Application Note

TI Sitara Processors Multi-Protocol Industrial Communication Designs

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ABSTRACT

Industrial automation systems impose increasingly critical requirements for deterministic, low-latency real-time communication. Texas Instruments (TI) Sitara processor series integrate industry-leading Programmable Real-Time Unit Industrial Communication Subsystem (PRU-ICSS), providing a unified hardware platform supporting multiple mainstream industrial Ethernet protocols, including EtherCAT, PROFINET and EtherNet/IP. This document describes the fundamental principles of industrial communication protocols, market development trends, underlying technical mechanisms of common protocols, and TI processors' protocol support capabilities and performance metrics, providing industrial equipment manufacturers with a comprehensive multi-protocol design reference.

Table of Contents

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1 Introduction

The core of industrial automation systems is achieving reliable and efficient communication between various components. Although traditional serial fieldbus protocols used in industrial environments (such as PROFIBUS, CAN, Modbus, and so on) are technologically mature, the protocols suffer from bandwidth limitations, poor scalability, and high latency. With the rapid development of Industry 4.0 and intelligent manufacturing, industrial Ethernet protocols have emerged and gradually become the standard communication infrastructure for industrial automation.

Multi-protocol coexistence is a common phenomenon in industrial systems. The different preferences for protocols across different regions and customers present a challenge for equipment manufacturers: how to use a unified hardware platform to support multiple protocols. TI has addressed this challenge by integrating the PRU-ICSS subsystem into Sitara processors, implementing a flexible and efficient multi-protocol communication engine and providing industrial equipment manufacturers with an integrated design.

2 Overview of Industrial Communication Protocols

2.1 Components of Industrial Communication Systems

Industrial automation systems consist of four main elements:

- PLC Controller: The brain of the system, providing logic control, motion control, and process control functions
- HMI Panel: Human-machine interface for operator command input and feedback output
- Industrial Drives: Motor controllers that execute motion and action commands
- Sensors: Real-time monitoring of system status and providing feedback data

These elements work together through communication networks to achieve efficient automated production.

