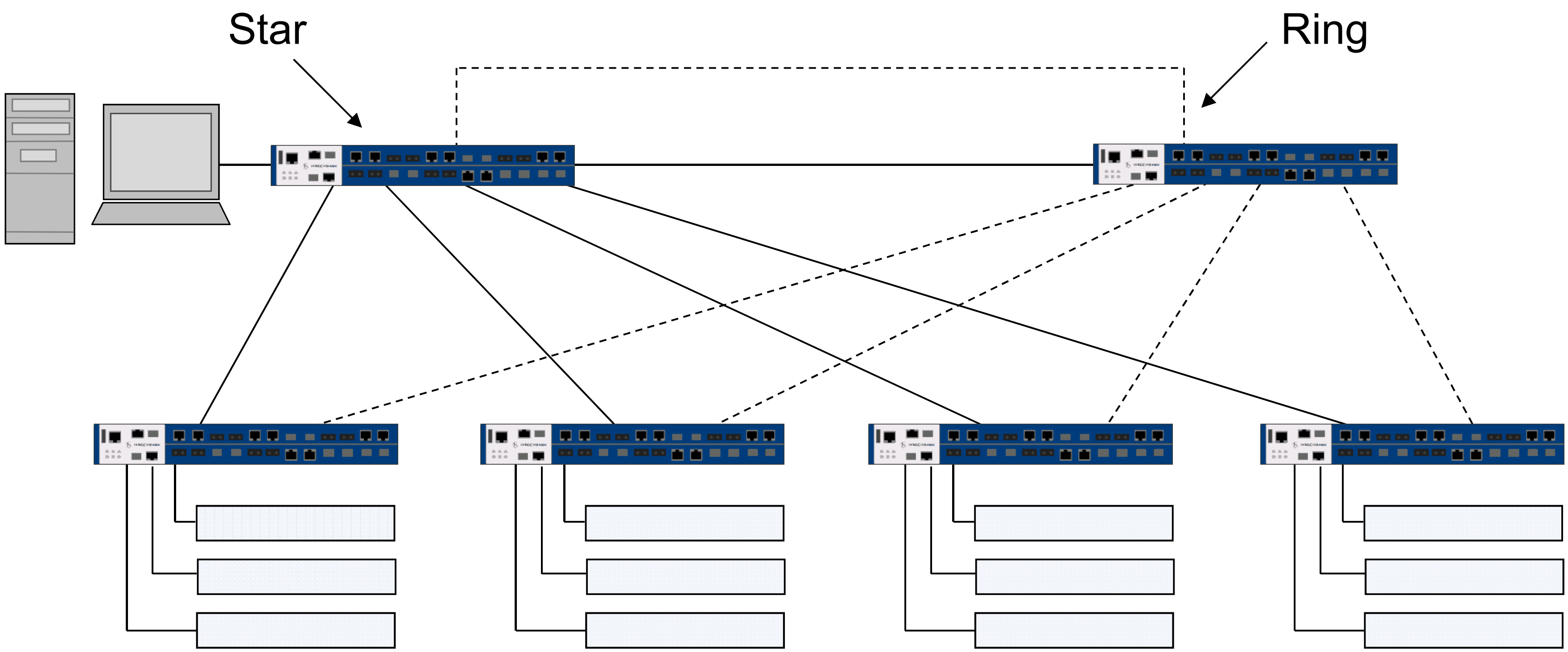
Ring Architecture



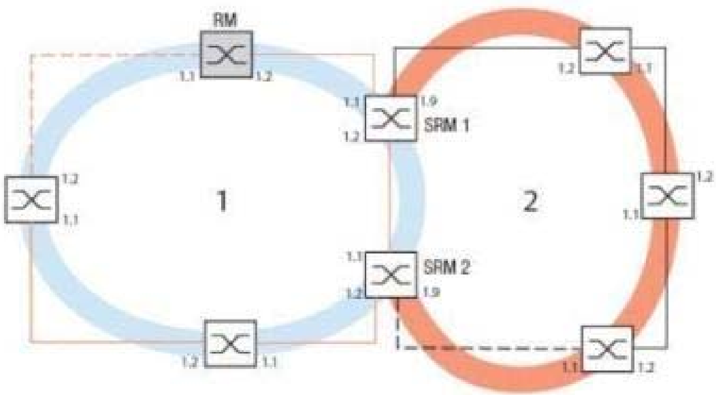
Star Architecture



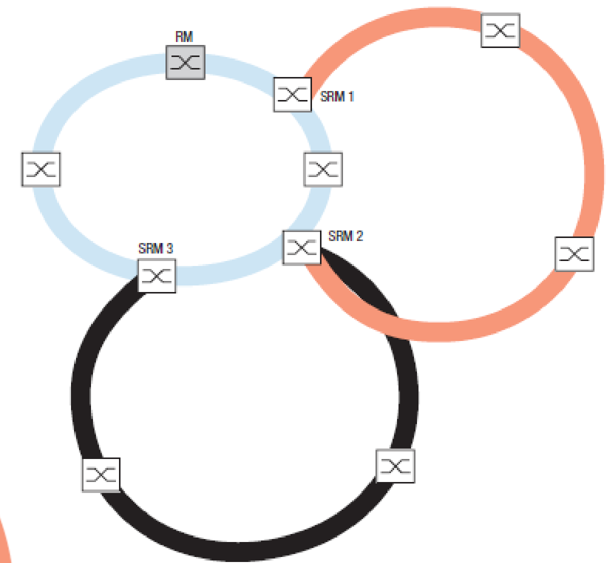
Hybrid Architecture

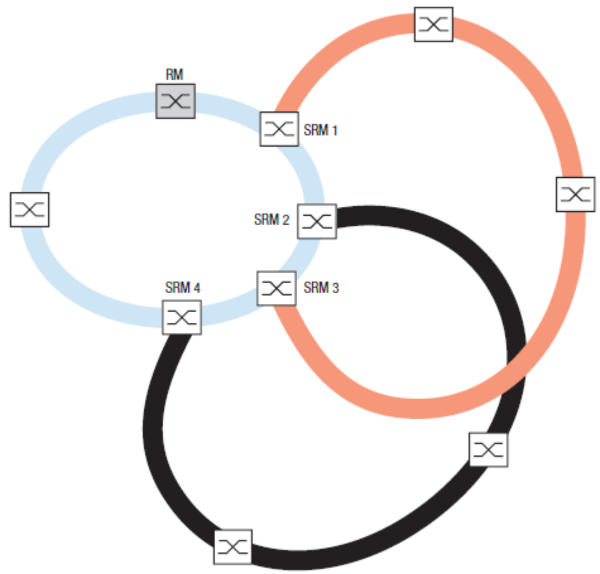


Ring Extension: Sub-Ring Concept



Example of a Sub-Ring structure
1 Blue ring = basis ring
2 Orange ring = Sub-Ring
SRM = Sub-Ring Manager
RM = Ring Manager





Based on RSTP

→ MRP + SRM?

