High availability process safety applications enabled by Concurrent Connections

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Abstract

In the Spring 2023 publication of the CIP family of specifications, ODVA announced the addition of an important new technology, **Concurrent Connections**. This technology enables **flexible, zero switchover time, end-to-end redundancy** solutions.

This presentation briefly introduces the basic terms and concepts related with **high availability**.

This presentation discusses characteristics of **process industry** systems and points out some of the deficiencies of current high availability solutions.

Finally, the presentation explains the Concurrent Connections technology and describes how **Concurrent Connections improve high availability and safety systems**.

Overview of High Availability

- Availability
  - Mean Time To Failure
  - Mean Time To Restore/Repair
- High Availability
- Redundancy
  - Hot, Warm, or Cold
  - Active or Passive synchronization
  - Switchover or Concurrent
- Fault Tolerance

Availability = MTTF / (MTTF+MTTR)

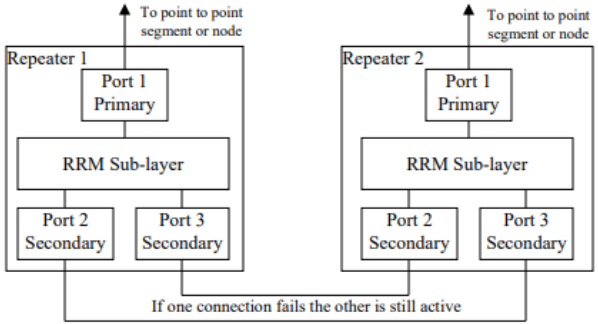
"Number of nines"	Availability %	Possible Downtime per Year
2	99 %	3.65 days
3	99.9 %	8.76 hours
4	99.99 %	52.6 minutes
5	99.999 %	5.26 minutes
6	99.9999 %	30 seconds

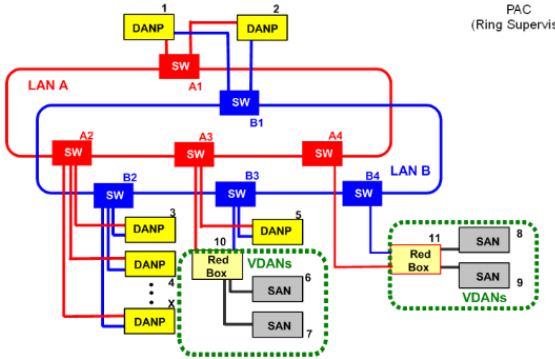
Process Industry

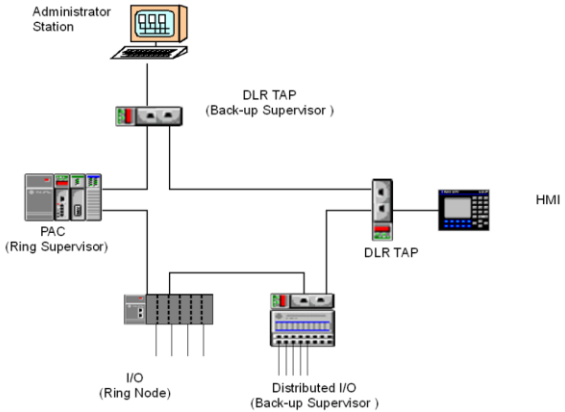
- Large-scale and complex installations
- Processes cannot be easily stopped
- Consequences of failure can be catastrophic
  - Bhopal gas tragedy
  - Piper Alpha oil rig explosion
  - Deepwater Horizon oil spill
  - Tianjin explosions
- High Availability is critical
- Highly regulated

High Availability and Redundancy in the CIP Specification

- CIP Networks Library, Volume 1 Common Industrial Protocol
  - Redundant Owner connection type, Ownership of Outputs (ROO) and Claim Output Ownership (COO) bits
- CIP Networks Library, Volume 2 EtherNet/IP Adaptation of CIP
  - PRP
  - DLR
- CIP Networks Library, Volume 4 ControlNet Adaptation of CIP
  - Media redundancy with ring topologies

