Implementing CIP Sync with 802.11 Wireless Technology in a Converged Plantwide Ethernet Architecture

The purpose of this document is to describe how to implement CIP Sync and the IEEE 1588™ Precision Time Protocol (PTP) in an industrial 802.11 Wireless Local Area Network (WLAN) as part of the Converged Plantwide Ethernet (CPwE) architecture. The document includes network architecture guidelines as well as configuration recommendations for time synchronization across wireless media.

This document assumes that the reader is familiar with general principles and recommendations on how to use IEEE 802.11™ wireless technology with Industrial Automation and Control System (IACS) applications and CPwE. The information about this topic can be found in the following publication:

Deploying Wireless LAN Technology within a CPwE Architecture Design Guide
http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td006_-en-p.pdf

LISTEN. THINK. SOLVE.

Allen-Bradley • Rockwell Software

Rockwell Automation

Overview

Wireless communication, in particular IEEE 802.11 wireless technology, has become prevalent in the industrial space. Increasingly, Industrial Automation and Control System (IACS) applications use wireless media as part of the critical real-time automation control as well as monitoring and managing the production process.

Many IACS applications require precise time synchronization between devices in the network. EtherNet/IP devices use CIP Sync and the IEEE 1588 PTP protocol to synchronize their clocks across a wired Ethernet network. The accuracy of clock synchronization depends on many factors:

- Quality and stability of device clocks
- PTP support by the network hardware such as switches
- Quality of Service (QoS) implementation
- Network latency and jitter

Wireless media present significant challenges for CIP Sync implementation in the network. Half-duplex communication and shared access to the wireless channel causes large amount of jitter or packet delay variation (PDV). In addition to that, latency across the wireless link can be asymmetrical depending on the traffic patterns and radio parameters, while the PTP algorithm relies on a symmetrical link to compensate for delays.

As of today, commercially available 802.11 wireless hardware, including the Stratix 5100™ access point, does not support PTP and cannot compensate for the delays in the wireless channel. Clock synchronization accuracy across the wireless media is expected to be considerably less than for wired Ethernet. However, network architecture design, choice of hardware and proper configuration of devices can improve CIP Sync accuracy across wireless media to make it suitable for a certain class of industrial applications.

CIP Sync Information

Information about CIP Sync and its application within the Rockwell Automation® Integrated Architecture® can be found in the following documents:

Integrated Architecture® and CIP Sync Configuration
http://literature.rockwellautomation.com/idc/groups/literature/documents/at/ia-at003_-en-p.pdf

Time Synchronization Protocol white paper
http://literature.rockwellautomation.com/idc/groups/literature/documents/wp/enet-wp030_-en-e.pdf

Converged Plantwide Ethernet (CPwE) Design and Implementation Guide: CIP Sync Sequence of Events
http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/CPwE_DIG/CPwE_chapter9.pdf

Some of the PTP definitions are included here for quick reference.

Ordinary clock: A device that has a single PTP port and either provides a source of time (a Master clock role), or synchronizes to another clock (a Slave clock role) in a network segment. Most EtherNet/IP devices in the network are ordinary clocks.

Boundary clock: A device that has multiple PTP ports where one port is typically a slave to an upstream master clock, while the remaining ports become masters to the downstream devices. A boundary clock can provide a PTP interface between different network segments, such as VLANs, or different types of networks, such as the Ethernet and a ControlLogix® backplane. Another function of a boundary clock is PDV filtering to reduce impact of network jitter in the upstream network path.

Examples of boundary clocks:

- ControlLogix® Ethernet modules
- Stratix® Managed Ethernet switches with PTP support

Transparent Clock: A network device with multiple PTP ports that improves time synchronization accuracy by compensating for the delay when a PTP message is received and transmitted. It cannot serve as a master or slave device on the network.