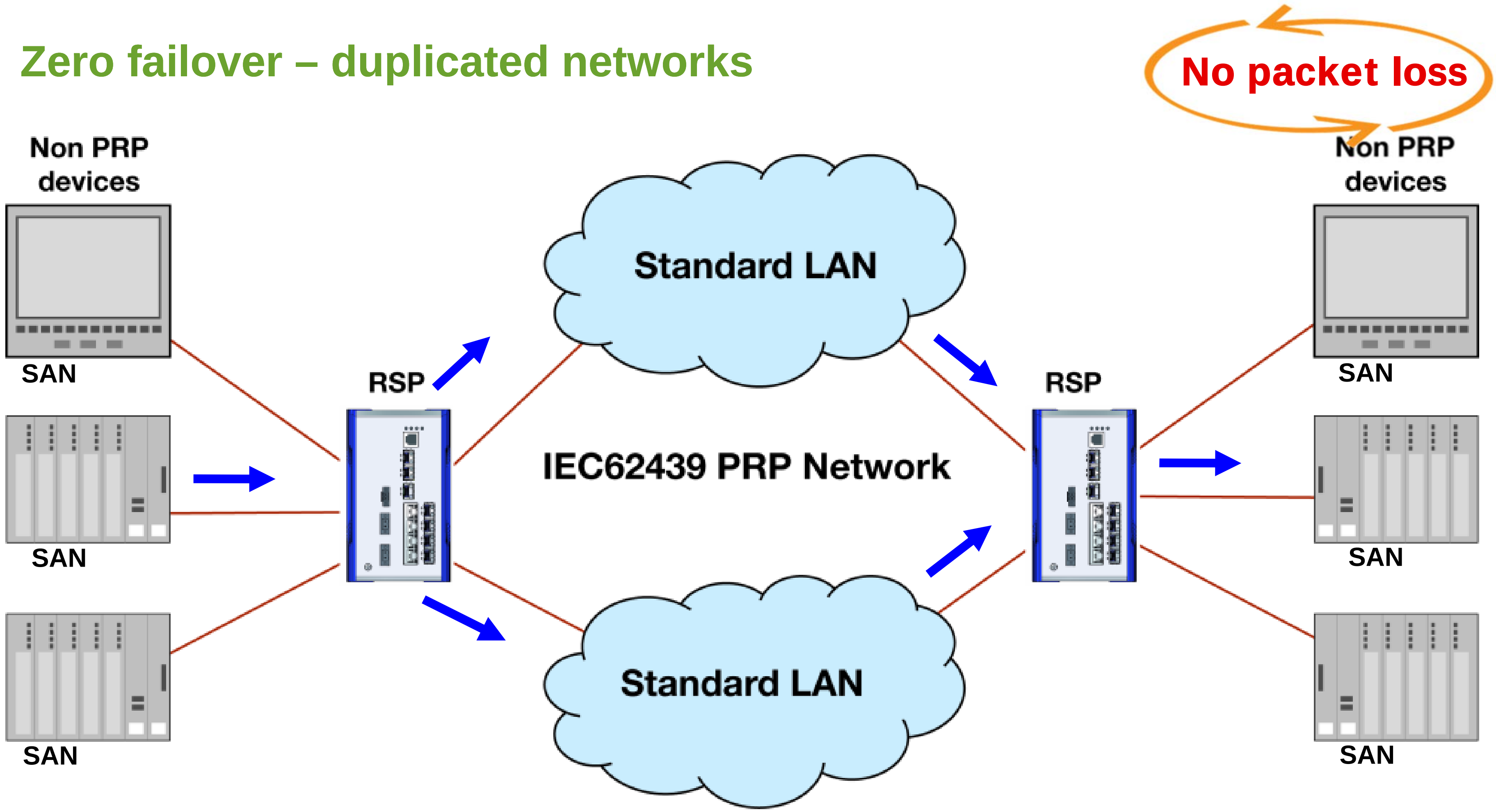
Comparison of Redundancy Protocols defined in IEC62439

Protocol		Most current Standard	Typical re-config	Remark	Available since
STP	Spanning Tree Protocol	IEEE 802.1d	30s	any topology/mesh, diameter limited	1990
RSTP	Rapid Spanning Tree Protocol	IEEE 802.1D-2004	2s	any topology/mesh, diameter limited	2004
CRP	Cross-Network Redundancy Protocol	IEC 62439-4:2010	1s worst case for 512 end nodes	any topology/ duplicated networks	2007
BRP	Beacon Redundancy Protocol	IEC 62439-5:2010	4...8ms worst case for 500 end nodes	Two top level switches with star, line or ring topologies	2007
DRP	Distributed Redundancy Protocol	IEC 62439-6:2010	100ms worst case for 50 switches	ring, double ring	2010
MRP	Media Redundancy Protocol	IEC 62439-2:2010	200ms worst case for 50 switches	ring	1998/2007
Fast MRP	Media Redundancy Protocol	IEC 62439-2:2010	30ms worst case for 50 switches 10ms worst case for 15 switches	ring	2010
Optimized RSTP	Rapid Spanning Tree Protocol	IEEE 802.1D-2004 (configuration requirements described in IEC 62439-1:2010)	5...20ms per switch	ring	2010
HSR	High-Availability Seamless Redundancy	IEC 62439-3:2012-07	0ms	ring	2010
PRP	Parallel Redundancy Protocol	IEC 62439-3:2012-07	0ms	any toplogy/ duplicated networks	2010

(1) pre-standard Hiper Ring since 1998, MRP since 2007
(2) pre-standard Fast Hiper Ring since 2007

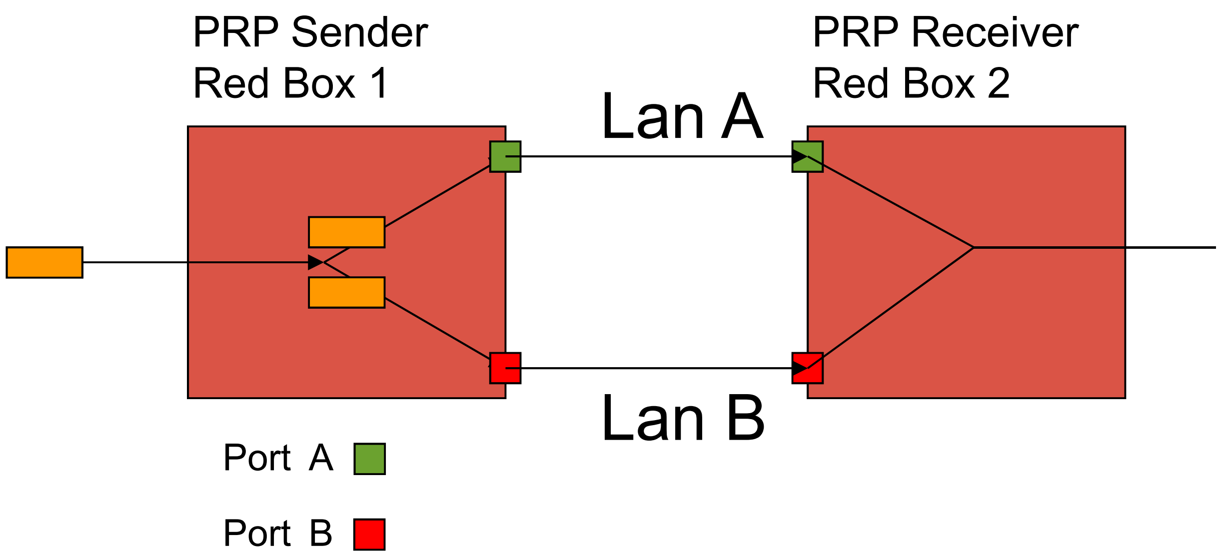
IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

