Technical White Paper

Industrial Communication Protocol Support for Arm®-based Microcontrollers and Processors

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ABSTRACT

Industrial communication protocols connect management and control systems to factory floor equipment, enabling the continuous collection and exchange of process data. This process data is used make real-time control decisions as well as longer term process optimizations resulting in lower factory costs through increased throughput, product quality, and equipment utilization rates.

This paper provides an overview of the industrial communication protocol support options for TI's AM243x and AM64x series of Arm®-based microcontrollers (MCUs) and processors. EtherCAT®, PROFINET®, EtherNet/IP™, HSR, PRP, and TSN support options are covered.

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1 Introduction

EtherCAT, PROFINET, EtherNet/IP and Time-Sensitive Networking (TSN) are rapidly gaining market share in the industrial communications market due to the high bandwidth, reliability, and real-time deterministic performance. These protocols are commonly used in factory automation and control applications such as Programmable Logic Controllers (PLCs), motor control, robotics, factory management systems, and field sensors and actuators.

High-availability Seamless Redundancy (HSR) or Parallel Redundancy Protocol (PRP) are high-availability Ethernet protocols that maintain network operation in the event of a node or link failure. HSR and PRP are found in networks such as the electrical grid that run 24 hours a day, 7 days a week and cannot afford any downtime.

TSN is a relatively new set of IEEE 802.1 standards that add real-time, deterministic services to Ethernet networks. TSN supports factory automation and control applications as well as high-availability applications. Many believe TSN is the dominant industrial communication technology of the future.

The AM243x and AM64x series of Arm-based MCUs and processors were specifically designed to support industrial communication protocols. Both series have dual-gigabit industrial communication subsystems (ICSSG), multiple 1Gbps Ethernet ports, and multiple Arm CPU cores to support industrial communication protocols and applications such as real-time control loops.

2 Industrial Communications Terminology

Unfortunately, different protocols use different terminology to reference the two types of devices attached to a industrial network. For example, EtherCAT uses the terms main and sub-device while EtherNet/IP uses scanner and adapter. Texas Instruments (TI) uses the terms ***Controller*** and ***Device*** throughout this paper.

Table 2-1. Industry Terminology by Protocol

Texas Instruments	***Controller***	***Device***
EtherCAT	Main	Sub-device
PROFINET	***Controller***	***Device***
EtherNet/IP	Scanner	Adapter
CC-Link	***Controller***	***Device***

An industrial communication network typically has a single ***Controller*** whose job is to mange and control the various network ***Devices***. Process data is continuously exchanged between the ***Controller*** and network ***Devices*** and is used to make real-time process control decisions as well as longer term process optimizations. The ***Controller*** can perform advanced analysis of the process data, utilizing machine learning algorithms or can simply issue commands based on simple analog or digital feedback from the field ***Devices.*** An example of an advanced ***Controller*** function is multi-axis motion planning of a robotic arm whose motion is controlled via multiple servo motors (***Devices***).

From a hardware perspective, ***Controllers*** run on standard compliant Ethernet ports while ***Devices*** typically require special Ethernet hardware.

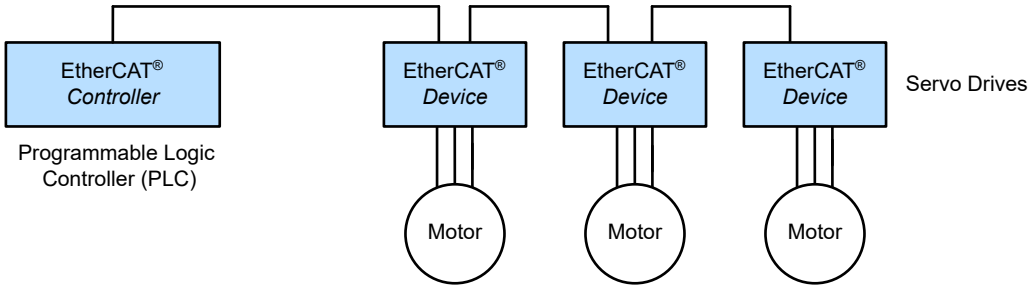

Figure 2-1. Example Network Showing Both *Controller* and *Devices*

3 Industrial Communication Feature Support

The AM243x MCU and AM64x processor series include a number of different configurations that support a broad range of application and performance requirements. The number of processing CPU cores, industrial communication support, peripheral mix, and functional safety support vary based on the device option selected.

