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Introduction

The first process control systems were understandably analog, simple devices with signal formats that were essentially determined by the need for an architecture with a minimum number of costly CPUs. Networking was introduced into industrial automation in the 1970s and first utilized in direct digital control (DDC) systems between computer and I/O (input/output). Later, it was used in distributed control systems (DCS) and programmable logic controller (PLC) systems to connect the controllers and operator consoles. However, digital communications in smaller devices such as transmitters on the plant floor was not seen until the 1980s, and true communication bus networking of field instruments did not gain wide acceptance until the 1990s.

At the other extreme, corporations network their plants across the globe to the corporate headquarters via the Internet. The coordination of production and other business functions has become an integral part of the corporate information technology (IT) structure. Networking has made it possible to collect more information from the plant and to disseminate it far and wide throughout the enterprise. Geographically distributed components with lots of “intelligence” are now expected to work together. Networking has become essential for automation and is changing the way plants and factories work.

Digital Communication Networks

Many networks, such as telephone, radio, and television, are primarily analog, but the trend is definitely toward all-digital communication. So too, the networking used in automation is

predominantly digital, that is, data is transmitted serially between devices as a stream of ones and zeroes. Digital communications now makes possible data transfer between devices such as transmitters, valve positioners, controllers, workstations, and servers.

More Information

A major advantage of digital communications is that a great deal of information can be communicated on a single cable. Instead of one hardwired cable for each variable, thousands and even millions of pieces of information can be communicated along just one network cable. This makes it possible to extract much more information from each device than was realistically possible using analog signals. For example, before digital communications was introduced it was impossible to remotely transmit anything other than simple I/O. Tuning and controller settings had to be done locally (figure 1-1). Therefore all controllers had to be placed in large panels lining the walls of the control room to enable operation directly from the controller faceplate. Sensors and actuators were hardwired to their controllers using an individual dedicated pair of wires and transmitting nothing more than a single process or manipulated variable. The analog signal only traveled in one direction, from the transmitter to the controller or from the controller to the positioner.

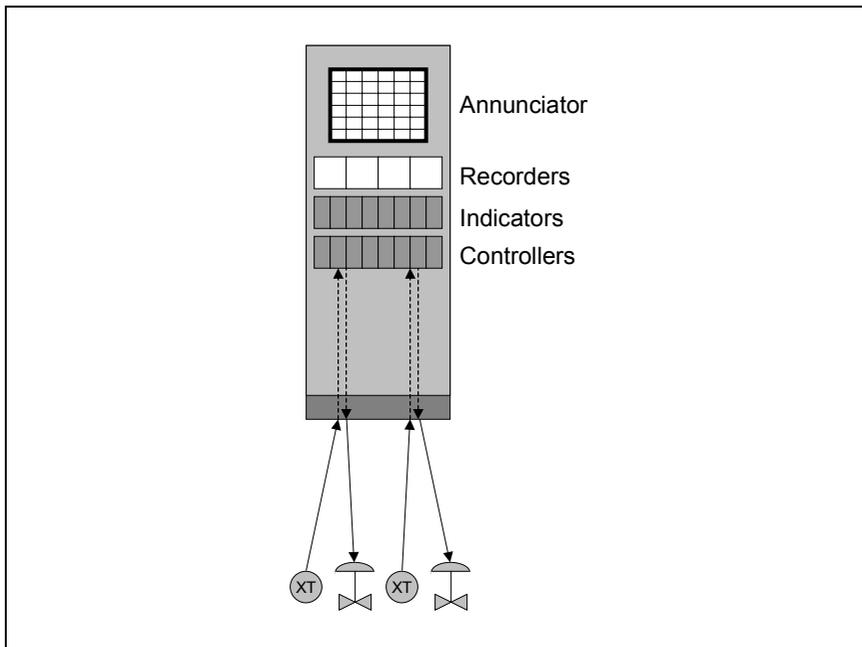


Figure 1-1. In the past, controllers had to be located in the control room panel.