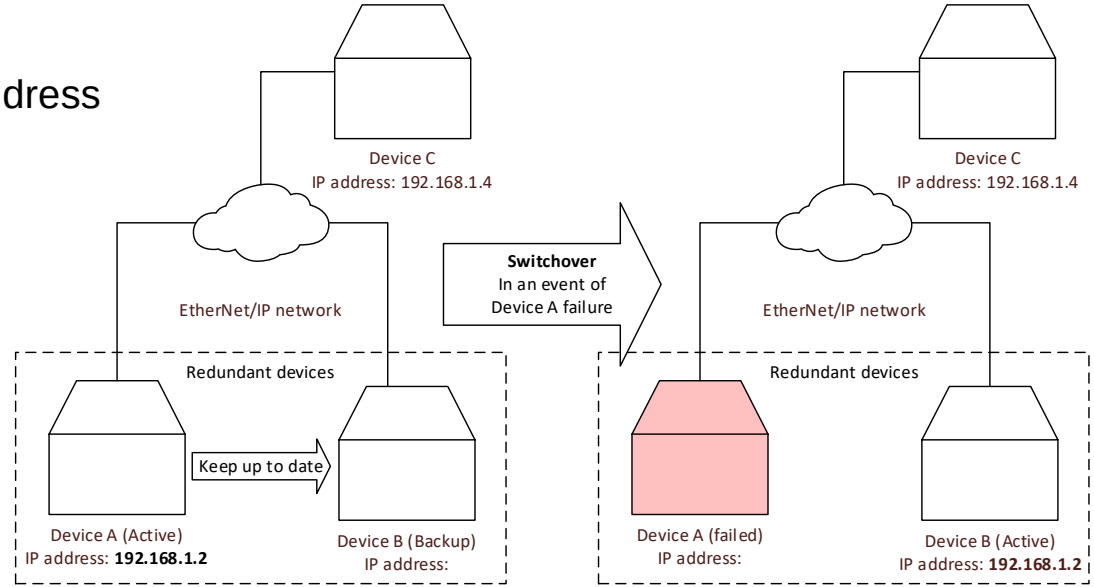






Existing Redundancy solutions and their problems

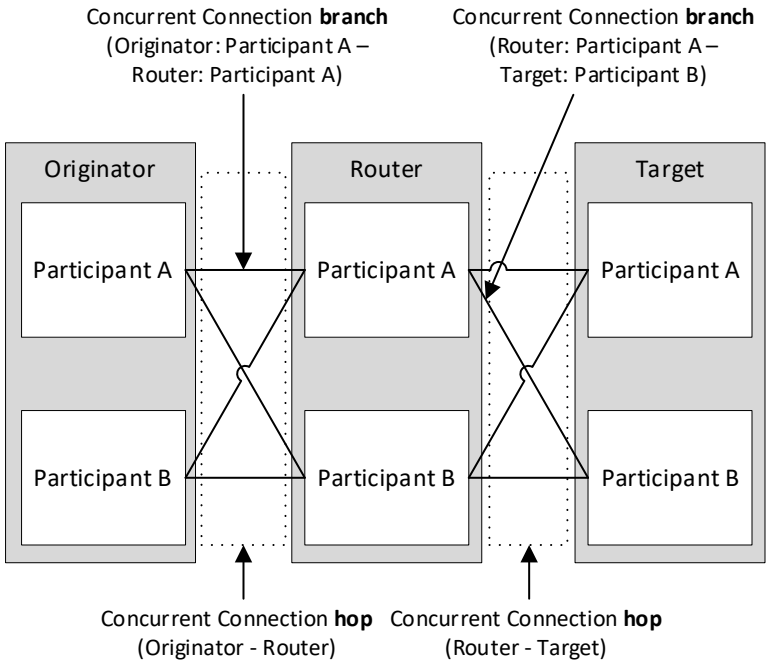
- Vendor specific
- Solution 1: switchover on IP address



- Solution 2: Delay applying connection fault action
- Solution 3: Redundancy realized at the application level
- …

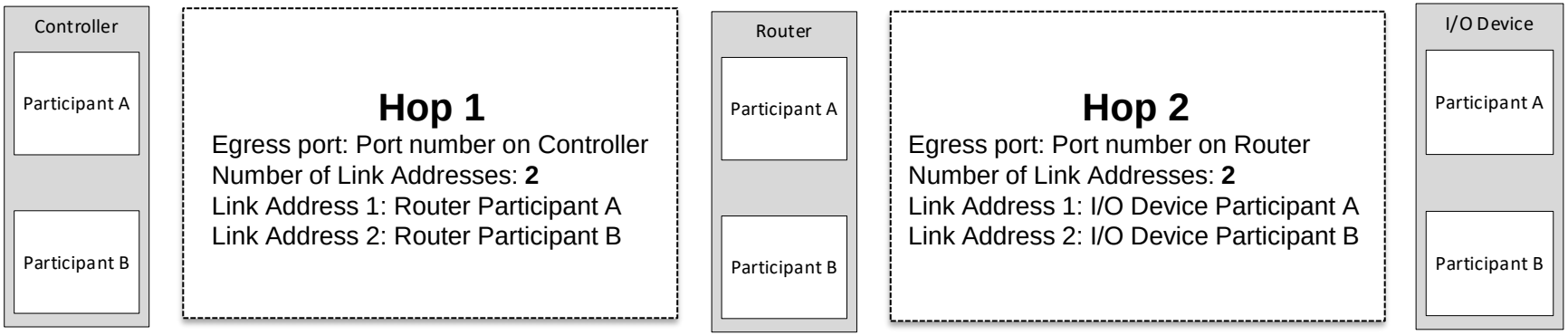
Concurrent Connections

- “PRP on the CIP connection level”
- Redundant participants
- Multiple paths for transferring CIP data
- One logical CIP connection from an application perspective

