Connectivity Solutions

I/O Redundancy using RSTP

Application Note

August

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I/O Redundancy Using RSTP

Introduction

Overview

Establishment of a stable and reliable I/O network is the most basic need of an automation system. Meeting this requirement with the least complexity, within cost constraints, and without limiting flexibility is the topic of this Application Note.

One of the simplest mechanisms to create a stable I/O network with built-in reliability is to implement an I/O ring, also known as an I/O daisy-chain loop. However, creating rings or loops in industrial Ethernet networks is a matter to be considered carefully.

Ring topologies can be extremely powerful mechanisms for an I/O network if designed with proper planning, understanding of the underlying principles, and clear performance expectations.

This Application Note focuses on the following:

- Understanding the principles of ring management in an I/O network
- Planning a network based on I/O ring topology
- Learning how to properly configure the ring for optimal performance
- Understanding what performance to expect from different I/O ring configurations

Note
In this document we do not make distinction between a “ring” and a “daisy-chain loop”. In general, we will use the term ring to signify the sequential connection of multi-port devices that end with the last device connecting to the first one.

Scope

Protocols

RSTP (Rapid Spanning Tree Protocol) is Schneider Electric's protocol of choice for ring topology management.

This Application Note will focus on architectures built with RSTP only.

Other options exist for ring management, however, in terms of performance and reliability RSTP has been selected for implementation by Schneider Electric.

Products involved

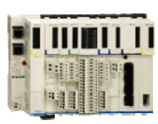
This Application Note addresses architectures based on the following set of Schneider Electric products:

BMX NOC 0401

M340 Ethernet communications module, capable of EtherNet/IP and Modbus TCP communications and equipped with 4 ports. Two of the ports support RSTP.

This product is available as of July 2010.

STB NIP 2311 ver 3.0



Version 3.0 of this STB Network Interface Module is equipped with RSTP for ring management.

The update to version 3.0 is available as of July 16, 2010.

TCSESMxxxx
TCSESMxxxx-E

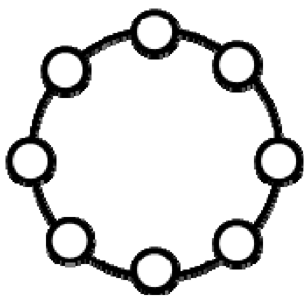
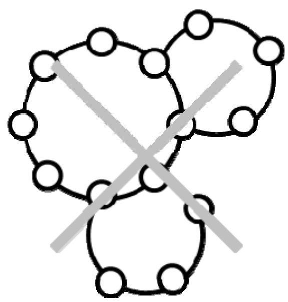
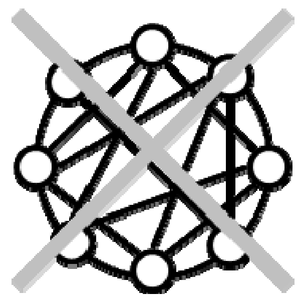
All ConneXium switches are equipped with RSTP. The Extended switches offer a faster network recovery time than the standard models.

Application scope

Although RSTP was originally designed to manage mesh topologies, and it is in use broadly in the IT community for that purpose, its implementation in Schneider Electric products is limited to ring topologies.

Mesh networks are not recommended in industrial Ethernet applications in general. But more specifically, Schneider Electric network products do not support mesh architectures at all.

This Application Note addresses ring topologies exclusively. And in particular, it addresses single ring topologies.

Single ring topology	Multi-ring topology	Mesh topology
		
Supported	**Not supported**	**Not supported**

Background Theory

Ethernet protocols

Ethernet networks are host to a large number of protocols that allow the network to operate properly. Each protocol has a specific function within the network. The following is a partial list of protocols that operate in the background of an Ethernet network:

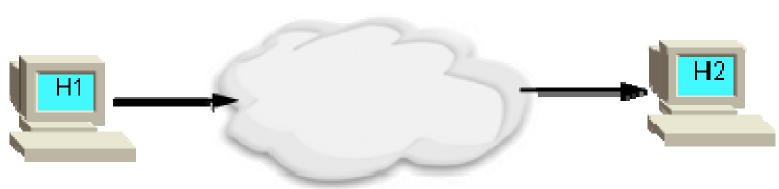
- ARP (Address Resolution Protocol): Matches a device's MAC address with its IP address. Used to ensure that ever device has a valid addressing scheme.
- DHCP (Dynamic Host Configuration Protocol): Allows a server to assign IP addresses to participating devices.
- ICMP (Internet Control Message Protocol): Provides services to manage the wellbeing of the network. The "ping" command is part of this protocol.
- FTP (File Transfer Protocol): Assists in the transfer of files from one host to another.
- SMTP (Simple Mail Transfer Protocol): Manages the traffic associated with electronic mail.

So even though an industrial network is established to primarily carry Modbus TCP or EtherNet/IP information, for example, it will have additional traffic associated with other network functions.

Traffic types

Traffic in an Ethernet network can be classified according to how it reaches its destination. In this classification we have three types of communications:

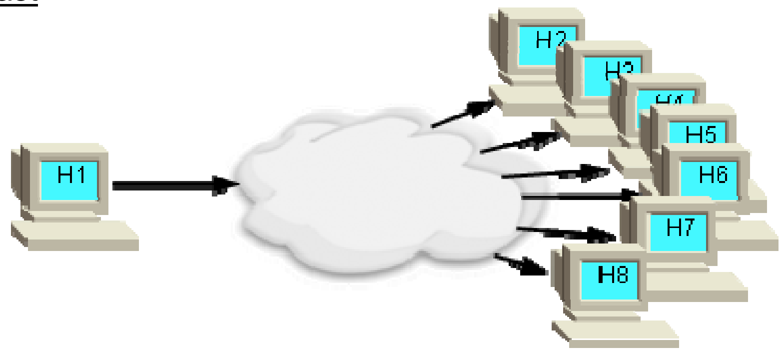
<u>Unicast</u>



Unicast messages travel from one node to another directly. The information is not shared by any other node.

Switches in the network maintain an address table that allows them to route the information through the proper ports so that the data reaches the correct node.

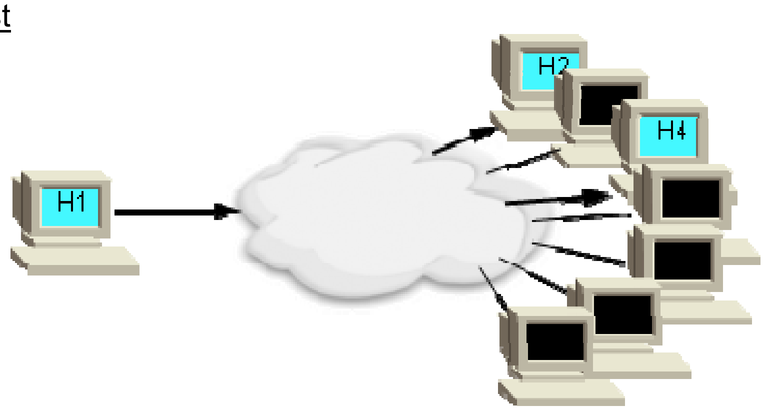
Broadcast



Broadcast messages consist of a single communication stream from the originator that is then distributed to all nodes in the network, even if the data is not relevant to them.

Switches in the network will replicate every broadcast packet and send copies of it through every port of the switch.

Multicast



Multicast messages are also a single stream of data from the originator, but the information only goes to nodes in the network that are interested in the information. A subscription mechanism allows the data to be delivered only to the desired nodes in the network.