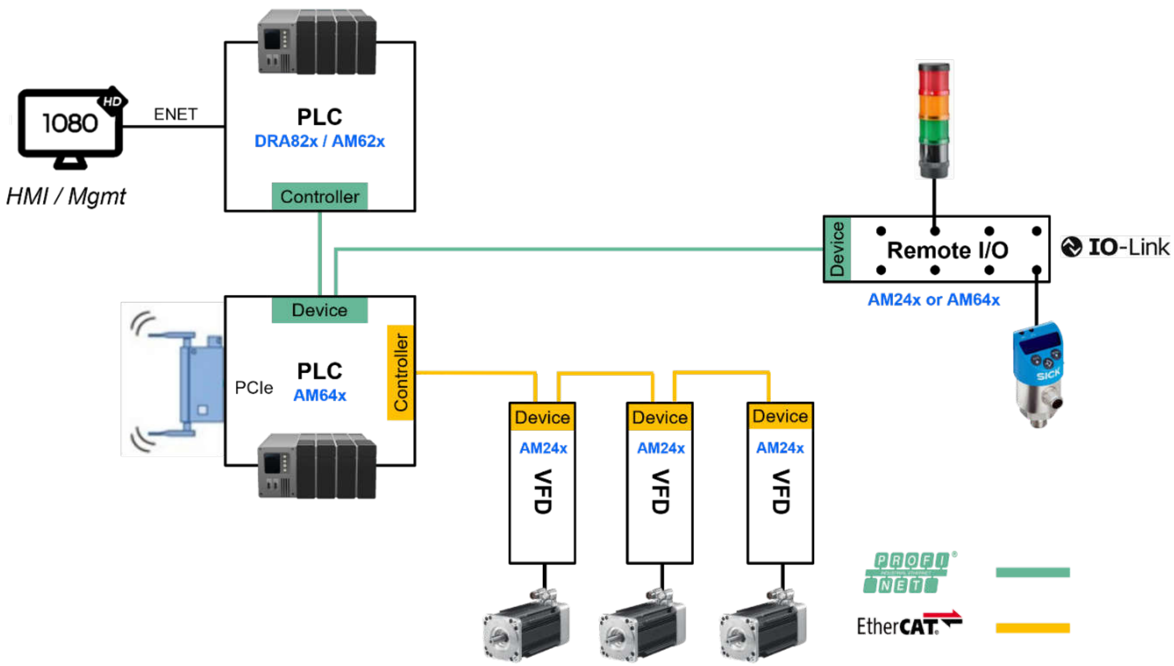

Figure 2-1. Industrial Automation System Topology Diagram

2.2 Evolution from Serial Fieldbus to Industrial Ethernet

Traditional industrial communication protocols are based on low-speed serial interfaces, including

Table 2-1. Traditional Industrial Communication Protocols and Key Features

Protocol	Data Rate	Node Count	Primary Applications
PROFIBUS	12Mbps	126 nodes	Factory automation
CAN	1Mbps	64-127 nodes	Automation systems
Modbus	115K baud	247 nodes	General control
CC-Link	10Mbps	64 nodes	Asian applications

As industrial Ethernet proliferates, multiple IEEE 802.3-based industrial protocols have emerged, providing higher bandwidth, lower latency, better scalability, and network flexibility.

3 Market Trends and Multi-Protocol Requirements

3.1 Market Scale of Industrial Ethernet

According to data from the PROFIBUS & PROFINET International (PI) association, 9.625 million new PROFINET nodes were added in 2024, demonstrating widespread adoption of industrial Ethernet protocols. The global industrial communication market (including PROFINET, EtherCAT, EtherNet/IP, and other protocols) totals $25.5 billion PROFINET_RT_IRT_Deepdive and shows continuing growth.

3.2 Reality of Multi-Protocol Coexistence

In practical industrial applications:

- **Regional Differences:** North American regions tend to select EtherNet/IP; European regions favor PROFINET and EtherCAT; Asian regions feature multiple coexisting protocols.
- **Industry Characteristics:** Motion control applications tend to select EtherCAT or PROFINET IRT; general I/O applications can choose from multiple protocols.
- **Supply Chain Requirements:** Original equipment manufacturers or tier-one suppliers often require multi-protocol support to adapt to global supply chains.

3.3 Necessity of Unified Platforms

To address multi-protocol requirements, industrial equipment manufacturers need:

1. **Single hardware design** supporting multiple protocols
2. **Protocol selection through firmware switching or boot parameters**
3. **Complete software stacks, drivers, and development tools**
4. **Single-vendor technical support**

This reduces product development costs, shortens time-to-market, and simplifies the complexity of global support.

3.4 Core Value of TI's Multi-Protocol Design

Scalability and Reusability

- Unified hardware platform supporting all Ethernet-based protocols.
- Same development toolchain and SDK applicable to different protocols.
- Single-point-of-contact vendor support.

Development Efficiency

- Pre-certified protocol stacks enabling rapid application development.
- Complete sample code and reference designs accelerating development cycles.
- Typically only one file needs modification to begin customized application development.

Future Protection

- ICSS + PRU architecture supporting new low-level features without requiring new SOC.
- Flexible firmware update mechanism supporting protocol standard evolution.
- Long-term support policy verifying stable product lifecycle.

4 Technical Introduction of Mainstream Industrial Protocols

4.1 EtherCAT (Ethernet for Control Automation Technology)

Operating Principle

EtherCAT employs an *on-the-fly processing* mechanism:

- **Master Transmission:** The EtherCAT master generates telegrams containing one or more datagrams, transmitted through a single Ethernet frame.
- **Slave Processing:** As the frame passes through each slave, it reads data intended for the frame in hardware fashion, executes commands, writes return data back into the frame, and updates the CRC.
- **Frame Forwarding:** The slave forwards the entire frame out through the second Ethernet port.

