

Terrestrial Timing for Substations with PTP G.8275.1

White Paper

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Executive Summary

Modern utility substations depend on high-precision time synchronization to support critical applications in protection, automation, and monitoring. Traditionally, the Precision Time Protocol (PTP) Primary Reference Time Clock (PRTC) relies on Global Navigation Satellite System (GNSS) signals for accurate timing. Today however, GNSS sources are increasingly vulnerable to interference, jamming, and spoofing, threatening grid reliability and operational safety. To mitigate these risks, a robust architecture centralizing GNSS protection and distributing secure time over a segment routing-enabled WAN using the PTP Telecom Profile G.8275.1 is proposed. In this solution, the microchip TP4100 serves as the G.8275.1 PRTC, distributing time to the WAN where Cisco NCS540 routers operate as segment routing-enabled WAN routers.

At the substation, the Cisco Catalyst IR8340 Rugged Substation Router acts as a boundary clock and PRP Redbox, converting the WAN-delivered G.8275.1 profile into the PTP power profile for LAN distribution. Using PRP on the Cisco Catalyst IR8340 Rugged Router, timing traffic is delivered over two independent LAN networks to IEDs, further enhancing reliability.

For critical substations, dual Cisco Catalyst IR8340 Rugged Routers can be deployed with WAN resiliency, each connecting to different WAN routers, and their PTP priorities appropriately set for efficient time transmission. This approach enables remote substations to receive trusted time synchronization without local GNSS receivers while ensuring secure, standards-based, and highly available local distribution. This white paper provides a technical overview, solution architecture, design considerations, and validation recommendations for engineering teams responsible for deploying and maintaining resilient substation time synchronization systems.

Introduction

The transition to digital substations and the adoption of standards such as IEC 61850 have elevated the importance of network-based time synchronization. PTP, as defined in IEEE 1588, delivers the sub-microsecond accuracy required by protection relays, IEDs, and measurement systems. However, the security and reliability of the time source—usually GNSS—are paramount. Disruption of GNSS signals can have cascading effects on grid stability and event traceability, making protection strategies essential for modern utility environments.

The Need to Protect GNSS for PRTC

PTP PRTCs synchronized to GNSS signals to maintain a traceable, precise time reference. If GNSS is compromised, devices relying on the PRTC may experience:

- Loss of synchronization and time drift,
- Protection relay misoperations,
- Inaccurate event and fault logs,
- Regulatory compliance issues.

To mitigate these risks, utilities must implement:

- **Physical security:** Secure GNSS antenna placement, shielding, and tamper detection.

- **Logical monitoring:** Continuous GNSS signal integrity checks, alarms for signal loss or spoofing, and redundancy strategies.

Solution Architecture: Microchip TP4100, Cisco NCS540, and IR8340 with PRP

Centralized Time Distribution with Microchip TP4100

A central, secure site is equipped with the Microchip TP4100, a highly reliable and precise PTP Telecom Profile G.8275.1 PRTC, referenced to a protected GNSS source. The TP4100 distributes time using the G.8275.1 profile to the WAN, which is built on Cisco NCS540 routers. The NCS540 routers, supporting Segment Routing (SR), provide explicit path control and high resiliency across the network. It is important to note that G.8275.1 operates at Layer 2, and its precise time delivery is managed through its inherent mechanisms, independent of SR routing capabilities.

Advantages of the Microchip TP4100 as a G.8275.1 PRTC are:

- **High Precision and Reliability:** The TP4100 offers leading GNSS receiver performance and ultra-stable oscillator options, ensuring consistent sub-microsecond timing accuracy even during GNSS disruptions.
- **Scalability and Interoperability:** Designed for telecom and critical infrastructure, the TP4100 supports large-scale PTP deployments and is fully compliant with ITU-T G.8275.1 and IEEE 1588 standards.
- **Robust Security and Monitoring:** Advanced monitoring, security, and holdover capabilities enable rapid detection of anomalies and maintain timing integrity during network or GNSS events.