The advent of digital communications made it possible for the DCS and PLC controllers to be placed away from the control room in an auxiliary rack room. All the supervisory information for hundreds of loops and monitoring points could be transmitted to the operator console in the control room over a single network. Digital communications carry not only I/O like process and manipulated variables but also operational information such as setpoint and mode, alarms, and tuning in both directions to and from the control room. Communications thus enabled distributed processing, and diagnostic, configuration, range, identification, and other information could now be added, initially in controllers but then also in field instruments such as transmitters and valve positioners. Thanks to communications, field instruments now perform not only a basic measurement or actuation but also have features and functions for control and asset management.

Multidrop

A second major benefit of digital communications is the capacity to connect several devices to the same single pair of wires to form a multidrop network that shares a common communications media (figure 1-2). Compared to running a separate wire for each device, this reduces the wiring requirement, especially for field-mounted instrumentation involving large distances and many devices. Even by putting just a few devices on each pair of wire, the amount of cable required is greatly reduced, translating into hardware and installation savings.

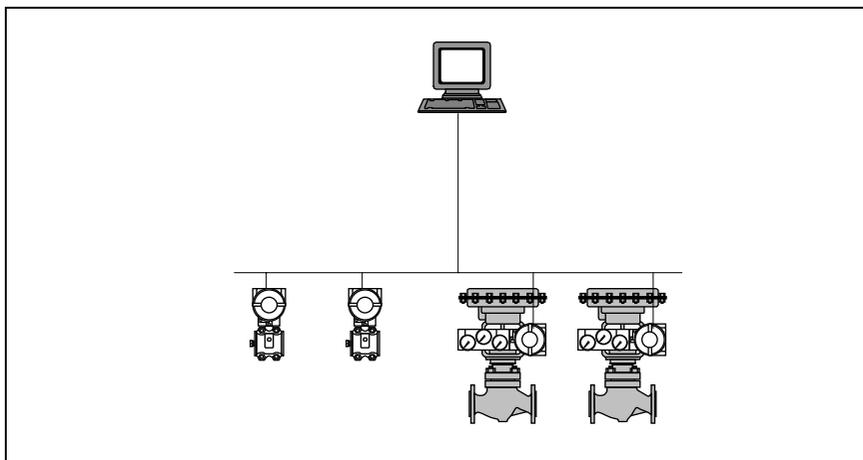


Figure 1-2. Network nodes sharing a common media.

The communicating devices on the network are called *nodes*, and each node is given a different address that distinguishes it from the other devices. This makes it possible to interrogate and send messages to any one specific device.

In the simplest form of communication, a device such as a host workstation or PLC is the master that sends requests to read or write a value to other devices such as field instruments, which are called *slaves* (figure 1-3). The slave that was addressed then responds to the request. An example of this is a HART® or PROFIBUS master configuration tool or handheld terminal writing a parameter in a slave positioner from time to time, acyclically. In networks with no specific master or slaves such as FOUNDATION™ Fieldbus this method is called “client/server”: a device acting as a client requests, and the device acting as server responds. Another example of the master/slave configuration is a master PLC reading a process value from a slave transmitter and then after executing a control algorithm writing the output to a slave positioner. For PROFIBUS closed-loop control this reading and writing is repeated cyclically.

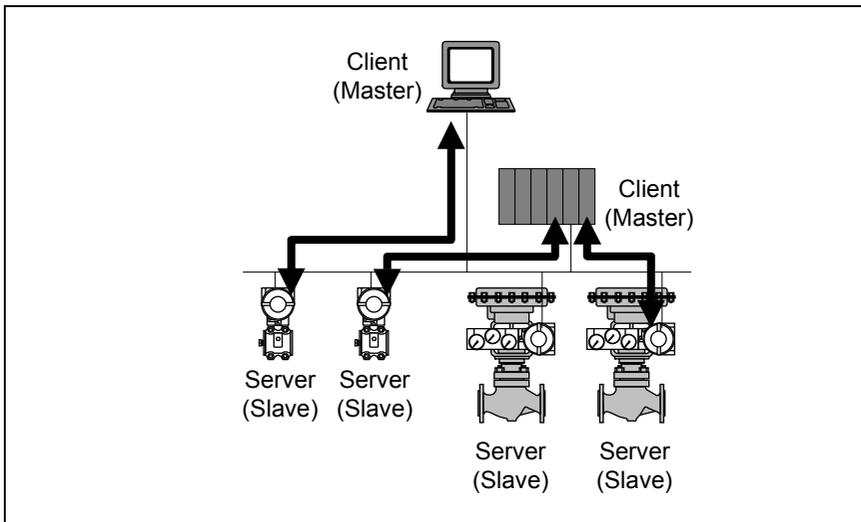


Figure 1-3. Client-server (master-slave) relationship.

