User Manual

Redundancy Configuration
Embedded Ethernet Switch (HiOS-2E EES)

UM RedundConfig HiOS-2E EES
Release 4.0 07/2014

Technical Support
https://hirschmann-support.belden.eu.com

You can get the latest version of this manual on the Internet at the Hirschmann product site (http://www.hirschmann.com).

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Hirschmann Automation and Control GmbH
Stuttgarter Str. 45-51
72654 Neckartenzlingen
Germany
Tel.: +49 1805 141538

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Contents

Safety instructions

⚠ WARNING
UNCONTROLLED MACHINE ACTIONS To avoid uncontrolled machine actions caused by data loss, configure all the data transmission devices individually. Before you start any machine which is controlled via data transmission, be sure to complete the configuration of all data transmission devices. **Failure to follow these instructions can result in death, serious injury, or equipment damage.**

About this Manual

The “GUI” reference manual contains detailed information on using the graphical interface to operate the individual functions of the device.

The “Command Line Interface” reference manual contains detailed information on using the Command Line Interface to operate the individual functions of the device.

The “Installation” user manual contains a device description, safety instructions, a description of the display, and the other information that you need to install the device.

The “Basic Configuration” user manual contains the information you need to start operating the device. It takes you step by step from the first startup operation through to the basic settings for operation in your environment.

The “Redundancy Configuration” user manual document contains the information you require to select the suitable redundancy procedure and configure it.

The document “HiView User Manual” contains information about the GUI application HiView. This application offers you the possibility to use the graphical user interface without other applications such as a Web browser or an installed Java Runtime Environment (JRE).

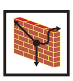
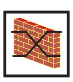
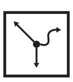
The Industrial HiVision network management software provides you with additional options for smooth configuration and monitoring:
- ActiveX control for SCADA integration
- Auto-topology discovery
- Browser interface
- Client/server structure
- Event handling
- Event log
- Simultaneous configuration of multiple devices
- Graphical user interface with network layout
- SNMP/OPC gateway

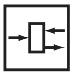
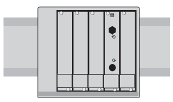
Key

The designations used in this manual have the following meanings:

▶	List
☐	Work step
■	Subheading
Link	Cross-reference with link
Note:	A note emphasizes an important fact or draws your attention to a dependency.
`Courier`	ASCII representation in the graphical user interface
	Execution in the Graphical User Interface
	Execution in the Command Line Interface

Symbols used:

	WLAN access point
	Router with firewall
	Switch with firewall
	Router
	Switch

	Bridge
	Hub
	A random computer
	Configuration Computer
	Server
	PLC - Programmable logic controller
	I/O - Robot

1 Network Topology vs. Redundancy Protocols

When using Ethernet, an important prerequisite is that data packets follow a single (unique) path from the sender to the receiver. The following network topologies support this prerequisite:

- Line topology
- Star topology
- Tree topology

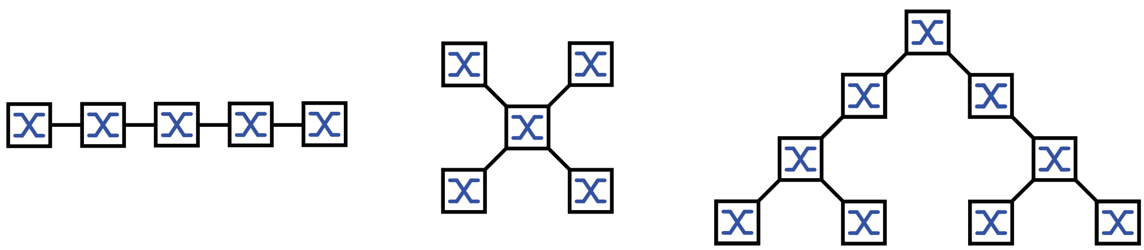


Figure 1: Network with line, star and tree topologies

To ensure that the communication is maintained when a connection fails, you install additional physical connections between the network nodes. Redundancy protocols ensure that the additional connections remain switched off while the original connection is still working. If the connection fails, the redundancy protocol generates a new path from the sender to the receiver via the alternative connection.

To introduce redundancy onto layer 2 of a network, you first define which network topology you require. Depending on the network topology selected, you then choose from the redundancy protocols that can be used with this network topology.

1.1 Network topologies

1.1.1 Meshed topology

For networks with star or tree topologies, redundancy procedures are only possible in connection with physical loop creation. The result is a meshed topology.

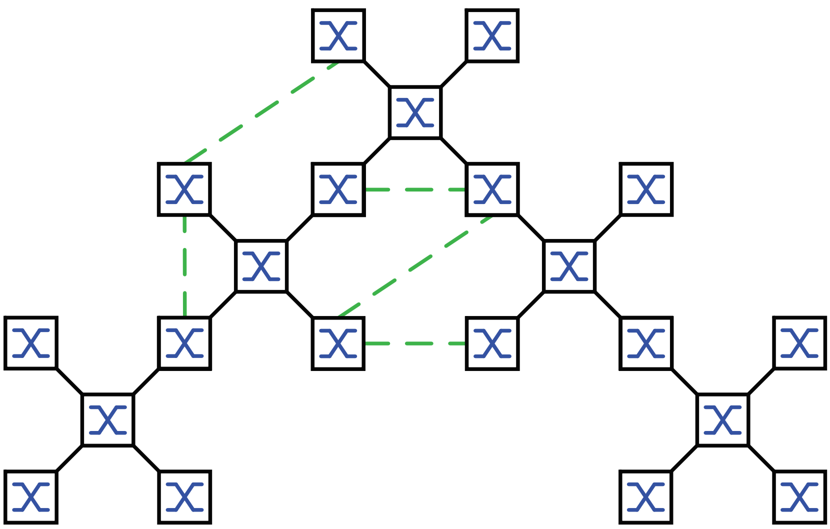


Figure 2: Meshed topology: Tree topology with physical loops

For operating in this network topology, the device provides you with the following redundancy protocols:
- Rapid Spanning Tree (RSTP)

1.1.2 Ring topology

In networks with a line topology, you can use redundancy procedures by connecting the ends of the line. This creates a ring topology.

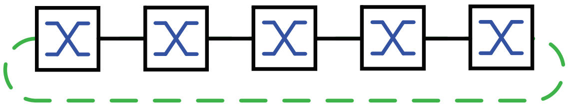


Figure 3: Ring topology: Line topology with connected ends

For operating in this network topology, the device provides you with the following redundancy protocols:
- Media Redundancy Protocol (MRP)
- High-availability Seamless Redundancy (HSR)
- Rapid Spanning Tree (RSTP)

1.2 Redundancy Protocols

For operating in different network topologies, the device provides you with the following redundancy protocols:

Redundancy protocol	Network topology	Comments
HSR	Ring	Uninterrupted availability. On the path from the sender to the receiver, HSR transports the data packets in both directions via a ring.
MRP	Ring	The switching time can be selected and is practically independent of the number of devices. An MRP-Ring consits of up to 50 devices that support the MRP protocol according to IEC 62439. If you only use Hirschmann devices, up to 100 devices are possible in the MRP-Ring.
PRP	Random structure of the PRP LANs	Uninterrupted availability. On the path from the sender to the receiver, PRP transports a data packet in parallel via 2 mutually independent LANs.
RSTP	Random structure	The switching time depends on the network topology and the number of devices. ▶ typ. < 1 s with RSTP ▶ typ. < 30 s with STP
Link Aggregation	Random structure	A Link Aggregation Group is the combining of 2 or more, full-duplex point-to-point links operating at the same rate, on a single switch to increase bandwidth.

Table 1: Overview of redundancy protocols

Note: When you are using a redundancy function, you deactivate the flow control on the participating device ports. If the flow control and the redundancy function are active at the same time, there is a risk that the redundancy function will not operate as intended.

2 Media Redundancy Protocol (MRP)

Since May 2008, the Media Redundancy Protocol (MRP) has been a standardized solution for ring redundancy in the industrial environment.

MRP is compatible with redundant ring coupling, supports VLANs, and is distinguished by very short reconfiguration times.

An MRP-Ring consists of up to 50 devices that support the MRP protocol according to IEC 62439. If you only use Hirschmann devices, up to 100 devices are possible in the MRP-Ring.

2.1 Network Structure

The concept of ring redundancy allows the construction of high-availability, ring-shaped network structures.
With the help of the RM (**R**ing **M**anager) function, the two ends of a backbone in a line structure can be closed to a redundant ring. The ring manager keeps the redundant line open as long as the line structure is intact. If a segment becomes inoperable, the ring manager immediately closes the redundant line, and line structure is intact again.

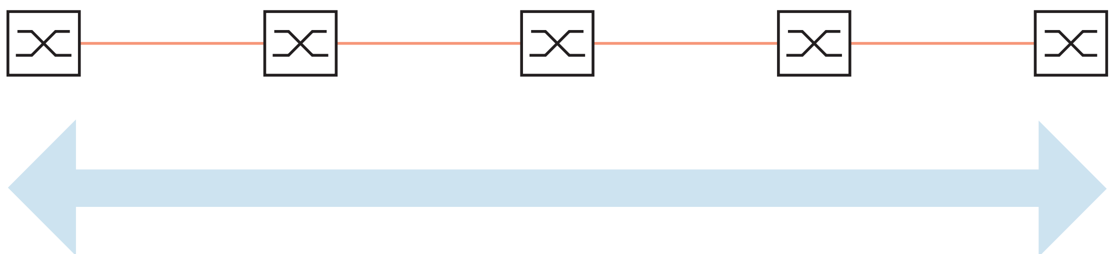


Figure 4: Line structure

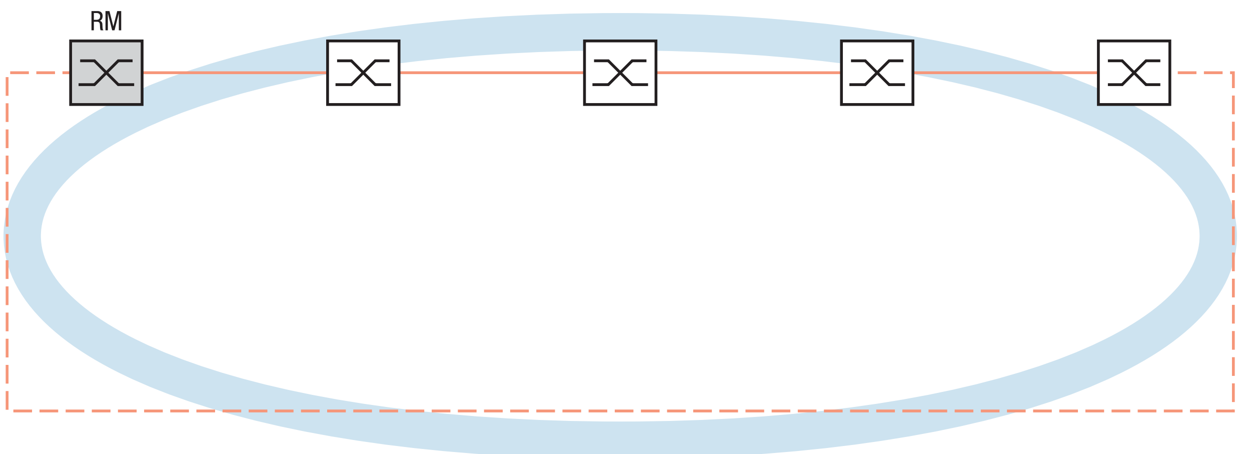


Figure 5: Redundant ring structure
RM = Ring Manager
—— main line
- - - redundant line

2.2 Reconfiguration time

If a line section fails, the ring manager changes the MRP-Ring back into a line structure. You define the maximum time for the reconfiguration of the line in the ring manager.

Possible values for the maximum delay time:
- 500 ms
- 200 ms
- 30 ms
- 10 ms

The delay times 30ms and 10ms are only available to you for devices with hardware for enhanced redundancy functions.

In order to use these fast delay times, load the Fast MRP device software.

Configure the delay time to 10ms, when you use up to 20 devices in the ring, that support this delay time. When you use more than 20 of these devices in the ring, configure a delay time to at least 30ms.

Note: You only configure the reconfiguration time with a value less than 500 ms if all the devices in the ring support the shorter delay time.
Otherwise the devices that only support longer delay times might not be reachable due to overloading. Loops can occur as a result.

2.3 Advanced mode

For times even shorter than the guaranteed reconfiguration times, the device provides the advanced mode. The advanced mode speeds up the link failure recognition when the ring participants inform the ring manager of interruptions in the ring via link-down notifications.

Hirschmann devices support link-down notifications. Therefore, you generally activate the advanced mode in the ring manager.

If you are using devices that do not support link-down notifications, the ring manager reconfigures the line in the selected maximum reconfiguration time.

2.4 Prerequisites for MRP

Before setting up an MRP-Ring, make sure that the following conditions are fulfilled:

- All ring participants support MRP.
- The ring participants are connected to each other via the ring ports. Apart from the device’s neighbors, no other ring participants are connected to the respective device.
- All ring participants support the configuration time defined in the ring manager.
- There is exactly 1 ring manager in the ring.

If you are using VLANs, configure every ring port with the following settings:

☐ Deactivate ingress filtering - see the Switching:VLAN:Port `Switching > VLAN > Port` dialog.

☐ Define the port VLAN ID (PVID) - see the `Switching > VLAN > Port` dialog.
  - PVID = `1` if the device transmits the MRP data packets untagged (VLAN ID = `0` in `Switching > L2-Redundancy > MRP` dialog)
    By setting the PVID = `1`, the device automatically assigns the received untagged packets to VLAN 1.
  - PVID = `any` if the device transmits the MRP data packets in a VLAN (VLAN ID ≥ `1` in the `Switching > L2-Redundancy > MRP` dialog)

☐ Define egress rules - see `Switching > VLAN > Configuration` dialog.
  - `U` (untagged) for the ring ports of VLAN 1 if the device transmits the MRP data packets untagged (VLAN ID = `0` in the `Switching > L2-Redundancy > MRP` dialog, the MRP ring is not assigned to a VLAN).
  - `T` (tagged) for the ring ports of the VLAN which you assign to the MRP ring. Select `T`, if the device transmits the MRP data packets in a VLAN (VLAN ID ≥ `1` in the `Switching > L2-Redundancy > MRP` dialog).

You will find further information about setting the MRP VLAN ID in the figure “Changing the VLAN ID” on page 30.

2.5 Example Configuration

A backbone network contains 3 devices in a line structure. To increase the availability of the network, you convert the line structure to a redundant ring structure. Devices from different manufacturers are used.All devices support MRP. On every device you define ports 1.1 and 1.2 as ring ports.

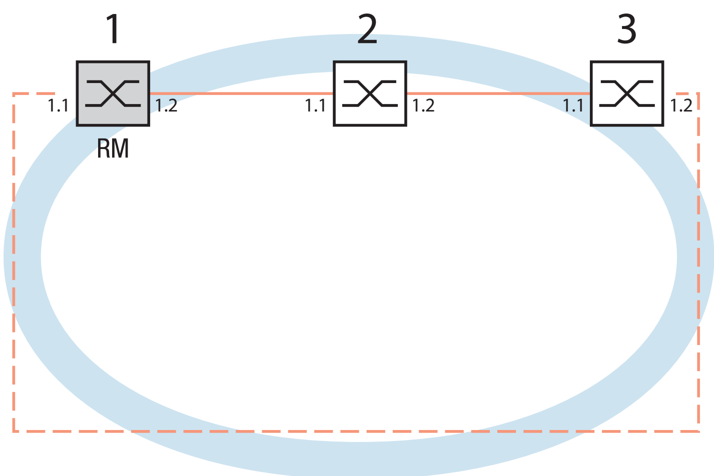


Figure 6: Example of MRP-Ring
RM = Ring Manager
—— main line
- - - redundant line

The following example configuration describes the configuration of the ring manager device (1). You configure the 2 other devices (2 to 3) in the same way, but without activating the ring manager function. This example does not use a VLAN. You have entered 200 ms as the ring recovery time, and all the devices support the advanced mode of the ring manager.

☐ Set up the network to meet your demands.
☐ Configure all ports so that the transmission speed and the duplex settings of the lines correspond to the following table:

Port type	Bit rate	Autonegotiation (automatic configuration)	Port setting	Duplex
TX	100 Mbit/s	off	on	100 Mbit/s full duplex (FDX)
Optical	100 Mbit/s	off	on	100 Mbit/s full duplex (FDX)

Table 2: Port settings for ring ports

Note: You configure optical ports without support for autonegotiation (automatic configuration) with 100 Mbit/s full duplex (FDX).

Note: Configure all the devices of the MRP-Ring individually. Before you connect the redundant line, you must have completed the configuration of all the devices of the MRP-Ring. You thus avoid loops during the configuration phase.

☐ You deactivate the flow control on the participating ports.
If the flow control and the redundancy function are active at the same time, there is a risk that the redundancy function will not operate as intended. (Default setting: flow control deactivated globally and activated on all ports.)

☐ Switch Spanning Tree off on all devices in the network:

☐ Open the `Switching > L2-Redundancy > Spanning Tree > Global` dialog.

☐ Switch off the function.
In the state on delivery, Spanning Tree is switched on on the device.

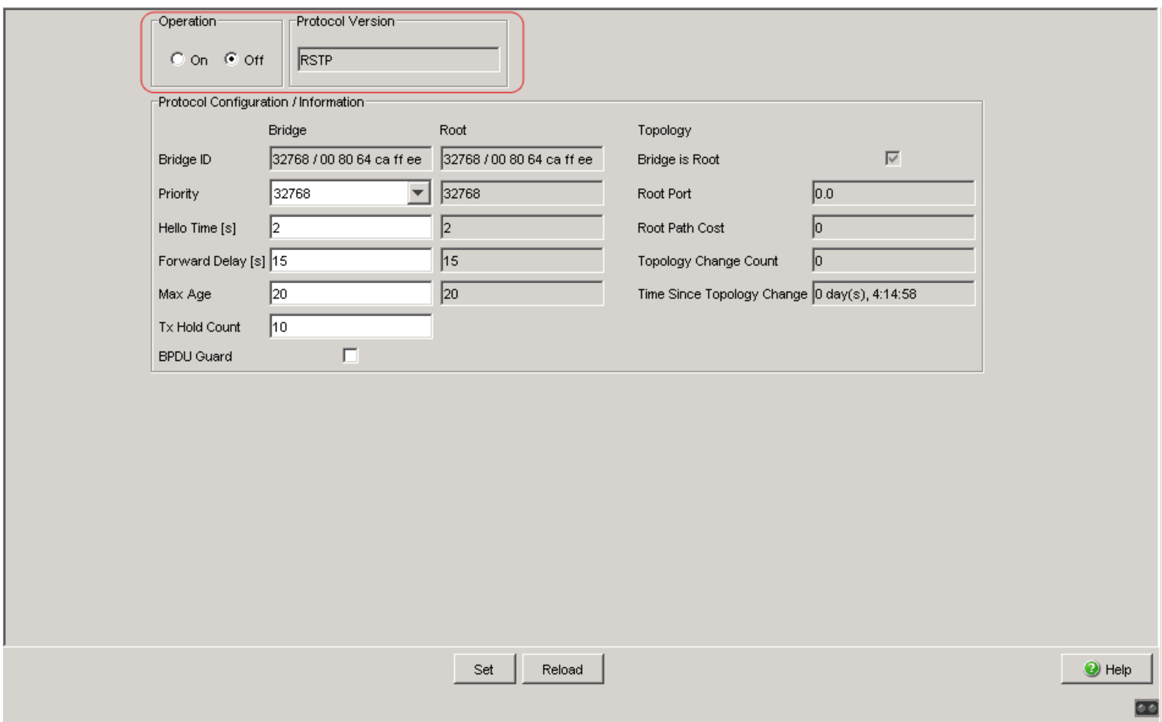


Figure 7: Switching the function off

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`no spanning-tree operation`	Switches Spanning Tree off.
`show spanning-tree global`	Displays the parameters for checking.

☐ Switch MRP on on all devices in the network:

☐ Open the `Switching > L2-Redundancy > MRP` dialog.

☐ Define the desired ring ports.

