Support All Industrial Ethernet Standards on Your Next "Drive" Design

WP-01186-1.0 White Paper

This white paper looks at Industrial Ethernet implementation options from the point of view of the factory automation vendor developing slave systems, such as I/O modules and drives.

Introduction

By now it is a well understood fact that Industrial Ethernet is becoming the dominant technology within factory automation for a variety of reasons that have been documented in countless articles, market research reports, and white papers.

What does not get quite the same attention is the implementation of this communication technology in vendor systems. But, in fact, how you implement this increasingly required function makes a difference in the cost, form factor, and power profile of your system. This white paper looks at Industrial Ethernet implementation options from the point of view of the factory automation vendor developing slave systems, such as I/O modules and drives.

The challenges faced by these OEMs are unique, so there are good reasons for reviewing the slave system architecture. Vendors designing slave systems are not wed to any one protocol variant. They must support any standard that may be implemented within a given factory and are not in a position to dictate the protocol variant. Rather, they must adapt their system to any one of the variants.

The newer slave protocol standards being developed also have unique hardware features. In fact, they cannot use the standard MAC implementation, which creates some unique challenges and impacts the choice of an implementation platform.

About Industrial Ethernet

Originally, Ethernet—"original" Ethernet at 10 Mbps, fast Ethernet at 100 Mbps, and Gigabit Ethernet at 1 Gbps—was a way to transmit a signal between devices over a shared medium, but was not useful for industrial applications. But the advent of fast Ethernet (100 Mbps) in switch mode with full duplex capability means a point-to-point link can now be built between devices, allowing Ethernet to be used for most industrial applications. All Industrial Ethernet protocols have a need for some level of determinism, which traditionally has been addressed by using a special software protocol stack.

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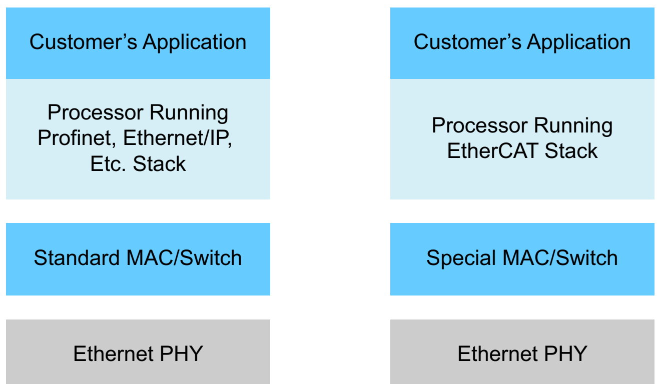
The Need for Speed (Or in This Case, Latency)

We all know that factory automation systems have real-time response requirements. But what exactly is “real time”? The answer is that it depends on the type of application. Sometimes it is measured in terms of hundreds of milliseconds and sometimes in terms of tens of microseconds. And there are different design approaches to get the communication protocol to support differing latency requirements.

As shown in Figure 1, the PHY layer usually is a separate analog device. However, the other functions can be implemented in a digital logic device with a processor to run the software for the protocol stack as well as the customer application. While all Industrial Ethernet protocols require a special software stack, some of the newer protocols (shown on the right side of the figure) use a non-standard, unique design for the media access control (MAC) and/or the switch.