Multicast requires the implementation of managed switches that will maintain the subscription information for each multicast stream (there can be multiple streams operating simultaneously). Unmanaged switches will treat multicast packets as broadcast packets and will forward them out of every port.

The trouble with rings

In industrial Ethernet networks, unmanaged or unintended loops or rings can cause serious problems to the performance of a network.

The primary issue in unmanaged or unintended rings is broadcast storms. When broadcasting messages, switches in the network replicate each broadcast packet and re-send it through the other ports. The broadcast message is sent around the network. If a loop exists, it enables the message to be received by switches that have already processed it, resulting in re-broadcast. As the packets continue to circulate in the ring they are multiplied to the point that they consume most, if not all, of the bandwidth.

Broadcast storms can overwhelm the processing capacity of smaller devices rendering them inaccessible to the network. But in most cases the broadcast storm would simply prevent other traffic from entering the ring, isolating the devices in it from the rest of the network.

Ring management protocols

Ring management protocols aim at preventing ring topology failures caused by broadcast storms. These protocols also manage the redundancy aspect of the Ethernet ring.

Media redundancy is achieved by the implementation of a ring management protocol such as RSTP, MRP, or HIPER-ring. Their objective is essentially the same:

> *If a segment of the ring should become compromised, the protocol will instruct the members of the ring to continue communications through an alternate path.*

The focus of this Application Note will be management of ring architectures using RSTP (Rapid Spanning Tree Protocol), as implemented in Schneider Electric products.

Theory of Operation

BPDUs

For RSTP, the nodes of a ring, or the devices in the network, are called *bridges*. A bridge is a multi-port device that supports RSTP.

RSTP essentially manages the behavior of the ports of the bridges engaged in a ring topology. The behavior of a port can be managed by changing its state (e.g. open or closed); or by changing its role in the RSTP configuration (e.g. root port or designated port).

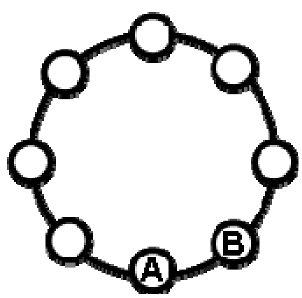
To execute these changes, RSTP makes use of Ethernet packets dedicated to this protocol. These packets are called BPDUs, or Bridge Protocol Data Units. BPDUs circulate through the network at regular intervals and whenever a node detects a change in the network configuration.

In general, BPDUs take up a negligible amount of bandwidth and will not interfere with other traffic, such as EtherNet/IP or Modbus TCP packets.

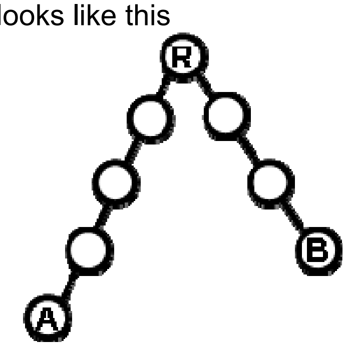
Resolving loops

RSTP resolves loops or rings in the network by converting any topology into a tree topology.

A topology that physically looks like this…



…is translated to a logical topology that looks like this



In order to generate the tree topology, RSTP has to execute two specific actions:

Selection of a root bridge.
In the topology depicted above, the node labeled with the letter "R" is the *root* of the tree. The root of the tree is the bridge with the lowest value in an RSTP parameter called *Bridge Priority*. If all devices have the same Bridge Priority value, then the device with the lowest MAC address will become root.

Disabling of redundant paths.
Once the root is selected, an algorithm is used to calculate the paths of lower cost to reach all nodes. The cost of a path is generally equivalent to the

relative speed of the links on a branch of a tree. In a ring consisting of similar devices and 100Mb/sec, full duplex links, the nodes will be distributed fairly evenly between the two branches of the tree. To do this, one of the ports connecting node A and node B, in the images above, will be disabled.

In this example, there is a physical connection between nodes A and B. However, since one of the ports associated with the cable connecting them is disabled, Ethernet traffic will not flow between these nodes.

The tree topology defined by RSTP remains unchanged until an event triggers its recalculation.

Ring recovery

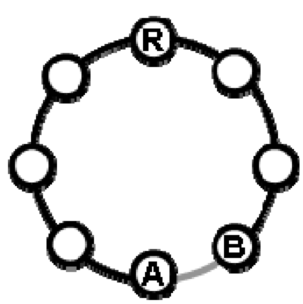
BPDUs transmitted at regular intervals allow devices to learn of changes in configuration. However, these are not the only means to trigger a change in the tree topology. Any change in the state of the communication ports can trigger a recalculation of the topology.

One particular case is the accidental disconnection of a segment of the ring. The two ports associated with that failure will detect a "link down" event that will trigger a new root bridge election and the enabling and disabling of ports as necessary.

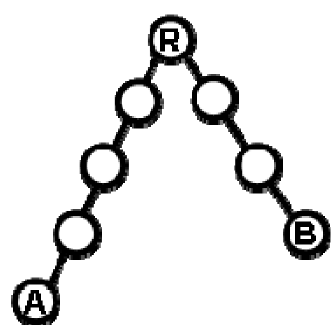
When a cable failure is detected, the devices will estimate the lowest cost to reach the root bridge and will enable any ports that had been disabled before in an attempt to overcome the link failure elsewhere in the ring.

In the previous example, the ring topology was redefined as a tree topology with near symmetry in the two branches.

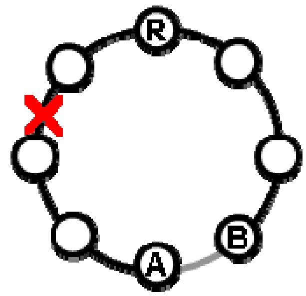
Physical topology



Logical topology

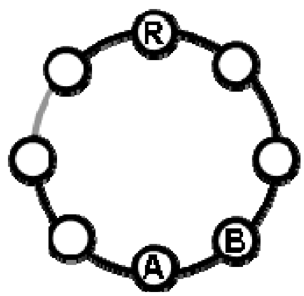


Failure of a ring segment would trigger a recalculation of the tree topology. For instance, a failure as depicted below would initiate the re-calculation process.

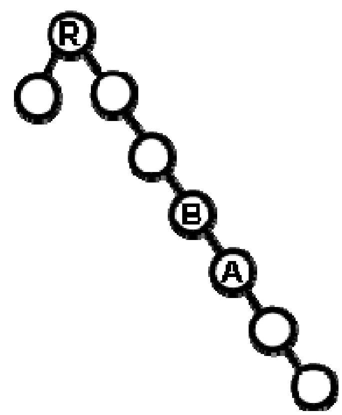


Since none of the devices were replaced in this example, the same device will remain as root. But the corresponding tree topology would change, as depicted in the images below.

Physical topology



Logical topology



Once the broken link is repaired, the original tree topology will be restored and the symmetry will be reestablished.

Commissioning an I/O Ring Using RSTP

Sequence of actions

A key rule in the commissioning of Ethernet rings is to close the ring only after all devices have been configured and the connections established.

By closing the ring at the last possible moment, you avoid unintended delays due to temporary broadcast storms that may arise during the commissioning process.

A typical sequence of events for setting up an I/O ring on Ethernet with Schneider Electric devices is as follows:

1) Perform all mechanical installations of the equipment to be used in the network.
2) Make all the network connections as planned, but do not close the ring. Keep the last segment of the ring disconnected.
3) Assign IP addresses to all devices.
4) Establish contact with the PLC, or PLCs, that will be collecting data from the devices, and configure all PLC communication parameters.
5) Configure each of the devices and establish communication with the corresponding PLC.
6) Enable ring redundancy functionality (RSTP) on all devices. Note that in the ConneXium switches, RSTP is enabled by port. Ensure that only the ports involved in the ring have RSTP set to "Enabled".
7) For advanced implementers: make any RSTP parameter changes at this time. Default settings will suffice for the majority of applications.
8) Check the status of the RSTP service for each device using its web page.
9) Close the ring by connecting the last segment.
10) Initiate the PLC program.