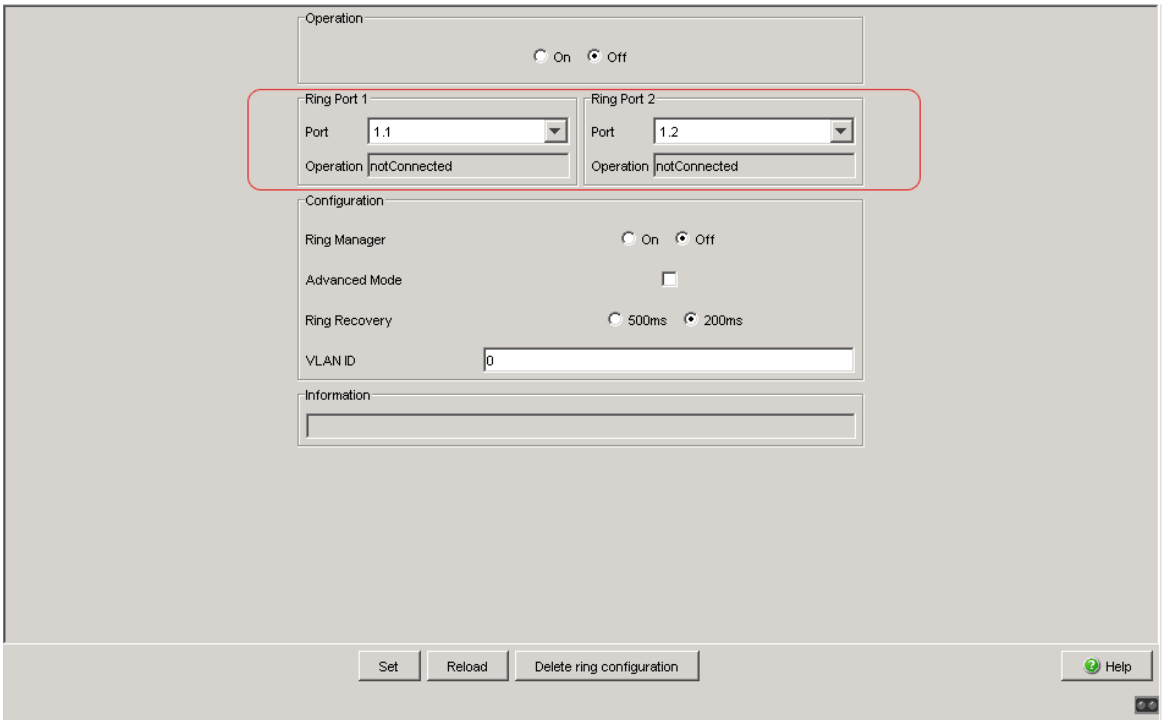


Figure 8: Defining the ring ports

In the Command Line Interface you first define an additional parameter, the MRP domain ID. Configure all the ring participants with the same MRP domain ID. The MRP domain ID is a sequence of 16 number blocks (8-bit values).

When configuring with the graphical user interface, the device uses the default value `255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255`.

`mrp domain add default-domain`	Creates a new MRP domain with the default domain ID.
`mrp domain modify port primary 1/1`	Defines port 1.1 as ring port 1 (primary).
`mrp domain modify port secondary 1/2`	Defines port 1.2 as ring port 2 (secondary).

☐ Activate the ring manager.
For the other devices in the ring, leave the setting as `Off`.

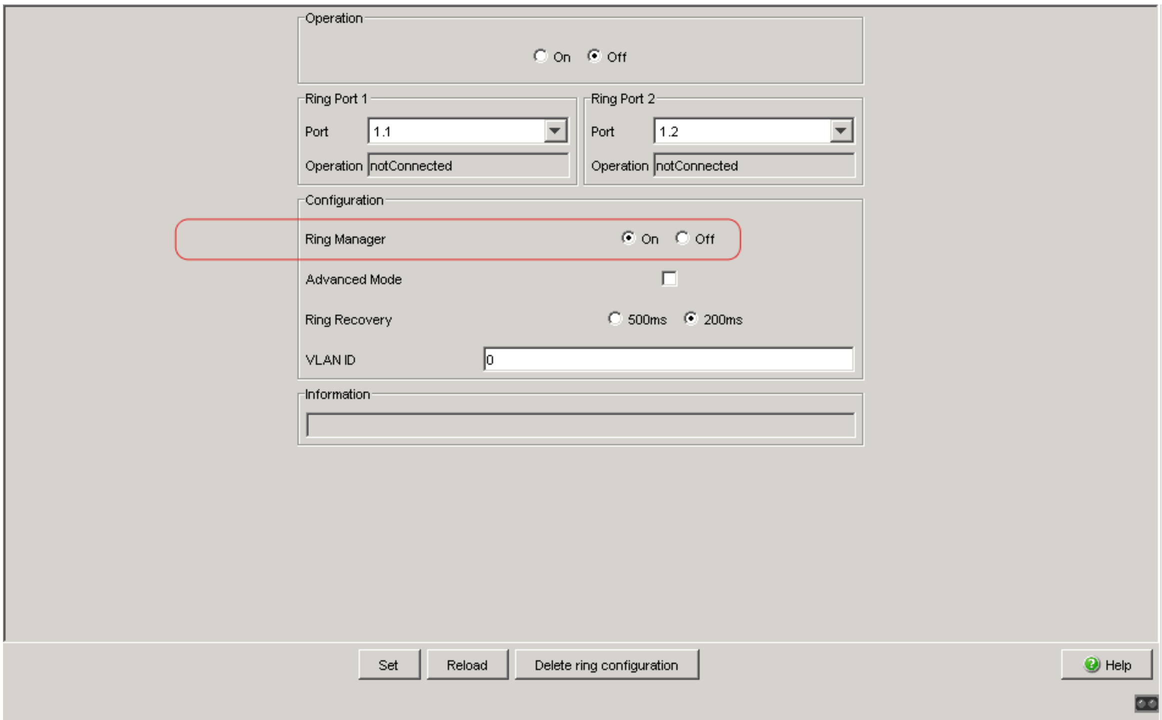


Figure 9: Activating the ring manager

`mrp domain modify mode manager`	Defines the device as the ring manager. Do not activate the ring manager on any other device.

☐ Select the checkbox in the "Advanced Mode" field.

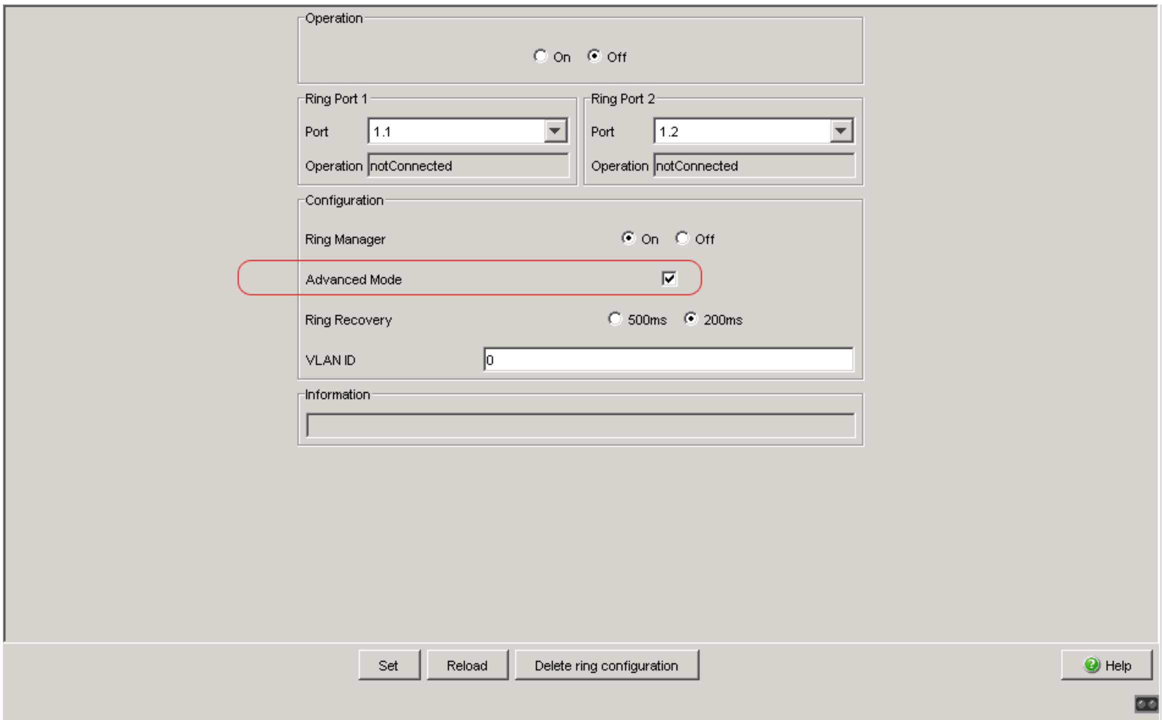


Figure 10: Activating the advanced mode

`mrp domain modify advanced-mode enabled`	Activates the advanced mode.

☐ In the "Ring Recovery" field, select the value `200ms`.

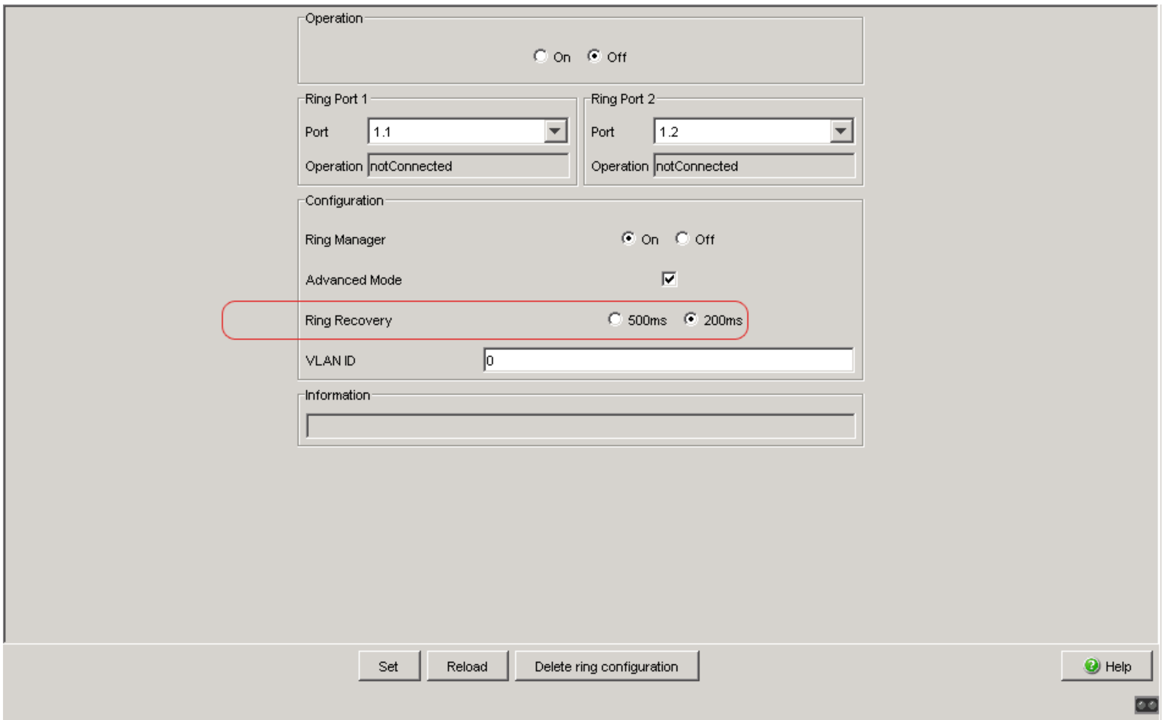


Figure 11: Defining the time for the ring recovery

`mrp domain modify recovery-delay 200ms`	Defines `200ms` as the max. delay time for the reconfiguration of the ring.

Note: If selecting 200 ms for the ring recovery does not provide the ring stability necessary to meet the requirements of your network, you select 500 ms.

You will find further information about setting the MRP VLAN ID in the figure “Changing the VLAN ID” on page 30.

☐ Switch the operation of the MRP-Ring on.

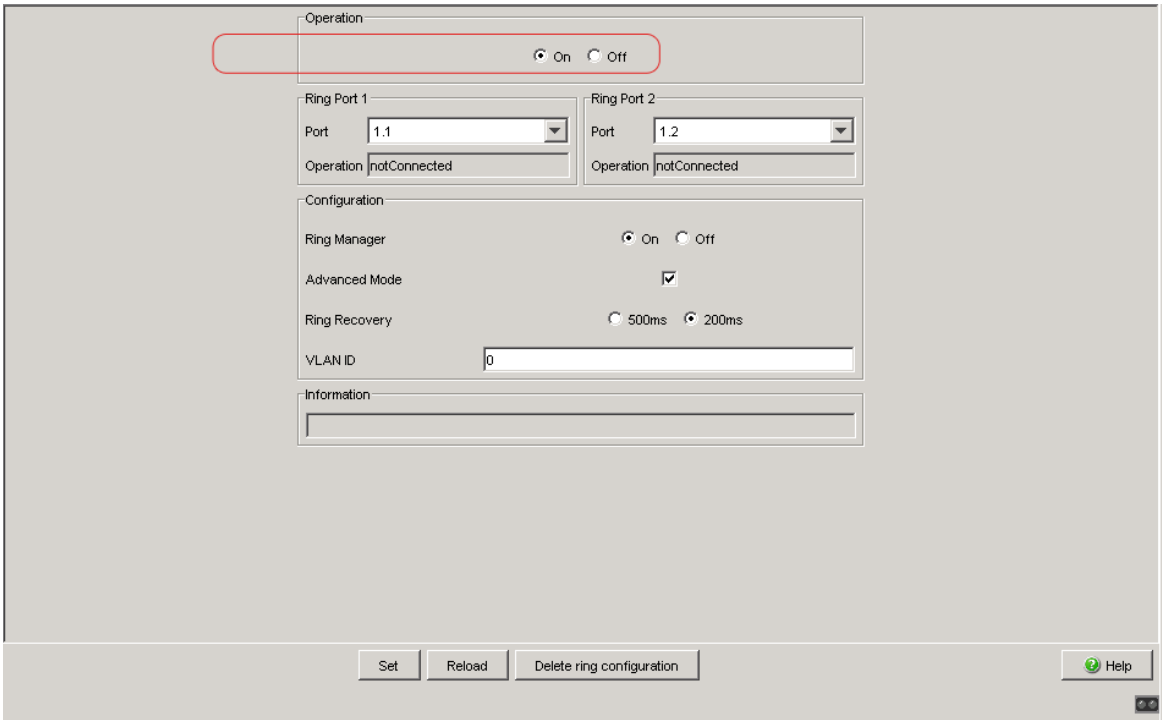


Figure 12: Switching on the MRP function

☐ Click on “Set” to save the changes.

`mrp domain modify operation enable`	Activates the MRP-Ring.

☐ When all the ring participants are configured, close the line to the ring. To do this, you connect the devices at the ends of the line via their ring ports.

☐ Check the messages from the device:

`show mrp`	Displays the parameters for checking.

The "Operation" field shows the operating state of the ring port.

Possible values:
- `forwarding`
  Port is switched on, connection exists.
- `blocked`
  Port is blocked, connection exists.
- `disabled`
  Port is disabled.
- `not connected`
  No connection exists.

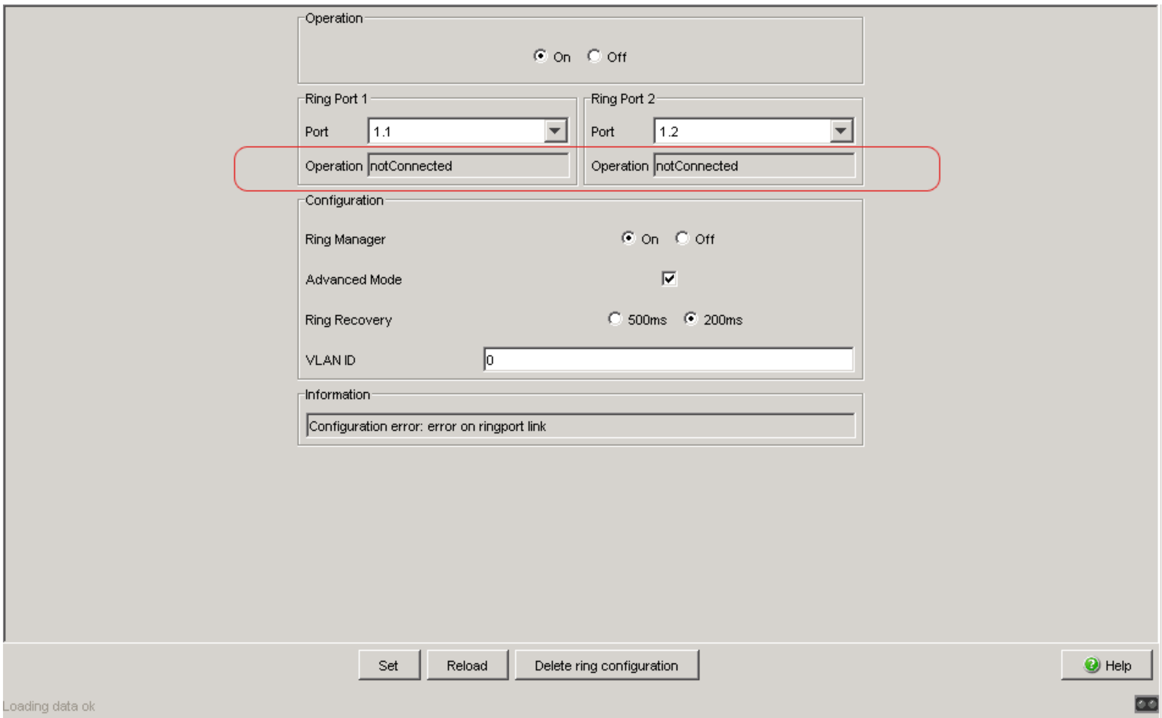


Figure 13: Messages in the "Operation" field

The "Information" field shows messages for the redundancy configuration and the possible causes of errors.

The following messages are possible if the device is operating as a ring client or a ring manager:

- `Redundancy Available`
  The redundancy is set up. When a component of the ring is down, the redundant line takes over its function.
- `Configuration error:Ring port link error`
  Error in the cabling of the ring ports.

The following messages are possible if the device is operating as a ring manager:

- `Configuration error:Packet of other ring manager received`
  Another device exists in the ring that is operating as the ring manager.
  Activate the "Ring Manager" function on exactly one device in the ring.
- `Configuration error:Connection in ring is connected to incorrect port`
  A line in the ring is connected with a different port instead of with a ring port. The device only receives test data packets on 1 ring port.

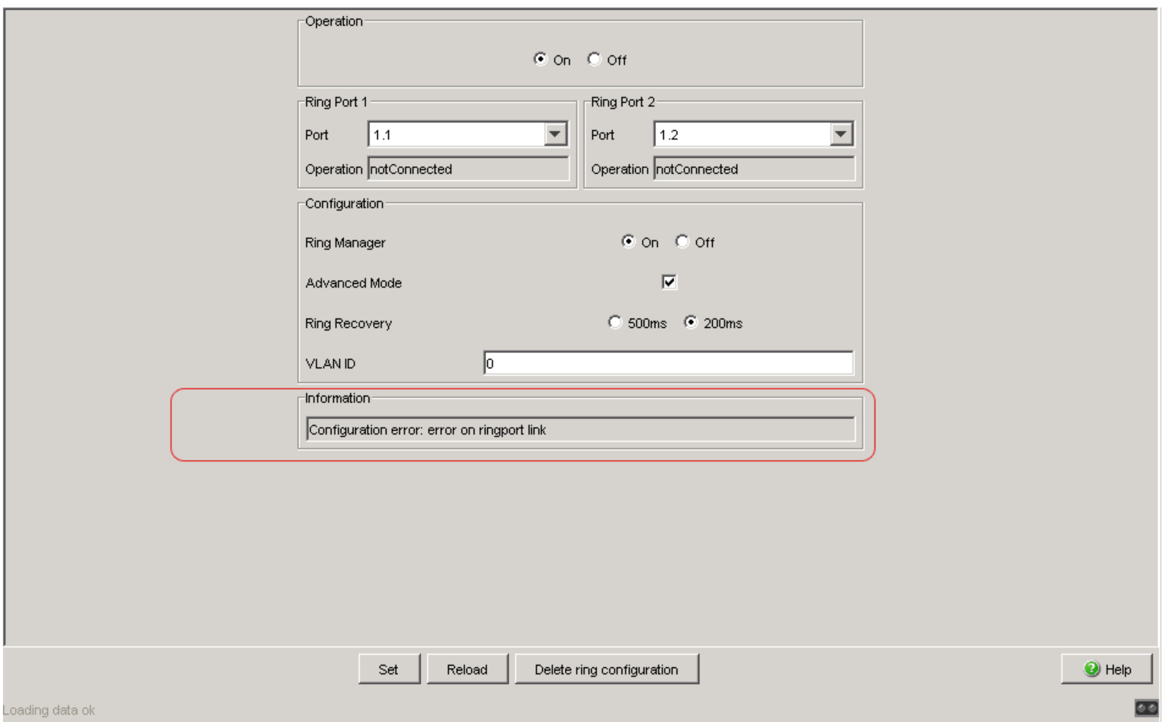


Figure 14: Messages in the "Information" field

☐ If applicable, integrate the MRP ring into a VLAN:

☐ In the "VLAN ID" field, define the MRP VLAN ID. The MRP VLAN ID determines in which of the configured VLANs the device transmits the MRP packets. To set the MRP VLAN ID, first configure the VLANs and the corresponding egress rules in the `Switching > VLAN > Configuration` dialog.
See “Prerequisites for MRP” on page 19.