Another mode of communications that is ideal for cyclic communication is where a device acting as a “publisher” broadcasts a value that is then used by all interested devices, which act as “subscribers” (figure 1-4). This is very efficient because the value is transmitted directly from one field device to another in one single communication, reaching several subscribers at once. This method

is used by FOUNDATION Fieldbus for closed-loop control. Communicating from one device to another without going through a central master is called peer-to-peer communication.

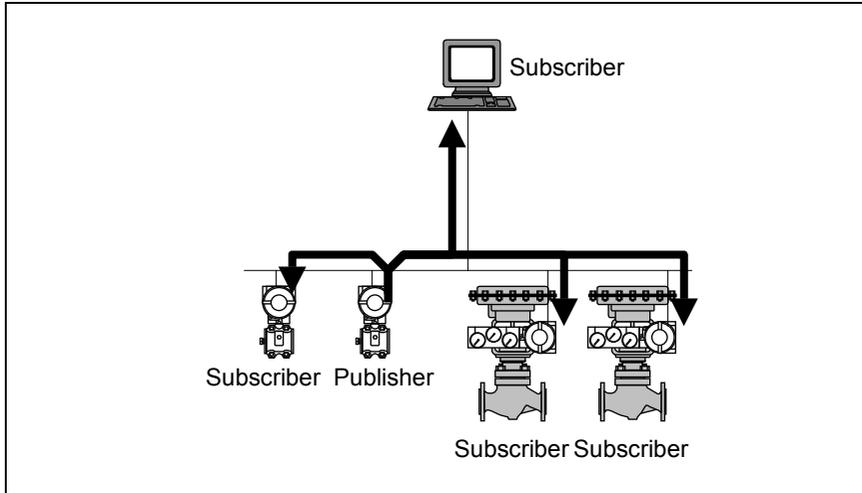


Figure 1-4. Publisher-subscriber relationship.

A third mode of communication is when a device acting as a “source” transmits a message to a device acting as a “sink” without the sink having to solicit the data (figure 1-5). While the state remains the same it is not communicated. The transmission is only made when there is a change of state sometimes called “report by exception”, e.g. when an alarm occurs. This configuration is ideal for environments where operators want devices to report process alarms or fault events as they occur, while otherwise remaining silent.

Rather elaborate schemes are used by all protocols to ensure that no two devices communicate at the same time. This and other aspects of digital communications networks are explained in chapter 11.

Robust

In a 4-20 mA analog system value is transmitted by the infinite variation of a current. A signal error just changes a valid signal into another valid signal. The signal from even the most accurate analog transmitter may be totally inaccurate by the time it reaches the controller. Digital communications has the advantage of being a very robust signal with only two valid states (one and zero). It is transmitted directly or encoded in some form and is therefore less

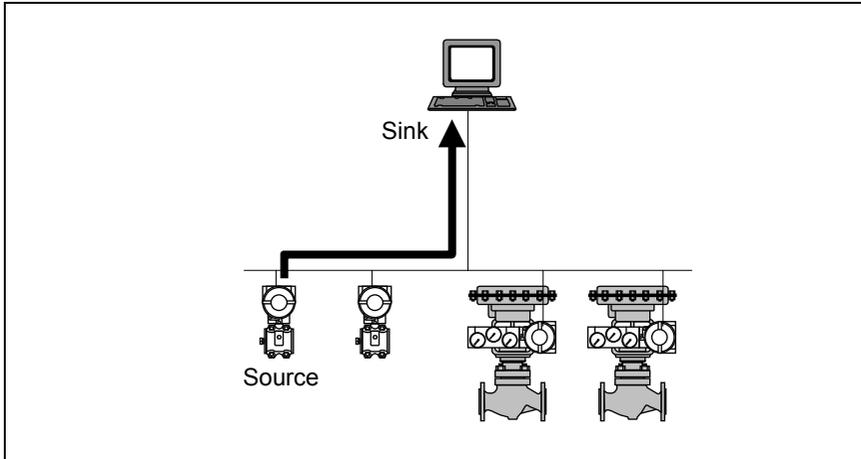


Figure 1-5. Source-sink relationship.