The level of industrial communication support for a given AM243x MCU or AM64x processor is indicated by the feature code of the device, which is the ninth digit of the part number. There are four levels of support indicated by the letters **C**, **D**, **E**, and **F**. For example, the "**F**" in the part number AM6442BS***F***GHAALV indicates that the device supports industrial communication protocols and includes TI's industrial communication software stacks.

Table 3-1 lists the industrial communication feature options and associated hardware and software support available for the AM243x and AM64x series.

Table 3-1. Industrial Communication Product Feature Options

Feature Option	Feature	Comment
C	2 × programmable real-time unit subsystems	Up to 80 real-time GPIOs with 3-ns toggles and 6-ns ISR. Direct connect to ADCs or other devices eliminating the need for small FPGAs. Industrial communication protocols, standard Ethernet and motor control features are not enabled but the CPSW Ethernet switch is enabled.
D	Option C + hardware support for industrial communication protocols	Adds support for the ICSSG industrial communication feature set which includes support for industrial communications via 4 × ICSSG 10/100/1000 Ethernet MAC ports (MII and RGMII interfaces), 36 × sigma delta decimation filters, and 12 × multiprotocol encoder interfaces (HDSL, EnDAT 2.2, Tamagawa, and so forth) **Note** ICSSG feature set support is dependent on how the device is configured and corresponding availability of pins and pin MUX options.
E	Option D + EtherCAT and CAN-FD support	Adds EtherCAT ***Device*** hardware accelerator and CAN-FD support; EtherCAT ***Device*** and CAN-FD licenses are included in purchase price. Feature option E or F is required to run the EtherCAT ***Device*** protocol
F	Option E + TI industrial communication protocol software	Includes EtherNet/IP, EtherCAT, PROFINET RT and IRT ***Device***, and IO-Link ***Controller*** certified industrial networking software stacks (R5F binaries)

The following definitions are provided for reference:

CPSW Stands for **C**ommon **P**latform **SW**itch. The CPSW supports up to 2 × independent 10/100/1000Mbps Ethernet MACs or a single 3-port 10/100/1000Mbps Ethernet switch (2 external + 1 internal port). The CPSW module supports TSN.

ICSSG Stands for **I**ndustrial **C**ommunication **S**ub**S**ystem **G**igabit. The ICSSG is a software programmable real-time processing module with Ethernet and industrial communication hardware accelerators. The ICSSG supports 10/100/1000Mbps Ethernet and industrial communication ***Device*** protocols. Each ICSSG module can support up to 2 × independent Ethernet ports or a single 3-port Ethernet switch (2 external + 1 internal port). TI provides ICSSG firmware binaries for many industrial communication protocols in the Software Development Kit (SDK) which can be run on device feature option **F**. The ICSSG module supports TSN.

Figure 3-1 shows the key functional blocks of the AM64x processor that support industrial communication protocols. The AM243x MCU is identical to the AM64x processor, except the AM243x does not have the Arm® Cortex® -A53 CPU cores and therefore cannot support Linux®-based protocol software stacks.