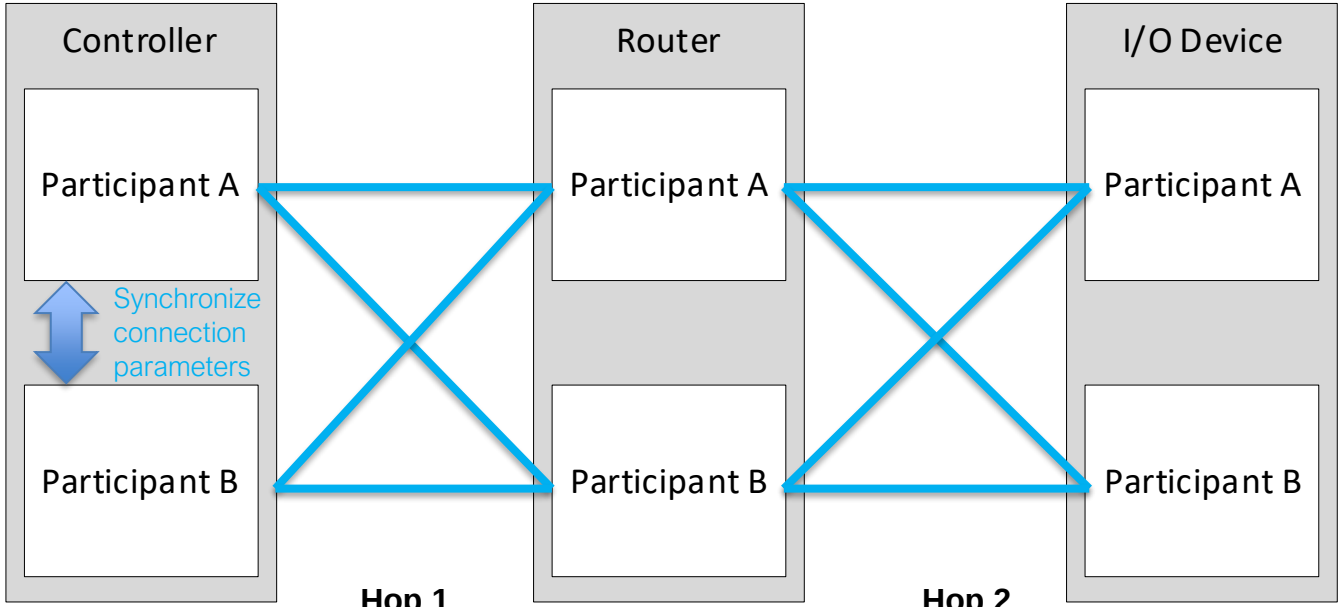


Concurrent Connections – connection management

- New Connection Manager services:
  - **Concurrent_Forward_Open** and **Large_Concurrent_Forward_Open**
    - "Forward_Open + Concurrent Connections Protocol Version field"
  - **Concurrent_Forward_Close**
    - Same format as Forward_Close
- New Extended Network Segment
  - **Concurrent Connection Path** (list of Concurrent Connection **Hops**)



Concurrent Connections - Connection Opening Process



Hop 1

Egress port: Port number on Controller
Number of Link Addresses: **2**
Link Address 1: Router Participant A
Link Address 2: Router Participant B

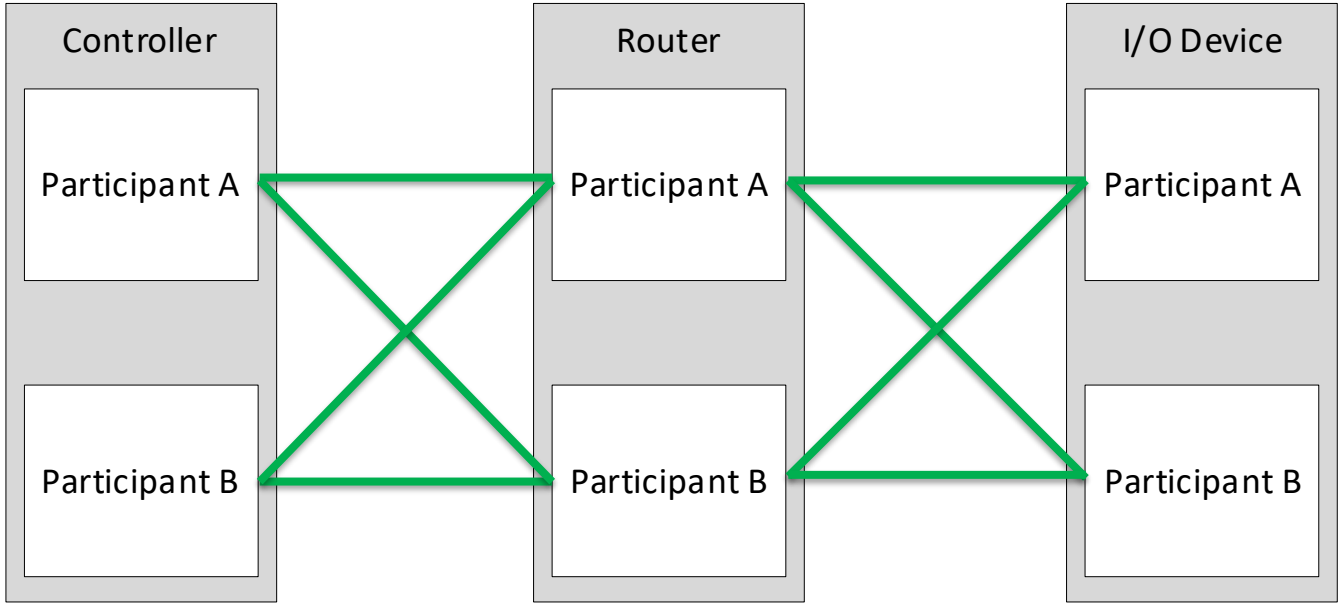
Hop 2

Egress port: Port number on Router
Number of Link Addresses: **2**
Link Address 1: I/O Device Participant A
Link Address 2: I/O Device Participant B

Legend:

- Concurrent Forward **Open request**
- Concurrent Forward **Open response**
- Open branch of Concurrent Connection

