

# Industrial Networks for Communication and Control

(Reading for "Elements of Industrial Automation" at ELDE)

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# 1. Historical Overview of Industrial Automation and Communication Networks

In the early 20th century, the process control systems and the manufacturing systems were designed based primarily on the mechanical technology and with analogue devices. After the period, the pneumatic control technology and the hydraulic power were introduced. The pneumatic control technology made it possible to control remote systems by a centralized control system. These technologies are still very common.

At the beginning of 1960, a digital computer was for the first time really applied as a digital controller. The term *direct digital control* (DDC) was used to emphasize that the computer directly controls the process. In the 1960s, the application of a minicomputer was still a fairly expensive solution for many control problems. In the meantime, programmable logic controller (PLC) was developed and it replaced the conventional, relay-based controller, having relatively limited control functions. In addition, many technologies were developed for machine tools and discrete production processes. The numerically controlled (NC) machine tool became to be controlled by computers and the robot was developed in this period.

With the more widespread use of digital computers and the associated technologies, industrial communication networks became to be developed with or converted to digital transmission. Proprietary digital communication networks for industrial use started in the 1960s as computers for automation systems were first linked together.

In mid 70s, the first distributed computer control system (DCCS) was announced by Honeywell as a hierarchical control system with a large number of microprocessors. Since its introduction in mid 1970s, the concept of the DCCS spread widely in many industrial automation systems such as power plant control systems, manufacturing systems, etc. The installation of distributed control systems in the newly planned plants or replacement of existing analogue or centralized control systems is presently a common decision of enterprise management.

The use of local area networks to interconnect computers and automation devices within an industrial automation system has become popular since 1980. The high capacity low cost communication offered by local area networks has made distributed computing a reality, and many automation services. The

industrial automation systems are often implemented as an open distributed architecture with communication over digital communication networks.

It is now common for users connected to a local area network to communicate with computers or automation devices on other local area networks via gateways linked by a wide area network.

As the industrial automation systems becomes large and the number of automation devices increases, it has become very important for industrial automation to provide standards which make it possible to interconnect many different automation devices in a standard way. Considerable international standardization efforts have been made in the area of local area networks. The Open Systems Interconnection (OSI) standards permit any pair of automation devices to communicate reliably regardless of the manufacturer.

Industrial networks span many manufacturing applications. Standard industrial networks using digital communication technologies cover a wide range of manufacturing applications. In many applications, the types of devices and performance determine the type of network. Contrast the needs of two devices -- a proximity sensor used on a conveyor belt compared to a control valve used in a petroleum refinery. The proximity sensor has a single function - to transmit a Boolean on/off signal indicating the proximity of an object. We can accommodate this signal in a few bits of data. Diagnostic information from the sensor is probably limited to a single "health" indicator, which again requires very little data. However, we can expect the control valve to provide very sophisticated control functions and diagnostics, such as number of cycles since last servicing, packing friction, and ambient operating temperature. These parameters can be extremely critical in an environment such as a refinery -- failures can result in dangerous situations and costly downtime. Clearly, the proximity sensor and the control valve have different network requirements. Therefore, different types of industrial networks must address a variety of different needs. We must select the right network to address our specific application requirements.

What is an *Industrial Network*? By definition, an industrial network requires geographical distribution of the physical measurement I/O and sensors or functional distribution of applications. Most industrial networks transfer bits of information serially. Serial data transfer has the advantage of requiring only a limited number of wires to exchange data between devices. With fewer wires, we can send information over greater distances. Because industrial networks work with several devices on the same line, it is easier to add a new device to existing systems.

To make all this work, our network must define a set of rules -- a communication protocol -- to determine how information flows on the network of devices, controllers, PCs, and so on. With improved communication protocols, it is now possible to reduce the time needed for the transfer, ensure better data protection, and guarantee time synchronization, and real-time deterministic response in some applications. Industrial networks also ensure that the system sends information reliably without errors and securely between nodes on the network.

For the lower level communication network for industrial automation, the industrial local area network solutions such as MAP are too expensive and/or do not reach the required short response times, depending on the application. The fieldbuses have been, therefore, developed to meet these requirements, and many efforts are now being made to make fieldbus standards for industrial automation applications.

## **2. Hierarchical Levels in Industrial Communication Networks**

The industrial automation systems can be very complex, and it is usually structured into several hierarchical levels. Each of the hierarchical level has an appropriate communication level, which places different requirements on the communication network. Figure 1.1 shows an example of the hierarchy of an industrial automation system.

Industrial networks may be classified in several different categories based on functionality - field-level networks (sensor, actuator or device buses), control-level networks (control buses) and information-level networks (Fig. 1.).

We primarily use sensor and actuator buses to connect simple, discrete devices with limited intelligence, such as a photo-eye, limit switch, or solenoid valve, to controllers and computers. Sensor buses such as ASI and CAN are designed so information flow is reduced to a few bits and the cost per node is a critical factor.

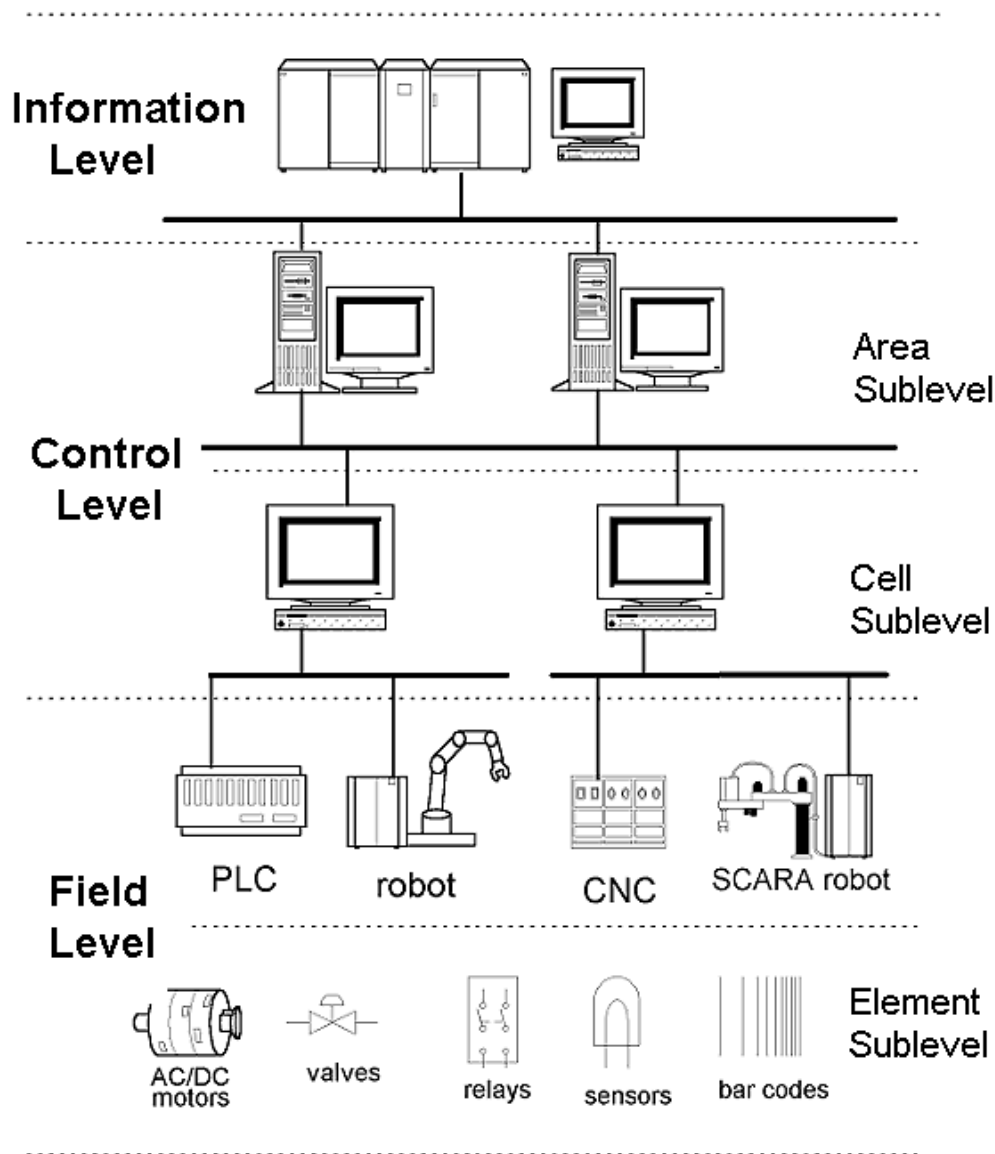


Figure 1. Hierarchy of an industrial automation system.

➤ **Field level**

The lowest level of the automation hierarchy is the field level, which includes the field devices such as actuators and sensors. The elementary field devices are sometimes classified as the element sublevel. The task of the devices in the field level is to transfer data between the manufactured product and the technical process. The data may be both binary and analogue. Measured values may be available for a short period of time or over a long period of time.