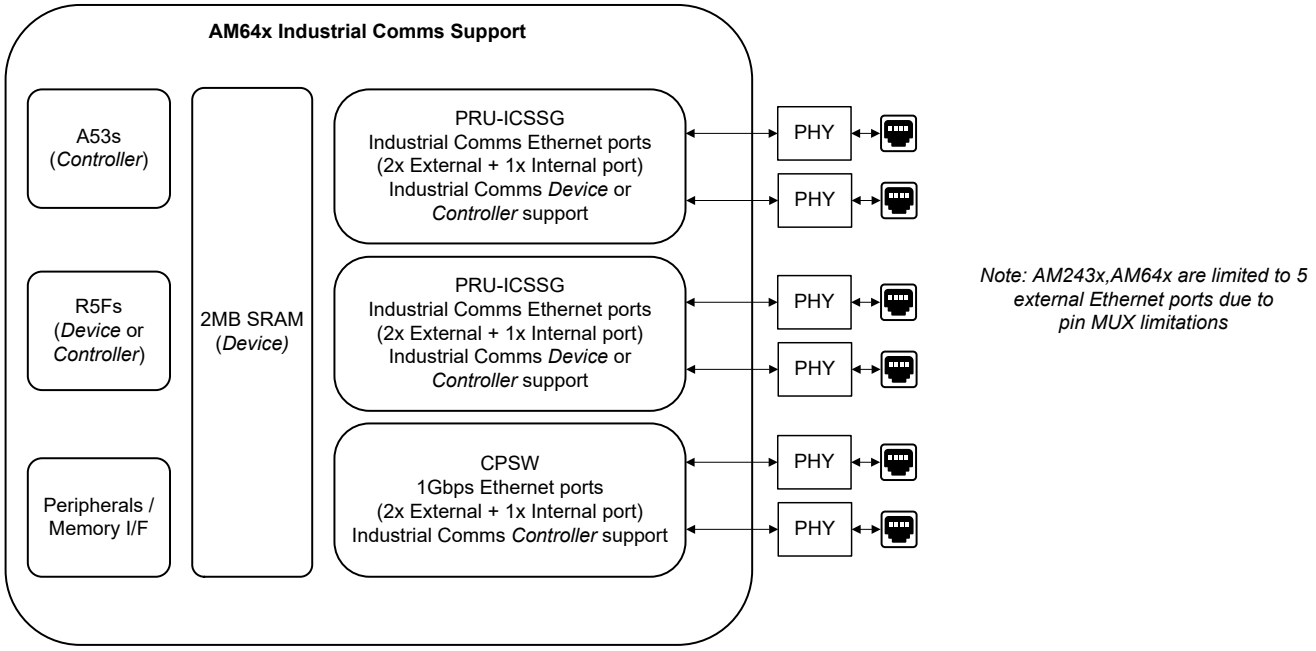

Figure 3-1. AM64x Block Diagram

The AM64x block diagram is described in the following list:

- AM64x, AM243x support up to 5 × 1Gbps Ethernet ports (There are 6 Ethernet MACs but due to pin MUX limitations only 5 external ports can be supported)
- PRU-ICSSG is a firmware-based module that supports 1Gbps ***Device***, ***Controller***, TSN, and standard Ethernet. Can be configured as a 3-port switch (2 × external + 1 × internal port) or 2 independent ports.
- CPSW is a hard IP Ethernet module that supports1Gbps ***Controller***, TSN, and standard Ethernet. Can be configured as 3-port switch (2 × external + 1 × internal port) or 2 independent ports.
- Industrial Communication ***Device*** protocols run on the R5Fs
- Industrial Communication ***Controller*** protocols run on either A53s or R5Fs
- 1Gbps HSR and PRP only runs on the PRU-ICSSG and A53
- When configured as a switch, both the PRU-ICSSG and CPSW support cut-through switching.

4 Industrial Communications *Device* Support

Both the AM243x MCU and AM64x processor series have options that include industrial communication ***Device*** protocol software stacks provided by TI, in addition to those available through third parties. The TI-provided protocol stacks are included with the purchase of device feature option F, as shown in Table 3-1, and have been certified on AM243x, AM64x evaluation hardware. Third-party stacks are supported on device feature options D, E, and F.