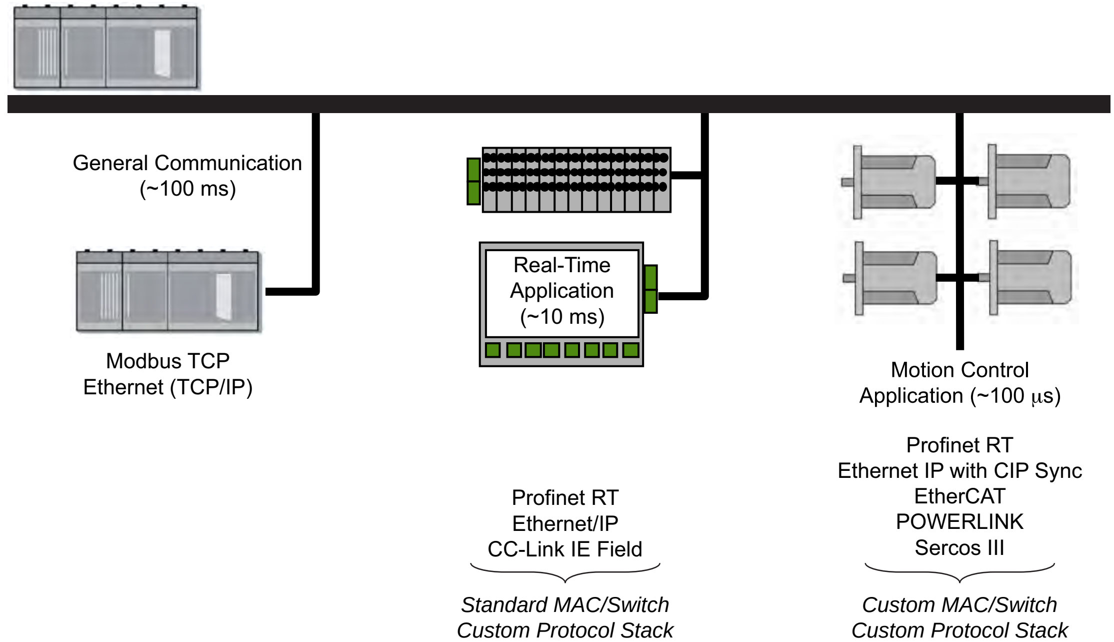
Figure 1. Architecture of the Industrial Ethernet Protocol



EtherCAT and Profinet IRT are two of the newer protocols that require a special MAC design. EtherCAT in particular uses an innovative methodology to pack more data packets within a single Ethernet frame. Data for multiple slave devices is packed into a single Ethernet frame. When a slave device reads the Ethernet frame, it must extract the data package meant for itself and ignore the others. More importantly, it must do this extraction “on-the-fly.” The data package is extracted in order to reach the very low latency requirements when many slave devices are connected. For example, if you are the 256^{th} slave device on the network, a single frame latency is incurred rather than a 256 frame latency. Typical applications are motion control or multi-axis robot drives.

To support the chosen protocol, the design of the MAC in the slave device differs from the traditional Ethernet MAC and requires a special design in an FPGA or ASIC. From a system design perspective, if you must support a standard MAC implementation as well as a special implementation, then the design should either include both the MAC designs or be reprogrammable in hardware. Figure 2 shows how different real-time requirements can lead to different architectures of the communication protocol standards.

Figure 2. Different Real-Time Requirements Lead to Different Implementations



Key Trends Affecting System Design

Some of the trends affecting Industrial Ethernet system design include the embedded communication protocols, the proliferation of Industrial Ethernet standards, and the movement towards Gigabit Ethernet.

Embedded Communication Protocol

The first trend in drives and I/O modules (typical slave devices in factory automation) is that the communication function has become deeply embedded, due to shrinking system cost, form factor, and power budgets. In the past, customers bought an off-the-shelf communication module costing hundreds of dollars, which could be then added to the drive module. This type of module is neither cost-effective nor appropriate for smaller form-factor drive designs. Another alternative was to include a separate ASSP dedicated to communication functions. This ASSP would be over-designed to support many protocols because different customers would use different Industrial Ethernet standards.

However, as vendors seek to integrate all their digital drive functions onto a single piece of silicon, the communication protocol is by necessity becoming a small function implemented as part of the entire “drive-on-chip” design. Figure 3 illustrates the transition of the Industrial Ethernet function implementation.

Figure 3. From Modules to Devices to an Integrated Function on the Chip

Proliferation of Industrial Ethernet Standards

The second trend is the proliferation of Industrial Ethernet standards. Just like the fieldbus protocols, there are many variants of Industrial Ethernet protocols, and most importantly, the market is not coalescing around any one or two standards.