Substation Time Conversion, PRP, and LAN Distribution with Cisco Catalyst IR8340 Rugged Router

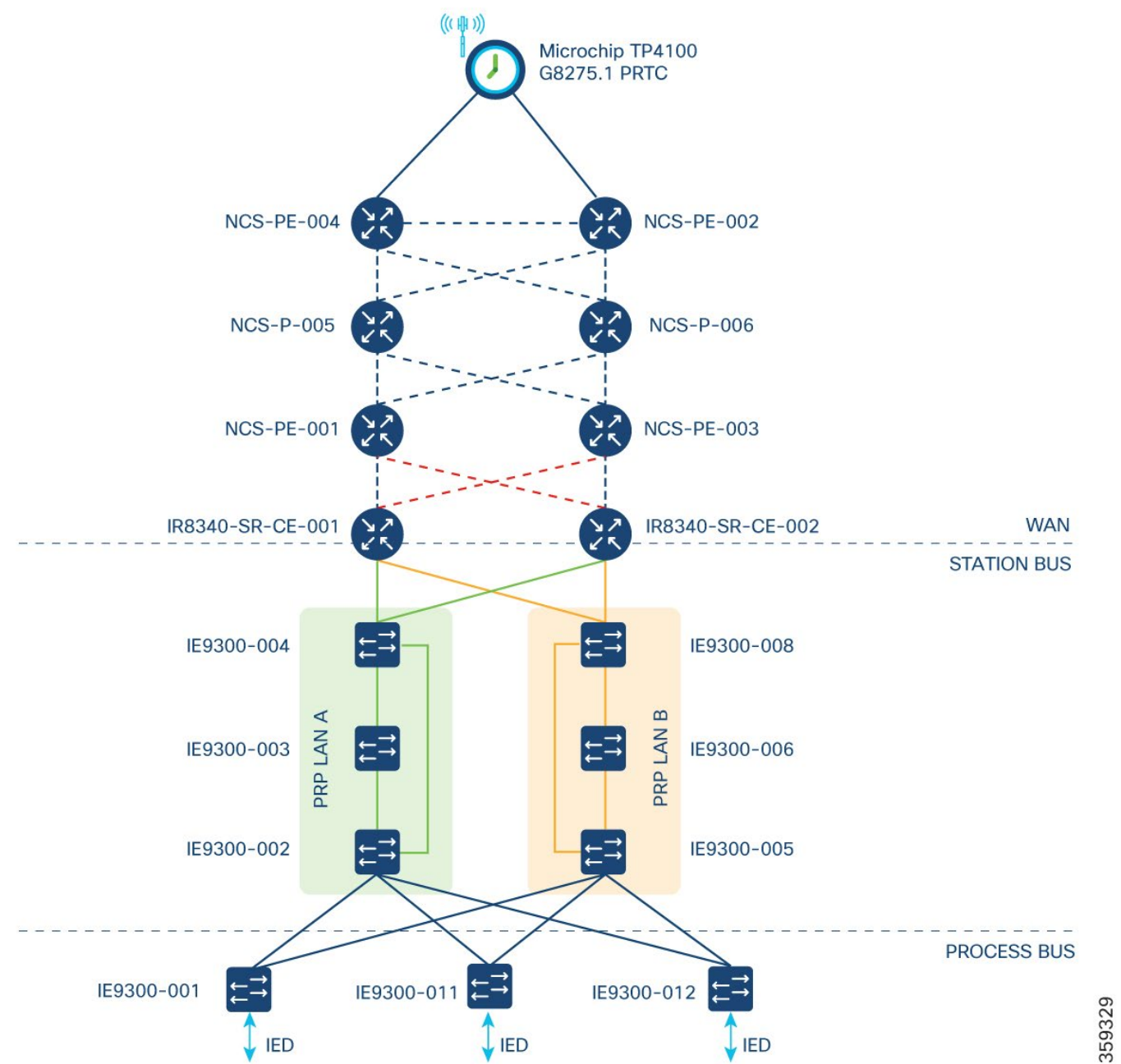
At each substation, the Cisco IR8340 Substation Router receives the PTP Telecom Profile G.8275.1 from the NCS540 WAN router. The Cisco Catalyst IR8340 Rugged router acts as a PTP Boundary Clock (BC) for the local area network for:

- **Profile Conversion:** The Cisco Catalyst IR8340 Rugged router translates the G.8275.1 profile (used for WAN transfer) to the PTP Profile IEEE 1588 2012, which is the utility substation standard for local device interoperability and microsecond accuracy.
- **PRP-Enabled LAN Distribution:** The Cisco Catalyst IR8340 Rugged router supports Parallel Redundancy Protocol (PRP), allowing timing traffic to be transmitted simultaneously over two independent LANs (LAN A and LAN B). IEDs and protection devices equipped with PRP receive both timing packets, ensuring seamless operation even if one network path fails or is under maintenance. This maximizes timing reliability and guarantees zero recovery time for time-critical applications.

Enhanced Resiliency for Critical Substations: In critical substation deployments, dual Cisco Catalyst IR8340 Rugged routers can be deployed to maximize redundancy and operational availability. These routers can be configured for WAN resiliency by connecting to different WAN routers (such as separate NCS540 nodes). For optimal performance and to ensure the most reliable and accurate PRTC is selected by the network, the PTP

priority settings on the Cisco Catalyst IR8340 Rugged routers should be appropriately configured. This ensures efficient and deterministic time transmission in the event of a device or link failure, maintaining continuous and accurate timing for substation operations.

Figure 1. Segment Routing WAN with Microchip TP4100, Cisco NCS540, and Dual PRP-Enabled Cisco Catalyst IR8340 Rugged Routers for G.8275.1 Profile Conversion and Redundancy



Design Considerations

Implementing a robust and scalable PTP-based time synchronization solution with Microchip TP4100, Cisco Catalyst IR8340 Rugged Router, and NCS 540 routers requires attention to several critical factors described below.

A. GNSS Source Security and Reliability

- **Physical Protection:** Place GNSS antennas in secure, tamper-evident locations at the central site, using shielding and anti-jam solutions as needed.
- **Redundancy:** Consider multiple, diverse GNSS receivers or auxiliary time sources for backup.
- **Signal Monitoring:** Employ real-time GNSS monitoring and automatic failover protocols at the central site.

B. PTP Profile Handling, PRP, and Network Design

- **Profile Selection:**
 - WAN: Use the PTP Telecom Profile G.8275.1 from the Microchip TP4100 PRTC over the Segment Routing-enabled WAN via Cisco NCS540 routers.
 - Substation LAN: The Cisco Catalyst IR8340 Rugged router is utilized to convert the incoming PTP Telecom Profile (G.8275.1) to the PTP Power Profile (IEEE 1588 2012) to serve local devices.
- **Boundary Clock Deployment:** The Cisco Catalyst IR8340's BC role ensures isolation between WAN and LAN time domains, filtering out network-induced jitter.
- **PRP Implementation:** Enable PRP on the Cisco Catalyst IR8340 Rugged router to support two independent LANs (LAN A, LAN B) for zero recovery time and seamless redundancy to all IEDs.
- **WAN Resiliency in Critical Sites:** Deploy dual Cisco Catalyst IR8340 Rugged routers with connections to different WAN routers. Ensure PTP priorities are configured so that timing selection and failover are deterministic and efficient, preventing timing loops or sub-optimal PRTC selection.

C. Infrastructure Resilience and Security

- **Redundant Paths:** To ensure the proper functioning and continuity of clock synchronization across the network, it is a fundamental requirement that all supported links within the WAN infrastructure are explicitly configured for G.8275.1 time delivery. This configuration is crucial for ensuring that clocking information is accurately and continuously propagated across all relevant network segments, allowing the PTP system to operate as intended. While Segment Routing enhances network infrastructure resilience through alternate path selection and failover, the continuity of G.8275.1 time delivery relies on its native mechanisms, such as the Best Master Clock Algorithm (BMCA) and

boundary clock configurations, rather than being directly influenced by Segment Routing path control.

- **Security:** Use access controls, segmentation, and encryption to protect PTP and management traffic.