For the field level communication, parallel, multiwire cables, and serial interfaces such as the 20mA current loop has been widely used from the

past. The serial communication standards such as RS232C, RS422, and RS485 are most commonly used protocols together with the parallel communication standard IEEE488. Those point-to-point communication methods have evolved to the bus communication network to cope with the cabling cost and to achieve a high quality communication.

Field-level industrial networks are a large category, distinguished by characteristics such as message size and response time. In general, these networks connect smart devices that work cooperatively in a distributed, time-critical network. They offer higher-level diagnostic and configuration capabilities generally at the cost of more intelligence, processing power, and price. At their most sophisticated, fieldbus networks work with truly distributed control among intelligent devices like FOUNDATION Fieldbus. Common networks included in the devicebus and fieldbus classes include CANOpen, DeviceNet, FOUNDATION Fieldbus, Interbus-S, LonWorks, Profibus-DP, and SDS.

Nowadays, the fieldbus is often used for information transfer in the field level. Due to timing requirements, which have to be strictly observed in an automation process, the applications in the field level controllers require cyclic transport functions, which transmit source information at regular intervals. The data representation must be as short as possible in order to reduce message transfer time on the bus.

### ➤ **Control Level**

At the control level, the information flow mainly consists of the loading of programs, parameters and data. In processes with short machine idle times and readjustments, this is done during the production process. In small controllers it may be necessary to load subroutines during one manufacturing cycle. This determines the timing requirements. It can be divided into two: cell and area sublevels.

#### *Cell sublevel*

For the cell level operations, machine synchronizations and event handlings may require short response times on the bus. These real-time requirements are not compatible with time-excessive transfers of application programs, thus making an adaptable message segmentation necessary.

In order to achieve the communication requirements in this level, local area networks have been used as the communication network. After the introduction of the CIM concept and the DCCS concept, many companies developed their proprietary networks for the cell level of an automation system. The Ethernet together with TCP/IP (transmission control protocol/internet protocol) was

accepted as a *de facto* standard for this level, though it cannot provide a true real-time communication.

Many efforts have been made for the standardization of the communication network for the cell level. The IEEE standard networks based on the OSI layered architecture were developed and the Mini-MAP network was developed in 1980s to realize a standard communication between various devices from different vendors. Some fieldbuses can also be used for this level.

#### *Area sublevel*

The area level consists of cells combined into groups. Cells are designed with an application-oriented functionality. By the area level controllers or process operators, the controlling and intervening functions are made such as the setting of production targets, machine startup and shutdown, and emergency activities.

We typically use control-level networks for peer-to-peer networks between controllers such as programmable logic controllers (PLCs), distributed control systems (DCS), and computer systems used for human-machine interface (HMI), historical archiving, and supervisory control. We use control buses to coordinate and synchronize control between production units and manufacturing cells. Typically, ControlNet, PROFIBUS-FMS and (formerly) MAP are used as the industrial networks for controller buses. In addition, we can frequently use Ethernet with TCP/IP as a controller bus to connect upper-level control devices and computers.

#### ➤ **Information level**

The information level is the top level of a plant or an industrial automation system. The plant level controller gathers the management information from the area levels, and manages the whole automation system. At the information level there exist large scale networks, e.g. Ethernet WANs for factory planning and management information exchange. We can use Ethernet networks as a gateway to connect other industrial networks.

### **3. Transmission Methods**

The data communication can be analogue or digital. Analogue data takes continuously changing values.

In digital communication, the data can take only binary 1 or 0 values. The transmission itself can be asynchronous or synchronous, depending on the way data is sent. In asynchronous mode transmission, characters are sent using start and stop codes

and each character can be sent independently at a nonuniform rate. The synchronous mode transmission is more efficient method. The data is transmitted in blocks of characters, and the exact departure and arrival time of each bit is predictable because the sender/receiver clocks are synchronized.

The transmission methods in industrial communication networks include baseband, broadband, and carrierband. In a baseband transmission, a transmission consists of a set of signals that is applied to the transmission medium without being translated in frequency.

Broadband transmission uses a range of frequencies that can be divided into a number of channels. Carrier transmission uses only one frequency to transmit and receive information.

Digital optical fibre transmission is based on representing the ones and zeros as light pulses.

The type of the physical cabling system or the transmission media is a major factor in choosing a particular industrial communication network. The most common transmission media for industrial communication network is copper wire, either in the form of coaxial or twisted-pair cable. Fibre optics and wireless technologies are also being used.

Coaxial cable is used for high-speed data transmission over distances of several kilometers.

The coaxial cable is widely available, relatively inexpensive, and can be installed and maintained easily. For these reasons it is widely used in many industrial communication networks.

Twisted-pair cable may be used to transmit baseband data at several Mbit/s over distances of 1 km or more but as the speed is increased the maximum length of the cable is reduced. Twisted-pair cable has been used for many years and is also widely used in industrial communication networks. It is less expensive than coaxial cable, but it does not provide high transmission capacity or good protection from electromagnetic interference.

Fibre optic cable provides increased transmission capacity over giga bits, and it is free from electromagnetic interference. However, the associated equipment required is more expensive, and it is more difficult to tap for multidrop connections. Also, if this is used for sensor cables in process plants, separate copper wiring would be required for instrument power, which might as well be used for the signal transmission.

In many mobile or temporary measurement situations, wireless is a good solution and is being used widely.



## Today's environment

Conventional point-to-point wiring using discrete devices and analog instrumentation dominate today's computer-based measurement and automation systems. Twisted-pair wiring and 4-20 mA analog instrumentation standards work with devices from most suppliers and provide interoperability between other 4-20 mA devices. However, this is extremely limited because it provides only one piece of information from the manufacturing process. Historically, measurement networks and automation systems have used a combination of proprietary and open digital networks to provide improved information availability and increased throughput and performance. Integrating devices from several vendors is made difficult by the need for custom software and hardware interfaces. Proprietary networks offer limited multi-vendor interoperability and openness between devices. With standard industrial networks, on the other hand, we decide which devices we want to use.

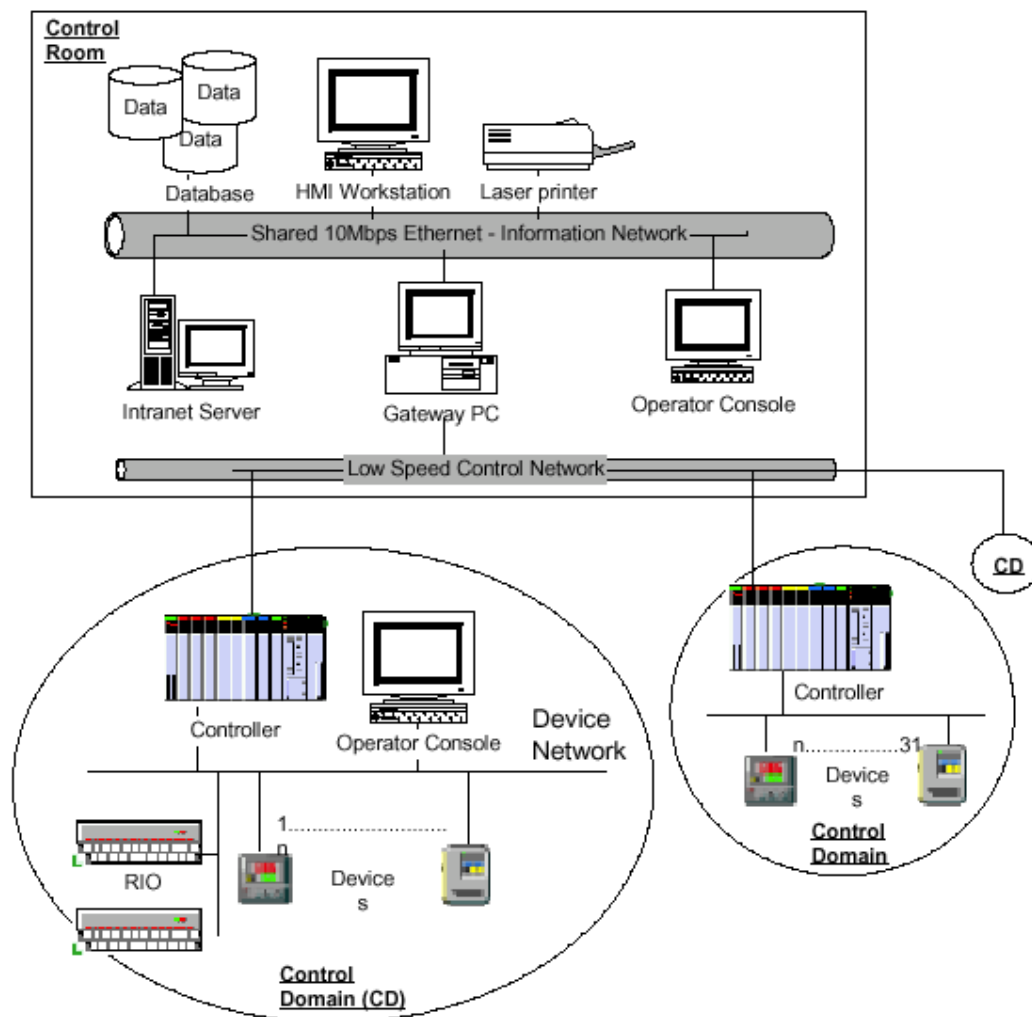


Figure 2.

