# The Comparison/Contrast of TSN Frame Replication and Elimination for Reliability (FRER) and Parallel Redundancy Protocol (PRP)

George Ditzel
Ethernet Architect
Schneider Electric

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**Abstract**

This paper will compare/contrast various protocols that can be used in providing high availability in EtherNet/IP™ systems. The protocols focused on in the paper are: The Time Sensitive Networks (TSN) feature Frame Replication and Elimination for Reliability (FRER) defined in the IEEE 802.1CB-2017 standard; And the Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR) protocol, both defined in the IEC 62439 standard.

Critical system applications are often required to maintain high availability of communication network components. For critical infrastructures and time sensitive processes, downtime is never allowed. The protocols focused on in this paper (FRER, PRP, HSR) provide zero recovery time.

This paper will compare/contrast the protocols in: Network Topology; frame structures; network convergence; and cost to deploy.

 

## Introduction

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This paper will compare/contrast the protocols in: Network Topology requirements; required frame structures; each protocols interoperability with the others; and cost to deploy.

## High Availability

High availability is based on the concept of availability. The availability of a network is the probability (in percent) that the network is in service and available for use at any instant in time.

High availability is represented as a percentage, usually referred to as the *9s*. If the availability metric is specified as *five nines*, it is understood to mean that the network should be functional for 99.999% of the desired duty cycle (24-hours/day).

Availability is expressed using the following measures of reliability.

Availability = MTTF / (MTTF+MTTR) (1)

where

> MTTF is the mean time to failure**;** a measure of the reliability of a network, otherwise known is its failure rate. The MTTF is the interval in which the network or element can provide service without failure.
>
> MTTR is the mean time to repair; a measure of reliability that represents the time it takes to resume service after a failure has been experienced.

As equation (1) shows, the availability of a network can be increased by designing network elements that are highly reliable (high MTTF), and/or by reducing the time required to repair the network and return it to service (low MTTR).

Since it is impossible to create networks that never fail, the key to high availability is to make recovery time as brief as possible. Availability is increased in networks by introducing redundancy.

 

**Redundancy**

High availability can be achieved economically by using techniques that detect points of failure and avoid service interruptions through redundancy in the system. There are two forms of redundancy, dynamic and static.

In dynamic (standby) redundancy the replicated components activate after a failure has been detected. Dynamic redundancy does not actively participate in the control. Switchover logic determines when to insert and activate redundancy. This requires detection and/or recovery as shown in Figure 1.

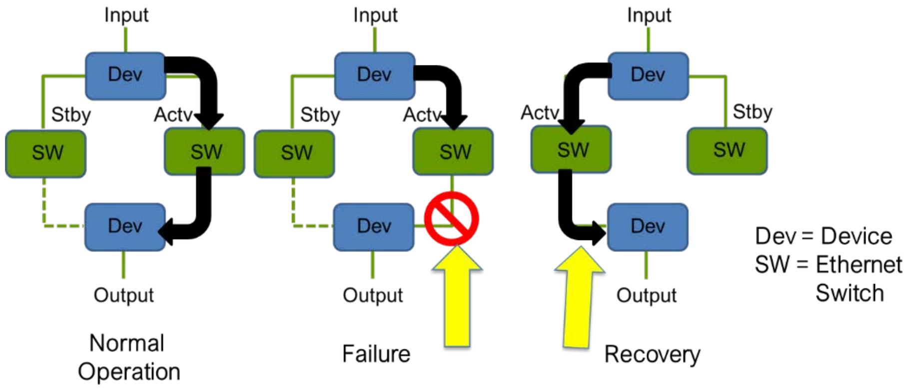


*Figure 1: Dynamic Redundancy*

In static (parallel) redundancy the replicated components are active concurrently. Static redundancy usually participates in the control. No special processing is needed on errors. This provides bumpless (0 ms) switchover, with continuously exercised redundancy and increased point-of-failure detection with fail-safe behavior. Static redundancy is provided at the cost of duplication, as shown in Figure 2.