Examples of transparent clocks:

- Two-port embedded switches in EtherNet/IP devices
- Stratix® Managed Ethernet switches with PTP support

Grandmaster Clock: Within a PTP domain, the Grandmaster clock is the primary source of time for clock synchronization using PTP. The Grandmaster clock is selected among available master clocks using the Best Master Clock Algorithm (BMCA). It can use a GPS clock or a Network Time Protocol (NTP) server as a time reference, or be a free running clock.

Examples of the devices that can operate as Grandmaster clocks:

- ControlLogix 5580 and 5570 controllers
- CompactLogix™ 5380 and 5370 controllers
- Stratix 5400™ and Stratix 5410™ switches in the hybrid Grandmaster / boundary clock mode
- Hiprom Time Synchronization Module 1756HP-TIME

Master clock: An ordinary or boundary clock that provides a master time reference for the slave clocks in the network segment. A master clock participates in the BMCA to choose a Grandmaster clock and responds to requests from slave clocks to measure network latency.

Slave clock: An ordinary or boundary clock that synchronizes to the master clock in the network segment. A slave clock occasionally generates requests to measure network latency, monitors clock quality of the master clocks and selects the best available master.

CIP Sync Architecture

Several types of IACS applications that use wireless media may also require CIP Sync for system-wide time synchronization:

- Alarms and events logging by multiple Programmable Automation Controllers (PAC), including on the mobile equipment
- Sequence of Events (SOE) applications that require high accuracy time stamps to capture faults and events
- Coordination of action between the fixed and mobile parts of the IACS, for example to do time-based events and scheduled outputs
- Coordination of motion between a supervisory PAC and mobile PACs using Produced Consumed tags

Examples of applications that may use this technology are packaging and assembly machines, overhead cranes, automated guided vehicles (AGV), entertainment rides and many others.

Note: CIP Sync accuracy over the wireless media may not be sufficient for applications requiring precise time coordination such as systems using Integrated Motion with EtherNet/IP. Application requirements, such as position accuracy at a certain speed and acceleration, should be evaluated. In addition to that, motion drive control across the wireless media is not recommended.

An example of the recommended network architecture is shown in Figure 1.

