# 9

# Communications Concepts and Considerations Important in the Reference Model

## COMMUNICATIONS IN COMPUTER CONTROL SYSTEMS

In addition to communicating with the outside world in terms of reading the process variables and sending out control actuator adjustments, each control computer must also communicate with the other computers in the hierarchy, and with its associated peripheral equipment, operators consoles, etc. This chapter will cover this topic.

## THE PROCESS/DATA SYSTEM INTERFACE AS A BEGINNING FOR COMPUTER SYSTEMS COMMUNICATIONS

In the earliest plant computer control system situations the plant wiring system could be effectively sketched as in Figure 9-1. Here the line connecting the sensor or actuator symbol to the computer represents a single pair of data wires. However, when the number of sensors and actuators becomes very large and the distances between them and the computer become long, the overall cost of such a wiring system becomes quite high and it is necessary to seek another, less expensive solution than that of having a separate pair of leads for each individual sensor or actuator running from their location to the computer's location.

Consolidation of all of the variables in one area of the plant into a remote multiplexer with its own analog-to-digital and digital-to-analog conversion equipment and transmission of the resulting consolidated data to the computer in digital form should greatly reduce the above costs as illustrated in Figure 9-2. The next stage is to put all of the remote multiplexers onto one data cable or data highway as shown in Figure 9-3. While not immediately obvious in this figure this method will further greatly reduce the total length of wiring and hence the overall wiring costs. However, by using this latter type of configuration, we immediately impose several conditions on the communications system which were not previously present.

1. The transmission speed must be at least three times faster than before in order to give the same effective rate of service as the three previously separate lines of Figure 9-2.

2. A permanent or temporary "line master" must be established to decide who obtains control of the common line in order to transmit messages at any one time. Otherwise, several of the potential senders may try to send a message at the same time resulting in a "contention" situation existing on the line.

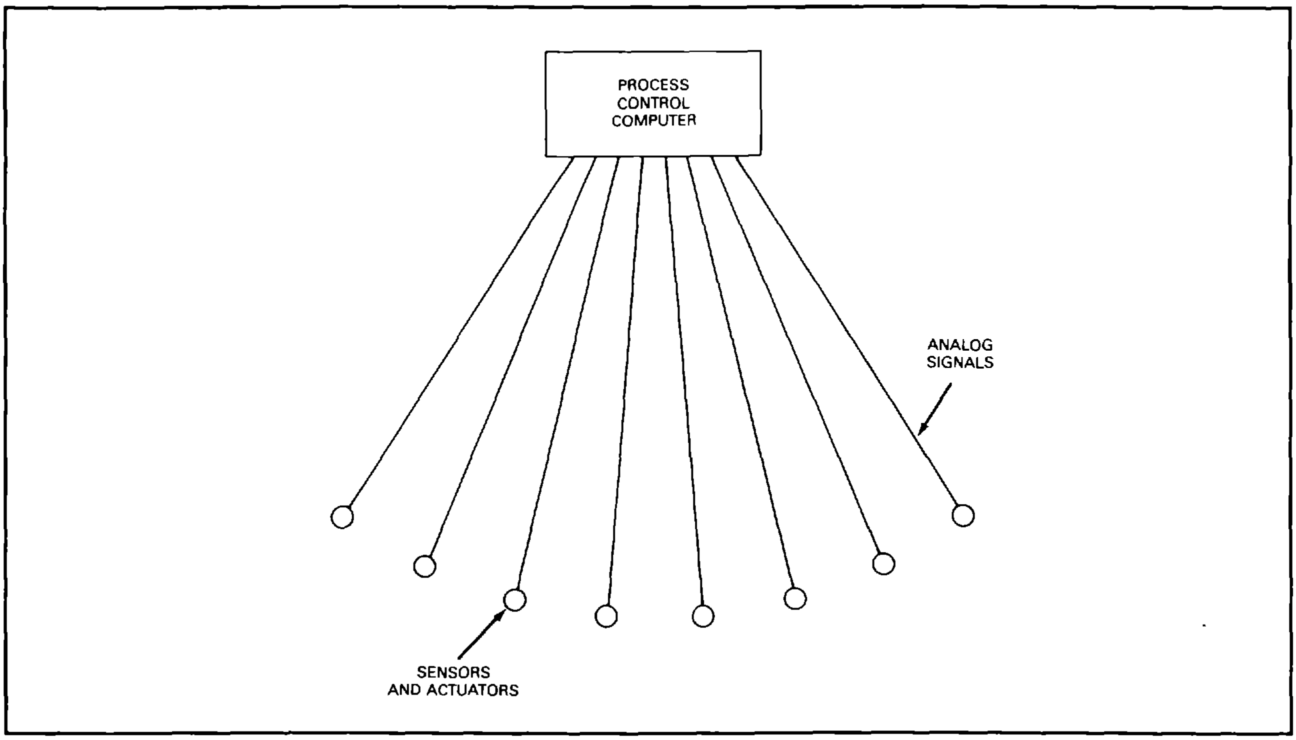



*Figure 9-1 Star or tree structure Plant Data System communications layout.*

3. A code or "protocol" system for use in the message must be established to indicate which of the multiplexers or the main computer is sending the message and to whom it is addressed. Otherwise, the remote multiplexers must be "polled" by the computer one by one in order to identify who is sending what message at any particular time. Note, that in the data highway system the remote multiplexers can theoretically talk with each other directly without going through the control computer provided one of the three has mastership of the line at that moment. This complicates the protocol or addressing requirement.

4. Reliability of the line is now more important than before since a failed line will now disable several remote multiplexers and not just one.

A generalization of the system of Figure 9-3 is given in Figure 9-4 where mastership resides permanently in the Highway Traffic Director and all units on the line including the computer are "polled" in turn as in Item 3 above. This is the system used by most of the distributed, microprocessor-based, digital control systems today.

It should be noted that each of the situations diagramed in Figures 9-3 and 9-4 could also exist as well between groups of computers and a central computer as between a single computer and a group of multiplexers.

An additional form of the data highway of Figure 9-3 is that of Figure 9-5 which shows a ring or loop structure. Its advantage is that a single break will not disable any part of the system provided two-way transmission of signals is possible on the remaining cable fragments [14].

## THE OPEN SYSTEM INTERCONNECTION MODEL OR DIAGRAM

In order to properly describe any system more complex than those just mentioned, a model is necessary to be sure that each of the discussors can always properly identify those aspects of the data system about which the other is speaking. In order to accomplish this, the International Standards Organization (ISO) has defined its Open System

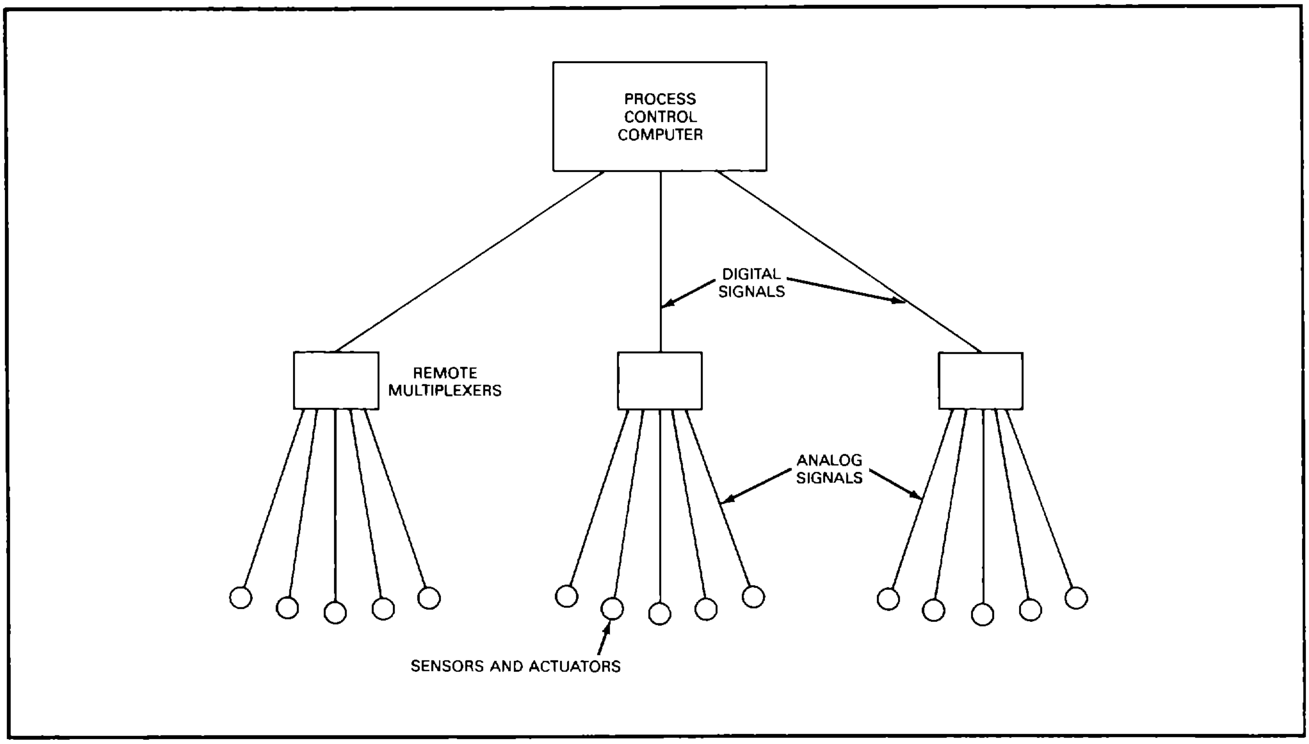



*Figure 9-2 Use of remote multiplexers to reduce wiring costs in large data and control systems.*

Interconnection Model (Figure 9-6) [8]. This divides the interconnection into seven layers as described below. It should be noted in passing that Figure 9-6 is the best example available of an Implementation Hierarchy View. It is described below.

Layering is a good approach to device interfacing because it divides the problem into smaller, more manageable segments. In performing its task, each layer communicates via the established protocols with its peer in another device as indicated in Figure 9-6 which shows communication between two transport layers. Within a device, each layer wraps the lower layers and isolates them from the higher ones. Each adds value to services provided by the lower set of layers, building them up until the highest level can perform distributed applications [46].

Layers 1-4 are called the transfer service since they are the ones responsible for moving messages from one point to another. Layers 5-7 are known as user layers, because they give the user access to data on the network. At present, formal standards have only been developed for the first three layers. The functions of all seven protocol levels are:

Layer 1 (Physical Layer) specifies the electrical, mechanical and functional characteristics for the interface, enabling it to exchange ones and zeroes. The layer defines voltages, signal control sequences, and the physical form of the cable and connector. The right hand side of Figure 9-6 further indicates the tasks assigned to Level 1 and to the media-access unit of the device. Standards include Electronic Industries Association's (EIA) RS-232C, RS-422A, RS-423 and RS-440 plus the IEEE 802 Standards (see below).

Layer 2 (Data Link Layer) describes the passage of data frames at the interface. It can address a frame or decode an address. The Link Layer defines the data format. It also performs error detection and error recovery. Standards for this layer include HDLC, ADCCP, DEC's DDCMP, and IBM's SDLC and BISYNC (described below).

