

July: Distributed Control

**Ethernet and TCP/IP: The future of distributed systems**  
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*New Industrial Ethernet protocols facilitate distributed control with intelligent devices*

Industrial Ethernet is a hot topic these days, and although it is not ideal for sensors, it is an excellent network for linking controllers and data acquisition systems because of TCP/IP's peer to peer capabilities. Outside the office environment, protocols are necessary for defining the meaning of automation and process data. Without a vendor like Microsoft to dictate these protocols many vendors are pushing standards. This article discusses some of the more popular standards including EtherNet/IP, Foundation Fieldbus and PROFINet, their relative strengths and weaknesses, and the issues that device manufacturers must consider in order to support these protocols.

**Ethernet is a fit for distributed control**

Just as millions of PC's around the world can work independently and then send and receive data over the Internet at will, distributed control means intelligent control devices work independently but still operate together within a larger system.

**Examples of distributed control**

*a. The ever-popular DCS*

In process control, "Distributed Control System" has been the term of choice for decades, with loop controllers operating locally and sending batch information to a mainframe computer.

*b. PLC's throughout a plant*

In discrete manufacturing, large plants may use hundreds of PLC's which are linked to a single backbone. Phillip Morris uses serial-to-Ethernet converters to verify each day that the program in each PLC has not changed. Millions of PLC's use serial networks based on RS-485 to pass data back and forth. But in both of those examples, the data rate is only a few thousand bits per second. Ethernet provides communication rates of 10Mbits/sec, 100Mbits/sec and 1000Mbits/sec.

The faster the data rate, the more transparent the network. On an office LAN, a remote hard drive is just as accessible as a local one because the network is able to quickly deliver the requested data.

Ethernet is the most common physical layer in these systems, but the transport mechanism itself is secondary. The real deal is the collection of protocols collectively referred to as TCP/IP. This set of protocols accommodates different kinds of data for different kinds of applications. SMTP for example supports mail, PPP supports point-to-point applications and HTTP supports the web. Of all the protocols in the TCP/IP suite, TCP (Transport Control Protocol) and IP (Internet Protocol) are most important to industrial automation.