This mechanism eliminates the inefficiency inherent in traditional Ethernet where the master must communicate separately with each slave.

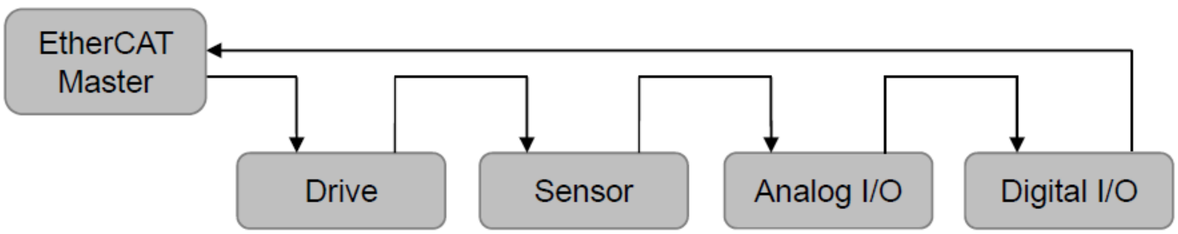

Figure 4-1. Example EtherCAT Network

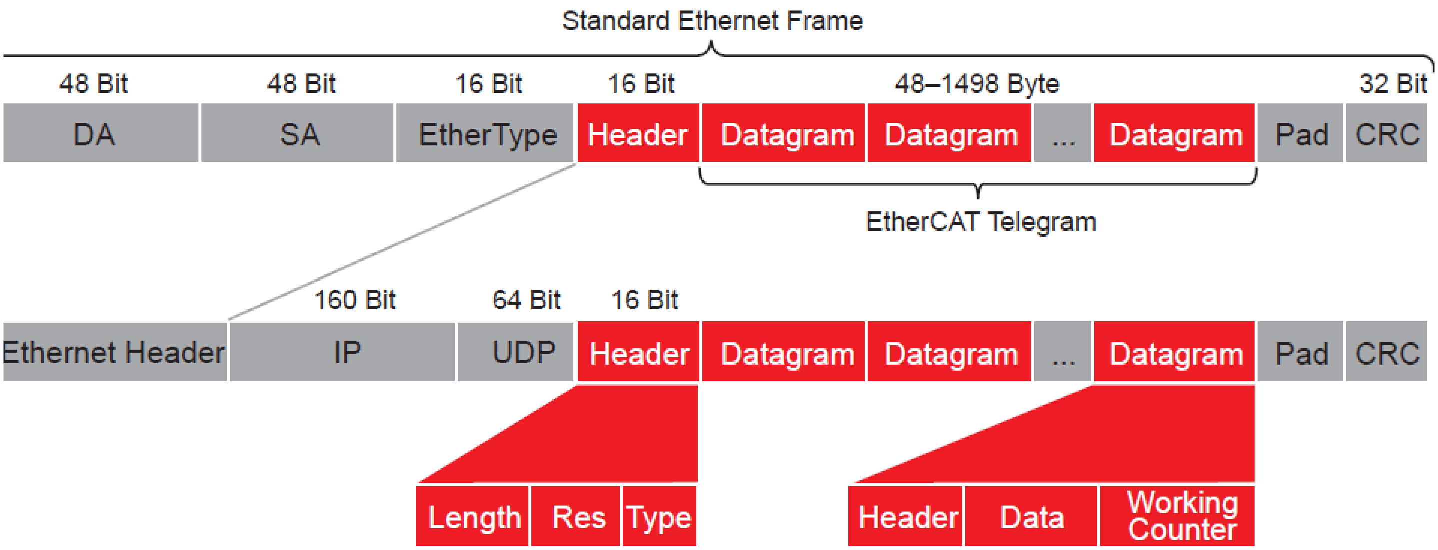

Figure 4-2. EtherCAT Telegram

Key Performance Metrics

- **Effective Bandwidth Utilization:** Over 90% on 100Mbps networks (versus only 5% for traditional Ethernet).
- **Communication Latency:** End-to-end latency less than 700 nanoseconds (ns).
- **Maximum Slave Count:** 65,536 nodes.
- **Address Space:** 4 GB logical address space.
- **Cycle Time:** Supporting cycle times from 31.25 microseconds.