Zero failover – duplicated networks



IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

Zero failover – duplicated networks

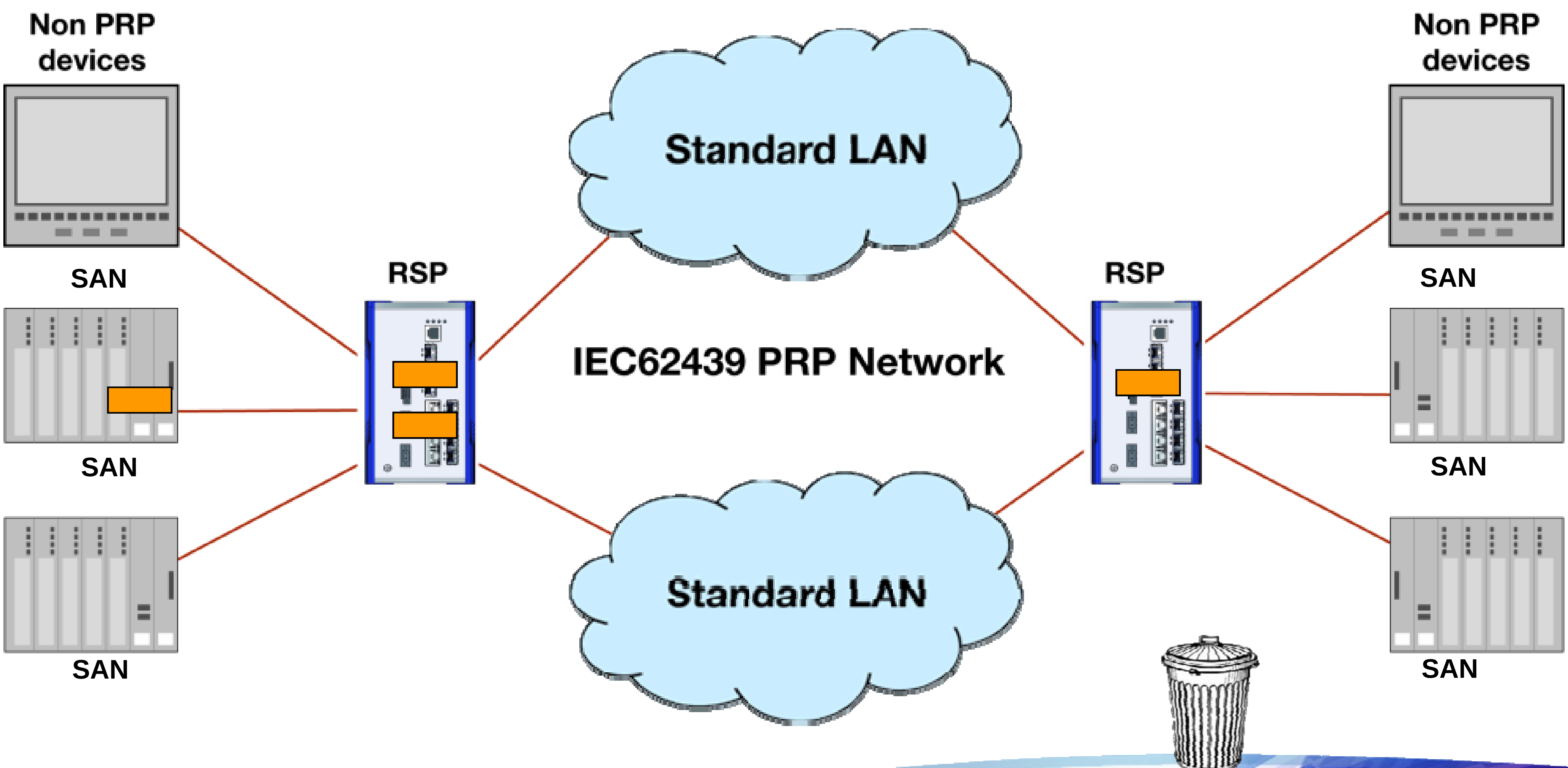


- Two redundant networks
- By doubling the packets no data loss if one packet fails
- PRP-Redundancy-Box = bidirectional splitter and combiner

IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

Zero failover – duplicated networks

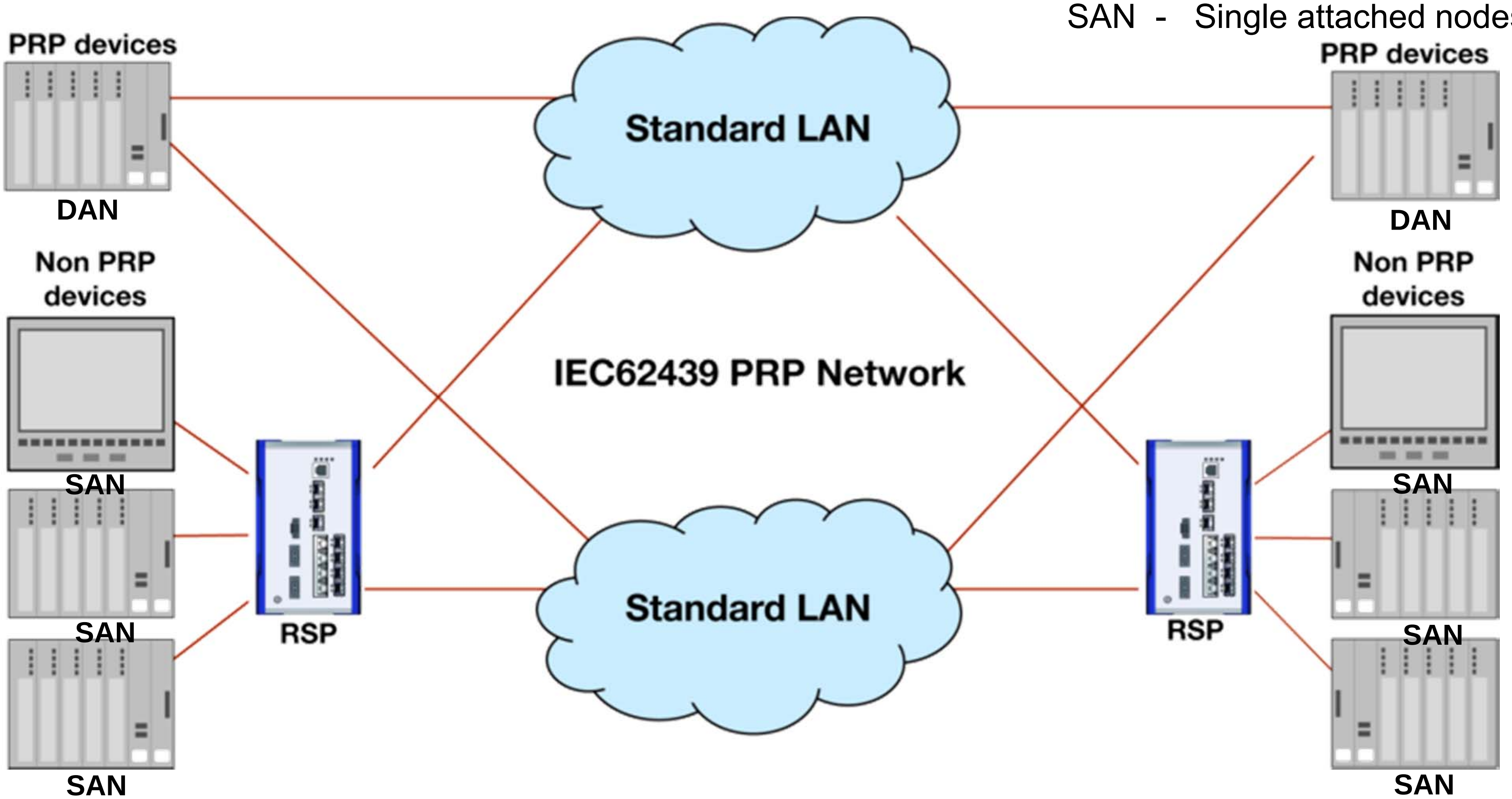
No packet loss



IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

DAN - Dual attached node implementing PRP
SAN - Single attached nodes

Zero failover – duplicated networks

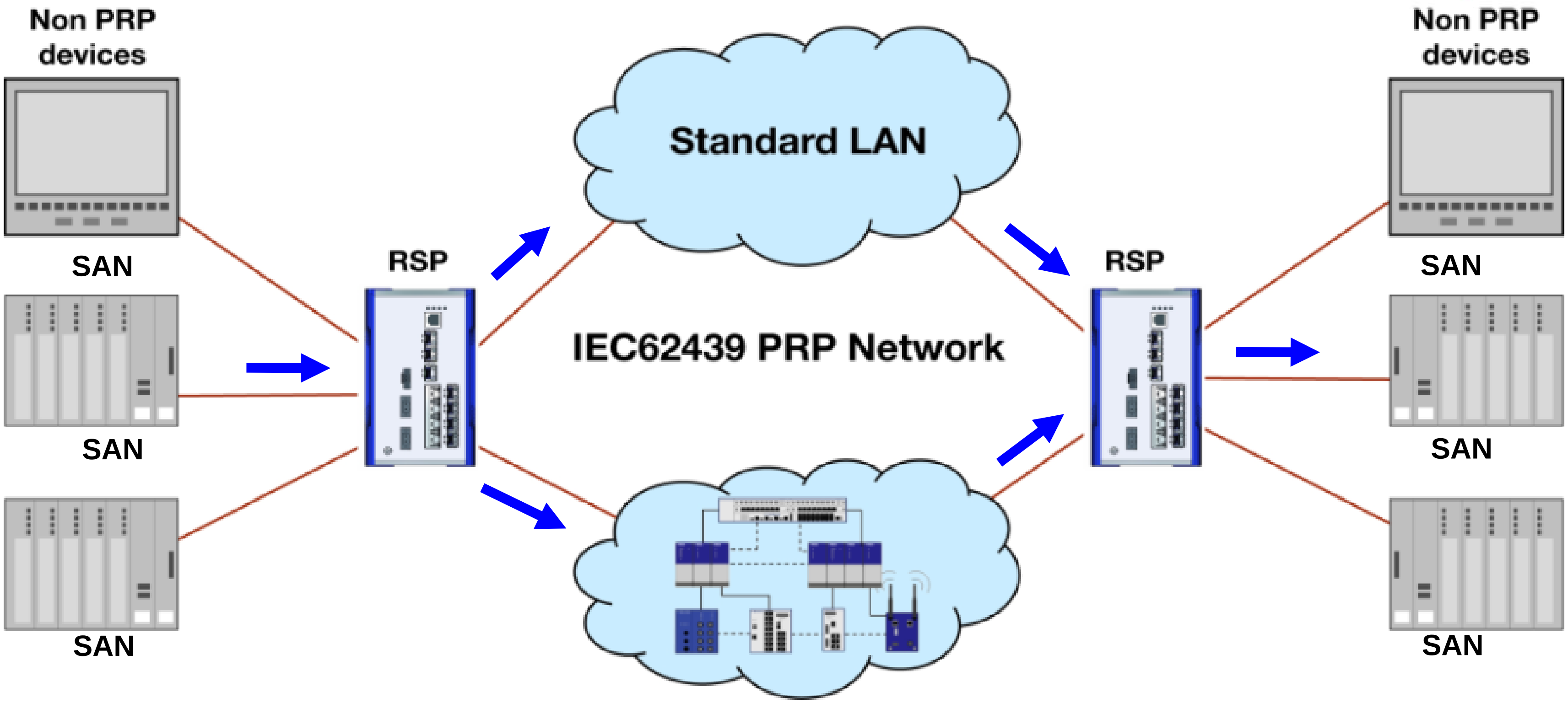


IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