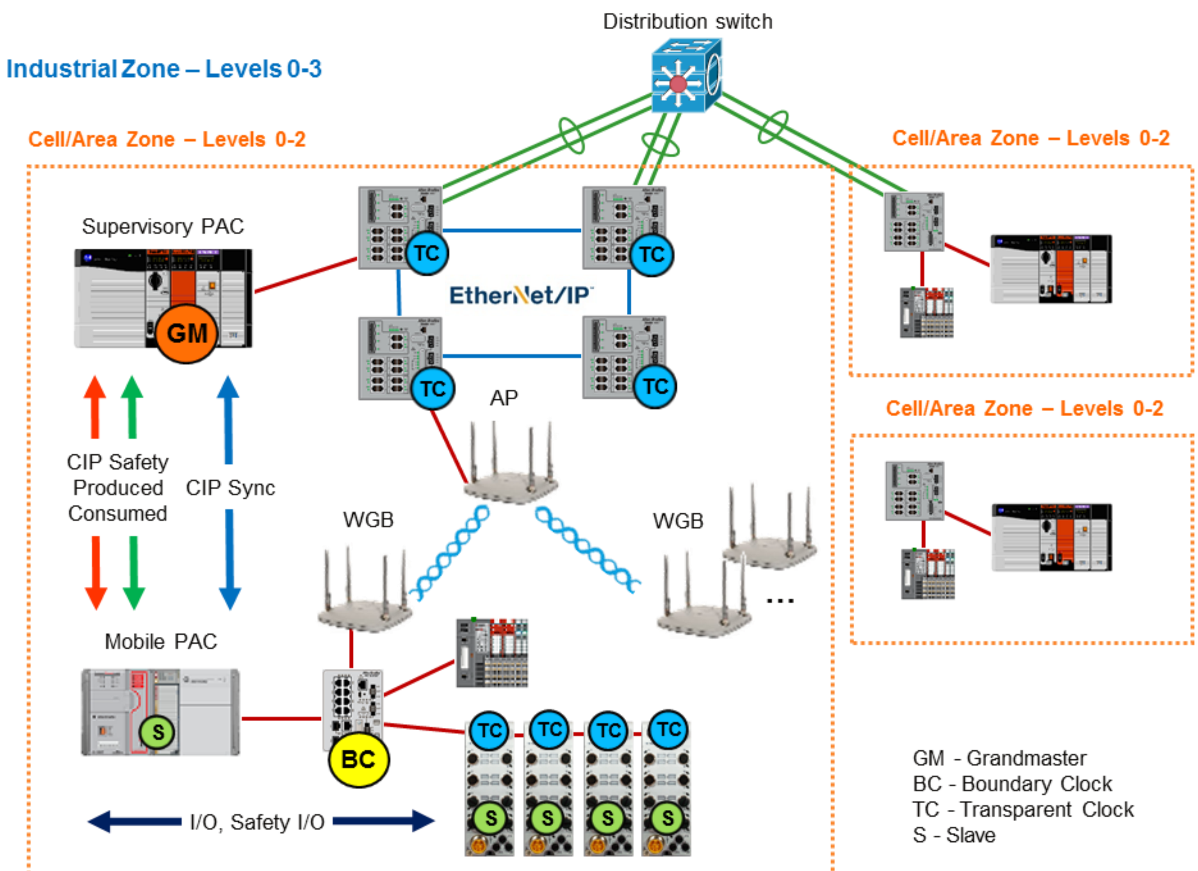


Figure 1 CIP Sync over Wireless Architecture

- Some of the important features of the architecture are listed below:
- A common time is distributed across the plant-wide network using a GPS clock or an NTP server as a time source. Each Cell/Area zone has a Grandmaster clock (GM) that uses the plant-wide time source and serves as a master clock for the PTP slaves.
- Depending on the application needs, a Cell/Area zone can also have a free-running GM clock without plant-wide synchronization.
- The Grandmaster clock (GM) is located in the wired network behind the AP which can be a Stratix 5100™ or Cisco access point. In this example, the supervisory PAC is the GM, but it can be any capable device.

- A PTP-enabled switch in the Boundary Clock (BC) mode is placed behind the Stratix 5100™ workgroup bridge (WGB) to connect slave PTP devices (S) on the mobile equipment. The primary purpose of the BC is to filter excessive clock jitter across the wireless link.
- Additional configuration of the BC parameters for PDV filtering is available on the following Stratix® switch platforms:
  - Stratix 5700™, firmware 15.2(4)EA and later, select catalog numbers with CIP Sync support
  - Stratix 8000™/Stratix 8300™, firmware 15.2(4)EA and later
  - Stratix 5400™ and Stratix 5410™, firmware 15.2(4)EA3 and later
- The specific commands to configure PDV filter is discussed later in the document.
- Switches in the wired infrastructure can be in the Transparent Clock (TC) mode or in the BC mode, depending on the network requirements. Typically, a multi-VLAN environment requires the BC mode on switches.
- A mobile PAC communicates with the I/O and drives in the wired network on the mobile machine or skid. Note that the supervisory PAC in the wired infrastructure does NOT control motion drives across the wireless link.

Several network topologies can be implemented on the mobile equipment, as illustrated below.

