Using Ethernet for Industrial I/O and Data Acquisition

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Abstract

The worldwide familiarity, standardization, and availability of Ethernet, along with its current and potential performance levels, has prompted increased consideration of Ethernet as a viable communications technology for distributing industrial IO and data acquisition tasks. This paper examines the use of Ethernet-based measurement and data acquisition systems, and some of the unique requirements and considerations that result. Specifically, the performance level and reliability of Ethernet is shown to be evolving to a level to deliver very high-performance measurement data. Technologies that are key to this evolution include intelligent switching hubs and Fast Ethernet. Implementation of Ethernet-based measurement systems can be classified into one of two categories - the PC-Based Measurement System, or the dedicated Ethernet-Based I/O Device.

1. Introduction

While becoming the dominant LAN technology, Ethernet has proven to be a very effective and very economical PC networking solution. With 10 Mbps and 100 Mbps Ethernet components widely available at a relatively low cost, users are increasingly interested in applying this familiar technology directly to their distributed measurement and control applications. However, the requirements of a real-time measurement or distributed control are very different from those of the office or campus LAN. Ethernet is now available as a direct communications link on a growing number of data acquisition instruments and industrial I/O devices. Before the unique issues of Ethernet-based data acquisition and I/O systems are examined, it is useful to described some of the of both data acquisition applications and of Ethernet technology.

2. Background and requirements of data acquisition and I/O

As used in this paper, the term *data acquisition and industrial I/O* refers to the process of acquiring and measuring real-world signals from sensors, transducers, and devices. Data acquisition and I/O devices typically consist of some combination of analog and digital input and output capabilities, including signal conditioning, analog-to-digital (A/D) converters, digital-to-analog (D/A) converters for analog outputs, and timing I/O. Data acquisition and I/O products are commonly used to interface directly to sensors, such as thermocouples, RTDs, strain gauges, load cells, pressure sensors, flowmeters, and 4-20 mA transmitters. High-speed data acquisition devices can capture waveform signals, such as electrical transients, vibration and audio waveforms.

Today, data acquisition and I/O products are usually used in conjunction with a desktop, industrial, or notebook PC. Plug-in boards with high-speed data acquisition capabilities are widely available for PCI, ISA, and even PCMCIA. External data acquisition devices typically connect to the PC using a serial (RS-232), IEEE-488, or USB connection. Products used in more industrial application provide I/O and control with interfaces for industrial networks, such as DeviceNet, Profibus, or other fieldbus.

The demands put on the communications interface by data acquisition and I/O applications vary widely. Many process and environmental monitoring applications involve relatively low bandwidth signals that are sampled at less than 10 Hz. Higher speed data acquisition applications such as audio and vibration measurement involve the capture of waveforms at sampling rates up to 100 kHz per channel. Electronic data acquisition applications with A/D sampling rates in the multiple-megahertz range are becoming more and more common. Measurement devices for these higher speed applications typically include local memory for temporary storage of data before it is transmitted over the communications port.

While the focus of this paper is on data acquisition and industrial I/O, a closely related function is that of real-time control, in both the equipment used and the nature of the functionality. Traditionally, real-time control devices integrate the processor and I/O into a single device, ensuring deterministic behavior in the execution of input measurement, control algorithm calculation, and control output generation. The use of remote I/O, however, requires a communications link between the control processor and I/O. For reliable control, this communications link must provide deterministic sampling or scanning of inputs.

3. Background of Ethernet technology

Less than 20 years ago, Xerox, Intel, and DEC published a specification that defined a networking technology intended for linking computers in an office environment. The specification evolved into IEEE Std 802.3 (and ISO/IEC 8802.3), and ISO/IEC8802.3, published in 1983 and 1985, respectively. These standards refined the original Ethernet specifications, defining a 10 Mbps network available on a variety of physical implementations, or media. These media included, among others, 10Base5 and 10Base2 (coax), fiber optic (10BaseFP), and 10Base-T (unshielded twisted pair). Table 1 summarizes the key attributes of some of these media.

