Network Design and Diagnostics

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Communication Network for PAC systems

- Mission critical component in protection applications, especially when GOOSE and Sampled Values are used

- Communication Architecture Design
  - Appropriate topology
  - Traffic control (e.g. VLANs)
  - Redundancy principles
- Network Hardware
  - Reliable components
  - Support the requirements of IEC 61850-3
  - IEEE 1588, protocols, features
- Network Software
  - SNMP
  - IEC 61850 data model and MMS

- Performance of communication network
  - Timely delivery of information
  - Reliable delivery of information → Redundancy

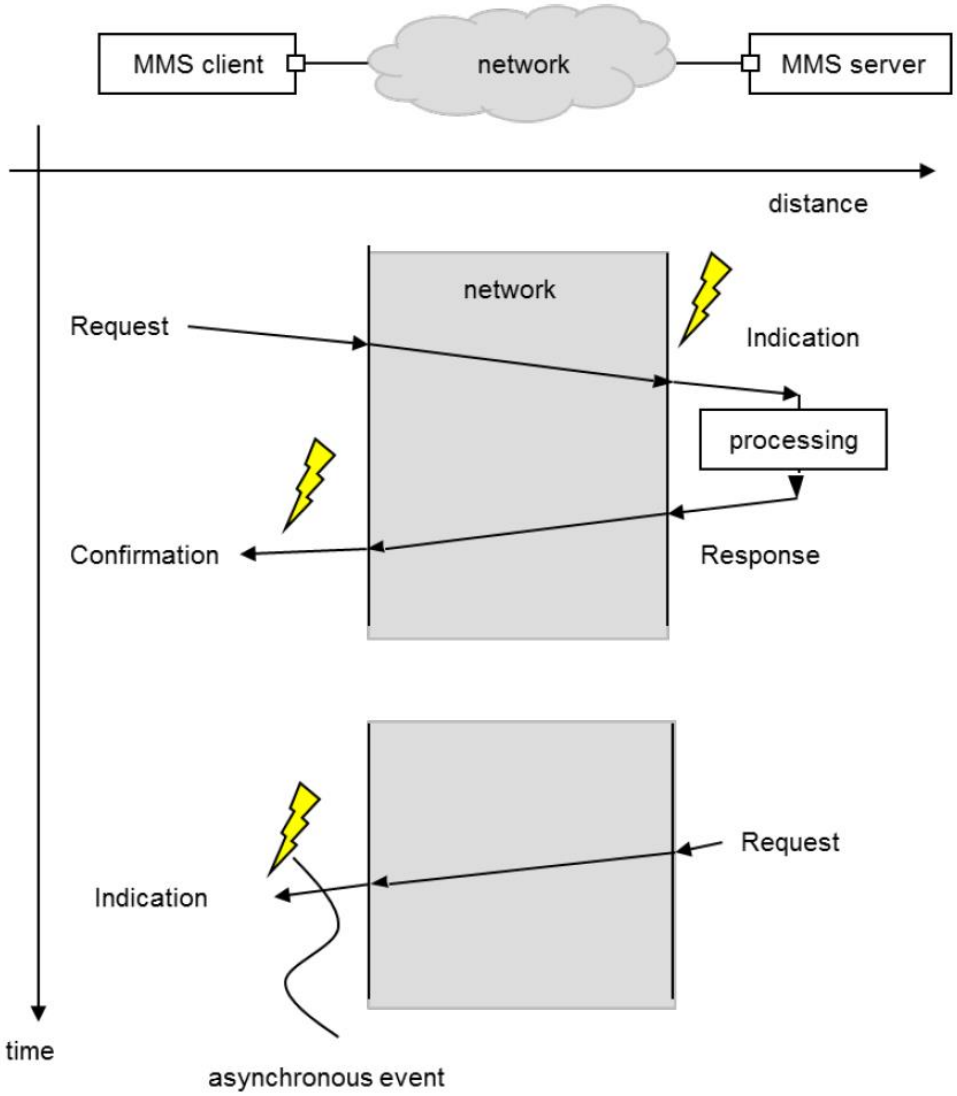
IEC 61850-90-4 Technical Report

- „Network Engineering Guidelines“
- Support engineers in the design of communication networks
- Analyzes and gives examples of:
  - Network Topologies
  - Network Redundancy
  - Clock synchronization
  - Latency
  - Traffic Control
- Addresses some network tests:
  - VLAN handling verification
  - RSTP recovery test
  - PRP/HSR seamless recovery test

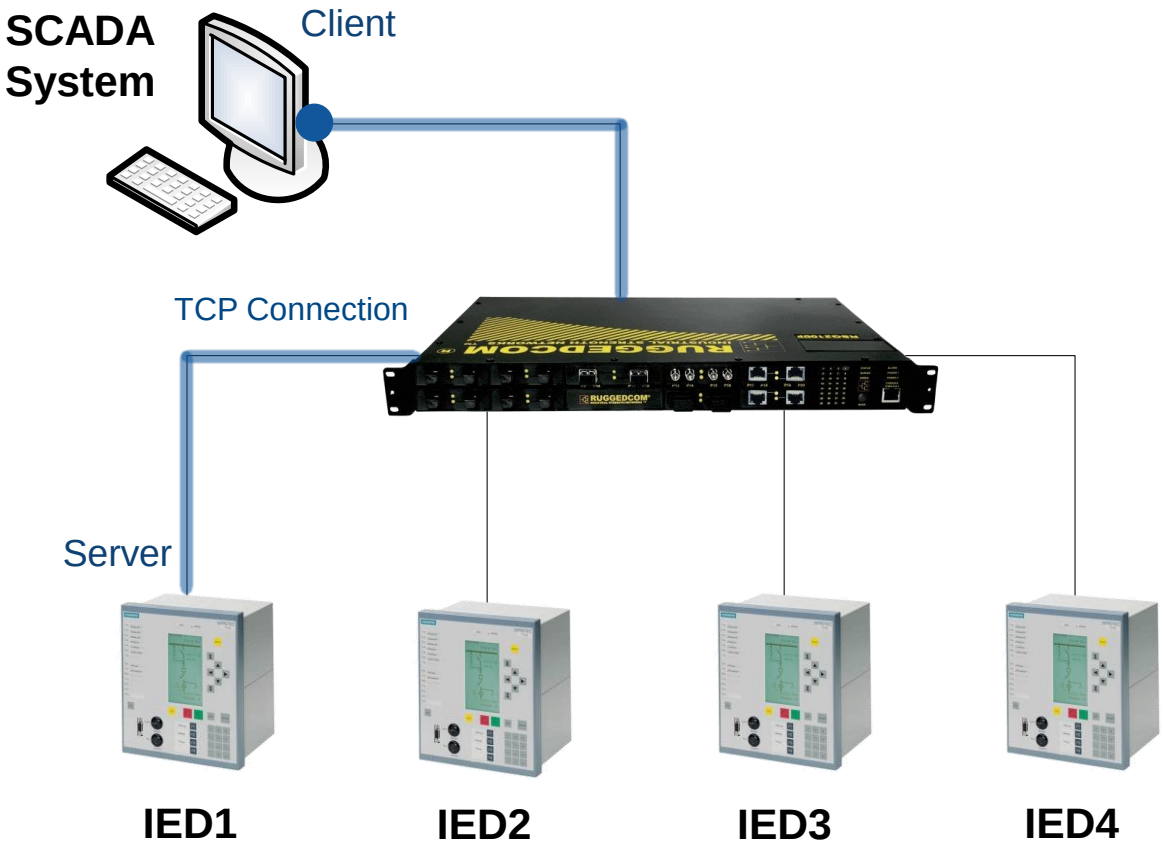
MMS protocol

> Client/Server (unicast) protocol

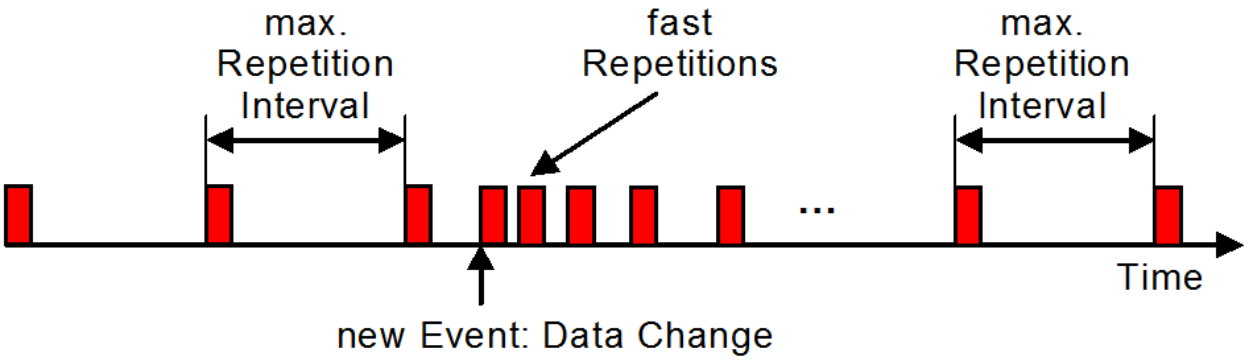
> SCADA



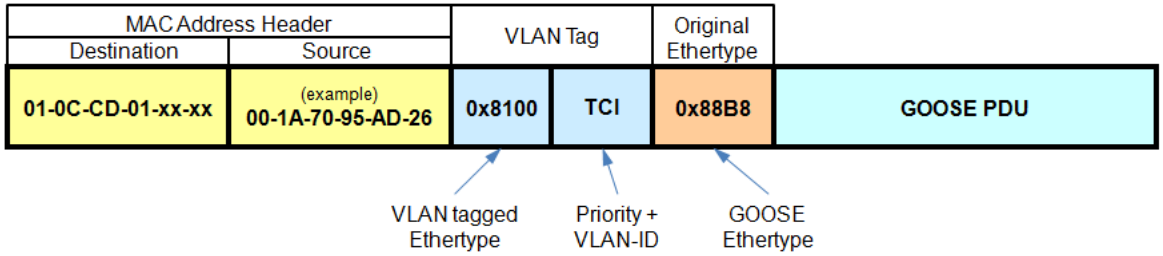
Client / Server unicast communication



GOOSE



- Configurable datasets
- Max packet size



SIEFEED1 • GOOSE • PROT • LLN0.Control_DataSet1

LLN0.Control_DataSet1

Details

GOOSE control block Ref.	SIEFEED1PROT/LLN0GOControl_DataSet1
Destination MAC-Adresse	01:0C:CD:01:00:03
MAC-Adresse Quelle	00:19:99:3F:E0:17
Application ID	03
GOOSE ID	3
DataSet-Name	SIEFEED1PROT/LLN0$DataSet1
Aktiviert	true
VLAN ID	00
VLAN Priorität	7
Inbetriebnahme erforderlich	false
Configuration revision	1
Simulation/Test	false
Zeitstempel	2026-06-10 11:17:59.261
Status number	1
Sequenznummer	2290823
Gültigkeitsdauer	2000
Verbleibende Gültigkeitsdauer	1710
Anzahl von DataSet-Einträgen	6