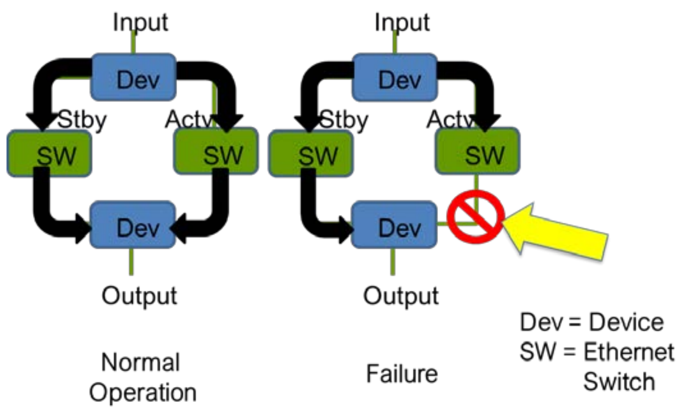


*Figure 2: Static Redundancy*

The two set of protocols discussed in this paper provide Static Redundancy. They Are:

- Parallel Redundancy Protocol (PRP) and Highly-available Seamless Redundancy (HSR) protocol, both defined in the IEC 62439-2 standard;
- Frame Replication and Elimination for Reliability (FRER) defined in the IEEE 802.1CB standard.

## Sample Target Solution

The following diagram represents a Sample Target Network that will be used in the paper as illustration for the comparison of PRP/HSR and FRER.

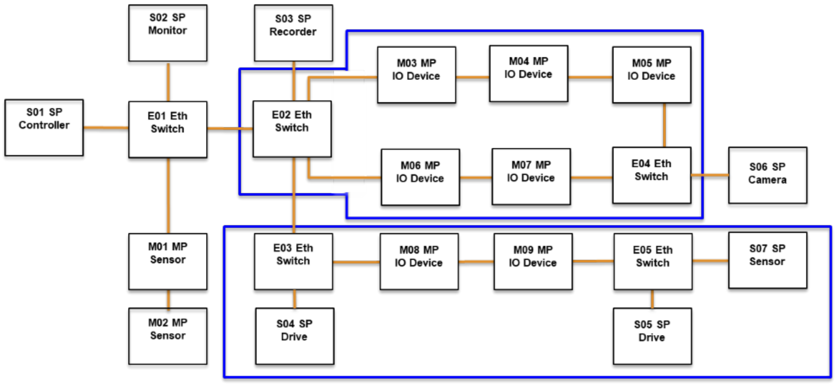


*Figure 3: Sample Target Network*

The Sample Target Network is a complex network consisting of the following: A basic Star network centered around the E01 Ethernet Switch; A Ring network with the Ethernet Switch E02 as the Head of the Ring; and a Line network with Ethernet switch E03 at the Head of the Line.

The Sample network is a network with a Control Applications consisting of Single Port Sensor and Drive devices (Sx), Multiple Port Sensor and IO devices (Mx), Ethernet Switches (Ex), and cables.

A video monitoring network (Camera, Monitor, and Recorder) has be converged with the control network.

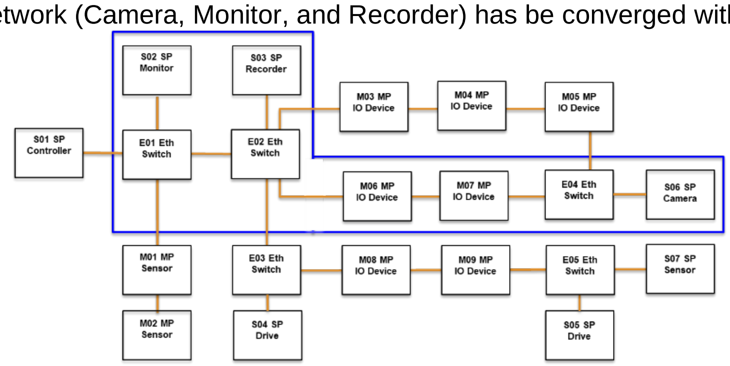


*Figure 4: Converged Video System*

The following table is an illustration of example cost for the Target network:

*Table 1: Sample Target Network Cost*

| Device | Quantity | Cost | Sub-totals |
|---|---|---|---|
| Single-port Devices [Sx] | 7 | 500 | 3500 |
| Multi-port Devices [Mx] | 9 | 1000 | 9000 |
| Ethernet Switches [Ex] | 5 | 1000 | 5000 |
| Cable | 21 | 50 | 1050 |
| Total = | | | 18550 |

This network will be converted to a PRP/HSR network and FRER network for comparative purposes.