Layer 3 (Network Layer) looks beyond the DTE-DCE (Data Terminal Equipment - Data Connection Equipment, i.e., between Levels 1 and 2) interface to control data frames between stations on a network. It establishes an end-to-end connection for transparent data delivery. This layer controls the actual switching and routing of mes-

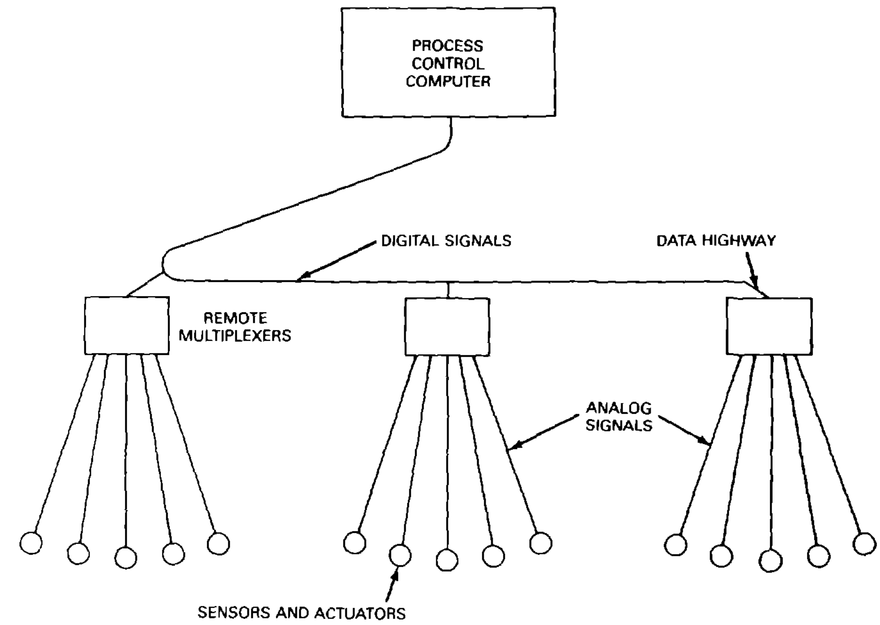



*Figure 9-3 Use of the Data Highway to further reduce wiring costs in large data and control systems (branch or bus configuration).*

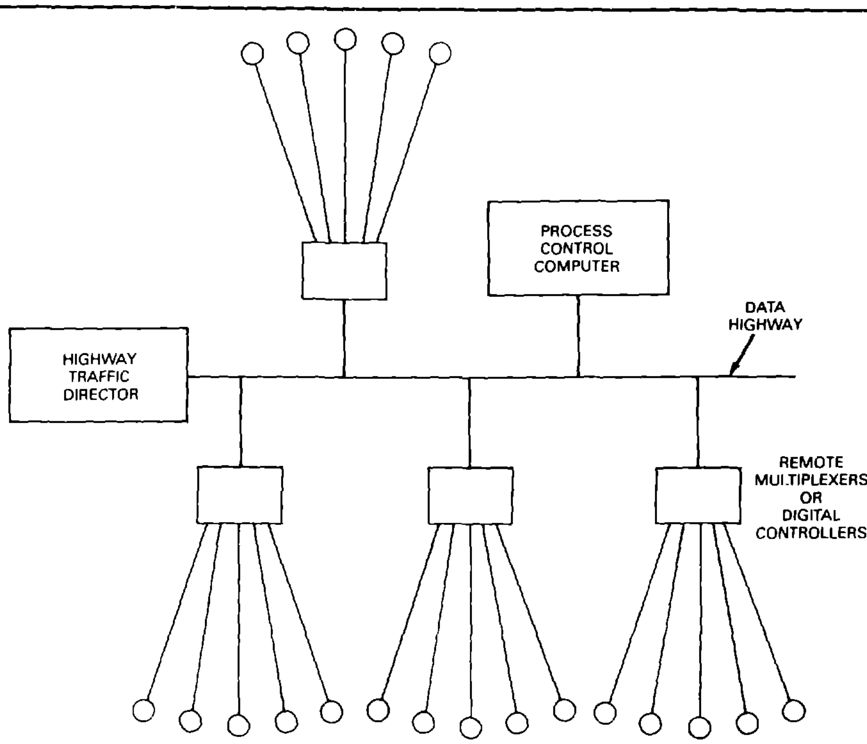



*Figure 9-4 The common form of the data highway with distributed, microprocessor-based digital control systems.*

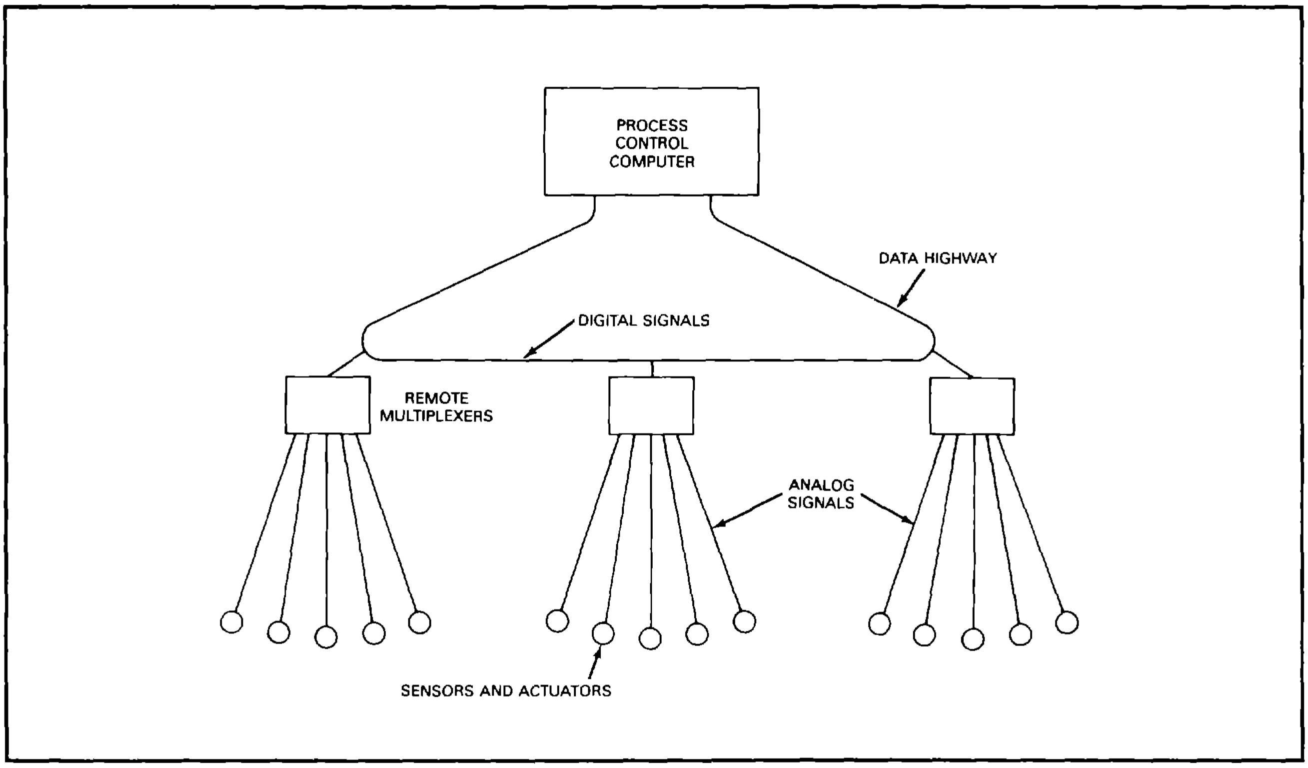



*Figure 9-5 Use of the data highway to furter reduce wiring costs in large data and control system (loop configuration).*

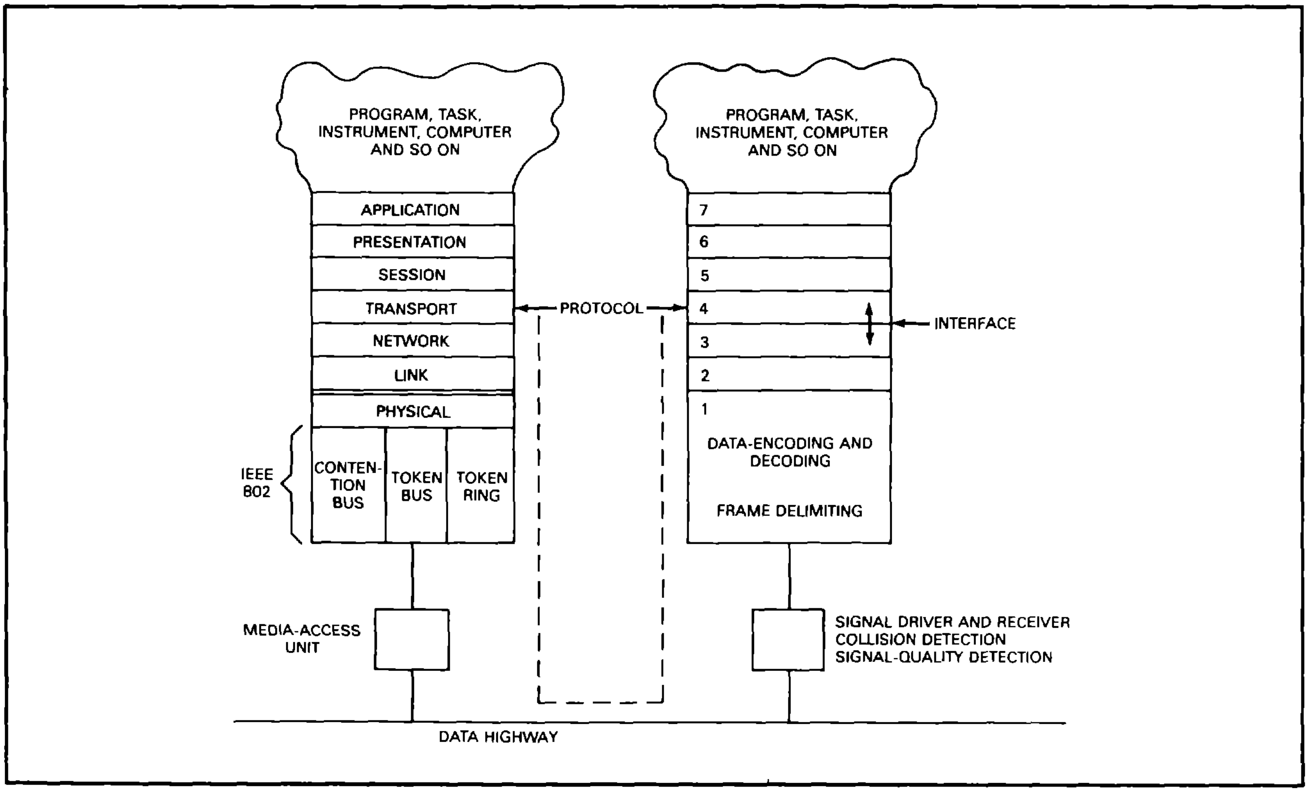



*Figure 9-6 The Open System Interconnect Diagram of the International Standards Organization.*

sages. CCITT's X.20, X.21, or X.25 may apply for this layer.

Layer 4 (Transport Layer) provides the user with a network-independent interface. It serves as an error check on the lower layers, and ensures a reliable connection between network devices.

Layer 5 (Session Layer) allows for a structured, logical exchange of messages between points on the network. For example, if many terminals are communicating with a central computer simultaneously, the Session Layer tracks and maintains each individual "conversation."

Layer 6 (Presentation Layer) presents the Application Layer (Layer 7) with a set of services, including management, display and control of structured data. It handles the transformation of messages between various computer, data terminal and database formats.

Layer 7 (Application Layer) is the highest DSI (data systems interface) layer. It applies end-user data to the network (e.g., through remote job entry or a virtual terminal). This layer also directly serves the end-user by providing data appropriate to a real application. The other six layers exist only to support this one.

Figure 9-7 presents another view of the ISO Open Systems Interconnection Model showing some existing standards at each of the first three layers of the diagram [46].

## SOME COMMERCIALLY AVAILABLE PLANT DATA COMMUNICATIONS SYSTEMS (LAYER 1)

If the equipments of more than one vendor are to be connectable to each other in the systems just discussed then some standard method of plant communications must be established through agreement between vendors (local standards), between major segments of the industry (national standards), or between the industries of many nations (international standards).