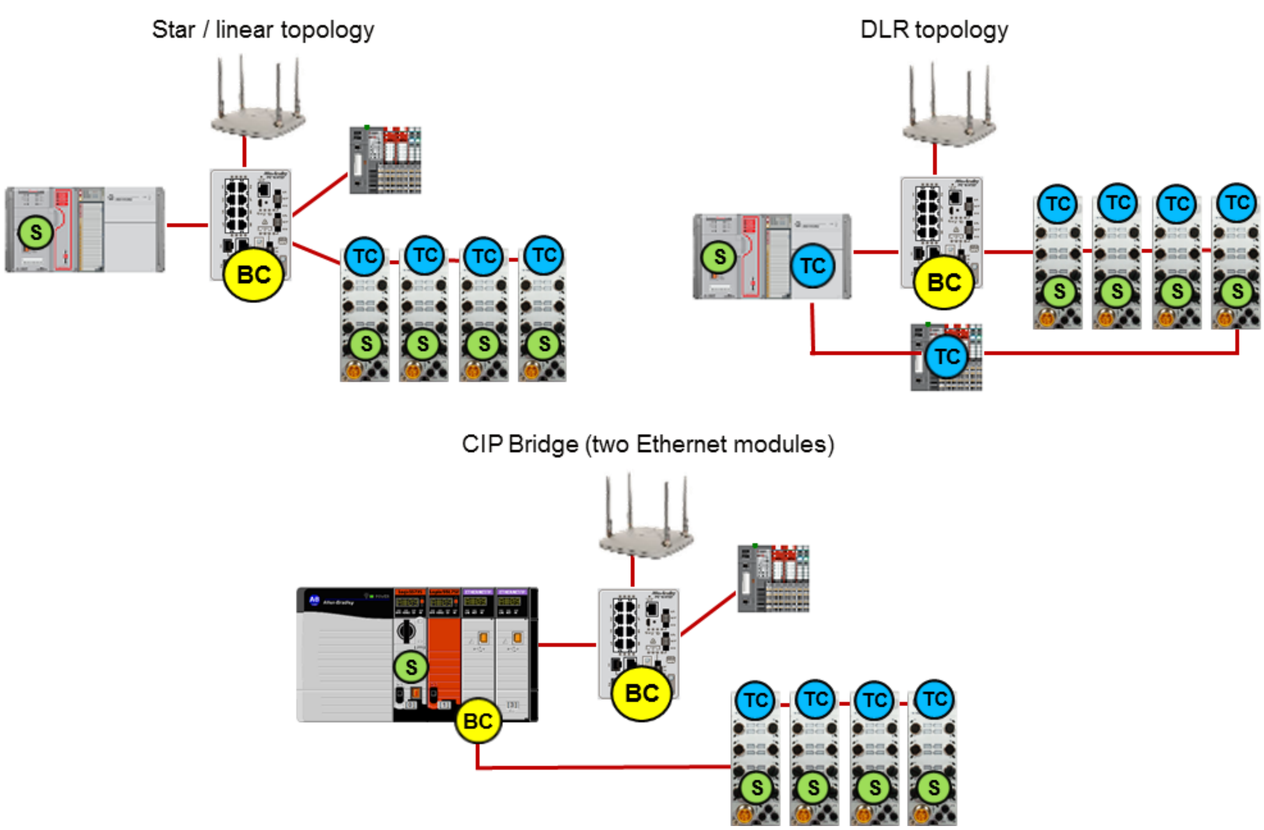


Figure 2 Mobile Equipment Topologies

- **Star/linear topology** - the most common topology.
- **Device Level Ring (DLR) topology** - DLR is supported on the Stratix 5700™ switches with PTP support (certain ports only).
- **Two Ethernet modules** in the mobile ControlLogix® chassis **-** in this design (sometimes called a CIP bridge) the mobile PAC uses a dedicated Ethernet module for motion drive control. This Ethernet module operates as an additional BC in the CIP Sync architecture. The downside of this approach is that devices on the second Ethernet module are not accessible via the web page or other protocol other than CIP.