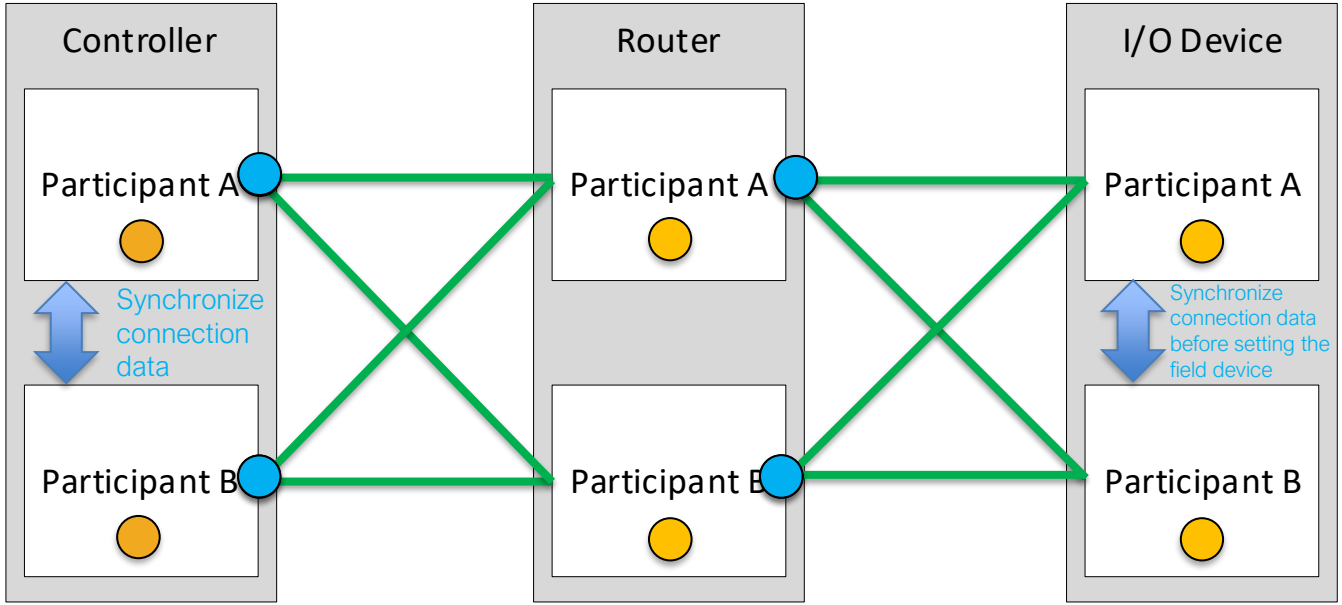
Concurrent Connections - Connection Closing Process



Legend:

- Open branch of Concurrent Connection
- Concurrent Forward Close request
- Concurrent Forward Close response

Concurrent Connections – Data flow

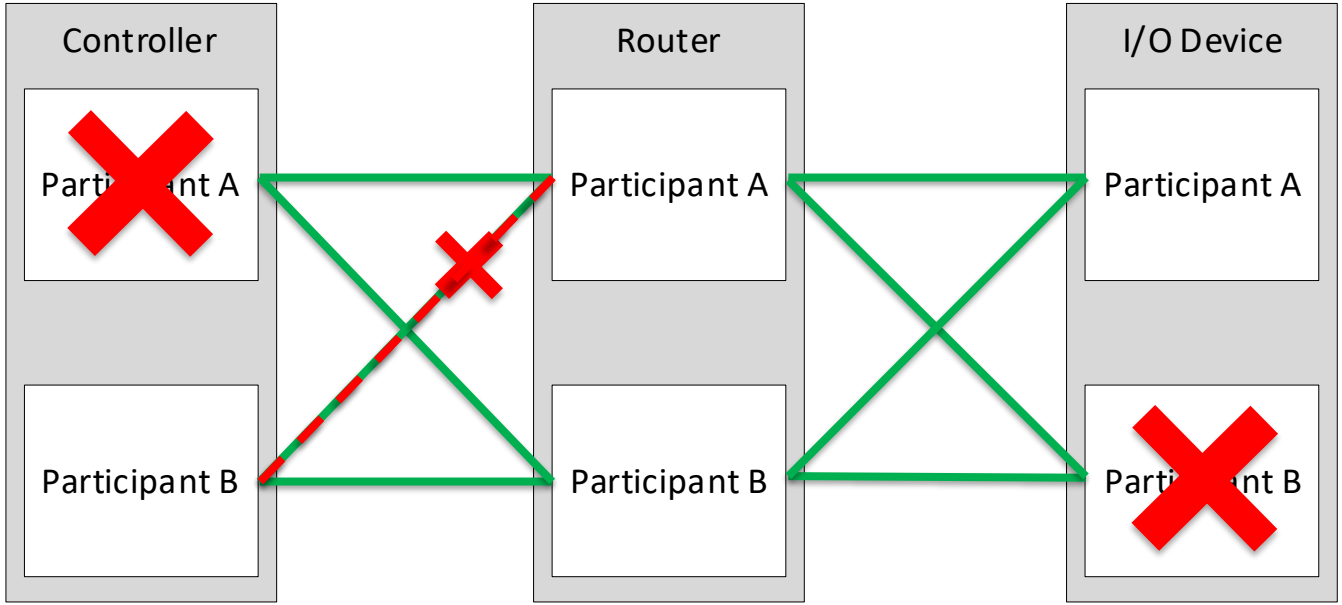


Legend:

- Open branch of Concurrent Connection
- Last Concurrent Connection Packet (CCSC=1)
- Fresh Concurrent Connection Packet (CCSC=2)
- Discarding the redundant packet

The same process happens in I/O Device to Controller direction.