sensitive to distortion than an analog signal. Even more importantly, by using error-checking techniques it is possible to detect if the digital signal has been distorted, and if it has, to discard the message and possibly ask to have it retransmitted. Signal distortion cannot be detected in an analog system because a distorted signal still looks like a valid process signal. An analog signal that should be 19 mA may jump between 18.97 and 19.03 mA because of electrical interference or be limited to 18 mA because of insufficient supply voltage. There is no way to tell this, however, because it is still a valid signal. Operators may suspect a noisy or limited signal, but there is no way to tell what is distortion and what is the real process change. However, a received digital signal is true to what was originally transmitted. The superior fidelity of digital signals over analog signals is why they are used in compact disks as well as in automation; it results not only in higher accuracy but also in greater confidence level.

Interoperability

A potential problem with digital communications is that there are many different ways to do it. The method of representing, encoding, and transmitting the data is called the *protocol*. Manufacturers have devised many different protocols, and products designed for one protocol cannot work with those designed for another. One of the goals of standardization committees is to define a standard protocol that all devices can follow, thus making it possible for products from different manufacturers to interoperate, that is, work with each other. A key point is that a system's power is not defined by the capability of each of its individual devices but by the ability of these devices to communicate with each other. Two

best-in-class and ever so powerful devices that don't integrate seamlessly do not create a solution as powerful as two simpler devices that use a standard protocol. For the same reason, the sub-systems for basic, critical, and advanced control in a plant must also have open interfaces. Chapter 11 describes exactly how some of these protocols used in process control work, their similarities as well as their differences. It is not necessary to understand how the buses work in order to use them, however. The buses are designed such that the complexity of their function is hidden; as a result, they are easy to use.

Automation Networking Application Areas

Networking is used in all areas of automation. In factory automation, process automation and building automation networks perform diverse tasks. Likewise, there are distinct differences between tasks performed for applications in different industry sectors that all have unique characteristics and consequently varying requirements. The way devices are connected, configured, and exchange data also differ.

There is no one-size-fits-all for industrial networks; rather, buses are optimized for different characteristics. For example, factory automation and process automation are often used in harsh and hazardous environments where people, nature, and expensive machinery are at stake or where a production interruption is costly. These requirements contrast significantly with building automation, for example, where keeping costs low is a main driving force.

Factory Automation

Factories with assembly-line manufacturing, as in the automotive, bottling, and machinery industries, are predominantly controlled using discrete logic and sensors that sense whether or not, for example, a process machine has a box standing in front of it. The network types ideal for simple discrete I/O focus on low overhead and small data packets, but they are unsuitable for larger messages like configuration download and the like. Examples of this network type are Seriplex®, Interbus-S, and AS-I (AS-Interface), which are sometimes called *sensor buses* or *bit level buses*. Other more advanced protocols oriented toward discrete logic include DeviceNet™, ControlNet™, and PROFIBUS (DP and FMS application profiles). These buses are sometimes referred to as *device buses* or *byte-level buses*. Factory automation involves fast-moving machinery and therefore requires quicker response than slower processes. Traditionally, these tasks have been handled by PLCs.

Process Automation

Process plants in industry segments like refining, pulp & paper, power, and chemicals are dominated by continuous regulatory control. Measurement is analog (here meaning scalar values transmitted digitally), and actuation is modulating. Of course, process industries also use some discrete control and the predominantly discrete manufacturing industries use some discrete. Fieldbus on/off valves are already available in the market, as are small remotely mounted I/O modules for discrete sensors. In the past, a DCS or single-loop controller did this.

Process-related networks include FOUNDATION Fieldbus, PROFIBUS (PA application profile), and HART—they are the focus of this book. All these buses as a category are now typically referred to as fieldbus (without the capital *f*), though some would argue that one or the other does not belong. These three protocols were specifically designed for bus-powered field instruments with predefined parameters and commands for asset management information like identification, diagnostics, materials of construction, and functions for calibration and commissioning. In terms of size, the networks used in industrial automation are considered to constitute local area networks (LAN) spanning areas no greater than a kilometer or two in diameter and typically confined to a single building or a group of buildings. Networks that extend only a few meters are insufficient, and networks that span cities or even the globe are overkill.