Daten

Name	Wert
PTOC6.Str.q [ST]	good
PTOC6.Str.general [ST]	false
PTOC6.Op.q [ST]	good
PTOC6.Op.general [ST]	false
PTRC1.Tr.q [ST]	good
PTRC1.Tr.general [ST]	false

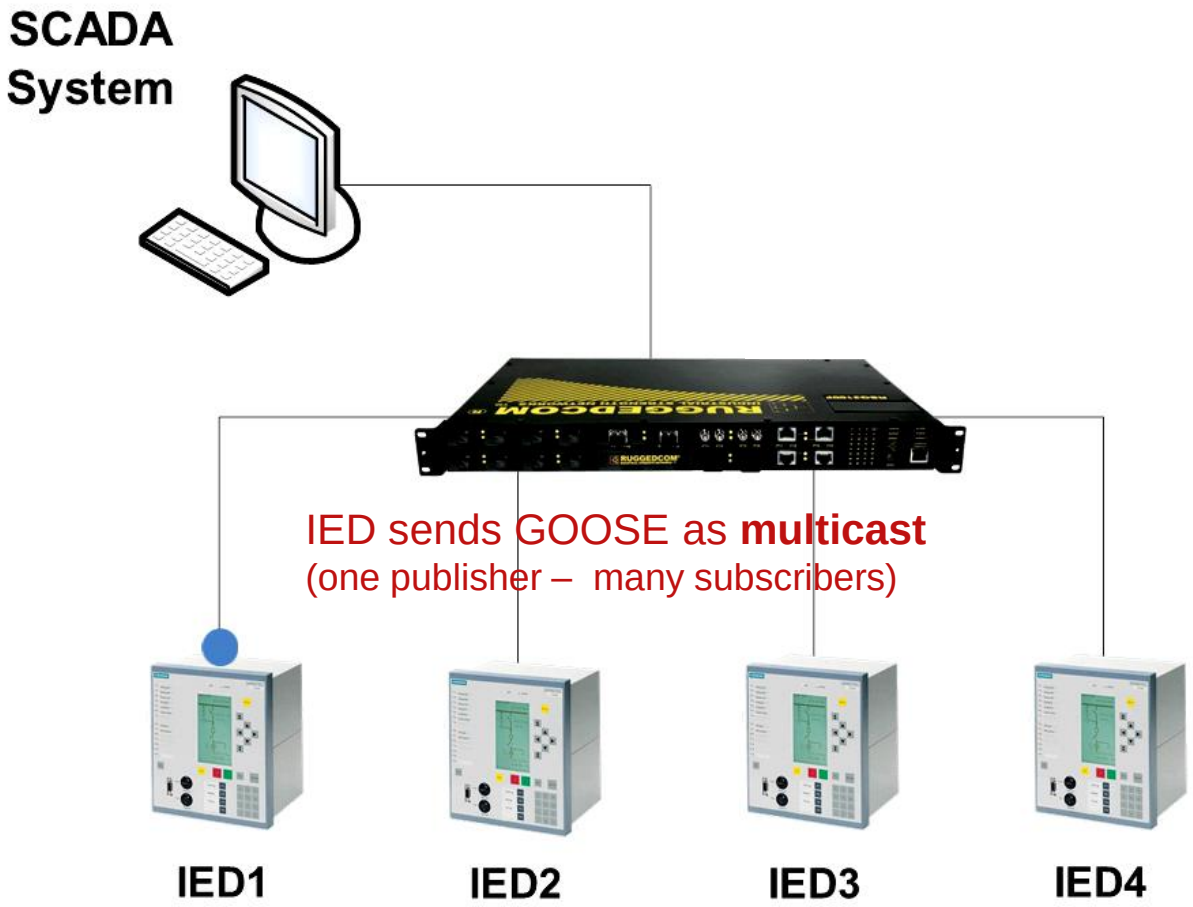
Sampled Values Profiles

> 9-2LE Implementation Guideline

> IEC 61869-9 Digital interface for instrument transformers

Sampling Frequency	Samples per Packet	Packet Frequency	
4000Hz (80SPC @ 50Hz)	1	4000Hz	9-2LE
4800Hz (80SPC @ 60Hz)	1	4800Hz	
12800Hz (256SPC @ 50Hz)	8	1600Hz	
15360Hz (256SPC @ 60Hz)	8	1920Hz	
4800Hz	2	2400Hz	New preferred
14400Hz	6	2400Hz	
5760Hz	1	5760Hz	96SPC @ 60Hz

Multicast communication

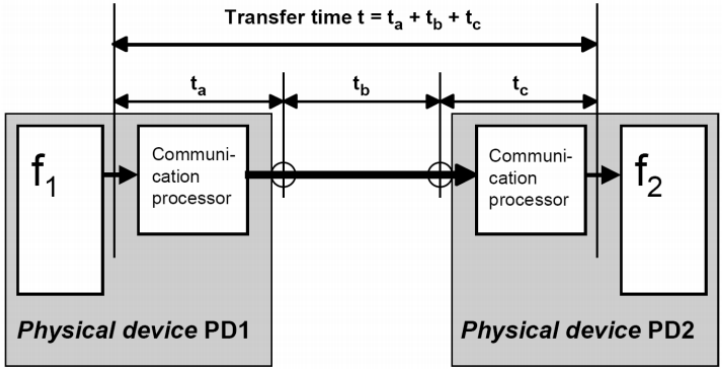


Theoretichal store and forward times

	10 MBit/s	100 MBit/s	1 GBit/s
Minimum Frame 64 Byte = 512 Bit	51 µs	5 µs	500 ns
SV 9-2 LE 127 Byte = 1016 Bit	101 µs	10 µs	1 µs
Maximum Frame 1518 Byte = 12.144 Bit	1,2 ms	121 µs	12 µs

Performance Requirements in IEC 61850-5

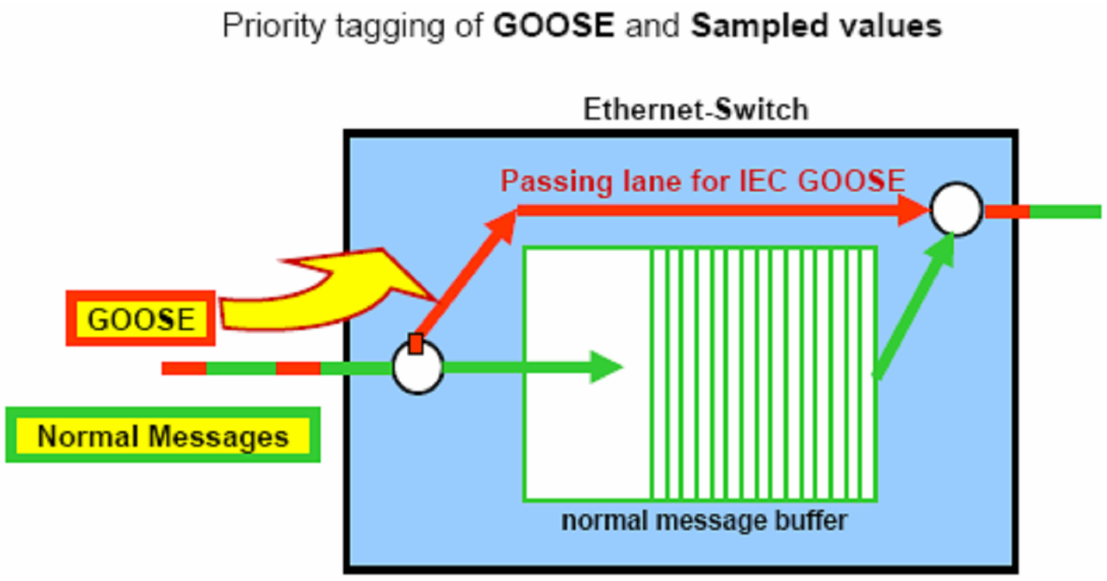
- Transfer time of information
  - What is a reasonable time?
  - Depends on type of information and specific application
- IEC 61850-5 categorizes the different requirements
  - Definition of an overall transfer time
  - Messages types, performance classes and transfer time classes



Message Type	Performance		Transfer Time	
	Class	Requirement description	Class	ms
1A. Trip (GOOSE)	P1	The overall transfer time shall be below the order of a quarter of a cycle	TT6	≤ 3
	P2	The overall transfer time shall be in the order of half a cycle	TT5	≤ 10
4. Raw Data (SV)	P7	Delay acceptable for protection functions using these samples	TT6	≤ 3
	P8	Delay acceptable for other functions using these samples	TT5	≤ 10

Fast Track For GOOSE & SVs

- Priority Tagging (IEEE 802.1Q)
- Priority is Part of VLAN Tag
- 8 Priority levels: 0 (low)... 7 (high)
- Ensure Delivery of Important Information