TI Protocol Software Stacks	Third-party Protocol Software Stacks
Fully bundled solution directly from TI	Stacks licensed from third parties
One license for all TI-offered stacks	Separate license per protocol
Licensing included with product purchase	Licenses available as buyout, per project, and per family
Stack support directly from TI	Stack support from third party
Stack certified using TI EVM	Certified solutions
Purchase AM243x or AM64x product feature F	Purchase AM243x or AM64x product feature D, E, or F

Figure 4-1. AM243x, AM64x Industrial Communication Software Support Options

All ***Device*** protocols run on one of the Arm Cortex-RF5 CPU cores (FreeRTOS) and require an ICSSG module (***Device*** protocols do not run on the CPSW Ethernet switch).

Product feature options **E** and **F** include an EtherCAT ***Device*** license and on-chip EtherCAT ***Device*** hardware accelerator. (**E** and **F** are the only two options that can run EtherCAT ***Device*** software.)

Table 4-1 lists the software stacks included with the purchase of option **F**. Demonstration versions and example application code of the ***Device*** protocols can be found in the AM243x SDK and AM64x SDK. Table 4-2 lists the third parties providing ***Device*** protocol support for the AM243x and AM64x.

Table 4-1. TI Provided *Device* Software (Option F)

Protocol Support	Minimum Cycle Time	Key Features Supported
EtherCAT ***Device***	31.25 µs	CiA402, CAN over EtherCAT (CoE), Servo Drive Profile (SoE), Ethernet over EtherCAT (EoE), File Access over EtherCAT (FoE), Distributed Clocks
EtherNet/IP ***Device***	1 ms	Address Conflict Detection (ACD), Quality of Service (QoS), Device Level Ring (DLR), Precision Time Protocol (PTP)
PROFINET ***Device***	1 ms (RT) 250 µs (IRT)	Conformance Class A, B (RT), and C (IRT), Precision Time Control Protocol (PTCP), Media Redundancy Protocol (MRP)

Table 4-2. 3rd Party *Device* Software Options

3rd Party	Website
Cannon-Automata	www.cannon-automata.com
CouthIT	www.couthit.com
Kunbus	www.kunbus.com
Molex	www.molex.com
Port	www.port.de
TMG	www.tmgte.de

For additional information on TI's third party network, please see TI's Partner directory.

Table 4-3 lists the AM243x and AM64x device options that include TI software stacks.

Table 4-3. AM243x, AM64x Device Options With TI-provided Software (Option F)

Device	Type	CPU Cores	Speed Grades	TSN	EtherCAT *Device*	PROFINET *Device*	EtherNet/IP *Device*	IO-Link *Controller*
AM2432	MCU	2 × R5F	800 MHz and 400 MHz	x	x	x	x	x
AM2434	MCU	4 × R5F	800 MHz	x	x	x	x	x
AM6421	Processor	1 × A53 2 × R5F	A53: 1 GHz R5F: 800 MHz	x	x	x	x	x
AM6441	Processor	1x A53 4x R5F	A53: 1 GHz R5F: 800 MHz	x	x	x	x	x
AM6442	Processor	2x A53 4x R5F	A53: 1 GHz R5F: 800 MHz	x	x	x	x	x

For additional information on the industrial communication protocols supported, see the *Industrial Communication Protocols Supported on Sitara™ Processors and MCUs* application note.

5 Industrial Communications *Controller* Support

Texas Instruments has worked closely with a number of third parties to support industrial communication ***Controller*** protocols on the AM243x MCUs and AM64x processors. Most ***Controller*** protocols do not require special Ethernet MAC hardware and can run on any of the AM243x and AM64x device options, using either the CPSW or ICSSG.

Table 5-1 lists AM243x and AM64x third party ***Controller*** software support options.