Field and Host Tier Networks

Even within control systems for the process sector there is a need for different network characteristics at each tier of the control system hierarchy. At the field end there are instruments such as transmitters and valve positioners that have their specific needs, and at the host level there are workstations, linking devices, and controllers that have other needs (figure 1-6).

When fieldbus began to evolve, the process industry put a large number of requirements on the field-level network that were not met by other types of networks. Many new design considerations needed to be taken into account. On the upper tier, data from all the field-level networks have to be marshaled onto a single host-level network that also serves any tasks the plant may have that seem related to factory automation.

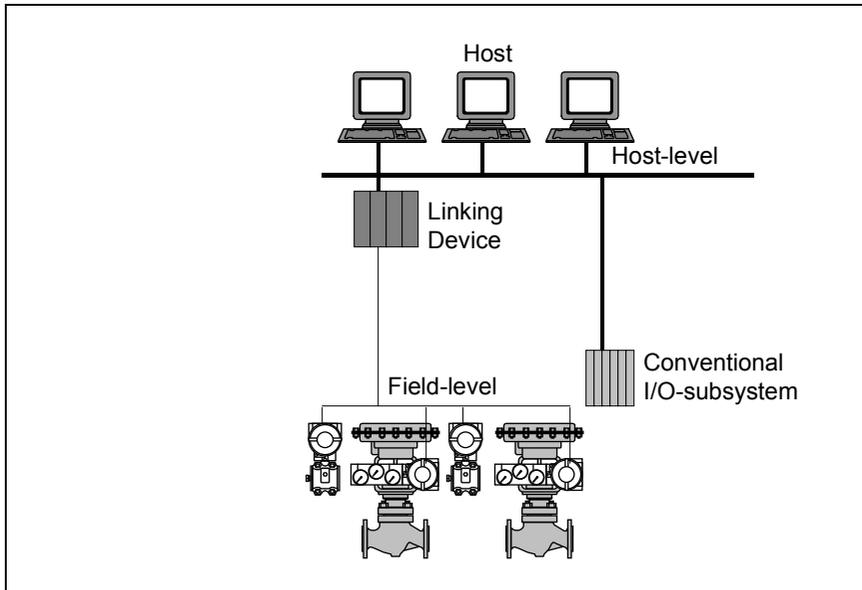


Figure 1-6. Two-tiered automation network architecture.

Field Level

At the field level, the dominant protocols for process instruments are HART, FOUNDATION Fieldbus H1, and PROFIBUS PA. HART is significantly different from the other two in that it is a so-called smart protocol, that is a combination of digital communication simultaneously superimposed on a conventional 4-20 mA signal. As such, the HART protocol has been an ideal intermediate solution in the transition from analog. HART is compatible with existing analog recorders, controllers, and indicators while at the same time it makes possible remote configuration and diagnostics using digital communication. The HART protocol does allow several devices to be multidropped on a single pair of wires, but this is a capability infrequently explored because of the low update speed, typically half a second per device. For a vast majority of installations HART devices are connected point to point, that is, one pair of wires for each device and a handheld connected temporarily from time to time for configuration and maintenance. Both FOUNDATION Fieldbus H1 and PROFIBUS PA are completely digital and even use identical wiring, following the IEC 61158-2 standard. However, beyond that there are major differences between these two protocols, and depending on the desired system architecture one may be more suitable than the other.

At the field level, instruments appear in large quantities, often in the hundreds or thousands. The wire runs are very long, as the net-

work cable must run from the control room all the way into the field, up towers, and then branching out to devices scattered throughout the site. Because there is a limit to the number of devices that can be multidropped on each network, even a medium-sized plant may have many network cables running into the field, although substantially fewer than if point-to-point wiring was used. The field-level networks were therefore designed to enable very long wire runs and to allow field devices to take their power from the network. Only a single pair of wires carries both the device's power and the digital communications signal. This eliminates the need for a separate power cable, thus keeping the wiring simple and inexpensive.