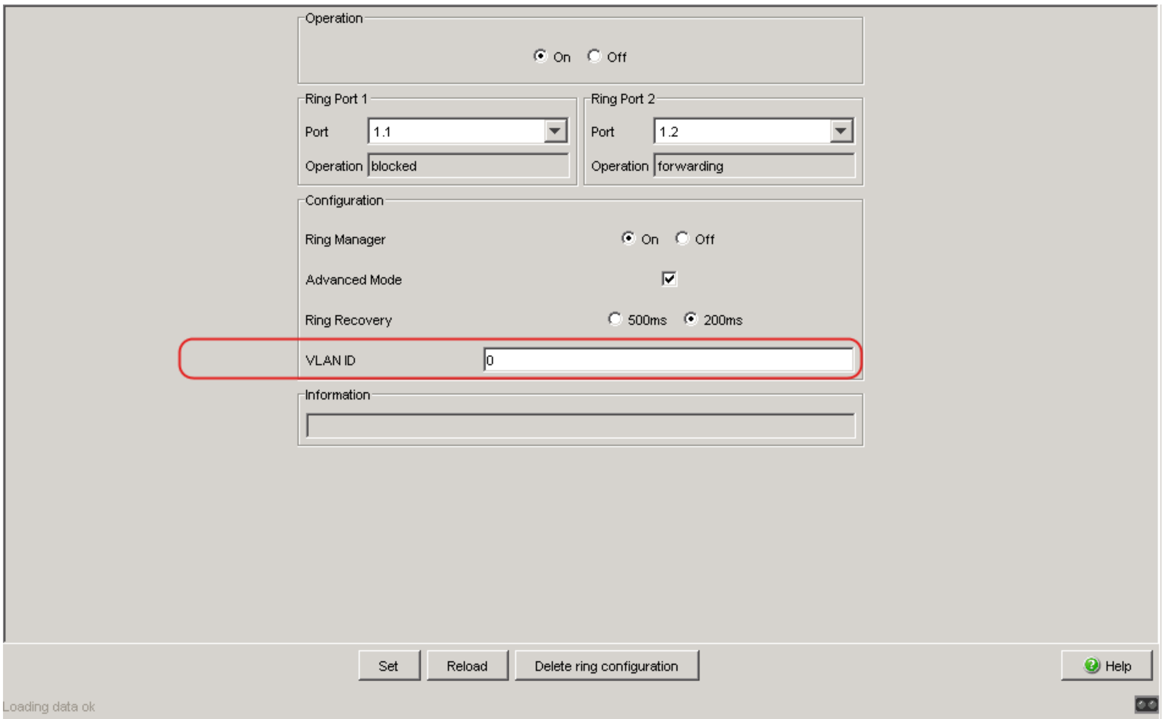


Figure 15: Changing the VLAN ID

▶ If the MRP-Ring is not assigned to a VLAN (like in this example), leave the VLAN ID as `0`.
In the `Switching > VLAN > Configuration` dialog, define the VLAN membership as `U` (untagged) for the ring ports in VLAN `1`.

▶ If the MRP-Ring is assigned to a VLAN, enter a VLAN ID >`0`.
In the `Switching > VLAN > Configuration`dialog, define the VLAN membership as `T` (tagged) for the ring ports in the selected VLAN.

`mrp domain modify vlan <0..4042>`	Assigns the VLAN ID ...

3 Parallel Redundancy Protocol (PRP)

Unlike ring redundancy protocols, PRP uses 2 separate LANs for uninterrupted availability. On the path from the sender to the receiver, PRP sends 2 data packets in parallel via the 2 mutually independent LANs. The receiver processes the first data packet received and discards the second data packet of the pair. The international standard IEC 62439-3 defines the Parallel Redundancy Protocol (PRP).

Note: If PRP is active, it uses the interfaces 1/1 and 1/2. As seen in the `Switching > VLAN`, `Switching > Rate Limiter` and `Switching > Filter for MAC Addresses` dialogs, the PRP function replaces the interfaces 1/1 and 1/2 with the interface prp/1. Configure the VLAN membership, the rate limiting, and the MAC filtering for the interface prp/1.

3.1 Implementation

When the upper protocol layers send a data packet, the PRP interface creates a “twin packet” from the original packet. The PRP interface then transmits 1 data packet of the pair to each participating LAN simultaneously. The packets traverse different LANs and therefore have different run times.

The receiving PRP interface forwards the first packet of a pair towards the upper protocol layers and discards the second packet. When viewed from the application, a PRP interface functions like a standard Ethernet interface.

The PRP interface or a Redundancy Box (RedBox) injects a Redundancy Control Trailer (RCT) into each packet. The RCT is a 48-bit identification field and is responsible for the identification of duplicates. This field contains, LAN identification (LAN A or B), information about the length of the payload, and a 16-bit sequence number. The PRP interface increments the sequence number for each packet sent. Using the unique attributes included in each packet, such as Physical MAC source address and sequence number, the receiving RedBox or Double Attached Node (DAN) interface identifies and discards duplicates.

Depending on the packet size, with PRP it attains a reduced throughput of the available bandwidth, due to the addition of the RCT trailer.

3.2 LRE Functionality

Each Double Attached Node implementing PRP (DANP) has 2 LAN ports that operate in parallel. The Link Redundancy Entity (LRE) connects the upper protocol layers with every individual port.

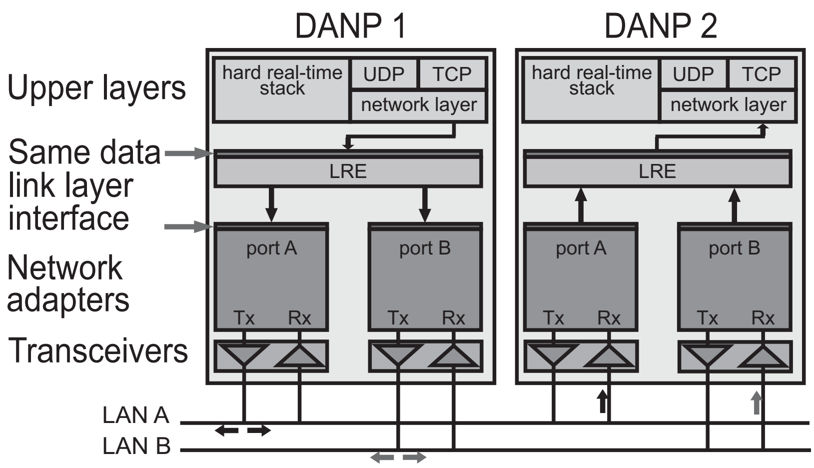


Figure 16: PRP LRE process

The LRE has the following tasks:
- Handling of duplicates
- Management of redundancy

When transmitting packets from the upper protocol layers, the LRE sends them from both ports at nearly the same time. The 2 data packets pass through the LANs with different delays. When the device receives the first data packet, the LRE forwards it to the upper protocol layers and discards the second data packet received.

For the upper protocol layers, the LRE behaves like a normal port.

To identify the twin packets, the LRE attaches an RCT with a sequential number to the packets. The LRE also periodically sends multicast PRP supervision packets and evaluates the multicast PRP supervision packets of the other RedBoxes and DANPs.

The device allows you to view the received supervision packet entries. The entries in the `Switching > L2-Redundancy > PRP > DAN/VDAN Table` are helpful for detecting redundancy and connection problems. For example, in an index when the "Last Seen B" timestamp resets and the "Last Seen A" timestamp remains the same. The "Last Seen A" and "Last Seen B" time-stamps steadily reseting indicate a normal condition.

Note: According to IEC 62439 the Entry Forget Time is 400 ms. The Entry Forget Time is the time after which the device removes an entry from the duplicate table. When the device receives the second frame of a pair after 400 ms, then the device processes the frame instead of discarding it. For this reason, Hirschmann recommends that the number of nodes installed in your PRP network remain under 10 nodes.

Note: If the inter-frame gap is shorter than the latency between the 2 LANs, a frame-ordering mismatch can occur. Frame-ordering mismatch is a phenomenon of the PRP protocol. The only solution for avoiding a frame-ordering mismatch is to verify that the inter-frame gap is greater than the latency between the LANs.

3.3 PRP Network Structure

PRP uses 2 independent LANs. The topology of each of these LANs is arbitrary, and ring, star, bus and meshed topologies are possible.

The main advantage of PRP is zero recovery time with an active (transit) LAN. When the terminal device receives no packets from one of the LANs, the second (transit) LAN maintains the connection. As long as 1 (transit) LAN is available, repairs and maintenance on the other (transit) LAN have no impact on the data packet transmission.

The elementary devices of a PRP network are the RedBox (Redundancy Box) and the DANP (Double Attached Node implementing PRP). Both devices have 1 connection each to the (transit) LANs.

The devices in the (transit) LAN are conventional switches. The devices transmit PRP data packets transparently, without evaluating the RCT information.

Note: The RCT trailer increases packet size. Configure the MTU size equal to or greater than 1524 for LAN A and LAN B devices.

Terminal devices that connect directly to a device in the (transit) LAN are SANs (Single Attached Nodes). SANs connected to a LAN have no redundancy. To use the PRP redundant network, connect the SAN to the PRP network via a RedBox.

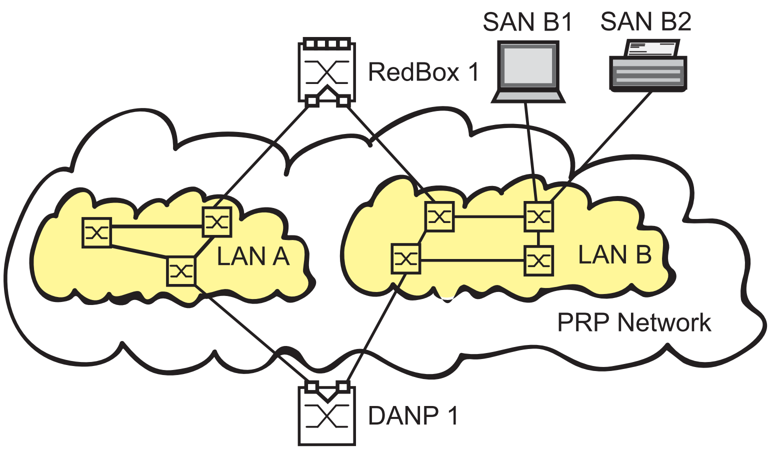


Figure 17: Parallel Redundancy Protocol Network

3.4 Connecting RedBoxes and DANPs to a PRP network

DANPs have 2 interfaces for the connection to the PRP network. A RedBox is a DANP that contains additional switch ports. Use the switch ports to intagrate one or more SANs into the PRP network redundantly.

The Link Redundancy Entity (LRE) in the RedBox creates a twin packet when sending a data packet to the PRP network. The LRE forwards 1 data packet of the twin pair when it receives it and discards the 2nd data packet of the twin pair.

Note: The Redbox supports up to 128 hosts. When attempt to support more than 128 with the Redbox, then device drops packets.

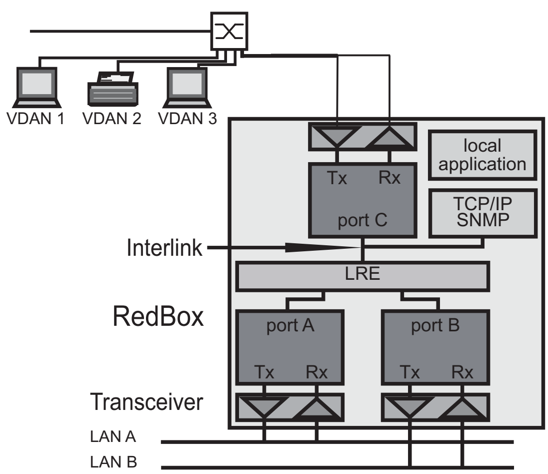


Figure 18: RedBox Transition from double to single LAN

3.5 Example Configuration

The following example uses a simple PRP network with 4 devices. Verify that the LAN A and LAN B ports contain 100 Mbit/s optical SFP interfaces. Connect Port A to LAN A and the Port B to LAN B.

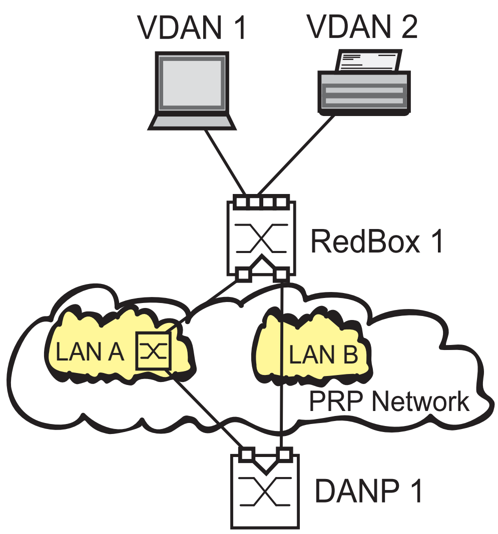


Figure 19: Example PRP Network

Note: PRP is available for devices with hardware for enhanced redundancy functions. In order to use the PRP functions, load the PRP device software.

The PRP function reserves ports `1/1` and `1/2`. This removes the possibility of using other redundancy protocols such as Spanning Tree or MRP in parallel on ports `1/1` and `1/2`.

- ☐ If you use Spanning Tree in parallel to PRP, deactivate Spanning Tree on ports `1/1` and `1/2`. Also deactivate the functions "Root Guard", "TCN Guard" and "Loop Guard" on ports `1/1` and `1/2`.
- ☐ If you use MRP in parallel to PRP, specify the other free device ports as MRP-Ring ports.

Perform the following steps on both the RedBox 1 and DANP 1 devices.

☐ Open the `Switching > L2-Redundancy > PRP > Configuration` dialog.

Perform the following step in the "Supervision Packet Receiver" frame:

☐ To analyze received PRP supervision packets, activate the "Evaluate Supervision Packets" checkbox .

Perform the following steps in the "Supervision Packet Transmitter" frame:

☐ To transmit PRP supervision packets from this device, activate "Active".

☐ The device sends either its own PRP supervision packets exclusively, or sends both its own supervision packets and packets of connected devices. To transmit packets for VDANs listed in the `Switching > L2-Redundancy > PRP > DAN/VDAN Table`, activate "Send VDAN Packets". When deactivated the device sends its own supervision packets exclusively. After installing new PRP devices, deactivate this function to maintain a clear overview of the PRP supervision packets on remote devices.

☐ To enable the ports, in the "Port A" and "Port B" frames, click `On`.

☐ To enable the PRP function, in the "Operation" frame click `On`.

☐ To temporarily save the changes, click "Set".

☐ To load the configuration saved in the volatile memory, click "Reload".

☐ Open the `Switching > L2-Redundancy > PRP > Proxy Node Table` dialog to view the terminating VDAN devices for which this device provides PRP conversion.

☐ To remove this list, click "Reset".

☐ To load the list of currently connected devices, click "Reload".

☐ Open the `Switching > L2-Redundancy > PRP > Statistics`dialog to view the quality of the traffic that traverses the device. The device detects errors and displays them according to MIB Managed Objects and the respective link.

☐ To remove the entry in the statistics table, click "Reset".

☐ To load the current statistics, click "Reload".

The device allows you to view the received supervision packet entries. The entries, in the `Switching > L2-Redundancy > PRP > DAN/VDAN Table` are helpful for detecting redundancy and connection problems. For example, in an index when the "Last Seen B" timestamp resets and the "Last Seen A" timestamp remains the same. The "Last Seen A" and "Last Seen A" timestamps steadily reseting indicate a normal condition.

Note: If you deactivate the PRP function, then deactivate either Port “A“ or “B“ to help prevent network loops.

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`no mrp operation`	Disable the option.
`no spanning-tree operation`	Disable the option.
`interface 1/1`	Change to the Interface Configuration mode of port 1/1.
`no shutdown`	Enable the interface.
`exit`	Switch to the Configuration mode.
`interface 1/2`	Switch to the interface configuration mode for interface 1/2.
`no shutdown`	Enable the interface.
`exit`	Switch to the Configuration mode.
`prp instance 1 supervision evaluate`	Enable evaluation of received supervision packets.
`prp instance 1 supervision send`	Enable supervision packet transmission.
`prp instance 1 supervision redbox-exclusively`	Enable sending of supervision packets for this RedBox exclusively. Use the no form of the command to send supervision packets for each connected VDAN and this RedBox (if send is enabled).
`prp operation`	Enable the PRP function.
`show prp counters`	Show prp counters
`show prp node-table`	Show node table.
`show prp proxy-node-table`	Show proxy node table.

3.6 PRP and Port Mirroring

The transceivers send traffic to the LRE, which separates the traffic. The LRE forwards the data frames to PRP Port A and the control frames to PRP Port B of the switch.

When you configure the PRP Port A as a source port, the device sends the control frames to the destination port. When you configure the PRP Port B as a source port, the device sends the data frames to the destination port. Configure Port A and Port B in the `Switching > L2-Redundancy > PRP > ` Configuration dialog.

The device also restricts the PRP interface and the PRP member ports from being destination ports.

4 High-availability Seamless Redundancy (HSR)

As with PRP, an HSR ring also offers zero recovery time. HSR is suited for applications that demand high availability and short reaction times. For example, protection applications for electrical station automation and controllers for synchronized drives which require constant connection.

Note: If HSR is active, it uses the interfaces 1/1 and 1/2. As seen in the `Switching > Rate Limiter` and `Switching > Filter for MAC Addresses` dialogs, the HSR function replaces the interfaces 1/1 and 1/2 with the interface hsr/1. Set up the VLAN membership and the rate limiting for the interface hsr/1.

4.1 Implementation

HSR Redundancy Boxes (RedBox) use 2 Ethernet ports operating in parallel to connect to a ring. An HSR RedBox operating in this configuration is a Doubly Attached Node implementing the HSR protocol (DANH). A standard ethernet device connected to the HSR ring through an HSR RedBox is a Virtual DANH (VDANH).

As with PRP, the transmitting HSR Node or HSR RedBox sends twin frames, 1 in each direction, on the ring. For identification, the HSR Node injects the twins with an HSR tag. The HSR tag consists of a port identifier, the length of the payload and a sequence number. In a normal operating ring, the destination HSR Node or RedBox receives both frames within a certain time skew. An HSR node forwards the first frame to arrive and discards the second frame when it arrives. An HSR RedBox on the other hand forwards the first frame to the VDANHs and discards the second frame when it arrives.

The HSR Nodes and HSR RedBoxs insert an HSR tag after the source MAC Address in the frame. The advantage to the HSR tag placement is that the device is able to forward the frame immediately after receiving the HSR header and performing duplicate recognition. Affectively decreasing the delay time within the device. In contrast to PRP where the RCT contains a PRP suffix near the end of the frame. Meaning that a PRP device receives the entire frame before forwarding the frame out of the correct port.

HSR Nodes and HSR RedBoxes also use the LRE function as described in the PRP chapter. As with PRP, the LRE in the HSR RedBoxes are responsible for tagging and duplicate recognition.

Limit the maximum number of nodes in an HSR ring to 10, so that a DAN or Redbox receives these packets within a specific time frame.

Note: HSR is available for devices with hardware for enhanced redundancy functions. In order to use the HSR functions, load the HSR device software.

4.2 HSR Network Structure

An HSR Network consists of a ring, where each HSR device performs a specific role in the network. An HSR device for example, connects standard ethernet devices to an HSR ring, or PRP LANs to an HSR ring.

4.2.1 Connecting SANs to an HSR Network

Standard ethernet devices, such as maintenance laptops or printers, have 1 network interface. Therefore, standard ethernet devices transmit traffic across an HSR ring through an HSR RedBox which acts as a proxy for the ethernet devices attached to it. The HSR RedBox interfaces transmit 1 twin in each direction around the network.

The host HSR RedBox forwards the first unicast frame to the destination VDANH exclusively and discards the second unicast frame when it arrives.

The HSR Nodes and RedBoxes forward multicast and broadcast traffic around the ring and also to the connected VDANH devices. To help prevent the traffic from endlessly looping around the ring, the node originally transmitting the traffic on the network discards the transmitted frames when received.