Concurrent Connections - Fault tolerance

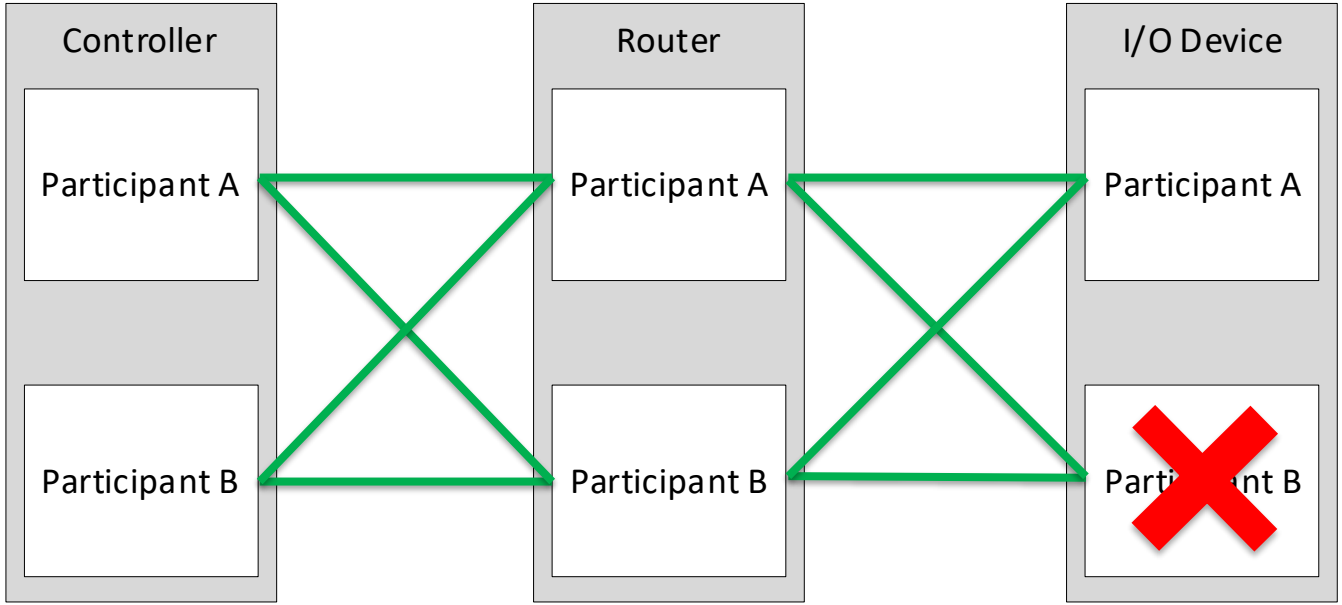


Legend:
- Open branch of Concurrent Connection
- Failure

- The connection remains open as long as there is at least one available path between connection endpoints
- **Zero switchover time**

- Redundant devices are functionally equivalent and participate in the process all the time
- Hot, active, and concurrent redundancy

Concurrent Connections – Branch recovery

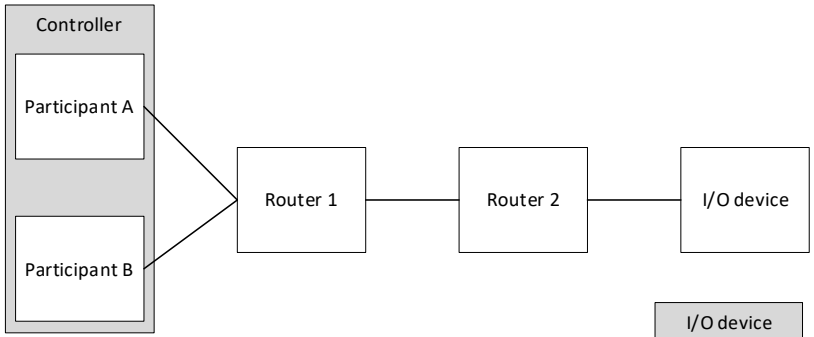


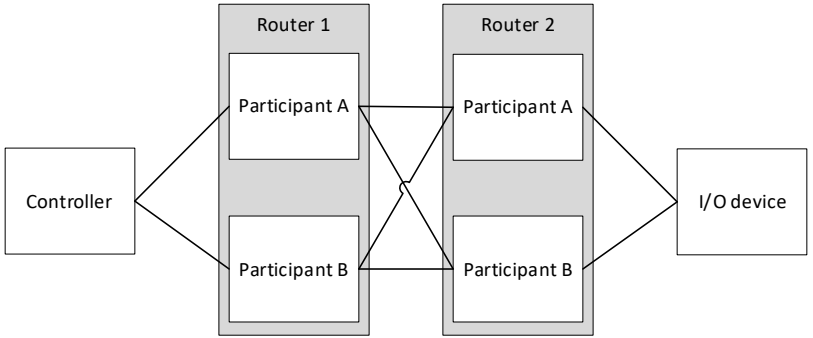
Legend:

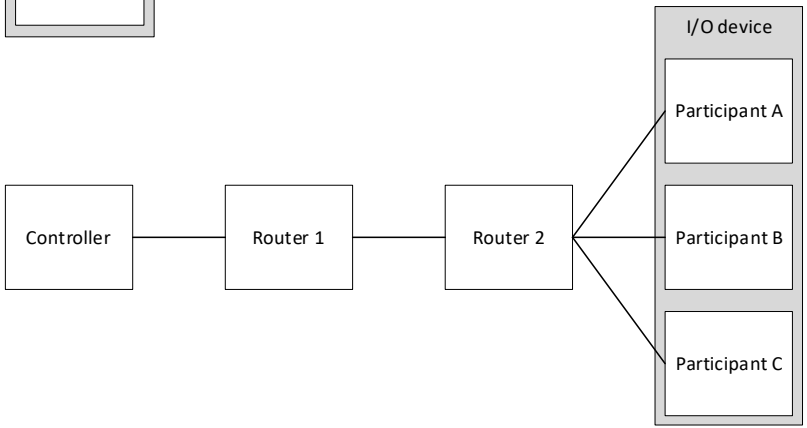
- Open branch of Concurrent Connection
- Failure
- Concurrent Forward Open request
- Concurrent Forward Open response

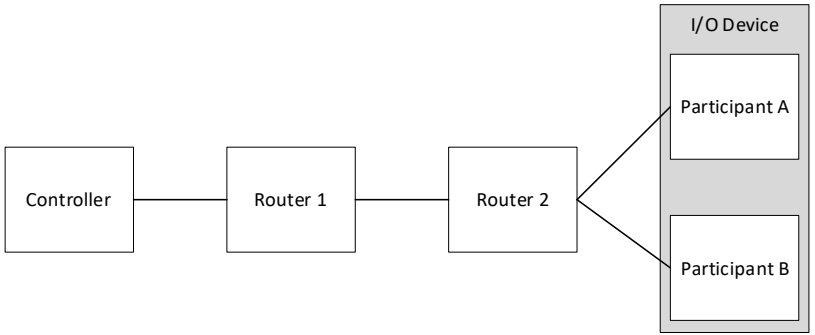
- Local, periodic attempts to reopen failed Concurrent Connection branches