Enabling RSTP

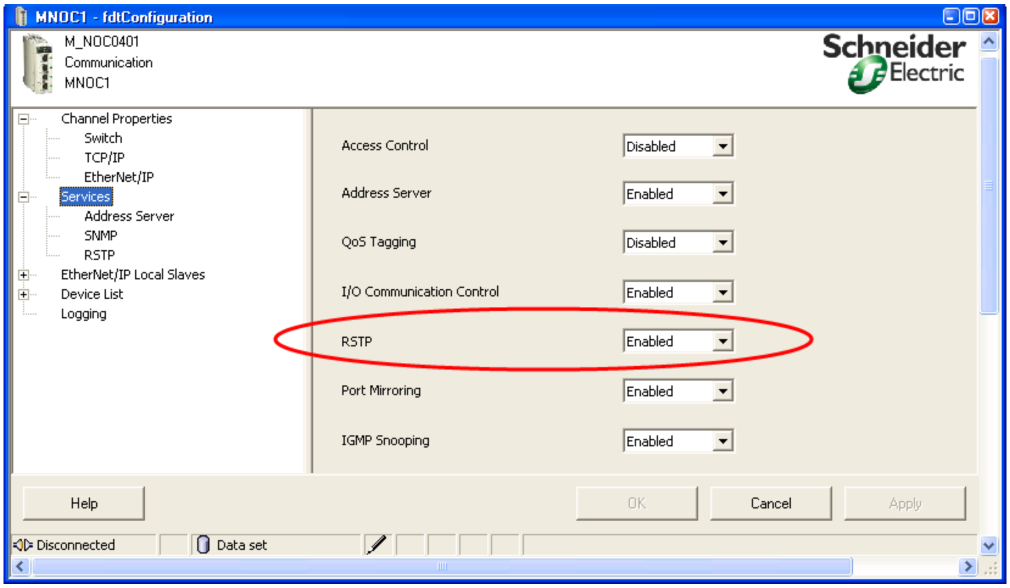
All nodes of a ring must have RSTP enabled in order to work properly. Here we describe how to enable RSTP-based redundancy in Schneider Electric products.

BMX NOC 0401 Ethernet module

The RSTP serviced is enabled within the Unity Pro application used to configure this module.

- If not visible already, display the DTM Browser by using the *Tools* pull-down menu and selecting *DTM Browser*.

- In the DTM Browser, double click the icon for the BMX NOC 04041 module to open the Device Editor.
- In the left panel of the Device Editor window, click on *Services*. Use the pull down menu on the right panel to set RSTP to *Enabled*.



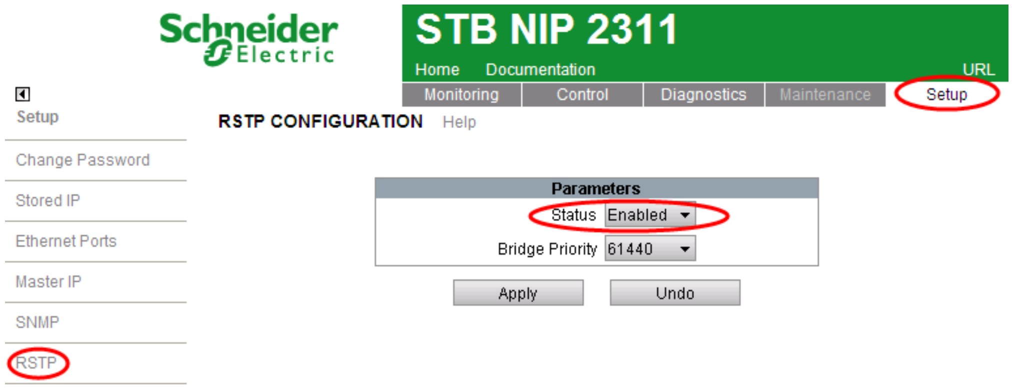
- Double click on the module in the rack viewer, update the application, build the application, and download it to the PLC. Please consult the Users Manual for more information.

<u>STB NIP 2311 I/O island</u>

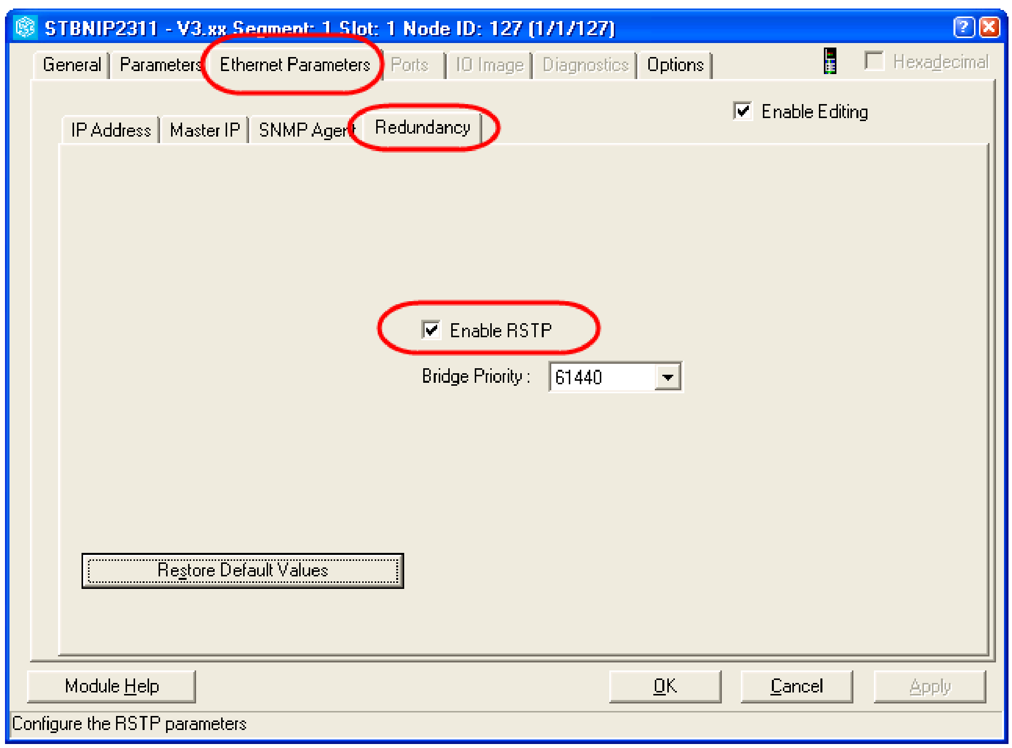
There are two mechanisms for enabling RSTP on the STB island:

- Through the STB's webpage
- Through the Advantys Configuration Tool

In the device's webpage, in the *Setup* section, select *RSTP*. From the pull-down menu for *Status*, select "*Enabled*".