Protocol Characteristics

- **Distributed Clocking:** All slave clocks synchronized to within one microsecond.
- **Flexible Addressing Modes:** Physical addressing, logical addressing, multicast, and broadcast.

- **Fieldbus Memory Management Unit (FMMU):** Enables EtherCAT to map various slave devices into a unified four GB memory space.
- **Network Topology:** Supports arbitrary topologies including line, star, and tree configurations.

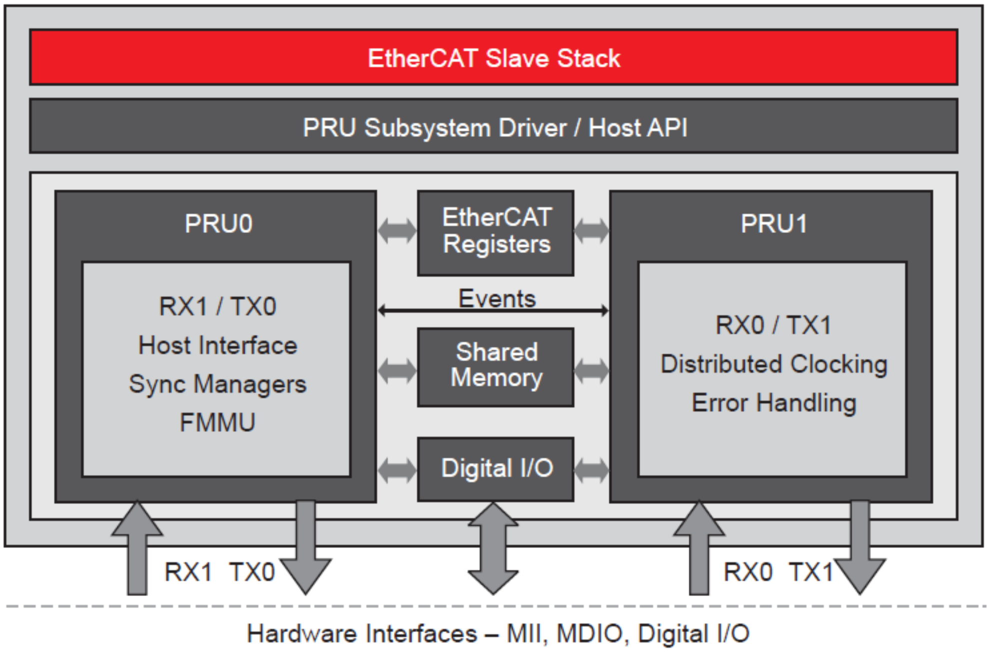

Figure 4-3. Hardware Interfaces – MII, MDIO, Digital I/O

4.2 PROFINET RT/IRT (Real-Time Industrial Ethernet)

Communication Classes

PROFINET defines multiple communication classes to meet different real-time requirements:

CC-A (Real-Time Communication)

- Cycle Time: Approximately 100ms
- Applications: Parameter data, cyclic I/O
- Typical Use Cases: Infrastructure and building automation

CC-B RT (Real-Time)

- Cycle Time: Approximately 10ms
- Software-based real-time approach
- Typical Use Cases: Factory automation, process automation

CC-C IRT (Isochronous Real-Time)

- Cycle Time: 31.25μs to 4ms
- Requires dedicated hardware support and switching devices
- Typical Use Cases: Multi-axis motion control, robotics

CC-D TSN (Time-Sensitive Networking, Under Development)

- Combines PROFINET with TSN standards
- Supports ultra-low latency and jitter
- Enables deterministic convergence of IT and OT traffic