Concurrent Connections - Flexibility



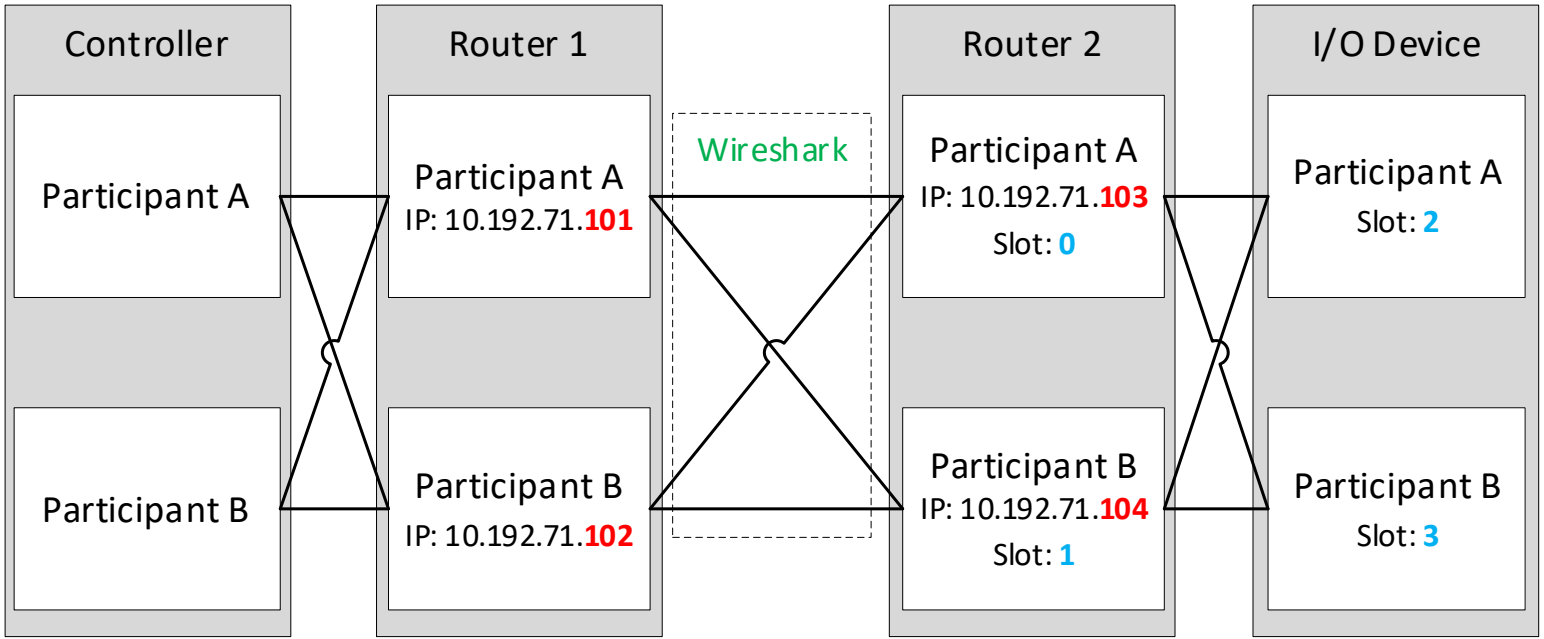






Concurrent Connections - real example

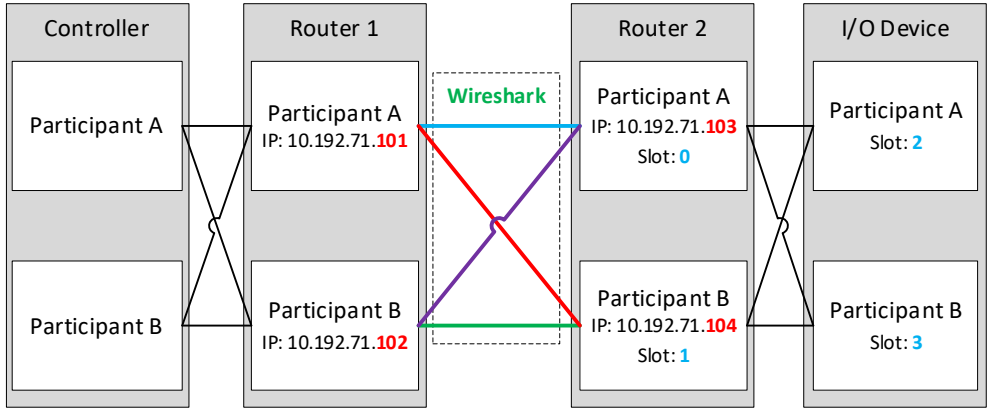
Concurrent Connections will be supported by **Wireshark 4.2** (November 2023 release)



Real example – Concurrent_Forward_Open

cip.cm.conn_serial_num == 0xcccc

No.	Time	Source	Destination	Protocol	Info
2320	0.966484	10.192.71.101	10.192.71.103	CIP CM	Connection Manager - Concurrent Forward Open
2321	0.966579	10.192.71.101	10.192.71.104	CIP CM	Connection Manager - Concurrent Forward Open
2329	0.982349	10.192.71.102	10.192.71.104	CIP CM	Connection Manager - Concurrent Forward Open
2331	0.984646	10.192.71.104	10.192.71.101	CIP CM	Success: Connection Manager - Concurrent Forward Open
2334	0.984744	10.192.71.104	10.192.71.102	CIP CM	Success: Connection Manager - Concurrent Forward Open
2347	0.982268	10.192.71.102	10.192.71.103	CIP CM	Connection Manager - Concurrent Forward Open
2354	0.984334	10.192.71.103	10.192.71.101	CIP CM	Success: Connection Manager - Concurrent Forward Open
2355	0.984431	10.192.71.103	10.192.71.102	CIP CM	Success: Connection Manager - Concurrent Forward Open