CIP Sync Configuration

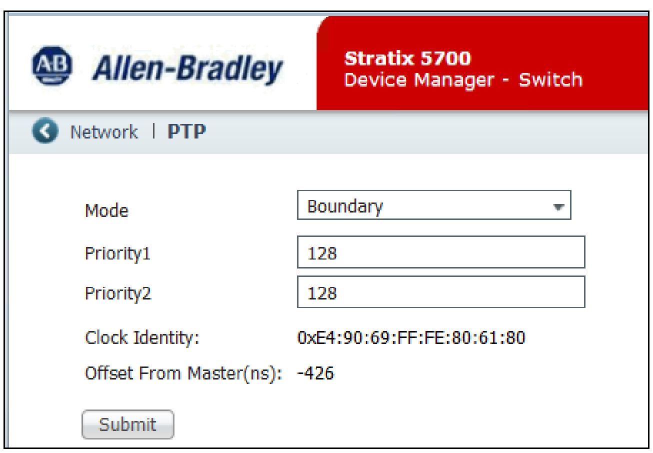
For general information on how to configure CIP Sync, refer to the documents referenced above. This section provides guidelines on how to configure PTP parameters on switches and some of the best practices in order to improve performance and reliability of CIP Sync with wireless media.

Switch Configuration

1.) Configure all Stratix® switches using the Express Setup procedure and apply appropriate Smartport macros to interfaces. This step helps to apply the correct QoS configuration and policy.

2.) Configure switches on the mobile equipment (behind the WGB) as the PTP Boundary Clock.

Figure 3 Boundary Clock Configuration



The CLI command to enable boundary clock is:

```
ptp mode boundary
```

3. Enable the adaptive PDV filter on the mobile switches (CLI only):

```
ptp transfer filter adaptive
```

By default, the BC uses a linear feedback controller that provides a small amount of PDV filtering and converges in an average amount of time. The **adaptive PDV filter** provides high quality time synchronization in the presence of large PDV over wireless media and switches that do not support PTP.

Note: The adaptive PDV filtering algorithm converges more slowly than a default linear filter. This should be considered during the system startup and network changes.

4. Disable IGMP querier on the *mobile* switches (CLI only):

   ```
   no ip igmp snooping querier
   ```

5. Verify that all other switches in the data path support PTP and are configured as BC or end-to-end transparent clocks.
6. Configure PTP VLAN on all *trunk* ports of the BC switches (if configured in the wired topology). This should be the VLAN with the IACS application traffic. By default, PTP traffic is sent on the native VLAN.
7. Verify that IGMP snooping is enabled on all switches, and at least one IGMP querier is present in the network. The default Stratix® switch configuration should provide that. Usually, the Layer 3 switch is the querier.

For information on Stratix® switch configuration refer to this publication:

Stratix® Managed Switches User Manual
http://literature.rockwellautomation.com/idc/groups/literature/documents/um/1783-um007_-en-p.pdf

Master Clock Configuration

1. Use the highest quality clock as a GM. Use the most reliable and stable time source, for example a GPS signal rather than an NTP server if available.
2. Manually configure the lowest PTP priority for the GM. In some cases, a network may have a primary and a backup GM based on the priority. One example is the system with two switches configured as hybrid GM / boundary clocks.
3. Reduce clock sync interval on the master clock in the *wired* network if the device allows it. Smaller sync interval may speed up the convergence during the startup and also improve clock jitter across the wireless.
   - The default sync interval on ControlLogix® controllers and Stratix® switches is 1 second (value “0” on the base 2 logarithmic scale)
   - Sync interval on a Stratix® switch port can be configured as low as 0.25 seconds (value “-2”)
   - Sync interval on the ControlLogix® EN2TR modules can be changed to 0.5 seconds using a MSG instruction (see publication IA-AT003, appendix B on how to change CIP Sync attributes).

Switch Diagnostics

This section describes some of the CLI commands and output examples that provide PTP diagnostic on Stratix® switches. Note that same PTP information can be obtained and used by a Logix program by sending a CIP message to the switch.

