An inside look at industrial Ethernet communication protocols

Texas Instruments

Zhihong Lin,
Strategic Marketing Manager
Texas Instruments

Stephanie Pearson,
Strategic Marketing Manager
Texas Instruments

In order to remain competitive and thrive, many businesses are increasingly turning to advanced industrial automation to maximize productivity, economies of scale and quality. The increasingly connected world is inevitably connecting the factory floors. Human machine interfaces (HMIs), programmable logic controllers (PLCs), motor control and sensors need to be connected in a scalable and efficient way.

Historically, many industrial components have been connected through different serial fieldbus protocols such as Control Area Network (CAN), Modbus®, PROFIBUS® and CC-Link. In recent years, industrial Ethernet has gained popularity, becoming more ubiquitous and offering higher speed, increased connection distance, and the ability to connect more nodes. There are many different industrial Ethernet protocols driven by various industrial equipment manufacturers. These protocols include Ether-CAT®, PROFINET®, EtherNet/IP™, and Sercos® III, among others. Time Sensitive Networking (TSN) is also rising in popularity in industrial Ethernet communications. In this paper, we will look at many industrial Ethernet protocols in detail and the increasing need for a unified hardware and software platform that enables multiple standards as well as delivers the real-time, determinism and low latency required for industrial communications.

Industrial automation components

There are four major components in industrial automation including PLC controllers, HMI panels, industrial drives and sensors.

The PLC controller is the brain of an industrial automation system; it provides relay control, motion control, industrial input and output process control, distributed system, and networking control. PLCs often need to work in harsh environmental conditions, withstanding heat, cold, moisture, vibration and other extreme conditions while providing precise, deterministic and real-time controls to the other parts of the industrial automation system through reliable communication links.

The HMI is the graphical user interface for industrial control. It provides a command input and feedback output interface for controlling the industrial machinery. An HMI is connected through common communication links to other parts of industrial systems.

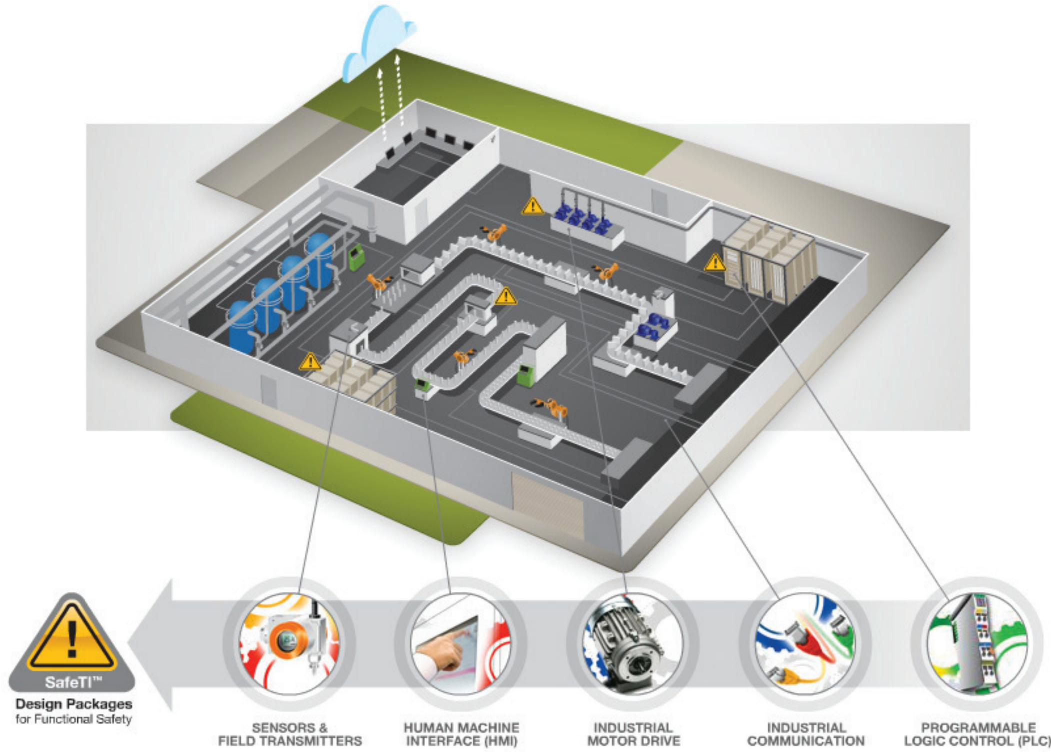

***Figure 1**. Industrial automation components and communication links.*

Industrial drives are motor controllers used for controlling optimal motor operation. They are used in a very diverse range of industrial applications and come with a wide range of voltage and power levels. Industrial drives include but are not limited to AC and DC drives as well as servo drives that use a motor feedback system to control and adjust the behavior and performance of servo mechanisms.