The earliest such standard for digital data transmission was the twenty milliampere current loop sometimes called the teletype standard because of the wide use of teletypes in early computer systems. This is an asynchronous transmission of digital data over a twisted pair of wires by turning a 20 mA current on and off. Start and stop bits are used to isolate data frames and to identify zeroes and spaces. A major drawback is that it cannot be used for complex networks. There are just not enough wires to carry the necessary control signals.

The RS 232C standard corrects many of the problems listed above for transmission over relatively short distances (up to 50 ft.). It uses voltage rather than current signals and provides both synchronous and asynchronous transmission over single or double twisted pairs of wires. The standard defines the physical characteristics of the connectors to be used and the electrical characteristics of the signals themselves. This standard was developed by the EIA (Electronic Industries As-

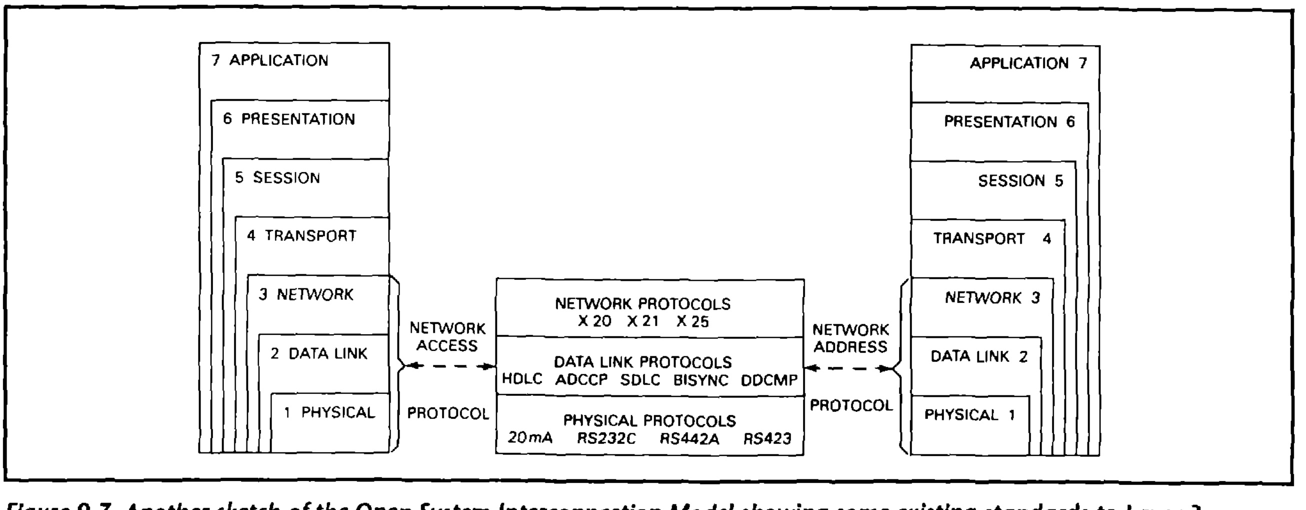



*Figure 9-7 Another sketch of the Open System Interconnection Model showing some existing standards to Layer 3.*

sociation). There are international standards also for this method.

The RS 422A standard (also by EIA) was developed for distances greater than 50 feet. It thus permits a daisy-chain or multi-drop network for devices to be assembled into a system. This standard specifies the use of a balanced voltage interface circuit, i.e., a differential transmitter is connected by a twisted pair cable to a differential receiver. It will support data rates up to 10 megabits per second and has far greater noise immunity than RS 232C. It is also far less susceptible to signal noise. RS 449 specifies the physical characteristics of the connectors for RS 422A. Again there are equivalent international standards for both.

The CAMAC Modular Instrumentation System for Data Handling [6] was an early conceived data system as shown in Figure 9-8. CAMAC means Computer Automated Measurement and Control. It was originally developed by the nuclear organizations of Europe and the United States for standardizing nuclear laboratory instrumentation. It has been widely accepted for this use and has had some industrial process control acceptance. This

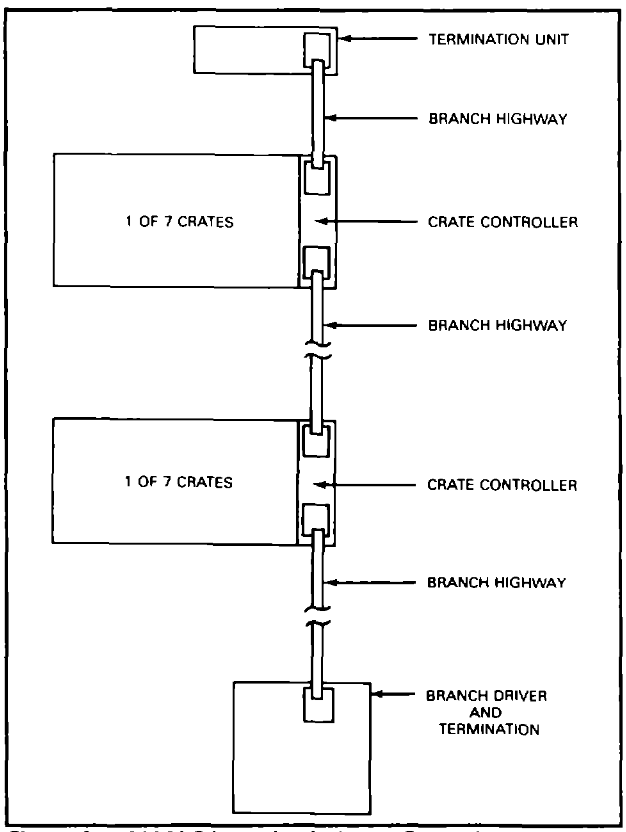



*Figure 9-8 CAMAC branch: chain configuration.*

equipment calls for a 132-wire cable or Branch Highway to connect up to seven crate units as shown in Figure 9-8. These could include a central computer and up to six remote multiplexers if so desired since a minicomputer or a remote multiplexer and their associated electronics can readily be included in any one crate. The Branch Highway has provision for the parallel transmission of 24-bit data in either direction on separate sets of wires. The desire for inexpensive data communications systems as mentioned earlier led to the subsequent development of the CAMAC Serial Highway which reduced the 132-wire cable of the Branch Highway system to two pairs of twisted wire as originally specified [6] or to a single coaxial cable in a revised implementation (Figure 9-9). However, its present specification calls for a unidirectional transfer of data and a requirement to pass through each module in turn. Both of these greatly increase its vulnerability to cable breaks and failed modules. This requirement for the system is called "store and forward" and is in direct contrast to the indications of Figures 9-3 and 9-4 where the elements are considered as "drops" and their individual failures would not necessarily cause total line failures.

The Hewlett-Packard Bus Interface System [7] (IEEE Standard 488) is a 15-wire cable which transmits data in "byte serial" form, i.e., eight bits parallel. Figure 9-10 diagrams a typical laboratory instrument application of this concept and the use of each of the 15 lines. The Hewlett-Packard scheme is primarily intended for laboratory-type systems and is very popular for such use. As presently conceived it has the following limitations [7]:

1. Number of connected devices or multiplexers - 15.

2. Data rate - 1 Megabyte per second maximum.

3. Transmission path length - 50 feet total accumulated cable length.

4. Data transfer is bidirectional.

These limitations if maintained would, of course, make it unsuitable for industrial systems of any convenient size.

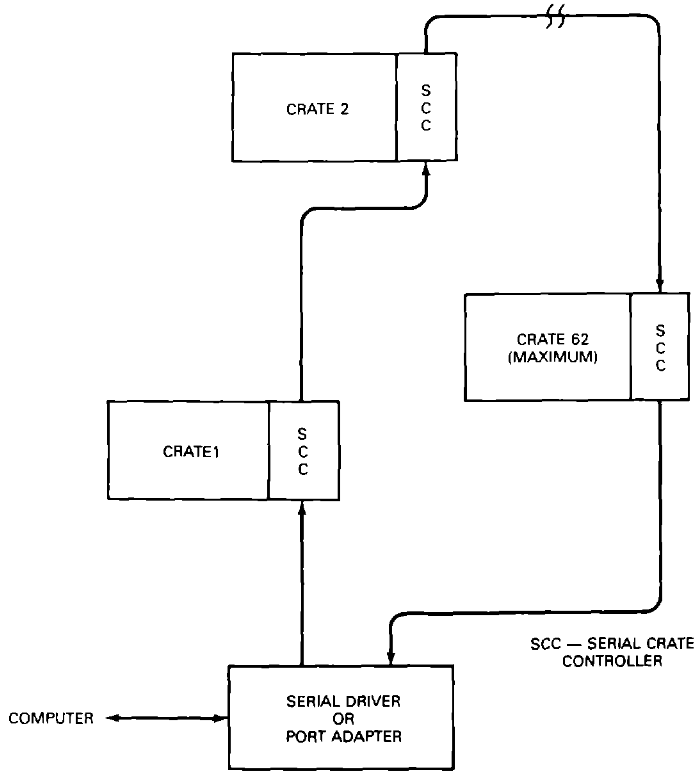



*Figure 9-9 CAMAC Serial Highway.*

## SOME PRESENT DAY MESSAGE CODING SCHEMES (LAYER 2) [46])

Message coding schemes or data link control protocols form the second layer in the communications architecture. They act as a kind of grammar for data communications, establishing rules for setting up a link between network stations and for accurately moving data across the link. They set up and terminate connections, ensure software synchronization, and perform error detection. Data link protocols come in two basic types: character- and bit-oriented.

Character-oriented protocols have been in use the longer of the two. They rely on a series of control characters within each frame to maintain accurate data transmission. (See Figures 9-11 and 9-12.) This makes code transparency, which is essential to any efficient protocol, a much more complex task. Another drawback to this type of protocol is its relatively slow speed; each frame must be acknowledged before the next is transmitted. Examples of character-oriented protocols are BISYNC of the International Business Machines Corporation (IBM) and DDCMP of the Digital Equipment Corporation (DEC).

IBM BISYNC - IBM's Binary Synchronous Communications Protocol (BSC) describes a byte-serial method of transmission that is limited to half-duplex. Even so, BISYNC is comparably fast, with a variable message format (Figure 9-11). But extensive software is needed for control. BISYNC uses a byte-stuffing method to ensure data transparency. But it can only perform error checking on data, not control characters.