While coax and fiber are common for medium and long distances, usually as the backbone of a network, inexpensive telephone wire is becoming the de factor standard for direct connection to desktop computers and other Ethernet devices. In particular 10Base-T (10Mbps) and 100Base-TX (100 Mbps) utilize unshielded twisted-pair wiring (UTP). The growing popularity of UTP, combined with the availability of multiport repeater hubs, has replaced the original trunkline topology of Ethernet with a star topology using point-to-point connections.

Ethernet defines a mechanism for resolving transmission conflicts on the wire, referred to as CSMA/CD (Carrier Sense Multiple Access with Collision Detect), whereby colliding devices back-off from an attempted transmission and retry after a random delay. This random delay ranges from 0 to 102 microseconds for the first retry, to 0 to 51 milliseconds on the sixteenth consecutive retry. For Fast (100 Mbps) Ethernet, the ranges are reduced to 0 to 10 microseconds, and 0 to 5 milliseconds for the sixteenth retry. Therefore, it is impossible to exactly predict the amount of time for colliding devices to successfully transmit information. This consequence of the CSMA/CD collision mechanism has brought up concerns over determinism, particularly in the areas of real time control and data acquisition.

Devices on a single Ethernet segment belong to the same collision domain, meaning that network access and transmission is governed by the CSMA/CD mechanism. The evolution of intelligent network bridges and switching hubs now enables segmentation of networks into separate collision domains. Strategic use of these technologies can therefore decrease the occurrence of collisions and yield significant performance improvements on loaded networks

Ethernet performance has continued to evolve with the development of Fast Ethernet and Gigabit Ethernet. Fast Ethernet, defined in IEEE 802.3u, increases throughput by an order of magnitude to 100 Mbps. In addition, the reduced collision recovery delays of Fast

Network	Rate	Topology	Segment	
			Length	Nodes
10Base-T (UTP)	10 Mb/s	Star	100 m	2
10Base-5 (thick coax)	10 Mb/s	Bus	500 m	100
10Base-2 (thin coax)	10 Mb/s	Bus	185 m	30
10Base-F (fiber optic)	10 Mb/s	Star	2000 m	2
100Base-TX (UTP)	100 Mb/s	Star	100 m	2
100Base-FX (fiber optic)	100 Mb/s	Star	412 m	2

Table 1. Some of the Ethernet network types defined in IEEE 802.3 and ISO/IEC 8802.3

Ethernet benefit loaded networks in particular. Fast Ethernet can run on fiber or UTP, Category 5 wiring, and is commonly used for high-traffic data servers, or as a backbone connection. Gigabit Ethernet, defined in IEEE 802.3z, is an emerging technology that further ups the bandwidth to 1000 Mbps.

4. Critical Measurement and I/O on Ethernet

Ethernet enjoys widespread usage in the office environment for information sharing and exchange, and as the enterprise-wide network. The popularity, performance, cost, and familiarity of Ethernet, along with standardized PC and Windows compatibility, have prompted it’s increased consideration and usage in industrial measurement and control applications. In particular, Ethernet is being integrated, or embedded, directly into measurement instruments, data acquisition devices, and industrial I/O systems. Where Ethernet was originally utilized exclusively for LAN connections of business computers, Ethernet is increasingly being moved down to the instrumentation communications and control layers of the industrial information infrastructure. (see Figure 1).

However, this relatively new application of Ethernet technology raises new issues and concerns about the appropriateness of Ethernet for critical measurement and control tasks. These concerns include lack of determinism, high data overhead, and availability of industrial-grade network components.