 

**IEC 62439-3 PRP/HSR Solution**

The Parallel Redundancy Protocol (PRP) and the High-availability Seamless Redundancy (HSR) protocol are described in this section. The IEC 62439-3 standard specifies two redundancy protocols designed to provide seamless recovery in case of single failure of an inter-bridge link or bridge in the network, which are based on the same scheme: duplication of the LAN, and/or duplication of the transmitted information. Further improvements in recovery time require managing of redundancy in the end nodes, by equipping the end nodes with several, redundant communication links. In general, doubly attached end nodes provide enough redundancy.

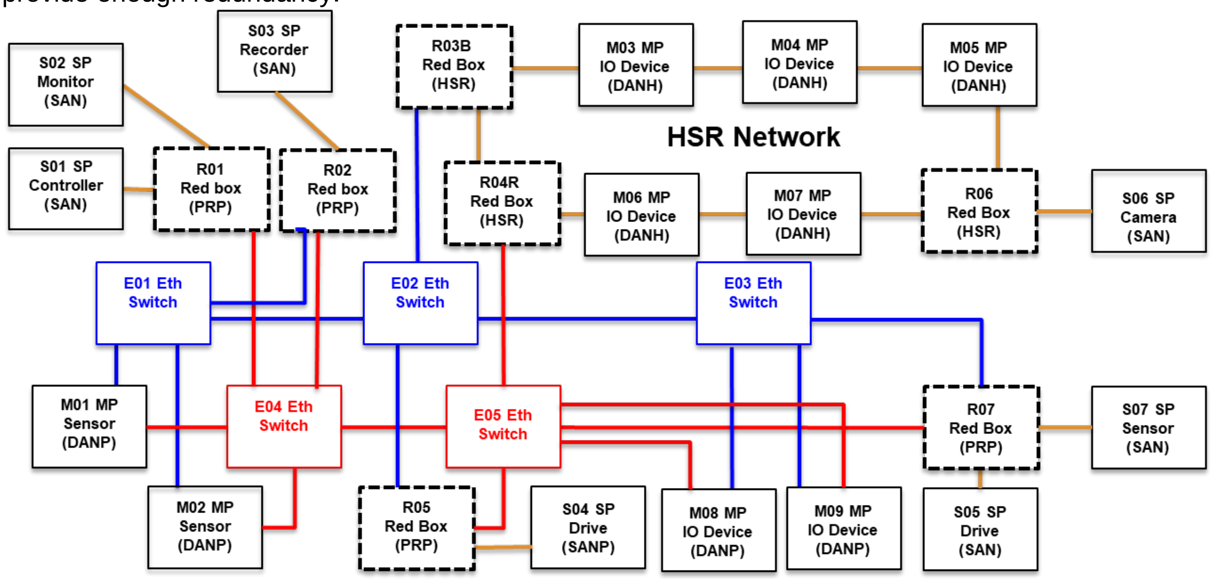


*Figure 5 Sample IEC 62439 Network*

<u>Conversion of the Ring.</u>
The conversion of the Sample Target Network the Ring portion of the network will be converted to an HSR Network. The Multiport Devices will be converted to Doubly Attached Nodes with HSR Protocol (DANH) and will stay arranged as a ring. These Dual Attached Nodes within the ring are restricted to be HSR-capable bridging nodes, thus avoiding the use of dedicated switches.

Single-port Devices, known as Singly Attached Nodes (SANs) cannot be attached directly to the ring, but need attachment through a Redundancy Box (RedBox). Ethernet Switch (E04) will need to be replaced with an HSR Redundancy Box (R06) to connect the Single-port Camera (S06).