Update Time

- The update time for PROFINET devices can vary within the same plant, resulting in differing **cycle times** for each device.
- The length of the **transmission cycle**, which ensures that all PROFINET devices can receive or transmit their data at least once, is determined by the device with the slowest update time, effectively pacing the network to accommodate the slowest device.
- The **phase time** is called **sendClock** and is defined by the controller for all I/O devices.
- **Profinet base clock** = 31.25μs
- SendClock = SendClockFactor * 31,25μs
- Update time = ReductionRatio × SendClock = ReductionRatio × SendClockFactor × 31,25 μs

In IRT mode, each send clock period is divided into several phases:

- **RED Phase:** Reserved for RTC3 and time-critical management only
- **GREEN Phase:** Other frames (behaving like normal switch operation)
- **YELLOW Phase:** Transmit buffer clearing

4.3 EtherNet/IP (Common Industrial Protocol)

Architecture Characteristics

- **Application Layer Protocol:** Application-layer protocol over TCP/IP using Common Industrial Protocol (CIP)
- **Standard Ethernet Stack:** Reuses standard Ethernet physical layer, data link layer, network layer, and transport layer
- **Multi-Protocol Unified:** Same CIP can work across different physical media (CIP over CAN is called DeviceNet, over dedicated networks is called ControlNet, over Ethernet is called EtherNet/IP)

Performance Characteristics

- **Node Count Limitation:** Unlimited, supporting deployment across switches and across facilities
- **Communication Mode:** Complete producer-consumer architecture supporting efficient peer-to-peer slave communication
- **Compatibility:** Compatible with standard Internet and Ethernet protocol stacks

5 TI Processors' Multi-Protocol Support Design

5.1 Key Technology: PRU-ICSS Subsystem

The multi-protocol support core of TI Sitara processors is the integrated Programmable Real-Time Unit Industrial Communication Subsystem (PRU-ICSS)

Advantages of PRU-ICSS:

- **Hardware Support:** Provides low-level MII interface access supporting hardware implementation of specialized communication protocols
- **Deterministic Processing:** Two independent real-time cores process datagrams with predictable latency
- **Firmware Programmability:** All EtherCAT MAC layer functionality implemented through firmware, providing flexibility
- **Cost-Effectiveness:** Lower cost and better power efficiency compared to FPGA and ASIC designs

5.2 Multi-Protocol Architecture Multi-Protocol

TI's multi-protocol implementation uses a unified hardware design, supporting different protocols through different firmware images.

Protocol Selection Mechanism

- **Boot-Time Selection:** Determine protocol at boot time through hardware switches or software parameters
- **Automatic Detection:** Device automatically listens to network and selects protocol based on received frame types
- **Firmware Independence:** Different protocols use independent firmware images without interference

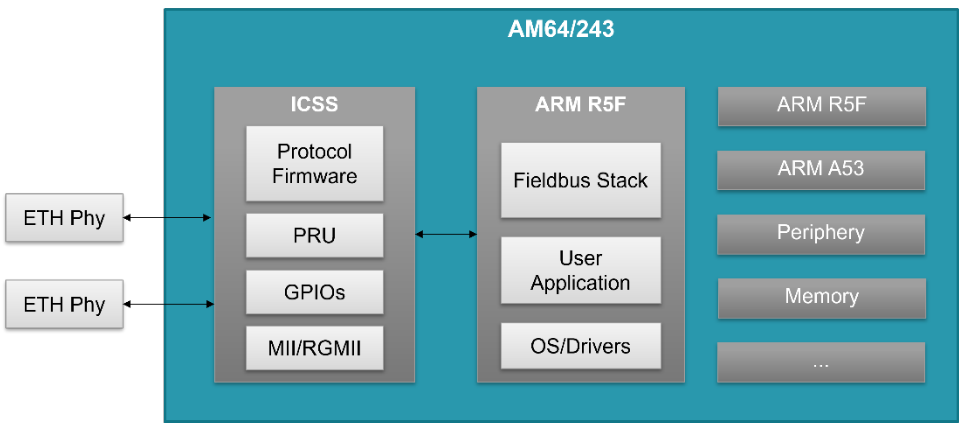

Figure 5-1. Multi-Protocol approach on AM64/AM243

Protocol Stack Structure (Example Ethercat on AM335)