Zero failover – duplicated networks

example standard LAN with RSTP

No packet loss

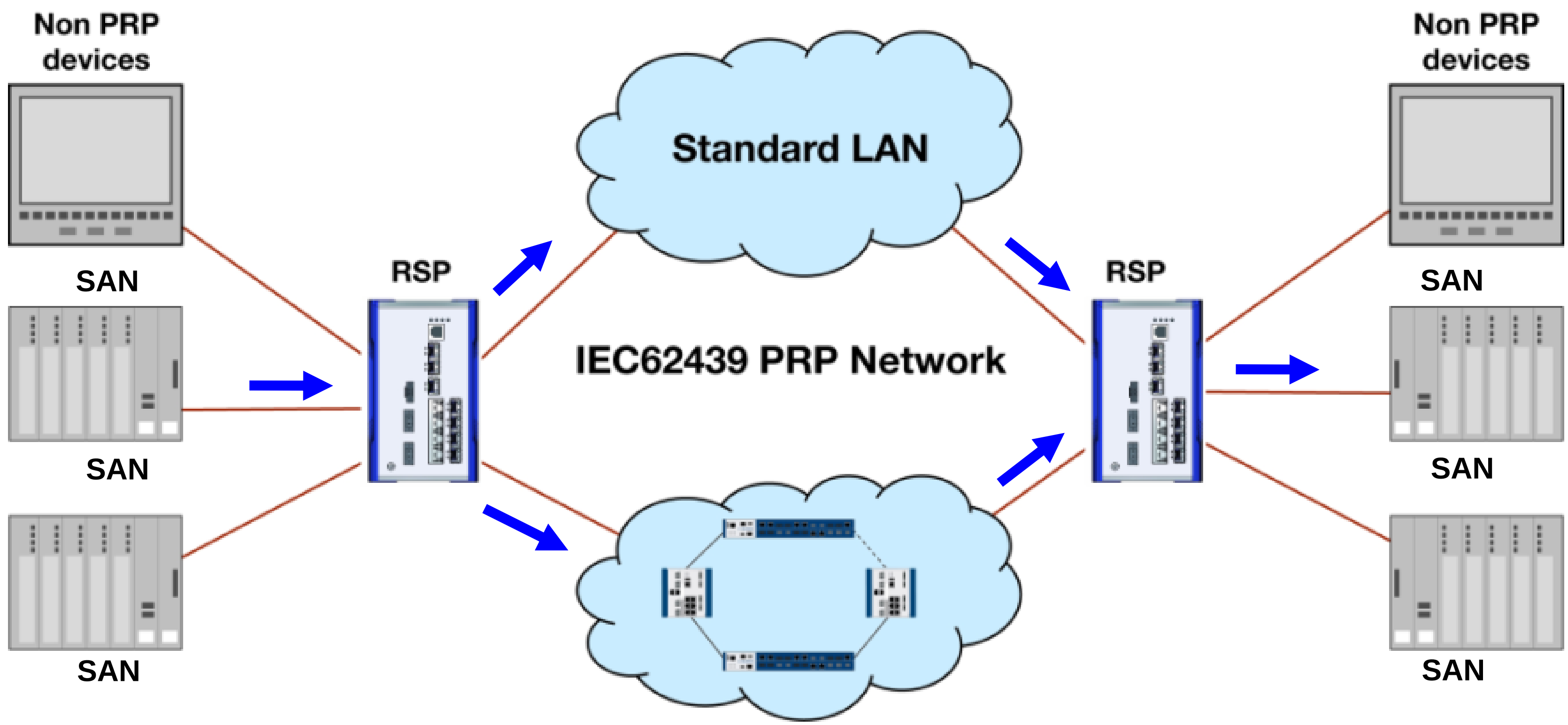


IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

Zero failover – duplicated networks

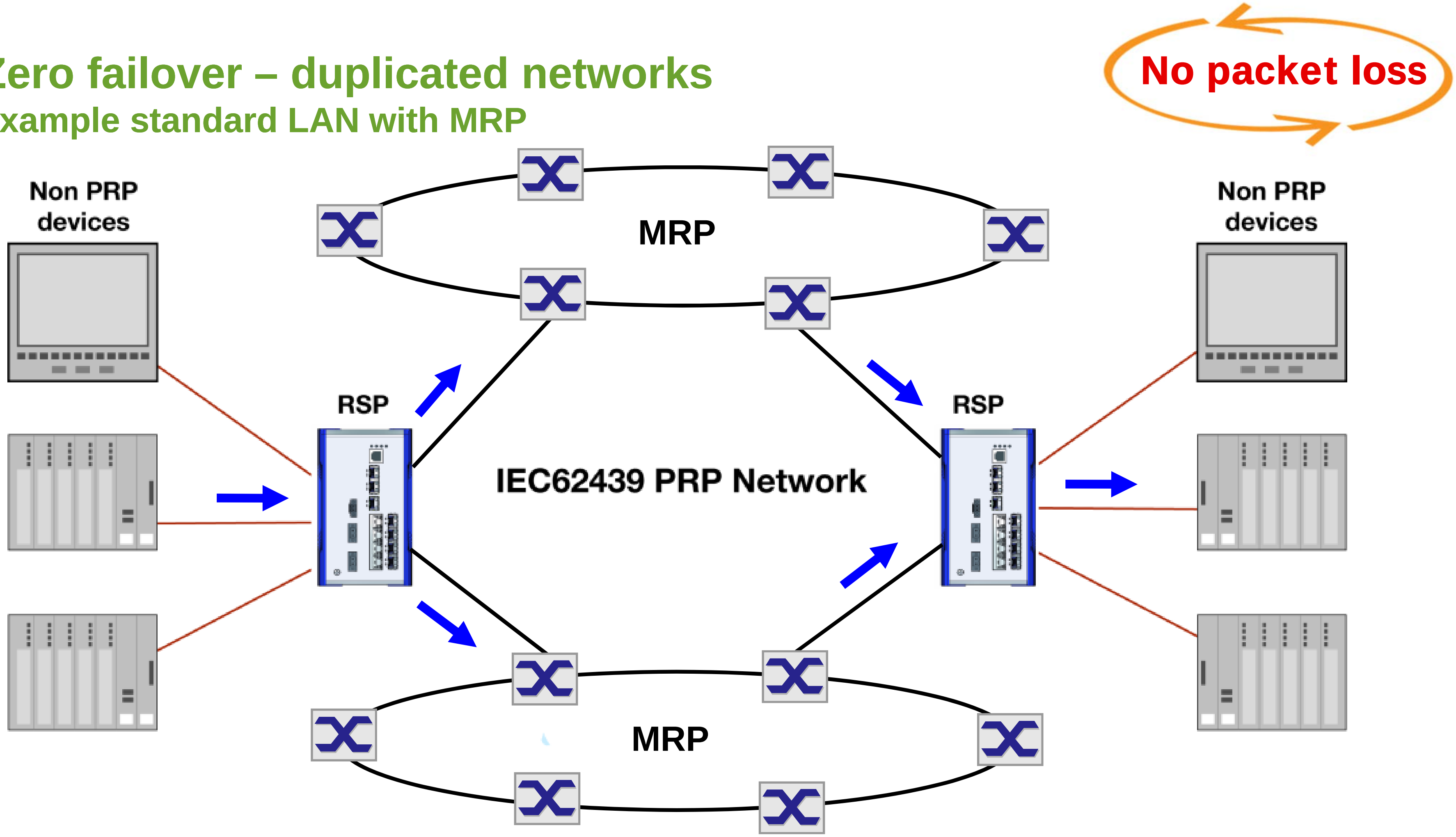
example standard LAN with MRP

No packet loss



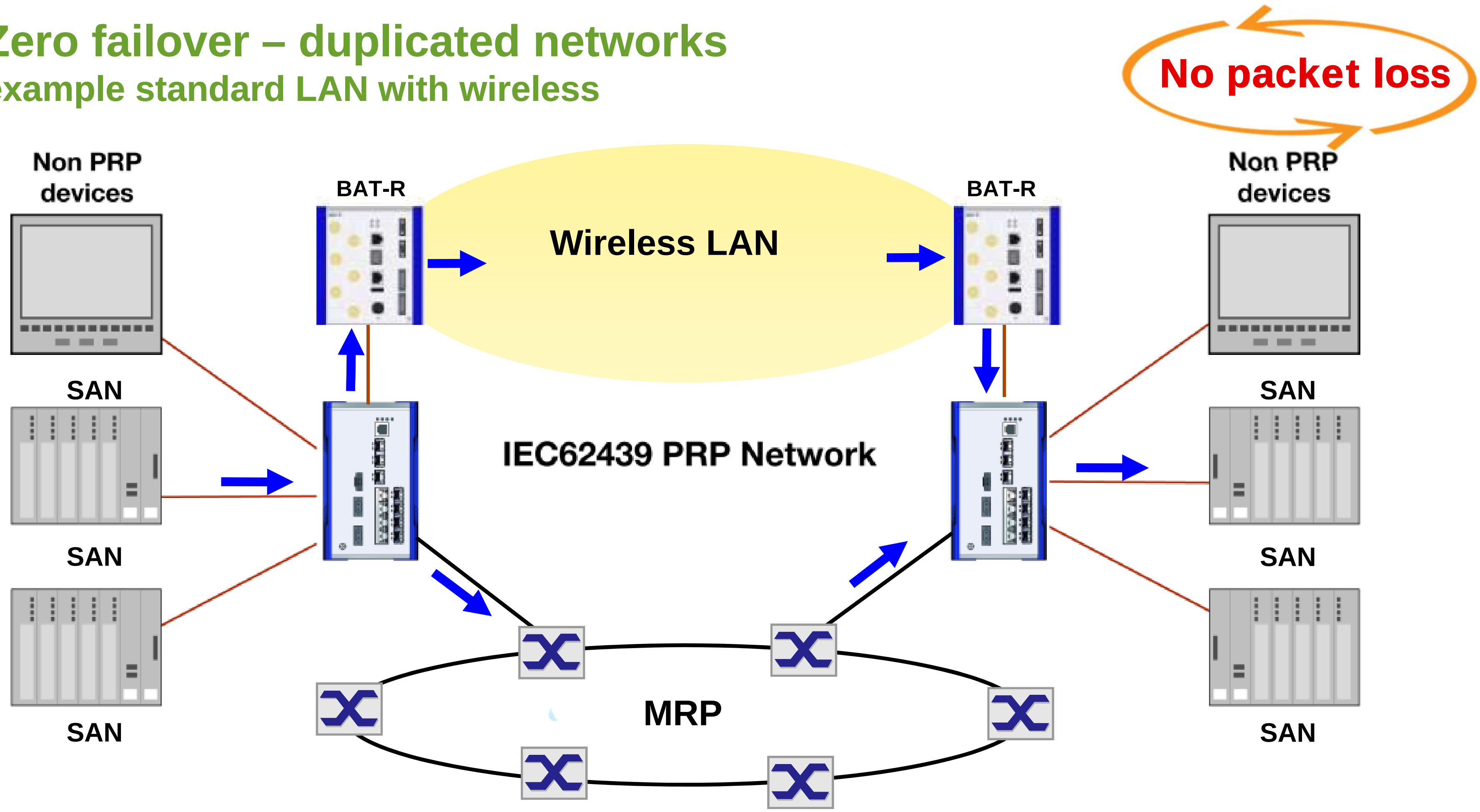
IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

