Robustness Requirement in Industry and Energy

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Redundancy requirements in Energy

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- IEC TC57 WG10 (POWER SYSTEM IED COMMUNICATION AND ASSOCIATED DATA MODELS)
  studied how long the substation automation application can tolerate the loss of communication without causing a malfunction of the protection system (next slide).
- In substation automation, redundancy fulfilling the (n-1) criteria (no single point of failure) is crucial
- Substation automation systems require communication networks that fulfill the (n-1) criteria as well
- Most important criteria for redundancy is the recovery time:
  How long does it take to restore service after a failure

Recovery delay demands as shown in IEC 61850-5 ED2

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Communicating partners	Service	Application recovery tolerated delay	Required Communication Recovery Time
SCADA to IED, client-server	IEC 61850-8-1	800 ms	400 ms
IED to IED interlocking	IEC 61850-8-1	12 ms (with Tmin set to 4 ms)	4 ms
IED to IED, reverse blocking	IEC 61850-8-1	12 ms (with Tmin set to 4 ms)	4 ms
Protection trip excluding Bus Bar protection	IEC 61850-8-1	8 ms	4 ms
Bus Bar protection	IEC 61850-9-2 on station bus	< 1 ms	Bumpless
Sampled Values	IEC 61850-9-2 on process bus	Less then two consecutive samples	Bumpless

To fulfill these requirements, IEC 61850-8-1 and -9-2 uses redundancy solutions standardized for Industrial Ethernet by **IEC 62439-3.**

Standard IEC 62439:
High Availability Automation Networks

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- Ethernet based high availability networks
- Specifies relevant principles
- Independent of application protocol
- Can be used for any application
  - Industrial automation
  - Energy automation
  - Transportation
  - Medical
  - …

Redundancy solutions of IEC 62439

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- Protocols using Reconfiguration (with small recovery time)
  - RSTP (Rapid Spanning Tree Protocol)
    IEEE 802.1D-2004
    IEC 62439-1 Annex A (recovery time calculation methods)
  - MRP (Media Redundancy Protocol)
    IEC 62439-2
- Protocols with “zero” switchover time (seamless)
  - PRP (Parallel Redundancy Protocol)
    IEC 62439-3 Clause 4
  - HSR (High-availability Seamless Redundancy)
    IEC 62439-3 Clause 5

Example of using Reconfiguration: Media Redundancy Protocol

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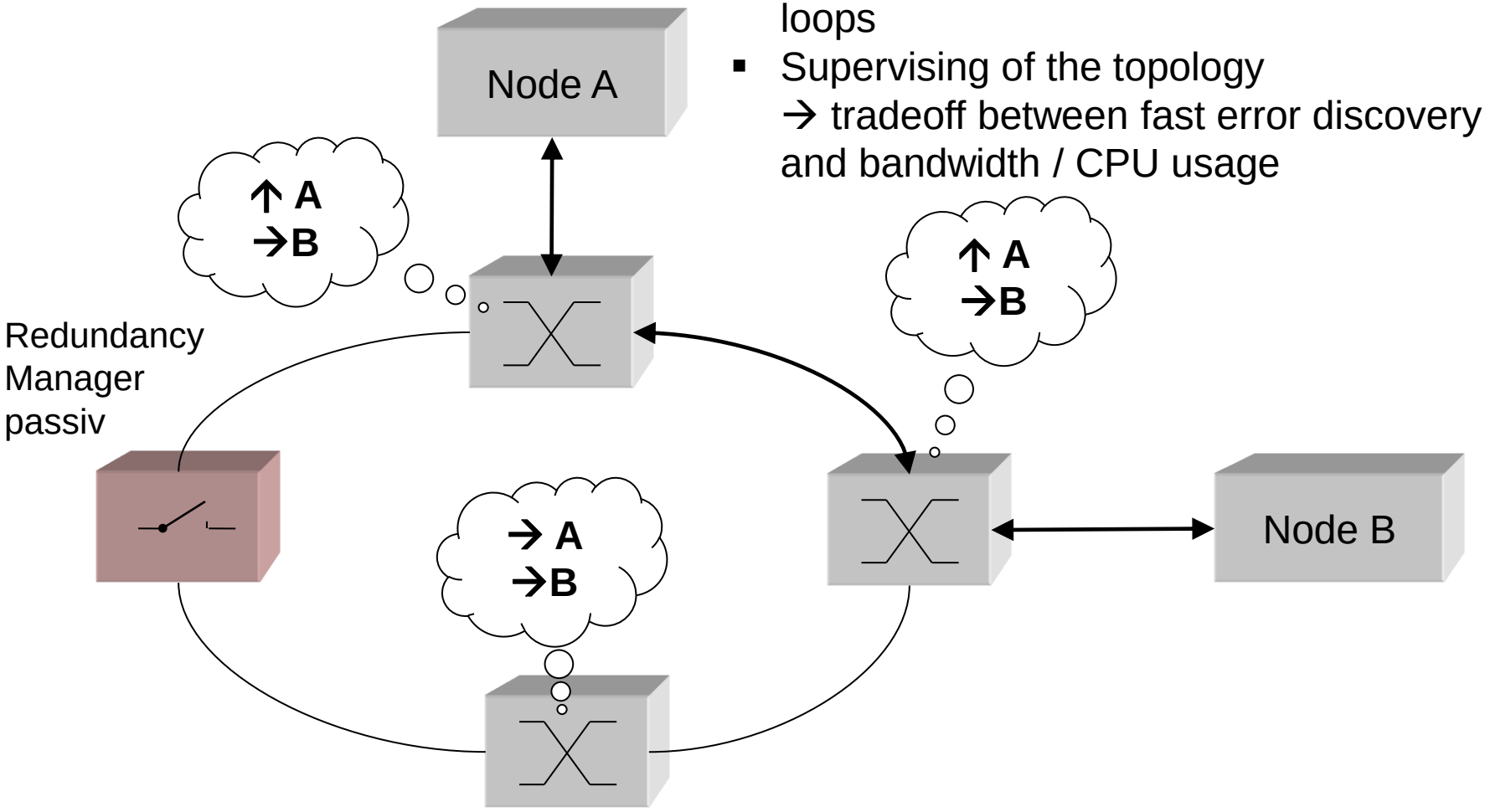
- Blocking redundant paths to prevent loops
- Supervising of the topology
  → tradeoff between fast error discovery and bandwidth / CPU usage