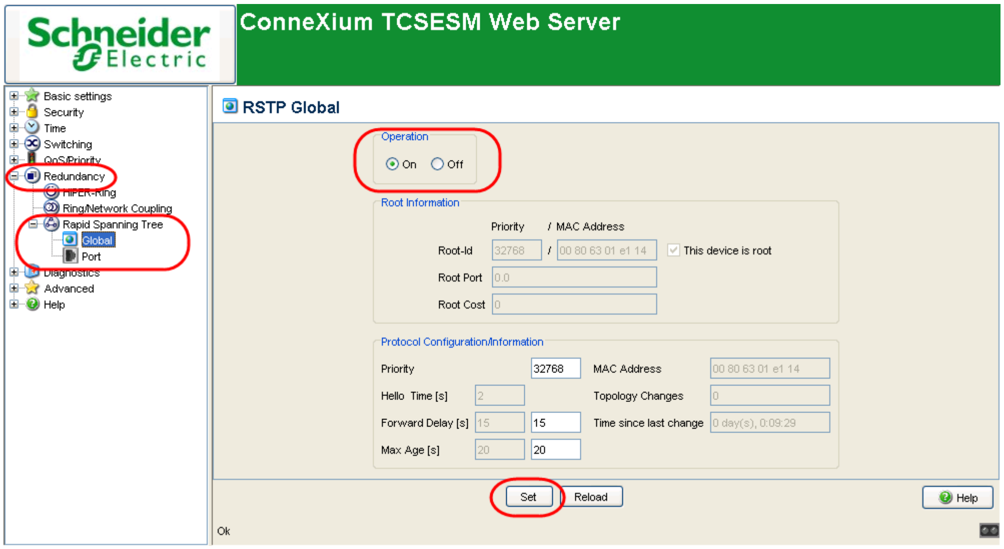


In the Advantys Configuration Tool, double-click on the NIM's image to open the configuration window. Under *Ethernet Parameters* find the *Redundancy* tab and check the *Enable RSTP* function.



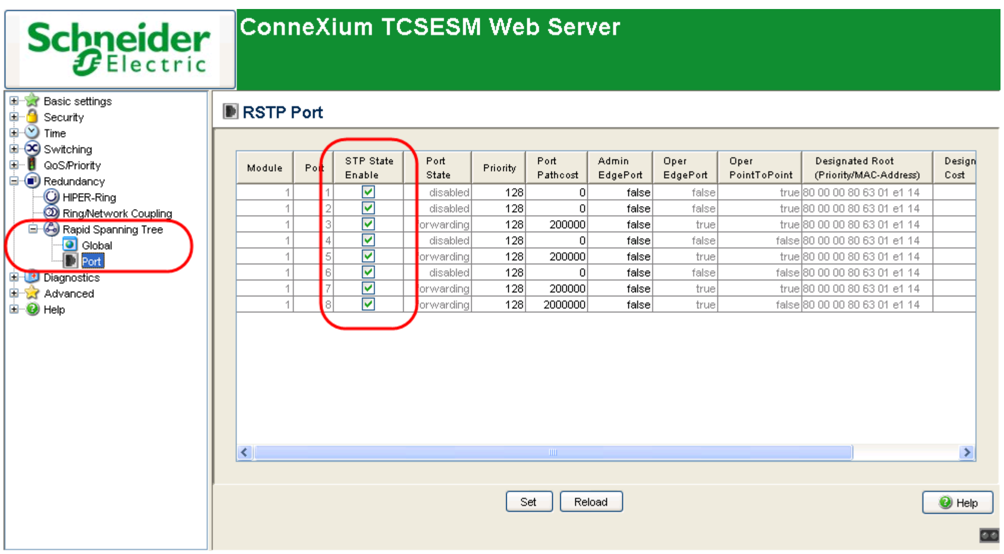
ConneXium switches

To enable RSTP functionality in a ConneXium switch, access the switch's web page as an administrator. The first action is to enable the switch for RSTP redundancy. In the main menu of the web page, open the *Redundancy* tree. Under *Rapid Spanning Tree* select *Global*. Change the *Operation* option from *Off* to *On* and press *Set*.



A second step may be necessary to ensure a faster network recovery time.

Select the *Port* option under *Rapid Spanning Tree*. This window displays the state of each port of the switch. The *STP State Enable* column offers the option to enable or disable RSTP by port.

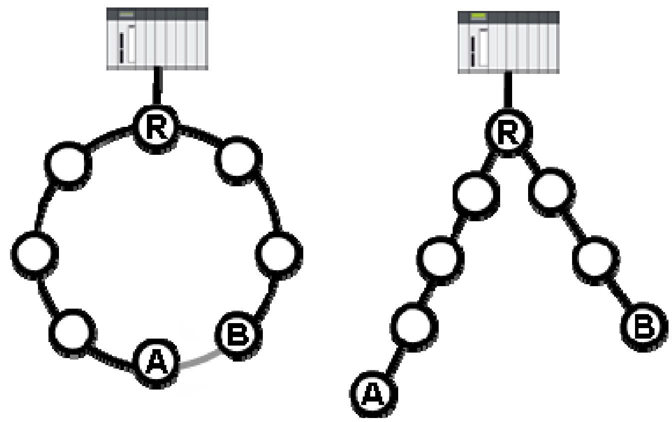


Disabling RSTP for specific ports causes the protocol to ignore those ports, thereby resolving topology changes only on the specified ports. This option may ensure fast recovery times along the ports that form part of a ring, but leaves the other ports unprotected in case of an accidental network loop. This configuration option should be used only in cases where network recovery performance is at the limit of what the application requires.

Optimal root selection

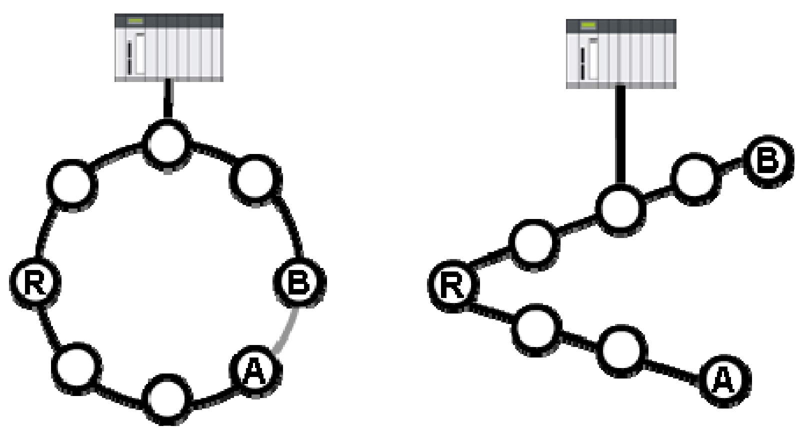
The selection of the root of the topology is important because it will define how the ring devices will be distributed along the two tree branches.

If your PLC connects to the ring devices through the root bridge, then distance to the farthest device is minimized, as shown here:



.

But if the PLC connects to the ring through a device that is not acting as the root, then some of the devices will be farther away form the PLC than in the previous example.



Topology rules

Recommendations to optimize performance of the ring are provided below.

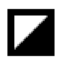
- Construct I/O rings with similar devices. A homogeneous I/O ring will have a more predictable behavior than one containing devices of different types, or different vendors.

- Use a common switch to link the ring to all the PLCs that will be collecting data from the ring devices. This will ensure that an optimal tree structure can be defined.

  For example, in a system with the following components:

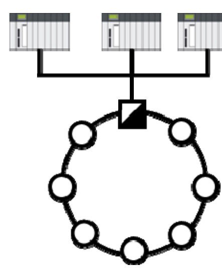
   PLCs not equipped with RSTP enabled modules

   RSTP enabled PLCs

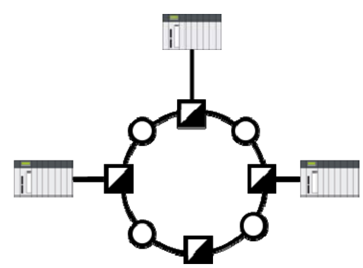
   RSTP enabled managed switches

   RSTP enabled nodes (i.e. I/O devices)

This topology would be easier to optimize.