TI's EtherCAT software stack comprises three main layers:

1. Layer 2 (Data Link Layer): PRU Firmware
   - – PRU cores handle EtherCAT telegram transmission and reception
     – Implements FMMU and Sync Managers
     – Distributed clock processing
2. Layer 7 (Application Layer): EtherCAT Slave Protocol Stack
   - – Runs on Arm core
     – Supports Beckhoff native stack or third-party stacks
     – Communicates with PRU through interrupts
3. Application Layer: User Industrial Application
   - Implements device-specific logic (I/O processing, sensor drivers, etc.)

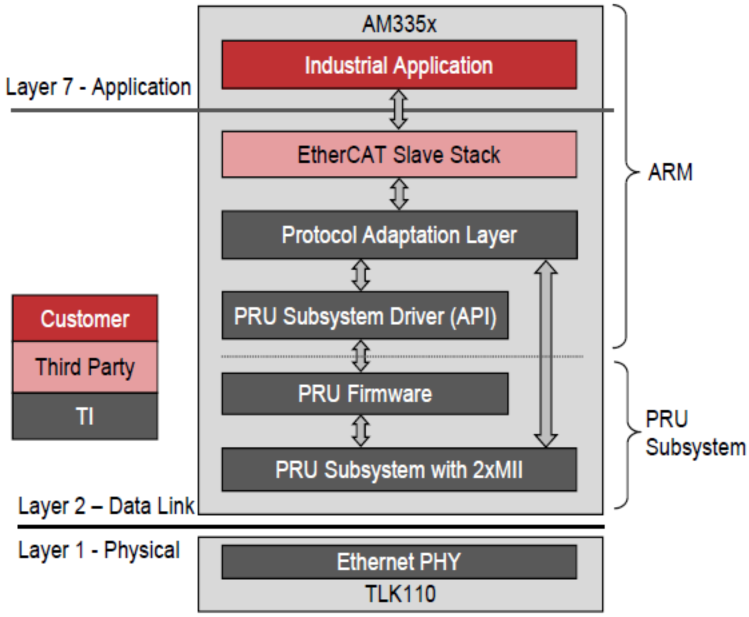

Figure 5-2. Software Architecture for EtherCAT Slave

Advantages of Single Hardware Platform

- No need for multiple development boards and reference designs
- Same schematic and PCB layout
- Shared power supply and EMI design
- Significantly lower BOM cost and time-to-market

5.3 Processor Selection Matrix

TI provides multiple processors supporting industrial communication

Table 5-1. TI Processor Industrial Communication Support Comparison

Feature	AM243x	AM62x	AM64x	DRA821	DRA829
Fastest Cycle Time	Approximately 100μs	Approximately 250μs	>200 μs	Approximately 100μs	Approximately 100μs
R5F/A Cores	4x R5F	4x A53	4x R5F + 2x A53	2x A72	2x A72
Processing Capacity	6.4k DMIPS	21k DMIPS	12.4k DMIPS	25k DMIPS	25k DMIPS
Controller Support	Yes	Yes	Yes	Yes	Yes
Slave Support	Yes	No*	Yes	No*	No*
Multi-Protocol Support	Yes	No	Yes	No	No
Gigabit Ethernet Ports	Up to 5	2	Up to 5	Up to 5	Up to 9
ICSS Count	2x	Standard ETH	2x	Multiple	Multiple
PCIe/USB3.0	1 lane/USB3	USB2	1 lane/USB3	4 lanes/USB3	8 lanes/USB3