Example of using Reconfiguration: Media Redundancy Protocol

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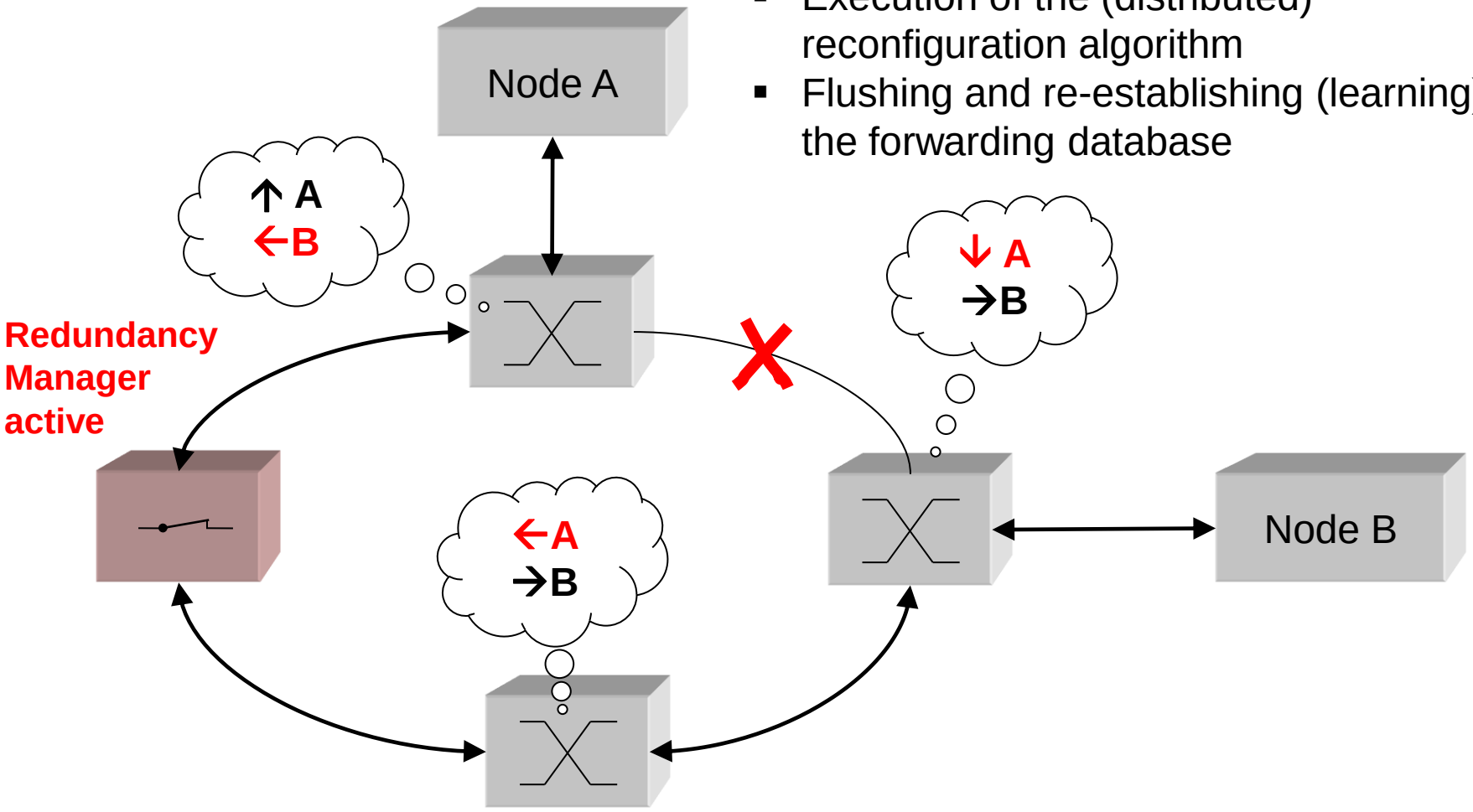
- Execution of the (distributed) reconfiguration algorithm
- Flushing and re-establishing (learning) the forwarding database



Parallel Redundancy (PRP)

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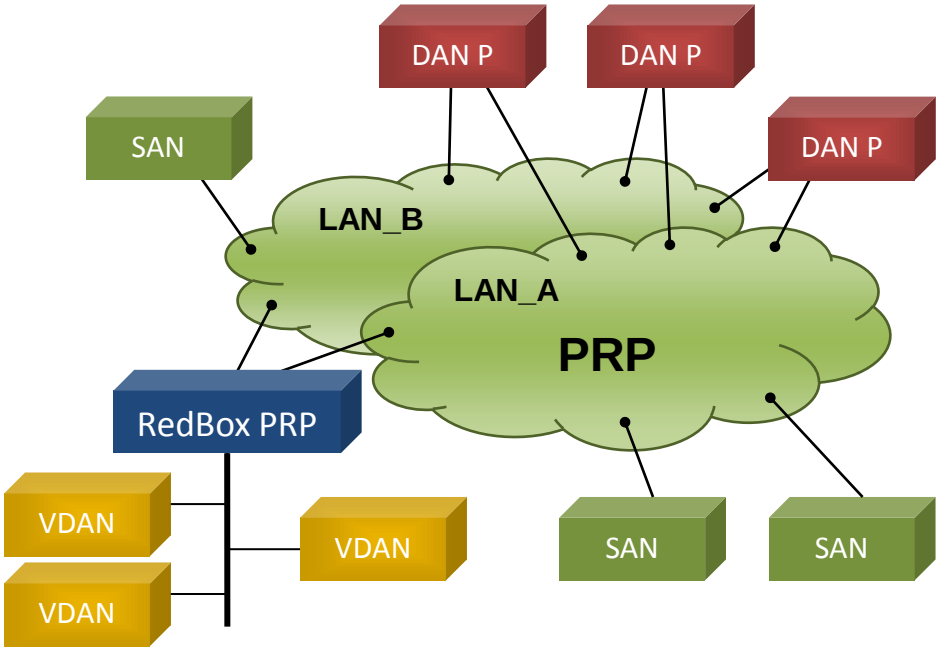
- PRP doubles network infrastructure
- Basic Redundancy Function requires Double Attached Nodes (DAN P): Same send/receive function on both ports
- No forwarding between the ports
- Standard Nodes directly attachable; but :
  - no redundancy support
  - no connectivity between LAN A /B
- Safe discard of duplicates by redundancy trailer added to frames (PRP 1: basically sender's frame sequence number)



Redundancy Box (RedBox)

- Full connectivity for Virtual Dual Attached Nodes (VDAN)
- Acts as proxi node for VDAN

PRP normal operation

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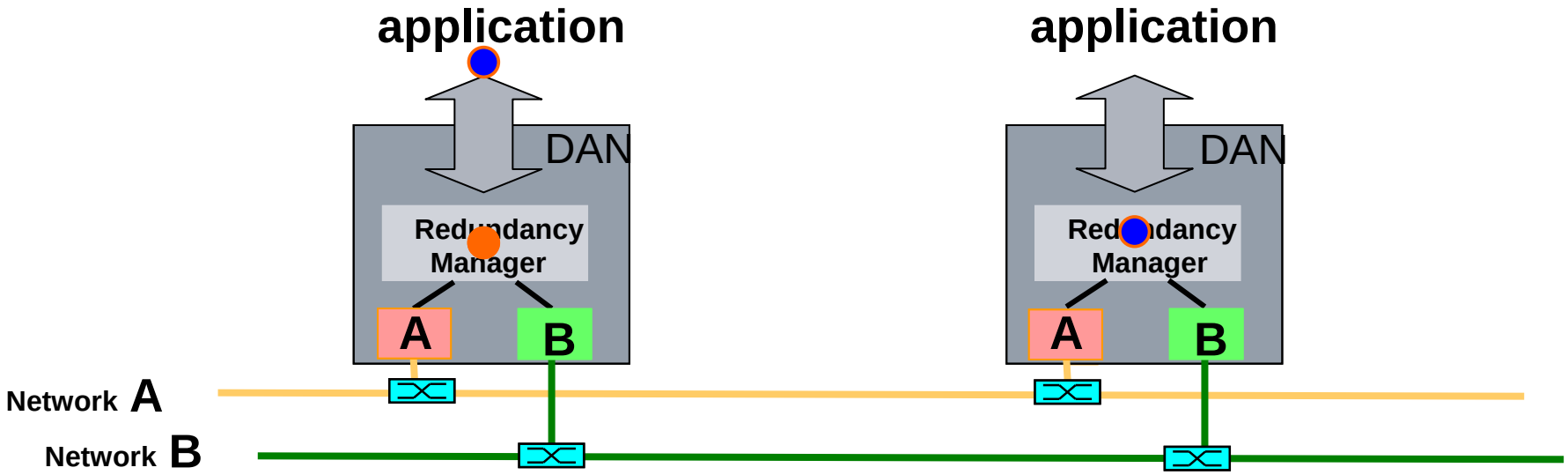