Each DANH has two identical interfaces, port A and port B. For each frame, the source node sends one copy over each of its two ports. The source node removes the frames it injected into the ring. Each node (between source and destination) relays a frame it receives from port A to port B and vice-versa, except if already forwarded. The destination node consumes the first frame of a pair and discards the duplicate. If the ring is broken, frames still arrive over the intact path, with no impact on the application. Loss of a path is easily detected since duplicates cease to arrive. HSR is not defined in this CIP specification but defined in the sub-clauses 5 and 7 of the IEC 62439-3 standard (IEC 62439-3:2012-7).

 

Star and Line Networks

The Star and Line Networks will be converted to two duplicate line networks and implement the PRP redundancy protocol. The PRP redundancy protocol implements redundancy in the devices such as Double attached nodes implementing PRP (DANPs) and Redundancy Boxes (Red Box).
A DANP is attached to two independent Local Area Networks (LANs) of similar topology (LAN_A [Blue] and LAN_B [Red]) which operate in parallel. One DANP (a source) sends the same frame over both LANs to another DANP (Destination) who receives it from both LANs, consumes the first frame and discards the duplicate. The same mechanism of duplicate generation and rejection can be implemented by a Red-Box. A Red-Box does the transition between a Singly Attached Node (SAN) and the doubled LANs (LAN_A and LAN_B). The Red-Box mimics the SANs connected behind it (called VDAN or virtual DANs) and multicasts supervision frames on their behalf. The Red-Box is itself a DANP and has its own IP address for management purposes, but it may also perform application functions.

The two LANs are identical in protocol at the MAC-LLC level, but they can differ in performance and topology. Transmission delays may also be different, especially if one of the networks reconfigures itself, e.g. using RSTP, to overcome an internal failure. The two LANs follow configuration rules that allow the network management protocols such as Address Resolution Protocol (ARP) to operate correctly.
The two LANs shall have no connection between them and are assumed to be fail-independent. Redundancy can be defeated by single points of failure, such as a common power supply or a direct connection whose failure brings both networks down. Refer to the installation guidelines in the IEC 62439-3 standard (IEC 62439-3:2012-7) to provide guidance to the installer to achieve fail-independence. PRP is not defined in the CIP specification but defined in the sub-clauses 4 and 7 of the IEC 62439-3 standard (IEC 62439-3:2012-7)

The following table is an illustration of example cost for the Target network:

*Table 2: Sample IEC 62439 Network Cost*

| Device | Quantity | Cost | Sub-totals |
|---|---|---|---|
| Single-port Devices [Sx] | 7 | 500 | 3500 |
| Multi-port Devices [Mx] | 9 | 1100 | 9900 |
| Ethernet Switches [Ex] | 5 | 1000 | 5000 |
| Redundancy Box [Rx] | 7 | 1100 | 7700 |
| Cable | 26 | 50 | 1300 |
| Total = | | | 27400 |
| | | | |

 

**IEEE 802.1CB FRER Solution**

The Frame Replication and Elimination for Reliability (FRER) is a static (parallel) redundancy high availability capability as defined the the IEEE 802.1CB-2017 standard. This solution is illustrated by transforming the Sample Target Network into an FRER supported network.