5.4 Industrial Protocol Support Matrix

Table 5-2. Industrial Protocol Key Features Comparison

Feature	PROFINET	EtherCAT	EtherNet/IP	IO-Link
Certification Standard	Spec 2.45	Beckhoff SSC + TI Stack	ODVA CT21	V1.1.4
Cycle Time	250 µs IRT	50 µs DC	Standard Ethernet	400 µs (up to 8 ports)
Key Features	Distributed clocking, shared device/input	Distributed clocking, CoE object dictionary	Standard objects, DHCP/ BOOTP	All frame types and baud rates
Reliability	System redundancy S2, MRP	Flexible topology	Network redundancy DLR, ACD	Low CPU load

5.5 Software Development Engagement Models

TI provides flexible software development engagement models to meet different customer needs:

Buy Directly from TI

- Complete stack design provided directly by TI
- Stack support provided by TI team
- License included with device
- Pre-certified solutions
- Single license supporting all TI-provided protocol stacks

Buy from Third Party

- Protocol stack provided by third-party licensor
- Stack support provided by third party
- Flexible licensing modes (buyout, per-project, per-family)
- Pre-certified designs
- Separate license required per protocol

Third-Party Solution Support

- Device Stacks: EtherCAT, EtherNet/IP, PROFIBUS, PROFINET, Powerlink, CC-Link IE TSN, OPC UA TSN, Modbus TCP
- Controller Stacks: EtherCAT, EtherNet/IP, PROFINET
- Safety Profiles: FSoE, CIP Safety, PROFIsafe
- Drive Profiles: PROFIdrive, CIP Motion, CiA402

6 Summary

TI Sitara processor series, through integrated PRU-ICSS subsystem, provide a unified hardware platform supporting mainstream industrial Ethernet protocols. Their multi-protocol solution offers the following advantages:

Core Value

1. **Single Chip Design:** Supporting multiple protocols with protocol selection achieved through firmware switching
2. **Industry-Leading Performance:** EtherCAT achieving <700ns end-to-end latency, PROFINET supporting 31.25 μs cycle time
3. **Complete Ecosystem:** Integrated solution from chip through software stack, development tools, and technical support
4. **Cost-Effectiveness:** Over 30% cost reduction compared to FPGA and ASIC designs
5. **Long-Term Support:** Ensuring stable product lifecycle and longevity

Problem solved

Scalability and Reusability

- Flexible product portfolio with all required components (PHY, power management, and so on) available
- Pre-certified protocol stacks enable rapid transition to customized applications
- Single point of contact from SoC through all protocol designs

Development Efficiency

- Single hardware platform supporting all Ethernet-based protocols
- Same tools and development framework applicable across all protocols
- Typically only one file requires modification for user application development

Future Protection and Support

- ICSS + PRU architecture supports adding new low-level features without requiring new SOC
- Long-term support policy ensures stable product lifecycle
- Flexible hardware and software architecture supports protocol standard evolution

Application Prospects

With the advancement of Industry 4.0 and intelligent manufacturing, industrial Ethernet communication will continue to evolve and converge. Future trends include:

- **TSN Convergence:** Integration of industrial protocols with Time-Sensitive Networking (TSN)
- **Enhanced Reliability:** Integrated security and network redundancy support
- **Universal Platform:** Programmable hardware platform supporting compatibility between new and legacy protocols

TI's PRU-ICSS architecture provides a solid foundation for implementing these trends, offering global industrial equipment manufacturers a flexible and forward-looking industrial communication solution.

7 References

1. Texas Instruments, *Multi-protocol industrial communication: empowering next-generation industrial automation*, webinar.
2. Texas Instruments, *EtherCAT® **onSitara**™ Processors*, marketing white paper.
3. Texas Instruments, *AM64x Sitara™ Processors*, datasheet.
4. Texas Instruments, *AM243x Sitara™ Microcontrollers*, datasheet.
5. Texas Instruments, *CPU (PLC controller) design resources*, product page.

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