PRP operation with fault

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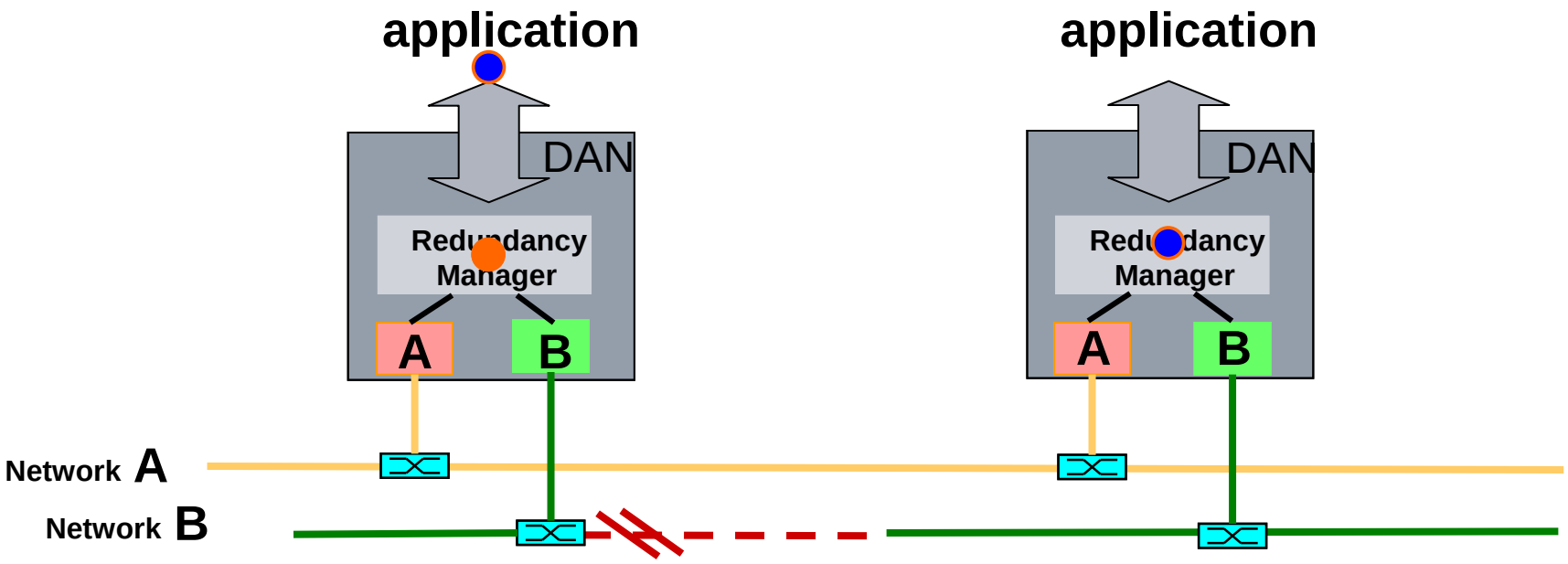

PRP normal operation (with long delay on Network B)

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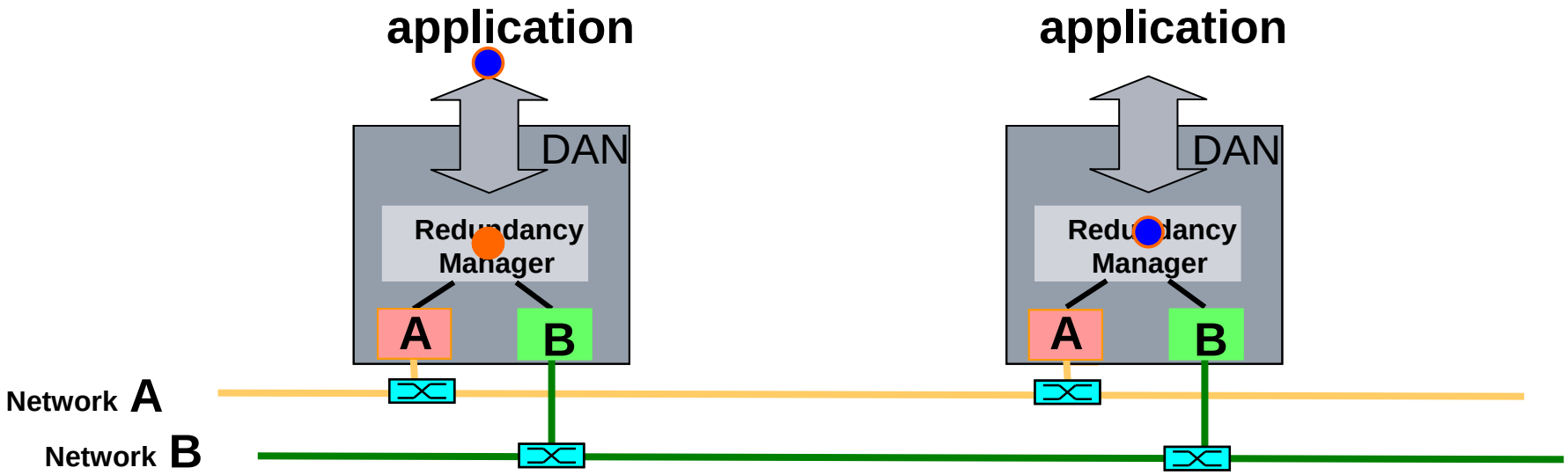

- «Memory» for previously received frames required (duplicate discard buffer)
- Buffer size depends on maximal difference of network delay
- In case of a «forgotten» frame the duplicate is not discarded → but (most likely) it will be eliminated by upper layers

PRP Parallel Redundancy Protocol (IEC 62439-3 Clause 4)

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- PRP provides (n-1) redundancy (no single point of failure) and availability increase is high.
- PRP requires the full duplication of the network, but only of those parts that require seamless redundancy.
- The two networks must be completely independent (power, topology changes etc.) to avoid common mode errors
- PRP allows to attach standard Ethernet devices to one of the LANs. Therefore, networks with redundant and non-redundant parts can be built.
- PRP can be easily implemented in software by a dedicated driver that manages two standard Ethernet ports.

HSR basics

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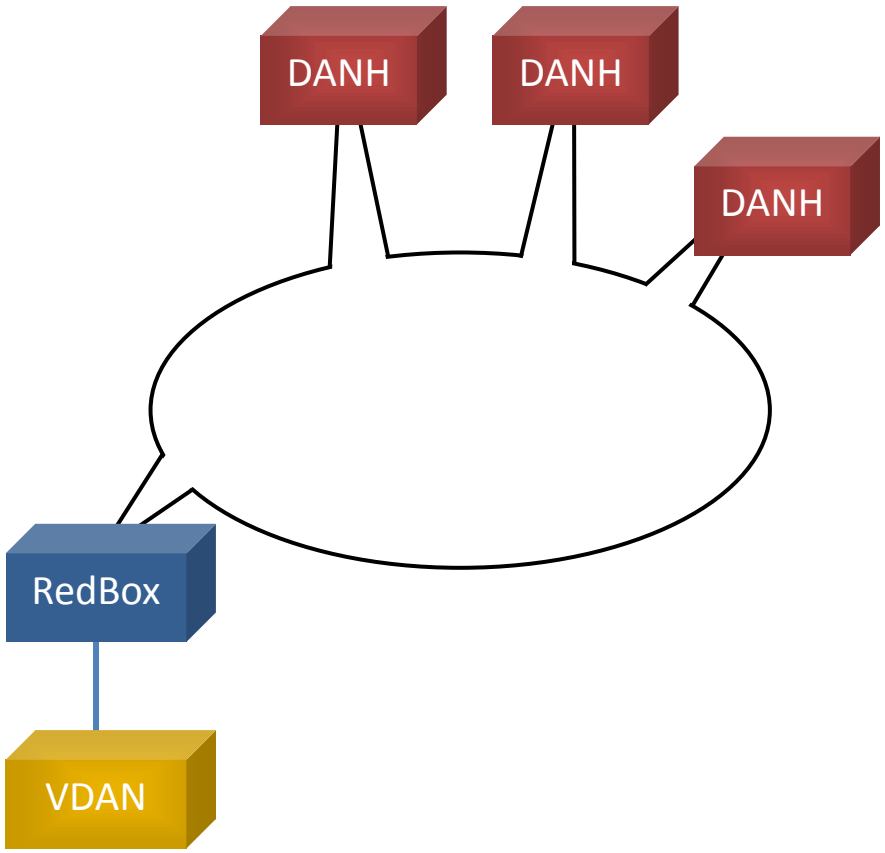

- HSR and PRP share same semantics (both in standard IEC 62439-3)
- Send/receive function same as PRP
- Forwarding between the ports
- Basic forwarding rule is broadcast-like:
  - Frames are forwarded on all ports
  - A frame is sent only once per port
- Cut through switching applied to minimize forwarding delay → redundancy header (instead of trailer)
- Loop suppression mechanism:
  - Receiver removes frame (unicast)
  - Sender removes sent frame
  - Frames found in duplicate discard buffer are removed (for extended topologies)