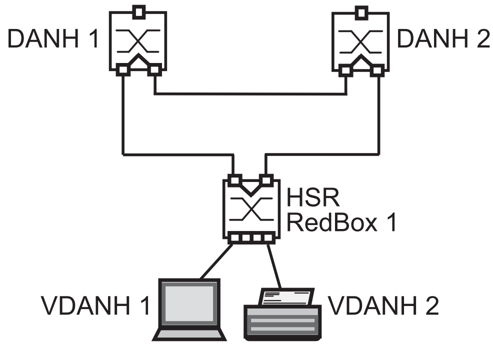


Figure 20: Connecting a VDANH to an HSR network

SAN Device Connection Example Configuration

A simple HSR network consists of 3 HSR devices as seen in the previous figure. The following example configures a host HSR RedBox for standard ethernet devices.

Deactivate STP on the PRP ports or globally. Also, deactivate MRP on the PRP ports or configure MRP on ports other than the PRP ports.

- ☐ Open the `Switching > L2-Redundancy > MRP` dialog.
- ☐ To disable the MRP function, in the Operation frame "Operation""Off".
- ☐ Verify that the ports in "Ring Port 1" and "Ring Port 2" frames, are different from the ports used by HSR.
- ☐ Open the `Switching > L2-Redundancy > Spanning Tree > Global` dialog.
- ☐ To disable the MRP function, in the Operation frame "Operation""Off".
- ☐ Open the `Switching > L2-Redundancy > Spanning Tree > Port` dialog.
- ☐ In the "CIST" tab, deactivate the ports used for HSR in the "Stp active" column.
- ☐ In the "Guards" tab, deactivate the ports used for HSR in the "Root Guard", "TCN Guard" and "Loop Guard" columns.

Note: If you deactivate the HSR function, then deactivate either Port “A“ or “B“ to help prevent network loops.

The device sends either its own HSR supervision packets exclusively, or sends both its own supervision packets and packets of connected devices. After installing new HSR devices, deactivate this function to maintain a clear overview of the HSR supervision packets on remote devices.

- ☐ Open the `Switching > L2-Redundancy > HSR > HSR > HSR >` Configuration dialog.
- ☐ To analyze received HSR supervision packets, activate the "Evaluate Supervision Packets"checkbox in the "Supervision Packet Receiver" frame.
- ☐ To transmit HSR supervision packets from this device, activate "Active"in the "Supervision Packet Transmitter" frame.
- ☐ To transmit packets for VDANs listed in the `Switching > L2-Redundancy > HSR > DAN/VDAN Table` dialog, activate "Send VDAN Packets".

Use the following steps to configure HSR RedBox 1:

- ☐ To configure the device to forward unicast traffic around the ring and to the destination device, set the "HSR Mode" to `modeu`.
- ☐ To configure the device as an HSR host, set t"Switching Node Type" to `hsrredboxsan`.

Note: Setting "Switching Node Type" to `hsrredboxsan` disables the "Redbox Identity" function.

- ☐ To enable the ports, in the Port "Port A" and Port "Port B"frames, click "On".
- ☐ To disable the HSR function, in the "Operation"frame, click "On".
- ☐ To save your changes in the volatile memory, click "Set".
- ☐ To load the configuration saved in the volatile memory, click "Reload".
- ☐ Open the `Switching > L2-Redundancy > HSR > DAN/VDAN Table` dialog to view the traffic received from the LAN. This information helps you in detecting how the LANs are functioning.
- ☐ To remove this list, click "Reset".
- ☐ To update the table entries, click "Reload".
- ☐ Open the `Switching > L2-Redundancy > HSR > Proxy Node Table` dialog to view the terminating VDAN devices for which this device provides HSR conversion.
- ☐ To remove the entries in the proxy table, click "Reset".

- ☐ To update the table entries, click "Reload".

The device detects errors and displays them according to MIB Managed Objects and the respective link.

- ☐ Open the `Switching > L2-Redundancy > HSR > Statistics` dialog to view the quality of the traffic that traverses the device.
- ☐ To remove the entry in the statistics table, click "Reset".
- ☐ To load the current statistics, click "Reload".

Another possibility is to configure the host HSR RedBox 1 using the following CLI commands:

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`no mrp operation`	Disable the option.
`no spanning-tree operation`	Disable the option.
`interface 1/1`	Change to the Interface Configuration mode of port 1/1.
`no shutdown`	Enable the interface.
`exit`	Switch to the Configuration mode.
`interface 1/2`	Switch to the interface configuration mode for interface 1/2.
`no shutdown`	Enable the interface.
`exit`	Switch to the Configuration mode.
`hsr instance 1 mode modeu`	The HSR host forwards unicast traffic to the connected VDANs and around the ring.
`hsr instance 1 port-a`	Activate the HSR Port A.
`hsr instance 1 port-b`	Activate the HSR Port B.
`hsr instance 1 switching-node-type hsrredboxsan`	Enable the device to process traffic destine for LAN B of the PRP network.
`hsr instance 1 supervision evaluate`	Enable evaluation of received supervision packets.
`hsr instance 1 supervision send`	Enable supervision packet transmission.
`hsr instance 1 supervision redbox-exclusively`	Enable sending of supervision packets for this RedBox exclusively. Use the no form of the command to send supervision packets for each connected VDAN and this RedBox. Prerequisite is that you enable the supervision frame send function.
`hsr operation`	Enable the HSR function.

View traffic statistics on a device using the show commands.

`show hsr counters`	Show the HSR counters.

`show hsr node-table`	Show node table.
`show hsr proxy-node-table`	Show proxy node table.

4.2.2 HSR and PRP network connections

When connecting PRP networks to an HSR network, the HSR device uses 2 interfaces to connect to the HSR ring. The HSR device uses a third interface to connect to either LAN A or LAN B of the PRP network as seen in the following figure. The HSR device transmitting the traffic across the HSR ring identifies traffic destine for PRP networks with the appropriate tag. The HSR devices then forward the PRP traffic through LAN A or LAN B. The PRP device receives the traffic and processes it as described in the PRP chapter.

The HSR devices tag and identify traffic for up to 7 PRP networks connected to 1 HSR ring.

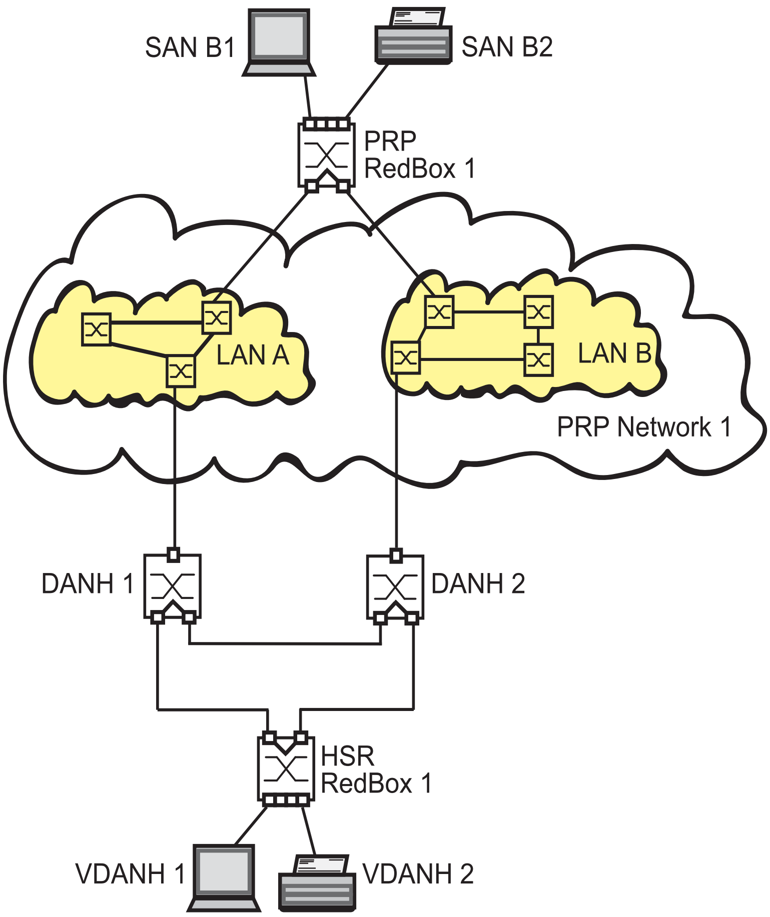


Figure 21: Connecting a PRP network to an HSR network

HSR Redboxes use 2 interfaces for the HSR ring. When configured to manage PRP traffic, a third interface connects to a LAN of the PRP network. The other interfaces provide HSR network access for VDANs. The HSR RedBox lists the connected VDANs in the `Switching > L2-Redundancy > HSR > Proxy Node Table`.

PRP Network Connection Example Configuration

The following example configures a simple HSR network with 3 HSR devices as shown in the previous figure. Use the HSR RedBox configured in the previous example to connect the standard ethernet devices to the HSR ring. HSR RedBox 1 sends 1 twin toward DANH 1 and 1 twin toward DANH 2. When the first frame of a pair arrives, DANH 1 sends frame to PRP network 1 LAN A and DANH 2 sends the frame to PRP network 1 LAN B.

Deactivate STP on the PRP ports or globally. Also, deactivate MRP on the PRP ports or configure MRP on ports other than the PRP ports.

Use the HSR RedBox configured in the previous example for HSR RedBox 1. Perform the following steps on the DANH 1 and 2.

- ☐ Open the `Switching > L2-Redundancy > MRP` dialog.
- ☐ To disable the MRP function, in the Operation frame "Operation""Off".
- ☐ Verify that the ports in "Ring Port 1" and "Ring Port 2" frames, are different from the ports used by HSR.
- ☐ Open the `Switching > L2-Redundancy > Spanning Tree > Global` dialog.
- ☐ To disable the MRP function, in the Operation frame "Operation""Off".
- ☐ Open the `Switching > L2-Redundancy > Spanning Tree > Port` dialog.
- ☐ In the "CIST" tab, deactivate the ports used for HSR in the "Stp active" column.
- ☐ In the "Guards" tab, deactivate the ports used for HSR in the "Root Guard", "TCN Guard" and "Loop Guard" columns.

Note: If you deactivate the HSR function, then deactivate either Port “A“ or “B“ to help prevent network loops.

The device sends either its own HSR supervision packets exclusively, or sends both its own supervision packets and packets of connected devices. After installing new HSR devices, deactivate this function to maintain a clear overview of the HSR supervision packets on remote devices.

- ☐ Open the `Switching > L2-Redundancy > HSR > HSR > HSR >` Configuration dialog.

- ☐ To analyze received HSR supervision packets, activate the "Evaluate Supervision Packets"checkbox in the "Supervision Packet Receiver" frame.
- ☐ To transmit HSR supervision packets from this device, activate "Active"in the "Supervision Packet Transmitter" frame.
- ☐ To transmit packets for VDANs listed in the `Switching > L2-Redundancy > HSR > DAN/VDAN Table` dialog, activate "Send VDAN Packets".

Use the following steps to configure DANH 1:

- ☐ Open the `Switching > L2-Redundancy > HSR > HSR > HSR >` Configuration dialog.
- ☐ To configure the device to forward unicast traffic around the ring and to the destination device, set the "HSR Mode" to `modeu`.
- ☐ To configure the device to forward traffic to PRP LAN A, set the "Switching Node Type" to `hsrredboxprpa`.
- ☐ To configure the device to forward traffic to PRP network 1 LAN A, set "Redbox Identity" to `id1a`.
- ☐ To enable the ports, in the Port "Port A" and Port "Port B"frames, click "On".
- ☐ To disable the HSR function, in the "Operation"frame, click "On".
- ☐ To temporarily save the changes, click "Set".
- ☐ To load the configuration saved in the volatile memory, click "Reload".

Use the following configuration for DANH 2:

- ☐ Open the `Switching > L2-Redundancy > HSR > HSR > HSR >` Configuration dialog.
- ☐ To configure the device to forward unicast traffic around the ring and to the destination device, set the "HSR Mode" to `modeu`.
- ☐ To configure the device to forward traffic to PRP LAN A, set the "Switching Node Type" to `hsrredboxprpb`.
- ☐ To configure the device to forward traffic to PRP network 1 LAN B, set "Redbox Identity" to `id1b`.
- ☐ To enable the ports, in the Port "Port A" and Port "Port B"frames, click "On".
- ☐ To disable the HSR function, in the "Operation"frame, click "On".
- ☐ To temporarily save the changes, click "Set".
- ☐ To load the configuration saved in the volatile memory, click "Reload".

Another possibility is to use the following CLI commands to configure the HSR devices 1 and 2.

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`no mrp operation`	Disable the option.
`no spanning-tree operation`	Disable the option.
`interface 1/1`	Change to the Interface Configuration mode of port 1/1.
`no shutdown`	Enable the interface.
`exit`	Switch to the Configuration mode.
`interface 1/2`	Switch to the interface configuration mode for interface 1/2.
`no shutdown`	Enable the interface.
`exit`	Switch to the Configuration mode.

Use the following CLI commands to configure DANH 1 to process traffic for PRP network 1 LAN A.

`hsr instance 1 mode modeu`	The HSR host forwards unicast traffic to the connected VDANs and around the ring.
`hsr instance 1 port-a`	Activate the HSR Port A.
`hsr instance 1 port-b`	Activate the HSR Port B.
`hsr instance 1 switching-node-type hsrredboxprpa`	Enable the device to process traffic destine for LAN A of the PRP network.
`hsr instance 1 redbox-id id1a`	Enable the device to process traffic destine for LAN A of the PRP network 1.
`hsr instance 1 supervision evaluate`	Enable evaluation of received supervision packets.
`hsr instance 1 supervision send`	Enable supervision packet transmission.
`hsr instance 1 supervision redbox-exclusively`	Enable sending of supervision packets for this RedBox exclusively. Use the no form of the command to send supervision packets for each connected VDAN and this RedBox. Prerequisite is that you enable the supervision frame send function.
`hsr operation`	Enable the HSR function.

Use the following CLI commands to configure DANH 2 to process traffic for PRP network 1 LAN B.

`hsr instance 1 mode modeu`	The HSR host forwards unicast traffic to the connected VDANs and around the ring.
`hsr instance 1 port-a`	Activate the HSR Port A.
`hsr instance 1 port-b`	Activate the HSR Port B.
`hsr instance 1 switching-node-type hsrredboxprpb`	Enable the device to process traffic destine for LAN B of the PRP network.

`hsr instance 1 redbox-id id1b`	Enable the device to process traffic destine for LAN B of the PRP network 1.
`hsr instance 1 supervision evaluate`	Enable evaluation of received supervision packets.
`hsr instance 1 supervision send`	Enable supervision packet transmission.
`hsr instance 1 supervision redbox-exclusively`	Enable sending of supervision packets for this RedBox exclusively. Use the no form of the command to send supervision packets for each connected VDAN and this RedBox. Prerequisite is that you enable the supervision frame send function.
`hsr operation`	Enable the HSR function.

View traffic statistics on a device using the show commands.

`show hsr counters`	Show the HSR counters.
`show hsr node-table`	Show node table.
`show hsr proxy-node-table`	Show proxy node table.

5 Spanning Tree

Note: The Spanning Tree Protocol is a protocol for MAC bridges. For this reason, the following description uses the term bridge for Switch.

Local networks are getting bigger and bigger. This applies to both the geographical expansion and the number of network participants. Therefore, it is advantageous to use multiple bridges, for example:

- to reduce the network load in sub-areas,
- to set up redundant connections and
- to overcome distance limitations.

However, using multiple bridges with multiple redundant connections between the subnetworks can lead to loops and thus loss of communication across of the network. In order to help avoid this, you can use Spanning Tree. Spanning Tree enables loop-free switching through the systematic deactivation of redundant connections. Redundancy enables the systematic reactivation of individual connections as needed.

RSTP is a further development of the Spanning Tree Protocol (STP) and is compatible with it. If a connection or a bridge becomes inoperable, the STP required a maximum of 30 seconds to reconfigure. This is no longer acceptable in time-sensitive applications. RSTP achieves average reconfiguration times of less than a second. When you use RSTP in a ring topology with 10 to 20 devices, you can even achieve reconfiguration times in the order of milliseconds.

Note: RSTP reduces a layer 2 network topology with redundant paths into a tree structure (Spanning Tree) that does not contain any more redundant paths. One of the Switches takes over the role of the root bridge here. The maximum number of devices permitted in an active branch (from the root bridge to the tip of the branch) is specified by the variable `Max Age` for the current root bridge. The preset value for `Max Age` is 20, which can be increased up to 40.

If the device working as the root is inoperable and another device takes over its function, the `Max Age` setting of the new root bridge determines the maximum number of devices allowed in a branch.

Note: The RSTP standard dictates that all the devices within a network work with the (Rapid) Spanning Tree Algorithm. If STP and RSTP are used at the same time, the advantages of faster reconfiguration with RSTP are lost in the network segments that are operated in combination.
A device that only supports RSTP works together with MSTP devices by not assigning an MST region to itself, but rather the CST (Common Spanning Tree).

5.1 Basics

Because RSTP is a further development of the STP, all the following descriptions of the STP also apply to the RSTP.

5.1.1 The tasks of the STP

The Spanning Tree Algorithm reduces network topologies built with bridges and containing ring structures due to redundant links to a tree structure. In doing so, STP opens ring structures according to preset rules by deactivating redundant paths. If a path is interrupted because a network component becomes inoperable, STP reactivates the previously deactivated path again. This allows redundant links to increase the availabiliy of communication. STP determines a bridge that represents the STP tree structure‘s base. This bridge is called root bridge.

Features of the STP algorithm:

- automatic reconfiguration of the tree structure in the case of a bridge becoming inoperable or the interruption of a data path
- the tree structure is stabilized up to the maximum network size,
- stabilization of the topology within a short time period
- topology can be specified and reproduced by the administrator
- transparency for the terminal devices
- low network load relative to the available transmission capacity due to the tree structure created

5.1.2 Bridge parameters

In the context of Spanning Tree, each bridge and its connections are uniquely described by the following parameters:

- Bridge Identifier
- Root Path Cost for the bridge ports,
- Port Identifier

5.1.3 Bridge Identifier

The Bridge Identifier consists of 8 bytes. The 2 highest-value bytes are the priority. The default setting for the priority number is 32,768, but the Management Administrator can change this when configuring the network. The 6 lowest-value bytes of the bridge identifier are the bridge's MAC address. The MAC address allows each bridge to have unique bridge identifiers.
The bridge with the smallest number for the bridge identifier has the highest priority.

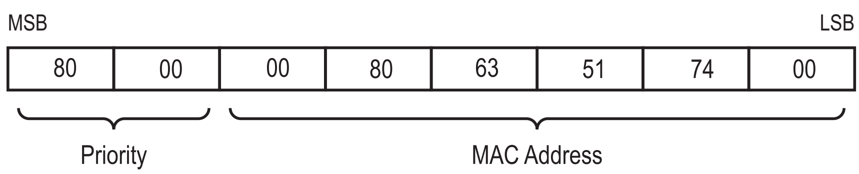


Figure 22: Bridge Identifier, Example (values in hexadecimal notation)

5.1.4 Root Path Cost

Each path that connects 2 bridges is assigned a cost for the transmission (path cost). The Switch determines this value based on the transmission speed (see table 3). It assigns a higher path cost to paths with lower transmission speeds.

Alternatively, the Administrator can set the path cost. Like the Switch, the Administrator assigns a higher path cost to paths with lower transmission speeds. However, since the Administrator can choose this value freely, he has a tool with which he can give a certain path an advantage among redundant paths.

The root path cost is the sum of all individual costs of those paths that a data packet has to traverse from a connected bridge‘s port to the root bridge.

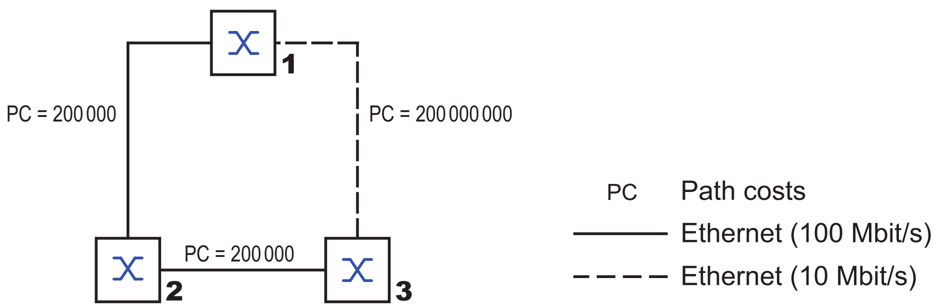


Figure 23: Path costs

Data rate	Recommended value	Recommended range	Possible range
≤100 Kbit/s	200,000,000[a]	20,000,000-200,000,000	1-200,000,000
1 Mbit/s	20,000,000[a]	2,000,000-200,000,000	1-200,000,000
10 Mbit/s	2,000,000[a]	200,000-20,000,000	1-200,000,000
100 Mbit/s	200,000[a]	20,000-2,000,000	1-200,000,000
1 Gbit/s	20,000	2,000-200,000	1-200,000,000
10 Gbit/s	2,000	200-20,000	1-200,000,000
100 Gbit/s	200	20-2,000	1-200,000,000
1 TBit/s	20	2-200	1-200,000,000
10 TBit/s	2	1-20	1-200,000,000

Table 3: Recommended path costs for RSTP based on the data rate.

a. Bridges that conform with IEEE 802.1D 1998 and only support 16-bit values for the path costs should use the value 65,535 (FFFFH) for path costs when they are used in conjunction with bridges that support 32-bit values for the path costs.