DEC DDCMP - DEC's Digital Data Communications Message Protocol also relies on control characters, though not as many as BISYNC. DDCMP can operate in both half and full-duplex and has a

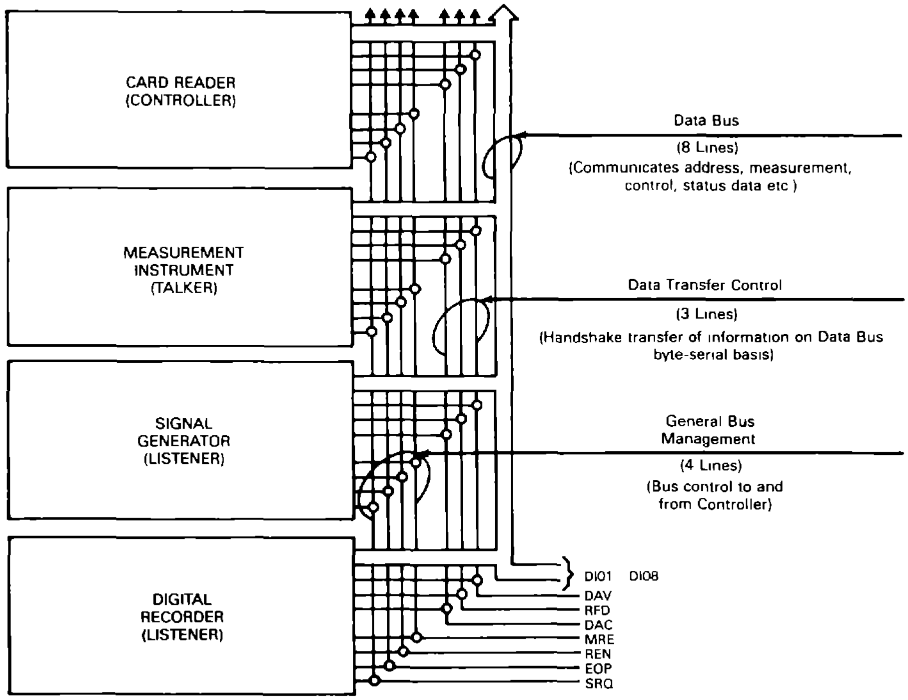



*Figure 9-10 The Hewlett-Packard Interface System. IEEE Standard 488. Information flow is bi-directional. Because of parallel connection, any device is potentially able to communicate directly with any other [7].*

IBM BINARY SYNCHRONOUS COMMUNICATIONS (BISYNC)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SYN | SYN | SOH | HEADER | STX | TEXT | ETX | BCC LRC-8 CRC-12 or CRC-16 |

DIGITAL DATA COMMUNICATIONS MESSAGE PROTOCOL (DDCMP)

| | | | HEADER | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SYN | SYN | SOH | COUNT (14 BITS) | FLAGS (2 BITS) | RESPONSE (8 BITS) | SEQUENCE (8 BITS) | ADDRESS (8 BITS) | CRC-16 (16 BITS) | INFO (8-BIT CHARACTERS) | CRC-16 (16 BITS) |

LEGEND

| | | | |
|---|---|---|---|
| SYN | SYNCHRONOUS IDLE | BCC | BLOCK CHECK CHARACTER |
| SOH | START OF HEADING | LRC | LONG REDUNDANCY CHECK |
| STX | START OF TEXT | CRC | CYCLIC REDUNDANCY CHECK |
| ETX | END OF TEXT | | |

*Figure 9-11 Examples of message coding schemes (frame structure) character-oriented protocols.*

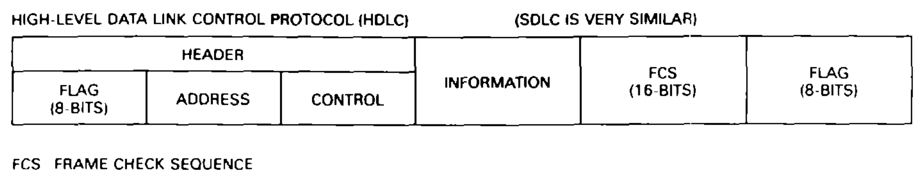



*Figure 9-12 Examples of message coding schemes (frame structures), a bit-oriented protocol.*

fixed message format (Figure 9-11). Error detection is done on both data and control characters via a 16-bit cyclic redundancy check. Half or full-duplex refers to whether one or two directional transmission is possible on the line at any one time.

Bit-oriented protocols need only two or three control characters to identify individual data frames (Figure 9-12). Because frames do not have to be acknowledged when they are received, this type of protocol can offer higher transmission speeds, at least twice the rate of character-oriented protocols. Part of this gain comes from the ability to transmit in full as well as half-duplex. Specialized ICs have been developed to implement such bit-oriented standards as HDLC, ADCCP, and IBM's proprietary protocol, SDLC.

HDLC (ISO) - High Level Data Link Control (HDLC) (Figure 9-12) is a protocol that has become a *de facto* industrial standard. The federal government, in its equivalent FED STD 1003, has made HDLC mandatory in all computer network procurements.

HDLC controls the flow of data between two or more stations. It does not specify the kind or amount of data, but the method by which remote stations are addressed. It defines two types of network stations: a primary, which issues commands and receives expected responses, and a secondary, which receives commands and sends out the required data. The primary station could be a computer operating system, a PC acting as a network master, or some other processing device. Because of this setup, HDLC is better suited than other data link protocols for multistation networks.

ADCCP (ANSI) - ANSI's Advanced Data Communication Control Procedures form a standard that is essentially identical to HDLC. It too sets up primary-secondary stations, uses a fixed message format, and operates in both half and full duplex. ANSI is the American National Standards Institute.

Another area in which the two standards agree is that of code transparency, for which both use a bit-insertion or "bit-stuffing" technique. This means that a device is able to communicate with a network while being completely ignorant of the network's data link procedure. The device does not have to dedicate any part of its message for data link control purposes. This is important because it allows devices to be connected to a network quickly and easily, and without re-programming.

IBM SDLC - The Synchronous Data Link Control protocol follows along the same lines as HDLC and ADCCP. Since this is IBM's standard, it has a large following in the data processing industry for computer-computer network uses. SDLC protocol is code-independent, requiring only that the transmitted data be eight bits or less. It should be noted that the other standards listed above are slight modifications of SDLC to make it more acceptable to IBM's competitor companies.

Note the FLAGS which initiate and end each bit-oriented message. These must be completely distinguishable from any codes used internally in the message to avoid truncating a true message and thus causing serious errors.

## MESSAGE TRANSMISSION METHODS (LAYER 3) [46]

Message transmission selection methods, often called network protocols, form the third layer in the communications architecture of Figure 9-6. Where data link protocols handle data at either end of the line, network protocols handle what goes on in between. They route messages from source to destination, but do not provide broader network control functions. They become important whenever there are several or many different paths by which the message could be sent between the two devices in question. This would occur, for example, when sending data some distance over the public telephone network. They are not important within a relatively limited plant data communications system. Network protocols come in two basic types: circuit-switching and packet-switching.

In circuit-switching, a device is given a discrete bit rate at which to transmit data (or a discrete bandwidth in the case of analog networks). Within this restriction the user is free to specify any mode of communication, including protocol, data format, speed, and error control methods. The only restriction placed on the user is that both transmitter and receiver operate under the same communication mode. CCITT protocols X.20 and X.21 are examples of circuit-switching protocols. CCITT is the International Telegraph and Telephone Consultative Committee.

X.20 (CCITT) - The X.20 standard establishes a network interface for asynchronous transmission. Electrical characteristics are compatible with standards RS-232C, 422A, and 423. There are two applicable bit rates for X.20 transmission: Class 1 specifies 300 bits/s, while Class 2 specifies a range from 40-200 bits/s. All control signaling between the station and the network must be done in ASCII code (CCITT equivalent V.3). ASCII is the American Standard Code for Information Interchange.

X.21 (CCITT) - This interface is a general purpose standard for synchronous operation, covering the first three layers of network architecture. It is applicable at 600, 2400, 4800, 9600, and 48,000 bits/s, and is completely transparent to data and procedures. The connection setup for the protocol is based on electrical signaling, rather than control messages, which is a major shortcoming. Japan, Germany and the Scandinavian countries have adopted the X.21 standard.

In packet-switching, network data from many users is formed into discrete packets, which travel over shared lines to their various destinations. The transmitter and receiver do not form a physical link in a packet-switching network. They communicate over a "virtual circuit," many of which can be maintained across a single physical link provided its bandwidth is sufficient.

Once data is on the network, it is sent to its destination by whatever route is fastest at that moment; this means higher data rates than those afforded by circuit-switching protocols. All of this routing, which is handled by the network protocol, is transparent to both devices. Another advantage of this type of protocol is speed transformation; the transmitter and receiver do not have to be running at the same speed to communicate.

X.25 (CCITT) - This protocol sets procedures for gaining access to a packet-switched network. It defines characteristics for the first three network layers, and is almost identical to HDLC at Layer 2. At Layer 3, it provides a virtual circuit service between devices connected to the network. X.25 permits up to 4096 such virtual circuits to be multiplexed on a single access link. It is a local rather than an end-to-end protocol. This means that the network can wrap X.25 packets in some other, more complex protocol, send them over the line, and have them unwrapped at the other end. This standard is most effective in multi-station networks that demand real-time monitoring of devices and rely on the integrity of network data.

## THE MASTERSHIP PROBLEM AND MODERN COMMUNICATIONS NETWORKS

As discussed in the first part of this section, the use of a common transmission system or data highway requires the establishment of mastership or the determination as to which unit has control of the transmission lines at any one time in terms of assigning the right to transmit messages. One obvious solution is to assign a permanent master such as the control computer in a relatively small data network (Figure 9-4). However, this imposes a rigid discipline on the system and may not allow sufficient system flexibility. Therefore a multiple-mastership system needs to be worked out for the larger systems. Two basic forms are currently popular - they are: contention and token passing.

*Contention.* In this method a link layer needing to transmit listens first to hear if any other device is transmitting. If the transmission line is busy, the device waits; if the line is not busy, the device transmits. Because of signal-propagation delays on the transmission line, two or more devices can start transmitting simultaneously or nearly simultaneously. If they do, the data on the transmission line will "collide." The protocol then is for each device to detect the collision and stop transmitting for a random amount of time, so the devices' messages do not collide again when they retry. If a collision does recur, each device refrains from transmitting for a random time twice as long as before. This method is called Carrier Sense Multiple Access with Collision Detection, or CSMA/CD. It forms the basis for the IEEE 802.3 Standard. While once considered for only office and laboratory communication schemes, CSMA/CD systems have proven themselves in the plant environment [1].

*Token passing.* In a network of devices there can be a line-access protocol that lets only one device at a time hold a "token," or access rights. When that device is through using the transmission line, it passes the token to another device via a special data unit. The token can be passed around from device to device, giving each access rights to the transmission line in turn. It forms the basis for the IEEE 802.4 and 802.5 Standards.

CSMA/CD is very simple to implement. However, access to the line is statistical rather than deterministic, so that it is possible (but highly unlikely) that a device's transmission could repeatedly collide with others and never be sent.

Token passing is more complex. For example, protocols must be established for how a new device just added to the network will get the token, what happens if the device then holding the token loses power, what happens if two devices pick up a token, and so on. These are not insurmountable problems, but they do make the token line-access method more involved.

Besides the data-unit structure and the line-access method, another consideration for the link layer (Layer 2) is the type of service it will give the network layer (Layer 3). The simplest service is called a datagram. Here a source can send one data unit and no more to a destination. The transmitting link layer takes no further responsibility for ensuring that the data have been transmitted correctly or for retransmitting the data if there were errors. With datagram service, the higher-layer protocols, typically the transport layer (Layer 4), must make sure the data are getting through correctly. In other situations, very complete services must be performed at the link level.

Connection service ensures that data are being correctly transmitted at the link level. This service involves numbering the frames to make sure they are received in proper sequence and that duplicate frames are not received. To do this, any particular source-destination pair must exchange information about their connections, such as the synchronizing of source and destination frame counters and the acknowledging of received data. The control field is used for this purpose, and it also indicates if a datagram or connection service is used.

Former long-distance networks relied exclusively on connection link-level service, and much communications software uses that service. The newer networks rely on datagrams only.

Local networks can be configured in several ways, with the basic configurations being buses, rings and stars. In a star network (Figures 9-1 and 9-2), the central hub is responsible for switching messages between the communicating points at the periphery, and though this has been a common topology in time-shared computer applications, it does not fulfill the requirement that failure of a single node should not affect the rest of the system.

The bus configuration (Figures 9-3 and 9-4) can be used for both token passing and collision sensing. The ring topology (Figure 9-5) can be used for token-passing, though not for CSMA/CD [14].