## 4. Industrial Network Components

In larger industrial and factory networks, a single cable is not enough to connect all the network nodes together. We must define network topologies and design networks to provide isolation and meet performance requirements. In many cases, because applications must communicate across dissimilar networks, we need additional network equipment. The following are various types of network components and topologies:

- Repeater -- a repeater, or amplifier, is a device that enhances electrical signals so they can travel greater distances between nodes. With this device, we can connect a larger number of nodes to the network. In addition, we can adapt different physical media to each other, such as coaxial cable to an optical fiber.
- Router -- a router switches the communication packets between different network segments, defining the path.
- Bridge -- with a bridge, the connection between two different network sections can have different electrical characteristics and protocols. A bridge can join two dissimilar networks and applications can distribute information across them.
- Gateway -- a gateway, similar to a bridge, provides interoperability between buses of different types and protocols, and applications can communicate through the gateway.

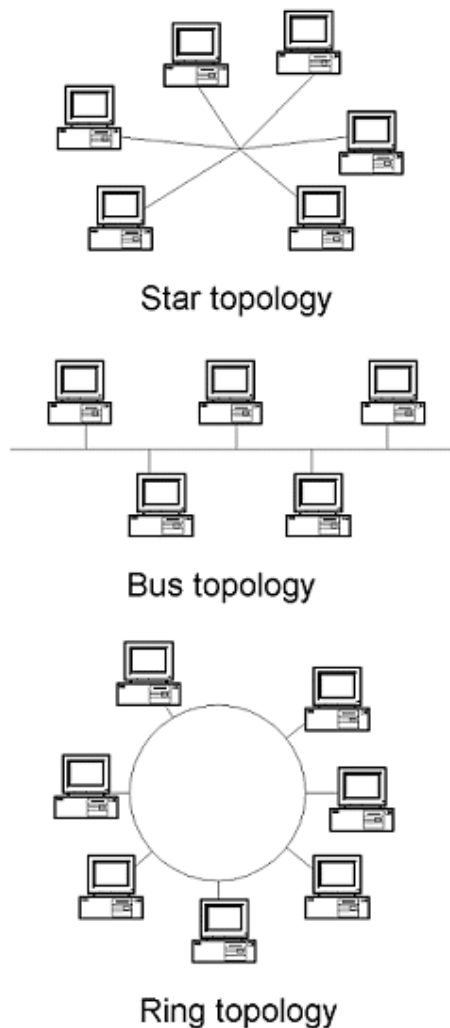
## 5. Network Topology

Industrial systems usually consist of two or more devices. As industrial systems get larger, we must consider the topology of the network. The most common network topologies are the bus, star, or a hybrid network that combines both. Three principal topologies are employed for industrial communication networks: star, bus, and ring as shown in Figure 3.

A *star configuration* contains a central controller, to which all nodes are directly connected. This allows easy connection for small networks, but additional controllers must be added once a maximum number of nodes are reached. The failure of a node in a star configuration does not affect other nodes. The star topology has a central hub and one or more network segment connections that radiate from the central hub. With the star topology, we can easily add further nodes without interrupting the network. Another benefit is that failure of one device does not impair communications between any other devices in the network; however, failure of the central hub causes the entire network to fail.

In the *bus topology*, each node is directly attached to a common communication channel. Messages transmitted on the bus are received by every node. If a node fails, the rest of the network continues in operation as long as the failed node does not affect the media.

In the *ring topology*, the cable forms a loop and the nodes are attached at intervals around the loop. Messages are transmitted around the ring passing the nodes attached to it. If a single node fails, the entire network could stop unless a recovery mechanism is not implemented.



*Figure 3. Network topologies.*

For most networks used for industrial applications, we can use hybrid combinations of both the bus and star topologies to create larger networks consisting of hundreds, even thousands of devices. We can configure many popular industrial networks such as Ethernet, FOUNDATION Fieldbus,

DeviceNet, Profibus, and CAN using hybrid bus and star topologies depending on application requirements. Hybrid networks offer advantages and disadvantages of both the bus and star topologies. We can configure them so failure of one device does not put the other devices out of service. We can also add to the network without impacting other nodes in the network.

### **Benefits of industry-standard networks**

Modern control and business systems require open, digital communications. Industrial networks replace conventional point-to-point RS-232, RS-485, and 4-20 mA wiring between existing measurement devices and automation systems with an all-digital, 2-way communication network. Industrial networking technology offers several major improvements over existing systems. With industry-standard networks, we can select the right instrument and system for the job regardless of the control system manufacturer. Other benefits include:

- Reduced wiring -- resulting in lower overall installation and maintenance costs
- Intelligent devices -- leading to higher performance and increased functionality such as advanced diagnostics
- Distributed control -- with intelligent devices providing the flexibility to apply control either centrally or distributed for improved performance and reliability
- Simplified wiring of a new installation, resulting in fewer, simpler drawings and overall reduced control system engineering costs
- Lower installation costs for wiring, marshalling, and junction boxes

Standard industrial networks offer the capability to meet the expanding needs of manufacturing operations of all sizes. As our measurement and automation system needs grow, industrial networks provide an industry-standard, open infrastructure to add new capabilities to meet increasing manufacturing and production needs. For relatively low initial investments, we can install small computer-based measurement and automation systems that are compatible with large-scale and long-term plant control and business systems.

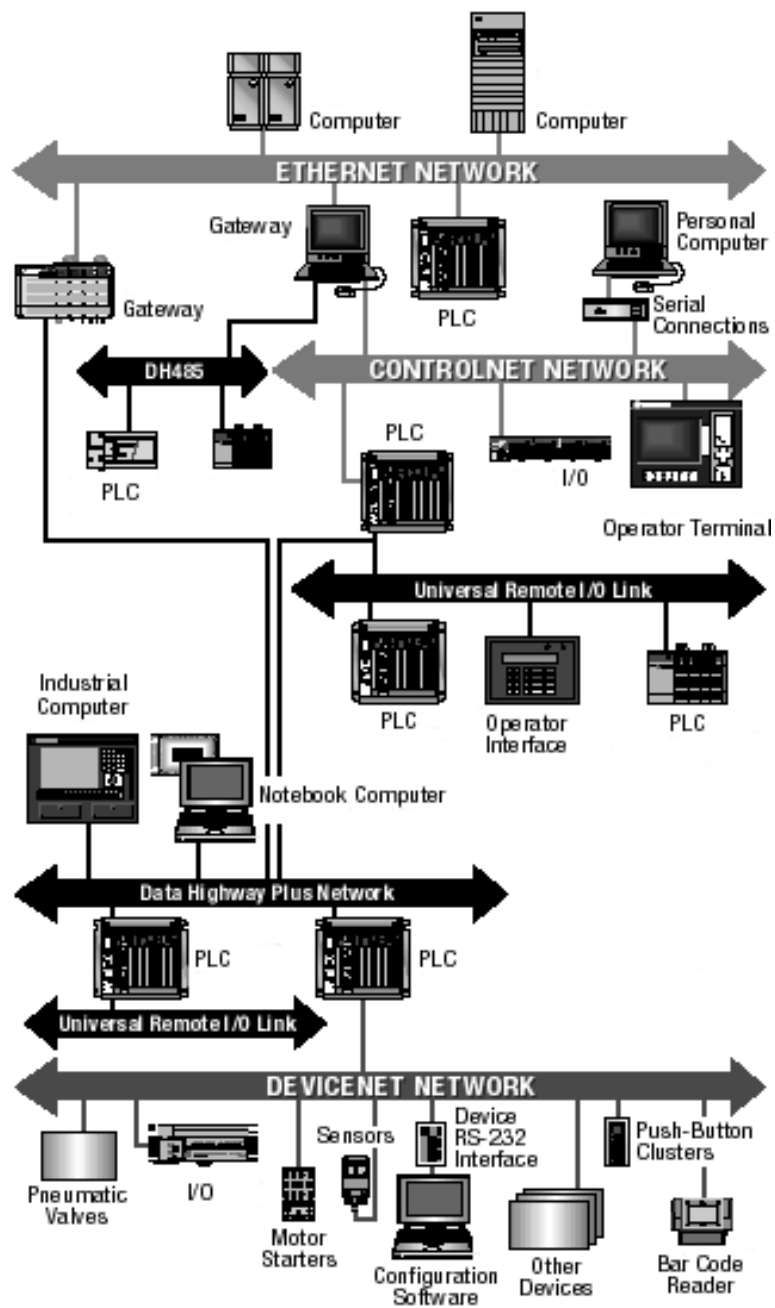


Figure 4.