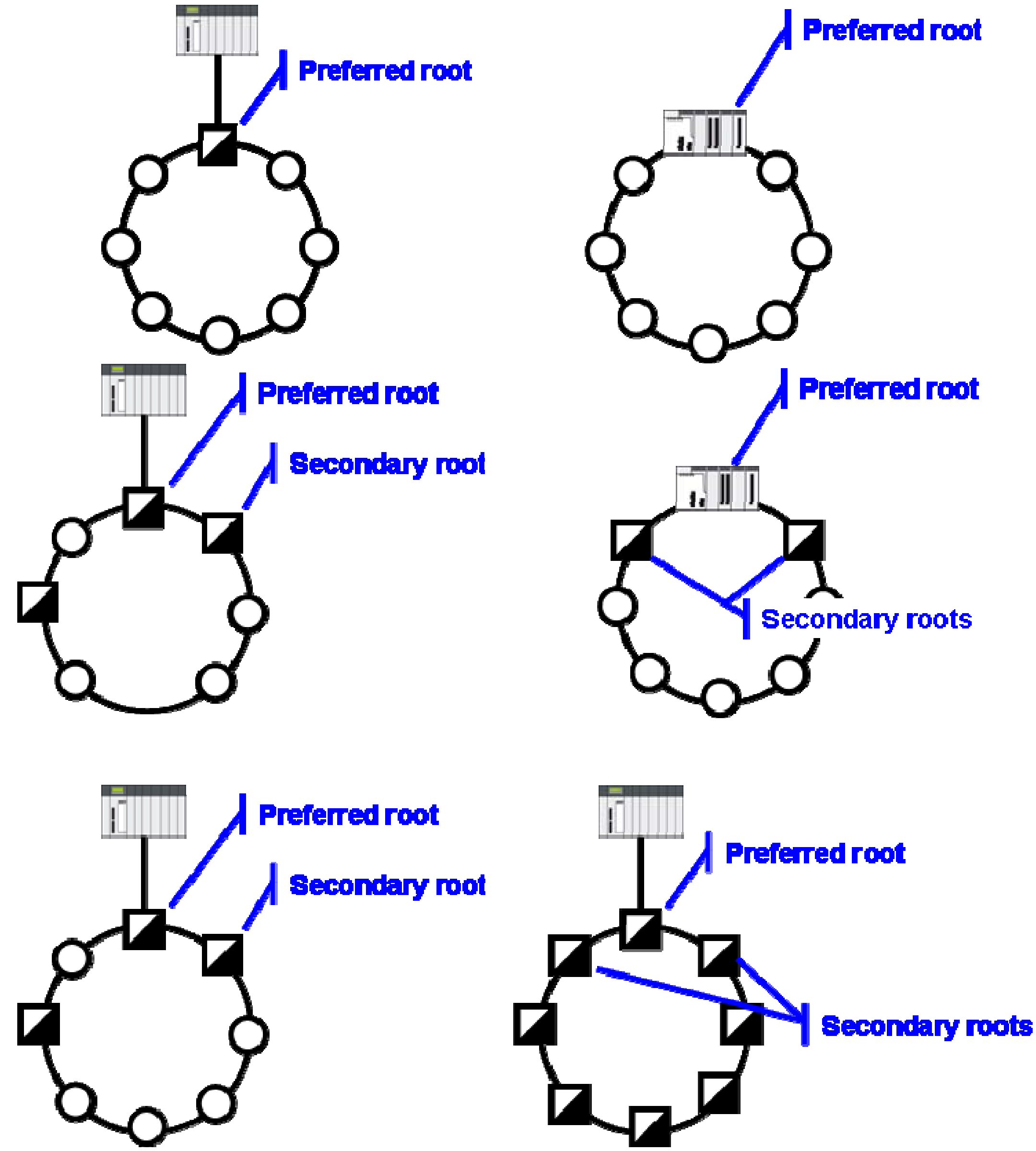


This topology would be more difficult to optimize.



- Select the device or bridge that is closest to the PLC as the primary root candidate. You may also select the devices or bridges adjacent to the primary root candidate as secondary root candidates. The next section explains how to change the priority of the devices so that they will be chosen as root.

  These are some suggestions as to how to assign root candidates in a ring.



Managing bridge priority

As mentioned earlier, in RSTP's root selection process, the device with the lowest Bridge Priority value will be elected as root. If all devices have the same value, then the lowest MAC address will identify the root bridge.

But as discussed in the previous section, sometimes it may be necessary to influence the root selection process. This is accomplished by changing the Bridge Priority value of the devices that we wish to affect.

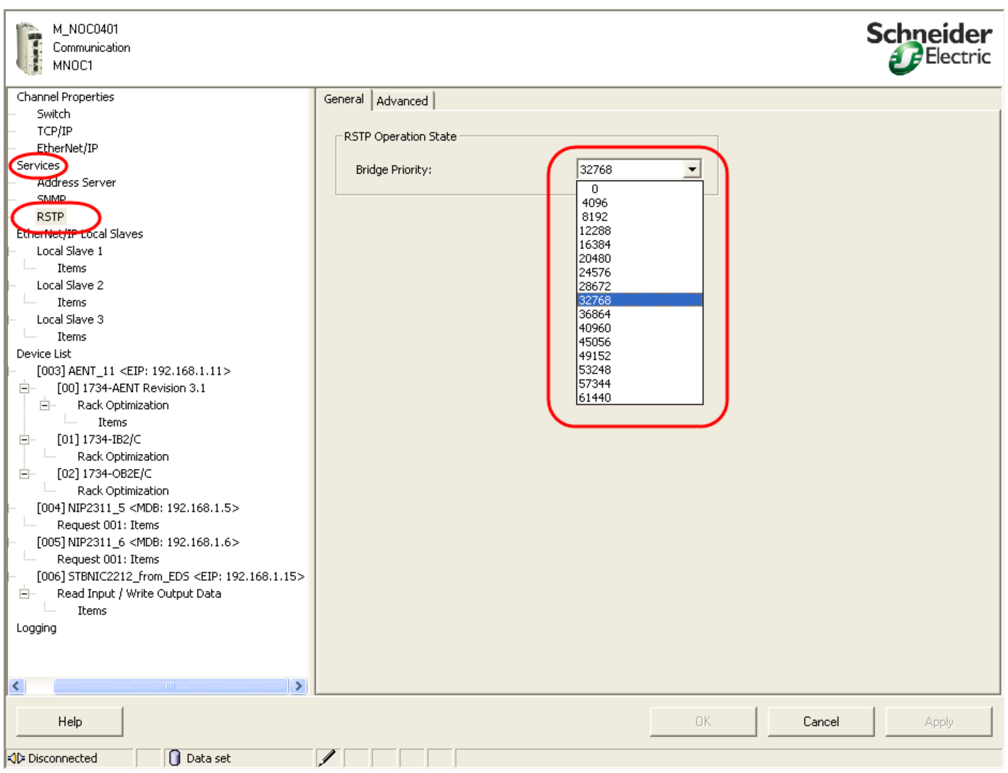
Bridge Priority is an RSTP parameter that can take values from 0 to 61440, in increments of 4096.

Schneider Electric products have the following default values for the Bridge Priority:

Product	Default Bridge Priority Value
BMX NOC 0401	32768
STB NIP 2311	61440
TCSESMxxxx and TCSESMxxxx-E switches	32768

Changing Bridge Priority in the BMX NOC 0401 modules

The BMX NOC 0401 modules are configured through Unity Pro, including the redundancy functionality. In Unity Pro's *DTM Browser*, double-click on the module's DTM to open the device editor. Under Services select *RSTP* to see the protocol parameters. The *General* tab shows the Bridge Priority options under a pull-down menu.