As another measure to keep costs down, designers chose a moderate field-level network speed so normal instrument-grade cable could be used instead of special data cable. No special connectors, couplers, or hubs are required either, which makes it possible to use rugged and weatherproof connections. The grade of cable used for conventional instrument connections on most sites is more than sufficient for fieldbus networking. As a result, it is possible to reuse that cable when an existing plant is migrated to fieldbus. In hazardous process environments where flammable fluids are present intrinsic safety is many times the preferred protection method. The field-level networks were therefore designed to allow safety barriers to be installed on the bus.

Because designers chose a moderate field-level network speed the devices connected to it do not require a great deal of CPU processing power to handle the communication quickly. As a result, they also consume very little power. Because the low power consumption results in low voltage drop along the wire, it is therefore possible to multidrop several devices on the network even for long wire distances and even when using intrinsic safety barriers. Another great advantage of field-level networks is that they provide a lot of freedom when it comes to network topology since wires can be run quite freely. Finally, these fieldbus networks were also designed to operate in the often rather harsh, electrically noisy environment found on site.

Host Level

At the host level, the Ethernet network standard is already the dominant wiring technology (figure 1-7). There are many protocols built on Ethernet wiring, including FOUNDATION Fieldbus HSE, PROFINet, Modbus/TCP, and the like. Sites employing fieldbus instrumentation and asset management software can expect to

encounter a steep rise in bandwidth requirements and must therefore have a high-speed network at the host level.

The field-level networks have made it possible to retrieve so much more data from the field instruments that an information explosion has resulted, one that old proprietary control level networks are unable to cope with. Ethernet provides the throughput required to transfer the large amount of data used for traditional plant operation and historical trending; for new capabilities for remote diagnostics, maintenance, and configuration; and for the quick response necessary for factory automation task. Ethernet was chosen for these applications because its high speed enables it to carry all this information. Moreover, Ethernet is already a standard and consequently is well understood and widely used. A large variety of equipment and solutions for Ethernet is available. Ethernet wiring is discussed in chapter 3, “Installation and Commissioning.”

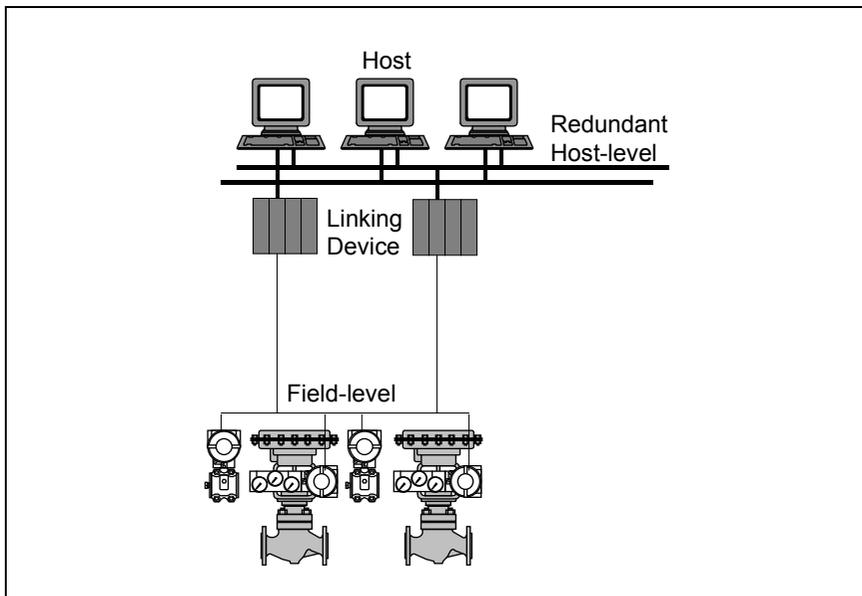


Figure 1-7. Host-level network redundancy for availability.

In many applications, one of the key requirements for the host-level protocol is availability. The network must be fault tolerant—up and running even in the presence of a fault. This is extremely critical at the host level since the entire site is operated and supervised over this network. Downtime can be very disruptive and cause heavy losses; a complete breakdown of the network would be extremely serious. Though Ethernet originated in the office environment, rugged industrial-grade (as opposed to commercial-