## 6. Functional comparison of contemporary industrial networks

### 6.1. Profibus: the world's most installed open field-level network

- Origin: German Government in cooperation with automation manufacturers, 1989
- Implemented on ASIC chips produced by multiple vendors. Based on RS485 and the European EN50170 Electrical specification.
- Formats: Profibus DP (Master/Slave), Profibus FMS (Multi-master/Peer to Peer), and Profibus PA (intrinsically safe).
- Connectors: 9-Pin D-Shell connector (impedance terminated) or 12mm IP67 quick-disconnect.
- Maximum Number of Nodes: 127
- Distance: 100M to 24 KM (with repeaters and fiber optic transmission)
- Baudrate: 9600 to 12M Bit/sec
- Message size: up to 244 bytes of data per node per message
- Messaging formats: Polling (DP/PA) and Peer-to-Peer (FMS)
- Supporting Trade Organization: Profibus Trade Organization, [www.profibus.com](http://www.profibus.com).

Profibus is commonly found in Process Control and large assembly, and material handling machines. Single-cable wiring of multi-input sensor blocks, pneumatic valves, complex intelligent devices, smaller sub-networks (such as AS-I), and operator interfaces.

**Advantages:** Profibus is the most widely accepted international networking standard. Nearly universal in Europe and also very popular in North America, South America, and parts of Africa and Asia. Profibus can handle large amounts of data at high speed and serve the needs of large installations. The DP, FMS and PA versions collectively address the majority of automation applications.

**Disadvantages:** High overhead to message ratio for small amounts of data; no power on the bus; slightly higher cost than some other buses; European- and Siemens- centricity is occasionally an obstacle for some North American users.

Profibus' substantial speed, distance and data handling capabilities make it ideal for many process control and data intensive applications. Profibus DP, which is the most commonly messaging format for I/O, is a polling network, meaning that its assigned master periodically requests the status of each node. This ensures that each device on the network (which can send up to 244 bytes of data per scan) is updated consistently and reliably. Each message contains 12 bytes of overhead for a maximum message length of 256 bytes.

### **Multi-Master**

Multiple masters are possible with Profibus DP, in which case each slave device is assigned to one master. This means that multiple masters can read inputs from the device but only one master can write outputs to that device.

### **Peer to Peer**

Profibus FMS is a peer to peer messaging format, which allows masters to communicate with one another. All can be masters if desired. FMS messages consume more overhead than DP messages.. "COMBI mode" is when FMS and DP are used simultaneously in the same network. This is most commonly used in situations where a PLC is being used in conjunction with a PC, and the primary master communicates with the secondary master via FMS. DP messages are sent via the same network to I/O devices.

### **Profibus DP V1 extension**

The older FMS specification is giving way to a new approach, DP with V1 extensions. This serves the needs of new devices with greater complexity. The Profibus Trade Organization has released a new specification which integrates many of the functions of Profibus FMS (multi-master, peer to peer communication) together with Profibus DP (master/slave I/O communication) so that the two types of messaging work together to combine synchronous scanning with on-the-fly configuration of devices. In the past, FMS and DP have been used together, but often for entirely different purposes. This integration enables Profibus to more effectively compete with some of the more advanced capabilities of its rivals, DeviceNet and Foundation Fieldbus.

### **Profibus DP V2 for motion control**

A recent addition to the Profibus specification is V2, which adds 1) a synchronization feature which allows multiple devices and axes of motion to work on the same time clock, and 2) publisher / subscriber messaging which allows devices to communicate to each other on a one-to-one or one-to-many basis. This allows the coordination of synchronized axes of motion.

### **Intrinsically safe**

The Profibus PA protocol is the same as the latest Profibus DP with V1 diagnostic extensions, except that voltage and current levels are reduced to meet the requirements of intrinsic safety (Class I div. II) for the process industry. Most master cards support Profibus PA, but barriers which convert between DP and PA are necessary (available from a number of companies). PA devices are powered by the network at intrinsically safe voltage and current levels.

## 6.2. Controller Area Network (CAN)

CAN is the foundation for several popular field-level networks: DeviceNet, CANopen, SDS and others. When the developers of DeviceNet, CANopen, SDS and other CAN based networks sought a bulletproof technology for critical factory networking purposes, they opted for a ready-made solution from the automotive industry. Bosch developed CAN in the early 1980's for eliminating large and expensive wiring harnesses in Mercedes automobiles. CAN was developed so that the primary control components in an automobile – brake lights, airbags, sensors, lights, electric windows and door locks, etc. – could be connected with a single cable instead of a bundle of cables 3" thick. Automotive manufacturers found that if a wiring harness is faulty, it's sometimes cheaper to scrap the entire car than to troubleshoot the wiring harness. In a network, we can do wiring in software, and the added hardware cost is more than paid for by labor savings. The same applies to automated equipment in a factory.

### **Robustness in the Extreme**

In a vehicle communication can be quite literally a life and death situation. Network errors are simply NOT TOLERABLE, regardless of origin. CAN lives up to the rigorous requirements, with a statistical probability of less than one faulty message per century.

### **Software Application Layers on top of CAN**

CAN itself is a low-level message arbitration protocol implemented on inexpensive (<\$1) chips, which are available from multiple vendors and manufactured by the millions. In order to have a fully functional network protocol, an additional software layer must be added. Higher layer protocols like DeviceNet can be thought of as a sophisticated set of 'macros' for CAN messages, specifically suited for automation. SDS and CAN-open are automation networks also based on CAN. (Another popular standard, J1939, was created by the Society of Automotive Engineers. It is CAN application layer used in trucks and buses.).

## 6.3. DeviceNet - fieldbus for low and mid-level factory networking

- Origin: Allen-Bradley, USA, 1994
- Based on CAN (Controller Area Network) technology, borrowed from the automotive industry
- Maximum Number of Nodes: 64
- Connectors: Popular 'Mini' 18mm and 'Micro' 12mm waterproof quick-disconnect plugs and receptacles, and 5 pin phoenix terminal block.
- Distance: 100M to 500M
- Baudrate: 125, 250 and 500 Kbits/sec



- Maximum Message size: 8 bytes of data per node per message
- Messaging formats: Polling, Strobing, Change-of-State, Cyclic; Explicit messaging for configuration and parameter data; UCMM for peer to peer messaging. Producer/Consumer based model.
- Supporting Trade Organization: Open DeviceNet Vendor Association, [www.odva.org](http://www.odva.org)
- Typical Applications: Most commonly found in assembly, welding and material handling machines. Single-cable wiring of multi-input sensor blocks, smart sensors, pneumatic valves, barcode readers, drives and operator interfaces. DeviceNet is especially popular in automotive and semiconductor.
- Advantages: Low cost, widespread acceptance, high reliability, and efficient use of network bandwidth, power available on the network.
- Disadvantages: Limited bandwidth, limited message size and maximum length.

### **Versatile, Available, and Competitive**

DeviceNet is a versatile, general purpose Fieldbus designed to satisfy 80% of the most common machine- and cell-level wiring requirements. Devices can be powered from the network so wiring is minimized. The protocol is implemented on many hundreds of different products from hundreds of manufacturers, from smart sensors to valve manifolds and operator interfaces.

One of DeviceNet's major benefits is its multiple messaging formats, which allow the bus to 'work smart' instead of work hard. They can be mixed and matched within a network to achieve the most information-rich and time-efficient information from the network at all times:

### **Messaging Types in DeviceNet**

**Polling:** The scanner individually asks each device to send or receive an update of its status. This requires an outgoing message and incoming message for each node on the network. This is the most precise, but least time efficient way to request information from devices.

**Strobing (broadcast):** The scanner broadcasts a request to all devices for a status update. Each device responds in turn, with node 1 answering first, then 2, 3, 4 etc. Node numbers can be assigned to prioritize messages. Polling and strobing are the most common messaging formats used.

**Cyclic:** Devices are configured to automatically send messages on scheduled intervals. This is sometimes called a 'heartbeat' and is often used in conjunction with Change of State messaging to indicate that the device is still functional.

**Change of State:** Devices only send messages to the scanner when their status changes. This occupies an absolute minimum of time on the

network, and a large network using Change of State can often outperform a polling network operating at several times the speed. This is the most time efficient but (sometimes) least precise way to obtain information from devices because throughput and response time becomes statistical instead of deterministic.

**Explicit Messaging:** The explicit-messaging protocol indicates how a device should interpret a message. Commonly used on complex devices like drives and controllers to download parameters that change from time to time but do not change as often as the process data itself. An explicit message supplies a generic, multipurpose communication path between two devices and provides a means for performing request/response functions such as device configuration.

**Fragmented Messaging:** For messages that require more than DeviceNet's maximum 8 bytes of data per node per scan, the data can be broken up into any number of 8 bytes segments and re-assembled at the other end. This requires multiple messages to send or receive one complete message. DeviceNet scanners typically fragment messages automatically as necessary, without intervention from the user.

**UCMM** (UnConnected Message Manager): DeviceNet UCMM interfaces are capable of peer-to-peer communication. Unlike the plain-vanilla Master/Slave configuration, each UCMM capable device can communicate with another directly, without having to go through a master first. UCMM devices must accept all generic CAN messages, then perform filtering of irrelevant or undesired message types in the upper software layer. This requires more RAM and ROM than ordinary Master/Slave messaging.