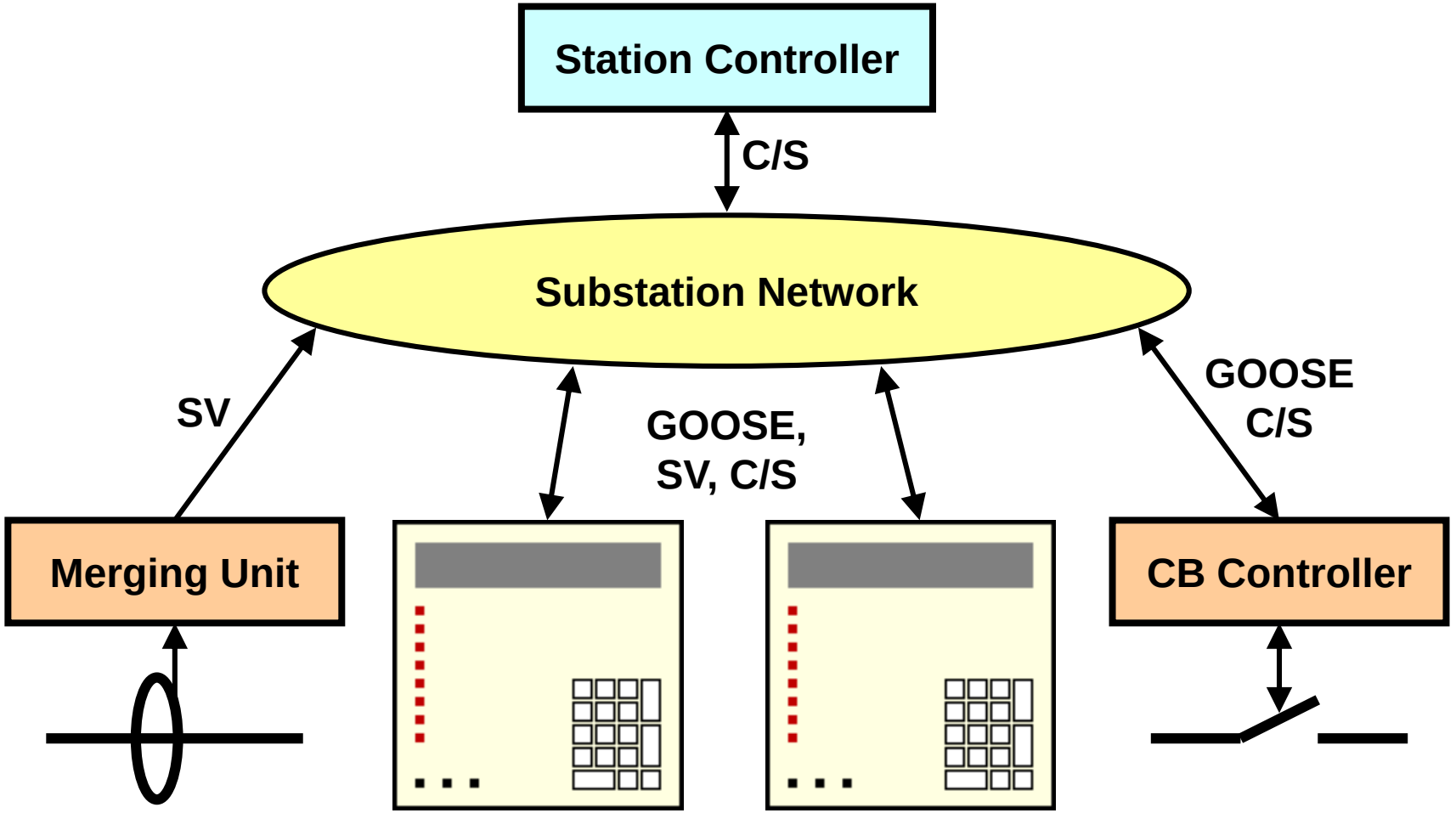


Network Topologies

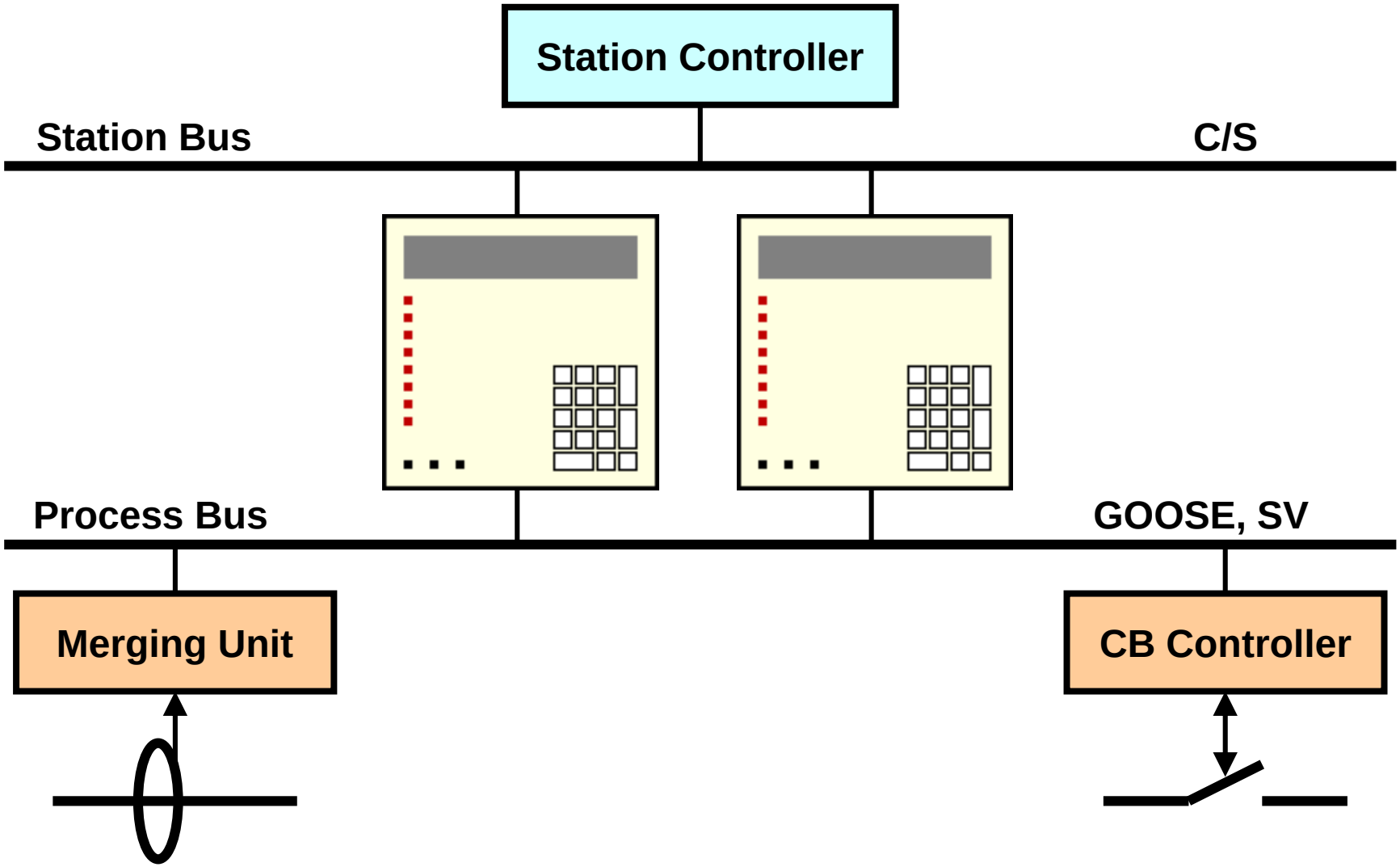
> Star, ring, redundancy...?

> Not defined in the Standard

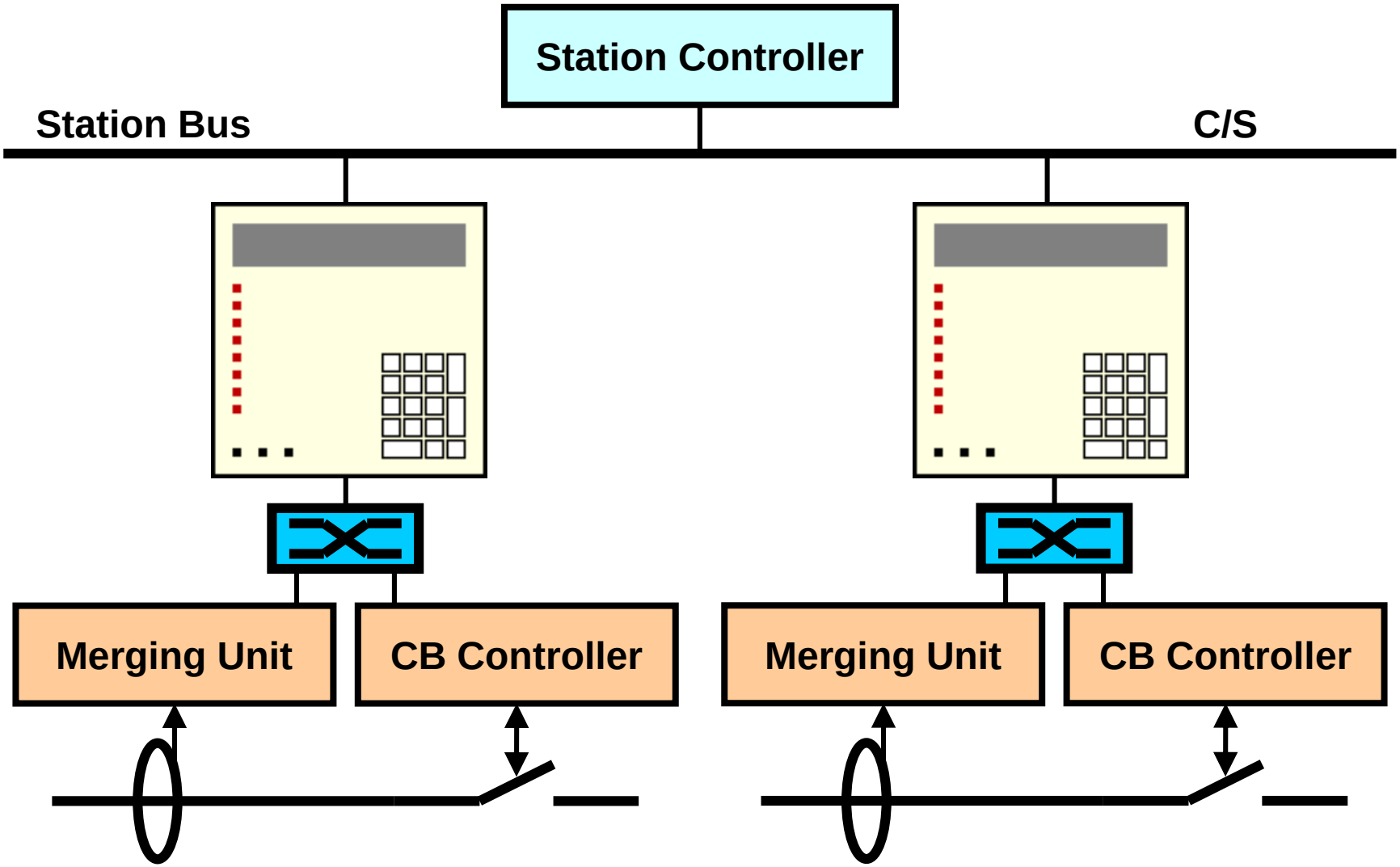
> No best topology for all cases – application specific