HSR RedBox in an open Environment

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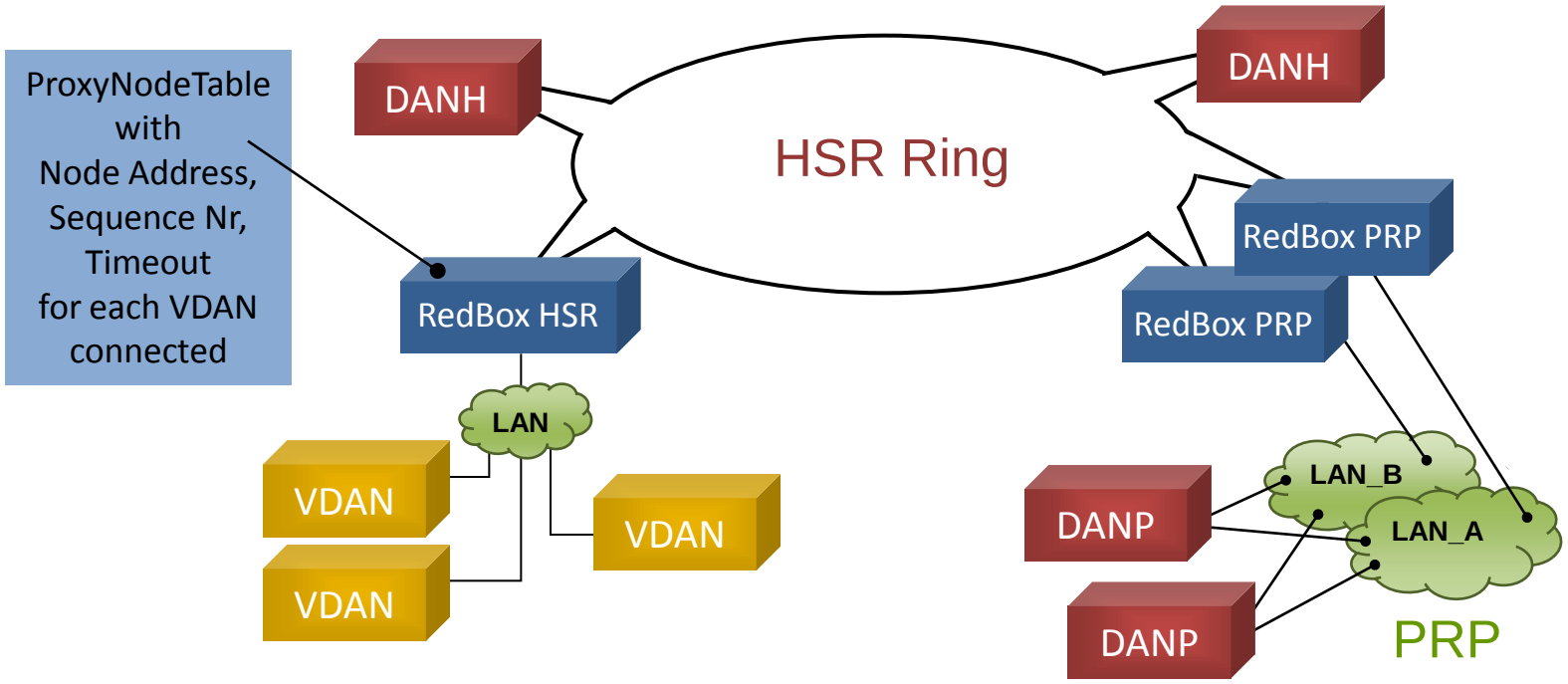

Standard Nodes Operation

- Redundancy Box (RedBox HSR) with 3 Ports (2 HSR, 1 Interlink)
- acts as proxy for VDAN (Virtualy Dual Attached Nodes)

PRP Coupling

- Redundancy Box (RedBox PRP)
- Conversion of Frame Format (Tag)
- Suppression of back feeding between LAN_A and LAN_B

HSR High-availability seamless redundancy IEC 62439-3 Clause 5

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- Provides (n-1) redundancy for all network components (no single point of failure)
- Provides seamless redundancy for station bus and process bus
- Allows to build rings without using switches
- Cost-effective solution
- Requires dedicated hardware to keep the forwarding delay low.

HSR normal operation (unicast)

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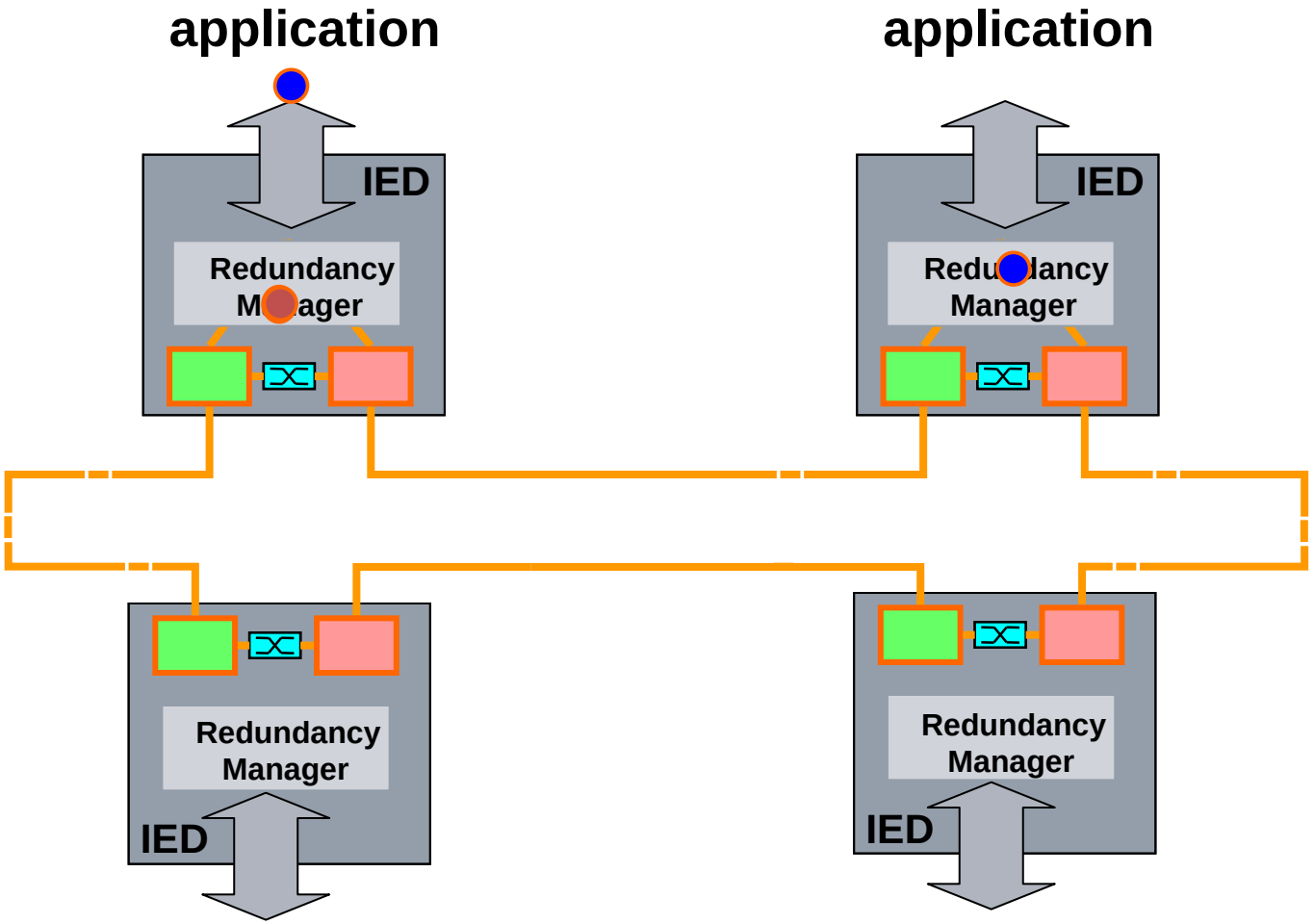