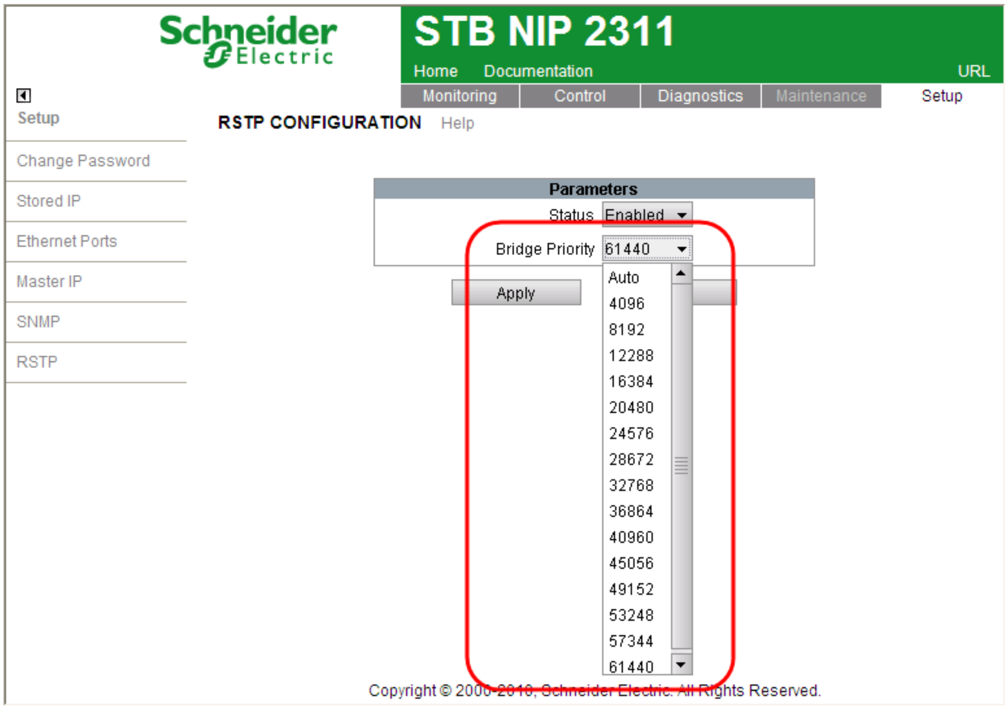


Changing Bridge Priority in the STB NIP 2311 I/O island

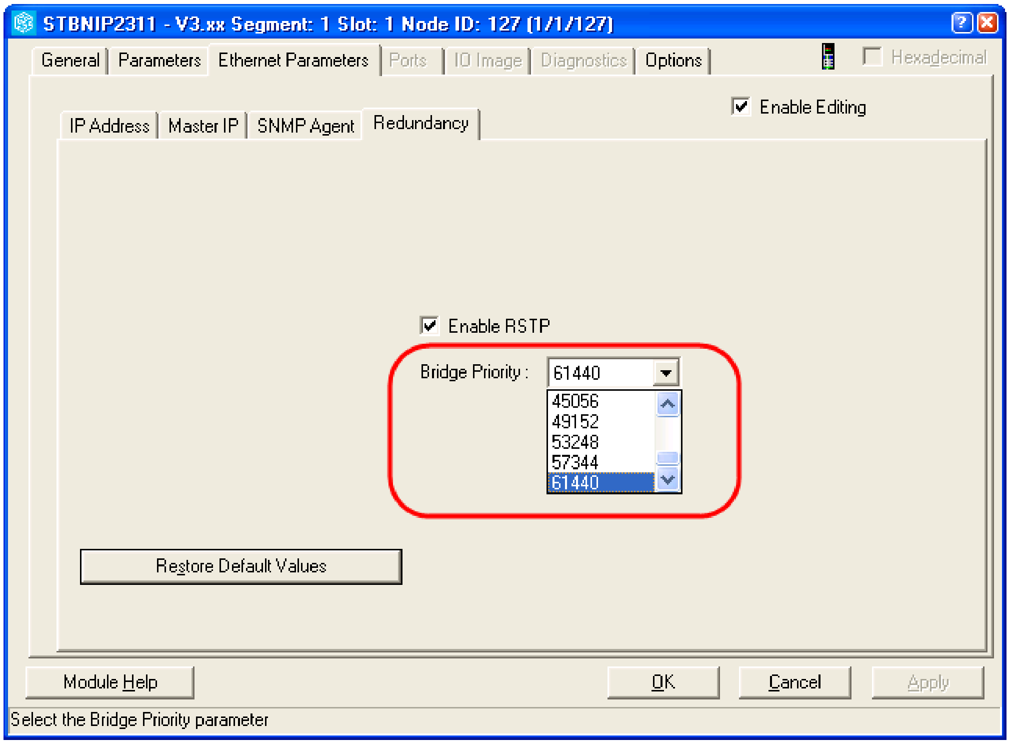
This parameter can be modified through two mechanisms on the STB island:

- STB's webpage
- Advantys Configuration Tool

In the device's webpage, in the *Setup* section, select *RSTP*. From the pull-down menu for *Bridge Priority*, select the desired value.

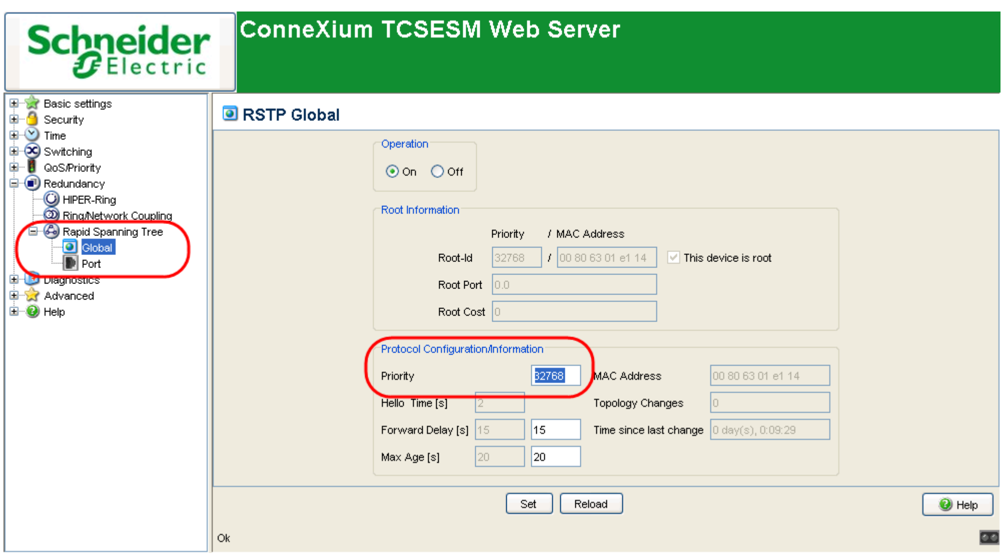


In the Advantys Configuration Tool, double-click on the NIM's image to open the configuration window. Under *Ethernet Parameters* find the *Redundancy* tab and select the desired value in the *Bridge Priority* pull-down menu.



Changing Bridge Priority in a ConneXium switch

In the switch web page, under the *Global* settings for *Rapid Spanning Tree*, the parameter labeled *Priority* holds the Bridge Priority value. Enter the desired value in the field and press *Set*.