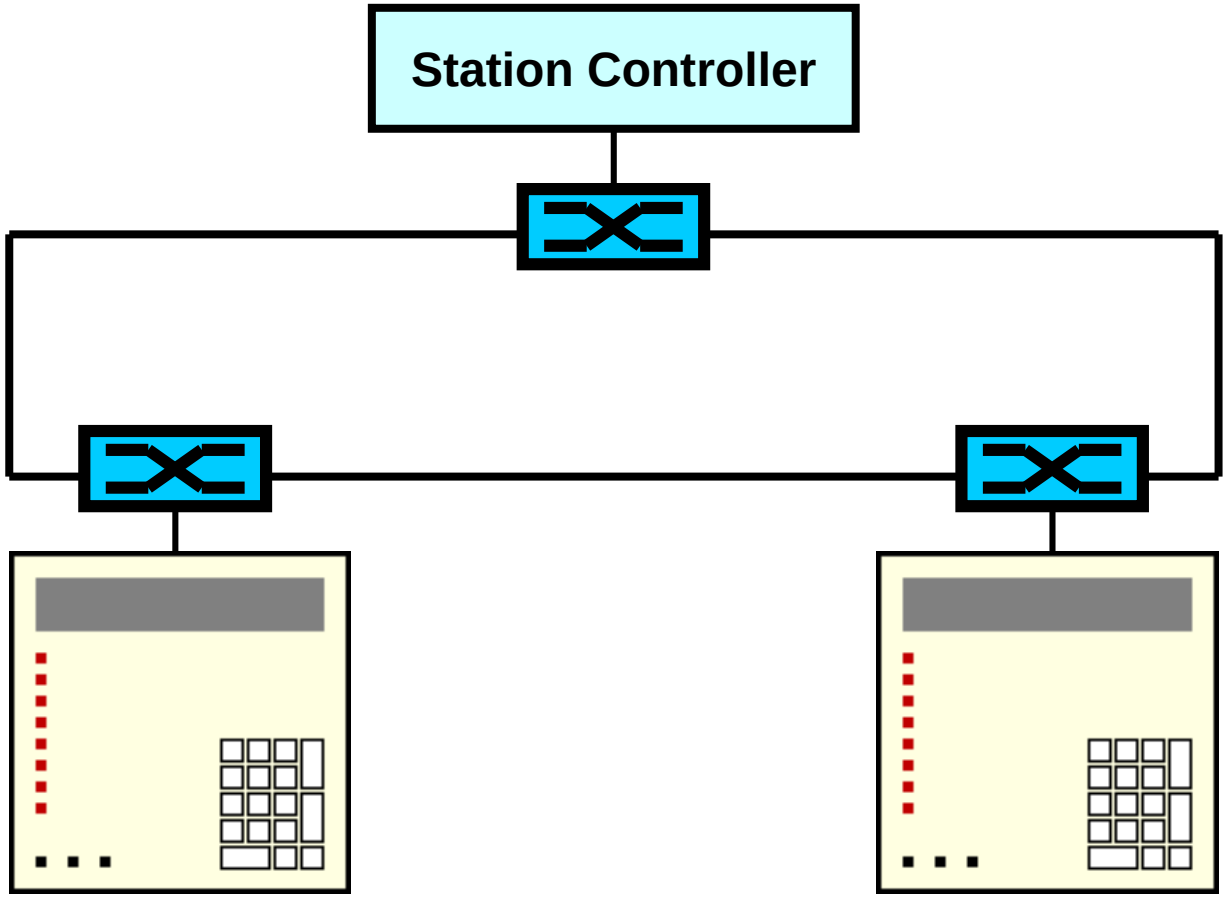
Station Bus – Process Bus



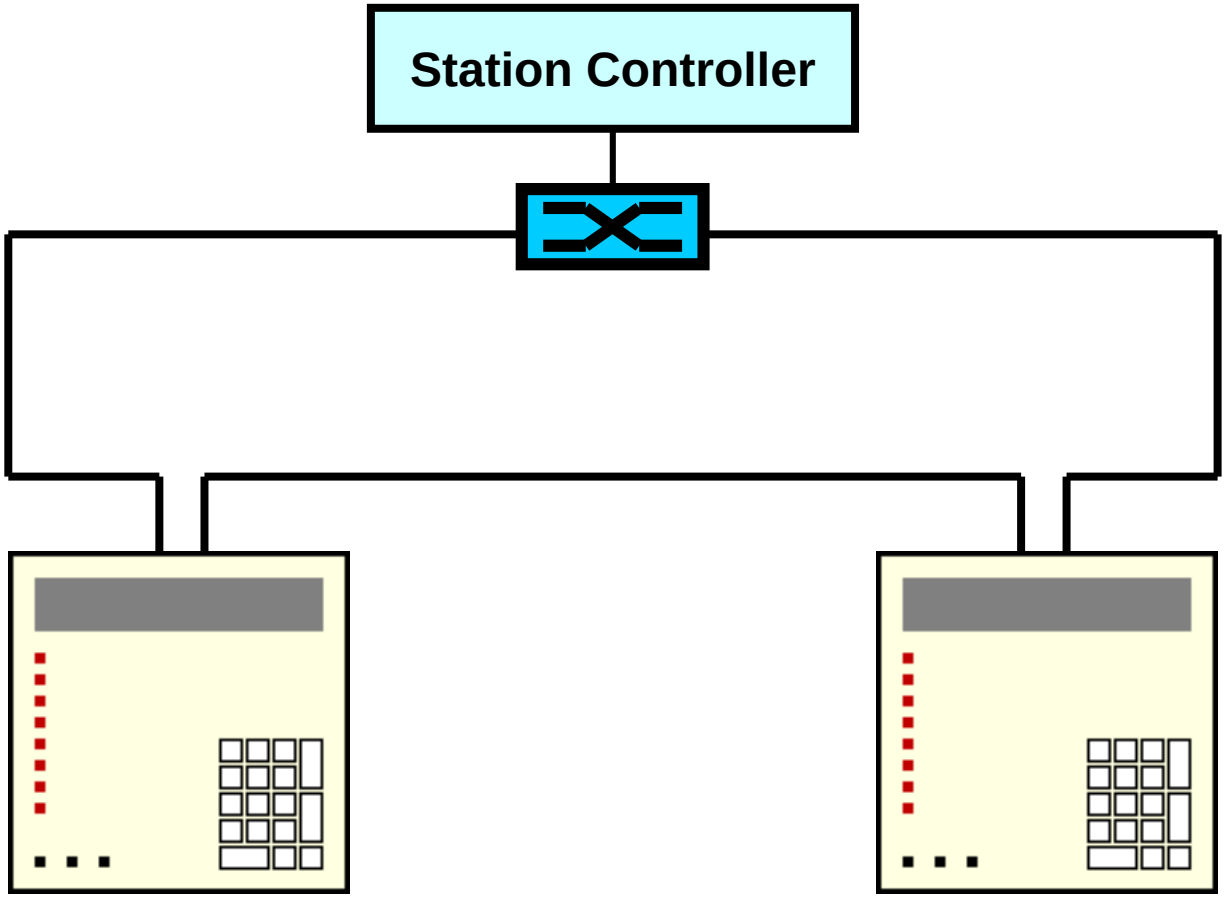
Process Bus per Bay



Ring Structures



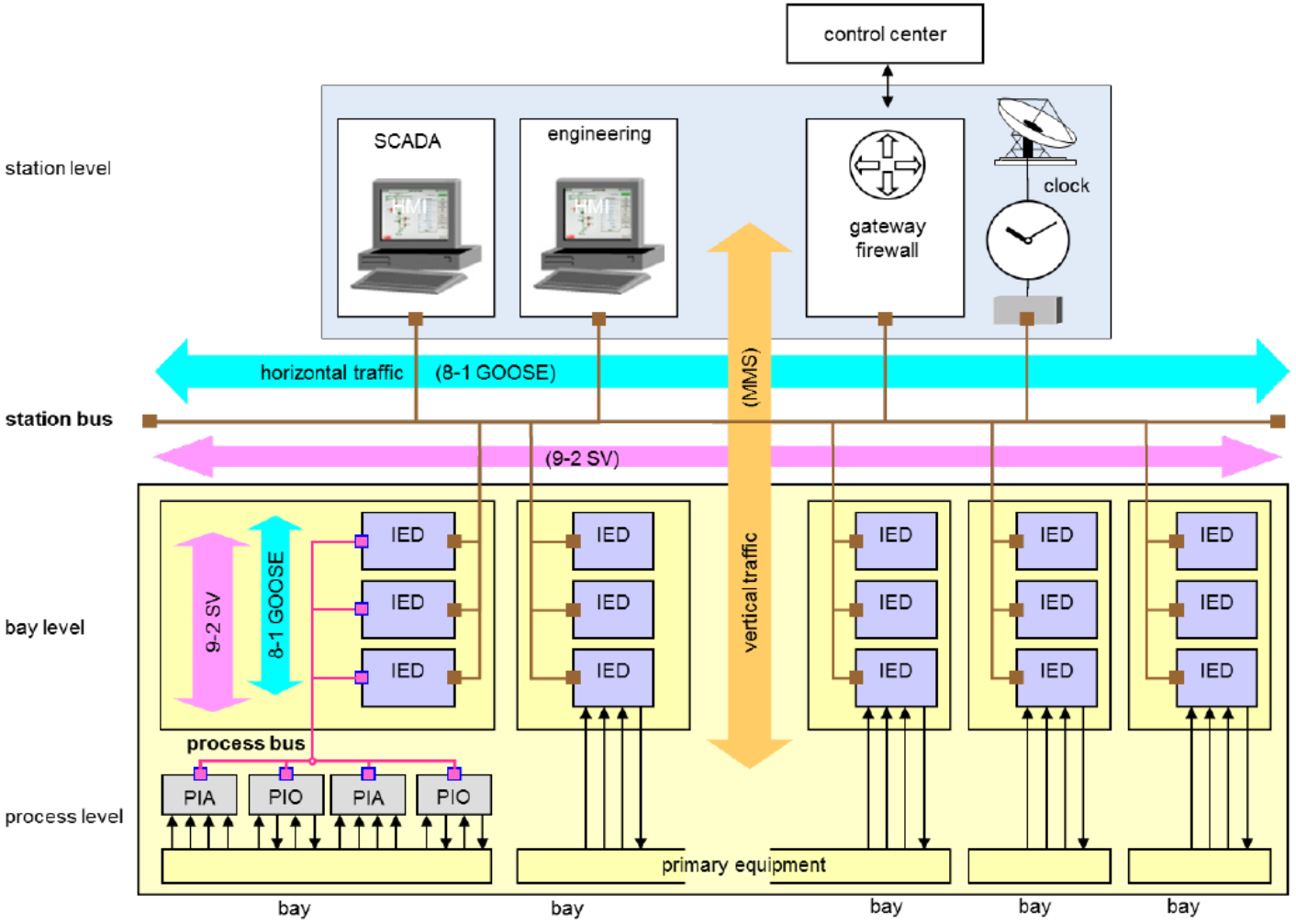
Ring with Switches in IEDs



Station bus, Process bus and Traffic example

> Engineering data flow

> MMS could also be in the process bus



VLAN and MAC Filtering

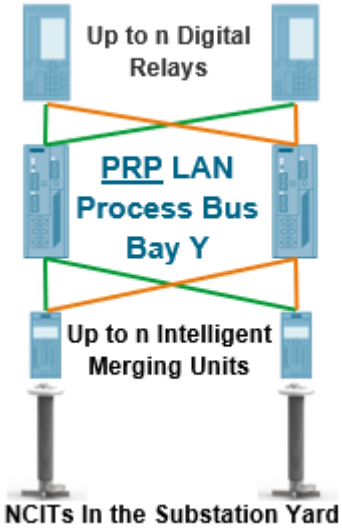
- Minimize overload of individual devices in the network
- Unnecessary traffic can be limited by 801 defining multicast domains or VLANs
- Traffic Control
  - Assignment of switch ports to logical separated networks (VLAN ID)
  - A port of a managed bridge has a configurable multicast filtering table, which indicates which multicast addresses may egress from that port

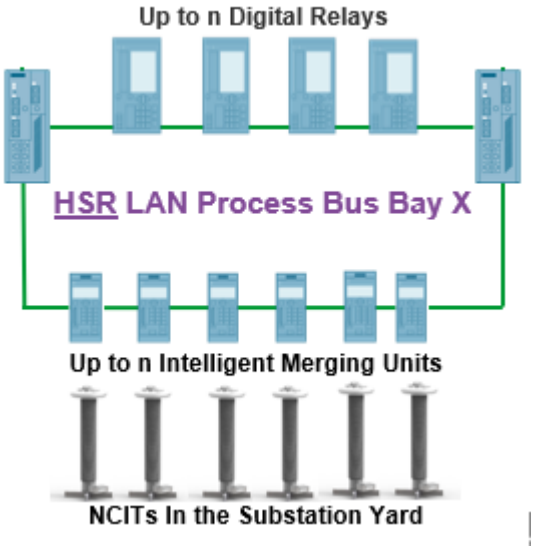
Redundancy

> IEC 62439-3 – Industrial communication networks – High availability automation networks