Cisco Catalyst IR8340 Rugged Router Boundary Clock Configuration

A crucial component of this architecture is the Cisco Catalyst IR8340 Rugged Substation Router, which serves as a PTP Boundary Clock (BC) for the substation LAN. Proper configuration of the Cisco Catalyst IR8340 Rugged router ensures accurate and resilient time distribution, profile conversion between PTP Telecom Profile G.8275.1 and PTP Power Profile, seamless support for Parallel Redundancy Protocol (PRP), and explicit clock-port management.

Key Configuration Steps

1. Configure PTP Telecom Profile (G.8275.1) on WAN Interfaces

Configure the Cisco Catalyst IR8340 Rugged router as a boundary clock in domain 24 using the hybrid G.8275.1 profile, mapping its WAN interfaces to clock ports. Ensure that domain number 24 is consistently used on both NCS routers in the WAN and on the IR8340.

```
ptp clock boundary domain 24 hybrid profile g8275.1
output 1pps R0
clock-port bc-port-1
transport ethernet multicast interface Gi0/0/0
clock-port bc-port-2
transport ethernet multicast interface Gi0/0/1
!
```

2. Configure SyncE on the WAN Interface

Configuring Synchronous Ethernet (SyncE) on the WAN interface is an important step to achieve better clock accuracy. SyncE provides physical-layer frequency synchronization, which helps reduce the effects of network jitter and supports PTP holdover during periods of packet loss or congestion. To enable SyncE, the interface should be set to synchronous mode and the appropriate network clock quality level should be specified.

```
interface GigabitEthernet0/0/0
description connected to NCS-PE-001 gig0/0/0/13
ip address 143.13.1.1 255.255.255.252
ip nat outside
ip ospf network point-to-point
ip ospf 1 area 0
```

```
negotiation auto
network-clock source quality-level QL-PRC rx
synchronous mode
end
!
!
interface GigabitEthernet0/0/1
description connected to NCS-PE-003 GigabitEthernet0/0/0/12
ip address 143.13.5.1 255.255.255.252
ip nat outside
ip ospf network point-to-point
ip ospf 1 area 0
load-interval 30
negotiation auto
network-clock source quality-level QL-PRC rx
synchronous mode
end
!
```

3. Configure PRP Interfaces for Substation LAN Distribution

Set up trunked interfaces to connect to PRP-enabled LANs, and group them into a PRP channel.

```
!
interface GigabitEthernet0/1/4
switchport trunk allowed vlan 111,301
switchport mode trunk
prp-channel-group 1
!
!
interface GigabitEthernet0/1/5
switchport trunk allowed vlan 111,301
switchport mode trunk
prp-channel-group 1
interface PRP-channel1
switchport
switchport trunk allowed vlan 111,301
```



```
switchport mode trunk
!
```

4. Configure PTP Power Profile (IEEE 1588 2012) for the Substation LAN (Domain 0)

Configure the Cisco Catalyst IR8340 Rugged router as a boundary clock for the Power Profile in domain 0, with explicit clock priorities and PRP clock-port assignments for VLAN 301.

```
!
ptp clock boundary domain 0 profile power
priority1 1
priority2 1
clock-port PRP-1
transport ethernet multicast interface Gi0/1/4
vlan 301
clock-port PRP-2
transport ethernet multicast interface Gi0/1/5
vlan 301
!
```

Notes:

- domain 0 and profile power ensure timing consistency with the PTP Power Profile for the utility LAN.
- priority1 and priority2 set to 1 make this clock highly preferred for the LAN.
- clock-port PRP-1 and PRP-2 map the PRP physical interfaces to the correct VLAN, ensuring redundant PTP delivery over both LAN A and LAN B.

5. General Best Practices

- · Test PTP Profile Conversion: Validate that the IR8340 correctly translates G.8275.1 to Power Profile, ensuring interoperability with all IEDs.
- · Monitor Both PRP Channels: Continuously monitor LAN A and LAN B for loss of redundancy or performance degradation.
- · Configure Unique Clock Identities: In dual IR8340 setups, ensure each boundary clock has a unique clock identity and appropriate priority for seamless failover.
- · Security: Limit PTP access to authorized ports.