A drive system vendor must be able to support about six to eight standards to be able to sell their products worldwide to different plants. For example, if you want to sell your drives in both Asia and Europe and want the drives to work with both Ethernet POWERLINK and EtherCAT, then you can:

- Design, develop, and maintain two sets of drive designs

OR

- Include a ASSP that support multiple protocols—and hope the protocols don’t change

OR

- Use a programmable platform

Table 1 shows some of the competing Ethernet standards that are popular worldwide.

Table 1. Competing Ethernet Standards Based on the Underlying Fieldbus Protocols

Fieldbus	Ethernet Variant	Interest Group
PROFIBUS	PROFINET	PI
DeviceNet/ControlNet	Ethernet/IP	ODVA
Sercos III	Sercos III	sercos international
CC-Link	CC-Link IE	CLPA
Modbus RTU	Modbus TCP	Modbus IDA

In the past when the Industrial Ethernet standards used a standard MAC/switch, it was easy to dedicate a microprocessor unit (MPU) for communications. If you had to support a new standard, you just swapped out the protocol stack (software). However, as discussed earlier, many of the newer standards require a specialized MAC implementation. It is clear that standardizing the communication protocol implementation on a standard MPU with a standard Ethernet MAC and switches falls short when dealing with such newer standards.

Some MPU vendors have developed techniques like developing custom microcode for a proprietary embedded processor to emulate a non-standard MAC. But these are esoteric methodologies with unknown pitfalls. Protocols that require a specialized MAC implementation are usually best applied with a custom hardware approach using either an ASIC or an FPGA depending upon the volume and the desired price-point. In addition, there is always a possibility that the MAC design may change as these standards evolve. To future-proof your design against such an eventuality, a programmable hardware approach is the safest.