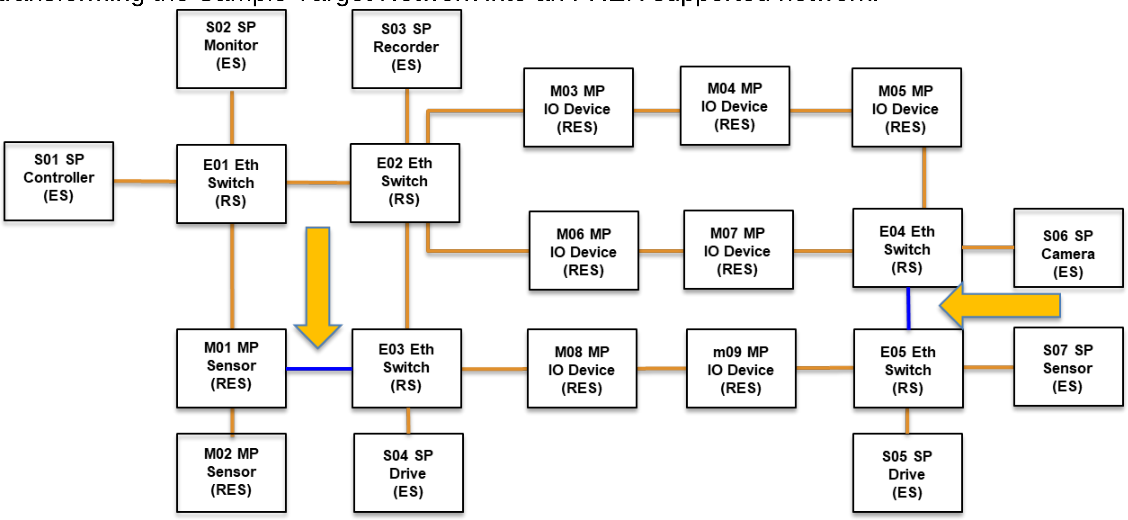


*Figure 6: Sample IEEE 802.1CB (FRER) Network*

The additional network interconnections needed within the network are representing by the dashed lines. These interconnections change an existing network into a Mesh network, which will be explained later in this paper.

FRER provides increased reliability (reduced packet loss rates) for a Stream by using a sequence numbering scheme, and by replicating every stream packet in the source. FRER also eliminates those replicated stream packets in the destination. FRER provides the following:

- **Packet replication:** sending replicated frames on separate paths, and then using inserted identification information to eliminate replicates, reducing the probability of frame loss.
- **Multicast or unicast:** A path on which a Stream is sent can be a point-to-point path or a point-to-multipoint tree.
- **Latent error detection:** some means of detecting a failure to deliver copies of each packet is provided at the point that the replicated packets are discarded.
- **Interoperability:** a small number of controls are provided that that make interoperation with other standards possible.
- **Backward compatibility:** To provide the ability to be connected to a network that is not aware of FRER, and for a network of conformant relay systems to offer these benefits to unaware end systems.
- **Zero congestion loss:** provide a Stream with zero (or very low) packet loss due to congestion.

 

The FRER protocol provides increased reliability (reduced packet loss rates) for a Stream by using a sequence numbering scheme, and by replicating every stream packet in the source end system and/or in relay systems in the network. FRER also eliminates those replicates in the destination end system and/or in other relay systems. The devices types described in the standard are:

**End Systems (ES):** End Systems may contain a Talker component, a Listener component, or both. End Systems are represented by: The Single-Port Devices (Sx): Controller; Drives, Sensor; IP Camera; Camera Recorder; and Monitor.

**Relay Systems (RS):** Relay Systems will either transfer packets belonging to redundant streams, or act as a proxy Talker or Listener for End Systems not capable of handling redundant streams. Relay Systems are represented by the Ethernet Switch(es).

**Relay-End Systems (RES):** Relay-End Systems are not defined in the IEEE Standard but are elements within the EtherNet/IP Network. The Rely-End System is created by combining the FRER End system and Relay System capabilities. Relay-End Systems are represented by the Multi-Port IO Device(s) and one Multi-Port Sensors.

The following table is an illustration of example cost for the Target network:

*Table 3: Sample FRER Network Cost*

| Device | Quantity | Cost | Sub-totals |
|---|---|---|---|
| Single-port Devices [Sx] | 7 | 500 | 3500 |
| Multi-port Devices [Mx] | 9 | 1100 | 9900 |
| Ethernet Switches [Ex] | 5 | 1100 | 5500 |
| Cable | 23 | 50 | 1150 |
| Total = | | | 20050 |
| | | | |

 

**PRP/HSR Topology Performance**
This section will discuss to operations within the HSR Ring in the sample PRP/HSR network as comparted to a similar operation within the FRER Mesh.