## THE DEVELOPING INTERNATIONAL STANDARDS IN INDUSTRIAL CONTROL COMMUNICATIONS SYSTEMS

## THE MAP/TOP SYSTEM

With the appearance of the IEEE 802 set of standards, the ever growing need of industry for a viable set of communications standards promises to be fulfilled. The General Motors Company in 1980 took the lead in defining MAP (the Manufacturing Automation Protocol) based on the token passing protocol of IEEE 802.4. This action by such a large and economically important company found a ready response with other companies. It quickly led to the formation of a nationwide MAP Users Group with several hundred user companies as members. This has since been expanded world wide in a World Federation (see definition below). In a welcomed spirit of cooperation, the vendor companies responded with a companion organization (the Corporation for Open Systems (COS)) pledged to work with the MAP group to bring about the needed standards.

As noted earlier the organizational structure was completed with the proposal for TOP (Technical and Office Protocol) by the Boeing Computer Services company and combined with the MAP group as the MAP/TOP Users Group.

These groups make proposals for additions and corrections to the existing standards through the technical societies (IEEE, ISA, etc.) and the national and international standards certifying bodies (ANSI, ISO, EIC, etc.) (see definitions below). A major part of their work is to propose or select suitable standards for the upper levels of the ISO/OSI model to interface with the IEEE 802 standards already specified at Layers 1 and 2.

Because of the worldwide interest and massive support for this effort, work has proceeded rapidly although the large number of players sometimes slows the development of the needed consensus on the technical details of the developing standards.

Figures 9-13 and 9-14 use the ISO/OSI model structure to show the recommended protocols and equipment standards at each layer of the model as of the time of writing of this report. As noted continued development is still necessary although final agreement seems assured.

The reader is referred to Appendix IV for the definitions of the major set of acronyms used in this field and appearing in this section.

The OSI Reference Model divides communication functionality into seven layers. The MAP 3.0 specification (issued in September 1987) [22] is a suite of ISO standard protocols that are most appropriate for manufacturing automation. Thus MAP and TOP support an open, multivendor environment within the arena of enterprise automation and integration.

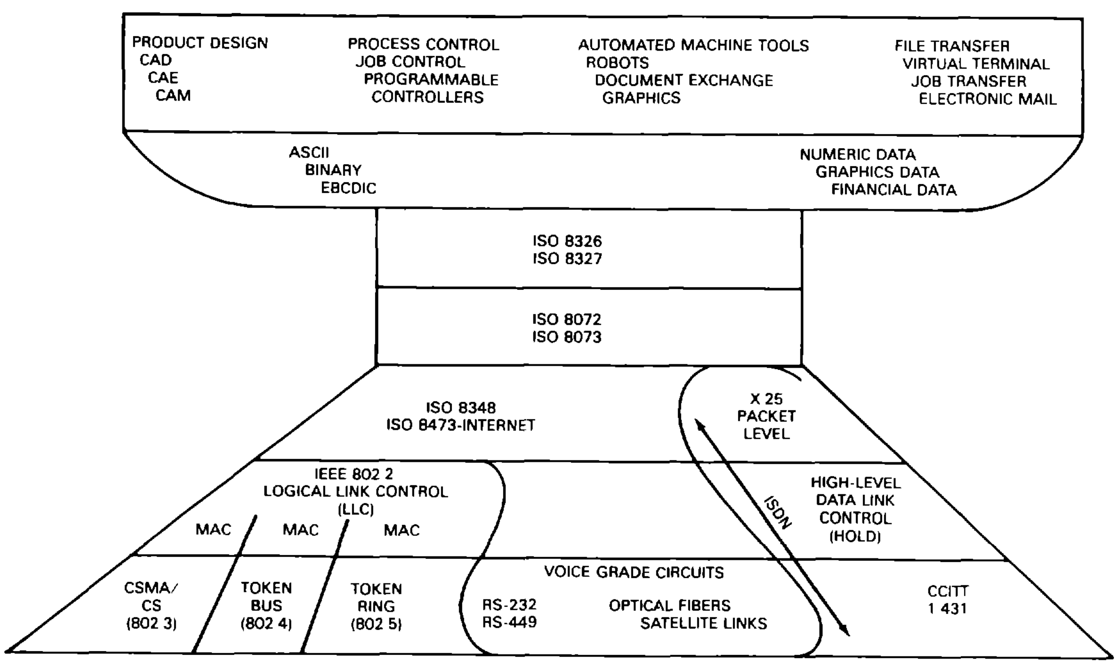



*Figure 9-13 Present-day suite of standards for application at the several layers of the ISO/OSI model (compare to Figure 9-7) [51].*

| LAYER | TOP VERSION 1 0 PROTOCOLS | MAP VERSION 3 0 PROTOCOLS |
|---|---|---|
| 7 | ISO FTAM (ISO 8571/1 4) FILE TRANSFER<br>X 400 ELECTRONIC MAIL | FILE TRANSFER ACCESS AND MANAGEMENT (FTAM) (ISO 8571/1-4)<br>MANUFACTURING MESSAGE SERVICE (MMS) (ISO 9506)<br>ASOCIATION CONTROL SERVICE ELEMENT (ACSE) (ISO 8650/2-8649/2) |
| 6 | ISO PRESENTATION (ISO 8822/8823) CONNECTION ORIENTED PRESENTATION | |
| 5 | ISO SESSION (ISO 8327/8326) BASIC CONNECTION-ORIENTED SERVICE | |
| 4 | ISO TRANSPORT (ISO 8073/8072) CLASS 4 | |
| 3 | ISO INTERNET (ISO 8473/8348) CONNECTIONLESS MODE NETWORK<br>END SYSTEM/INTERMEDIATE SYSTEM PROTOCOL (ES-IE) | |
| 2 | ISO LOGICAL LINK CONTROL (ISO 8802/2) (IEEE 802 2)<br>LOGICAL LINK CONTROL CLASS 1, CLASS 3 (LLC)<br>MEDIA ACCESS CONTROL (MAC) | |
| 1 | ISO CSMA/CD (ISO 8802/3)<br>(IEEE 802 3) CSMA/CD | ISO TOKEN-PASSING BUS (ISO 8802/4)<br>(IEEE 802 4) TOKEN-PASSING-BUS |

*Figure 9-14 Top and Map network architectures.*

## MAP IN THE PROCESS INDUSTRIES [27]

Until recently, the process and process control industries had not recognized the need for, or had input into, the MAP/TOP specification to the same extent as the discrete parts industries. However, as competition from off-shore intensifies, the press for true integration of continuous and batch processes will accelerate. This trend will limit the viability of the current generation of single-vendor Distributed Control Systems (DCS). An equally important trend is the growing recognition of the need for a Multivendor Field Bus to connect sensors and actuators to DCS controllers and SCADA systems. Work on the Field Bus is underway in ISA SP 50 and IEC SC65A-WG6.

The MAP in the Process Industries white paper, developed by the MAP in the Process Industries Initiative (MPII) of the U.S. MAP/TOP Users Group with support from ISA, addresses many of the issues listed above, as well as new issues, that are important to the process industries. Process related issues cited by the white paper include:

1. Environmental concerns, including Intrinsic Safety (IS) and Electro-Magnetic Interference (EMI), which are addressed by Fiber Optics.

2. A MAP Compatible Field Bus for connecting sensors and valves to controllers and consoles.

3. Real-time Performance, i.e., Transactions, including user program functions, completed in a "few" milliseconds (msec).

4. Reliability and redundancy of networks and media.

5. Availability, i.e., network component MTBF of many years.

6. Security, i.e., preventing unauthorized access to and disclosure/change of sensitive information.

7. Network support and management.

8. Support for multivendor DCS using a common process control language.

What started out as the "MAP Process Industries Initiative" is now a legitimate Special Interest Group of the MAP Users' Group. The European MAP/TOP Users Group (EMUG) is interested in many of the same issues. They will play a leading role in the process control and fiber optics arenas.

## STRUCTURE OF MAP AND THE CELL ARCHITECTURE

The MAP Cell architecture adds a 5 Megabit per second Carrier Band (CB) physical signaling option to MAP. CB is applicable to small networks, such as Cells, which are limited to roughly 500 meters and 20 nodes. This is defined in the IEEE 802.4 Phase Coherent CB standard. A very high speed Fiber Optic standard is also being developed in the IEEE 802.4G committee. This proposed standard is applicable both to complete plants and to smaller cells and in typical process environments. Thus there is strong user interest in its inclusion in MAP.

The Cell architecture also allows use of the Confirmed Data Link services, originally standardized by ISA-S72.01 1985 and IEC 955:PROWAY, Send Data with Acknowledge (SDA) and Request Data with Reply (RDR), which were later combined in the IEEE 802.2 Type 3 Link Control service. The PROWAY standard makes restrictions on IEEE 802.2 and 802.4 protocols that are needed in industrial networks. The Cell architecture provides performance improvements of 300 to 500 percent or more over the Backbone architecture, as well as offering significant cost advantages.

## MINI-MAP AND PROCESS CONTROL ARCHITECTURE [104]

The reliable data link service allows the cell architecture to contain "MiniMAP", which uses only three of the seven layers of the OSI reference model. ("Full MAP", which is based entirely on seven layers, is also contained in the cell architecture.) The layers present in Mini MAP are the Physical layer, the Data Link layer, and the Application layer. MiniMAP promises to provide real-time capabilities not found in Full MAP, as well as cost savings. MiniMAP does not support all of the capabilities of Full MAP, however. Some of the Full MAP facilities not present in MiniMAP are the ability to send arbitrarily long application messages, route messages transparently to a destination node almost anywhere in the world, and use ISO application protocols other than MMS. MAP Enhanced Performance Architecture (EPA) combines MiniMAP and Full MAP in the same station to obtain both the real-time capabilities of MiniMAP and the flexibility of Full MAP.

The Instrument Society of America (ISA) Working Group SP72 is currently completing a standard known as the Process Communication Architecture (PCA). A working draft of this standard is referenced by MAP 3.0 as the definition of the MiniMAP part of EPA.

Figure 9-15 (copied from the latest draft of the PCA standard) shows the relationship between the protocol layers of both a pure PCA node as well as an OSI/PCA node which is a MAP EPA node (containing both MiniMap and Full MAP). Table 9-I lists the functions of each of the seven OSI layers found in Full Map and also explains why the layers not found in PCA are not needed, either because the function is not needed, or because the function is better done in a different layer.

## COMPARING PERFORMANCE OF FULL MAP AND PCA

Table 9-II compares the performance of Full MAP and the Process Control Architectures. All times are given in msec (milliseconds) and assume no access to the Name/Address Directory is required.