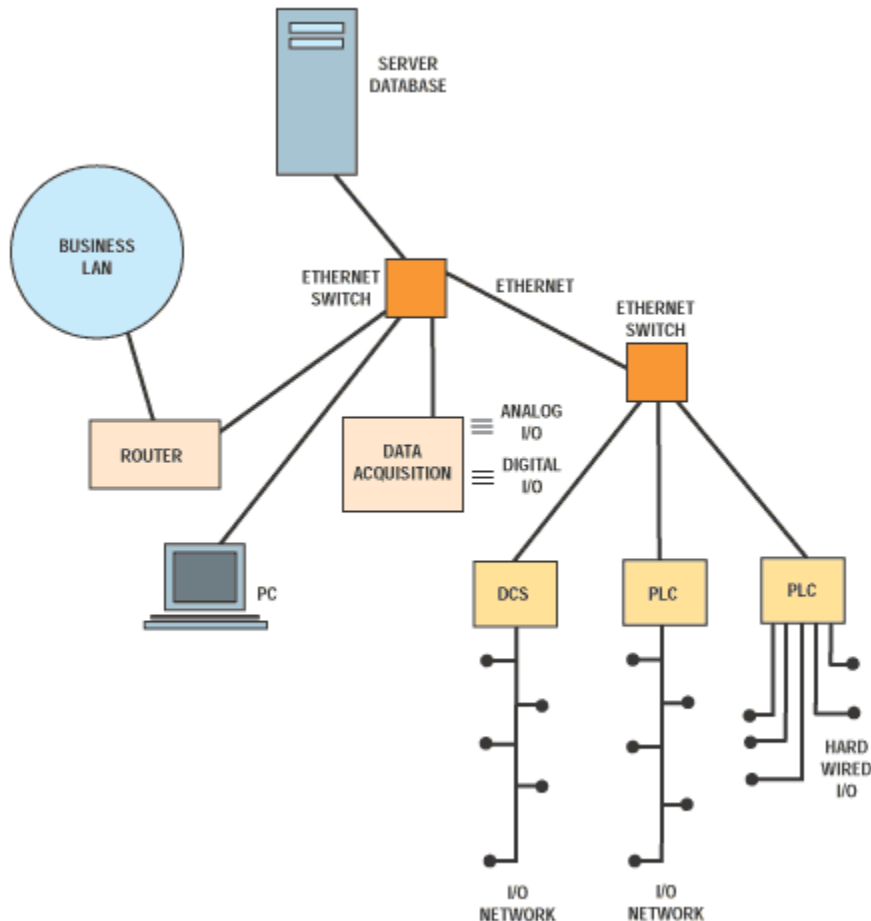


Figure 1. Distributed control is the sharing of control functions between multiple processors and smart devices, and connecting them with a network. Advanced Ethernet protocols, such as EtherNet/IP, Foundation Fieldbus HSE, and Profinet offer messaging services designed for automation and process control.

### ***Yes, even Google***

It certainly ain't an industrial application, but the search engine Google is powered by over 10,000 Linux PC's, operating in tandem. Whether you're searching for pressure transducers or bootleg CD's of *The Eagles*, it's distributed control of information that makes that search possible.

### **Switches segment the network**

Ethernet hubs indiscriminately distribute packets in all directions, but switches only pass packets to their intended destinations. This means that traffic between devices that are close together does not clog up other parts of the network. So a data acquisition system that uses Ethernet I/O can easily co-exist with a device passing high speed motion commands on a different segment.

Intelligent switches provide the capability to make deterministic segments. Even though Ethernet is by definition not a deterministic network, thoughtful planning of your network can create zones of determinism. Using intelligent switches to isolate devices on a network segment can provide enough determinism for all but the most demanding applications.

## Services in TCP/IP that cater to distributed systems

There are two major “general messaging” services in TCP/IP: TCP and UDP.

**TCP (Transmission Control Protocol)** is like sending a certified letter with “proof of receipt.” The message is only assumed to have been properly received after the acknowledgement comes back. This virtually guarantees data integrity but requires no less than seven “handshakes” to open a connection, send a packet, verify its safe arrival, and close the connection. Of course if there’s an error, the process has to start over again.

TCP is inherently peer-to-peer; each node is assumed to be “equal” to others. It is “full duplex” meaning that it can handle simultaneous data streams in both directions.

**UDP (User Datagram Protocol)** is like ordinary first class mail. The message can be sent in a single packet but there is no acknowledgment of receipt. To continue the mail analogy, a UDP “envelope” is also less bulky – UDP protocol has less overhead.

UDP lends itself to “master / slave” relationships which are common in I/O networks like DeviceNet and Profibus. UDP is generally used for real-time applications like online streaming and gaming, where missing packets need not be re-sent and would probably be too old if they were. It is also used where upper-layer protocols handle flow control and data stream checking and correcting.

## Automation has Special Needs

Automation systems perform very specific tasks, and data must be represented in a standardized format. Digital and analog values, commands and recipes can all be represented in a variety of ways, and to avoid a Tower of Babel, definite protocols must be employed.

It’s not enough just to send packets of data back and forth, because parsing those packets is too tedious. A more elegant way is to use object oriented data.

There are several major contenders that use objects, each approaching the problem from a different vantage point, including EtherNet/IP, Foundation Fieldbus HSE and PROFINet. Except for specific process control applications where Foundation Fieldbus is the bus du jour, EtherNet/IP is the most commercially viable solution on the market. It has a small but growing list of supporting vendors, and the most attention will be given to that here. PROFINet is not as far along in the commercialization process and some aspects of the specification is still under development.

## PROFINet

This is the Profibus Trade Organization’s answer to the need for interoperability between automation devices and subsystems, which are linked together via Ethernet.

To understand what PROFINet is, you must understand what it is not. PROFINet is not the Profibus protocol on Ethernet in the same way that Modbus/TCP is the old familiar Modbus on Ethernet. PROFINet is not really a “fieldbus” as the term is normally understood, either.

An analogy to the office environment may help you understand what it is intended to do.