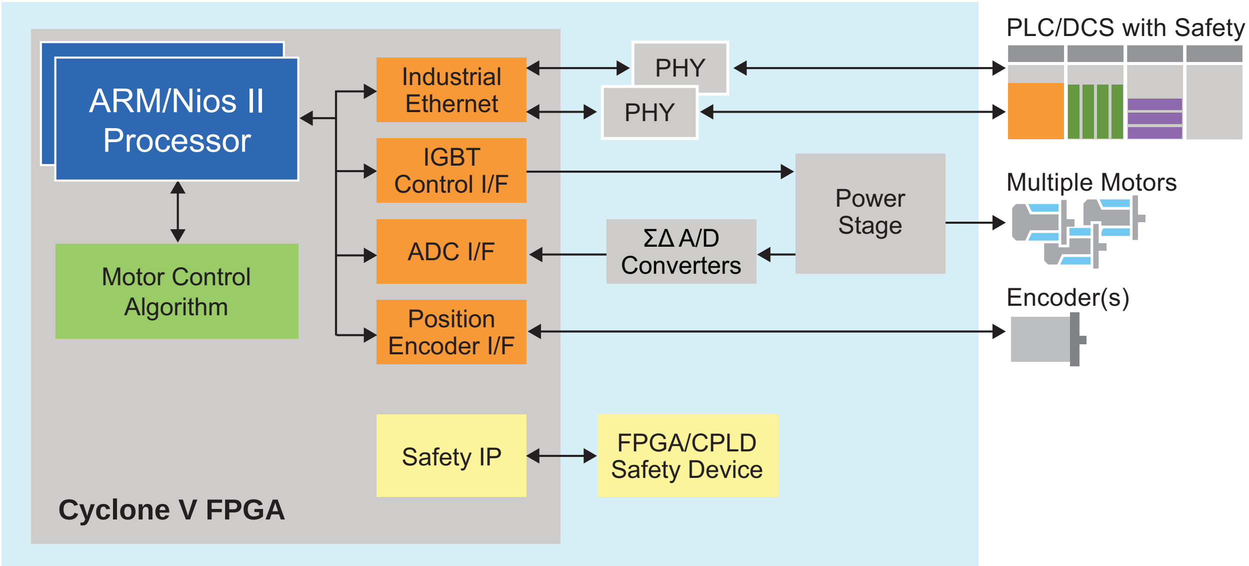
Movement Towards Gigabit Ethernet

Another consideration is the potential movement towards Gigabit Ethernet in the future. Since almost all FPGAs can support Gigabit Ethernet, even if the standards start to move towards the higher 1 Gbps speeds, a well-thought-through system design would need just a new FPGA programming file to support any such standard evolution. Implementing the Industrial Ethernet protocol as a deeply embedded function within a programmable fabric thus gives you not only the flexibility of supporting multiple protocols with the same hardware but also all the benefits that flow from a highly integrated design: power, cost, and form factor.

The Future is Drive-on-a-Chip

Unlike traditional drive technologies based on ASICs, ASSPs, MCUs, and DSP devices, a drive system based on a single FPGA platform, such as the Altera® Cyclone® V FPGA shown in Figure 4, provides a scalable platform that supports diverse drive needs.

Figure 4. The Drive-on-a-Chip System Design for Lowest BOM Cost and Form Factor



Altera FPGAs allow you to leverage multiple processor architectures, such as the Nios® II embedded soft processor or the more powerful dual-core ARM® Cortex™-A9 MPCore™ hard processor. With support for multiple types of operating systems, the latest Industrial Ethernet protocols, digital encoder interfaces, floating-point arithmetic, and device-hardened features such as memory controllers, variable-precision DSP blocks, and transceivers, an FPGA-based motor control system lets you integrate traditional FPGA functions with the drive control loop and the communication protocol functions. As these digital functions on a drive system are implemented using a single chip, Industrial Ethernet becomes just one of many function blocks integrated in a FPGA.

Simplifying Industrial Ethernet Licensing and Design

Let's look at some of the pain points from the perspective of a system architect designing a drive module:

- The system must be able to be reprogrammed with multiple Industrial Ethernet protocols so the system can work with any programmable logic controller (PLC)
- OEMs need access to multiple hardware-tested Industrial Ethernet protocols. Because time to market and budgets are being compressed all the time, it is not practical to negotiate with each protocol vendor individually
- Different drive modules support different feature-sets and have different price and feature characteristics, so it is important that the protocol intellectual properties (IPs) can work in a range of FPGAs.

To ease these pain points, designers need a way to provide most of the slave Industrial Ethernet protocols to OEMs with no up-front licensing and no separate royalties. Such a solution is offered by Altera and Softing Industrial Automation Gmbh, a leading provider of industrial communication products and technologies for manufacturing and process automation. The Altera and Softing solution gives you access to all the protocols shown in Figure 5 with no licensing negotiation, up-front licensing costs, or separate per-unit royalty. Instead, the solution is available via four quick steps:

1. Choose the Industrial Ethernet protocol to implement—even choosing more than one .
2. Download the custom slave protocol IP and software stack from Softing, which works with all Altera Cyclone series FPGAs.
3. Evaluate the IP in your own design in the Quartus® software and in hardware (development kits).
4. Purchase a special security CPLD from Altera to enable any one of the selected protocols in production.

Figure 5. Using an Altera FPGA and Softing IP Allows You to Design Most of the Slave Industrial Ethernet Protocols with Complete "Hassle-Free" Licensing