5.1.5 Port Identifier

The port identifier consists of 2 bytes. One part, the lower-value byte, contains the physical port number. This provides a unique identifier for the port of this bridge. The second, higher-value part is the port priority, which is specified by the Administrator (default value: 128). It also applies here that the port with the smallest number for the port identifier has the highest priority.

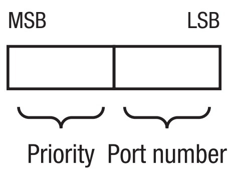


Figure 24: Port Identifier

5.1.6 Max Age and Diameter

The “Max Age” and “Diameter” values largely determine the maximum expansion of a Spanning Tree network.

Diameter

The number of connections between the devices in the network that are furthest removed from each other is known as the network diameter.

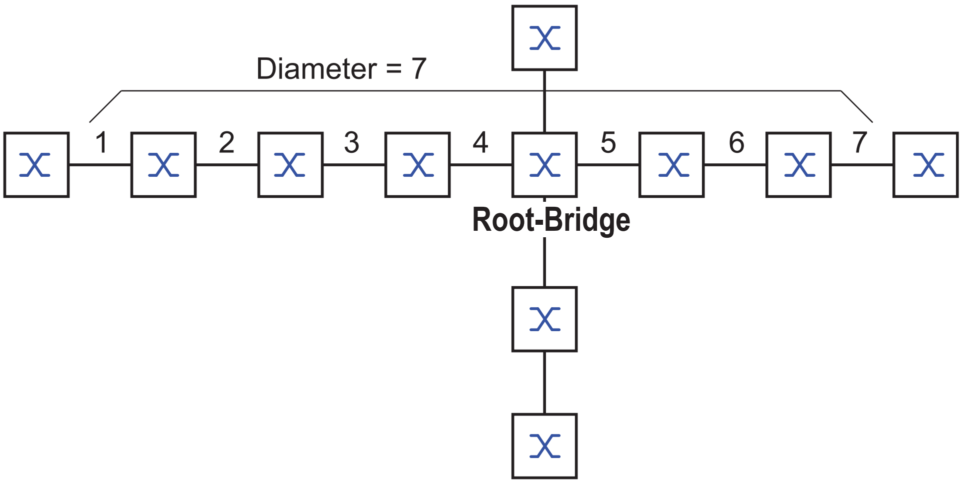


Figure 25: Definition of diameter

The network diameter that can be achieved in the network is MaxAge-1. In the state on delivery, MaxAge=20 and the maximum diameter that can be achieved=19. If you set the maximum value of 40 for MaxAge, the maximum diameter that can be achieved=39.

MaxAge

Every STP-BPDU contains a “MessageAge” counter. When a bridge is passed through, the counter increases by 1.
Before forwarding a STP-BPDU, the bridge compares the “MessageAge” counter with the “MaxAge” value defined in the device:

- ☐ If MessageAge < MaxAge, the bridge forwards the STP-BPDU to the next bridge.
- ☐ If MessageAge = MaxAge, the bridge discards the STP-BPDU.

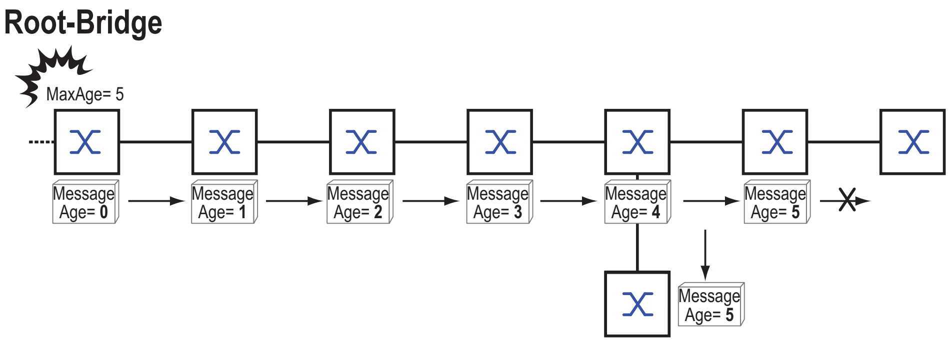


Figure 26: Transmission of an STP-BPDU depending on MaxAge

5.2 Rules for Creating the Tree Structure

5.2.1 Bridge information

To determine the tree structure, the bridges need more detailed information about the other bridges located in the network.
To obtain this information, each bridge sends a BPDU (Bridge Protocol Data Unit) to the other bridges.

The contents of a BPDU include

- bridge identifier,
- root path costs and
- port identifier

(see IEEE 802.1D).

5.2.2 Setting up the tree structure

- The bridge with the smallest number for the bridge identifier is called the root bridge. It is (or will become) the root of the tree structure.
- The structure of the tree depends on the root path costs. Spanning Tree selects the structure so that the path costs between each individual bridge and the root bridge become as small as possible.

- If there are multiple paths with the same root path costs, the bridge further away from the root decides which port it blocks. For this purpose, it uses the bridge identifiers of the bridge closer to the root. The bridge blocks the port that leads to the bridge with the numerically higher ID (a numerically higher ID is the logically worse one). If 2 bridges have the same priority, the bridge with the numerically larger MAC address has the numerically higher ID, which is logically the worse one.
- If multiple paths with the same root path costs lead from one bridge to the same bridge, the bridge further away from the root uses the port identifier of the other bridge as the last criterion (see figure 24). In the process, the bridge blocks the port that leads to the port with the numerically higher ID (a numerically higher ID is the logically worse one). If 2 ports have the same priority, the port with the higher port number has the numerically higher ID, which is logically the worse one.

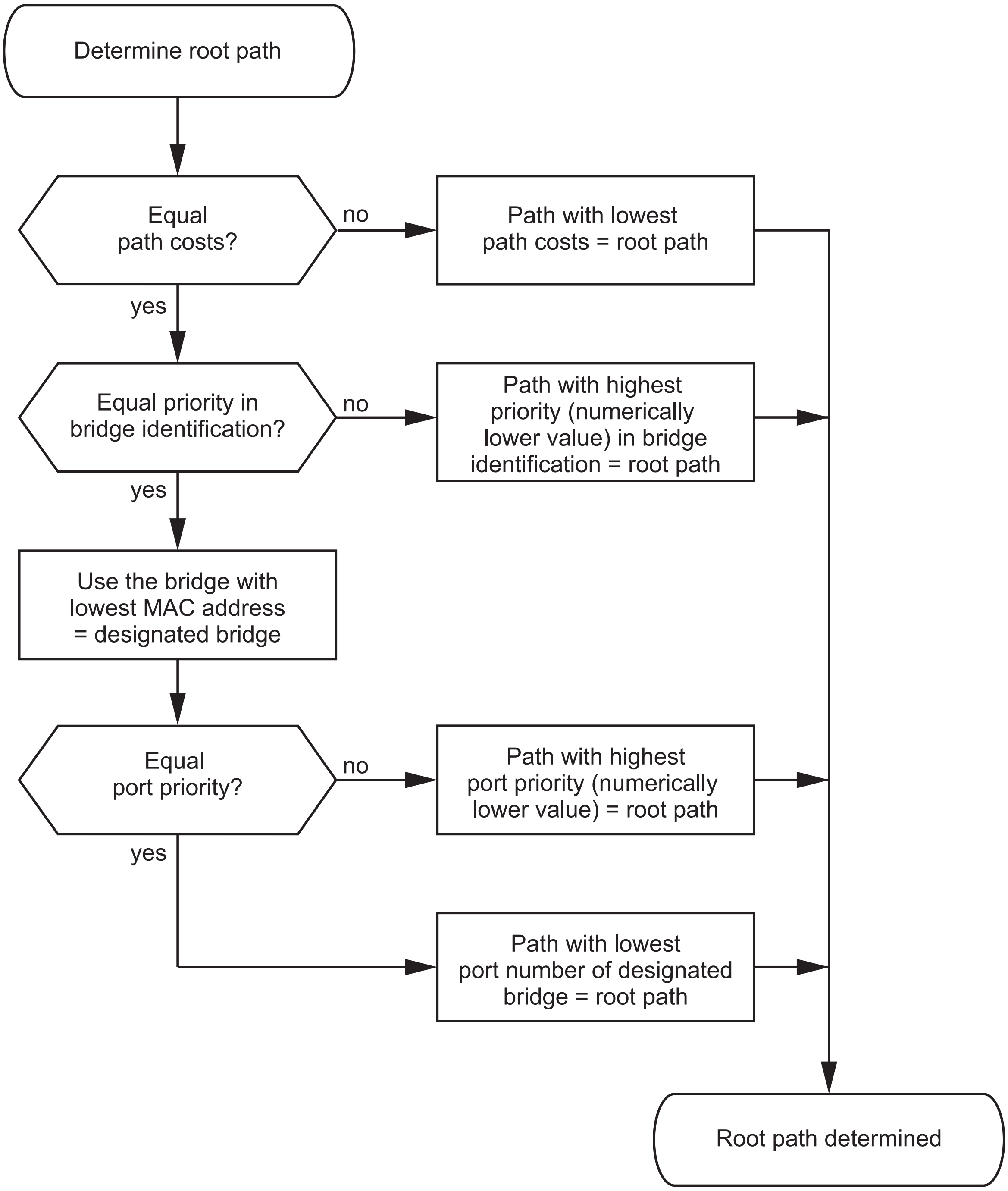


Figure 27: Flow diagram for specifying the root path

5.3 Examples

5.3.1 Example of determining the root path

You can use the network plan (see figure 28) to follow the flow chart (see figure 27) for determining the root path. The administrator has specified a priority in the bridge identification for each bridge. The bridge with the smallest numerical value for the bridge identification takes on the role of the root bridge, in this case, bridge 1. In the example all the sub-paths have the same path costs. The protocol blocks the path between bridge 2 and bridge 3 as a connection from bridge 3 via bridge 2 to the root bridge would result in higher path costs.

The path from bridge 6 to the root bridge is interesting:

- The path via bridge 5 and bridge 3 creates the same root path costs as the path via bridge 4 and bridge 2.
- STP selects the path using the bridge that has the lowest MAC address in the bridge identification (bridge 4 in the illustration).
- There are also 2 paths between bridge 6 and bridge 4. The port identifier is decisive here (Port 1 < Port 3).

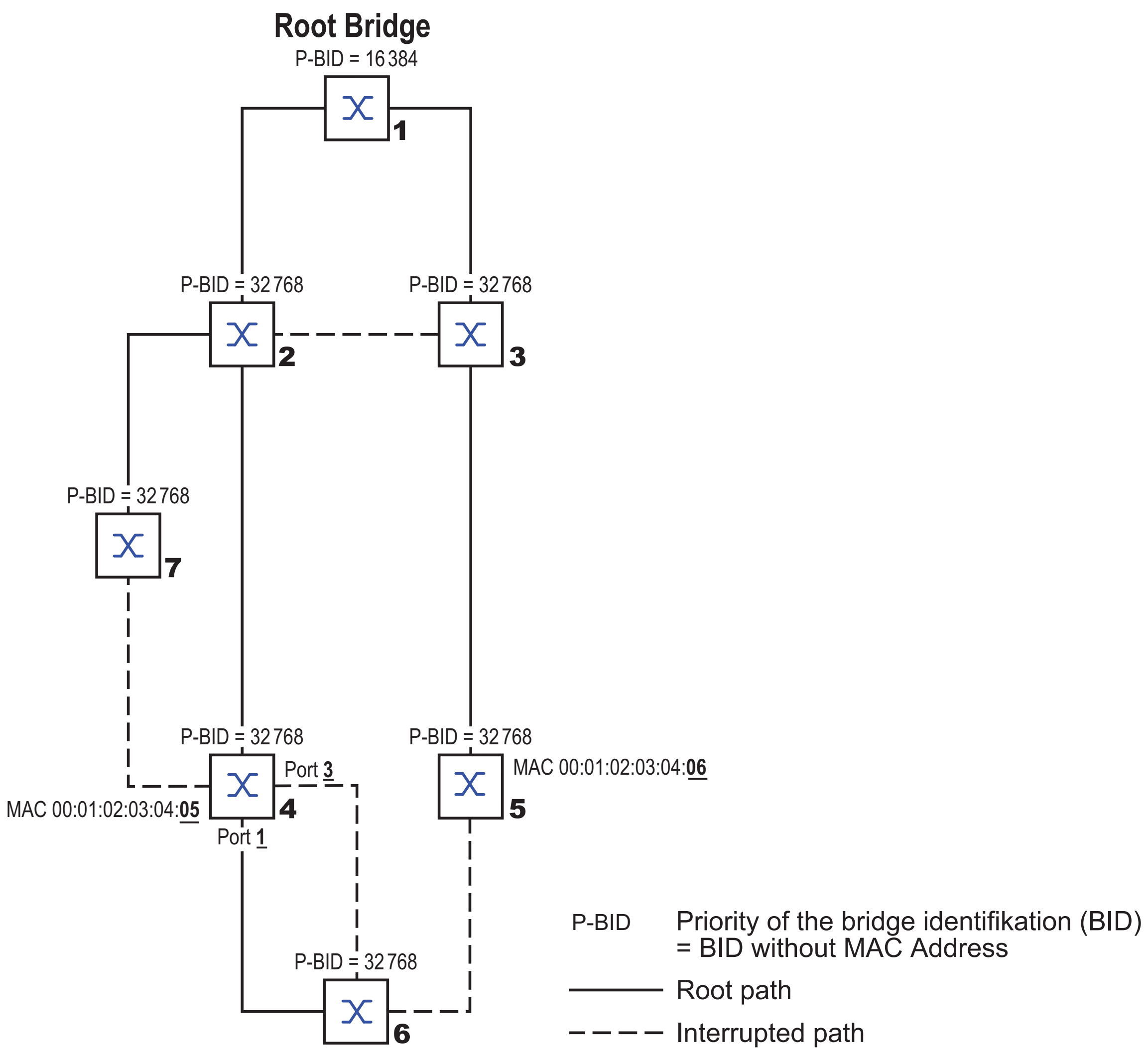


Figure 28: Example of determining the root path

Note: Because the Administrator does not change the default values for the priorities of the bridges in the bridge identifier, apart from the value for the root bridge, the MAC address in the bridge identifier alone determines which bridge becomes the new root bridge if the current root bridge goes down.

5.3.2 Example of manipulating the root path

You can use the network plan (see figure 29) to follow the flow chart (see figure 27) for determining the root path. The Administrator has performed the following:

- Left the default value of 32,768 (8000H) for every bridge apart from bridge 1 and bridge 5, and
- assigned to bridge 1 the value 16,384 (4000H), thus making it the root bridge.
- To bridge 5 he assigned the value 28,672 (7000H).

The protocol blocks the path between bridge 2 and bridge 3 as a connection from bridge 3 via bridge 2 to the root bridge would mean higher path costs.

The path from bridge 6 to the root bridge is interesting:

▶ The bridges select the path via bridge 5 because the value 28,672 for the priority in the bridge identifier is smaller than value 32,768.

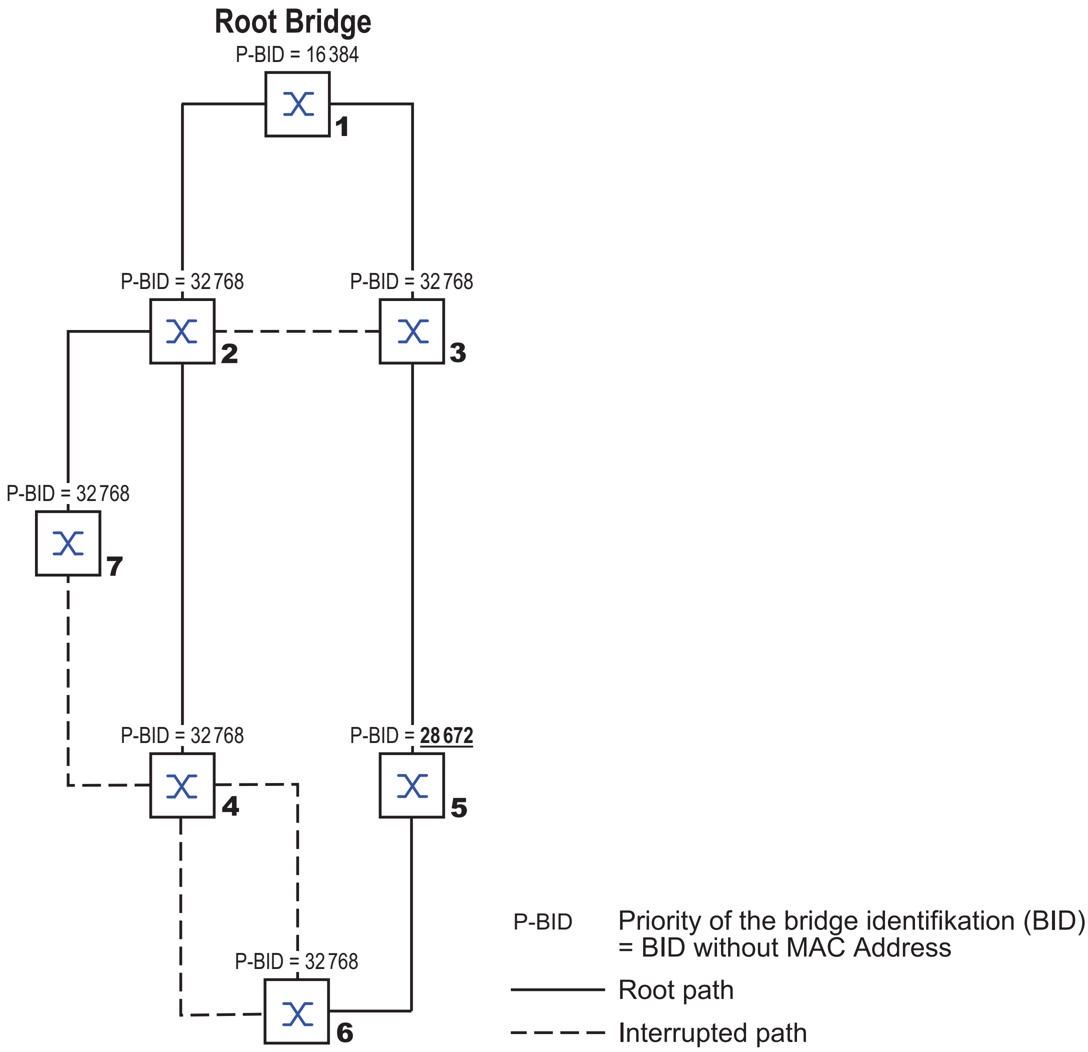


Figure 29: Example of manipulating the root path

5.3.3 Example of manipulating the tree structure

The Management Administrator soon discovers that this configuration with bridge 1 as the root bridge (see on page 66 “Example of determining the root path”) is invalid. On the paths from bridge 1 to bridge 2 and bridge 1 to bridge 3, the control packets which the root bridge sends to all other bridges add up. If the Management Administrator configures bridge 2 as the root bridge, the burden of the control packets on the subnetworks is distributed much more evenly. The result is the configuration shown here (see figure 30). The path costs for most of the bridges to the root bridge have decreased.