Real example – Concurrent_Forward_Open format

```
> Internet Protocol Version 4, Src: 10.192.71.101, Dst: 10.192.71.103
> Transmission Control Protocol, Src Port: 57386, Dst Port: 44818, Seq: 101, Ack: 91, Len: 104
> EtherNet/IP (Industrial Protocol), Session: 0x4000000E, Send RR Data
> Common Industrial Protocol
v CIP Connection Manager
  > Service: Concurrent Forward Open (Request)
  v Command Specific Data
      ...0 .... = Priority: 0
      .... 0100 = Tick time: 4
      Time-out ticks: 186
      Actual Time Out: 2976ms
      O->T Network Connection ID: 0x00000000
      T->O Network Connection ID: 0x0020401a
      Connection Serial Number: 0xcccc
      Originator Vendor ID: Rockwell Automation/Allen-Bradley (0x0001)
      Originator Serial Number: 0x4148384c
      Concurrent Connections Protocol Version: 1
      Connection Timeout Multiplier: *16 (2)
      Reserved: 0x000000
      O->T RPI: 100.000ms
    > O->T Network Connection Parameters: 0x440e
      T->O RPI: 100.000ms
    > T->O Network Connection Parameters: 0x4422
    > Transport Type/Trigger: 0x81, Direction: Server, Trigger: Cyclic, Class: 1
      Connection Path Size: 10 words
    > Connection Path: [Network], Assembly, Instance: 0xBF, Connection Point: 0xC7, Connection Point: 0x0434
    > [Connection Information]
```

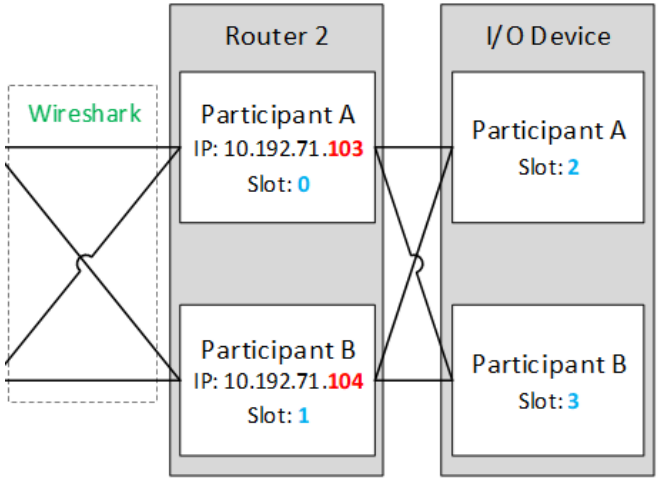
Legend:

- Originators shall use the same values
- Routers and Targets shall check if values are the same for a given Connection Triad
- Difference from Forward_Open

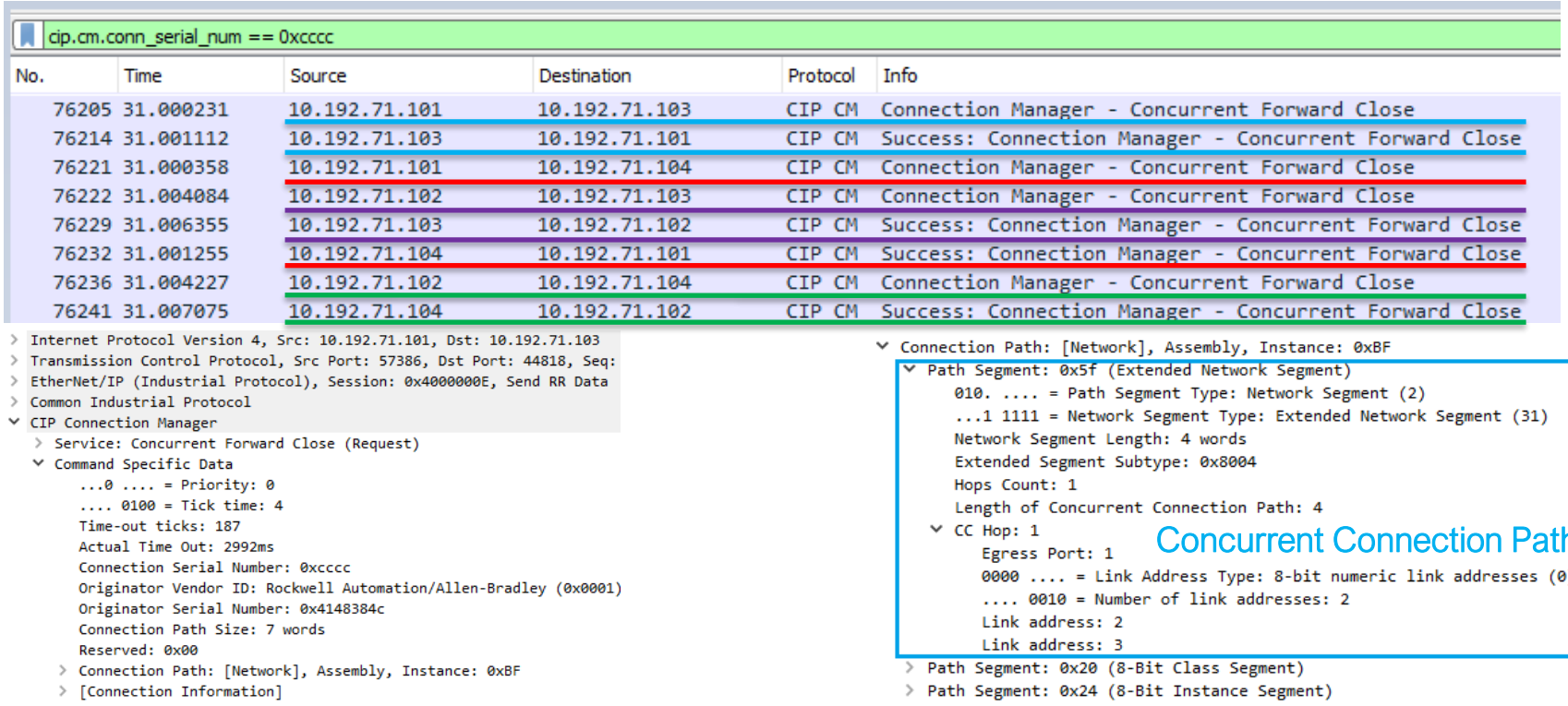
Real example – Concurrent Connection Path

```
Connection Path: [Network], Assembly, Instance: 0xBF, Connection Point: 0xC7, Connection Point: 0x0434
  Path Segment: 0x5f (Extended Network Segment)
      010. .... = Path Segment Type: Network Segment (2)
      ...1 1111 = Network Segment Type: Extended Network Segment (31)
      Network Segment Length: 4 words
      Extended Segment Subtype: 0x8004
      Hops Count: 1
      Length of Concurrent Connection Path: 4
    CC Hop: 1
        Egress Port: 1
        0000 .... = Link Address Type: 8-bit numeric link addresses (0)
        .... 0010 = Number of link addresses: 2
        Link address: 2
        Link address: 3
  Path Segment: 0x20 (8-Bit Class Segment)
  Path Segment: 0x24 (8-Bit Instance Segment)
  Path Segment: 0x2c (8-Bit Connection Point Segment)
  Path Segment: 0x2d (16-Bit Connection Point Segment)
```