You work in an office with a PC at your desk, networked with a dozen other PCs and a file server. Your office LAN (Ethernet 100BASE-T) is also linked to a T1 Internet line. You open Microsoft Word and create a complex document. You write some text and create some tables. Your co-worker Jeff has a PowerPoint presentation on his PC; you open it via the network and copy and paste two different graphics images into your Word document, which are transferred intact as objects. Your other co-worker Leslie has an Excel spreadsheet, which you also open remotely and embed in your document—it's as simple as cut and paste. In this case, the Excel data is not "static," it's live: Leslie updates this spreadsheet every Tuesday, and every time you open your document, it's going to retrieve the latest data from her document on her PC. You get on the Internet and copy and paste text and graphics from a Web site, and your document also contains hyperlinks to other Web sites.

Behind this transparency among applications is a very complex object model created by Microsoft. Savvy PC users are quite accustomed to this level of sophistication and its benefits. This expectation naturally extends to the integration of business applications throughout an entire company and of course to devices in an automation system. PROFINet in fact uses Microsoft COM (Communication Object Model) and DCOM (Distributed Communication Object Model) to extend this transparency to all devices on a TCP/IP network, further defining object models for many kinds of device and programming parameters.

And rather than being specific to only one manufacturer's hardware or software (as is often the case with Microsoft), PROFINet purports to be an industry standard available to all Profibus members.

PROFINet is an open communications and multi-vendor engineering model. This means that a pre-configured, pre-programmed, and pre-tested machine such as a transport conveyor can be set up using the vendor-specific electrical devices and applications as it has been in the past.

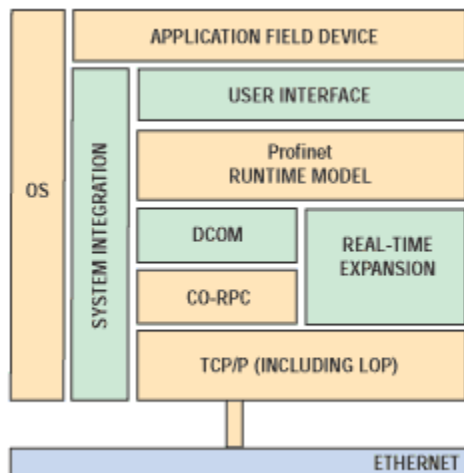


Figure 2. Profinet is an object-oriented architecture designed to allow the distribution of programs, device profiles, and data across a large networked system, similar to the way Microsoft Office applications, programs, and objects can be shared across an office LAN.

## Foundation Fieldbus High-Speed Ethernet

This protocol uses the Foundation Fieldbus H1 process control protocol on TCP/IP.

Foundation Fieldbus H1 is a sophisticated, object-oriented protocol that operates at 31.25 Kbps on standard 4-20 mA wiring. It uses multiple messaging formats and allows a controller to recognize a rich set of configuration and parameter information ("device description") from devices that have been plugged into the bus. Foundation Fieldbus even allows a device to transmit parameters relating to the estimated reliability of a particular piece of data. Foundation

Fieldbus uses a scheduler to guarantee the delivery of messages, so issues of determinism and repeatability are solidly addressed. Each segment of the network contains one scheduler.

Foundation Fieldbus HSE is the same H1 protocol, but instead of 31.25 Kbps, it runs on TCP/IP at 100 Mbps. It provides the same services and transparency of network objects but operates at a higher level.

Foundation Fieldbus is specifically focused on the process-control industry and will likely be the dominant Ethernet I/O standard there. Installations in this segment of the world typically have the following characteristics:

- Very large campuses (e.g., chemical refineries) with large numbers of nodes
- Data does not have to move quickly, but there's a lot of it to move (large packets)
- Large quantities of analog data
- Explosion-proof requirement, that is, Class I, Div II.

Foundation Fieldbus H1 links local islands of transducers and actuators; HSE links controllers and transmits a high level of information over large distances.

## **ETHERNET/IP**

This is the DeviceNet/ControlNet object on Ethernet. It is backed by Open DeviceNet Vendor Association and Rockwell/Allen-Bradley and therefore has a strong political advantage. It is considerably more complex, adding expense for developers, but the complexity brings advantages.