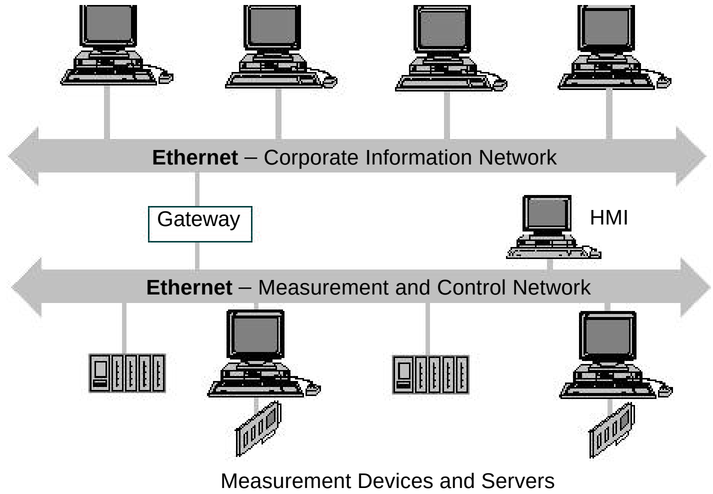


Figure 1. Ethernet is increasingly being used at both the information and measurement network layers

4.1 Performance and Determinism with Ethernet

Concerns over the lack of determinism center around the use of the CSMA/CD mechanism. The CSMA/CD method of collision detection and random retries indicates inherent non-determinism. However, the increasingly high bandwidth of Ethernet and Fast Ethernet, along with the use of intelligent switches has proven to deliver predictable, even deterministic, I/O over Ethernet.

Intelligent switching hubs are high-performance, low latency switches that route Ethernet messages to the destination only. Switches effectively segment a network into separate collision domains, resulting in much increased efficiency of the network bandwidth.

According to one estimate, Ethernet remains deterministic for a load of 10% of bandwidth for shared (non-switched) Ethernet and 50% of bandwidth for switched Ethernet[1]. This translates to 120 kbytes/sec and 1200 kbytes/sec for shared 10 Mbps and 100 Mbps Ethernet, respectively. For switched Ethernet, this increases to 600 kbytes/sec and 6000 kbytes/sec for 10 Mbps and 100 Mbps Ethernet, respectively.

A performance study by LANQuest Labs on switched Ethernet performance demonstrates the performance improvements in a switched multi-client/server environment [2]. While this test involved the download of a 127 MB file from a single server by multiple clients, the test results indicate the type of performance benefits realized by a measurement system with multiple measurement nodes networked to a single PC. For example, with 16 clients,a 100 Mbps switched network improved performance by a factor of 6 or more.

Informal benchmarking at National Instruments using NI-DAQ with Remote Device Access (RDA) indicate that data can be continuously acquired over a 10 Mbps shared LAN at 170 ksamples/sec (340 kbytes/sec). In a dedicated point-to-point Ethernet section, sustained throughputs of 350 ksamples/sec to 550 ksamples/sec have been observed [3,4].

Other technical developments are taking place that will help allay the performance and determinism concerns. In addition to Fast Ethernet, Gigabit Ethernet (IEEE 802.3z) boosts Ethernet bandwidth even further to 1000 Mbps. While Gigabit Ethernet uses the same frame format, addressing, and CSMA/CD mechanism as regular Ethernet, the currently high cost of this emerging technology is slowing its deployment. Also, the question of determinism is being met head-on with the new standardization of Ethernet message prioritization, defined in IEEE 802.1p.

4.2 Moving Ethernet into Industrial Environments and Applications

Measurement, control, and I/O applications often require industrial grade components that can endure temperature extremes, shock and vibration, high levels of EMI, etc. This is now beginning to be addressed by network suppliers recognizing this opportunity. However, this current lack of industrial-grade media components (hubs, switches, routers, etc.) may at least temporarily slow the acceptance of Ethernet into the harsher industrial applications.

A number of proprietary and open fieldbus networks are in use in industrial automation applications today. Ethernet is also poised to penetrate the market for these high-speed control networks, such as Profibus, DeviceNet, and ControlNet, and FOUNDATION Fieldbus. While an in-depth comparison of Ethernet to these networks is beyond the scope of this paper, it is worthwhile to note some key comparisons. When compared to these control networks, the main strengths of Ethernet are its total installed base, cost per node, and high data rate. On the other hand, some control networks include standardization the user/application layers of the OSI model, providing higher level of interoperability of devices. Also, these control networks tend to support solid determinism, redundancy, and bus-powered devices.