Table 5-1. 3rd Party *Controller* Software Options

3rd Party	Family	Web Site
Acontis	AM64x AM243x	www.acontis.com
Cannon Automata	AM64x	www.cannon-automata.com
Codesys	AM64x	www.codesys.com
CouthIT	AM64x	www.couthit.com
IBV	AM64x AM243x	www.ibv-augsburg.de
Molex	AM64x	www.molex.com
Port	AM64x	www.port.de
TMG	AM64x	www.tmgte.de

For additional information on TI's third party network, see TI's Partner directory.

Table 5-2 lists the ***Controller*** software stacks included with the purchase of feature option F. Demonstration versions and example application code of the ***Controller*** protocols can be found in the AM243x SDK and AM64x SDK.

Table 5-2. TI-Provided *Controller* Software (Option F)

Protocol Support	Minimum Cycle Time	Key Features Supported
IO-Link ***Controller***	All communication classes supported	Up to 8-channel IO-Link ***Controller*** per ICSSG, IO-Link standard-compliant with Standardized Master Interface (SMI)

6 PRP Support

Rapid Spanning Tree Protocol (RSTP) and Media Redundancy Protocol (MRP) are two common protocols used in Ethernet networks supporting high-availability applications. Recovery time from a fault with RSTP is measured in seconds while recovery time with MRP is measured in milliseconds. For most networks, these recovery times are more than adequate. But for mission critical networks that require zero recovery time and zero downtime, protocols such as PRP and HSR are often used.

PRP is an IEC standard (IEC 62439-3 clause 4) that protects Ethernet networks against single point failures, providing high-availability operation with zero downtime. PRP networks can remain operational in the event of a node or link failure as well as during equipment maintenance or replacement cycles.

PRP provides high-availability service by using two independent networks. A PRP node has two Ethernet ports with identical MAC addresses and is referred to as a dual attached node (DAN). Each Ethernet port is connected to one of two independent networks. When a node needs to communicate with another node, the node sends duplicate frames via the two networks to the destination node. Upon receipt, the destination node passes the 1st frame to the application layer and drops the 2nd frame.

Single-port Ethernet equipment can be connected to the PRP network through the use of a redundancy box (RedBox) which connects to both networks. Single-port nodes are referred to as single-access nodes (SAN).

One of the disadvantages of a PRP network is the need for two independent networks and the resulting high cost. The total cost of a PRP network is somewhat offset by the use of standard off-the-shelf 802.1-compliant networking equipment.

PRP is referenced in the IEC 61850 standard for use in electrical substations.

The AM243x SDK includes support for 100Mbps PRP and the AM64x SDK includes support for 1Gbps PRP. See Table 9-1 and Table 9-2 for details.

Figure 6-1 illustrates the source node sending duplicate frames simultaneously to two independent networks. If there is a failure point in one of the two networks, there is still a path for one of the frames to arrive at the destination node.

Figure 6-2 shows a SAN connecting to the PRP network via a RedBox.