HSR operation with fault

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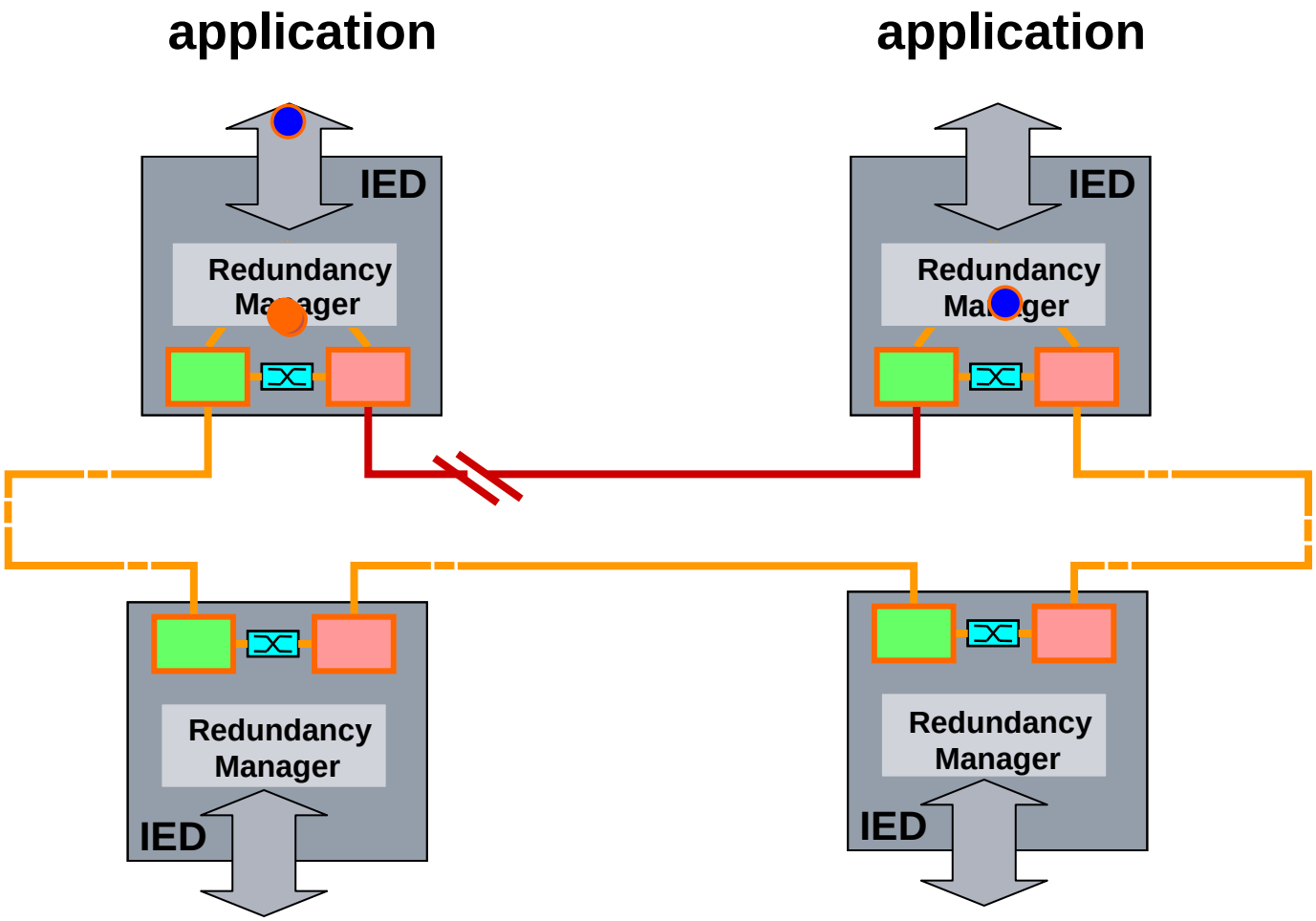

HSR: rings of rings: three levels

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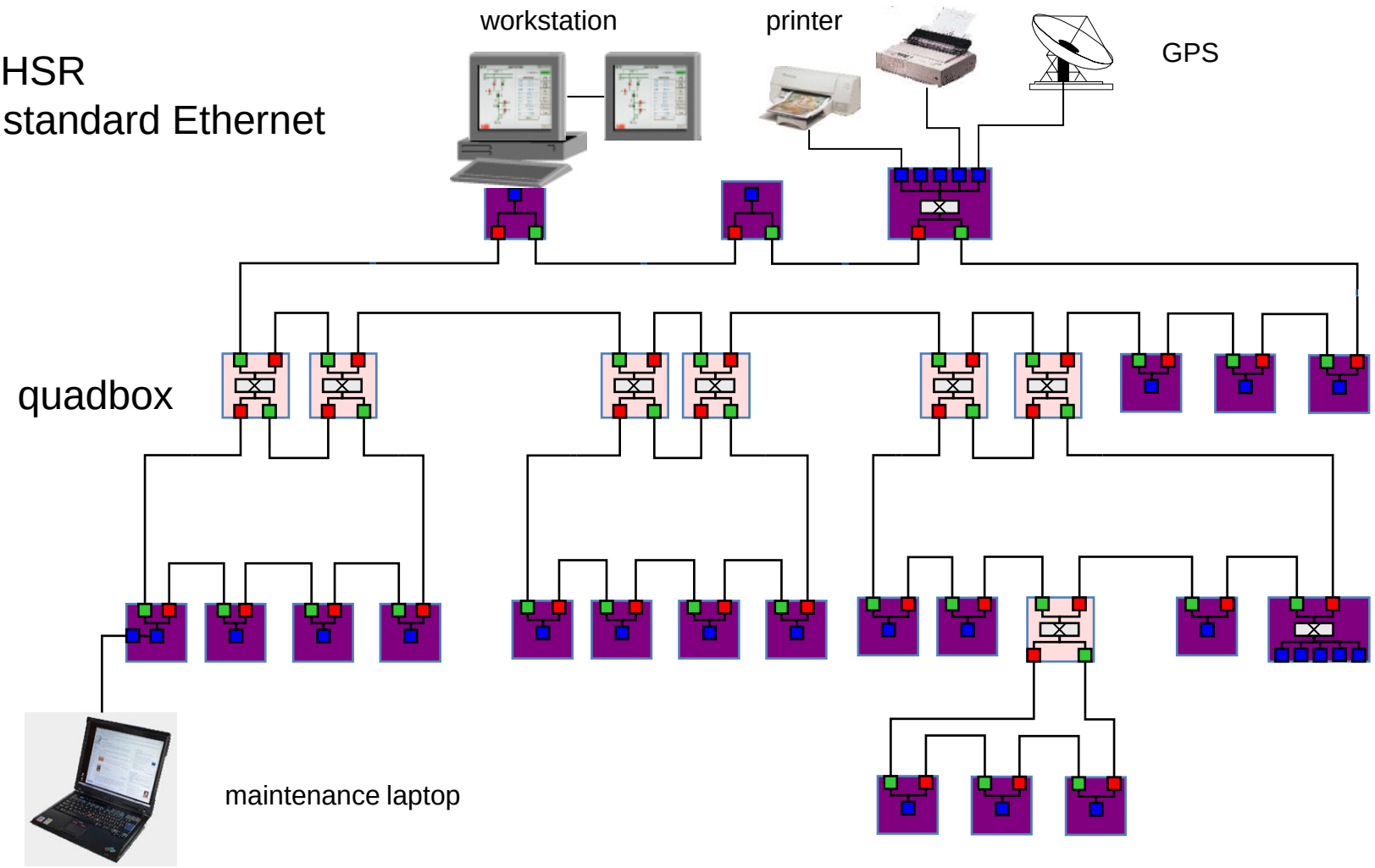
- HSR
- standard Ethernet



- no RSTP protocol any more (but can be used)
- note that level 3 is singly attached (only one quadbox)

Summary

IEC 61850 specifies several redundancy methods

PRP seamless, for high-end substations, combines topologies redundant and not redundant, easily to implement in software
SW-Drivers available from at least two suppliers (ZHAW, NetModule);
RedBox IP (VHDL and Code) for FPGA-Implementation from ZHAW.

HSR seamless, for voltage levels and process bus, rings and rings of rings
Requires nodes with dedicated hardware, but after this initial investment, provides a cost-effective redundancy.
Allows ring and parallel topologies, but not mixing redundant and non-redundant devices on the same network (RedBox is required).
Several companies are developing components with the support of the KTI project of ZHAW.