Of course, one additional, very important advantage of Ethernet is its openness, worldwide connectivity, and built-in compatibility with the dominant PC platform, Microsoft Windows. For example, you can connect measurement nodes to an Ethernet network and almost automatically have access to the data across the world via the internet.

5. Implementation and Device Requirements

Implementation of an Ethernet-based measurement system can be classified into one of two broad categories, referred to here as Networked PC Measurement Systems, and Ethernet-Based I/O Devices.

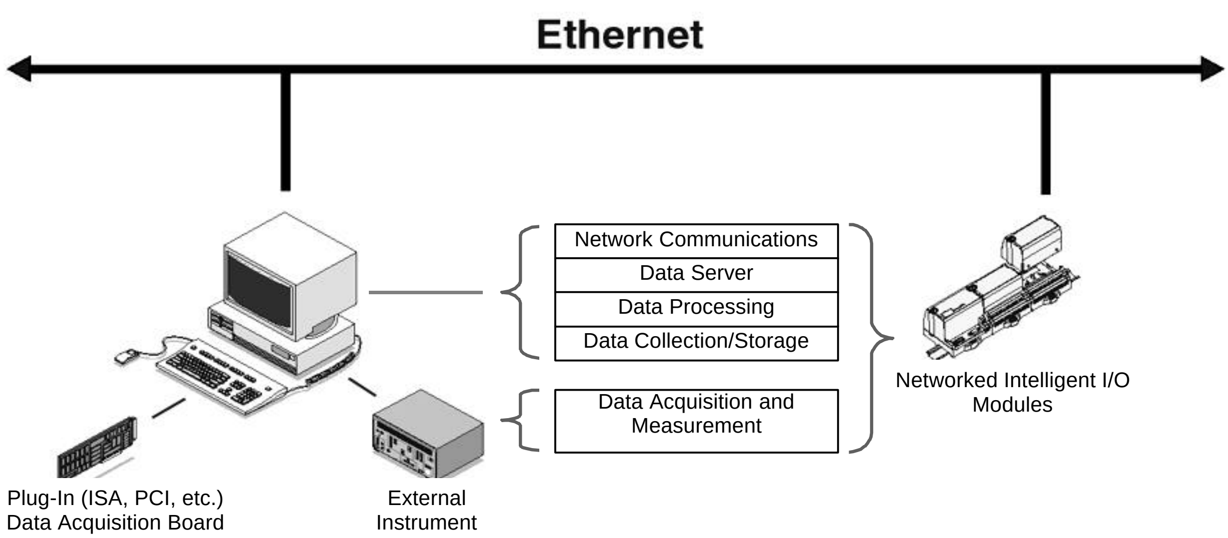
5.1 Networked PC Measurement Systems

The first approach to Ethernet-based measurement systems is to apply standard, commercial PC networking technology and measurement technology to turn PCs into networked measurement servers. In other words, a Networked PC Measurement System is simply a PC-based data acquisition or measurement system, with the necessary network interface card and software to serve measurement data over Ethernet (see Figure 2.a).

For example, using plug-in PCI data acquisition boards, or RS-232 devices linked to a PC, you can use standard data acquisition software on the PC to collect the data, process and minimize the data as needed, and then publish the data to the network. Network communications can be accomplished using a number of different approaches. For example, the PC system could utilize standard networking software provided by Microsoft, such as TCP/IP protocol, remote procedure calls (RPC), distributed component object model (DCOM), or OLE for process Control (OPC).

These different software approaches require a varying degree of end-user development and expertise. Two high-level approaches that can require little networking expertise are OPC and RPC. OPC, developed and maintained by a consortium of suppliers in the industrial automation marketplace, provides a standard interface for application software packages to communicate with I/O devices [5]. Because OPC is built upon COM an DCOM, OPC operates transparently over the network. As an example, if the PC Measurement System is outfitted with I/O devices and an OPC server for those I/O devices, clients with OPC capabilities on the network can read and write data to and from the server.