Ethernet/IP is based on an object model called CIP (Control and Information Protocol), which is carefully mapped to both TCP/IP and UDP. It incorporates the following message hierarchies and scheduling mechanisms:

- Exchange of basic I/O, PLC style.** All control networks have this capability: exchanging data with racks of I/O, for example, or collecting readings from a temperature controller or encoder. This is handled in a simple Client/Server relationship using UDP.
- Upload/download of parameters and setpoints; transfer of programs and recipes.** In DeviceNet, these are called "explicit messages" and are sent only on a sporadic basis. An Ethernet/IP temperature controller maps its data in a very similar way. Ethernet/IP uses TCP/IP for this task.
- Polled, cyclic, and event-driven data.**
- One-to-one, one-to-many, and broadcast.** TCP/IP is inherently one-to-one (and peer-to-peer) but this poses a significant disadvantage when many devices must be updated in a short period of time because each connection eats up valuable milliseconds. UDP allows messages to be sent to many nodes simultaneously and this saves time.

Four independent groups have joined forces to develop and promote EIP as a public domain Ethernet application layer for Industrial Automation. These groups include the Open DeviceNet Vendor Association (ODVA), the Industrial Open Ethernet Association (IOANA), Control Net International (CI) and the Industrial Ethernet Association (IEA). The goals of this effort illustrate how EIP provides a wide-ranging, comprehensive, certifiable standard suitable to a wide variety of automation devices.

## **Takes Advantage of TCP/IP Features**

Ethernet/IP uses all the transport and control protocols used in traditional Ethernet including the Transport Control Protocol (TCP), the Internet Protocol (IP) and the media access and signaling technologies found in off-the-shelf Ethernet interface cards. Building on these standard PC technologies means that EIP works transparently with all the standard off-the-shelf Ethernet devices found in today's marketplace. It also means that EIP can be easily supported on standard PCs and all their derivatives. Even more importantly, basing EIP on a standard technology platform ensures that EIP will move forward as the base technologies evolve in the future.

The groups supporting EIP plan to ensure a comprehensive, consistent standard by careful, multi-vendor attention to the specification and through certified test labs as has been done with DeviceNet and ControlNet. Certification programs modeled after the programs for DeviceNet and ControlNet will ensure the consistency and quality of field devices.

### **EIP is built on a widely accepted protocol layer**

EIP is constructed from a very widely implemented standard used in DeviceNet and ControlNet called the Control and Information Protocol (CIP) and is illustrated on the attached drawing. This standard organizes networked devices as a collection of objects. It defines the access, object behavior and extensions which allow widely disparate devices to be accessed using a common mechanism. Over 300 vendors now support the CIP protocol in present day products. Using this technology in EIP means that EIP is based on a widely understood, widely implemented standard that does not require a new technology shakedown period.

### **Is There Interoperability Between Application Layer Protocols?**

Basically, no. Foundation Fieldbus HSE devices will not talk to Modbus/TCP devices, nor will EtherNet/IP devices talk to IDA devices. However, the situation is not quite as bad as it might appear.

First, they all use TCP/IP and Ethernet. So ISO layers 1–4 are already agreed upon. That's a huge step forward. Second, they all can coexist on the same wire at the same time. Third, there's nothing to prevent vendors from making devices that support more than one protocol. Some vendors do, and some devices can automatically recognize which protocol(s) are being used on the network. Furthermore, any number of protocols can be used by a device *simultaneously*. You take advantage of this on your computer every day. Finally, objects that define the relationships between protocols will be adopted by standards organizations. The issue of low-level device compatibility will slowly fade as the technology matures, and standards will compete at higher levels, that is, system-level integration of objects and profiles such as those found in PROFINet, IDA, and OPC.

But in the meantime, *always* be certain what protocol(s) are supported by the I/O and smart devices you purchase.

## **"Embedding Industrial Ethernet in your product"**

### **Important Questions You Must Ask Yourself First**

Once you decide that your products must support Ethernet, the big question becomes "how can I get it done and get it done quickly"?

