Understanding Ethernet-based industrial communication protocols

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By exchanging information across the Web with open application protocols such as HTTP, SMTP, and FTP, people across the world can share and collaborate. These protocols rely on the physical layer of Ethernet. Engineers and managers in industrial automation are also using protocols based on Ethernet, of which one example is Modbus TCP/IP. New protocols including Ethernet/IP and PROFINET highlight a clear trend where industrial protocols are in transition to the Ethernet physical layer.

Open communication protocols Modbus TCP/IP is an open industrial protocol based on standard Ethernet. Modbus provides connectivity to programmable automation controllers (PACs), PLCs, and legacy devices to preserve hardware and software investments. According to the ARC Advisory Group, Modbus TCP/IP was the leading industrial bus for devices shipped in 2004.

Modbus TCP/IP is a client/server-based architecture. The general Modbus frame, which contains a function code, a data packet, and error checking, is referred to as an Application Data Unit (ADU). The Modbus TCP/IP ADU is an extension of the existing Modbus protocol, which contains a dedicated 7-byte header called the Modbus Application Protocol header (MBAP), a Modbus function code from the Modbus specification, and the data packet which from the Protocol Data Unit (PDU).

Figure 1: Modbus TCP/IP Application Data Unit over TCP/IP.

Technologies for adding determinism or synchronization to Ethernet-based networks

Several technologies are being developed to add either synchronization or different levels of determinism to the standard Ethernet physical layer. There are two basic requirements for determinism: Software scheduling to ensure that packets are transferred without loss Hardware clock or custom ASIC for scheduling packet transfers Deterministic Ethernet-based networks are being developed based on a wide range of technologies including software-based time triggering, IEEE 1588, and custom hardware ASICs.

Time-triggered networking Time-Triggered networking is a software-based technology that schedules packet transfers on TCP/IP. It does not rely on additional hardware to implement a clock
source, and is limited by the speed of the Ethernet network and accuracy of the processor clock.

One implementation is the time-triggered network feature in National Instruments LabVIEW Real-Time. This protocol uses a private Ethernet network between nodes, and all traffic is predetermined by a schedule. Developers use software to define when each node can send data messages. The size of each data message is fixed prior to execution to ensure that the schedule is met. This configuration requires a private subnet and places implementation requirements on the system developer.

IEEE 1588 The IEEE 1588 precision time protocol (PTP) is a technology for sharing clocks between distributed systems. IEEE 1588 does not provide determinism unless it is combined with a protocol that handles software scheduling. Technically, IEEE 1588 provides a distributed time base used to timestamp data with submicrosecond precision. Synchronization skew depends on the resolution of the clocks at each device, the synchronization rate, and network topology. Custom ASICs Hardware ASICs provide determinism by setting priorities of packets or by inserting messages into the TCP/IP network frame at the hardware level, only adding a few nanoseconds of delay. Depending on the implementation and whether the ASICs is implemented on the client, master, or the networking equipment, there are advantages and disadvantages for ASICs. Industrial protocols based on Ethernet physical layer

Ethernet/IP is a protocol developed managed by the Open Device Vendors Association (ODVA) that extends the Communication and Information Protocol (CIP) to Ethernet. Ethernet/IP is an application layer protocol that uses TCP for general messages and User Datagram Protocol (UDP) for I/O messaging and control. UDP is a multicast protocol that routes packets from the controller to multiple destinations. Although this is an efficient communication method for one controller to broadcast data to multiple receivers, it can create broadcast storms that consume network bandwidth. To prevent broadcast storms, managed switches with Internet Group Management Protocol (IGMP) capabilities are required.

PROFINET is an application protocol that extends the PROFIBUS protocol to Ethernet and relies on TCP/IP and UDP/IP for packet communication. PROFINET uses information in the standard Ethernet frame header to identify packets that are real-time and then relies on Ethernet switches that implement Quality of Service (QoS) to prioritize these packets.

Adding technologies such As IEEE 1588 or custom ASICs to industrial protocols

Several Ethernet-based protocols implement software scheduling and additional features to make Ethernet well suited for industrial applications. New technologies such as IEEE 1588 and custom ASICs are also being added to these protocols to deliver hard real-time determinism for demanding motion and distributed control applications.

CIP Sync is an addition to Ethernet/IP that uses IEEE 1588 technology to distribute clocks and synchronize timebases. The level of determinism available with CIP Sync networks depends on the availability of an IEEE 1588 clock on Ethernet switches in the network and the implementation of the CIP Sync protocol on distributed devices. System determinism is highly dependent on system design and Ethernet throughput. Ethernet switches with IEEE 1588 clocks are not available as of February 2007; however, vendors including Hirschmann have announced plans to release commercially available IEEE 1588 switches.

Profinet IRT uses the IEEE 802.3 physical layer and adds IEEE 802.1Q and custom ASICs on both the device and Ethernet switch to interpret and correctly route messages based on priority levels. Industrial switches that offer quality of service (QoS) are suitable for PROFINET non-Real Time (NRT) and Real Time (RT) However, to achieve the highest level of performance, similar to that of
CIP Sync, use switches with the ERTEC ASIC to ensure routing priority for deterministic communication with PROFINET Isochronous Real-Time (IRT), which enables clock rates of <1 ms and jitter precision of <1 ms.

Figure 2: Networking Requirements for Industrial Protocols.

Open, flexible hardware and software platforms are key to Ethernet benefits. The trend toward Ethernet-based industrial protocols is clear. It is critical to take full advantage of the economies of scale of Ethernet open software and hardware platforms, with which system designers can integrate different industrial protocols. With the ability to connect different protocols using a single software API and migrate existing code forward, you can build hybrid systems that offer best-in-class hardware from different vendors.

<table>
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<th>Physical Protocol</th>
<th>Standard Ethernet Switches</th>
<th>Real-Time Protocol</th>
<th>Switch Requirements</th>
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<tbody>
<tr>
<td>Time Triggered</td>
<td>TCP and UDP</td>
<td>Yes</td>
<td>Software Scheduling</td>
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<td>Modbus TCP/IP</td>
<td>TCP</td>
<td>Yes</td>
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<td>TCP and UDP</td>
<td>No</td>
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