Sensors are the hands and legs of the industrial automation system that monitor the industrial operation conditions, inspections, measurements, and more, in real time. They are an integral part of industrial automation systems and provide trigger point and feedback for system control.

Communication is the backbone of all the industrial components for efficient automation production systems. **Figure 1** shows an example of how all the components work together through communication links.

Legacy industrial communication protocols

Historically, industrial communications have been developed on serial-based interfaces that were originally created by different companies and later became standards. The result is many different standards in the market. Because big companies are behind these standards, there is a need for industrial automation equipment companies to implement many of these protocols within an industrial system. Due to long life cycle of industrial systems, many serial-based protocols, including PROFIBUS®, CAN bus, Modbus® and CC-Link® with master slave configurations, are still very popular today.

PROFIBUS is the world's most successful fieldbus technology and is widely deployed in industrial automation systems including factory and process automation. PROFIBUS provides digital communication for process data and auxiliary data with speeds up to 12 Mbps and supports up to 126 addresses.

Control Area Network (CAN) bus, a high-integrity serial bus system, was originally created as an automotive vehicle bus and later came to be used as one of the fieldbuses for industrial automation. It provides a physical and data link layer for serial communication with speeds up to 1 Mbps. CANopen® and DeviceNet are higher level protocols standardized on top of CAN bus to allow interoperability with devices on the same industrial network. CANopen supports 127 nodes on the network while DeviceNet supports 64 nodes on the same network.

Modbus is a simple, robust and openly published, royalty free serial bus that connects up to 247 nodes in the link. Modbus is easy to implement and run on RS-232 or RS-485 physical links with speeds up to 115K baud.

CC-Link was originally developed by Mitsubishi and is a popular open-architecture, industrial network protocol in Japan and Asia. CC-Link is based on RS-485 and can connect with up to 64 nodes on the same network with speeds up to 10 Mbps.

Industrial Ethernet communication protocols

Ethernet is becoming ubiquitous and cost effective, with common physical links and increased speed. As such, many industrial communication protocols are moving to Ethernet-based solutions. Ethernet communications with TCP/IP typically are non-deterministic, and reaction time is often around 100 ms. Industrial Ethernet protocols use a modified Media Access Control (MAC) layer to achieve very low latency and deterministic responses. Ethernet also enables a flexible network topology and a flexible number of nodes in the system. Let's look at some of the popular Industrial Ethernet protocols in detail.

EtherCAT was originally developed by Beckhoff to enable on-the-fly packet processing and deliver real-time Ethernet to automation applications and that can provide scalable connectivity for entire automation systems, from large PLCs all the way down to the I/O and sensor level.

EtherCAT, a protocol optimized for process data, uses standard IEEE 802.3 Ethernet Frames. Each slave node processes its datagram and inserts the new data into the frame while each frame is passing through. The process is handled in hardware so each node introduces minimum processing latency, enabling the fastest possible response time. EtherCAT is the MAC layer protocol and is transparent to any higher level Ethernet protocols such as TCP/IP, UDP, Web server, etc. EtherCAT can connect up to 65,535 nodes in a system, and EtherCAT master can be a standard Ethernet controller, thus simplifying the network configuration. Due to the low latency of each slave node, EtherCAT delivers flexible, low-cost and network-compatible industrial Ethernet solutions.

EtherNet/IP is an industrial Ethernet protocol originally developed by Rockwell. Unlike EtherCAT, which is MAC-layer protocol, EtherNet/IP is application-layer protocol on top of TCP/IP. EtherNet/IP uses standard Ethernet physical, data link, network and transport layers, while using Common Industrial Protocol (CIP) over TCP/IP. CIP provides a common set of messages and services for industrial automation control systems, and it can be used in multiple physical media. For example, CIP over CAN bus is called DeviceNet, CIP over dedicated network is called ControlNet and CIP over Ethernet is called EtherNet/IP. EtherNet/IP establishes communication from one application node to another through CIP connections over a TCP connection, and multiple CIP connections can be established over one TCP connection.

EtherNet/IP uses the standard Ethernet and switches, thus it can have an unlimited number of nodes in a system. This enables one network across many different end points in a factory floor. EtherNet/IP offers complete producer-consumer service and enables very efficient slave peer-to-peer communications.