Topology Rules for I/O Rings

Overview

The effectiveness, efficiency, and reliability of any industrial network are significantly influenced by its layout. Redundant I/O networks are no exception. Implementing a network topology properly will ensure proper functionality of the I/O rings.

The following are some basic rules to consider when deploying a redundant I/O network using RSTP.

Rings only

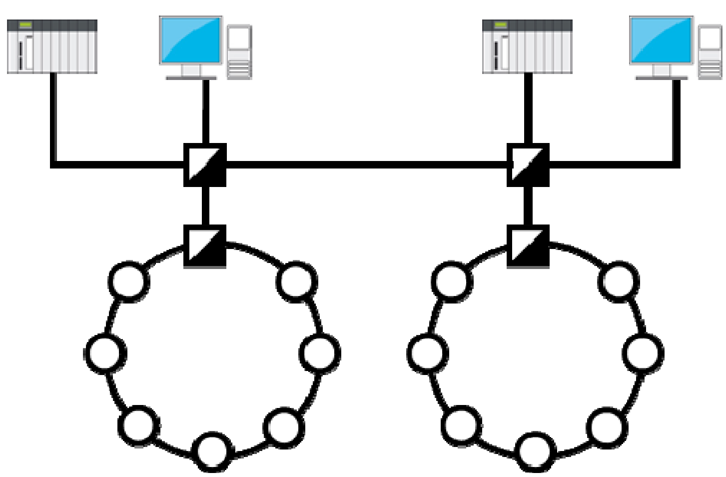
Schneider Electric's implementation of RSTP includes the optimization of some of the protocol parameters to achieve faster network recovery times. This optimization targets ring topologies.

The performance expectations described in this document apply only to ring topologies.

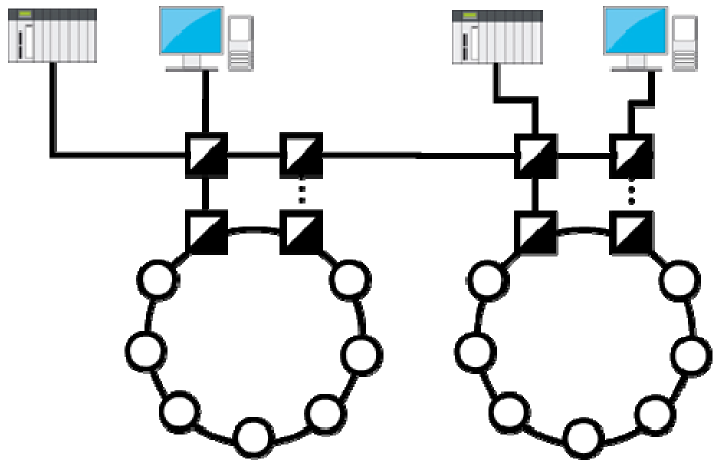
Single rings

The present implementation of RSTP requires that all I/O rings in a network remain independent from each other. Future changes to ConneXium switch functionality will allow multiple rings to be connected together.

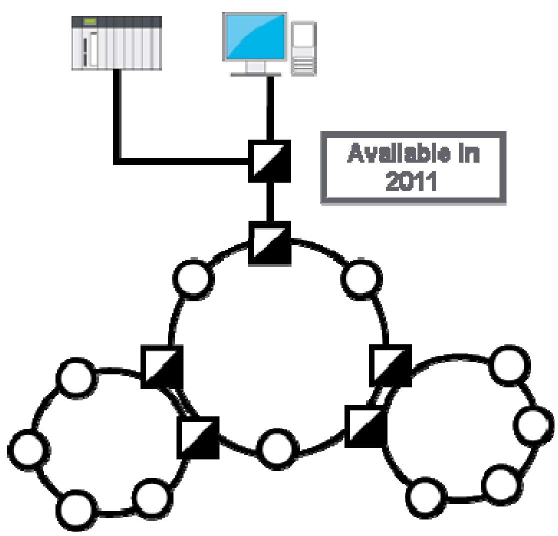
For example, a network could consist of multiple rings connected to a primary network via switches, as depicted below. With respect to RSTP, each ring operates independently; although the nodes of the rings are accessible from anywhere in the network.



To eliminate the single connection to the rings, an alternative is to make use of the Port Coupling function of the ConneXium switches. In that case, the topology would appear as follows:



In 2011 improvements are planned for the ConneXium line and "shared rings" will be possible. An example of the topologies that will be possible appears below.



Performance Expectations

Performance metrics

Network Recovery Time

In an RSTP-based ring topology, Network Recovery Time is the time it takes for the protocol to reconstruct a topology enabling access all the active nodes of the ring.

When a failure triggers RSTP to execute a topology change a flurry of BPDUs will be exchanged between the nodes attempting to identify a new path. Once that path has been established normal traffic can resume along the network.

The main factors affecting Network Recovery Time are:

- Number of nodes in the ring - Smaller rings will have faster recovery times.
- Location of the failure with respect to the location of the Root bridge - Following the recommendations provided in this document for the location of root candidates should optimize network recovery.
- Device RSTP implementation - Devices from different vendors may implement RSTP differently. Deploying devices with known behavior will ensure consistent performance.

Application Recovery Time

In most cases the Network Recovery Time is significantly shorter than any application time out thresholds. This means that the change in topology managed by RSTP generally goes undetected by the application.

If in the process of re-establishing a topology an application time-out is triggered, then the application will have to re-establish connection with one of more devices. The length of time required to re-establish a connection will depend entirely on the device and the PLC application.

Application Recovery Time is not provided here as a performance value, as it is dependant on the conditions of the application itself.

Network recovery time

Configuration A – ring of 32 nodes

A maximum of 32 nodes can be arranged in a ring when they consist of the following elements:
Up to 2 ConneXium switches
Up to 31 STB NIP 2311 I/O islands

Network recovery time due to cable or device failure will be less than 50ms. (Note: recovery from a failure at the root bridge may be slightly longer)

Configuration B – ring of 32 nodes

A maximum of 32 nodes can be arranged in a ring when they consist of the following elements:
M340 BMX NOC 0401 communication modules
STB NIP 2311 I/O islands

Network recovery time due to cable or device failure will be less than 50ms. (Note: recovery from a failure at the root bridge may be slightly longer)

Configuration C – ring of 16 nodes

Ring consisting of:
Up to 16 ConneXium Extended switches

Network recovery time due to cable or device failure will be less than 50ms. Standard switches or larger node counts will result in slower network recovery times. (Note: recovery from a failure at the root bridge may be slightly longer).

Monitoring and Diagnostics

Diagnostic tools

In order to monitor and diagnose an I/O ring based on RSTP, there are a few parameters that offer the most information.

<u>Bridge Parameters</u>

Bridge ID	This parameter identifies each RSTP node in the network.
Designated Root ID	Identifies the device in the ring that is acting as a root
Topology changes or RSTs counter	Each time that RSTP initiates a topology change triggered by a change in the physical network, all the affected devices will generate RSTP packets. This counter is a good indicator that one or more network topology changes have taken place.

<u>Port parameters</u>

Status	Describes the RSTP state of the port. It could take any of the following values: ● Disabled, when not connected to any device. ● Discarding, established by RSTP to prevent a loop. ● Learning, during a root negotiation. ● Forwarding, when participating in a network.
Role	A port can take different roles in an RSTP topology: ● Root ports indicate which port has the path to the root of the ring. ● Designated ports point in the direction of the rest of the devices in the ring. ● Alternate ports appear when multiple ports could be used to reach a common destination. This is not commonly found in a ring. ● Backup ports are also rarely seen in a ring configuration as they refer to equivalent paths from a multi-port device. ● Disabled ports are not included in the network.