The 30 msec Status Read on a PCA Cell closely approaches the goal for Real-time Performance (Transactions completed in a "few", perhaps 20, msec, including User program functions) stated in

**TABLE 9-I**

**TASK RELATIONSHIPS OF FULL MAP AND MINIMAP**

| Full MAP | Mini MAP |
|---|---|
| **Physical Layer** | |
| Ph1) Transparent Transmission of bit streams. | Ph1) Same as Full MAP. |
| **Data Link Layer** | |
| L1) Message delimiting. | L1) Same as Full MAP. |
| L2) Identification of endpoints. | L2) Same as Full MAP. |
| L3) Error detection. | L3) Same as Full MAP. |
| L4) Detection and recovery from lost or duplicated information not performed in the Data Link Layer. | L4) Detection and recovery from lost or duplicated information is performed by the Type 3 Data Link service. |
| L5) Flow control is not performed in the Data Link layer. | L5) Flow control is performed by the Type 3 Data Link service with assistance by the user. |
| **Network Layer** | |
| N1) Routing frames between nodes on different subnetworks. | N1) Routing between subnets not directly performed by PCA. Network Adapter provides access to OSI including OSI Network Layer routing. |
| N2) Addressing to a "real" DL address. | N2) DL address is directly carried in all PCA frames. |
| N3) Reporting routing statistics. | N3) Routing statistics are not significant on one Subnet. |
| **Transport Layer-Class 4** | |
| T1) Maintaining a Connection-Oriented environment. | T1) A-Associations are maintained by use of Confirmed Data Transfers and management of MMS Invoke IDs. |
| T2) Coordination (negotiation) of Transport resources and capabilities. | T2) Transport specific actions are not required. |
| | T2-1) The ALP can prevent excessive usage of Data Link resources by use of Management services. Also the MMS ALP is inherently Request/Response oriented and can provide a measure of flow control using the DLP indication of a lack a resources to the ALP. Negotiation of DATA Link capabilities is not required since the Conformance Profiles define a specific set of capabilities shared by all conforming nodes. |

*continued*

*Table 9-1 continued*

| | |
|---|---|
| T3) Guaranteeing reliable insequence non-duplicated data delivery. | T3) On a single subnetwork, reliable non-duplicated delivery is guaranteed by the DLP. In addition, when delivery is not possible the User is notified. In-sequence delivery is not required for Request/Response ALPs which allows limiting the data in a request or response. |
| | T3-1) Over a network composed of multiple subnetworks, reliable non-duplicated delivery is guaranteed by the ALP and by the Network Adapter. |
| T4) Flow control. | T4) See T2-1 |
| T5) Multiplexing AP-Associations (P-,S-Connections) over one T-Connection. | T5) Multiple Users and AEs are supported over individual LSAPs. |
| T6) Notification of loss of underlying N-service (& possibly of A-Association). | T6) Loss of communication with an addressed peer node is detected by the DLP confirmation. |
| | T6-1) When using the Token Bus DLP and the Alive List, the status of all Token Holding nodes is also available from Station Mgmt. |
| **Session Layer** | |
| S1) Coordination (negotiation) of Session resources and capabilities. | S1) Session specific actions are not required. |
| S2) Full duplex data transfers. | S2) Full duplex data transfers are provided. This is adequate for the Request/Response ALP. |
| S3) Graceful close of A-Associations (P-Connections) without loss of data. | S3) Graceful close is not necessary since there is no connection and segmentation is not used. A-Abort is provided. |
| S4) Allow unlimited User data. | S4) See T2-1, T3-1 |
| **Presentation Layer** | |
| P1) Coordination (negotiation) of presentation resources and capabilities. | P1) Presentation specific actions are not required. |
| P2) Conveying A-Protocol (P-Context) identification. | P2) The A-Protocol (Companion Standard) is identified in the ALP Initiate.Request PDU. |
| **Application Layer** | |
| A1) Identification of communication partners and setup of their association using ACSE. | A1) ACSE no present, identification is determined by the Link Service access point. The application state machine keeps track of associations. |
| A2) Communication of semantics specific to the task to be performed. | A2) Same specific application protocol as in Full MAP. |

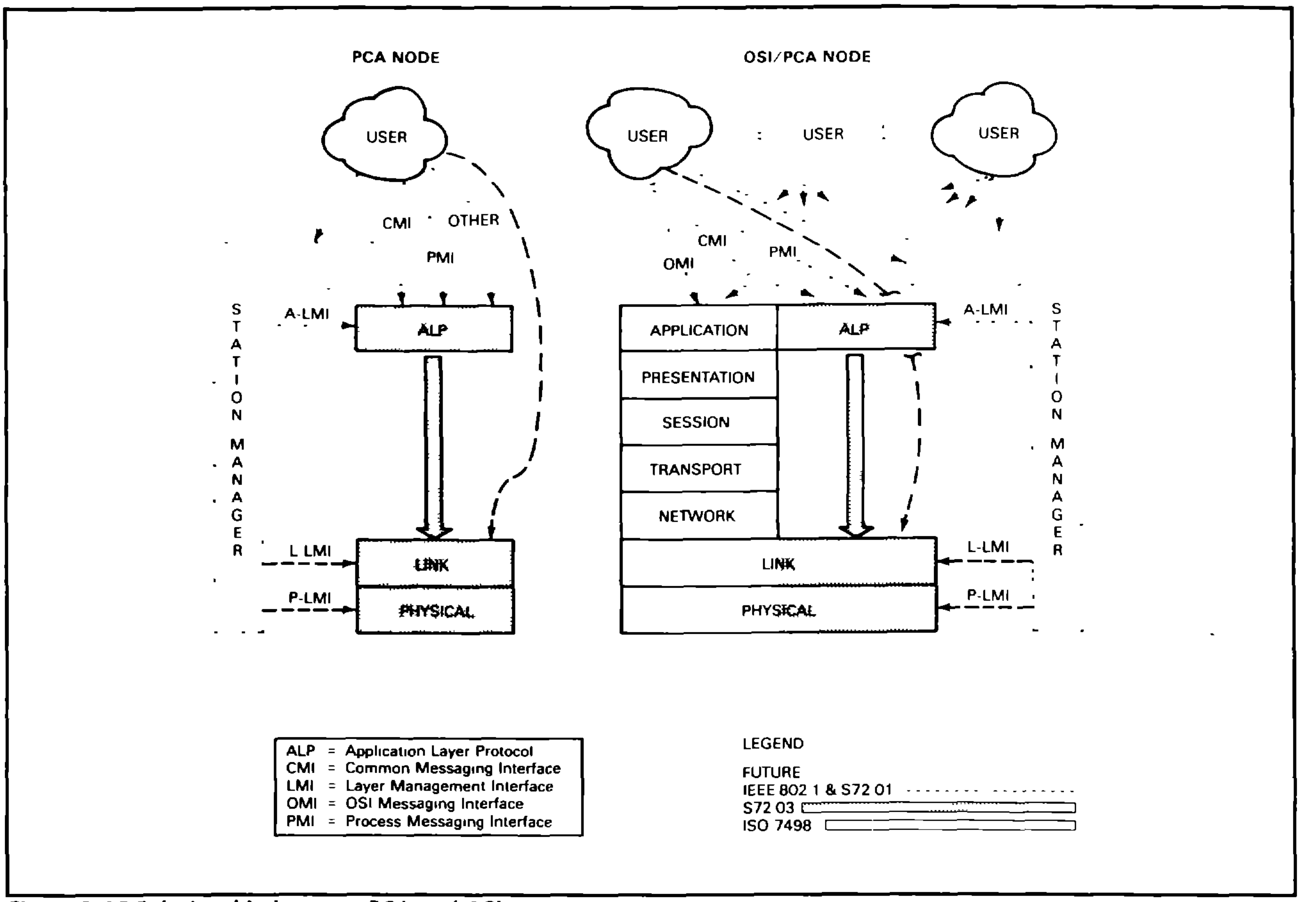



*Figure 9-15 Relationship between PCA and OSI.*

"The MAP in the Process Industries," white paper. Even more encouraging is the 65 msec activation of Alarms over PCA, which yields a 5X improvement over Full MAP.

From this analysis we conclude that the Process Control Architecture's real-time performance yields a 3X to 5X improvement over Full MAP. This performance is achieved without making the assumptions about Cell Controller capabilities or Cell size that are needed to achieve maximum performance over Full MAP.

## ACHIEVING LOWER COST

The process control industry has cost requirements that are more severe than those of much of the automotive industry, where the cost of a $5,000 Full MAP communication board may be allocated to a $30,000 robot. In the process control industry this same board might be needed in a $1,500 single-loop controller or Programmable Logic Controller.

The PCA is one answer to these cost requirements. It is able to communicate with any OSI/PCA node or other PCA nodes. Thus Real-Time PCA Performance is achieved. Very simple PCA nodes can be constructed using the RDR service. These nodes need not pass the token. This improves performance by decreasing token latency. It also allows use of much simpler token bus chips, which will significantly reduce cost. PCA/RDR nodes are appropriate for sensors, bar code readers and other simple devices.

Because four protocols are eliminated and management is simplified in PCA nodes, these nodes will always be less expensive than both Full MAP and OSI/PCA nodes. OSI/PCA nodes will be the most expensive, since they must support a dual communications architecture. We can expect PCA/SDA connect cost to show a 2X to 3X improvement over Full MAP connect cost in 1988. PCA/RDR nodes will be significantly lower cost than PCA/SDA nodes when reduced Token Bus chips are available.

**TABLE 9-II**

**RESPONSE TIMING CAPABILITIES OF FULLMAP AND PROCESS CONTROL ARCHITECTURE**

| BACKBONE to CELL using | Full MAP | PCA |
|---|---|---|
| Status Read/ Temporary Associations | 800 | n/a |
| Status Read/ Permanent Associations | 160 | n/a |
| Alarm Activate/ Temporary Associations | 800 | n/a |
| File Transfer | ? | n/a |
| **CELL to CELL using** | **Full MAP** | **PCA** |
| Status Read/ Temporary Associations | 330 | 65 |
| Status Read/ Permanent Associations | 85 | 30 |
| Alarm Activate/ Temporary Associations | 330 | 65 |

## MMS AND MMS COMPANION STANDARDS BACKGROUND

MMS (*M*anufacturing *M*essage *S*pecification) is an Application Layer protocol intended to standardize communication services required to control and monitor factory and plant floor devices in a vendor-independent fashion. Being in the Application Layer of the ISO Open System Interconnection (OSI) reference model, MMS specifies the abstract semantics for factory communication, but does not specify the mechanism for moving information from one device to another. The other standard protocols specified by full MAP or MiniMAP to be used in conjunction with MMS handle the actual movement of the information.

The MMS family of standards is composed of two primary parts, base documents and companion documents. It was recognized that all plant floor devices provide a certain set of common services. Hence, a core commonality could be maintained between plant floor devices. On the other hand, most devices provide some functionality specific to their device class. Base documents are generic, in the sense that they provide a large number of services for a wide variety of devices. Services are described in a generic sense, with further specifications for devices having certain classes of functionality provided by companion standards.

One main reason why MMS will affect the LAN marketplace for factory floor LANs is that the services offered to the applications programmers are greatly enhanced from those provided in most proprietary LANs today. MMS services are loosely categorized into clauses for ease of description and understanding. These clauses are MMS context management, VMD support, domain management, program invocation management, variable access, semaphore management, operator communication, event management, journal management, and file management. It is possible for a device to support some of the services in a clause without supporting all capabilities.

During the development of MMS, it became obvious that the development group lacked the necessary expertise in each of the separate application areas to specify all that is necessary to standardize communications in those areas. Thus, the group created the concept of "MMS companion standards" as good as possible for communication to "generic" factory-plant floor devices. The concept of the MMS companion standard is that standards bodies, expert in their own fields, are encouraged to write standards which specify how MMS is used in their field. Currently, MMS companion standards are being written by various standards bodies (one of which is the ISA for process control applications). An MMS companion standard gives additional requirements for a particular class of device or application. The effect of a companion standard is to extend the scope of standardization beyond the "generic" device, to standardized aspects of devices within particular device or application classes.

Each companion standard specifies, for a particular type of plant floor device or application, the set of services and protocols that must be supported, the options and selections required, and, in some cases, the format of fields for a particular industry. For example, several levels of MMS support for process control are being developed, and the format of the process control status fields will be defined in the ISA Process Messaging Service standard, which is the MMS companion standard for process control.

Companion standards may also prescribe the existence of "predefined" (preexistent) objects, which exist in a device without explicit creation of these objects using MMS services. As an example of a predefined object, the process control draft companion standard specifies predefined variables representing the attributes of a particular control loop, such as the process variable, the set point, the control output, and the various tuning parameters.

While companion standards are developed for each of the plant floor device types by groups of experts independently, commonality is ensured via the use of a common base document and by the efforts of the MMS development group to monitor and coordinate the development of companion standards. Hence, a degree of interoperability between devices of different classes is provided by MMS.