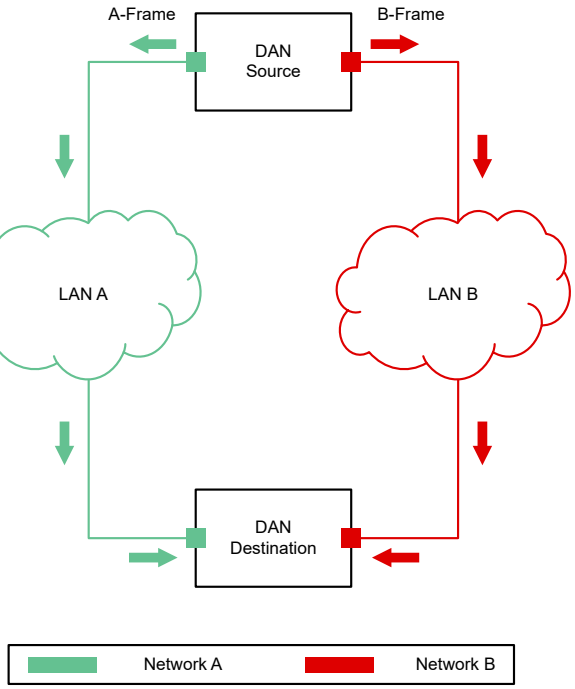

Figure 6-1. PRP Network Example

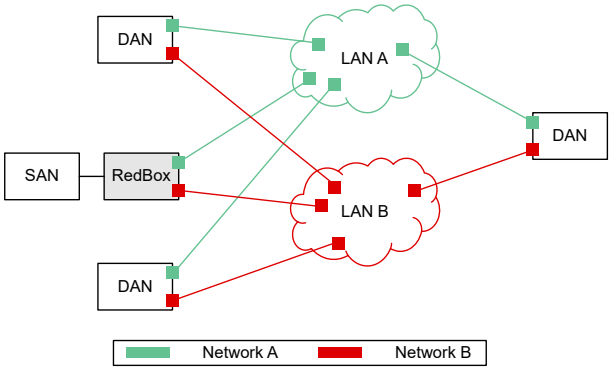

Figure 6-2. SAN Connection to a PRP Network

7 HSR Support

HSR (IEC 62439-3 Clause 5), like PRP supports high-availability, zero down time networks. But instead of two independent networks, HSR uses a ring topology. When a node needs to use the network, the node sends duplicate Ethernet frames in opposite directions on the ring. The 1st frame received by the destination node is passed to the application layer while the 2nd frame is dropped.

In a ring topology, the forwarding delay of each node is a critical. Forwarding delay is the time required to receive and then transmit the frame back out onto the ring. As network size increases, the number of nodes increases, and thus the total latency increases. To reduce latency to acceptable levels, high-speed cut-through switching is required.

Similar to a PRP network, HSR provides high-availability service with zero recovery time and can remain operational during maintenance or equipment replacement cycles. If a non-HSR compliant device needs to connect to the HSR network, a RedBox can be used.

One of the disadvantages of an HSR network is that special hardware is required to support the HSR cut-through switching, adding to the cost of the network. Historically, FPGAs have been used in HSR networks, but FPGAs tend to be expensive. Off-the-shelf processor options like the AM64x that can support high-performance cut-through switching are helping to reduce HSR deployment costs.

HSR is referenced in the IEC 61850 standard for use in electrical substations.

The AM243x SDK includes support for 100Mbps HSR and the AM64x SDK includes support for 1Gbps HSR. See Table 9-1 and Table 9-2 for details.

Figure 7-1 illustrates a source node sending two copies of the frame simultaneously in both directions on the ring. If there is a failure point in one of the connecting network links or nodes, there is still a path for one of the frames to arrive at the destination node.