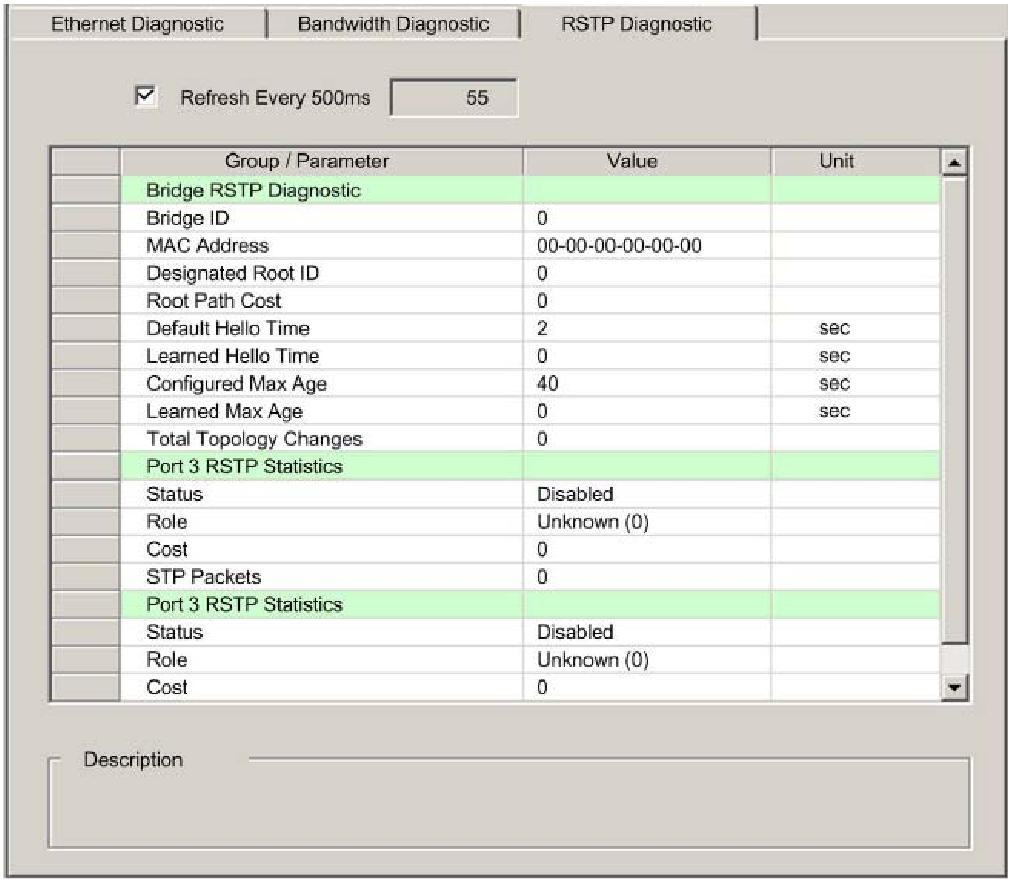
Diagnostics access

RSTP diagnostics can be obtained from the following sources:

- Unity Pro, for devices such as the BMX NOC 0401 Ethernet module
- The device’s web page

Below are examples of screens

BMX NOC diagnostics



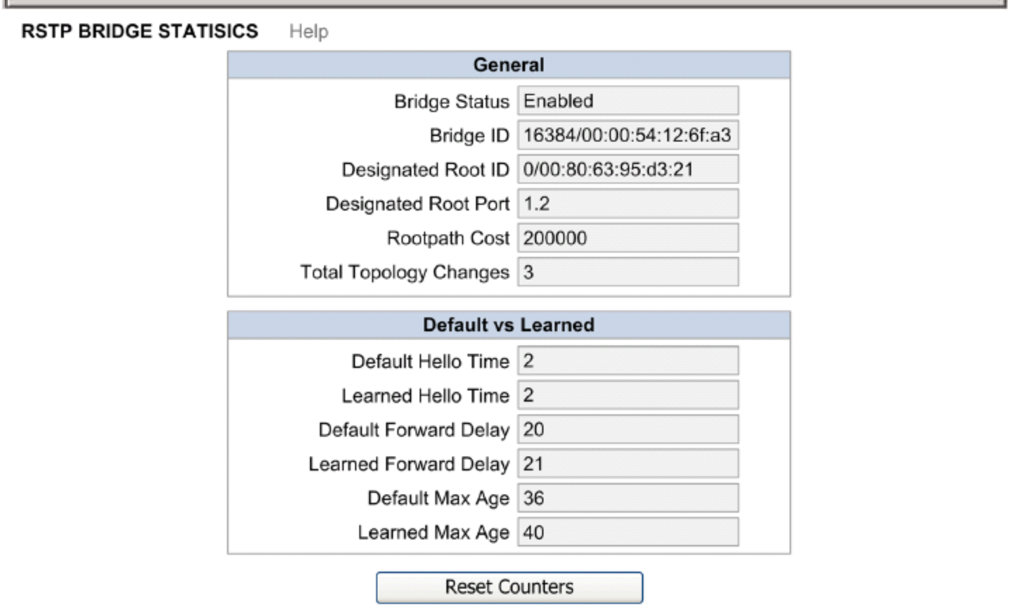
Ethernet Diagnostic | Bandwidth Diagnostic | RSTP Diagnostic

☑ Refresh Every 500ms 55

Group / Parameter	Value	Unit
Bridge RSTP Diagnostic		
Bridge ID	0	
MAC Address	00-00-00-00-00-00	
Designated Root ID	0	
Root Path Cost	0	
Default Hello Time	2	sec
Learned Hello Time	0	sec
Configured Max Age	40	sec
Learned Max Age	0	sec
Total Topology Changes	0	
Port 3 RSTP Statistics		
Status	Disabled	
Role	Unknown (0)	
Cost	0	
STP Packets	0	
Port 3 RSTP Statistics		
Status	Disabled	
Role	Unknown (0)	
Cost	0	

Description

STB NIP diagnostics



RSTP BRIDGE STATISICS Help

General	
Bridge Status	Enabled
Bridge ID	16384/00:00:54:12:6f:a3
Designated Root ID	0/00:80:63:95:d3:21
Designated Root Port	1.2
Rootpath Cost	200000
Total Topology Changes	3

Default vs Learned	
Default Hello Time	2
Learned Hello Time	2
Default Forward Delay	20
Learned Forward Delay	21
Default Max Age	36
Learned Max Age	40

Reset Counters

RSTP PORT STATISICS Help

Port Number	1
	1
	2

Port Status	
Port State	Forwarding
Role	Designated
Priority	128
Port Path Cost	2000000
Designated Port ID	256
Received RSTs	0
Transmitted RSTs	70

Reset Counters

Additional Resources

Resources

For additional information on Schneider Electric's redundant topologies and the products described here please refer to the following:

Data sources

- Pl@net
- Ethernet products community site in Quickr
  (Network Solutions Site)
- Next Generation Ethernet Launch Site in Quickr
  (Plant Solutions Launch Site > Connectivity > Ethernet modules)

Documents

S1A34009 (EN) S1A34010 (FR) S1A34011 (DE) S1A34012 (ES) S1A34013 (IT) S1A34014 (CN)	BMX NOC 0401 User Manual
EIO0000000051 (EN) EIO0000000052 (FR) EIO0000000053 (DE) EIO0000000054 (ES) EIO0000000055 (IT)	STB NIP 2311 User Manual
31007126 (EN) 31007127 (FR) 31007128 (DE) 31007129 (ES)	ConneXium Ethernet Cabling System TCSESM, TCSESM-E Managed Switch Redundancy Configuration User Manual