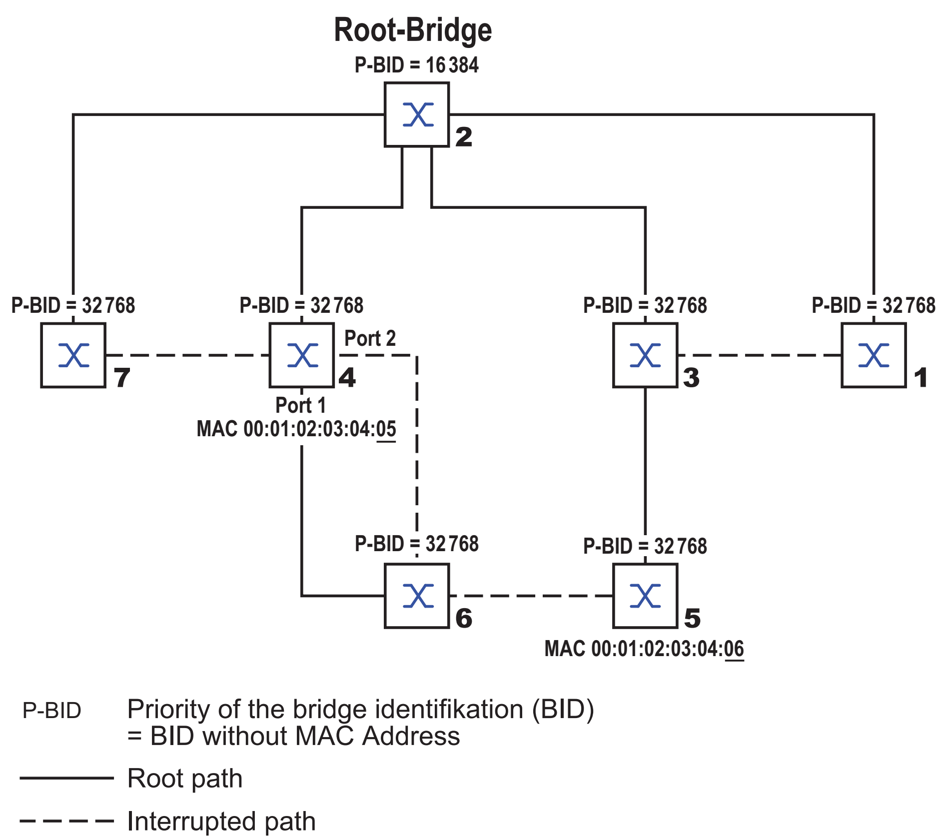


Figure 30: Example of manipulating the tree structure

5.4 The Rapid Spanning Tree Protocol

The RSTP uses the same algorithm for determining the tree structure as STP. RSTP merely changes parameters, and adds new parameters and mechanisms that speed up the reconfiguration if a link or bridge becomes inoperable.
The ports play a significant role in this context.

5.4.1 Port roles

RSTP assigns each bridge port one of the following roles (see figure 31):

- Root Port:
  This is the port at which a bridge receives data packets with the lowest path costs from the root bridge.
  If there are multiple ports with equally low path costs, the bridge ID of the bridge that leads to the root (designated bridge) decides which of its ports is given the role of the root port by the bridge further away from the root.
  If a bridge has multiple ports with equally low path costs to the same bridge, the bridge uses the port ID of the bridge leading to the root (designated bridge) to decide which port it selects locally as the root port (see figure 27).
  The root bridge itself does not have a root port.
- Designated port:
  The bridge in a network segment that has the lowest root path costs is the designated bridge.
  If more than 1 bridge has the same root path costs, the bridge with the smallest value bridge identifier becomes the designated bridge. The designated port on this bridge is the port that connects a network segment leading away from the root bridge. If a bridge is connected to a network segment with more than one port (via a hub, for example), the bridge gives the role of the designated port to the port with the better port ID.

- Edge port
  Every network segment with no additional RSTP bridges is connected with exactly one designated port. In this case, this designated port is also an edge port. The distinction of an edge port is the fact that it does not receive any RST BPDUs (Rapid Spanning Tree Bridge Protocol Data Units).
- Alternate port
  This is a blocked port that takes over the task of the root port if the connection to the root bridge is lost. The alternate port provides a backup connection to the root bridge.
- Backup port
  This is a blocked port that serves as a backup in case the connection to the designated port of this network segment (without any RSTP bridges) is lost
- Disabled port
  This is a port that does not participate in the Spanning Tree Operation, i.e., the port is switched off or does not have any connection.

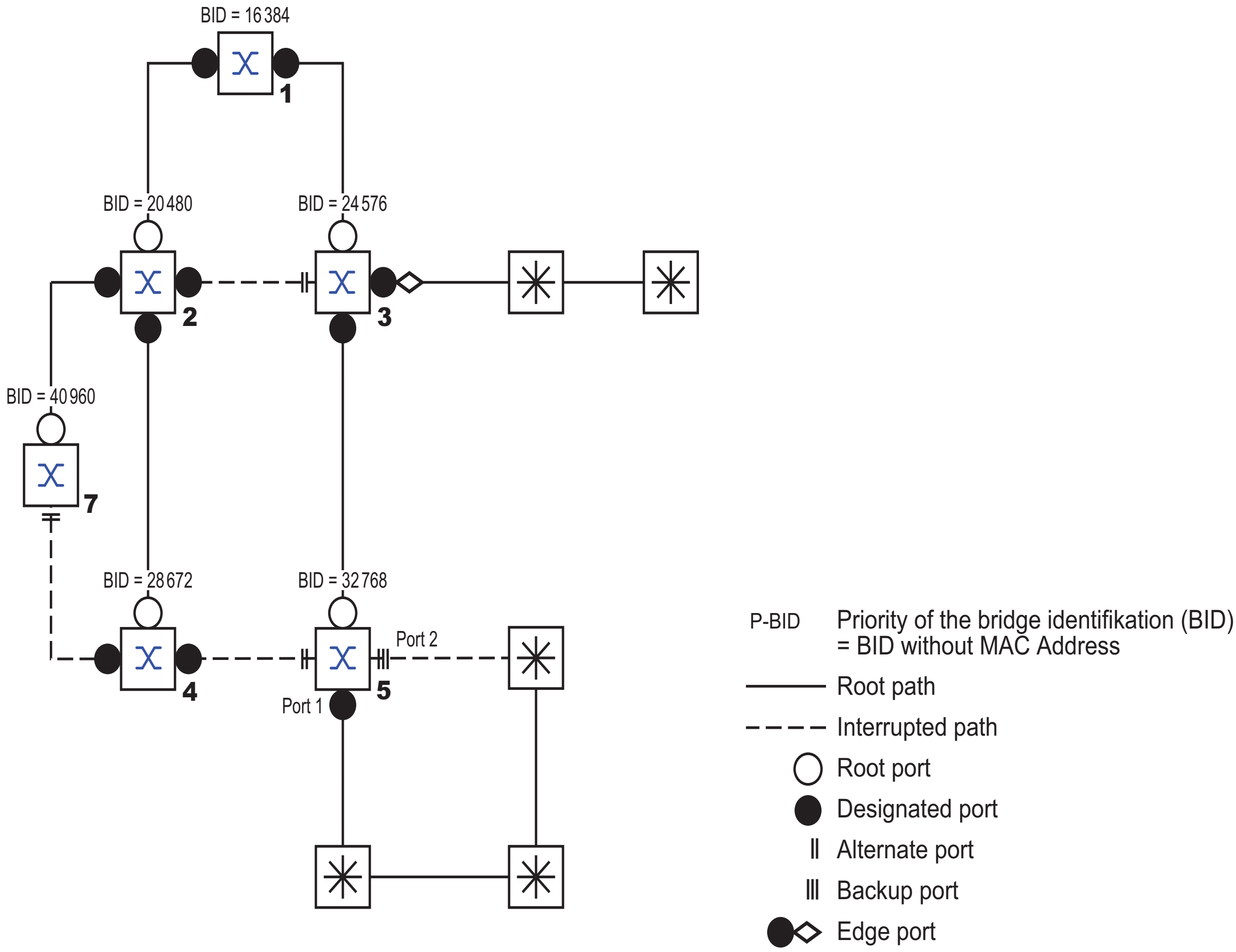


Figure 31: Port role assignment

5.4.2 Port states

Depending on the tree structure and the state of the selected connection paths, the RSTP assigns the ports their states.

STP port state	Administrative bridge port state	MAC operational	RSTP Port state	Active topology (port role)
DISABLED	Disabled	FALSE	Discarding[a]	Excluded (disabled)
DISABLED	Enabled	FALSE	Discarding[a]	Excluded (disabled)
BLOCKING	Enabled	TRUE	Discarding[b]	Excluded (alternate, backup)
LISTENING	Enabled	TRUE	Discarding[b]	Included (root, designated)
LEARNING	Enabled	TRUE	Learning	Included (root, designated)
FORWARDING	Enabled	TRUE	Forwarding	Included (root, designated)

Table 4: Relationship between port state values for STP and RSTP.

a. The dot1d-MIB displays “Disabled”
b. The dot1d-MIB displays “Blocked”

Meaning of the RSTP port states:

- Disabled: Port does not belong to the active topology
- Discarding: No address learning in FDB, no data traffic except for STP BPDUs
- Learning: Address learning active (FDB) and no data traffic except for STP BPDUs
- Forwarding: Address learning is active (FDB), sending and receipt of all frame types (not only STP BPDUs)

5.4.3 Spanning Tree Priority Vector

To assign roles to the ports, the RSTP bridges exchange configuration information with each other. This information is known as the Spanning Tree Priority Vector. It is part of the RSTP BPDUs and contains the following information:

- Bridge identification of the root bridge
- Root path costs of the sending bridge
- Bridge identification of the sending bridge
- Port identifiers of the ports through which the message was sent
- Port identifiers of the ports through which the message was received

Based on this information, the bridges participating in RSTP are able to determine port roles themselves and define the port states of their own ports.

5.4.4 Fast reconfiguration

Why can RSTP react faster than STP to an interruption of the root path?

- Introduction of edge-ports:
  During a reconfiguration, RSTP switches an edge port into the transmission mode after three seconds (default setting) and then waits for the "Hello Time" to elapse, to be sure that no bridge sending BPDUs is connected.
  When the user ensures that a terminal device is connected at this port and will remain connected, there are no waiting times at this port in the case of a reconfiguration.
- Introduction of alternate ports:
  As the port roles are already distributed in normal operation, a bridge can immediately switch from the root port to the alternate port after the connection to the root bridge is lost.
- Communication with neighboring bridges (point-to-point connections):
  Decentralized, direct communication between neighboring bridges enables reaction without wait periods to status changes in the spanning tree topology.

- Address table:
  With STP, the age of the entries in the FDB determines the updating of communication. RSTP immediately deletes the entries in those ports affected by a reconfiguration.
- Reaction to events:
  Without having to adhere to any time specifications, RSTP immediately reacts to events such as connection interruptions, connection reinstatements, etc.

Note: The downside of this fast reconfiguration is the possibility that data packages could be duplicated and/or arrive at the recipient in the wrong order during the reconfiguration phase of the RSTP topology. If this is unacceptable for your application, use the slower Spanning Tree Protocol or select one of the other, faster redundancy procedures described in this manual.

5.4.5 STP compatibility mode

The STP compatibility mode allows you to operate RSTP devices in networks with old installations. If an RSTP device detects an older STP device, it switches on the STP compatibility mode at the relevant port.

5.5 Configuring the device

RSTP configures the network topology completely independently. The device with the lowest bridge priority automatically becomes the root bridge. However, to define a specific network structure regardless, you specify a device as the root bridge. In general, a device in the backbone takes on this role.

☐ Set up the network to meet your requirements, initially without redundant lines.

☐ You deactivate the flow control on the participating ports.
If the flow control and the redundancy function are active at the same time, there is a risk that the redundancy function will not operate as intended. (Default setting: flow control deactivated globally and activated on all ports.)

☐ Switch MRP off on all devices.

☐ Switch Spanning Tree on on all devices in the network.
In the state on delivery, Spanning Tree is switched on on the device.

☐ Open the `Switching > L2-Redundancy > Spanning Tree > Global` dialog.

☐ Activate the function.

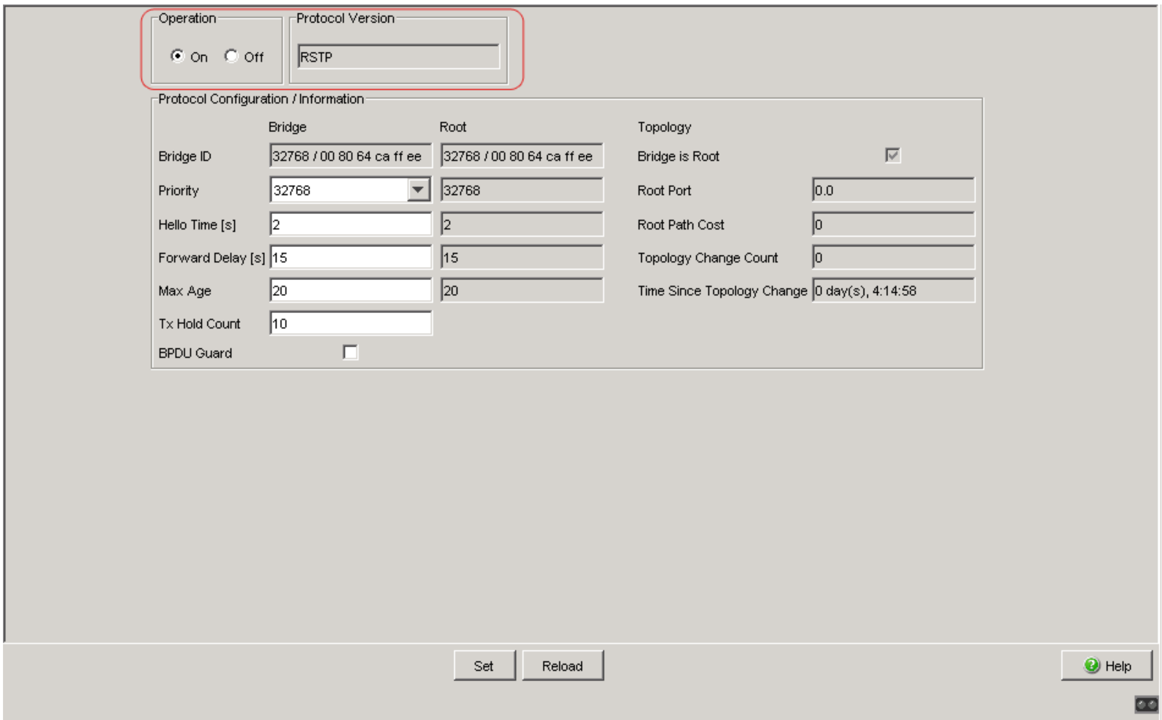


Figure 32: Switching the function on

☐ Click "Set" to save the changes.

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`spanning-tree operation`	Switches Spanning Tree on.
`show spanning-tree global`	Displays the parameters for checking.

☐ Now connect the redundant lines.

☐ Define the settings for the device that takes over the role of the root bridge.

☐ In the "Priority"field you enter a numerically lower value.
The bridge with the numerically lowest bridge ID has the highest priority and becomes the root bridge of the network.

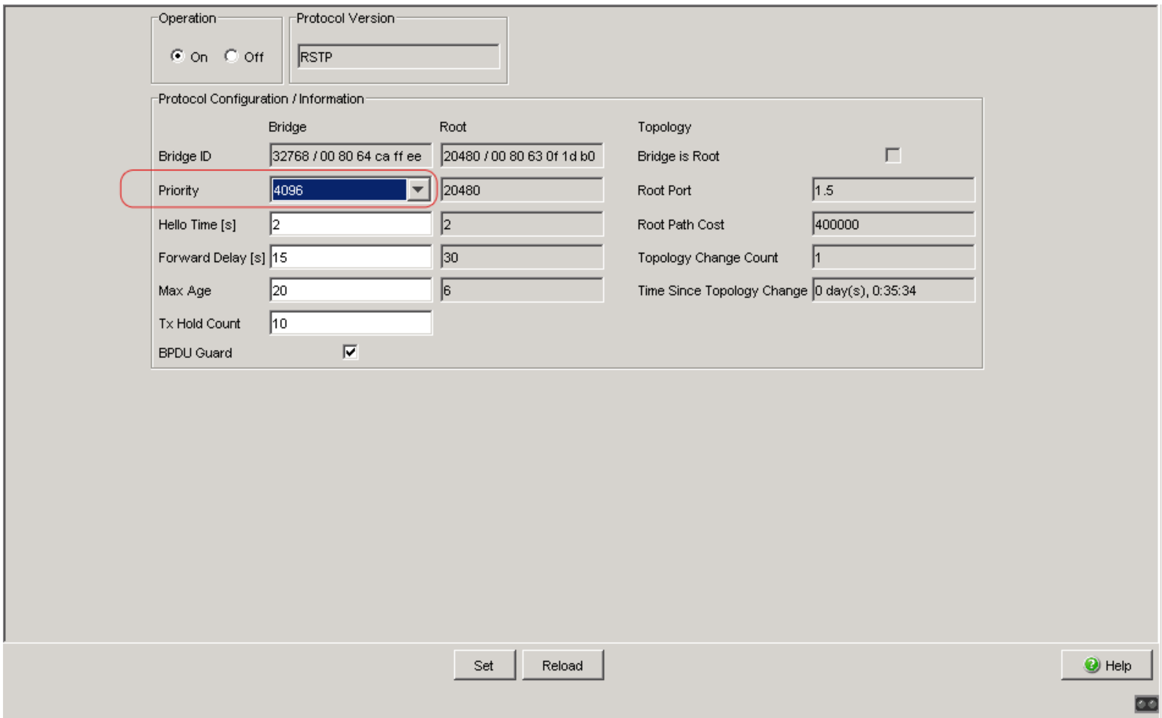


Figure 33: Defining the bridge priority

☐ Click "Set" to save the changes.

`spanning-tree mst priority 0 <0..61440 in 4096er-Schritten>`	Defines the bridge priority of the device.

After saving, the dialog shows the following information:
- The "Bridge is Root" checkbox is marked.
- The "Root Port" field shows the value `0.0`.
- The "Root Path Cost" field shows the value `0`.

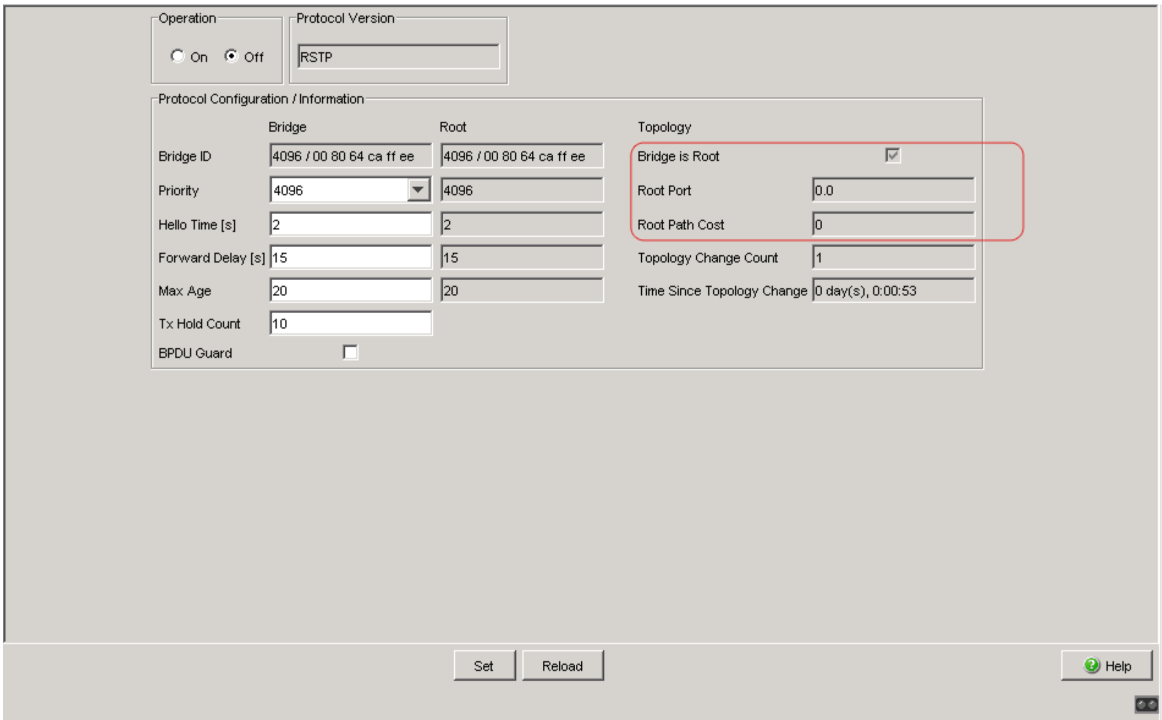


Figure 34: Device is operating as root bridge

`show spanning-tree global`	Displays the parameters for checking.

☐ If applicable, change the values in the "Forward Delay [s]" and "Max Age" fields.

– The root bridge transmits the changed values to the other devices.