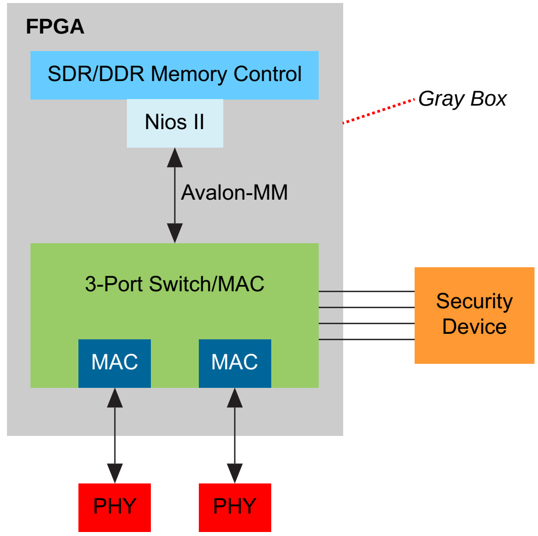
Structure of the Protocol IP

Let's look at the structure of the protocol IP that you can download to implement your favorite Industrial Ethernet protocol(s). The protocol IP for Industrial Ethernet has both a logic component and a software (stack) component. The logic component implements necessary hardware blocks for the various protocols, such as a switch for PROFINET and EtherNet/IP, a hub for POWERLINK, etc. The IP is made available as a "black-box IP," which means that the internal source RTL is not made available. This IP must be accessed via a defined and documented interface.

The software component includes the protocol stack running on a free operating system (OS), such as eCOS, that is made available as an .elf binary file within the Nios II Integrated Development Environment (IDE). Again, the source code is in the form of a black box, and the binary software file must be run on a Nios II/f processor.

It is important to put these components together as shown in Figure 6 to create the "gray box." The gray box consists of the Nios II/f processor, the black box IP, and the memory controller, and must be put together exactly as shown in the reference design that ships with each protocol IP. You can hook up the rest of your (logic) design to this black box via a defined logic interface and access the protocol stack via a defined software application programming interface (API) common to all the Industrial Ethernet protocols.

Figure 6. Structure of the Industrial Ethernet Protocol IP



Note:

(1) Altera Avalon® Memory -Mapped Interface (Avalon-MM)

Once the design is complete, you can choose to perform software simulations within the Quartus software or even a hardware evaluation using either the Cyclone IV FPGA-based Industrial Networking Kit (INK) from Altera or the Cyclone III FPGA-based Real-Time Ethernet Module (RTEM) from Softing. The Industrial Ethernet protocol IPs developed by Softing for Altera have been validated in hardware using these development kits.

Conclusion

Like many other communications functions, Industrial Ethernet implementation is moving from the module to the device to becoming a deeply embedded function. This evolution is standard for many functions over time as system vendors work hard to optimize their design for cost, power, form factor, and more. What is unique about Industrial Ethernet is the number of worldwide standards and the need for a slave module vendor to support multiple standards.

The only cost-effective and efficient way of supporting 8 to 10 different standards, as well absorbing any hardware and software updates over the life cycle of these slave products, is to make sure the implementation is done in a device that is both hardware and software programmable. A hardware- and software-programmable device allows the system vendor to support Industrial Ethernet variants that use a standard MAC with a special software stack as well as variants that need a custom MAC design and a special software stack. Also, regular software stack updates and not-so-regular logic updates can be accommodated using the same hardware.

Recognizing the fact that Industrial Ethernet implementation increasingly makes sense in a programmable device, Altera has partnered with Softing to bring you a simple, no-hassle way to get the most of the top Industrial Ethernet protocols, using a Cyclone series FPGA and a small, low-cost security CPLD.

Further Information

- Industrial Ethernet:
  www.altera.com/industrialethernet
- Design Efficient Motor Control Systems with an FPGA:
  www.altera.com/end-markets/industrial/motor-control/ind-motor-control.html
- Webcast: "Simplifying Industrial Ethernet Design"
  www.altera.com/education/webcasts/all/wc-2012-simplify-industrial-ethernet-design.html
- Softing:
  www.softing.com

Acknowledgements

- Suhel Dhanani, Sr. Strategic Marketing Manager, Industrial and Automotive Business Unit, Altera Corporation
- Frank Iwanitz, Product Manager, Softing AG

Document Revision History

Table 2 shows the revision history for this document.

Table 2. Document Revision History

Date	Version	Changes
November 2012	1.0	Initial release.