PTP Operational Status and Verification on Cisco IR8340

The following show ptp commands provide insight into the operational status of the PTP Boundary Clock on the Cisco IR8340, demonstrating its role in converting and distributing time between the WAN (G.8275.1) and the LAN (Power Profile).

- **show ptp clock running:** This command displays the summary of the PTP Boundary Clocks configured on the device, showing their state, number of ports, packet statistics, and redundancy mode.

```
IR8340-002#show ptp clock running
PTP Boundary Clock [Domain 0] [Profile: power]
State Ports Pkts sent Pkts rcvd Redundancy Mode
FREERUN 2 4069123 2034605 Hot standby
PORT SUMMARY
PTP Master
Name Tx Mode Role Transport State Sessions Port Addr
PRP-1 mcast negotiated Ethernet Master 1 UNKNOWN
PRP-2 mcast negotiated Ethernet Master 1 UNKNOWN
PTP Boundary Clock [Domain 24] [Hybrid] [Profile: g8275.1]
State Ports Pkts sent Pkts rcvd Redundancy Mode
PHASE_ALIGNED 2 5425785 21834325 Hot standby
PORT SUMMARY
PTP Master
Name Tx Mode Role Transport State Sessions Port Addr
bc-port-1 mcast negotiated Ethernet Passive 1 UNKNOWN
bc-port-2 mcast negotiated Ethernet Slave 1 UNKNOWN
IR8340-002#
```

- **Domain 0 (Power Profile):** Shows the IR8340 acting as a PTP Master on its PRP interfaces (PRP-1, PRP-2) for the substation LAN, distributing the Power Profile. The "FREERUN" state indicates it is currently acting as the primary time source for this domain, generating its own timing signals.
- **Domain 24 (G.8275.1 Hybrid Profile):** Shows the IR8340's WAN interfaces. "bc-port-2" is in "Slave" state, indicating it is successfully synchronizing to an upstream PTP Telecom Grandmaster (e.g., TP4100). "bc-port-1" is in "Passive" state, likely acting as a redundant path. The "PHASE_ALIGNED" state confirms successful synchronization to the WAN time source.

- **show ptp clock dataset time-properties:** This command displays the time-related properties of the clock, including UTC offset, leap second flags, and traceability information.

```
IR8340-002#show ptp clock dataset time-properties
CLOCK [Boundary Clock, domain 0]
Current UTC Offset Valid: TRUE
Current UTC Offset: 37
Leap 59: FALSE
Leap 61: FALSE
Time Traceable: TRUE
Frequency Traceable: TRUE
PTP Timescale: TRUE
Time Source: GPS
CLOCK [Boundary Clock, domain 24]
Current UTC Offset Valid: TRUE
Current UTC Offset: 37
Leap 59: FALSE
Leap 61: FALSE
Time Traceable: TRUE
Frequency Traceable: TRUE
PTP Timescale: TRUE
Time Source: GPS
IR8340-002#
```

- **Both domains show Time Traceable:** TRUE and Time Source: GPS, indicating that the time being distributed by the IR8340 (in Domain 0) is ultimately traceable back to a GNSS source (via the G.8275.1 profile in Domain 24). The Current UTC Offset: 37 reflects the current difference between UTC and TAI (International Atomic Time).
- **show ptp clock dataset parent:** This command provides details about the parent clock from which the current clock is synchronizing, including its identity, quality, and observed offset.

```
IR8340-002#show ptp clock dataset parent
CLOCK [Boundary Clock, domain 0]
Profile: power
Parent Clock Identity: 0x00:B0:AE:FF:FE:0A:DF:20
Parent Port Number: 0
Parent Stats: No
Observed Parent Offset (log variance): 0
Observed Parent Clock Phase Change Rate: 0
```

```
Grandmaster Clock:
Identity: 0x00:B0:AE:FF:FE:0A:DF:20
Priority1: 1
Priority2: 1
Clock Quality:
Class: 6
Accuracy: Within 100ns
Offset (log variance): 20061
CLOCK [Boundary Clock, domain 24]
Profile: g8275.1
Parent Clock Identity: 0x00:B0:AE:FF:FE:0A:DF:20
Parent Port Number: 0
Parent Stats: No
Observed Parent Offset (log variance): 0
Observed Parent Clock Phase Change Rate: 0
Grandmaster Clock:
Identity: 0x00:B0:AE:FF:FE:0A:DF:20
Priority1: 128
Priority2: 128
Clock Quality:
Class: 6
Accuracy: Within 100ns
Offset (log variance): 20061
IR8340-002#
```