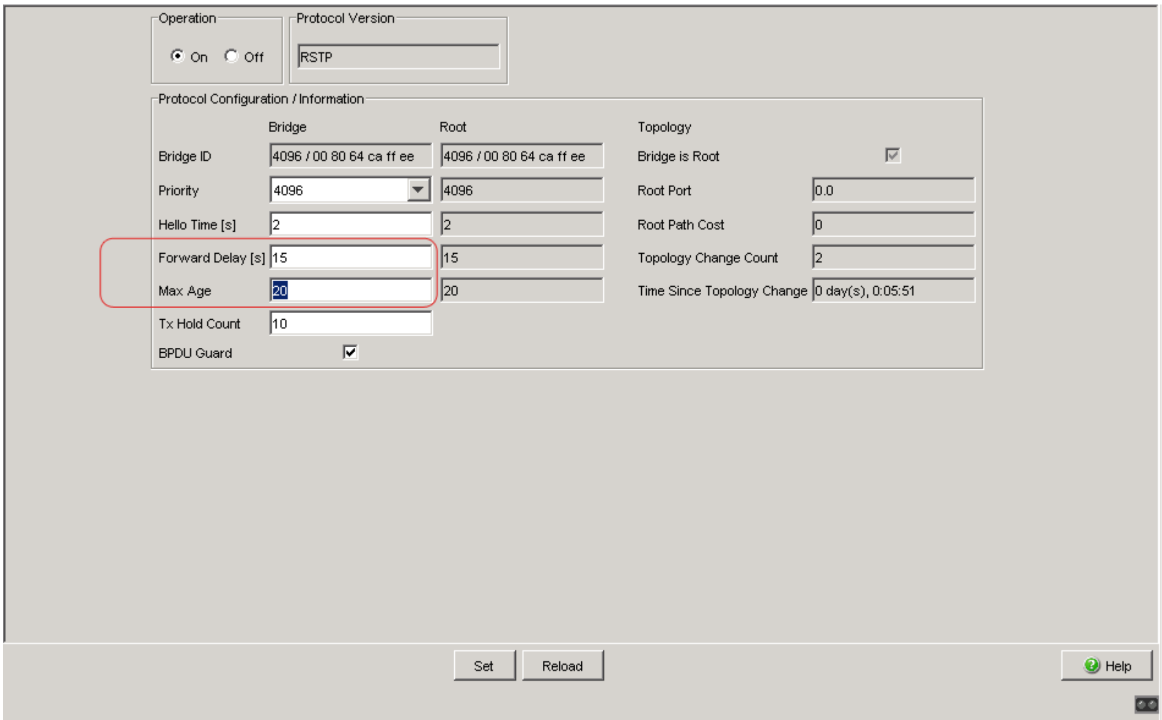


Figure 35: Changing Forward Delay and Max Age

☐ Click "Set" to save the changes.

`spanning-tree forward-time <4..30>`	Specifies the delay time for the status change in seconds.
`spanning-tree max-age <6..40>`	Specifies the maximum permissible branch length, i.e. the number of devices to the root bridge.
`show spanning-tree global`	Displays the parameters for checking.

Note: The parameters "Forward Delay [s]" and "Max Age" have the following relationship:
"Forward Delay [s]" ≥ ("Max Age"/2) + 1
If you enter values in the fields that contradict this relationship, the device replaces these values with the last valid values or with the default value.

Note: If possible, do not change the value in the “Hello Time” field.

☐ Check the following values in the other devices:
– Bridge ID (bridge priority and MAC address) of the corresponding device and the root bridge.
– Number of the device port that leads to the root bridge.
– Path cost from the root port of the device to the root bridge.

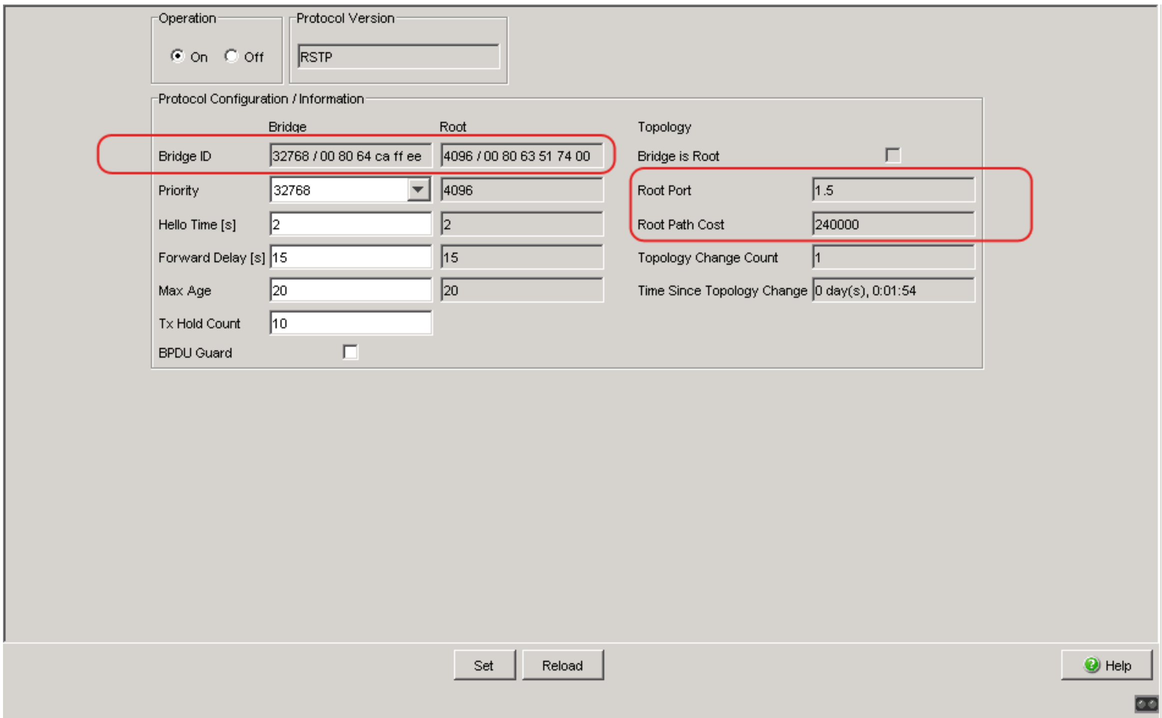


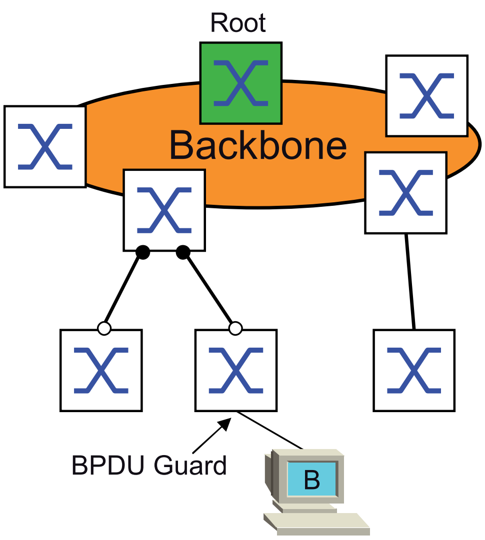
Figure 36: Check values

`show spanning-tree global` Displays the parameters for checking.

5.6 Guards

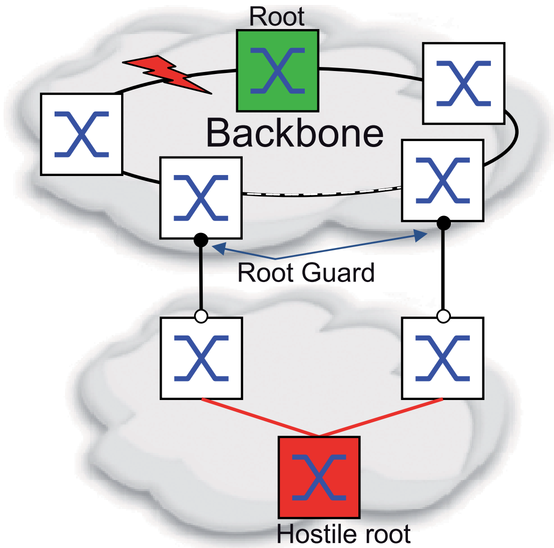
The device allows you to activate various protection functions (guards) on the device ports.
The following protection functions help protect your network from incorrect configurations, loops and attacks with STP-BPDUs:

- BPDU Guard – for manually defined terminal device ports (edge ports)
  You activate this protection function globally in the device.



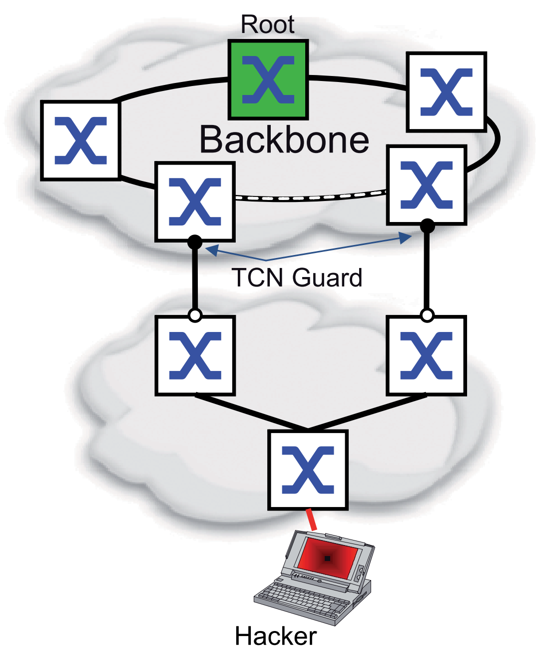
  Terminal device ports do not normally receive any STP-BPDUs. If an attacker still attempts to feed in STP-BPDUs at this port, the device deactivates the device port.

- Root Guard – for designated ports
  You activate this protection function separately for every device port.



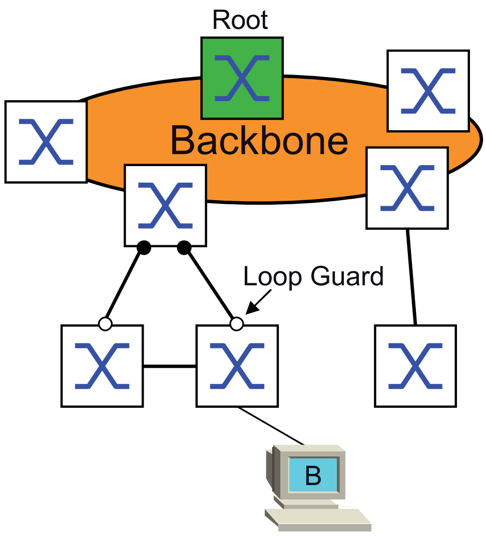
If a designated port receives an STP-BPDU with better path information to the root bridge, the device discards the STP-BPDU and sets the transmission state of the port to `discarding` instead of `root`.
If there are no STP-BPDUs with better path information to the root bridge, after 2 x `Hello Time` the device resets the state of the port to a value according to the port role.

- TCN Guard – for ports that receive STP-BPDUs with a Topology Change flag
You activate this protection function separately for every device port.



If the protection function is activated, the device ignores Topology Change flags in received STP-BPDUs. This does not change the content of the address table (FDB) of the device port. However, additional information in the BPDU that changes the topology is processed by the device.

- Loop Guard – for root, alternate and backup ports
  You activate this protection function separately for every device port.



This protection function prevents the transmission status of a port from unintentionally being changed to `forwarding` if the port does not receive any more STP-BPDUs. If this situation occurs, the device designates the loop status of the port as inconsistent, but does not forward any data packets.

5.6.1 Activating the BPDU Guard

- ☐ Open the `Switching > L2-Redundancy > Spanning Tree > Global` dialog.
- ☐ Mark the "BPDU Guard" checkbox.

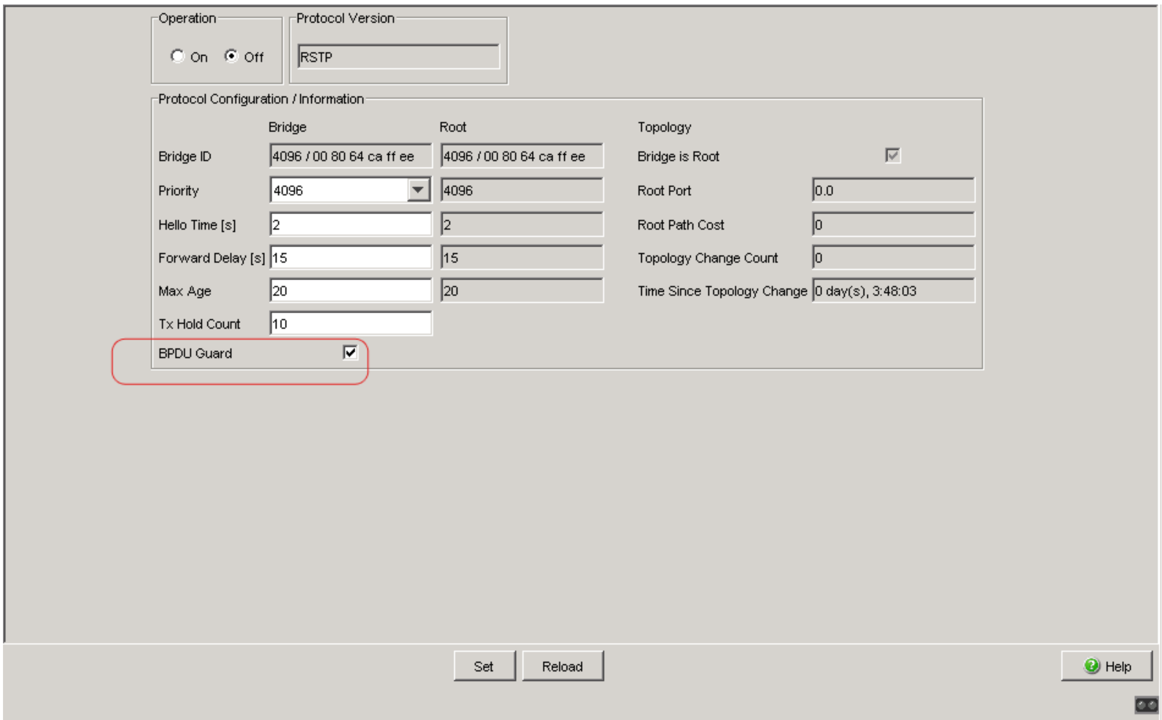
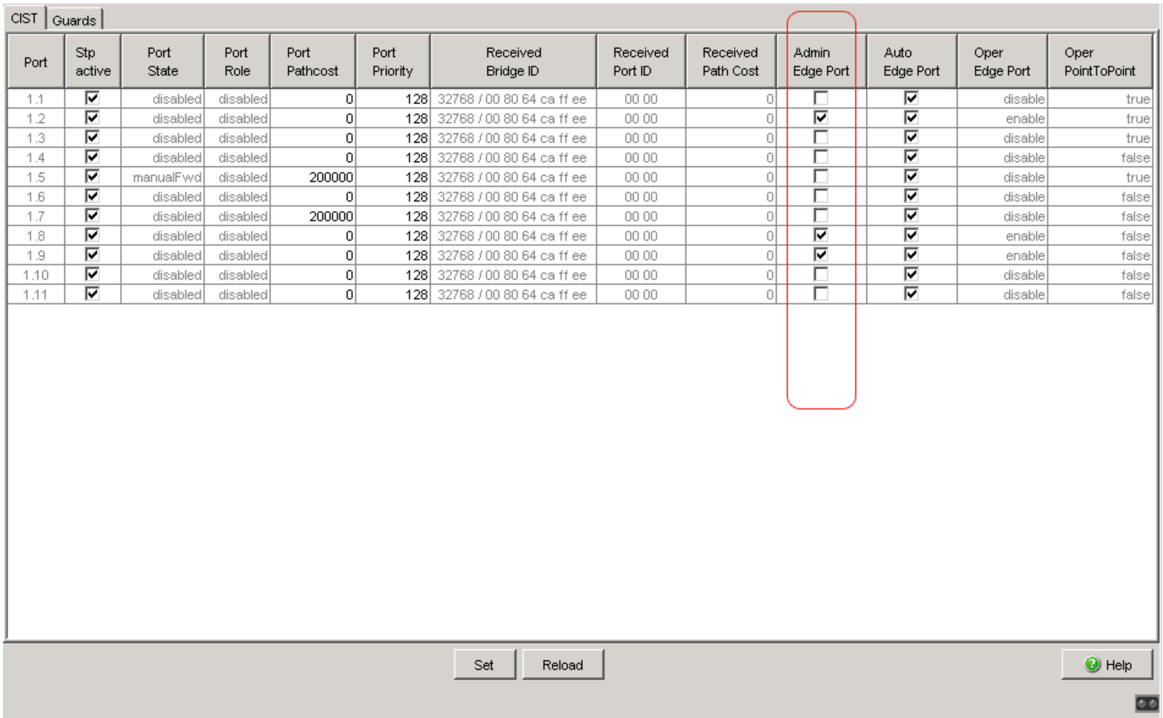


Figure 37: Activating the BPDU Guard

- ☐ Click "Set" to save the changes.

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`spanning-tree bpdu-guard`	Activates the BPDU Guard.
`show spanning-tree global`	Displays the parameters for checking.

- ☐ Open the `Switching > L2-Redundancy > Spanning Tree > Port` dialog.
- ☐ Switch to the "CIST" tab.
- ☐ For terminal device ports, mark the checkbox in the "Admin Edge Port"column.



Port	Stp active	Port State	Port Role	Port Pathcost	Port Priority	Received Bridge ID	Received Port ID	Received Path Cost	Admin Edge Port	Auto Edge Port	Oper Edge Port	Oper PointToPoint
1.1	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☐	☑	disable	true
1.2	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☑	☑	enable	true
1.3	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☐	☑	disable	true
1.4	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☐	☑	disable	false
1.5	☑	manualFwd	disabled	200000	128	32768 / 00 80 64 ca ff ee	00 00	0	☐	☑	disable	true
1.6	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☐	☑	disable	false
1.7	☑	disabled	disabled	200000	128	32768 / 00 80 64 ca ff ee	00 00	0	☐	☑	disable	false
1.8	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☑	☑	enable	false
1.9	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☑	☑	enable	false
1.10	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☐	☑	disable	false
1.11	☑	disabled	disabled	0	128	32768 / 00 80 64 ca ff ee	00 00	0	☐	☑	disable	false

Figure 38: `Switching > L2-Redundancy > Spanning Tree > Port` *dialog, "CIST" tab*

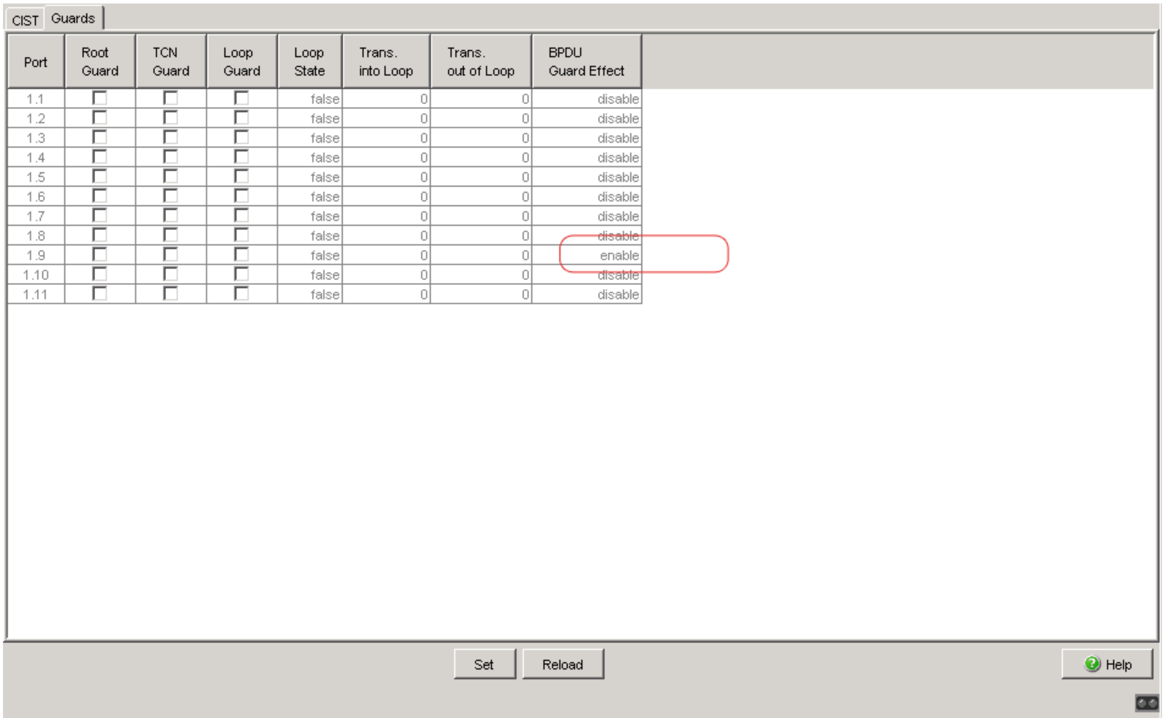
- ☐ Click "Set" to save the changes.