EtherNet/IP is compatible with many standard Internet and Ethernet protocols but has limited real-time and deterministic capabilities.

PROFINET is widely used industrial Ethernet by major industrial equipment manufacturers such as Siemens and GE. It has three different classes. PROFINET Class A provides access to a PROFIBUS network through proxy, bridging Ethernet and PROFIBUS with a remote procedure calling on TCP/IP. Its cycle time is around 100 ms, and it is mostly used for parameter data and cyclic I/O. The typical application includes infrastructure and building automation. PROFINET Class B, also referred as PROFINET Real-Time (PROFINET RT), introduces a software-based real-time approach and has reduced the cycle time to around 10 ms. Class B is typically used in factory automation and process automation. PROFINET Class C (PROFINET IRT), is Isochronous and real-time, requiring special hardware to reduce the cycle time to less than 1ms to deliver the sufficient performance on the real-time industrial Ethernet for motion control operations.

PROFINET RT can be used in PLC-type applications, while PROFINET IRT is a good fit for motion applications. Branch and Star are the common topology used for PROFINET. Careful topology planning is required for PROFINET networks to achieve the required performance of the system.

POWERLINK was originally developed by B&R. Ethernet POWERLINK is implemented on top of IEEE 802.3 and, therefore, allows a free selection of network topology, cross connect and hot plug. It uses a polling and time slicing mechanism for real-time data exchange. A POWERLINK master or "Managed Node" controls the time synchronization through packet jitter in the range of 10s of nanoseconds. Such a system is suitable for all kinds of automation systems ranging from PLC-to-PLC communication and visualization down to motion and I/O control. Barriers to implement POWERLINK are quite low due to the availability of open-source stack software. In addition, CANopen is part of the standard which allows for easy system upgrades from previous fieldbus protocols.

Sercos III is the third generation of Serial Real-time Communication System (Sercos). It combines on-the-fly packet processing for delivering real-time Ethernet and standard TCP/IP communication to deliver low latency industrial Ethernet.

Much like EtherCAT, a Sercos III slave processes the packet by extracting and inserting data to the Ethernet frame on-the-fly to achieve low latency. Sercos III separates input and output data into two frames. With cycle times from 31.25 microseconds, it is as fast as EtherCAT and PROFINET IRT. Sercos III supports ring or line topology. One key advantage to using ring topology is communication redundancy. Even if the ring breaks due to failure of one slave, all remaining slaves still get the Sercos III frames with input/output data. Sercos III can have 511 slave nodes in one network and is most used in servo drive controls.

Time-sensitive networking (TSN) is an Ethernet extension defined by the Institute of Electrical and Electronic Engineers (IEEE) designed to make Ethernet-based networks more deterministic. TSN is a local area network (LAN)-level solution that can work with non-TSN Ethernet, but timeliness is only guaranteed inside the TSN LAN. You can group TSN standards based on what use case it solves: a common view of time, guaranteed maximum latency, or co-existence with background or other traffic. Like any popular standard, the TSN toolbox of standards is evolving.

Industrial communication enabler from Texas Instruments

To enable industrial equipment manufacturers with an economic and flexible means to implement a variety of industrial communication protocols, Texas Instruments has integrated a low-latency, Programmable-Realtime Unit Industrial Communications Subsystem (PRU-ICSS) many of its system on chips. The PRU-ICSS provides a more cost-effective, flexible and future-proof solution for industrial communications as compared to FPGAs, ASICs and other alternative solutions. By integrating the PRU-ICSS into a single chip, TI's flexible hardware platform empowers manufacturers to implement more cost-effective, deterministic, efficient and software-programmable industrial automation systems.

Future trend

We are at the dawn of the fourth industrial revolution in which industrial automation will again drive the economy. The success of industrial automation depends on a reliable and efficient communication network that connects all the components of the factory to work together effectively. The popularity and ubiquity of Ethernet will continue to motivate the legacy factory to upgrade to industrial Ethernet. Many different industrial Ethernet protocols have been implemented in the field, each with its own pros and cons. Future industrial Ethernet protocols will continue to evolve and converge to deliver hard real-time, deterministic communication links with better reliability and integrated safety. Ethernet also requires a common, programmable hardware platform, such as Texas Instruments' Sitara™ processors with integrated PRU-ICSS to enable a low-cost, flexible system capable of supporting multiple protocols and forward-looking implementation for new protocols to power the industrial communication engine of the industrial automation.

For more information on the Sitara product line, please visit TI's Processors for Industrial Ethernet overview page.

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