RPC is a Microsoft Windows service that can be used to remotely execute functions on a networked PC. This



a. PC-Based Measurement System with Network Interface Card

b. Ethernet-Based I/O Device

Figure 2. Two implementation options are a) using standard PC-based data acquisition and measurement system with networking interfaces or software, or b) intelligent, networked I/O device

technology can be exploited to provide very easy-to-use networked data acquisition. For example, National Instruments has implemented Remote Device Access (RDA) which provides their entire library of data acquisition and I/O functions (NI-DAQ) with RPC capabilities. In other words, you can develop a measurement application that makes NI-DAQ I/O calls to a data acquisition board that is installed in the same PC, or to a remote networked computer with data acquisition boards. Internally, the NI-DAQ driver software makes RPC calls to remotely perform the networked data acquisition.

In general, Networked PC Measurement Systems has several advantages. Because the approach uses standard PC-based technology, this approach provides the greatest amount of options and flexibility. Any PC-based measurement system can be transformed into a Networked PC Measurement System with the appropriate software. On the other hand, this approach does require the use of a PC at every remote measurement location. Depending on the application, this may be prohibitively expensive, or too bulky. In these applications, it is more appropriate to use a smaller, dedicated Ethernet-Based I/O Device.

5.2 Ethernet-Based I/O Device

Much attention has been focused on the use of Ethernet technology directly at the device level. The decreasing cost and increasing capabilities of network interfaces and microprocessors have accelerated the movement of communications network connections down to the instrument and device level. The Ethernet-Based I/O Device is a measurement or I/O device with an Ethernet connection directly on the device itself (see Figure 2.b). This approach provides a relatively inexpensive option for networked data acquisition, and provides greater versatility in terms of locating the measurement device in size-constrained areas or harsh environments.

Compared to some other simpler communications links in use today, Ethernet does typically require a more powerful microprocessor and more memory to execute the communications stack. However, the evolution of Ethernet technology indicates that the implementation cost will continue to decrease.

The commercial availability of Ethernet-Based I/O Devices is increasing rapidly as manufacturers convert existing systems over to Ethernet. Typically, the Ethernet-Based I/O Device is a measurement device with a standard Ethernet interface, usually 10Base-T, incorporated into the communications interface.

An Ethernet-based measurement device does have a unique set of requirements, relative to a standalone or PC-based measurement system. Reliable, autonomous operation of a distributed measurement device requires a more intelligent device with a local microprocessor that handles communications, system management, and diagnostics. This is in addition to the needed components to collect and process the actual measurements. Many devices also implement embedded data servers, improving the efficiency and ease-of-use of accessing collected measurement data. For example, Figure 3 shows the functional diagram of a typical Ethernet-Based I/O Device

6. Summary

Ethernet's potential as a network for distributed measurement and control is virtually unlimited. As Ethernet continues to be enhanced with greater performance, higher determinism, and lower cost implementations, Ethernet can provide a very capable measurement network, and even consolidate control network applications.

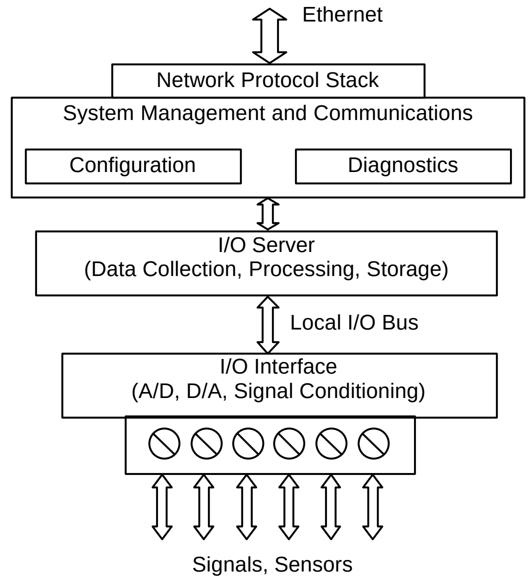


Figure 3. Typical Functional Diagram of Networked I/O device

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