`interface x/y`	Switches to the interface mode.
`spanning-tree edge-port`	Designates the port as a terminal device port (edge port).
`show spanning-tree port x/y`	Displays the parameters for checking.
`exit`	Leaves the interface mode.

If an edge port receives an STP-BPDU, the device behaves as follows:

- The device deactivates this port.
  In the `Basic Settings > Port` dialog, "Configuration" tab, the checkbox in the "Port on" column is not marked for this port.
- The device designates the port.

In the `Switching > L2-Redundancy > Spanning Tree > Port` dialog, "Guards" tab, the device shows the value `enable` in the "BPDU Guard Effect" column.



Port	Root Guard	TCN Guard	Loop Guard	Loop State	Trans. into Loop	Trans. out of Loop	BPDU Guard Effect
1.1	☐	☐	☐	false	0	0	disable
1.2	☐	☐	☐	false	0	0	disable
1.3	☐	☐	☐	false	0	0	disable
1.4	☐	☐	☐	false	0	0	disable
1.5	☐	☐	☐	false	0	0	disable
1.6	☐	☐	☐	false	0	0	disable
1.7	☐	☐	☐	false	0	0	disable
1.8	☐	☐	☐	false	0	0	disable
1.9	☐	☐	☐	false	0	0	enable
1.10	☐	☐	☐	false	0	0	disable
1.11	☐	☐	☐	false	0	0	disable

Figure 39: `Switching > L2-Redundancy > Spanning Tree > Port` dialog, "Guards" tab

`show spanning-tree port x/y`	Displays the parameters of the port for checking. The value of the "BPDU Guard Effect" parameter is `enable`.

To reset the status of the device port to the value `forwarding`, you proceed as follows:

☐ If the device port is still receiving BPDUs:
  – Remove the manual definition as an edge port.
    or
  – Deactivate the BPDU Guard

☐ Activate the device port again.

5.6.2 Activating Root Guard / TCN Guard / Loop Guard

- ☐ Open the `Switching > L2-Redundancy > Spanning Tree > Port` dialog.
- ☐ Switch to the "Guards" tab.
- ☐ For designated ports, select the checkbox in the "Root Guard" column.
- ☐ For ports that receive STP-BPDUs with a Topology Change flag, select the checkbox in the "TCN Guard" column.
- ☐ For root, alternate or backup ports, mark the checkbox in the "Loop Guard" column.

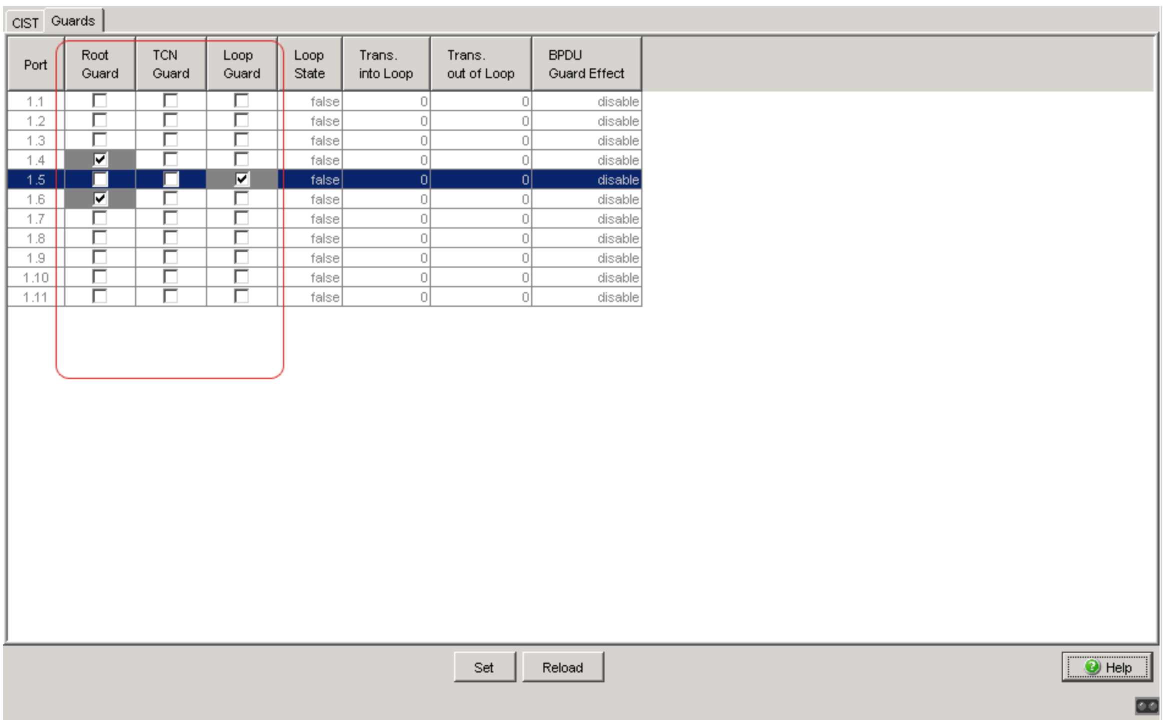


Figure 40: Activating Guards

Note: The "Root Guard" and "Loop Guard" functions are mutually exclusive. If you switch on the "Root Guard" function while the "Loop Guard" function is switched on, the device switches off the "Loop Guard" function.

- ☐ Click "Set" to save the changes.

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`interface x/y`	Switches to the interface mode.
`spanning-tree guard-root`	Switches the Root Guard on at the designated port.
`spanning-tree guard-tcn`	Switches on the TCN Guard on the port that receives STP-BPDUs with a Topology Change flag.
`spanning-tree guard-loop`	Switches the Loop Guard on at a root, alternate or backup port.
`exit`	Leaves the interface mode.
`show spanning-tree port x/y`	Displays the parameters of the port for checking.

6 Link Aggregation

Link Aggregation using the single switch method helps you overcome 2 limitations with ethernet links, namely bandwidth, and redundancy.

The first problem that the Link Aggregation Group (LAG) function helps you with is bandwidth limitations of individual ports. LAG allows you to combine 2 or more links in parallel, creating 1 logical link between 2 devices. The parallel links increase the bandwidth for traffic between the 2 devices.

You typically use Link Aggregation on the network backbone. The function provides you an inexpensive way to incrementally increase bandwidth.

Furthermore, Link Aggregation provides for redundancy with a seemless failover. With 2 or more links configured in parallel, when a link goes down, the other links in the group continue to forward traffic.

The default settings for a new Link Aggregation instance are as follows:
- "Active" is marked
- "Link Trap" is enabled
- "Static Link Aggregation" is disabled
- "Hashing Option" for new trunks is `sourceDestMacVlan`
- "Min. Active Ports" is `1`

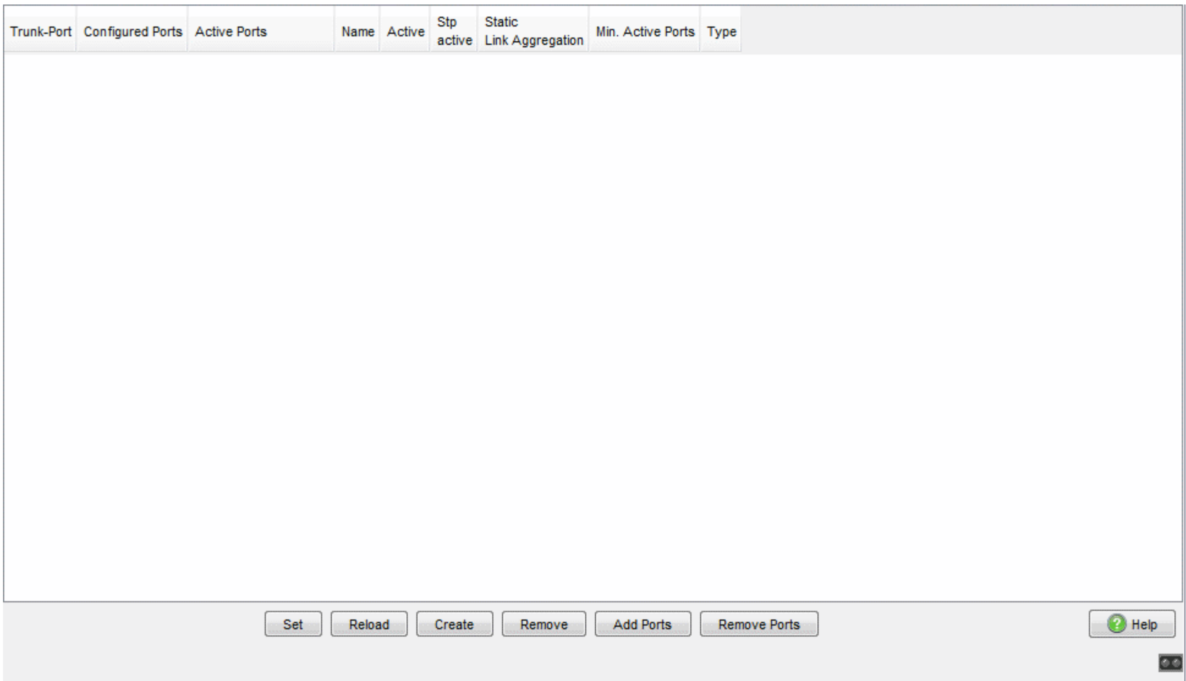


Figure 41: `Switching > L2-Redundancy > Link Aggregation` *dialog*

6.1 Methods of Operation

The device operates on the Single Switch method. The Single Switch method provides you an inexpensive way to grow your network. The single switch method states that you need 1 device on each side of a link to provide the physical ports. The device balances the traffic load across the group member ports.

The device also uses the Same Link Speed method in which the group member ports are full-duplex, point-to-point links having the same transmission rate. The first port the user adds to the group is the master port and determines the bandwidth for the other member ports of the Link Aggregation Group.

The device allows you to configure up to 2 Link Aggregation Groups with up to 2 ports in each group.

■ Hash Algorithm

The frame distributor is responsible for receiving frames from the end devices and transmitting them over the Link Aggregation Group. The frame distributor implements a distribution algorithm responsible for choosing the link used for transmitting any given frame or set of frames. The hash option helps you achieve load balancing across the group.

The device uses the MAC address, VLAN ID, EtherType, and incoming port associated with the packet for link selection.

Static and Dynamic Links

The device allows you to set up static and dynamic links.

- Static Links - The administrator sets up and maintains the links manually. For example, when a link fails and there is a media converter between the devices, the media converter continues forwarding traffic on the link causing the link to fail. Another possibility is that cabling or an undetected configuration mistake causes undesirable network behavior. In this case, the network administrator manually changes the link setup to restore traffic.
- Dynamic Links - The device confirms that the setup on the remote device is able to handle link aggregation and failover occurs automatically.

6.2 Link Aggregation Example

Connect multiple workstations using one aggregated link group between switch 1 and 2. By aggregating multiple links, higher speeds are achievable without a hardware upgrade.

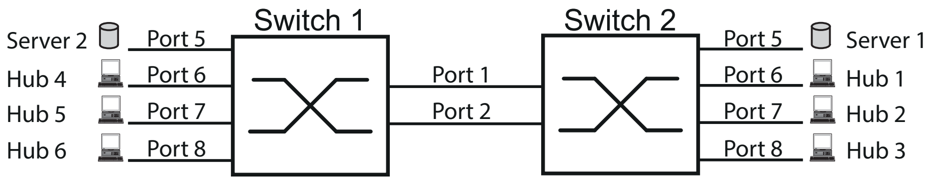


Figure 42: Link Aggregation Switch to Switch Network

Use the following worksteps to setup switch 1 and 2 in the graphical user interface.

- ☐ Open the `Switching > L2-Redundancy > Link Aggregation` dialog.
- ☐ To make a new entry in the table, click "Create".
- ☐ In the "Create" dialog, select `lag/1` from the "Lag Index" pull down menu.
- ☐ Click "OK".
- ☐ To add available ports, highlight the new entry and click "Add Ports".
- ☐ In the "Select Ports to add"dialog select ports `1/1`, and `1/2`.
- ☐ Click "OK".

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`link-aggregation add lag/1`	Create a Link-Aggregation group lag/1
`link-aggregation modify lag/1 addport 1/1`	Adds port 1/1 to the Link Aggregation Group.
`link-aggregation modify lag/1 addport 1/2`	Adds port 1/2 to the Link Aggregation Group.

7 Link Backup

Link Backup provides a redundant link for traffic on Layer 2 devices. When the device detects an error on the primary link, then the device transfers traffic to the backup link. You typically use Link Backup in service-provider or enterprise networks.

You set up the backup links in pairs, one as a primary and one as a backup. When providing redundancy for enterprise networks for example, the device allows you to set up more than 1 pair. The maximum number of link backup pairs is: total number of physical ports / 2. Furthermore, the device sends an SNMP trap when the state of a port participating in a link backup pair changes.

When configuring link backup pairs remember the following rules:
- A link pair consists of any combination of physical ports. For example, when 1 port is a 100 Mbit port and the other is a 1000 Mbit SFP port.
- A specific port is a member of 1 link backup pair at any given time.
- Verify that the ports of a link backup pair are members of the same VLAN with the same VLAN ID. When the primary port or backup port is a member of a VLAN then, assign the second port of the pair to the same VLAN.

The default setting for this function is inactive without any link backup pairs.

Note: Verify that the Spanning Tree Protocol is disabled on the Link Backup ports.

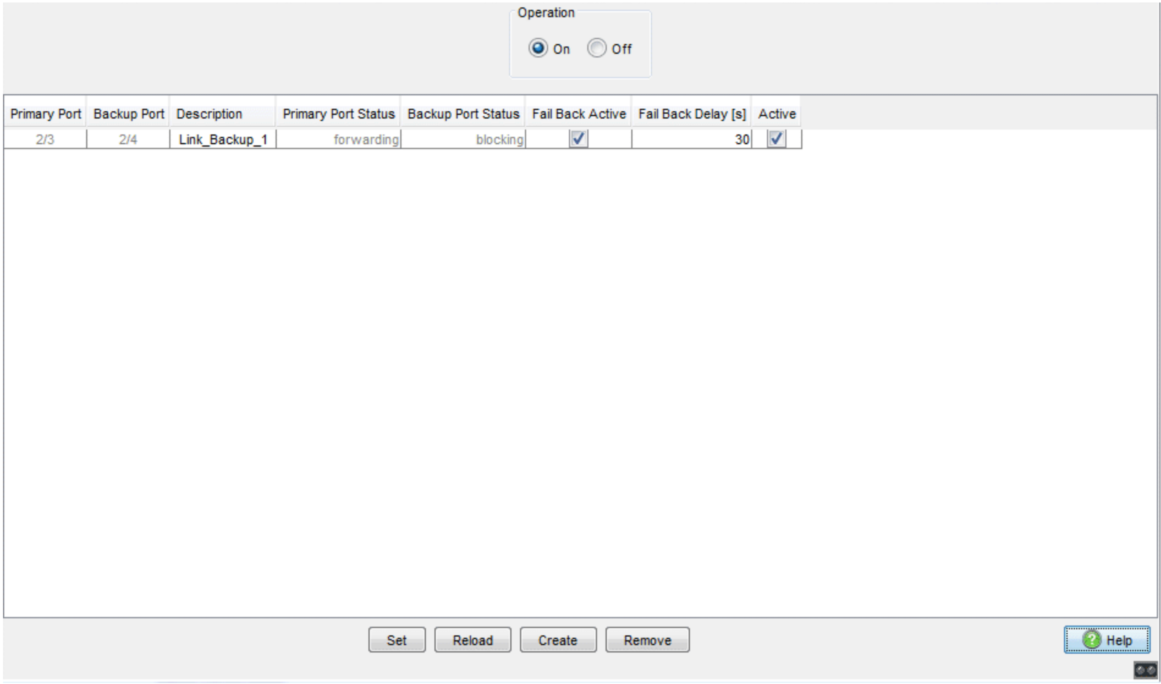


Figure 43: "Link Backup" dialog

7.1 Fail Back Description

Link Backup also allows you to set up a Fail Back option. When you activate the fail back function and the primary link returns to normal operation, the device first blocks traffic on the backup port and then forwards traffic on the primary port. This process helps protect the device from causing loops in the network.

When the primary port returns to the link up and active state, the device supports 2 modes of operation:

- When you inactivate "Fail Back Active", the primary port remains in the blocking state until the backup link fails.
- When you activate "Fail Back Active", and after the "Fail Back Delay [s]" timer expires, the primary port returns to the forwarding state and the backup port changes to down.

In the cases listed above, the port forcing its link to forward traffic, first sends a "flush FDB" packet to the remote device. The flush packet helps the remote device quickly relearn the MAC addresses.

7.2 Example Configuration

In the example network below, you connect ports 2/3 and 2/4 on switch A to the uplink switches B and C. When you set up the ports as a Link Backup pair, 1 of the ports forwards traffic and the other port is in the blocking mode.

The primary, port 2/3 on switch A, is the active port and is forwarding traffic to port 1 on switch B. Port 2/4 on switch A is the backup port and is blocking traffic.

When switch A disables port 2/3 because of a detected error, then port 2/4 on switch A starts forwarding traffic to port 2 on switch C.

When port 2/3 returns to the active state, „no shutdown“, with "Fail Back Active" activated, and "Fail Back Delay [s]" set to 30 s. After the timer expires, port 2/4 first blocks the traffic and then port 2/3 starts forwarding the traffic.

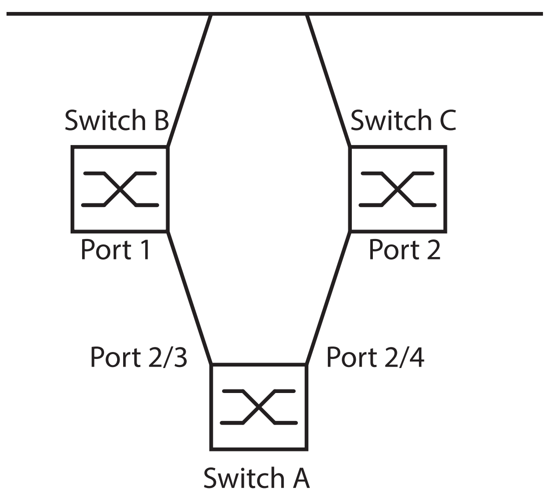


Figure 44: "Link Backup" example network

The following tables contain examples of parameters for Switch A set up.

- ☐ Open the `Switching > L2-Redundancy > Link Backup` dialog.
- ☐ To enter a new Link Backup pair in the table, click "Create".

- ☐ In the "Create" window, from the "Primary Port" drop-down menu select `2/3` and from the "Backup Port" drop-down menu select `2/4`.
- ☐ Click "OK".
- ☐ In the "Description" textbox, enter `Link_Backup_1` as the name for the backup pair.
- ☐ To activate the Fail Back function for the link backup pair, mark the "Fail Back Active" checkbox.
- ☐ Set the fail back timer for the link backup pair, enter `30` s in "Fail Back Delay [s]".
- ☐ To activate the the link backup pair, mark the "Active" checkbox.
- ☐ To enable the Link Backup function globally, in the "Operation" frame, mark the "On" radio button.

`enable`	Switch to the privileged EXEC mode.
`configure`	Switch to the Configuration mode.
`interface 2/3`	Switch to the Interface 2/3 Configuration mode.
`link-backup add 2/4`	Creates a Link Backup instance where port 2/3 is the primary port and port 2/4 is the backup port.
`link-backup modify 2/4 description Link_Backup_1`	Defines `Link_Backup_1` as the name of the backup pair.
`link-backup modify 2/4 fail-back-status enable`	Enables the fail back timer.
`link-backup modify 2/4 fail-back-time 30`	Defines the fail back delay time as `30` s.
`link-backup modify 2/4 status enable`	Enables the Link Backup instance.
`exit`	Switch to the Configuration mode.
`link-backup operation`	Enables the Link Backup function globally on the device.

A Readers’ Comments

What is your opinion of this manual? We are always striving to provide as comprehensive a description of our product as possible, as well as important information that will ensure trouble-free operation. Your comments and suggestions help us to further improve the quality of our documentation.

Your assessment of this manual:

	Very good	Good	Satisfactory	Mediocre	Poor
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Structure	O	O	O	O	O
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