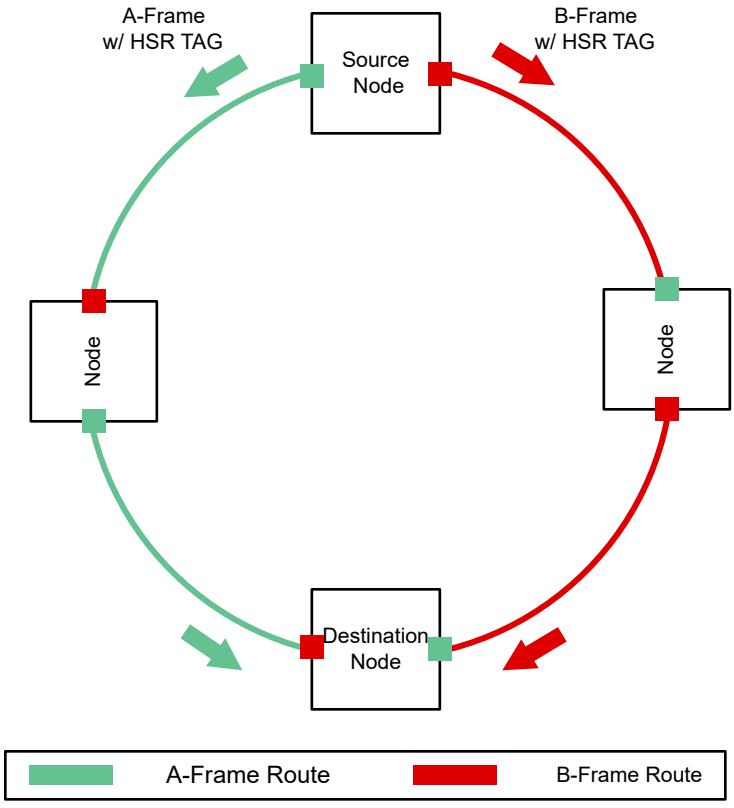

Figure 7-1. HSR Network Example

8 TSN Support

TSN is collection of IEEE standards developed by the 802.1 Working Group (WG) that adds real-time, deterministic services to Ethernet networks. TSN offers similar levels of performance in terms of determinism and reduced latency as found in current industrial communication protocols but adds additional features, flexibility, and the advantage of being an IEEE standard. TSN was developed to support industrial, automotive, aviation and aerospace, and audio, video networks.

TSN enables the convergence of information technology (IT) and operation technology (OT) networks, with real-time and non-real-time traffic sharing a common network at Gbps speeds.

The individual TSN standards can be grouped into 4 categories of service:

1. **Time Synchronization**: To support real-time, deterministic networking services, each network element must share a common definition of time. 802.1 AS-2020 is based on IEEE 1588v2 PTP and provides timing synchronization based on a Grand Master timing source to within < ±1 µs.
2. **Real-time determinism**: 802.1AS-2020 along with traffic shaping, double buffering and bridge synchronization, frame preemption, and cut-through switching support real-time deterministic traffic as well as non-time-critical traffic on the same network. IT and OT traffic can share a common network significantly reducing deployment and network management costs.
3. **High-Availability Networking**: TSN supports high-availability, zero down time performance similar to HSR and PRP.
4. **Network Management and Configuration:** TSN defines a common network management and configuration method using industry standard YANG data models and NETCONF to simplify and reduce network management costs. Both IT and OT network traffic can be managed via a common tool set.

Figure 8-1 lists the current published TSN standards grouped by function. Which individual standards get implemented in a network depend on the performance and feature set requirements of the network. Many current TSN networks support only 802.1AS-2020 (Time Synchronization) and 802.1Qav (Credit Based Traffic Shaping).

The TSN Task Group is working on additional standards as well as amendments to the existing standards. Access to the draft standards is available to IEEE 802.1 WG members on the IEEE 802.1 website.