> PPR: Parallel Redundancy Protocol

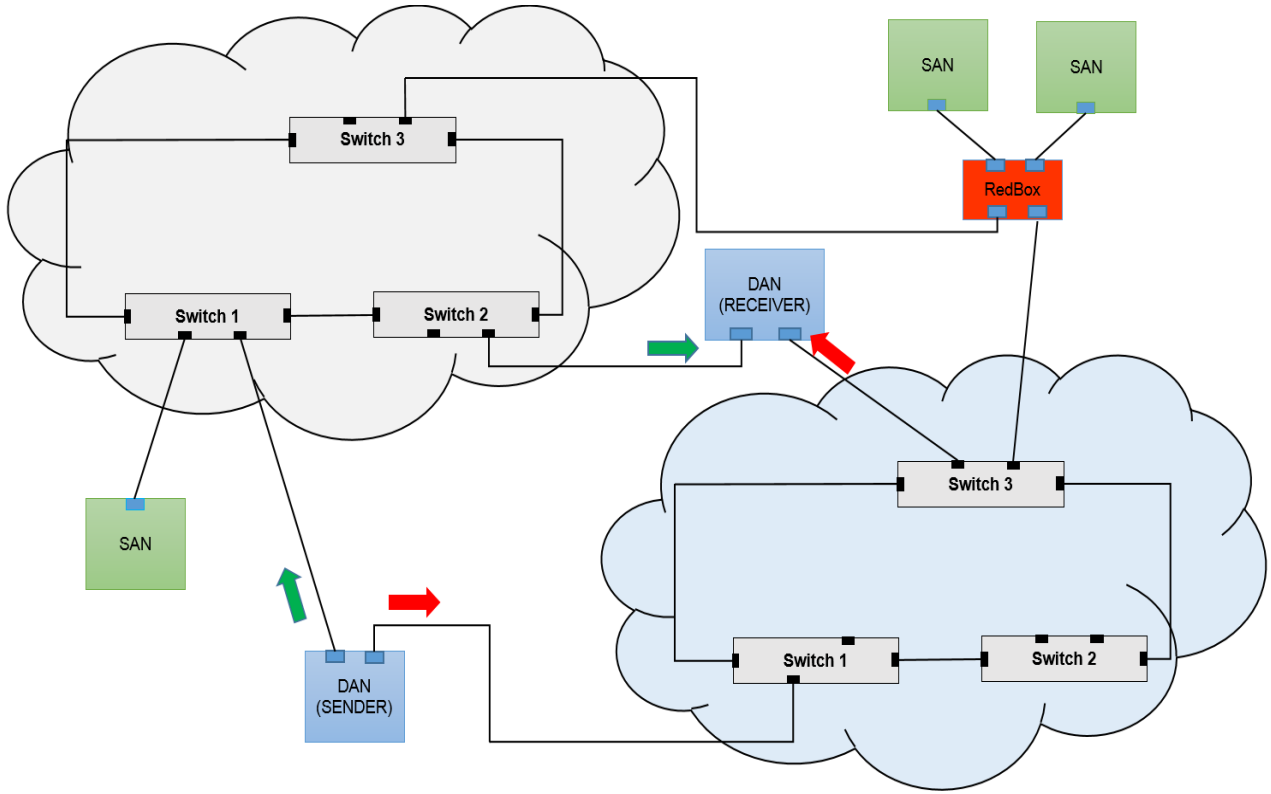
> HSR: High-availability Seamless Redundancy





Pictures: Siemens

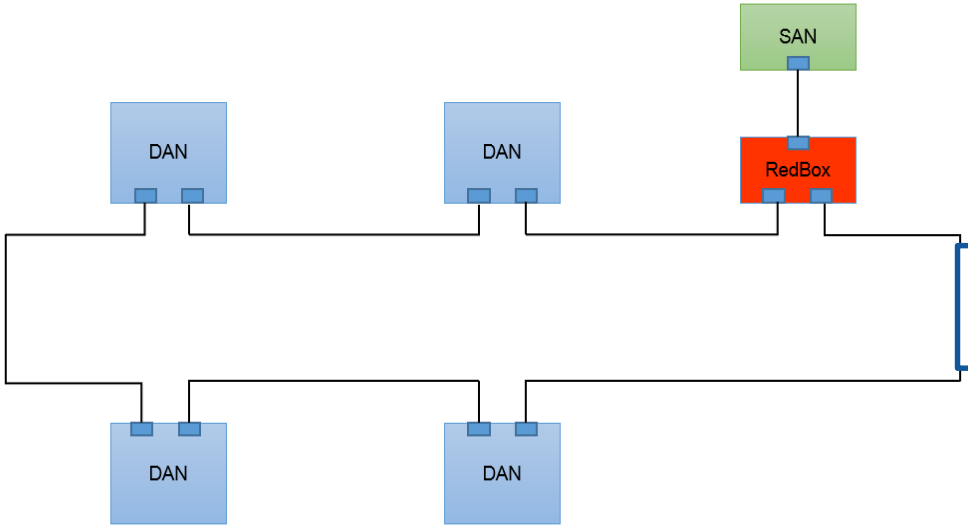
Parallel Redundancy Protocol (PRP)



Elements in a PRP redundant network:

- DANs = Double Attached nodes
- SANs = Single Attached nodes
- RedBox = Redundancy Boxes

High-availability Seamless Redundancy protocol (HSR)

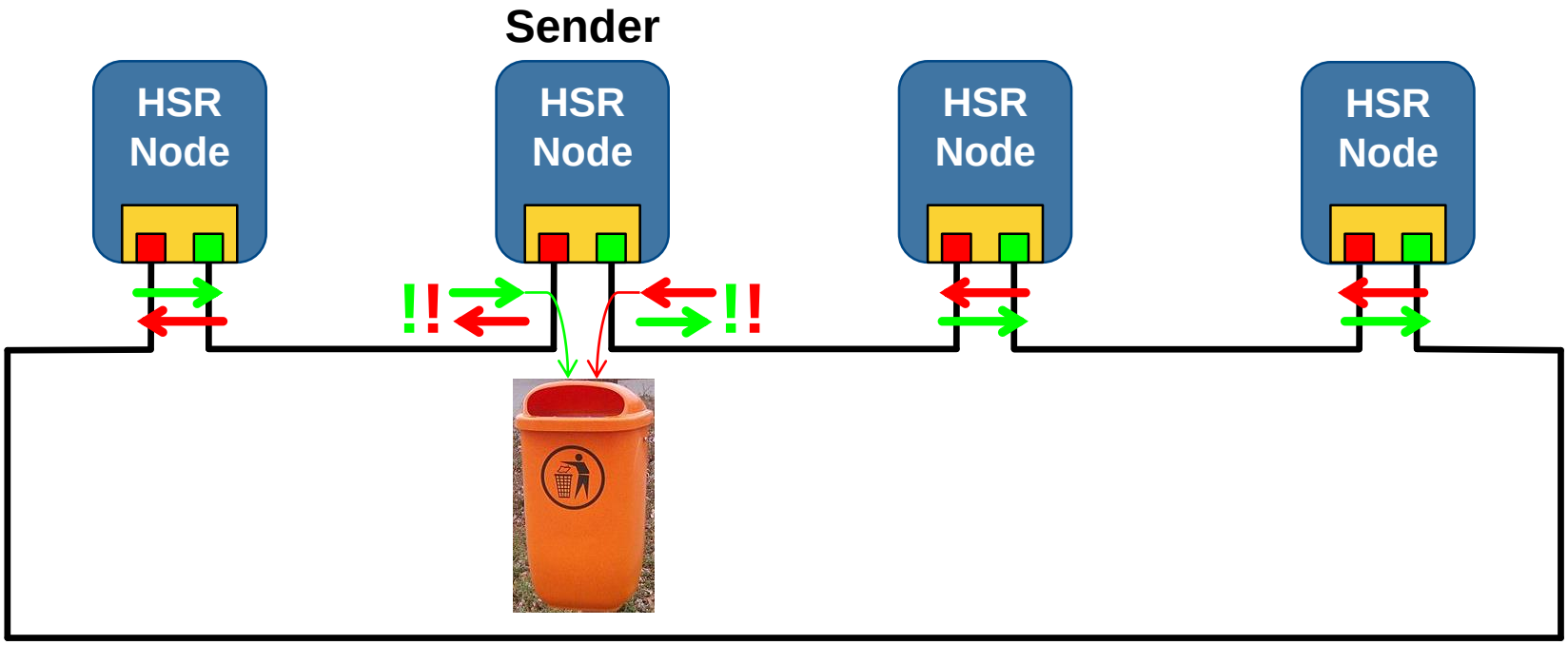


1. 2 paths for each Packet
2. Reduction of HW costs

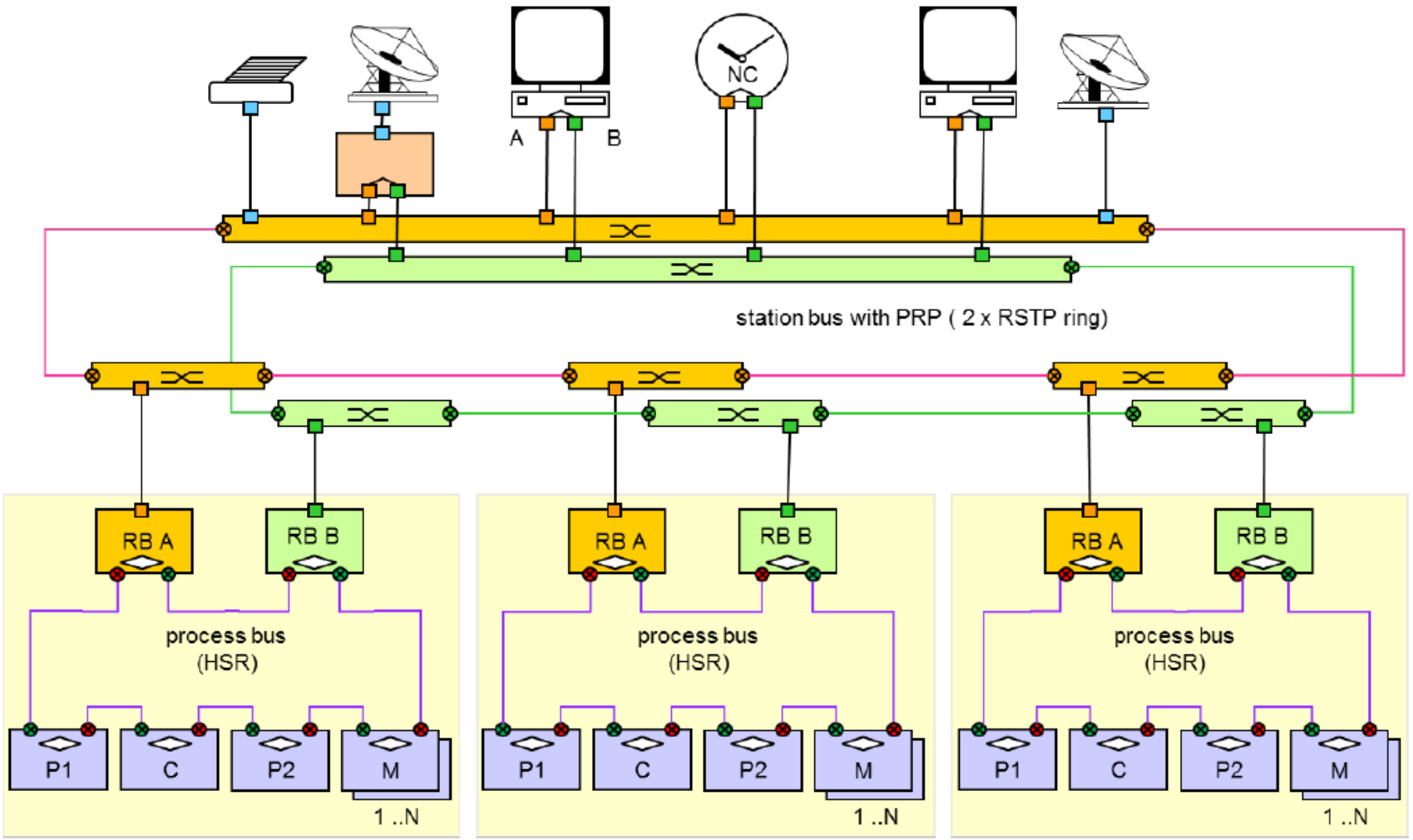
Elemente eines HSR:

- DANs = Double Attached nodes
- SANs = Single Attached nodes
- RedBox = Redundancy Boxes

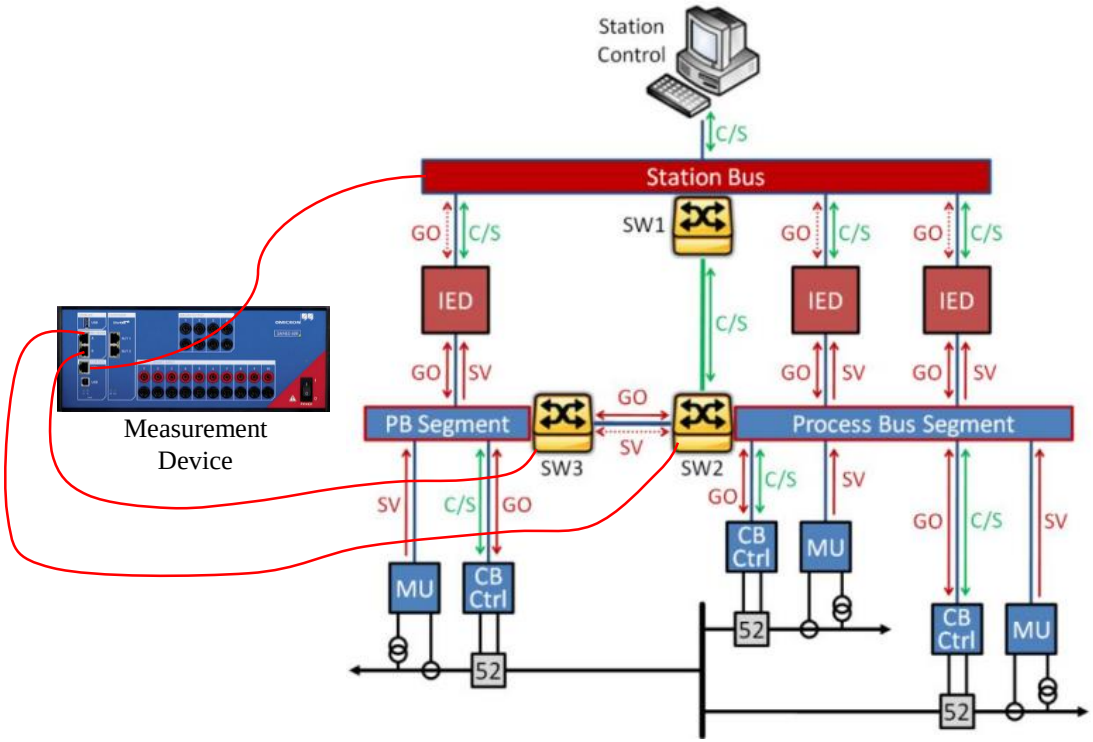
HSR handling of duplicates

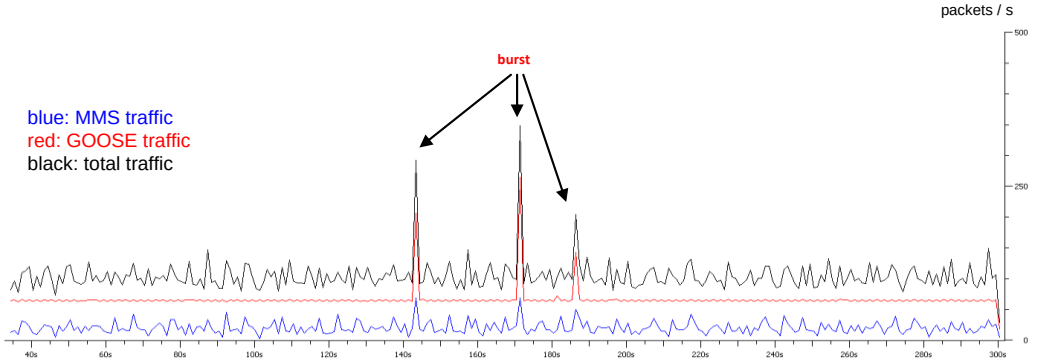


Example


A
B
NC
station bus with PRP (2 x RSTP ring)
RB A
RB B
process bus
(HSR)
P1
C
P2
M
1 ..N
RB A
RB B
process bus
(HSR)
P1
C
P2
M
1 ..N
RB A
RB B
process bus
(HSR)
P1
C
P2
M
1 ..N

Load Assessment and VLAN Handling



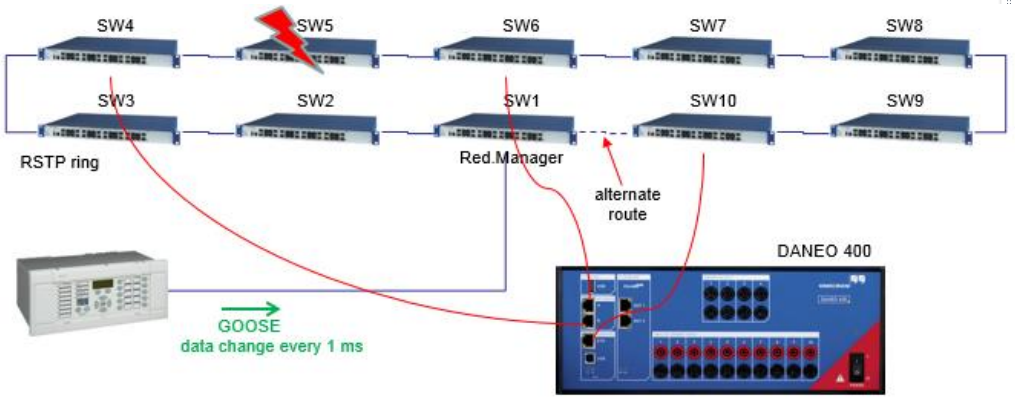


DataSet - Q0_SCB/LLN0$GOODS

Name	Type	Value	Ports
BitStringAttribute 1	BitString [2]	10	A B ETH
BitStringAttribute 2	BitString [13]	0000000000000	A B ETH
IntegerAttribute 1	Integer	0	A B ETH
BitStringAttribute 3	BitString [13]	0000000000000	A B ETH
BooleanAttribute 1	Boolean	False	A B ETH
BitStringAttribute 4	BitString [13]	0000000000000	A B ETH
BooleanAttribute 2	Boolean	False	A B ETH
BitStringAttribute 5	BitString [13]	0000000000000	A B ETH

Measurements in RSTP Redundant Networks

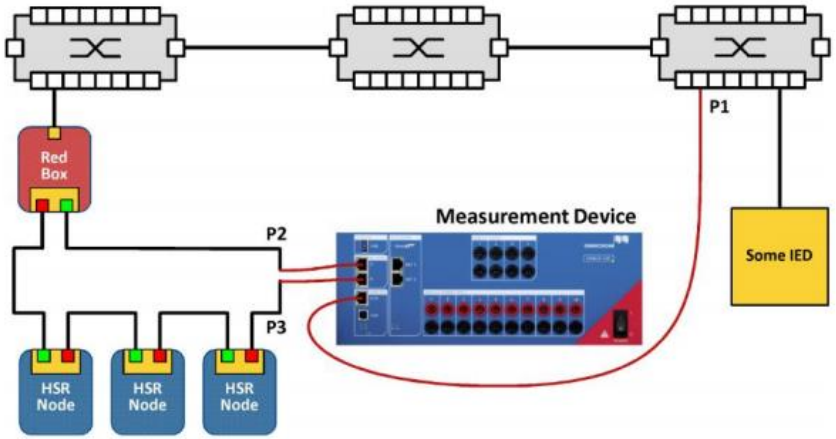
> RSTP: Assessment of the Recovery Time



21 packets lost / 20.996 ms

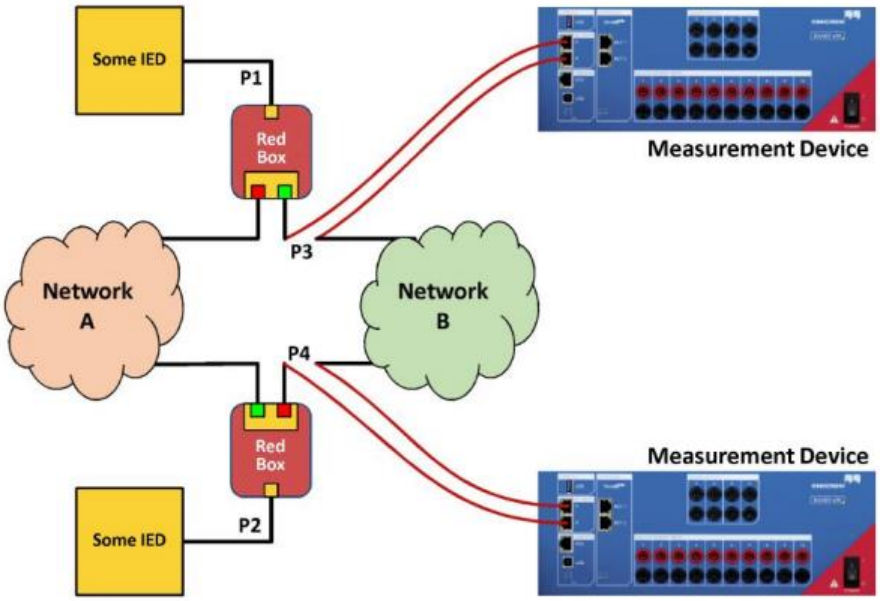
Measurements in PRP & HSR Redundant Networks

- Assessment of:
  - propagation times
  - differences of times in the redundant paths
  - zero-loss of packets
- Measurements in a HSR network:

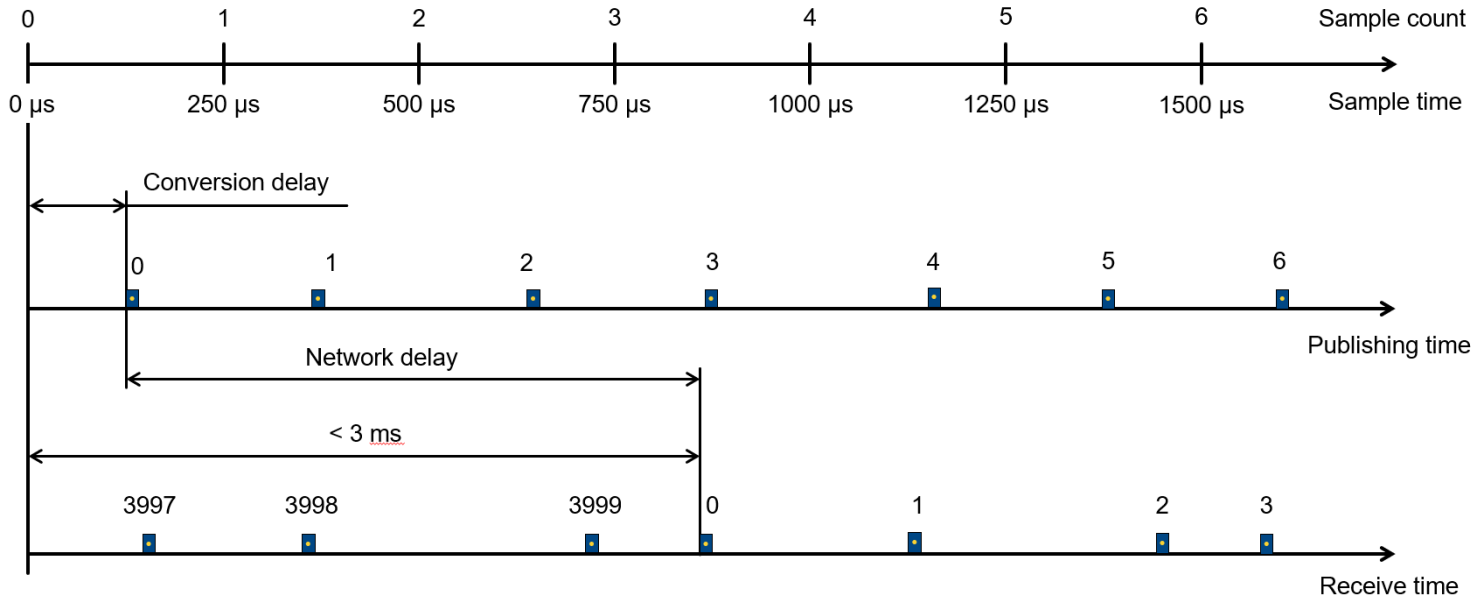


Measurements in PRP & HSR Redundant Networks

> Measurements in a PRP network:



Measurement of Overall Time (e.g. SV @4000spc)



- Packet delay
- Measured by Monitoring device
- Measured by Subscriber IED

Statistics

	A	B	ETH
Receive time		2017-03-27 13:49:57.775	
Samples seen		16000	
Samples missed		0	
Sampling rate		4,000 kHz	
Last packet smpCnt=0		2017-03-27 13:49:57.001	
Clock drift (current)		-7,34 µs	
Clock drift (since start)		-5,01 µs	
Timed out		False	
Timed out count		0	
Packet interval:			
Minimum		223,84 µs	
Maximum		277,37 µs	
Average		250,00 µs	
Packet delay:			
Minimum		515,49 µs	
Maximum		556,25 µs	
Average		527,35 µs	

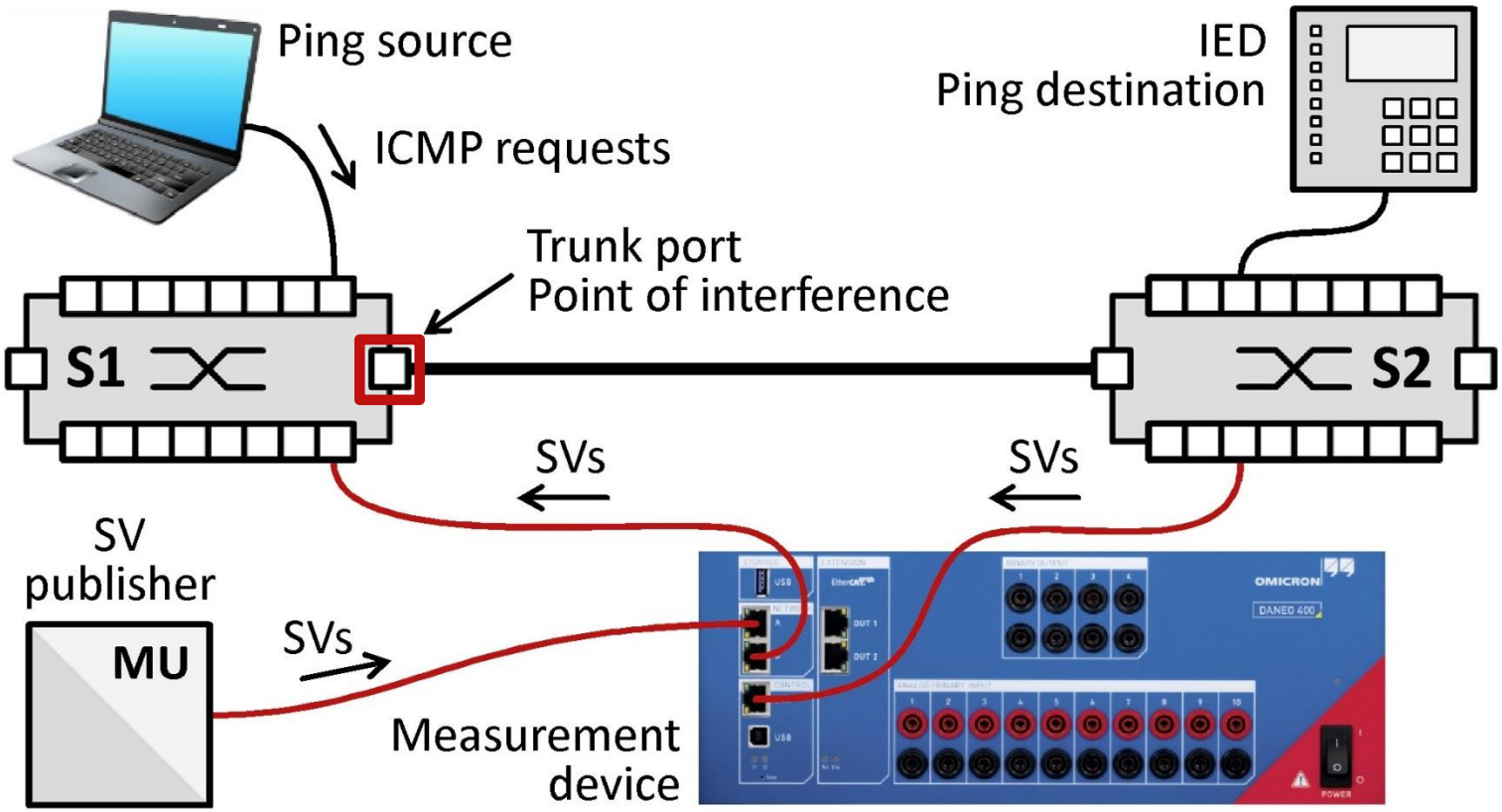
Delay time measurement

> Capturing traffic at different locations

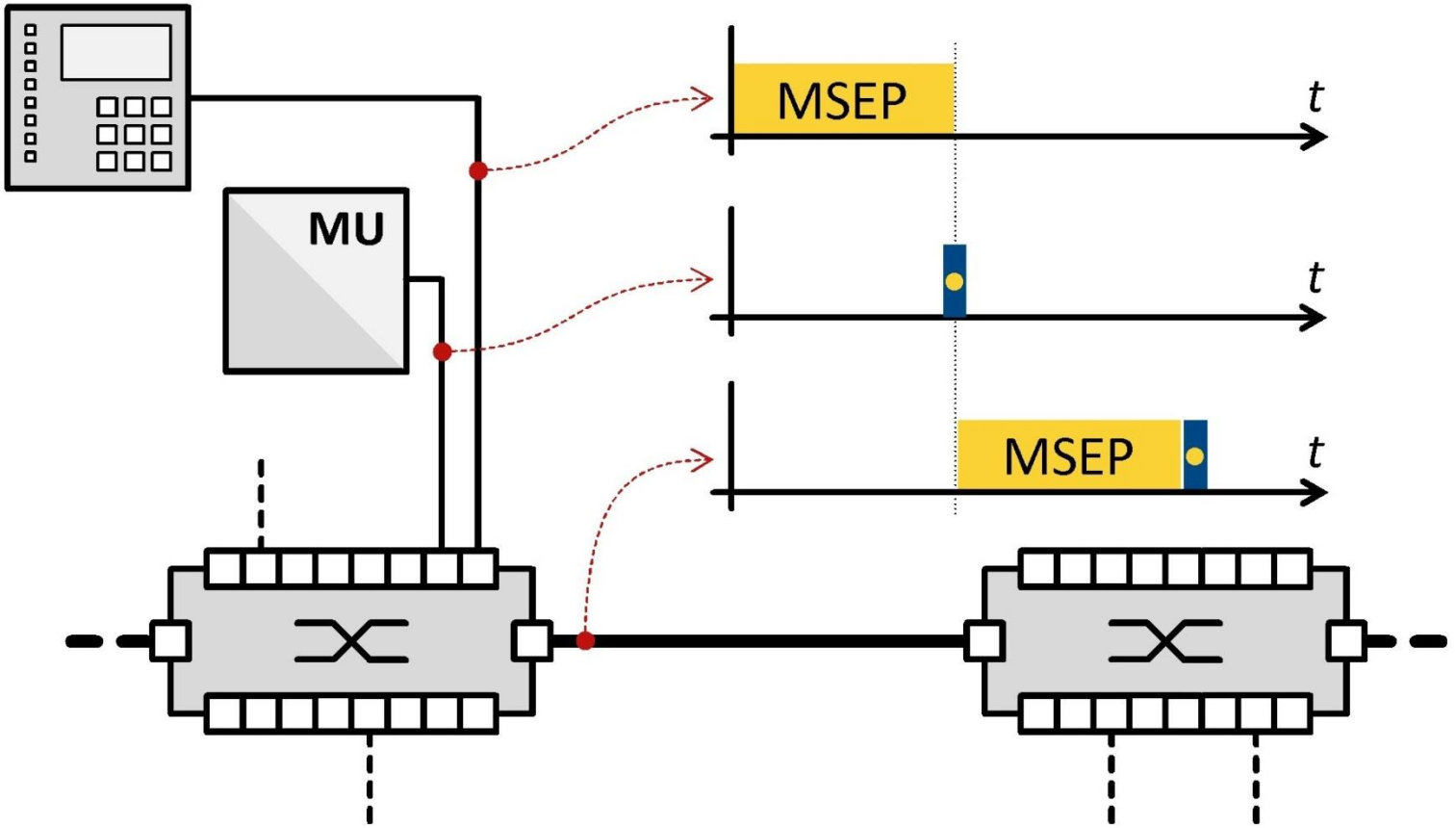
> Difference of times of occurrence

> Local Area Networks or Wide Area Networks

Measuring the effects of interferences



Ethernet packet interference



Influence of interfering traffic

Ping (ICMP) traffic to interfere with Sampled Values

Packet size	Packet duration @ 100Mbit/s	Packet frequency	Probability for interference
500 bytes (4000 bits)	40 µs	1000 s^{-1}	4 %
1538 bytes (12304 bits)	123 µs	885 s^{-1}	10.9 %