## THE ISA PROCESS MESSAGING SERVICE

As mentioned previously, the ISA S72.02 Process Messaging Service (PMS) standard (being developed by the ISA SP72 Working Group) is the process control companion standard to MMS. The standard is too large to completely describe in this section, but an overview along with some samples of specific detail is worthwhile. Figure 9-16 shows the relationship between the PMS and the other standards required to complete the communication requirements.

The PMS standard begins with the usual scope, definitions, references, and such. Then an architectural model is presented to specify the intended kinds of applications and to indicate how the communications in those applications are structured. Communications using the Process Messaging Service takes place between entities known as "Communications Agents". Communications agents are essentially logical in nature.

Typical functions performed by Communications Agents are the provision of a means to direct communications to a single process control server device (such as a loop controller), the representation and the making available of all process control objects, by name, on the entire process control system, and the provision of a method to uniquely control the sequencing and management of process batch manufacturing operations. Not all process control systems will contain agents

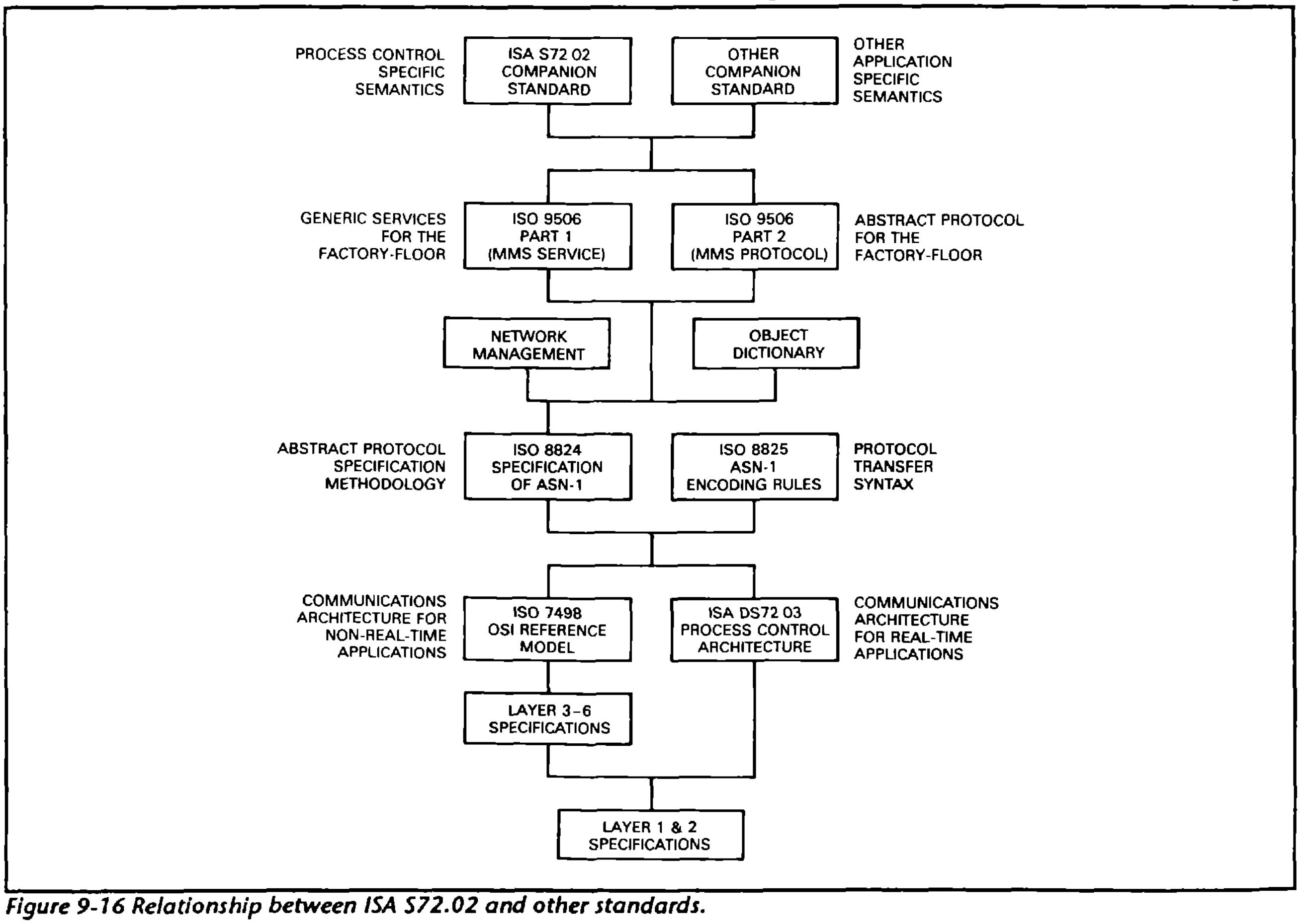
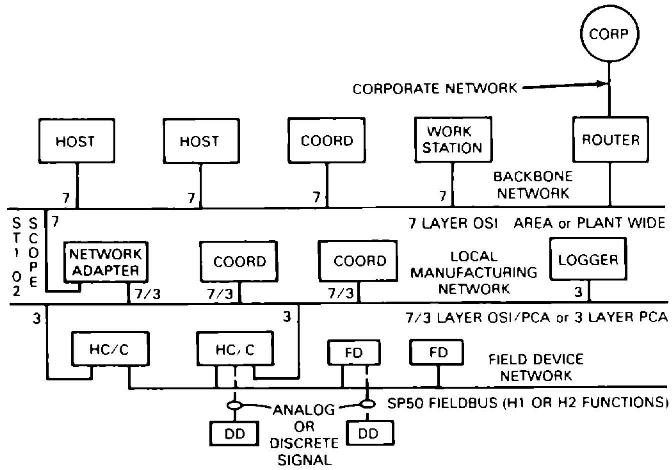



*Figure 9-16 Relationship between ISA S72.02 and other standards.*




**EXAMPLES OF DEVICES**

COORDINATOR
- Operator Console
- Supervisory Console
- Cell Controller

FIELD DEVICE (FD)
- Smart Transmitter
- Analyzer (e.g. GC)
- Scanner
- Smart Actuator
- Field Multiplexer
- Field Data Concentrator
- Field Single Loop Controller
- Field PL Controller

WORKSTATION
- Process Window

DUMB DEVICE (DD)
- Thermocouple
- Valve
- Pressure Sensor
- Tachometer

HIERARCHICAL CONCENTRATOR/CONTROLLER (HC/C)
- Multiplexer
- Data Concentrator
- Single Loop Controller
- Multi Loop Controller
- Batch Controller
- PL Controller

LOGGER
- Data Logger
- Historian

HOST
- File Server
- Plant Data Base Manager (Process Std Recipes)
- Area Controller
- Optimizer
- Quality Control
- Batch Scheduler
- Material Requirements Planning

NETWORK ADAPTER
- Transparent communication at Layers 3 or 7

*Figure 9-17 Example set of interconnected process plant equipment.*

to perform all of the listed functions, and agents may also exist to perform other functions. Each individual Communications Agent performs one specific function. Physical implementation of each agent, and the relative positioning of each agent within the process control system hardware architecture, are issues left to the implementator.

Figure 9-17 (out of the PCA document) shows an example of a set of process plant devices interconnected by communications links. The exact organization of the devices and the communications links as shown in the figure is only an example of an interconnection plan.

A set of process control specific communication functions is described in the PMS standard. Some of the items included in this set are initiating and concluding communications, reading and writing the attributes of process control objects (such as loop control structures), defining events, specification of communications to be performed on an event, passing alarm information, communicating with an operator, hardware status and control, controlling a program or recipe, sending unsolicited information, identifying a device, setting up and performing the logging of events, reading the log of event occurrences, and downloading or uploading of information. For each process control specific function, the required MMS service is specified and details for the use of that service are given.

Another chapter of the PMS standard defines standard attribute names for process control objects. A sample of such names are the process control object type (which may be input, output, calculation, control server, analog, discrete, accumulation, counter, or timer), the process variable, the quality of the process variable information (e.g., ok, out of range, manually entered, hardware error, etc.), the set point, the output of the process control object, the mode of the object (manual, auto, cascade, remote cascade, or remote manual), the process variable high and low trip points, the rate of change trip points, the alarm status of a process control object, the controller gain, and the controller rate time.

There is also a set of names for specific events such as the reaching of the various trip points or the occurrence of various kinds of hardware failures. In addition to names, the PMS standard defines a set of extra fields which are attached to the generic MMS messages when MMS is used in a process control environment. These fields provide process control specific information on such things as the status of specific devices and the nature of events and alarms.

A further important area covered by the PMS standard is the subject of conformance to the standard. The base MMS standard is very weak on conformance. The problem is that the MMS standard is so all-encompassing, that it is unlikely that any device will support the entire standard. MMS does provide a means to specify exactly what subset of services is supported by a device, and what level of support is provided for types of data, but very little is said about what combination of services should be supported to perform a specific job. The PMS standard, like the other companion standards, defines a set of conformance classes based on the application area of the standard. For each class, PMS specifies the intended functions to be performed and the set of MMS services which must be supported. Classes are based on types of process equipment, types of application within the process control and monitoring area, and on levels of performance.

Finally, the PMS standard provides much needed examples. The base MMS standard does not have examples, because it was felt that the best examples are those based on actual applications, and the base standard is supposed to be generic.

## MAP OR TOP? [103]

By providing a standard communications language and a shared medium, Manufacturing Automation Protocol (MAP) networks allow dissimilar computers and devices in factories to communicate with each other. With computers and devices able to communicate, manufacturing efficiency and flexibility is increased, helping companies reap higher returns from their investments in CIM systems.

MAP specifies a 10 megabits-per-second (Mbps) token-passing bus network operating on broadband cable. Its origins date back to 1980, when General Motors (GM) began investigating alternatives after determining that its point-to-point wiring system was expensive, inflexible and inefficient relative to performance. GM determined that linking all devices with a single, contiguous cable and allowing them to communicate with a common set of protocols was the best solution.

MAP on broadband satisfies a manufacturers' most important factory communications needs; multivendor connectivity, predictable network access and response time, wide area coverage and multiple data channels.

Why MAP? The answer lies in the multivendor nature of most factories. Unlike proprietary networks, which interconnect devices from a single manufacturer, MAP's standards-based architecture allows a diversity of computers and production devices to communicate through a common set of protocols over a single cable.

With the worldwide, standards-based protocol system provided by MAP, and TOP (10 megabits-per-second CSMA/CD system operating on either baseband or broadband cable) manufacturers are free to select the best computer or tool for each production task, and not compromise the choice by having to accept whatever will run on the proprietary system.

Why not use TOP as a factory floor network? Except for task-dependent, time-critical applications found in production areas where CSMA/CD is not appropriate, TOP provides an acceptable network solution. In those cases where a deterministic solution is required MAP is recommended.

MAP's token-passing method provides predictable network access and response times because the token is passed in turn to all workstations. Because only the station with the token can send data, the possibility of collisions is eliminated.

Predictable access and assured response times help satisfy the wide area coverage requirement of factory networks. Many plants are hundreds of thousands, and sometimes millions, of square feet, and have hundreds of networked workstations. The performance of such a large system would be severely limited without assured access and response times.

Why broadband? With multiple channels, broadband is suitable for use as an enterprise-wide cable because it can support multiple types of transmissions, such as data, voice, video and utility. A typical configuration is to run MAP in factory areas over several of the broadband channels, Ethernet and token ring in offices and laboratories, and video and utilities throughout the company.

ETHERNET may also be found in the factory either as an existing system or in application areas not requiring the time-critical, predictability of MAP. These ETHERNET plus TOP segments can be linked to the MAP network via bridges.

## MODULAR STRUCTURE OF THE COMMUNICATIONS INTERFACE (HARDWARE AND SOFTWARE)

### GENERAL

This section describes the communications requirements of each level of the CIM Reference Model in more detail; see Figures 9-18 to 9-21. The purpose here is to define the architecture, module boundaries, connections, interface points, communication needs, and areas for future standards.