Concurrent Connection Path



Real example – Concurrent_Forward_Close

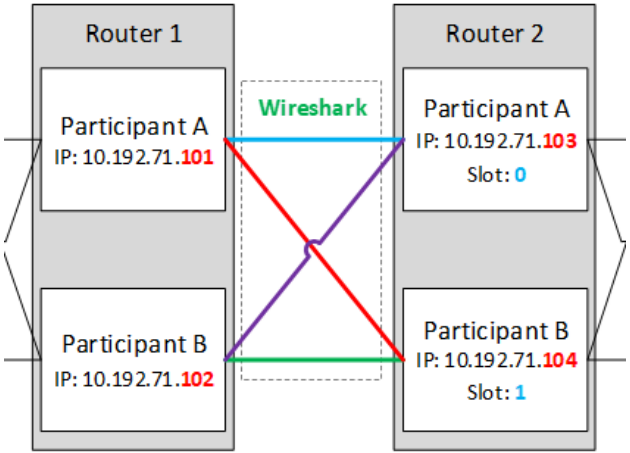


Real example – Real-Time data O->T

cip.cc.packet.sequence_count == 31900

No.	Time	Source	Destination	Protocol	Info
124	1.105903	10.192.71.101	10.192.71.104	CIP I/O	CC_SEQ=0000031900
112	1.105912	10.192.71.101	10.192.71.103	CIP I/O	CC_SEQ=0000031900
123	1.105465	10.192.71.102	10.192.71.104	CIP I/O	CC_SEQ=0000031900
111	1.105486	10.192.71.102	10.192.71.103	CIP I/O	CC_SEQ=0000031900

```
> Internet Protocol Version 4, Src: 10.192.71.101, Dst: 10.192.71.104
> User Datagram Protocol, Src Port: 2222, Dst Port: 2222
> EtherNet/IP (Industrial Protocol)
v Concurrent Connection Packet
  v Packet Type and Keep-alive: 0x0001, Packet Type: Concurrent Connection Packet Format
      .... .... ...0 0001 = Packet Type: Concurrent Connection Packet Format (1)
      .... .... ..0. .... = Keep-alive Flag: 0x0
      .... ...0 00.. .... = Keep-alive Hop Count: 0
      0000 000. .... .... = Reserved: 0x00
    Packet Length: 10
    Concurrent Connection Sequence Count: 31900
    CRC: 0xcde1f4fd
> Common Industrial Protocol, I/O
```



Concurrent Connections implementation hints

Concurrent Connections extend existing CIP connections

Concurrent Connections functionality	ODVA CIP Specification Vol 1
Concurrent Connection Path Extended Network Segment	C-1.4.3.6.2, 3-7.1
Concurrent_Forward_Open Connection Manager service	3-5.6.5, 3-7.2
Concurrent_Forward_Close Connection Manager service	3-5.6.6, 3-7.3
Concurrent Connection Packet production and consumption	3-7.4.1.1, 3-7.4.3, 3-7.4.4
Branch recovery	3-7.5
Diagnostics	3-5.3.1.10, 3-5.3.1.11, 3-5.3.1.12
Originators synchronization of Concurrent Connection parameters	3-7.2
Endpoints synchronization of produced connection data	3-7.4.2

Concurrent Connections Summary

Pros

- **Standardized end-to-end solution for redundant device communication across a system with devices from multiple vendors**
- Enable high availability systems, maximize system MTTF
- Flexible
- Eliminate switchover solution deficiencies
- Relatively easy to implement (extension of existing CIP connections)

Cons

- Higher use of network bandwidth
- Additional packet processing steps
- Require active synchronization of the redundant endpoints (vendor-specific)


2023
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