HSR/PRP Communication Flow
The following diagram illustrates part of the message flow between the MP IO Device (D08) and the SP Controller (D01).

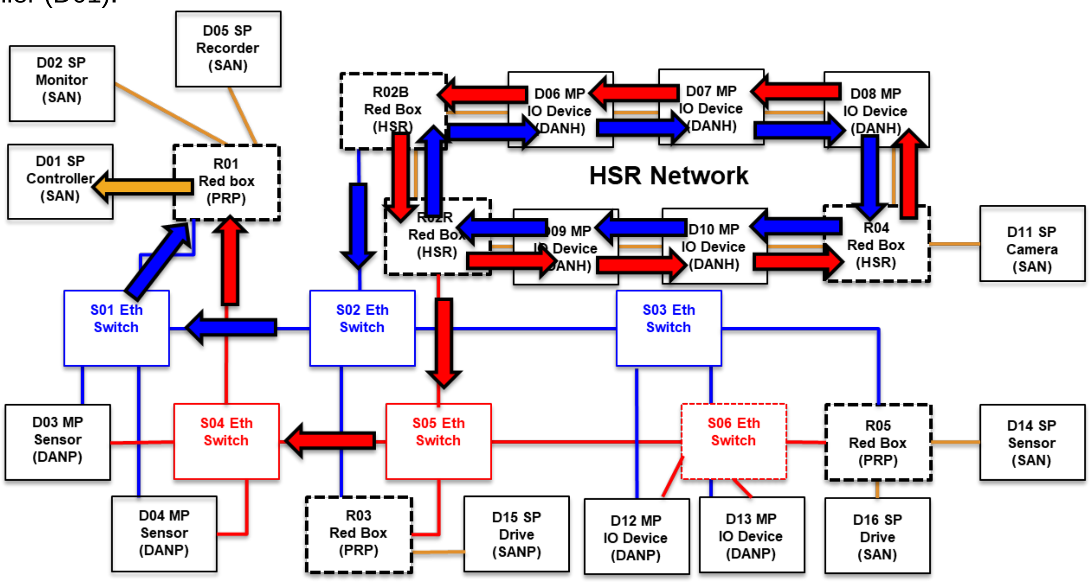

*Figure 7: HSR/PRP Communication Flow*

The message from IO Device (D08) is duplicated along two paths (Red, Blue). The messages transition to the HSR Redundancy Boxes who job it is to transfer the messages to the respective PRP networks (Red, Blue). The message traverses the two separate PRP networks until reaching the PRP Redundancy Box supporting the SP Controller (D01).

The “Red” and “Blue” messages will also traverse back through the HSR Network to their source to be removed from the network. This is demonstrating the need to account to double the bandwidth for messages within an HSR Network

The “Blue” message traverses 8 hops, while the “Red” message only traverses 7 hops. The “Red” message will arrive at the R01 Red box first and be selected to generate the message to the D01 controller. The “Blue” message will be dropped once it reached the R01 Red box as it has arrived later then the “Red” message.

 

An error may occur within the HSR Ring. The error in this example is illustrated as a break in the cable between R02B Red box and D06 MP IO Device.