#### **6.4. CANopen: the European CAN bus**

- Origin: CAN in Automation, 1993
- Based on CAN (Controller Area Network) technology, borrowed from the automotive industry, and the RS485 electrical specification.
- Maximum Number of Nodes: 64
- Connectors: Popular 'Mini' 18mm and 'Micro' 12mm waterproof quick-disconnect plugs and receptacles, and 9 pin D-shell.
- Distance: 100M to 500M
- Baudrate: 125, 250 500 and 1000 Kbits/sec
- Maximum Message size: 8 bytes of data per node per message
- Messaging formats: Polling, Strobing, Change-of-State, Cyclic, and others
- Supporting Trade Organization: CAN In Automation, <http://www.can-cia.de>

- Typical Applications: Commonly found in motion control systems, assembly, welding and material handling machines. Single-cable wiring of multi-input sensor blocks, smart sensors, pneumatic valves, barcode readers, drives and operator interfaces.

- Advantages: Better suited for high-speed motion control and feedback loop closure than other CAN based networks. High reliability, efficient use of network bandwidth, power available on the network.

- Disadvantages: Acceptance limited outside of Europe. Protocol is complex and involved from developers' point of view. Same general limitations as other CAN based networks (limited bandwidth, limited message size and maximum network length).

### **CANopen capabilities**

CANopen is a family of profiles based on CAN, a higher-layer protocol (CAN application layer or CAL, and communication profile) providing additional functionality such as standardized communication objects for process data, service data, network management, synchronization, time-stamping and emergency messages. CANopen was developed within the CAN in Automation (CiA) international users and manufacturers group, over 300 companies strong. CANopen networks provide multi-master functionality and broadcast communication, because they are based on CAN. In CANopen there are different methods specified to achieve real-time communications. CANopen specifies also a pre-defined master/slave connection set to unburden the newcomer from the task of distributing identifiers as required in CAN data link layer solutions. One of the important functions is the fragmentation of data blocks larger than 8 bytes. The transport protocol uses confirmed services to guarantee that the communication profile layer correctly receives configuration data. The CANopen communication profile makes products from different vendors interoperable. The general difference of CANopen to master/slave-oriented fieldbuses is the capability that each node can access the bus and communicate directly to each other node without any master. Because CANopen is based on CAN, the communication profile provides event-driven process data transmission, which reduces communication as much as possible. For motion control applications there is also synchronous operation (cyclic and acyclic).

### **Object Orientation**

CANopen, DeviceNet and Smart Distributed System are all object-oriented and provide a similar functionality regarding the transmission of real-time data, configuration data, and network management information. However, DeviceNet and Smart Distributed System are more connection-oriented, and CANopen is more message-oriented. There are also some minor differences in the fragmentation of larger data blocks. The three mentioned CAN-based higher-layer protocols are supported by the CiA

organization and specify also the behavior and functionality of standard devices such as I/O modules, drives etc. to achieve interchangeability of devices produced by different manufacturers.

### **Applications in Multiple Industries**

Besides the use in machine control systems (e.g. textile, printing, packaging, injection molding and other applications), CANopen is implemented by robotics manufacturers and in medical equipment such as computer tomographs and X-ray apparatus. CANopen networks are also used in forklifts and cranes. Other applications are public transportation (passenger and driver information systems) and ship control systems. But the main application area is decentralized machine control.

## **6.5. Interbus - a high-speed, deterministic, European field-level specification.**

- Origin: Phoenix Contact, 1984
- High Speed Shift Register topology
- Maximum Number of Nodes: 256
- Connectors: 9 Pin D-Shell and 23mm circular DIN; Cabling options allow for twisted pair, fiber optic and infrared connections
- Distance: 400M per segment, 12.8 KM Total
- Baudrate: 500 Kbits/sec (2Mbit also available)
- Message size: 512 bytes of data per node, unlimited block transfers
- Messaging formats: I/O scanning and PCP channel for data transfer
- Supporting Trade Organization: The Interbus Club, [www.interbusclub.com](http://www.interbusclub.com)

- Typical Applications: Commonly found in assembly, welding and material handling machines. Single-cable wiring of multi-input sensor blocks, pneumatic valves, barcode readers, drives and operator interfaces.

- Advantages: Auto-addressing capability makes configuration very simple; Extensive diagnostic capability, widespread acceptance (especially in Europe), low overhead, fast response time and efficient use of bandwidth, power (for input devices) available on the network.

- Disadvantages: One failed connection disables entire network; limited ability to transfer large amounts of data.

### **Data handling**

Interbus is popular because of its versatility, speed, diagnostic and auto-addressing capabilities. Physically it has the appearance of being a typical line-and-drop based network, but in reality it is a serial ring shift register. Each slave node has two connectors - one, which receives data,

and one, which passes data on to the next slave. Address information is not contained in the protocol; data is pushed through the network in a circular fashion and the master is able to determine which node is being read or written to by its position in the circle, so to speak. Therefore the protocol has minimal overhead, and for typical installations, which might incorporate a few dozen nodes and perhaps a dozen I/O per node, few buses are faster than Interbus.

### **Self-Configuring**

Because of the unusual network topology, Interbus has two other advantages. First, a master can configure itself because of the ring topology. Some masters can configure itself without intervention from the user - Interbus has the potential to be 'idiot proof'. Second, precise information regarding network faults and where they have occurred can drastically simplify troubleshooting.

### **Data Types**

Interbus handles both Analog and Digital I/O with ease, and the PCP channel is a mechanism by which block transfers of configuration data or downloads can be packed within the Interbus protocol without interfering with the transmission of normal I/O data..

## **6.6. AS-I (Actuator Sensor Interface) - simple and inexpensive field-level network.**

- Origin: AS-I Consortium, 1993
- Maximum Number of Nodes: 31 slaves, 1 master
- Connectors: Insulation displacement connectors on flat yellow cable, 2 position terminal block or 12mm 'micro' quick-disconnect connectors.
- Distance: 100M, 300M with repeaters
- Baudrate: 167 Kbits/sec
- Message size: 8 bits (4 inputs, 4 outputs) per node per message
- Messaging formats: Strobing
- Supporting Trade Organization: AS-I Trade Organization, <http://www.as-interface.com/>
- Typical Applications: Commonly found in assembly, packaging and material handling machines. Single-cable wiring of multi-input sensor blocks, smart sensors, pneumatic valves, switches and indicators.
- Advantages: simplicity, low cost, widespread acceptance, high speed, power available on the network. AS-I is extremely suitable for wiring discrete I/O devices.
- Disadvantages: problems when connecting analog I/O; limited network size;

ASI is developed by a consortium of European automation & sensor companies, which saw a need for networking the simplest devices at the lowest level. ASI is easy to configure and low in cost. It is most often used for proximity sensors, photo-eyes, limit switches, valves and indicators in applications like packaging machines and material handling systems. ASI is designed for small systems employing discrete I/O. It allows for up to 31 slaves, which can provide up to 4 inputs and 4 outputs each for a total of 248 I/O. ASI is arguably the simplest Fieldbus to use. ASI uses number of sophisticated and clever mechanisms to ensure fast and reliable data transmission and user friendliness. The only configuration issues are choosing the address of each node and assigning individual inputs and outputs within those nodes.

### **The flat yellow cable**

ASI is best known for its flat yellow cable, which is pierced by insulation displacement connectors so that the expense of tees and complex connectors is avoided. Devices are simply clamped onto the cable and a connection is made. In addition to the popular flat cable, ordinary lamp cord can be used and normally no adverse effects will be experienced.

### **Power on the bus**

The signal cable also carries 30VDC at low current to power input devices; supplemental power for outputs can be provided via an additional flat (black) cable. Most output devices have provisions for this extra cable.

### **EMI/RFI immunity**

A common question with AS-I is the lack of shielding and the obvious concerns about noise immunity. Digital signals are encoded on the cable in a sinusoidal signal, which has a very narrow frequency bandwidth. Filtering which is distributed through the network rejects all extraneous frequencies, and in this way ASI can be operated in electrically noisy environments (even on robotic welders) without experiencing transmission errors.

### **Analog I/O**

Analog signals can be transmitted on ASI, but a node can represent only one analog device, and fragmented messaging must be used to transmit signals requiring more than 4 bits.

### **Determinism and Scan Time**

ASI is deterministic; meaning that one can know with certainty how long it will take for status changes to be reported to the master. To calculate scan time, multiply the number of nodes (including the master) by 150 microseconds. The maximum network delay is 4.7mS, which is certainly speedy enough for most applications (most PLC's have a scan time of 20mS or more!).