PRP/HSR in Parallel and Ring Redundancy

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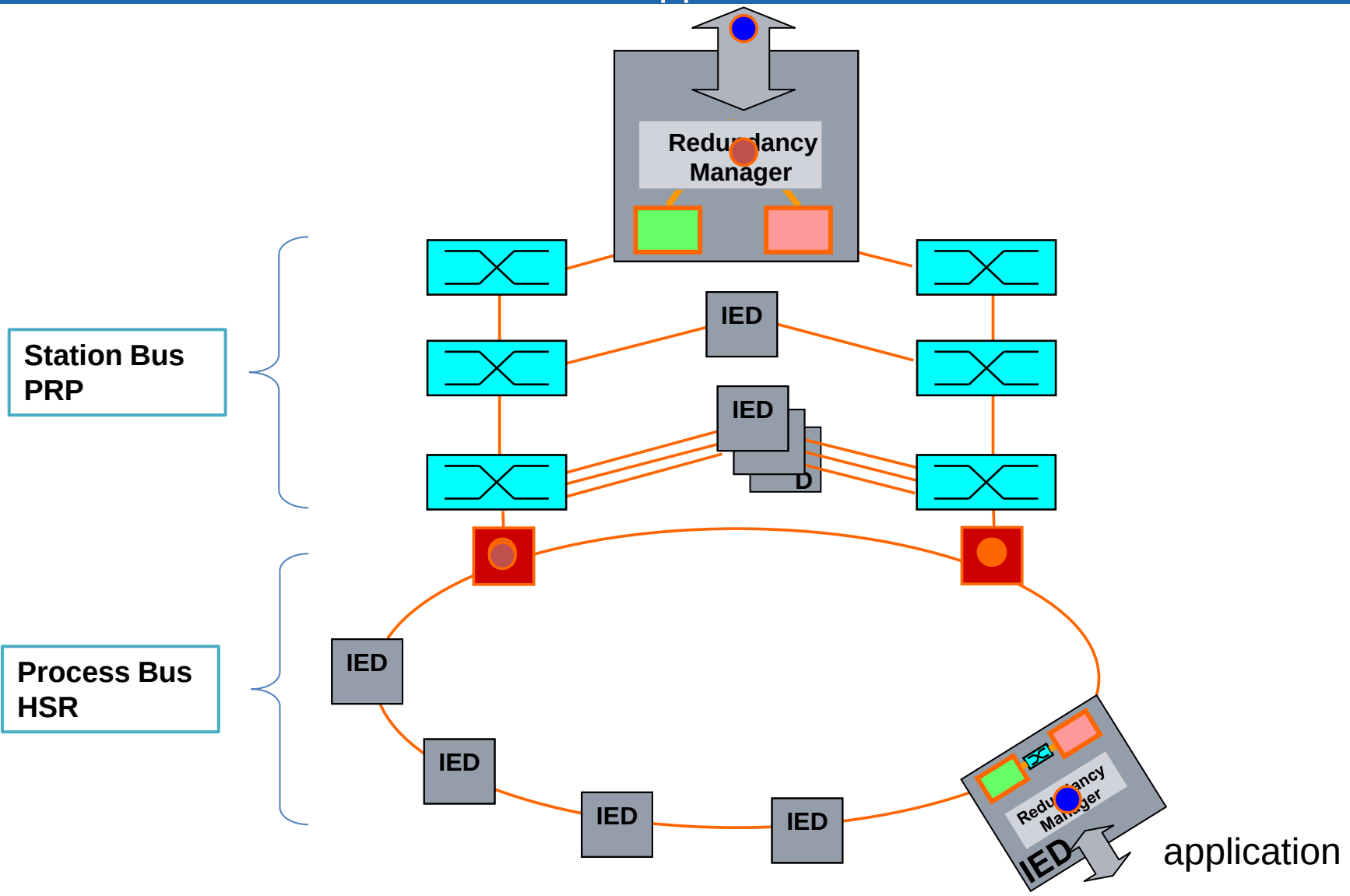

PRP/HSR in Parallel and Ring Redundancy

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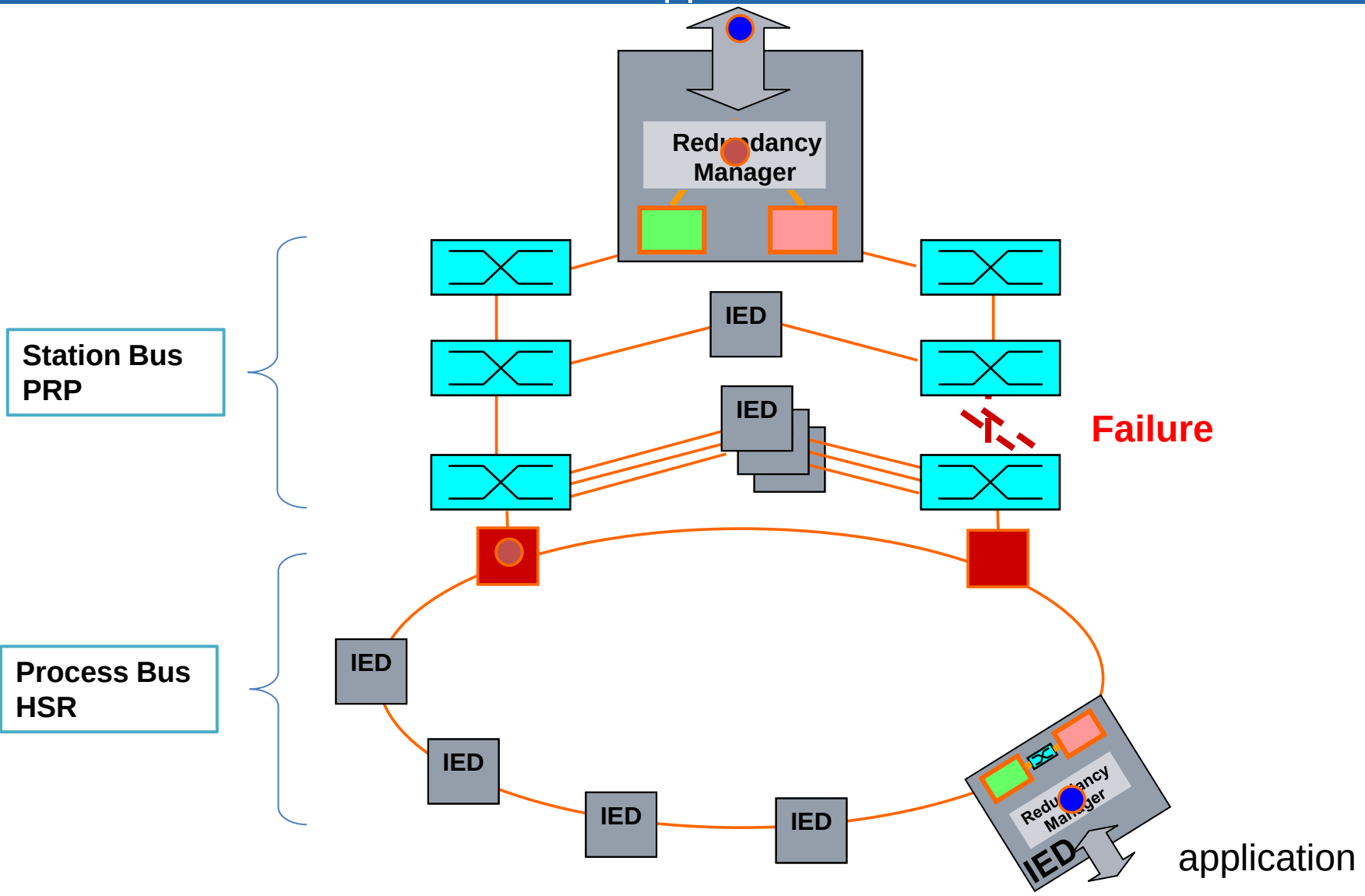