Zero failover – duplicated networks
example standard LAN with MRP



IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

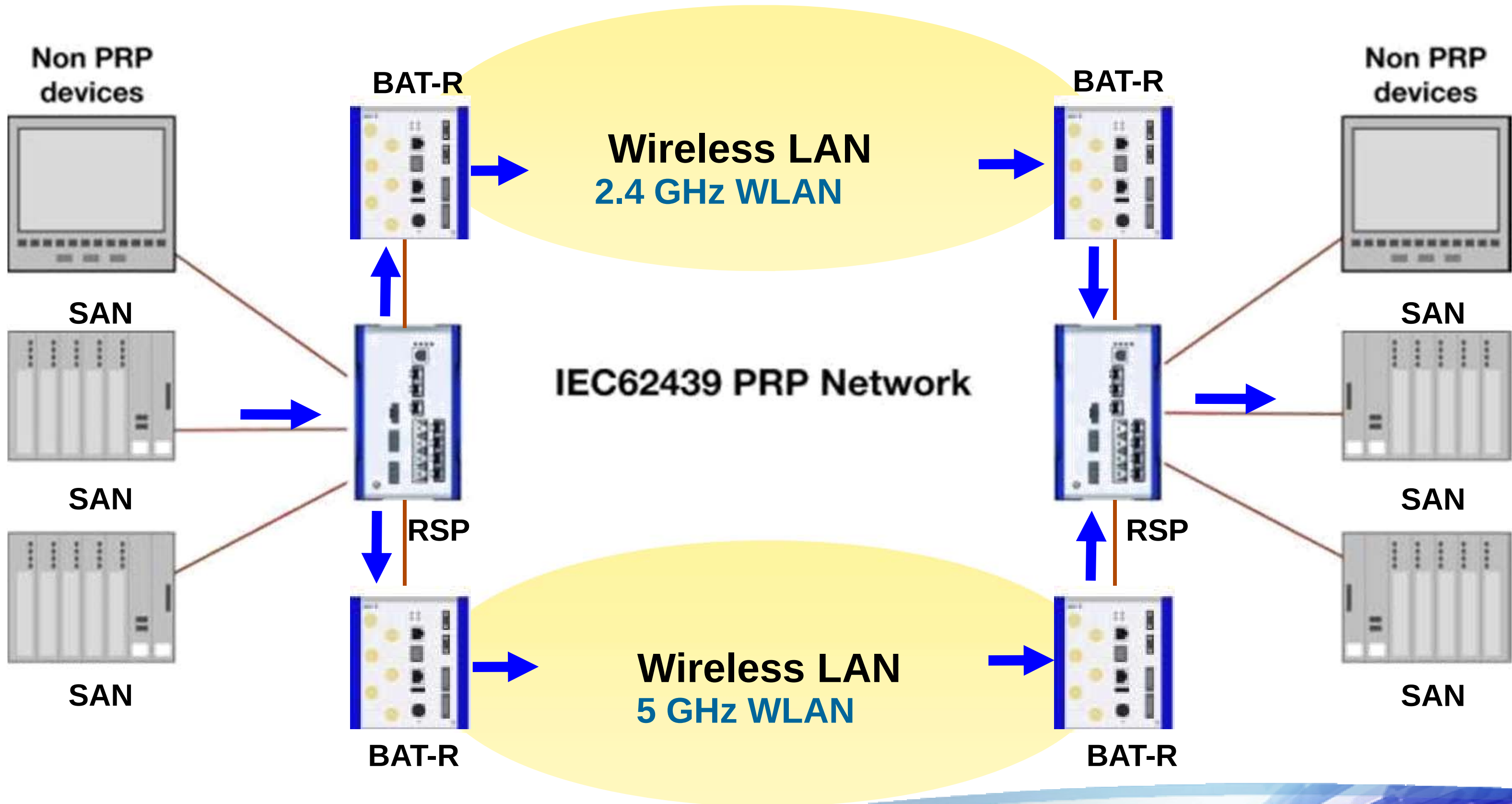
Zero failover – duplicated networks
example standard LAN with wireless



IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

Zero failover – duplicated networks
example standard LAN with wireless

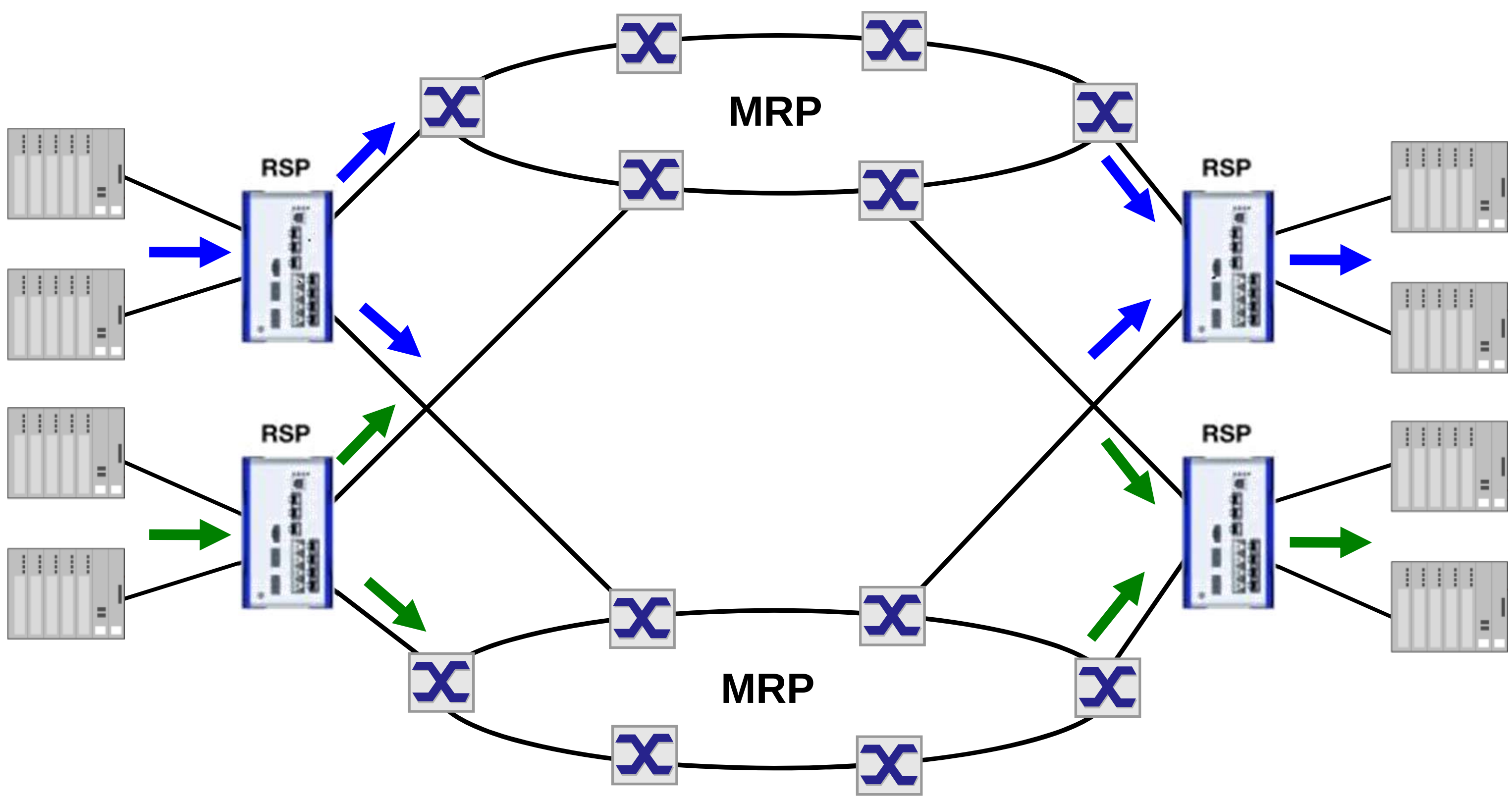
No packet loss



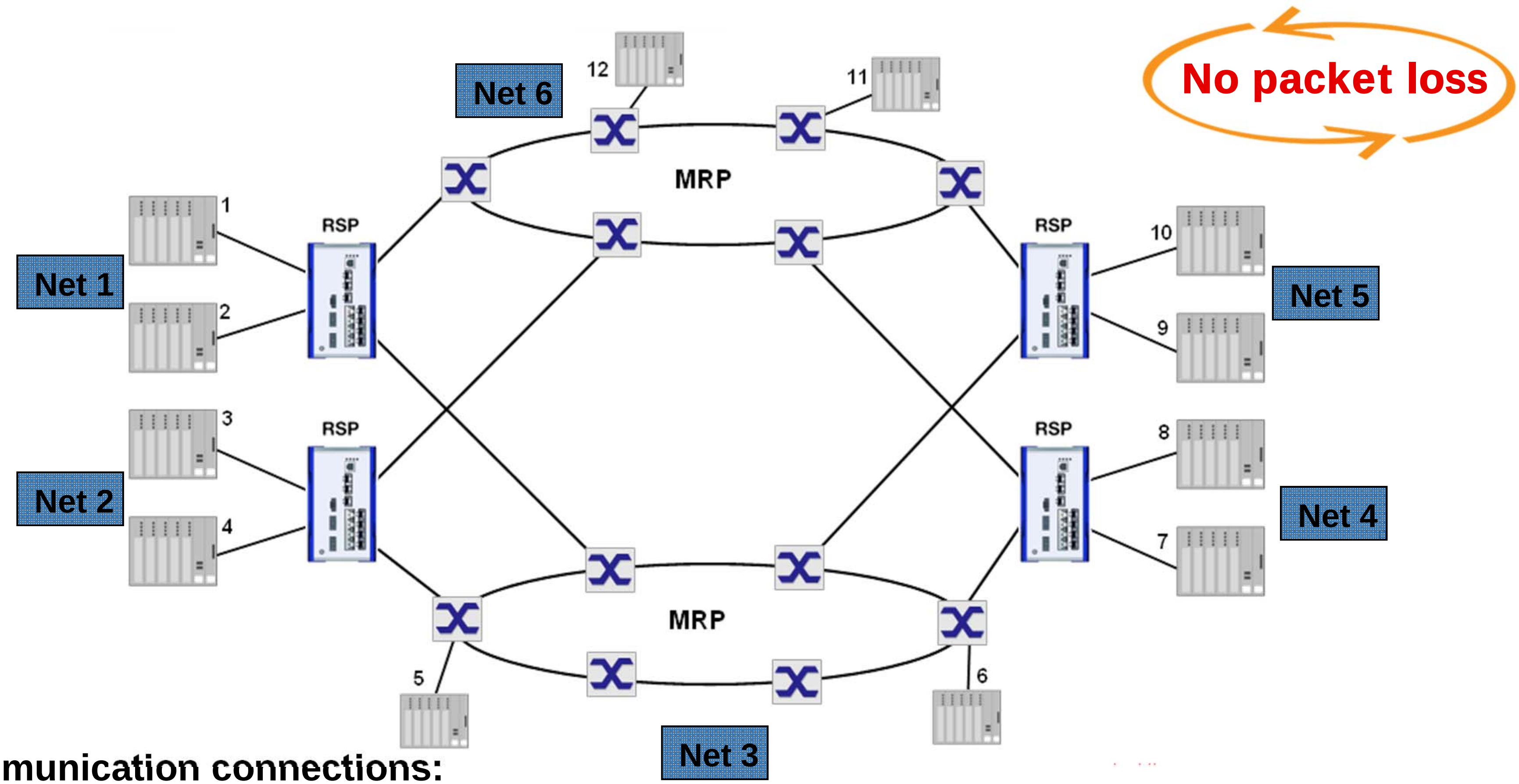
IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)

Zero failover – duplicated networks
example standard LAN with MRP and several „Red boxes“

No packet loss



IEC62439 Redundancy
PRP – (Parallel Redundancy Protocol)



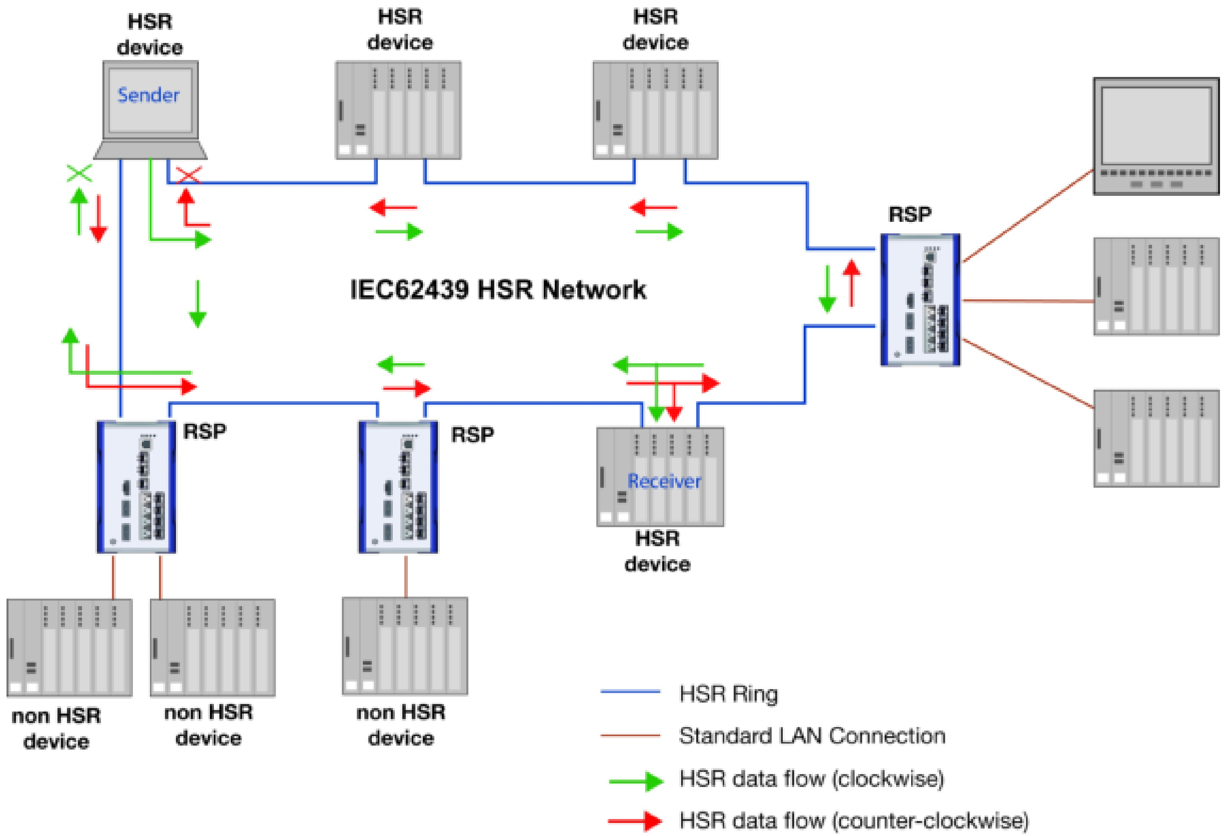
communication connections:

net 1,2,4,5 → net 1,2,3,4,5,6
net 3 → net 1,2,3,4,5 not 6
net 6 → net 1,2,4,5,6 not 3

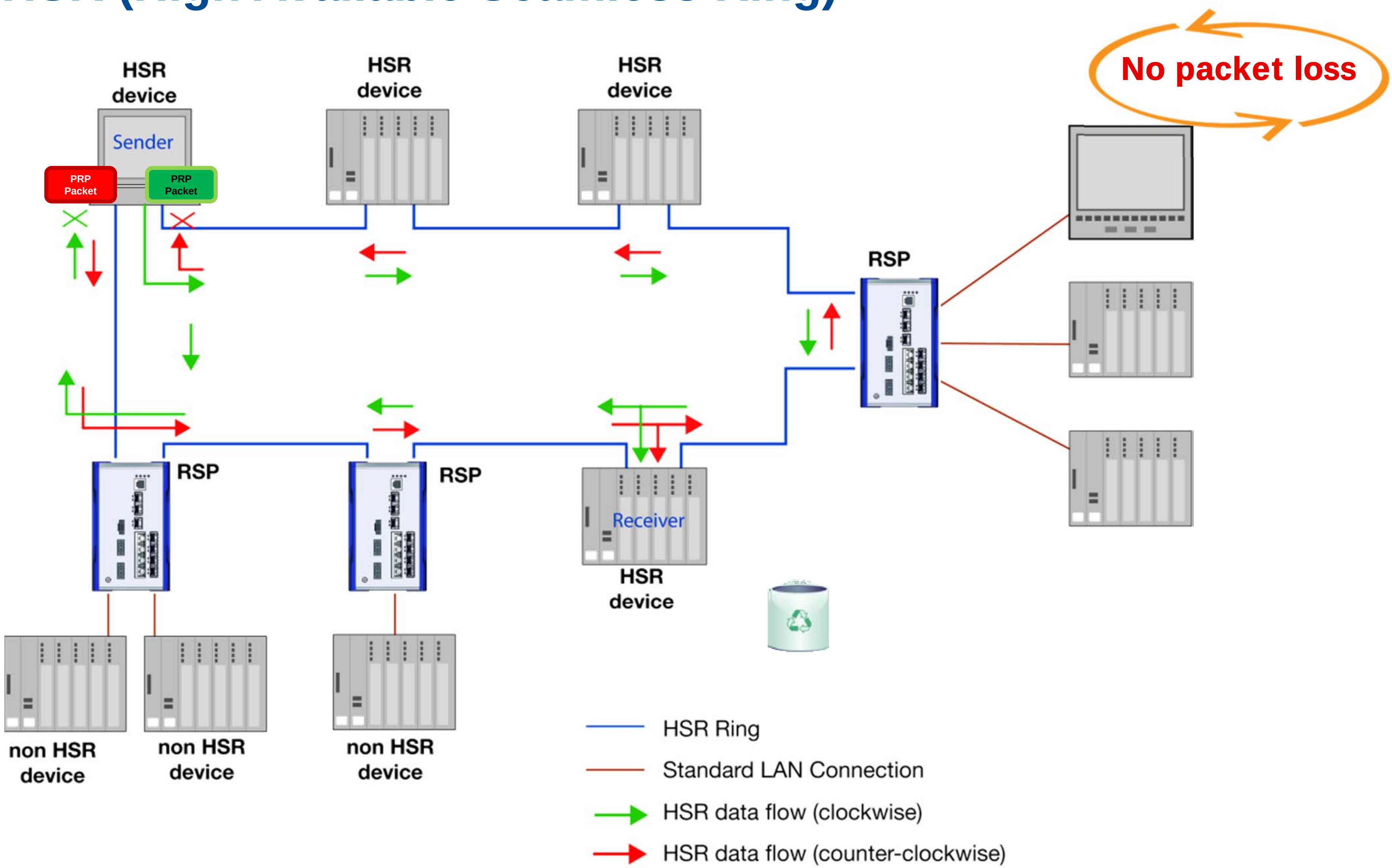
HSR (High Available Seamless Ring)

Zero failover Redundant Ring

No packet loss

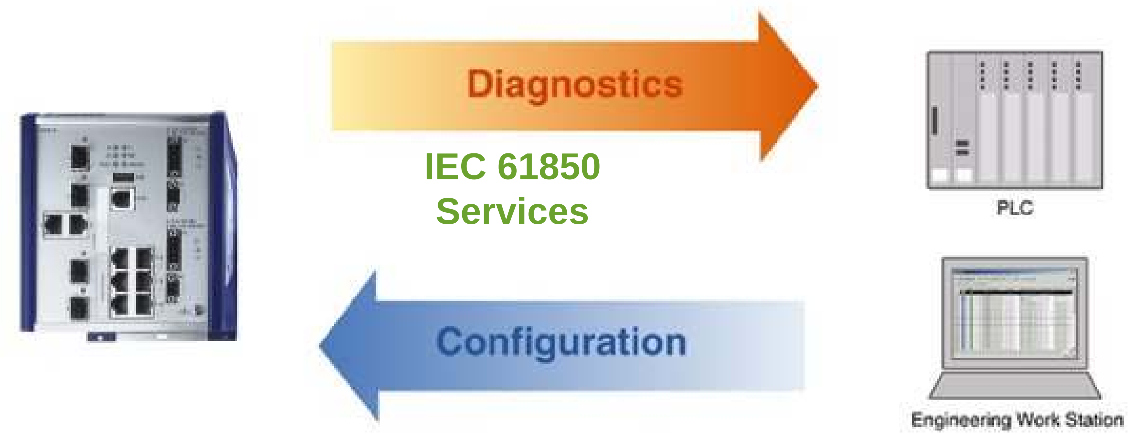


HSR (High Available Seamless Ring)



IEC 61850 Integration in Switches

Management of Switches by use of IEC 61850 Mechanisms



IEC 61850 Server

IEC 61850 SCADA
Workstation

BELDEN
SENDING ALL THE RIGHT SIGNALS

Additional Resources & Assistance

1. Obtain further Substation Communication resources from our website:
   - www.belden.com/power-td/
   - This webpage includes substation communication diagrams and other useful tools

3. Contact a Belden representative for assistance:
   - Call 510-438-9071 if you are in the U.S. or Canada
   - Or complete the form at www.belden.com/contact/

Thank you for your interest in this presentation!