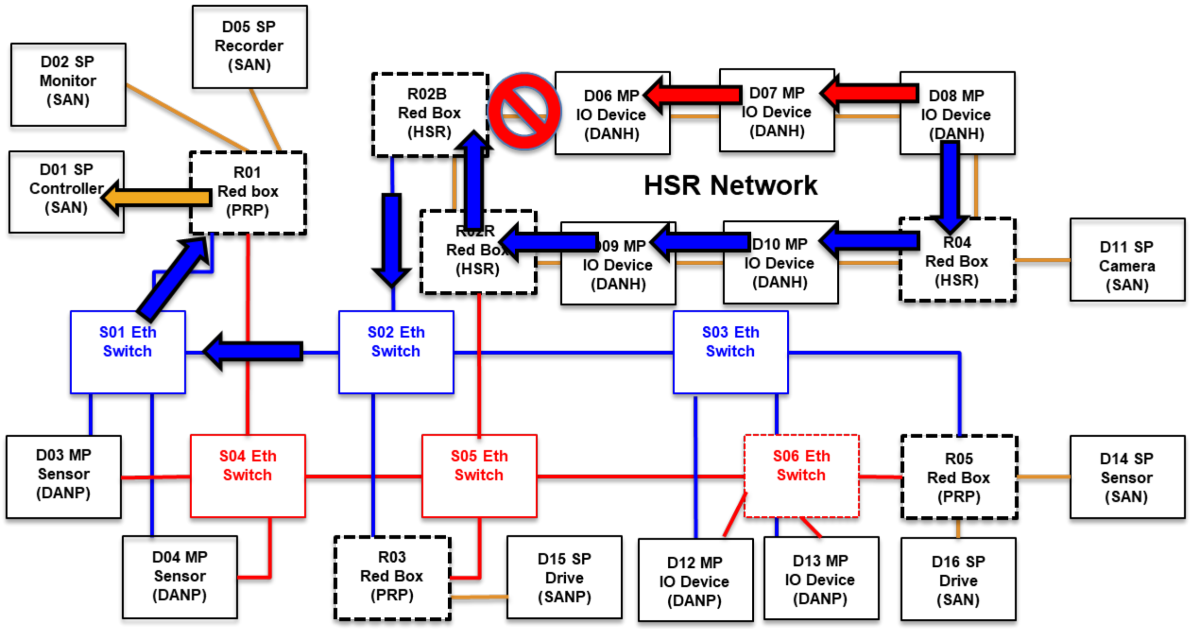


*Figure 8: Failure in PRP/HSR Network*

The message from IO Device (D08) is duplicated along two paths (Red, Blue). The “Red” message has stopped transitioning due to the cable break, but the “Blue” message continues to the HSR Redundancy Boxes. The “Blue” message continues to traverse the 8 hops, while the “Red” message has been stopped.

The “Blue” message will be used this time by the R01 Red box since it is the only message to arrive, though it will arrive 1 hop later then the “Red” message.

**FRER Mesh Topology Performance**

This section describes the use of FRER in the Mesh network topology portion of the EtherNet/IP Network example. The Mesh network is supported any of the Network Control Protocols defined in the IEEE 802.1Q-2018 Standard (i.e. RSTP, MSTP, SBB, etc.).

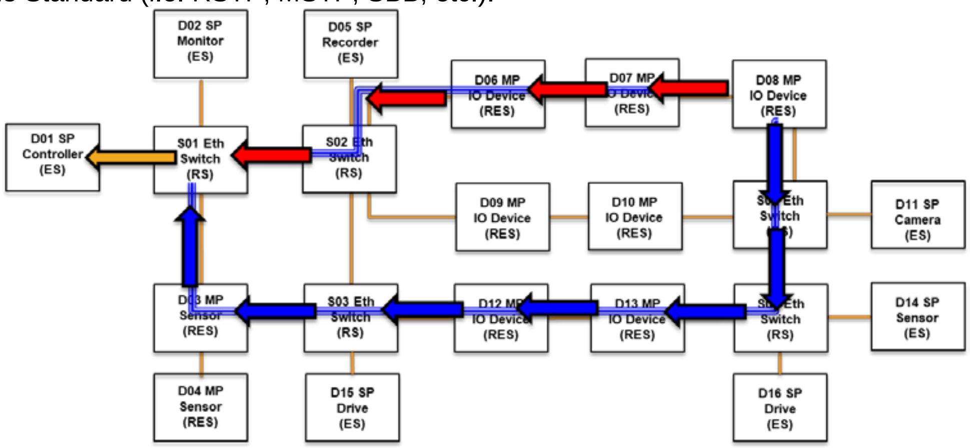


*Figure 9: Mesh Network With Redundant Streams*

In this scenario the D08 MP IO Device is an End System (RES) acting as a Talker that transmits a redundant stream to the D01 SP Controller (ES). The Talker proxy will generate redundant streams:

- Supplies sequencing information in frames;
- Replicates each frame passed to it, assigning each replicate a different stream handle, at most one of which can be the same as the original passes unchanged;
- Triggers the sending of one stream (Blue) before the other (Red) to keep the propagation delay within the network the same at the destination (7 hops).
- Encodes the sequencing information into the frame in a manner such that it can be decoded by its peer.