- **For Domain 24 (G.8275.1)**, the output shows the Grandmaster Clock identity and its Clock Quality (Class 6, Accuracy within 100ns), confirming it is synchronizing to a high-quality PTP Telecom Grandmaster from the WAN.
- **For Domain 0 (Power Profile)**, the Grandmaster Clock identity is the same as the parent for Domain 24, but its Priority1 and Priority2 are set to 1 (as configured), making it the preferred source for the local LAN. This output confirms the IR8340 is successfully translating and distributing the time from the WAN PTP Telecom profile to the local PTP Power Profile domain.
- **show network-clocks synchronization**: This command provides a summary of the clock synchronization status, including nominated interfaces and their quality levels.

```
IR8340-002#show network-clocks synchronization
```

Symbols: En - Enable, Dis - Disable, Adis - Admin Disable

NA - Not Applicable

* - Synchronization source selected

- Synchronization source force selected

& - Synchronization source manually switched

Automatic selection process : Enable

Equipment Clock : 2048 (EEC-Option1)

Clock Mode : QL-Enable

ESMC : Disabled

SSM Option : 1

T0 : GigabitEthernet0/0/0

Hold-off (global) : 300 ms

Wait-to-restore (global) : 0 sec

Tsm Delay : 180 ms

Revertive : No

Nominated Interfaces

Interface	SigType	Mode/QL	Prio	QL_IN	ESMC Tx	ESMC Rx
Internal	NA	NA/Dis	251	QL-SEC	NA	NA
Gi0/0/1	NA	Sync/En	2	QL-PRC	-	QL-PRC
*Gi0/0/0	NA	Sync/En	1	QL-PRC	-	QL-PRC

IR8340-002#

Conclusion

Secure, scalable, and standards-based time synchronization is essential for the reliable operation of digital substations. By centralizing GNSS protection and distributing time over a Segment Routing-enabled WAN using the Microchip TP4100 as the PTP Telecom Profile G.8275.1 PRTC and Cisco NCS540 routers, then converting and distributing time locally via Cisco IR8340 Substation Routers with the PTP Power Profile, utilities achieve robust, interoperable, and resilient timing. **With PRP enabled on the IR8340, timing delivery to IEDs is highly available and seamless, even in the event of a network path failure—further maximizing operational uptime and reliability.**

For critical substations, the deployment of dual IR8340 routers with WAN and PRP LAN resiliency, and properly configured PTP priorities, ensures maximum uptime and precise, reliable time distribution, further strengthening grid operations. This architecture not only reduces operational risk and complexity but also streamlines management and validation for engineering teams, supporting the ongoing evolution to smarter, more resilient grids.

References

1. IEEE 1588-2019: "IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems"
2. IEEE C37.238-2017: "IEEE Standard Profile for Use of IEEE 1588 Precision Time Protocol in Power System Applications"
3. ITU-T G.8275.1: "Precision time protocol telecom profile for phase/time synchronization with full timing support from the network"
4. IEC 61850: "Communication networks and systems for power utility automation"
5. IEC 62439-3: "Industrial communication networks – High availability automation networks – Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR)"
6. [NERC Guidelines](#): "NERC: Time Synchronization in Substation Automation Systems"
7. Microchip TP4100 [Product Page](#)
8. Cisco IR8340 Rugged Series Router [Product Page](#)
9. Cisco NCS540 Series Routers [Product Page](#)
10. Cisco Segment Routing Technology Overview [White Paper](#)