## 6.7. CONTROLNET - mission critical control-level network

- Origin: Allen-Bradley, 1995
- Based on RG6/U cabling (popular in cable TV applications) and
- Rockwell ASIC chip
- Maximum Number of Nodes: 99
- Connectors: Twin redundant BNC
- Maximum Distance: 250 to 5000M (with repeaters)
- Baud rate: 5M bit/Sec
- Message Size: 0-510 bytes
- Messaging Formats: Based on Producer/Consumer model; multi-master, peer to peer, fragmented, prioritized and deterministically scheduled repeatable messages; dual transmission paths for built-in redundancy.
- Supporting Trade Organization: ControlNet International, <http://www.controlnet.org/>
- Typical Applications: Mission critical, plant-wide networking between multiple PC's, PLC's and sub-networks (i.e. DeviceNet, Foundation FieldBus H1, etc.) and process control, and situations requiring high-speed transport of both time-critical I/O and messaging data, including upload/download of programming and configuration data and peer-to-peer messaging.
- **Advantages:** Deterministic, repeatable, efficient use of network bandwidth, provides redundancy at lower cost than most other available networks including Ethernet. Can be transmitted on any IP transport protocol via Ethernet, Firewire or USB.
- **Disadvantages:** Limited multi-vendor support and expensive Rockwell ASICs (Application-Specific Integrated Circuits).

ControlNet was conceived as the ultimate high-level Fieldbus network, and was designed to meet several high-performance automation and process control criteria. Of primary importance is the ability of devices to communicate to each other with 100% determinism while achieving faster response than traditional master/slave poll/strobe networks. (Determinism means knowing absolute worst-case response times with 100% certainty.) This is made possible by the Producer/Consumer communication model and the scheduler, which rigorously prioritizes messages.

### **Multi-Master and repeatability**

ControlNet allows multiple masters to control the same I/O points. Repeatability ensures that transmit times are constant and unaffected by devices connecting to, or leaving, the network. These features are further enhanced with user selectable I/O and controller interlocking update times to match application requirements.

### **Large quantities of data and complex devices.**

ControlNet is specifically designed to accommodate the high-level information and control needs of literally dozens of sub-networks and controllers. In process control situations where hazardous materials are involved and absolute certainty with respect to control processes is required, the deterministic capabilities of ControlNet are extremely important.

### **Redundancy**

The ControlNet architecture has redundant connectivity as an integral feature. Redundancy is rather difficult to achieve with other networks, but each ControlNet node has dual connections for this very purpose.

## **6.8. Foundation Fieldbus (H1 and HSE) - a two-layer solution for the process industry.**

- Foundation Fieldbus: The Open International Standard for Mission Critical, Process Control and Intrinsically Safe Environments
  - Origin: ISA, 1998
  - Implemented on chips produced by multiple vendors.
  - “H1” Intrinsically Safe, 31.25Kbit/sec; “HSE” High Speed Ethernet, 100Mbit/sec. Based on ISA SP50/IEC 61158
  - Maximum Number of Nodes: 240 per segment; 65,000 possible segments.
  - Distance: 1900M for H1
  - Baudrate: 31.25K and 100M Bit/sec
  - Message size: 128 Octets
  - Messaging format: Client/Server, Publisher/Subscriber, Event Notification
  - Supporting Trade Organization: Fieldbus Foundation ([www.fieldbus.org](http://www.fieldbus.org))
  - Typical Applications: Distributed Control Systems; Continuous process control, Batching, Oil and Gas
  - Advantages: Flexible, sophisticated protocol with many capabilities; Intrinsically safe; Integrated device level/plant level approach; Very strong contender as future process industry standard.
  - Disadvantages: “Process Industry” centric; limited availability of compatible devices; **slow** process of standardization and industry adoption.
- Foundation Fieldbus has finally come into its own, and is rapidly establishing itself as the future standard for process industry networking. Since its official introduction in 1997, many DCS vendors have been embracing Foundation Fieldbus, developing and certifying devices. Foundation Fieldbus contends with Modbus, HART and Profibus-PA as a standard.



### **The requirements of the process industry**

Process industry installations tend to be “campus wide”: much larger than the cell-level and “production line” sized applications more typical of the automation industry. Upgrades and changes tend to be done much less often and are more expensive. The process industry is usually very cautious about new technology. The installations can be extremely hazardous and there is no room for error.

### **Complexity of FF**

FF is a relatively sophisticated, object-oriented protocol, which uses multiple messaging formats and allows a controller to recognize a rich set of configuration and parameter information (“Device Description”) from devices which 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 (High Speed Ethernet), is a 100Mbit Ethernet standard which uses the same protocol and objects as FF H1, on TCP/IP.

## **6.9. Ethernet: the worldwide de facto standard for business and PC Networking**

- Origin: Digital Equipment Corporation, Intel and Xerox, 1976
- Implemented on Multitudes of chips produced by many vendors. Based on IEEE 802.3
- Formats: 10 Base 2, 10 Base T and 100 Base T, 100 Base FX, 1 Gigabit; Copper (Twisted Pair / Thin Coax) and Fiber
- Connectors: RJ45 or Coaxial
- Maximum Number of Nodes: 1024, Expandable with Routers
- Distance: 100M (10 Base T) to 50 KM (Mono mode, Fiber with Switches)
- Baudrate: 10M to 100M Bit/sec
- Message size: 46 to 1500 bytes
- Messaging format: Peer-to-Peer
- Supporting Trade Organization: Industrial Ethernet Association ([www.IndustrialEthernet.com](http://www.IndustrialEthernet.com)) and IAONA ([www.iaona.com](http://www.iaona.com)).
- Typical Applications: Nearly universal in office / business Local Area Networks. Widely used also in PC to PC, PLC to PLC and supervisory control applications. After 2000 Ethernet is gradually working its way toward the “sensor level” in plant floor applications.

- Advantages: Ethernet is the most widely accepted international networking standard. Nearly universal worldwide. Ethernet can handle large amounts of data at high speed and serve the needs of large installations.
- Disadvantages: High overhead to message ratio for small amounts of data; No power on the bus; Physically vulnerable connectors and greater susceptibility to EMI/RFI than most fieldbuses; Confusion based on multiple open and proprietary standards for process data.

The networking of millions of PC's in offices and the proliferation of the Internet across the world has made Ethernet a universal networking standard. Ethernet hardware and related software has evolved to the point where even inexperienced users can build simple networks and connect computers together. Ethernet hardware is cheap and can be purchased in office supply stores, computer stores and e-commerce sites. A study by an automotive manufacturer showed that Ethernet could potentially serve up to 70% of plant floor networking applications. But there are at least four major issues, which must be addressed satisfactorily for Ethernet to become a viable, popular, plant-floor network:

1. A common "Application Layer" must be established. When our device receives a packet of data, what format is that data in? Is it a string of I/O values, a text document or a spreadsheet? Is it a series of parameters for a Variable Frequency Drive? How is that data arranged? There are several competing standards resolving this issue.

2. Industrial grade connectors will be necessary for many applications. Cheap plastic "telephone connectors" and the RJ45 connectors are not suitable for the plant floor; industrial strength connectors are needed.

3. Many users desire 24 Volt power on the Bus (like DeviceNet is). This is advantageous from a practical standpoint – it reduces wiring and power supply problems -- but it adds cost and introduces noise and other technical problems.

4. Some applications require determinism. Ethernet - as it is typically used - is not deterministic or repeatable; in other words, throughput rates are not guaranteed. However, methods exist for architecting deterministic Ethernet systems. In reality, most applications don't need determinism - they just need speed.

### **"Industrial Ethernet" and interoperability**

Ethernet is just a physical layer standard, in much the same way an RS232, or a telephone line, is. Having a physical connection means that messages can be transmitted, but it does not assure successful communication. Just because we can make a telephone ring in Shanghai doesn't mean we can speak Mandarin.

There are many transmission protocols that can be used on Ethernet. The most popular, and the one used on the World Wide Web, is TCP/IP, which stands for Transmission Control Protocol/Internet Protocol. When we download a file from the web, we can see the speed of the transmission speed up and slow down as network traffic levels change. TCP/IP is the mechanism that breaks the downloaded file into any number of bits and pieces and re-assembles them at the other side. TCP/IP was developed at Stanford University in the 1970's as a "handshaking" mechanism that would assure that 'the message would always eventually get through.' To carry the Web example a bit further, we've all had the experience of downloading a large file, only to discover that our PC "cannot find an associated application for this file type." So we end up downloading a plug-in like Shockwave or RealAudio or Winamp or Adobe Acrobat Reader so we can open the file. The exact same problem applies to industrial controls. We can send any file or piece of process data we want to over Ethernet or the Internet, but the receiving end has to know what to do with the data. TCP/IP doesn't assure we of opening the file; it just guarantees that it will arrive.

### **Existing fieldbuses on Ethernet.**

The next frontier for the established fieldbus organizations is to produce Ethernet TCP/IP application layers of their protocols. Presently, there are four major contenders: Modbus/TCP (Modbus protocol on TCP/IP), EtherNet/IP (the ControlNet/DeviceNet objects on TCP/IP), Foundation Fieldbus High Speed Ethernet, and Profinet (Profibus on Ethernet). One could propose an infinite number of potential application layer protocols, and in fact right now there are, in addition to the above protocols, a myriad of other, proprietary standards from various vendors. But there are several significant advantages to employing the existing bus architectures:

- Profiles for many devices have already been defined, and can be transferred to Ethernet with relatively little effort.
- In systems which use, for example, Profibus as an I/O level network, and Profibus on Ethernet at the supervisory level, the relationship between the two networks is relatively transparent. Data can be transferred between the upper and lower network fairly easily.
- Many developers and users are familiar with these existing protocols, and this speeds the process of product development and adoption.