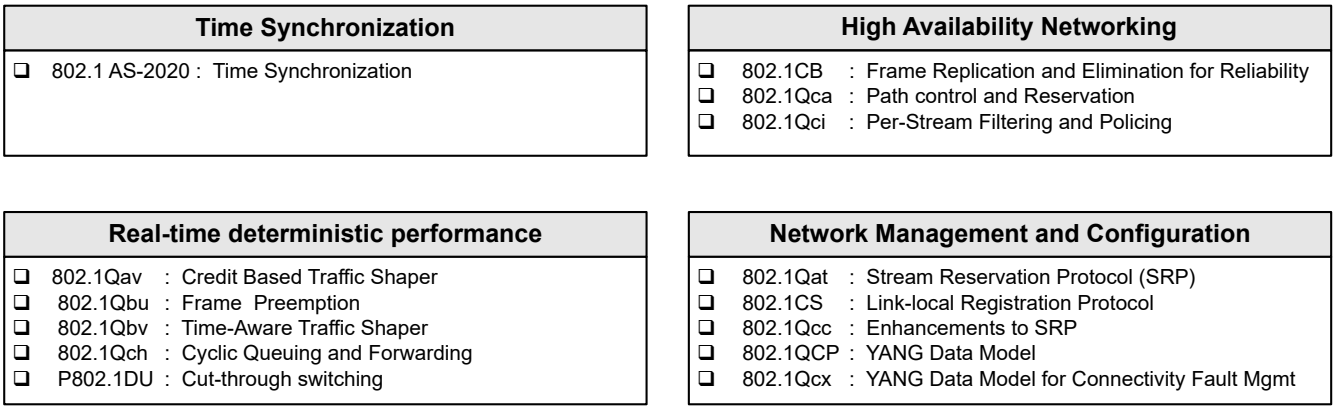

Figure 8-1. TSN Standard Groupings

Today's industrial communication protocols are being modified to coexist with TSN. The idea is to use TSN at layers 1 and 2 of the OSI model and implement the industrial communication protocol at layers 3–7. This provides the best of both worlds, extending the life of existing industrial protocols and leveraging industry standards to reduce equipment costs and simplify hardware development. Examples include PROFINET over TSN, EtherNet/IP over TSN, OPC UA over TSN, and CC-Link IE TSN.

TSN is supported on all AM243x and AM64x device options (on both the CPSW and ICSSG). For the specific TSN standards supported, please see the AM243x SDK and AM64x SDK . Table 9-1 and Table 9-2 summarize AM243x and AM64x TSN support.

For additional information on TSN, see the *Time Sensitive Networking for Industrial Automation* white paper.

9 Summary

Industrial communication protocols are a critical element of the modern factory, connecting factory equipment to control and management systems to improve production efficiency and lower total cost of ownership. The AM243x MCU and AM64x processor series support a number of different industrial protocols provided directly by TI or through a robust third party ecosystem. Table 9-1 summarizes the AM243x industrial protocol support while Table 9-2 summarizes the AM64x industrial communications protocol support.

Table 9-1. AM243x Industrial Communications Support Summary

Protocol	10/100/1Gbps Support	TI SDK or 3rd Party	ICSSG Support	CPSW Support	R5F Support
HSR(1)	10/100Mbps	TI SDK	Yes	No	Yes
PRP(1)	10/100Mbps	TI SDK	Yes	Yes	Yes
TSN	Yes	TI SDK	Yes	Yes	Yes (FreeRTOS)
Industrial communications ***Device***	Yes	TI SDK (feature option F) or 3rd Party	Yes	No	Yes (FreeRTOS)
Industrial communications ***Controller***	Yes	3rd Party	Yes	Yes	Yes (FreeRTOS)

(1) 1Gbps HSR, PRP support planned for the future. Please check on current software status via TI's E2E

Table 9-2. AM64x Industrial Communications Support Summary

Protocol	10/100/1Gbps Support	TI SDK or 3rd Party	ICSSG Support	CPSW Support	A53 Support	R5F Support
HSR	Yes	TI SDK	Yes	No	Yes (Linux)	10/100Mbs
PRP	Yes	TI SDK	Yes	Yes	Yes (Linux)	10/100Mbps
TSN	Yes	TI SDK	Yes	Yes	Yes (Linux)	Yes (FreeRTOS)
Industrial communications ***Device***	Yes	TI SDK (feature option F) or 3rd Party	Yes	No	No	Yes (FreeRTOS)
Industrial communications ***Controller***	Yes	3rd Party	Yes	Yes	Yes (Linux)	Yes (FreeRTOS)

10 Additional Resources

1. Texas Instruments, *AM64x/AM243x Evaluation Module* User's Guide
2. Texas Instruments, *AM243x Industrial Communications Evaluation Module*
3. Texas Instruments, *AM64x Industrial Communications Evaluation Module*
4. Texas Instruments, *Industrial Communication Protocols Supported on Sitara™ Processors and MCUs* Application Note
5. Texas Instruments, *Time Sensitive Networking for Industrial Automation* White Paper
6. Texas Instruments, *Partner Directory*
7. Texas Instruments, *AM243x Software Development Kit (SDK)*
8. Texas Instruments, *AM64x Software Development Kit (SDK)*

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