HSR Ring Coupling

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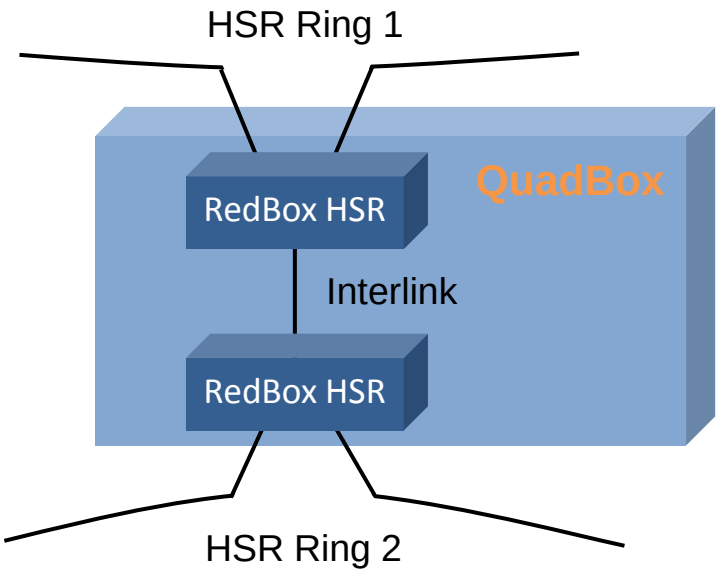
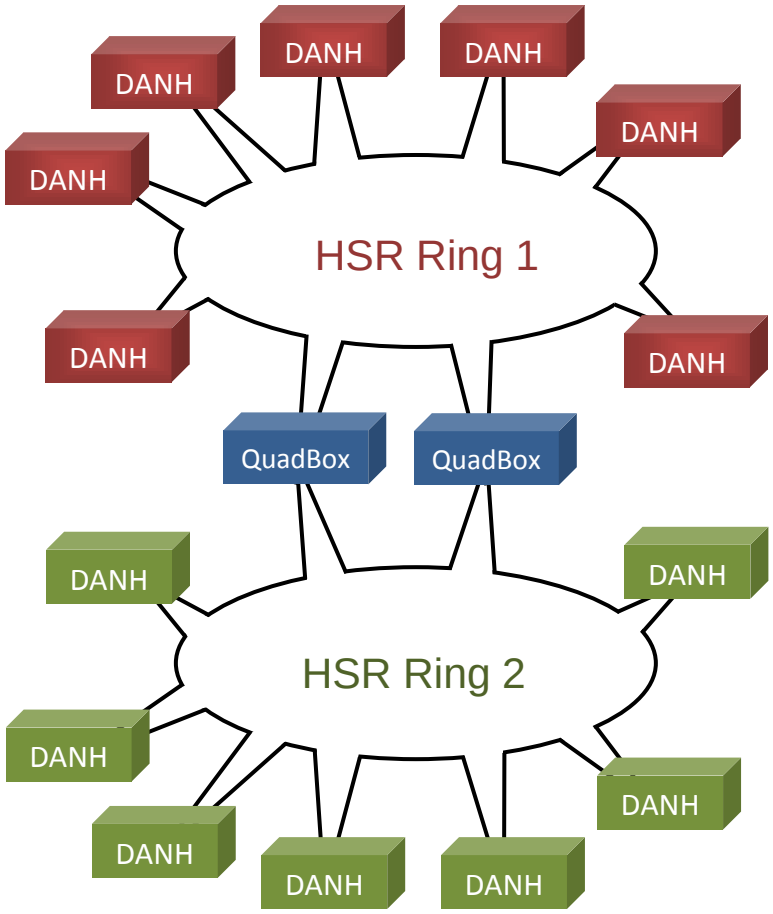
- Ring Coupling connects networks – not a single node
- Basic QuadBox can be implemented using 2 standard RedBoxes HSR





- This basic two ring topology does no traffic partitioning because all frames are forwarded to both rings

HSR Enhanced Ring Coupling (future)

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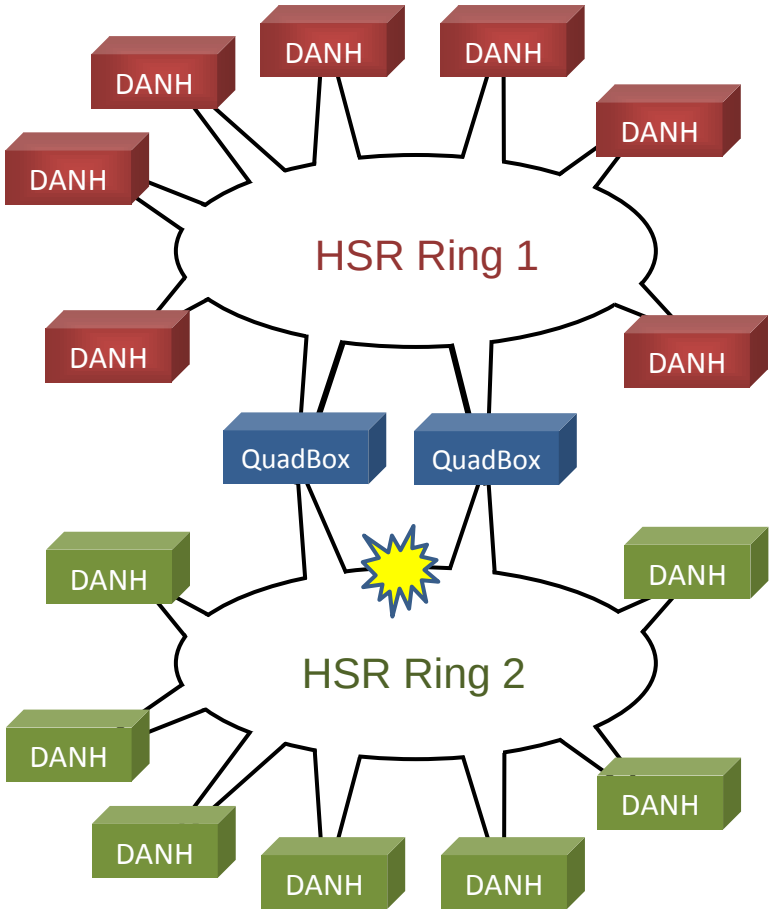
- Use of any possible path is NOT a good idea:
  - In presence of high network load
  - Different wire speed

→ Enhance HSR RedBoxes with duplicate Filtering and Forwarding Rules

- Shall ring 1 (2) be used as bypass for link errors?

→ Overload can cause duplicate detection to fail: Problem of circulating frames



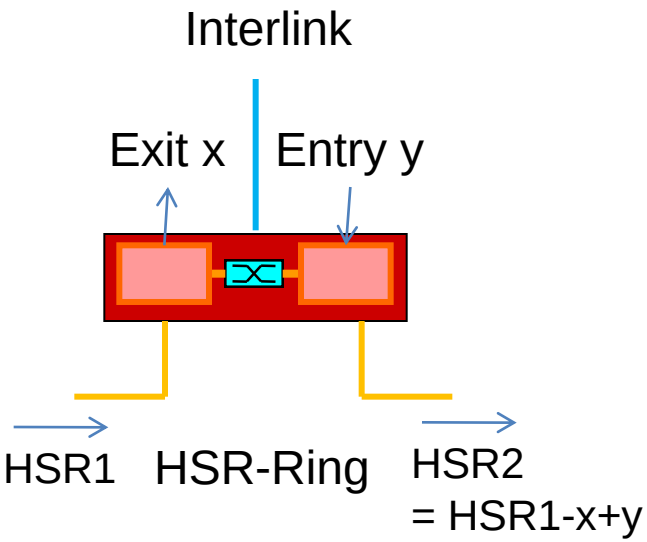
Effects of Overload

Critical load situation occur

- with increased number of nodes
- with sporadic traffic pattern
- In presence of network errors
- in emergency situations

Effects

- Queuing of frames in ring
- Additional resources needed
- Increased latencies
- Frame losses or duplication
- Thread (for availability)