For more information on Industrial Ethernet, see the following links:

**Modbus/TCP** - <http://www.modbus.org>.

**Ethernet/IP** - <http://www.odva.org/>. Ethernet/IP is essentially the ControlNet / DeviceNet objects on TCP/IP and UDP.

**Profibus on Ethernet** - <http://www.profibus.com/>. This specification combines the existing Profibus protocol with open source OPC/XML services.

**Foundation Fieldbus High Speed Ethernet (HSE)** - <http://www.fieldbus.org>. HSE puts the Foundation Fieldbus H1 protocol on TCP/IP and also adds OPC, XML, and Simple Object Access Protocol on TCP/IP.

### **The value of information**

When we invest in connectivity, we are really investing in information. Let, for example, we have at the factory floor a control system installed on a packaging line that seals 500 boxes per minute. Using simple calculations, if each box sells for \$3, then down time costs \$1500 per minute. 15 minutes of down time costs \$22,500. If we design diagnostic features into our controller, which, via a fieldbus, transmit critical data that alerts a maintenance electrician to a potential failure *before* it happens, this is going to save us \$90,000 per hour. Automotive plant down time is much more expensive than that – by an order of magnitude. Semiconductor industry down time is yet an order of magnitude more expensive than that. So the cost of the Networked Control System we buy can quickly pay back due to such potential benefits.

BACKGROUND INFORMATION				
Network Specification	Technology Developer	Year Introduced	Governing Standard	Openness
PROFIBUS DP/PA	PNO/PTO	DP-1994, PA-1995	EN 50170 DIN 19245 part 3 (DP) part 4 (PA), IEC 1158-2 (PA)	ASICs from Siemens and Profichip, Products from over 300 vendors
INTERBUS-S	Phoenix Contact	1984	DIN 19258 EN 50.254	Products from over 400 manufacturers
DeviceNet	Rockwell Allen-Bradley	March 1994	ISO 11898 ISO 11519	17 chip vendors, 300+ products, Open specification
ARCNET	Datapoint/ SMC	1977	ANSI/ATA 878.1	Chips, boards, ANSI docs
AS-I	AS-I Consortium	Fall 1993	Submitted to IEC	AS-II.C. Market item
Foundation FieldBus H1	FieldBus Foundation	1995	ISA SP50 IEC TC65	Chips/software/products from multiple vendors
Foundation FieldBus High Speed Ethernet (HSE)	FieldBus Foundation	In development, Preliminary	IEEE 802.3u RFC for IP, TCP and UDP	Chips/software/products from multiple vendors that supply Ethernet products
IEC/ISA SP50 Fieldbus	ISA & FieldBus Foundation	1992 - 1996	IEC 1158 ANSI 850	Multiple chip vendors
Seriplex	APC, Inc. now AEG Modicon	1990	Seriplex spec	Chips available multiple interfaces
WorldFIP	WorldFIP	1988	IEC 1158-2	Multiple chip vendors
LonWorks	Echolon Corp.	March 1991		Public documentation on protocol

BACKGROUND INFORMATION				
Network Specification Developer	Technology	Year Introduced	Governing Standard	Openness
SDS	Honeywell	Jan., 1994	Honeywell Specification, Submitted to IEC, ISO11989	17 chip vendors, 200+ products
ControlNet	Rockwell Allen-Bradley	1996	ControlNet International	Open Specification, 2 chip vendors
CANOpen	CAN in Automation	1995	CiA	17 chip vendors, 300 product vendors, Open specification
Modbus Plus	AEG Modicon	1980's	None	Controlled by AEG Modicon many vendor support through modconnect program
Modbus RTU/ASCII	AEG Modicon	1970's	EN 1434-3 (layer 7) IEC 870-5 (layer 2)	Open specification, uses UART (RS232,422/485), no special hardware required
Industrial Ethernet	Intel/DEC/Xerox	Late 1970's	IEEE802.2	The most open network worldwide thousands of vendors, hundreds of different chip suppliers.

PHYSICAL CHARACTERISTICS				
Network	Network Topology	Physical Media	Max. Devices (nodes)	Max. Distance
PROFIBUS DP/PA	Line, star & ring	Twisted-pair or fiber	127 nodes (124 slaves, 4 segments, 3 repeaters) up to 3 masters	100m between segments @ 12Mbaud; 24 Km (fiber) baud rate and media dependent
INTERBUS-S	Segmented with "T" drops	Twisted-pair, fiber, and slip-ring	256 nodes	400 m/segment, 12.8 Km total
DeviceNet	Trunkline/dropline with branching	Twisted-pair for signal & power	64 nodes	500m (baudrate dependent) 6Km w/repeaters
ARCNET	Star, Bus, distributed star	Twisted-pair, coax, fiber	255 nodes	Coax 2000 feet; Twisted pair 400 feet; Fiber 6000 Feet
AS-I	Bus, ring, tree star, of al	Two wire cable	31 slaves	100 meters, 300 with repeater
FieldBus Foundation H1	Star or bus	Twisted-pair, fiber	240/segment, 65,000 segments	1900m @ 31.25K
FieldBus Foundation HSE	Star	Twisted-pair, fiber	IP addressing - unlimited nodes	100m @ 100Mbaud 2000m @ 100Mbaud fiber full duplex
IEC/ISA SP50 Fieldbus	Star or bus	Twisted-pair fiber, and radio	IS 3-7 non IS 128	1700m @ 31.25K 500M @ 5Mbps
Seriplex	Tree, loop, ring, multi-drop, star	4-wire shielded cable	500+ devices	500+ ft
WorldFIP	Bus	Twisted-pair, fiber	256 nodes	up to 40 Km
LonWorks	Bus, ring, loop, star	Twisted-pair, fiber, power line	32,000/domain	2000m @ 78 kbps
SDS	Trunkline/Dropline	Twisted-pair for	64 nodes.	500m (baudrate dependent)

PHYSICAL CHARACTERISTICS				
Network	Network Topology	Physical Media	Max. Devices (nodes)	Max. Distance
		signal & power	126 addresses	
ControlNet	Linear, Tree, Star, Coax, fiber or Combination		99 nodes	1000m (coax) 2 nodes 250m with 48 nodes 3km fiber, 30km fiber w/repeaters
CANOpen	Trunkline/Dropline	Twisted Pair + optional signal & power	127 nodes	25-1000m (baud rate dependent)
Modbus Plus	linear	Twisted Pair	32, 64 max. pcr segment with bridge capabilities	500m per segment
Modbus RTU/ASCII	Line, star, tree, network w/segments	Twisted Pair	250 nodes per segment	350m
Industrial Ethernet	STAR, BUS	10BASE-T, 10-Base-FL (FIBER) 100 Base TX	48 bit address	



TRANSPORT MECHANISM						
Network	Communication Methods	Transmission Properties	Data Transfer Size	Arbitration Method	Error Checking	Diagnostics
PROFIBUS DP/PA	Master/slave peer to peer	DP: 9.6, 19.2, 93.75, 187.5, 500 Kbps, 1.5, 3, 6, 12 Mbps PA 31.25 kbps	0-244 bytes	Token passing	HD4 CRC	Station, module & channel diagnostics
INTERBUS-S	Master/slave with total frame transfer	500kBits/s, full duplex	1-64 bytes data, 246 bytes parameter, 512 bytes h.s., unlimited block	None	16-bit CRC	Segment location of CRC error and cable break
DeviceNet	Master/slave, multi-master, others	500 kbps, 250 kbps, 125 kbps	8-byte variable message	Carrier-Sonac Multiple Access w/ non-destructive bitwise arbitration	CRC check	Bus monitoring
ARCNET	Peer to peer	19.53K to 10M	0-507 bytes	Token passing	16-bit CRC	Built in Acknowledgements at Data link layer
AS-I	Master/slave with cyclic polling	Data and power, EMI resistant	31 slaves with 4 in and 4 out	Master/slave with cyclic polling	Manchester Code, hamming-2	Slave fault, device fault
Fieldbus Foundation H1	Client/server publisher/subscriber, Event notification	31.25 kbps	128 octets	Scheduler, multiple backup	16-bit CRC	Remote diagnostics, network monitors, parameter status
Fieldbus Foundation	Client/server publisher/	100Mbps	Varies, Uses Standard TCP/IP	CSMA/CD	CRC	