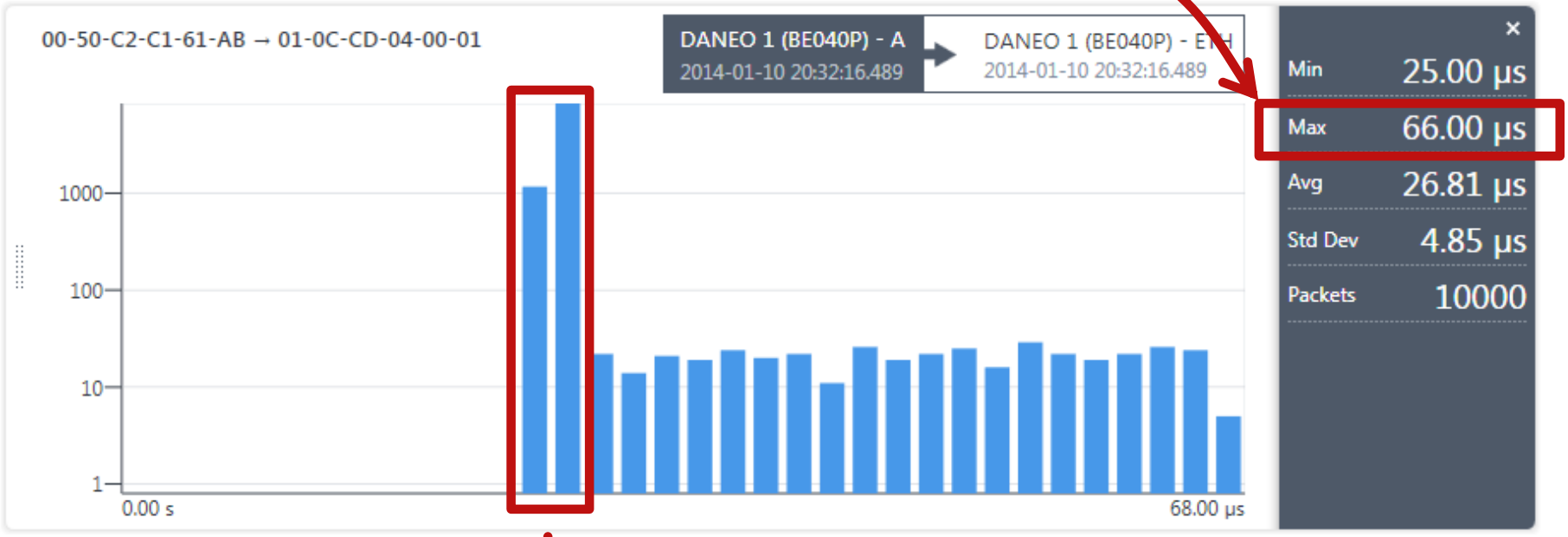
Occupied bandwidth ≡ probability for interference

Only Sampled Values – no interferences

Baseline for following measurements: 26µs

500 bytes packets interfering

40µs + 26µs

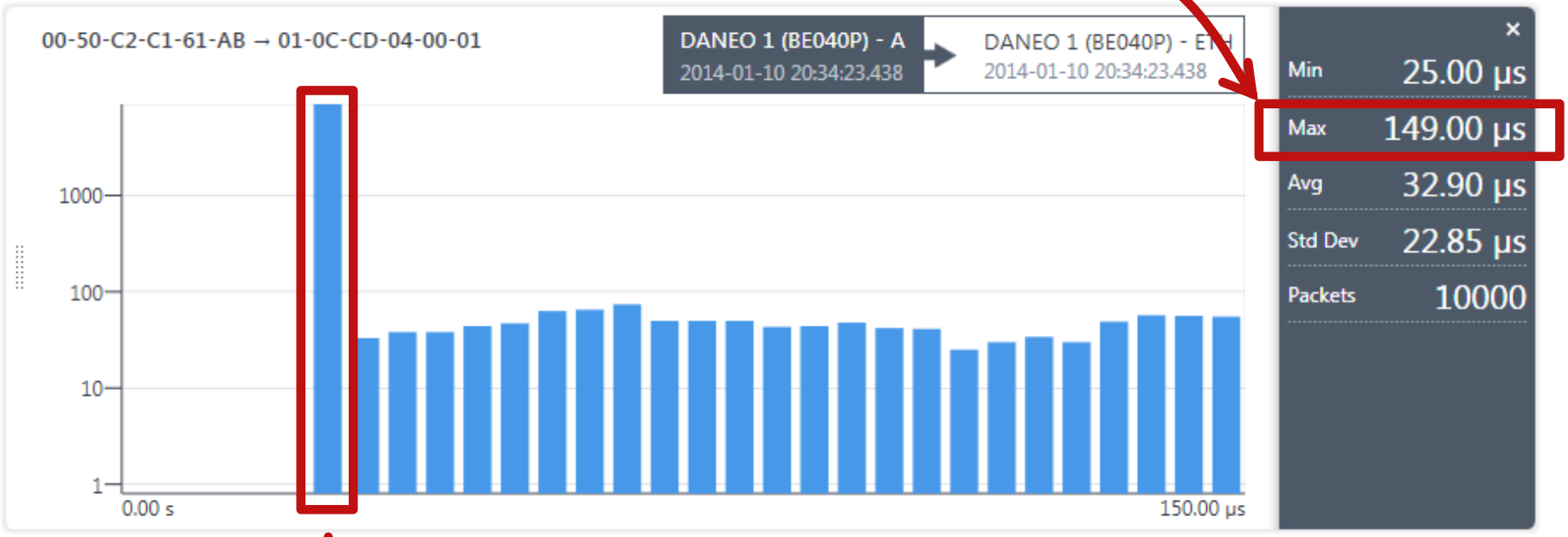


9592 = 96%

Packet size	Packet duration @ 100Mbit/s	Probability for interference
500 bytes (4000 bits)	40 µs	4 %

1538 bytes packets interfering

123µs + 26µs



8894 = 89%

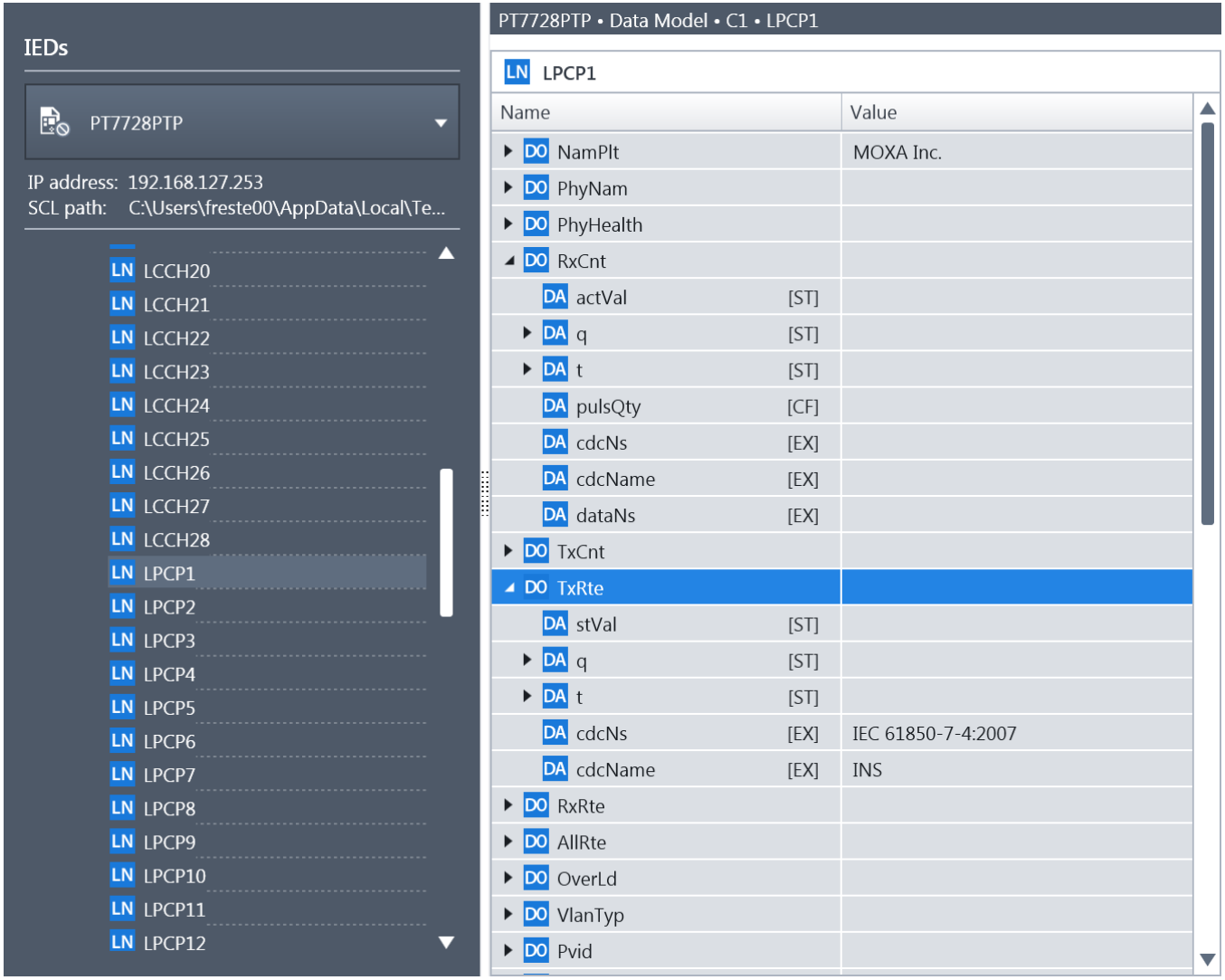
Packet size	Packet duration @ 100Mbit/s	Probability for interference
1538 bytes (12304 bits)	123 µs	10.9 %

Theoretical examination vs. measurements

- Perfect match
- Measurements reveal the expected effects
- Measurements reveal timing behavior in power utility communication networks

MMS and Bridge Object Model for Ethernet Switches

> Allows integration of Ethernet switches in Substation Automaton Systems



Summary

- Communication Network is a crucial component in the substation
- IEC 61850-90-4 offers an engineering guideline for designing networks
- IEC 61850-5 defines timing performance requirements
- Theoretical examination is important for the design, but not sufficient for the assessment. It shows the expected behavior.
- Measurement supports the verification of the design criteria

Thank you for your attention!

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