show ptp clock

This command displays the PTP clock information on the switch, including the clock type and PDV filter mode.

```
5700-Mobile#show ptp clock
 PTP CLOCK INFO
  PTP Device Type: Boundary clock
  PTP Device Profile: Default Profile
  Clock Identity: 0xE4:90:69:FF:FE:80:61:80
  Clock Domain: 0
  Number of PTP ports: 10
```

```
Time Transfer: Adaptive Filter
Priority1: 128
Priority2: 128
Clock Quality:
      Class: 248
      Accuracy: Unknown
      Offset (log variance): N/A
Offset From Master (ns): 0
Mean Path Delay (ns): 0
Steps Removed: 2
Local clock time: 16:57:32 UTC Jun 6 2016
```

show ptp parent

This command provides the information about the parent (master) clock and the Grandmaster clock. Depending on the topology, the master clock can be the upstream BC switch, the Ethernet module in the GM chassis or same as the GM clock. In a stable network, this information should not change.

```
5700-Mobile#show ptp parent
 PTP PARENT PROPERTIES
  Parent Clock:
  Parent Clock Identity: 0x0:0:BC:FF:FE:60:3C:E
  Parent Port Number: 2
  Observed Parent Offset (log variance): N/A
  Observed Parent Clock Phase Change Rate: N/A

  Grandmaster Clock:
  Grandmaster Clock Identity: 0xFF:FF:0:1:0:81:EC:2E
  Grandmaster Clock Quality:
        Class: 187
        Accuracy: Within 10s
        Offset (log variance): N/A
        Priority1: 1
        Priority2: 128
```

show ptp port

This command shows the PTP state of the switch port, as well as various PTP parameters and timers. Examples below show information about a master port and a slave port on a BC switch. As with the previous command, the information here helps to identify any incorrect clock assignments in the network.

```
5700-Mobile#show ptp port gi1/2
 PTP PORT DATASET: GigabitEthernet1/2
  Port identity: clock identity: 0xE4:90:69:FF:FE:80:61:80
  Port identity: port number: 10
  PTP version: 2
  Port state: MASTER
  Delay request interval (log mean): 5
  Announce receipt time out: 3
  Announce interval (log mean): 1
  Sync interval (log mean): 0
  Delay Mechanism: End to End
  Peer delay request interval (log mean): 0
  Sync fault limit: 500000000
  Port VLAN Id: 10

5700-Mobile#show ptp port fa1/2
 PTP PORT DATASET: FastEthernet1/2
  Port identity: clock identity: 0xE4:90:69:FF:FE:80:61:80
  Port identity: port number: 2
  PTP version: 2
  Port state: SLAVE
  Delay request interval (log mean): 5
  Announce receipt time out: 3
  Announce interval (log mean): 1
  Sync interval (log mean): 0
  Delay Mechanism: End to End
  Peer delay request interval (log mean): 0
  Sync fault limit: 500000000
```

During network changes or immediately after rebooting the BC switch, you may see the slave PTP port in the *Uncalibrated* state. This means that the BC clock on the switch is not yet converged with the master upstream. The application should monitor this state and possibly delay the operation until the clock converges.

```
5700-Mobile#show ptp port fa1/3
 PTP PORT DATASET: FastEthernet1/3
  Port identity: clock identity: 0xE4:90:69:FF:FE:80:61:80
  Port identity: port number: 3
  PTP version: 2
  Port state: UNCALIBRATED
```

Summary

Use of CIP Sync technology with wireless media is possible for certain classes of applications with not very strict requirements for clock synchronization accuracy. Architecture, hardware selection and proper switch configuration can improve the reliability and accuracy of CIP Sync operation.

www.rockwellautomation.com

Power, Control and Information Solutions Headquarters

Americas: Rockwell Automation, 1201 South Second Street, Milwaukee, WI 53204-2496 USA, Tel: (1) 414.382.2000, Fax: (1) 414.382.4444
Europe/Middle East/Africa: Rockwell Automation NV, Pegasus Park, De Kleetlaan 12a, 1831 Diegem, Belgium, Tel: (32) 2 663 0600, Fax: (32) 2 663 0640
Asia Pacific: Rockwell Automation, Level 14, Core F, Cyberport 3, 100 Cyberport Road, Hong Kong, Tel: (852) 2887 4788, Fax: (852) 2508 1846

Publication ENET-WP014A-EN-P– August 2016