TRANSPORT MECHANISM						
Network	Communication Methods	Transmission Properties	Data Transfer Size	Arbitration Method	Error Checking	Diagnostics
HSE	subscriber, Event notification					
IEC/ISA SP50 Fieldbus	Client/server Publisher/subscriber	31.25 kbps IS+1, 2.6, 5 Mbps	64 octets high & 256 low priority	Scheduler, tokens, or master	16-bit CRC	Configurable on network management
Seriplex	Master/slave peer to peer	200 Mbps	7680/transfer	Sonal multiplexing	End of frame & echo check	Cabling problems
WorldFIP	Peer to peer	31.25 kbps, 1 & 2.5 Mbps, 6 Mbps fiber	No limit, variables 128 bytes	Central arbitration	16-bit CRC, data "freshness" indicator	Device message time-out, redundant cabling
LonWorks	Master/slave peer to peer	1.25 Mbs full duplex	228 bytes	Carrier Sense, Multiple Access	16-bit CRC	Database of CRC errors and device errors
SDS	Master/slave, peer to peer, multi-cast, multi-master	1Mbps, 500 kbps, 250 kbps, 125 kbps	8-byte variable message	Carrier-Sonac Multiple Access	CRC check	Bus monitoring, Diagnostic slave
ControlNet	Producer / Consumer Device object model	5 Mbps	0-510 bytes variable	CTDMA time slice multiple access	Modified CCITT with 16 bit polynomial	Duplicate Node ID, Device, Slave Faults
CANOpen	Master/slave,	10K, 20K,	8-byte variable	Carrier-Sonac Multiple	CRC check	Error Control &

TRANSPORT MECHANISM						
Network	Communication Methods	Transmission Properties	Data Transfer Size	Arbitration Method	Error Checking	Diagnostics
	multi-master, others	50K, 125K, 250K, 500K, 800K, 1Mbps	message	Access w/ non-destructive bitwise arbitration		Emergency Messages
Modbus Plus	Token Passing	1 MBPS	256 bytes data + header	peer to peer, token passing	16-bit CRC	Local Chip and Software
Modbus RTU/ASCII	Master/Slave	300 bps - 38.4K bps	0-254 bytes			
Industrial Ethernet	CSMA/CD	10MBPs, 100 MBPs	1500 Bytes Data.	Collision Detection	32 bit CRC.	CD, Network Management

PERFORMANCE			
	Cycle Time: 256 Discrete 16 nodes with 16 I/Os	Cycle Time: 128 Analog 16 nodes with 8 I/Os	Block transfer of 128 bytes 1 node
PROFIBUS DP/PA	Configuration dependent typical <2ms	Configuration dependent typical <2ms	not available
INTERBUS-S	1.8 ms	7.4 ms	140 ms
DeviceNet	2.0 ms Master-slave polling	10 ms Master-slave polling	4.2 ms
ARCNET	Application layer dependent	Application layer dependent	Application layer dependent
AS-I	4.7 ms	not possible	not possible
Fieldbus Foundation H1	<100 ms @ 31.25k	<600 ms @ 31.25k	36 ms @ 31.25k
Fieldbus Foundation HSE	Not Applicable; Latency <5ms	Not Applicable; Latency <5ms	<1ms
IEC/ISA SP50	Configuration dependent	Configuration dependent	0.2 ms @ 5 Mbps 1.0 ms @ 1 Mbps
Seriplex	1.32 ms @ 200 kbps, m/s	10.4 ms	10.4 ms
WorldFIP	2 ms @ 1 Mbps	5 ms @ 1 Mbps	5 ms @ 1 Mbps
LonWorks	20 ms	5 ms @ 1 Mbps	5 ms @ 1 Mbps
SDS	<1 ms, event driven	<1 ms per event	2 ms @ 1 Mbps
ControlNet	<0.5ms	<0.5ms	<0.5ms
CANOpen	<1ms	<1ms	<1ms
Modbus Plus			
Modbus RTU/ASCII			
Industrial Ethernet	Not Applicable; Latency <5ms	Not Applicable; Latency <5ms	<1ms

TABLE 1							
Type of network	Ethernet	Modbus RTU/ASCII	Profibus	Foundation Fieldbus	DeviceNet	CANopen	J1939
Origin	Digital Equipment Corp., Intel, and Xerox - 1976	Modicon - 1978	German govt. and automation manufacturers - 1989	ISA - 1998	Allen-Bradley - 1994	CAN in Automation - 1993	SAE 1994
Implementation	Produced on chips by many vendors; based on IEEE 802.3	Produced on any medium, but it is typically found on RS-232, -422, or -485; no special ASICs required	Produced on ASICs by multiple vendors; based on RS-485 and the European EN50170	Produced on chips by multiple vendors	Produced on chips by many vendors; based on CAN	Produced on chips by many vendors; based on CAN	Produced on chips by many vendors; based on CAN
Formats	10Base-2, 10Base-T, 100Base-T, 100Base-FX, 1 Gb; copper (twisted pair/thin coaxial), and fiber	Typically RS-232, RS-422, RS-485	Profibus DP (master/slave), Profibus FMS (multimaster/ peer to peer), and Profibus PA (intrinsically safe)	H1 intrinsically safe and High-Speed Ethernet (HSE); based on ISA SP50/ IEC61158			
Connectors	RJ-45 or coaxial	Typically DB9 or terminal block	9-pin D-shell connector (impedance terminated) or 12 mm IP 67 quick disconnect	Application dependent	Mini 18 mm and micro 12 mm waterproof quick disconnect plugs and receptacles; 5-pin Phoenix terminal block	Mini 18 mm and micro 12 mm waterproof quick disconnect plugs and receptacles; 9-pin D-shell	Application dependent
Max. nodes	1024, expandable with routers	250	127	240/ segment; 65,000 possible segments	64	64	30/ segment
Distance	100 m (10Base-T) to 50 km (mono mode, fiber with switches)	350 m for RS-485	100 m (copper, no repeaters, max. speed) to 24 km (with repeaters and fiber optic transmission)	1900 m for H1	100-500 m	100-500 m	40 m
Bit rate	10 Mbps to 1	Can run at any	9600 bps to 12 Mbps	H1 31.25 Kbps	125, 250, and 500	125, 250, and 500	250 Kbps

TABLE 1							
Type of network	Ethernet	Modbus RTU/ASCII	Profibus	Foundation Fieldbus	DeviceNet	CANopen	J1939
	Gbps	speed, but it is most commonly used between 9600 and 38,400 bps		and HSE 100 Mbps	Kbps	Kbps	
Message size	46-1500 bytes	0-254 bytes	Max. 244 bytes/ node / message	128 octets	8 bytes/ node/ message	8 bytes/ node/ message	4-8 bytes/ node/ message
Messaging format	Peer to peer	Master/ slave; discrete and analog I/O and parameters	Polling (DP/PA) and peer to peer (FMS)	Client/ server, publisher/ subscriber, and event notification	Polling, strobing, change-of-state, cyclic; explicit messaging for configuration and parameter data; UCMM for peer to peer messaging; producer-consumer-based model	Polling, strobing, change-of-state, cyclic, and others	Broadcast, one-to-one
Supporting trade organization	<u>Industrial Ethernet Assoc. and Industrial Automation Open Networking Assoc.</u>	<u>Modicon/ Groupe Schneider</u>	<u>Profibus Trade Org.</u>	<u>Fieldbus Foundation</u>	<u>Open DeviceNet Vendor Assoc.</u>	<u>CAN In Automation</u>	<u>Society of Automotive Engineers</u>

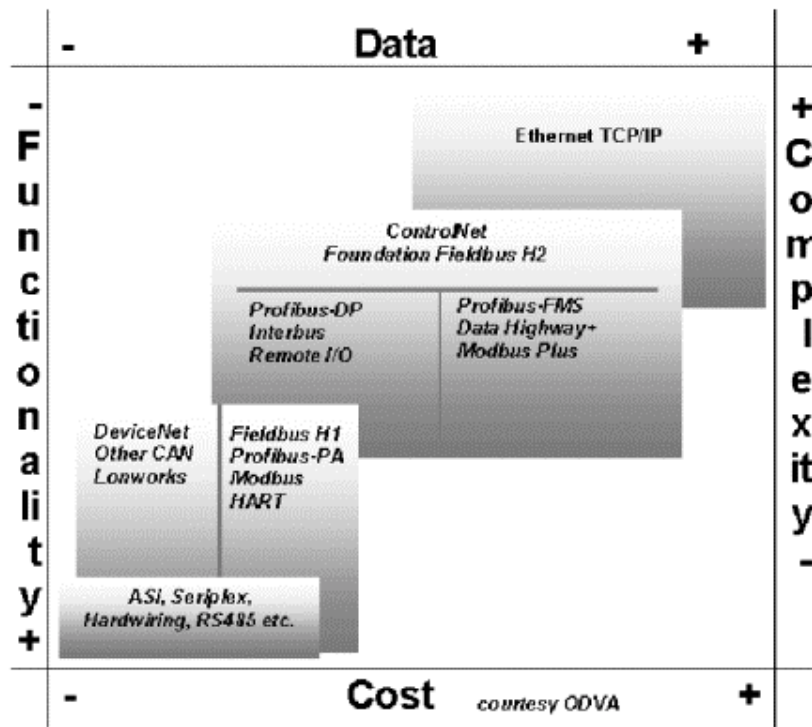


Fig. 3