Do you have excess Engineering resources to commit to the project? Can / should your existing opportunities and customers for EtherNet be put off until next year? Is your engineering staff intimately familiar with the TCP/IP and the specifications for EtherNet/IP, PROFINet or Foundation Fieldbus?

Once you've made a decision to add Ethernet connectivity you have a number of ways to proceed. The choices vary in time-to-market, supportability, resource requirements and price.

### **1.Use an off-the-shelf Serial Gateway**

An off-the-shelf serial gateway is the least economical approach with the fastest time-to-market. To implement a serial gateway your product must support a common serial communication protocol such as Modbus, DF/1 or even dumb ASCII. Data from your product will transfer to the gateway at serial baud rates (1200-19200).

Other than time-to-market (typically a week or two), there are few real advantages to this approach and many negatives. Gateways require an additional footprint, they can be costly, they rarely support messaging characteristics needed for your data, and the gateway vendor name appears on the screens of network configuration tools.

Most importantly, your data is represented as generic data. The characteristics of your device are lost to the network. This option is only attractive if you expect low volume requests for EtherNet/IP connectivity.

### **2.Add-on Daughter Boards**

An add-on daughter board is another fast time-to-market method of adding EtherNet/IP to your product. An Add-on PCB plugs into your device internally (usually TTL-level communications) and acts as a serial gateway with less cost and sometimes more benefits.

Internal daughter boards contain all the disadvantages described previously for gateways unless the vendor is able to customize the data representation and messaging characteristics. If your product contains a spare communication port and you can get a customized implementation, this approach is great for medium volume applications (i.e. a few hundred units per year).

### **3.Design in an IC containing EtherNet/IP**

Several companies are offering MPUs (Microprocessor Units) with Ethernet and TCP/IP protocols embedded into the MPU. If you are building a new device from scratch and these MPUs fit your budget and taste they can be a very attractive option. You control the Object Model implementation and messaging characteristics without the speed constraints imposed by gateways. It is also possible to create a similar solution by combining a System-On-a-Chip (SoC) with option number four:

### **4.Purchase a TCP/IP and Application Layer Stack for your existing design**

For a one time charge with no royalties, these stacks offer you the latest in capabilities while giving you absolute control of your development, network presentation and implementation.

This approach requires a dedicated resource to integrate your MPU, TCP/IP Stack, EtherNet/IP stacks and OS (if needed).

The advantages to this approach are relative low cost and tightly integrated firmware. Disadvantages include the cost of dedicating internal resources to this effort and the resulting time-to-market issues.

### **5.Custom PCBs**

Contract Engineering companies can provide you with a completely custom communications card for your application usually in 90 days or less depending on the complexity of your application.

## **6.Do-It-Yourself**

The most costly, lengthy and risky approach is to form an internal effort to build it yourself. While this is admittedly what you'd expect to hear from a company whose business is selling custom networking hardware and software, the facts still speak for themselves.

Like all complex protocol implementations there are nuances to the specifications that are not readily discernable. The internal resources required for internal build are usually much more costly than using an outside resource or buying a component. The risk of missing seemingly innocuous nuances and missing a ship date is much higher than the cost of outside software or engineering.

### **Where to go for more information**

Portions of this article were taken from "Industrial Ethernet: A Pocket Guide" by Perry S. Marshall ©2002 ISA Press. Details at [www.perrymarshall.com/ethernet](http://www.perrymarshall.com/ethernet) and "Industrial Ethernet in 90 Days or Less" by John Rinaldi, Real Time Automation, for a copy email [sensors@rtaautomation.com](mailto:sensors@rtaautomation.com)

EtherNet/IP, DeviceNet and ControlNet: [www.odva.org](http://www.odva.org)  
Foundation Fieldbus HSE and H1: [www.fieldbus.org](http://www.fieldbus.org)  
PROFINet and Profibus: [www.profibus.com](http://www.profibus.com)

#### **Books and Papers:**

Ethernet: The Definitive Guide by Charles E. Spurgeon, O'Reilly  
"10 Things to Consider Before Installing Industrial Ethernet" by George Thomas, Contemporary Controls – for a copy, email [sensors@ccontrols.com](mailto:sensors@ccontrols.com)