Load grows if x < y

Application example: Meetering and Functional Safety

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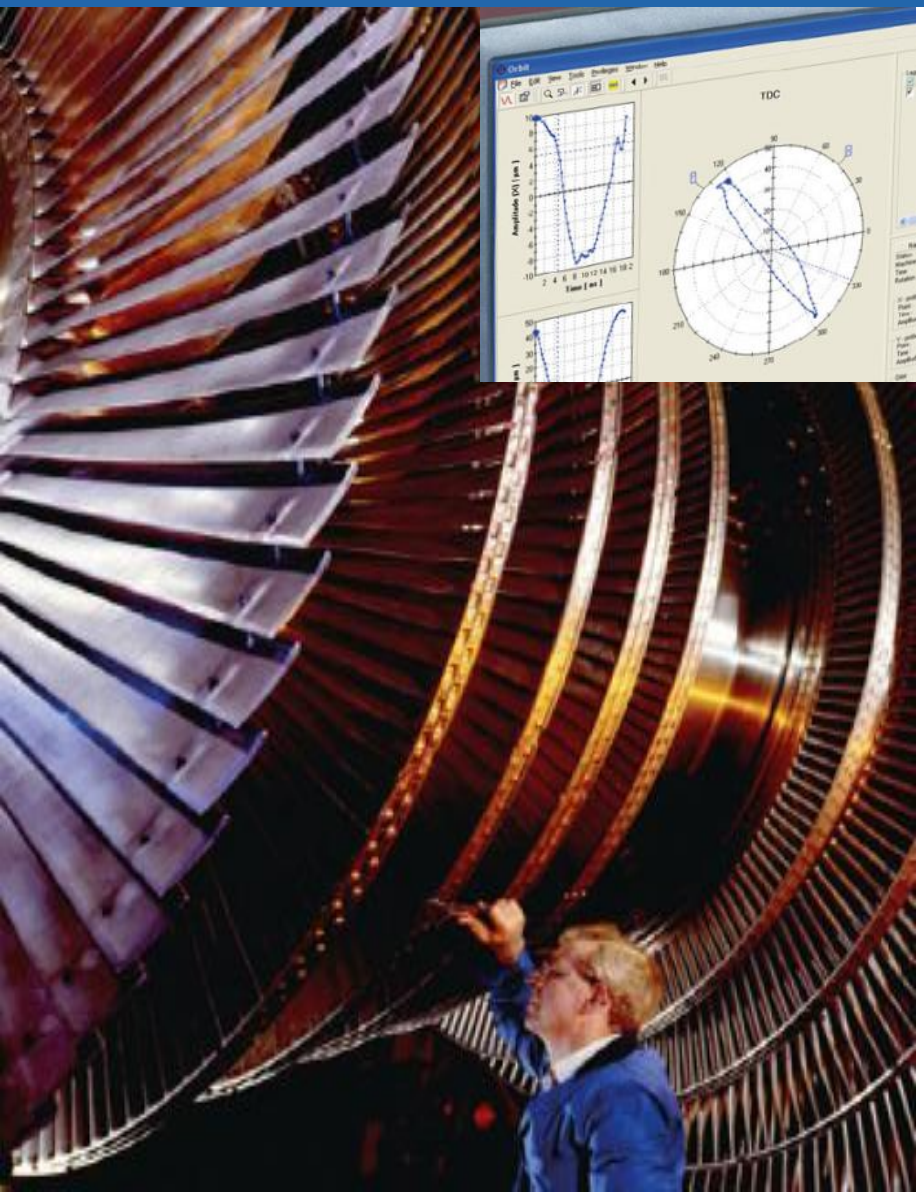

Requirements/characteristics:

- Robust synchronization
- Guarantied Transmission of Taco-Signal
- High peek bandwidth in case of error- or diagnoses operation
- Safety-critical alarms
- High availability

Solution:

- Synchronization using PTP (IEEE 1588)
- Reserved time slot for time- and safety-critical frames
- HSR as redundancy protocol

Audio / Video

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Goal:
Replacement of
cross-point switchers

- by the network in
- Broadcasting Centers
- Theaters, opera houses
- Live events (concerts)

Requirements:

- Highly scalable design (from one up to thousands of channels)
- Phase locked word clocks with short synchronization time
- Streaming with low latency
- Seamless redundancy

Solution: again PTP and HSR like redundancy (merging in play out buffer)

Application example: Interlocking Network

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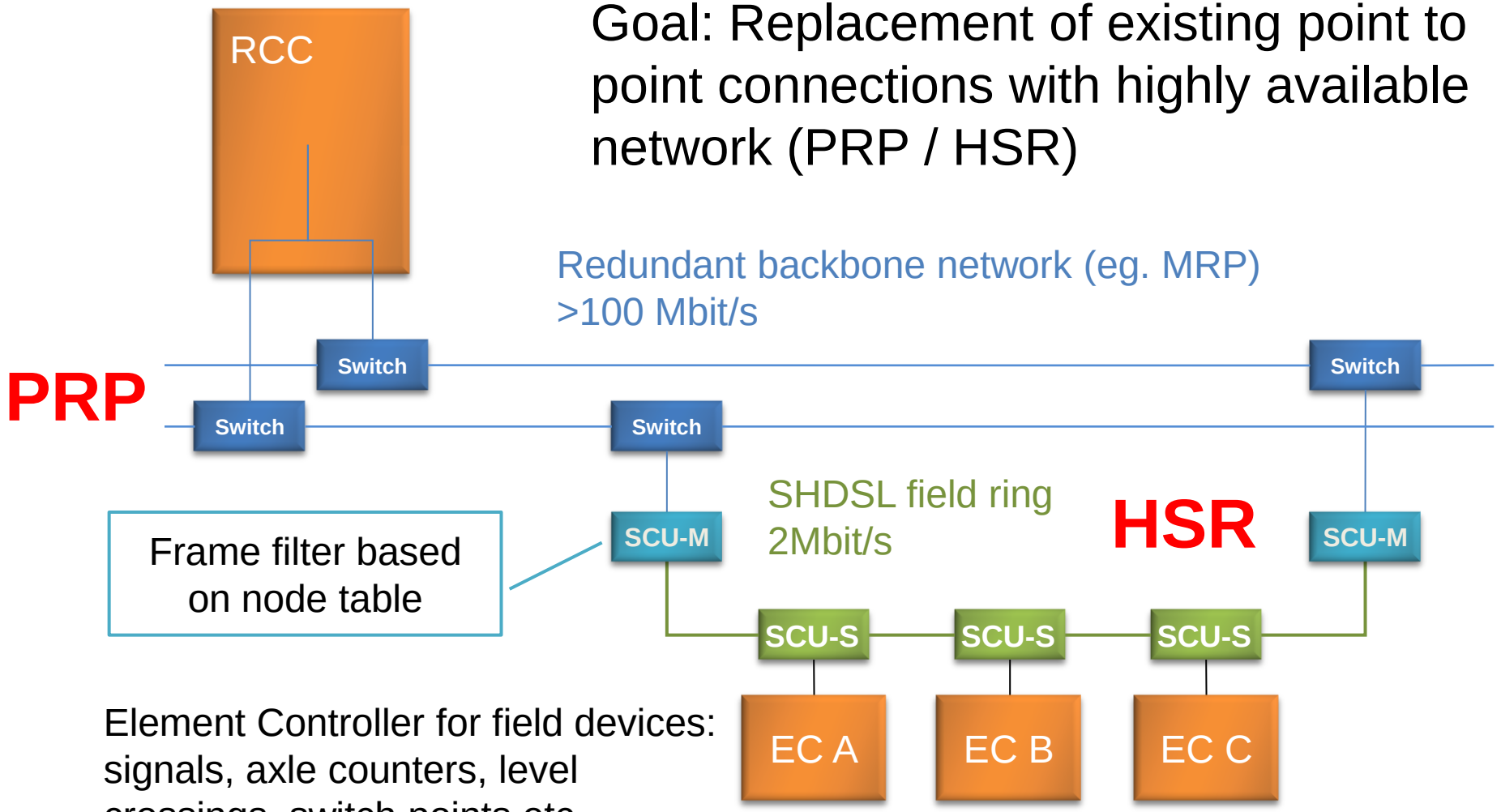
Railway Control Center



Application example: Interlocking Network (II)

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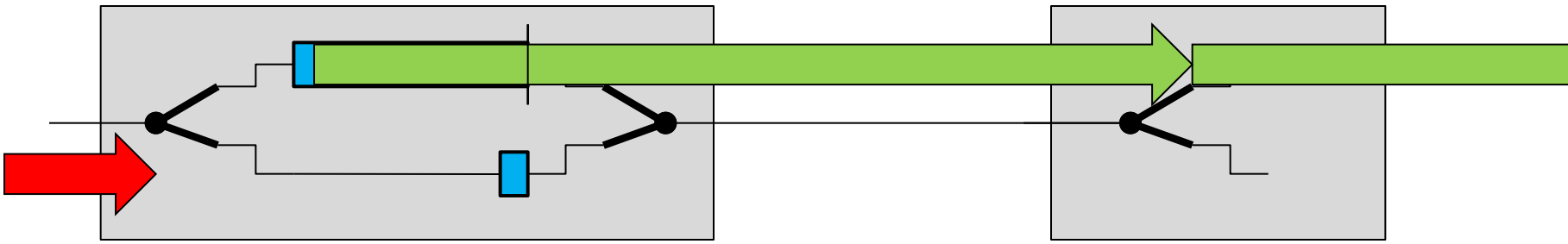
- Problem:
  - Security protocol allows only minimal delay of acknowlege

  → Avoid delay of RT-Frames by long Non-RT-Frames
- Solution:
  - Suspend (not abort) transmission of Non-RT-Frames

  → Layer 1 signaling is required (implemented in SHDSL-MAC)



Application example:
Interlocking Network Demonstrator

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