The S01 Ethernet Switch (RS) are connected to the D01 SP Controller and acting as Listener for the Redundant stream from D08 MP IO Device. When the Listener proxy receives redundant streams:

- Extracts and decodes the sequencing information from a received frame.
- Examines this sequencing information in received frames packets and discards frames indicated to be a duplicate of a frame previously received and forwarded; Also monitors the variables to detect latent errors of Streams;

 

An error may occur within the Mesh Network. The error in this example is illustrated as a break in the cable between So2 Ethernet Switch and D06 MP IO Device. The network recovery time of these control protocols is irrelevant due to the seamless redundancy nature of the FRER protocol.

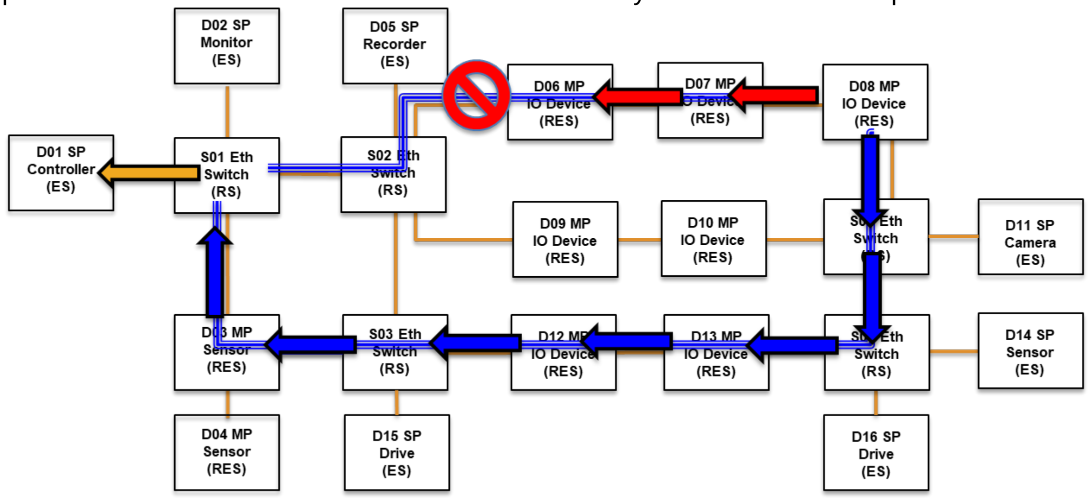


*Figure 10: Error in the Mesh Network*

In this scenario the D08 MP IO Device is an End System (RES) acting as a Talker that transmits a redundant stream to the D01 SP Controller (ES). The Talker proxy will generate redundant streams:

- Supplies sequencing information in frames;
- Replicates each frame passed to it, assigning each replicate a different stream handle, at most one of which can be the same as the original passes unchanged;
- Triggers the sending of one stream (Blue) before the other (Red) to keep the propagation delay within the network the same at the destination (7 hops).
- Encodes the sequencing information into the frame in a manner such that it can be decoded by its peer.

## Conclusion

Using the FRER reduces the cost of deployment, as shown in the following table:

*Table 4: Comparison Costs*

| Device | Sample | PRP/HSR | TSN-FRER |
|---|---|---|---|
| Single-port Devices [Sx] | 3500 | 3500 | 3500 |
| Multi-port Devices [Mx] | 9000 | 9900 | 9900 |
| Ethernet Switches [Ex] | 5000 | 5000 | 5500 |
| Red Boxes [Rx] | 0 | 7700 | |
| Cable | 1050 | 1300 | 1150 |
| Total = | 18550 | 27400 | 20050 |
| Cost Difference = | | 48% | 9% |
| [(S-T)/S] | | | |

Using the FRER and TSN updates does not change the cabling significantly and has better performance