The small arrows denote connections with tight coupling and free access between modules. The large arrows represent a yet-to-be-determined structure that imposes a strict, standardized paradigm for communications. The scheme should be powerful, flexible, and easily configurable. The relatively new discipline of object-oriented programming may provide some insight into a workable solution, but solutions are not the purpose here. The goal is to accommodate interchangeable applications modules in a standardized way.

### DESCRIPTION OF MODULES

**Translators** (Levels 1, 2, 3, and 4)

Translators (rope-bordered boxes) are functions intended to indicate points for the focus of standardization. They are interfacing functions that accept requests or data from applications and hand them to device-dependent drivers and perhaps work in the other direction as well. The function is most likely to be handled by the executive and could be as simple as a shared data base. Another solution could involve named variables and commands (e.g., read, write, initialize, and I/O control codes) handled by a data base manager. It is not the purpose here to prescribe the solution; only the intended function. In any event, the idea is to insure that different device drivers do not adversely influence the applications code and vice versa.

**Data Communications** (Levels 1, 2, 3, and 4)

To move from one level to another in a hierarchy a service is needed that provides the paths for the communications. The committee has agreed that direct communications should not be prohibited. In the interest of simplicity and efficiency these functions should be provided by the same service. In this model the following is proposed: The communications paths could be configured hierarchically as discussed earlier. In this case the direct-communications messages might follow the same paths through the network passing through appropriate nodes but only being read by the destination node. Earlier nodes would only provide the routing functions.

**Human Operator** (Level 1)

The human operator is the person or persons responsible for the operation of the manufacturing process; the user of Level 1 (Figure 9-18) of the process control system.

**Process** (Level 1)

The process is the focus of the entire system. It receives energy and material from the world, control from the operator and the control system, and generates a product.

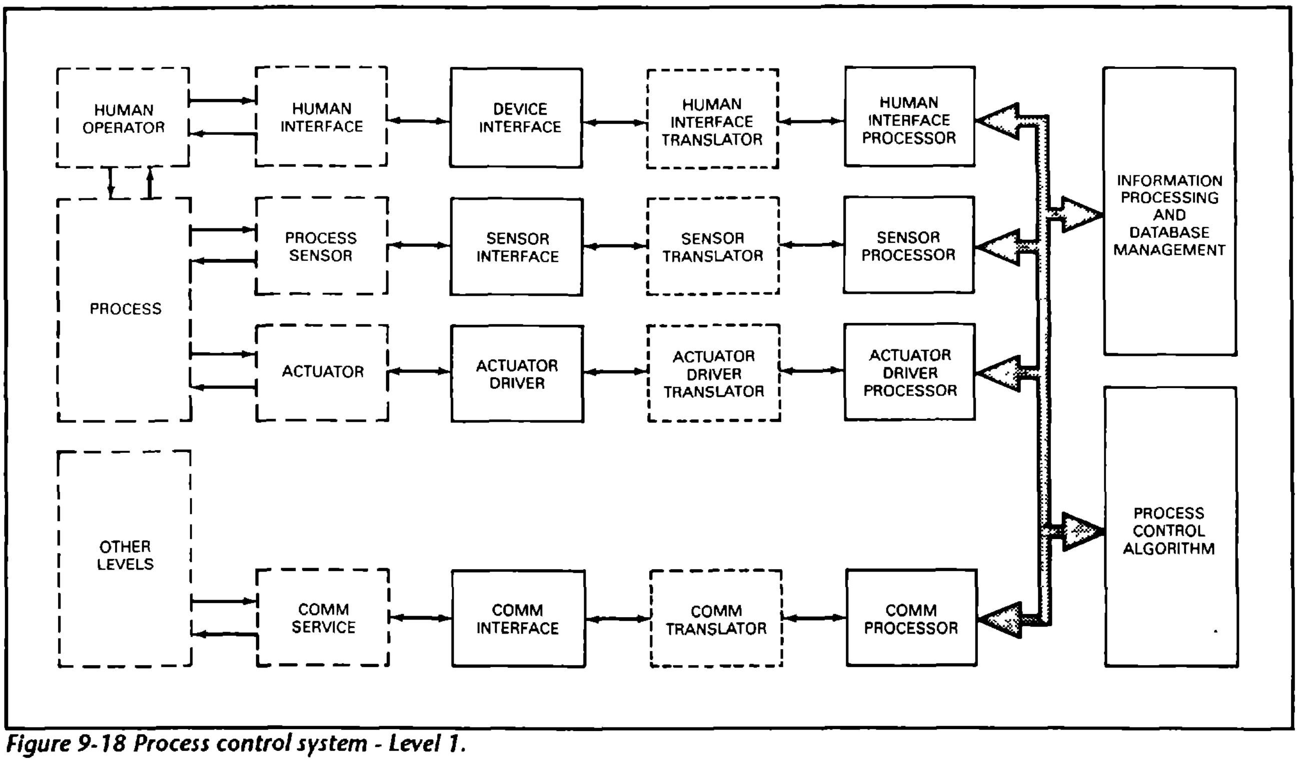



*Figure 9-18 Process control system - Level 1.*

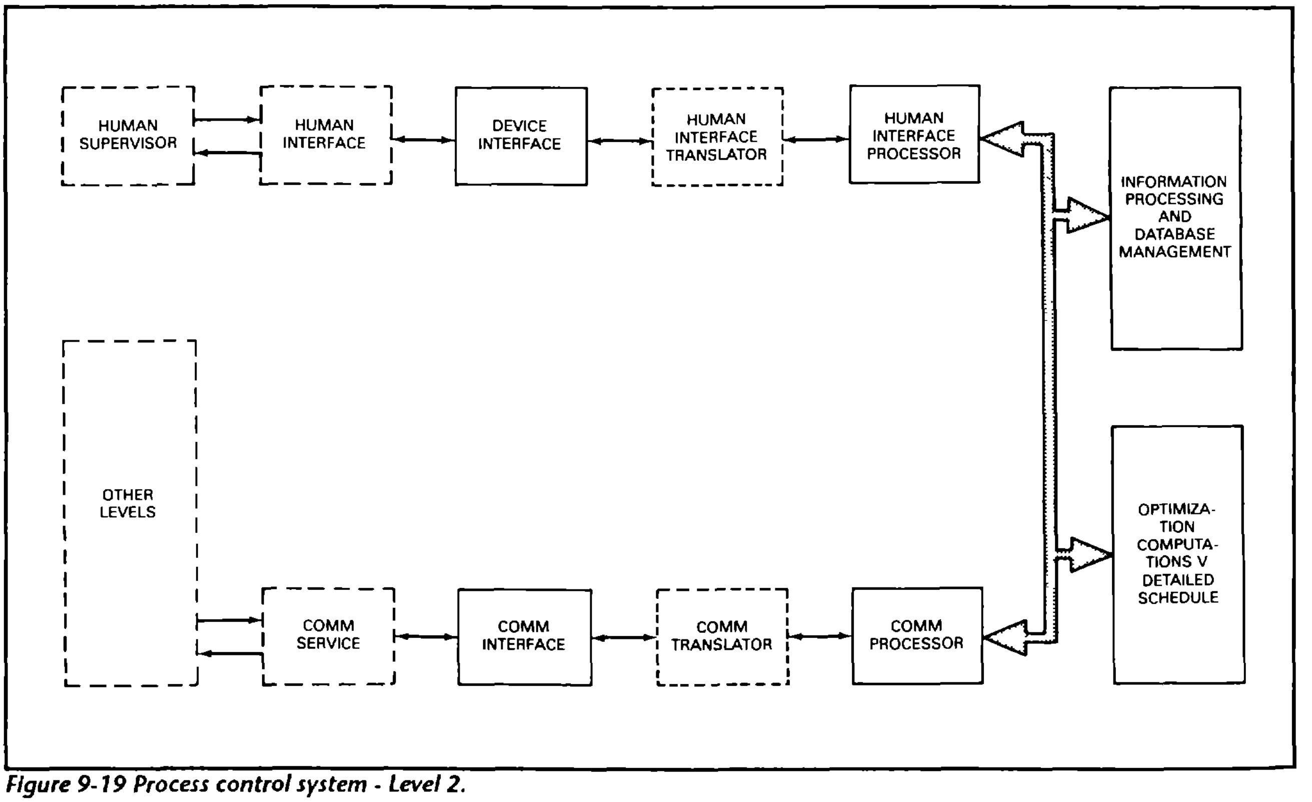



*Figure 9-19 Process control system - Level 2.*

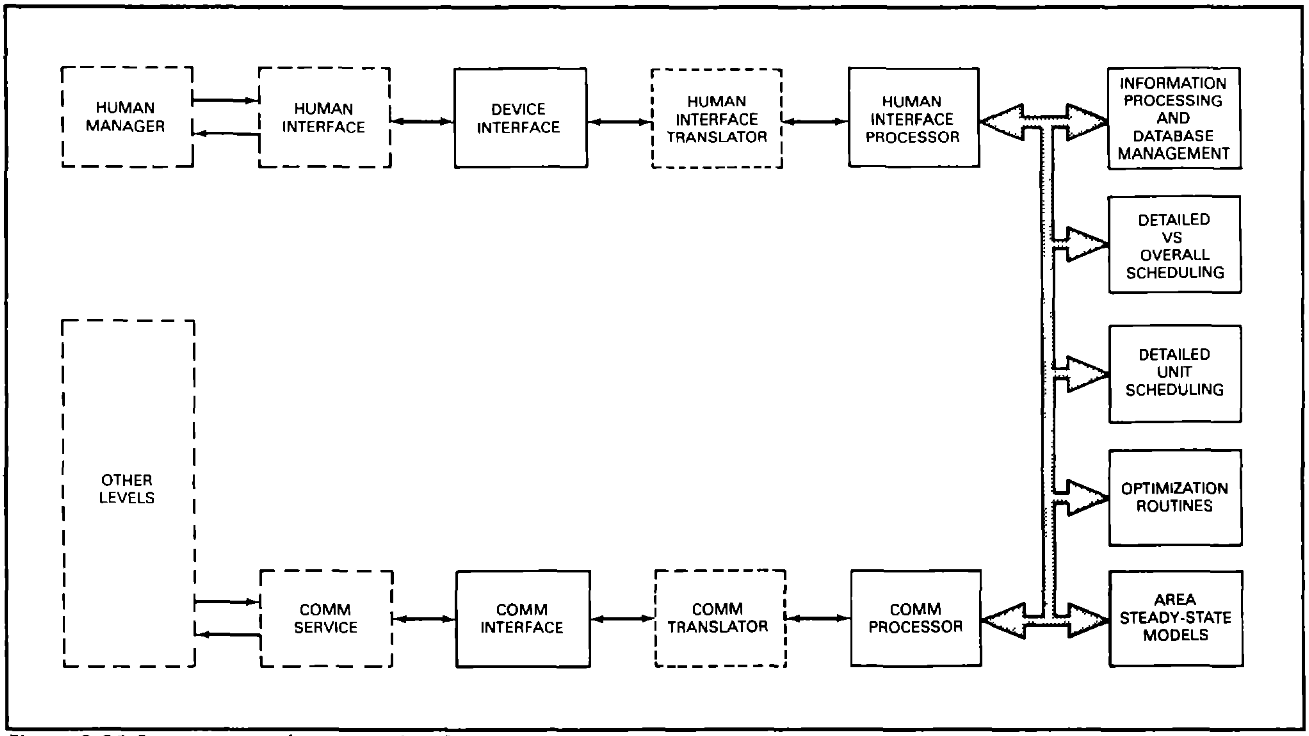



*Figure 9-20 Process control system - Level 3.*

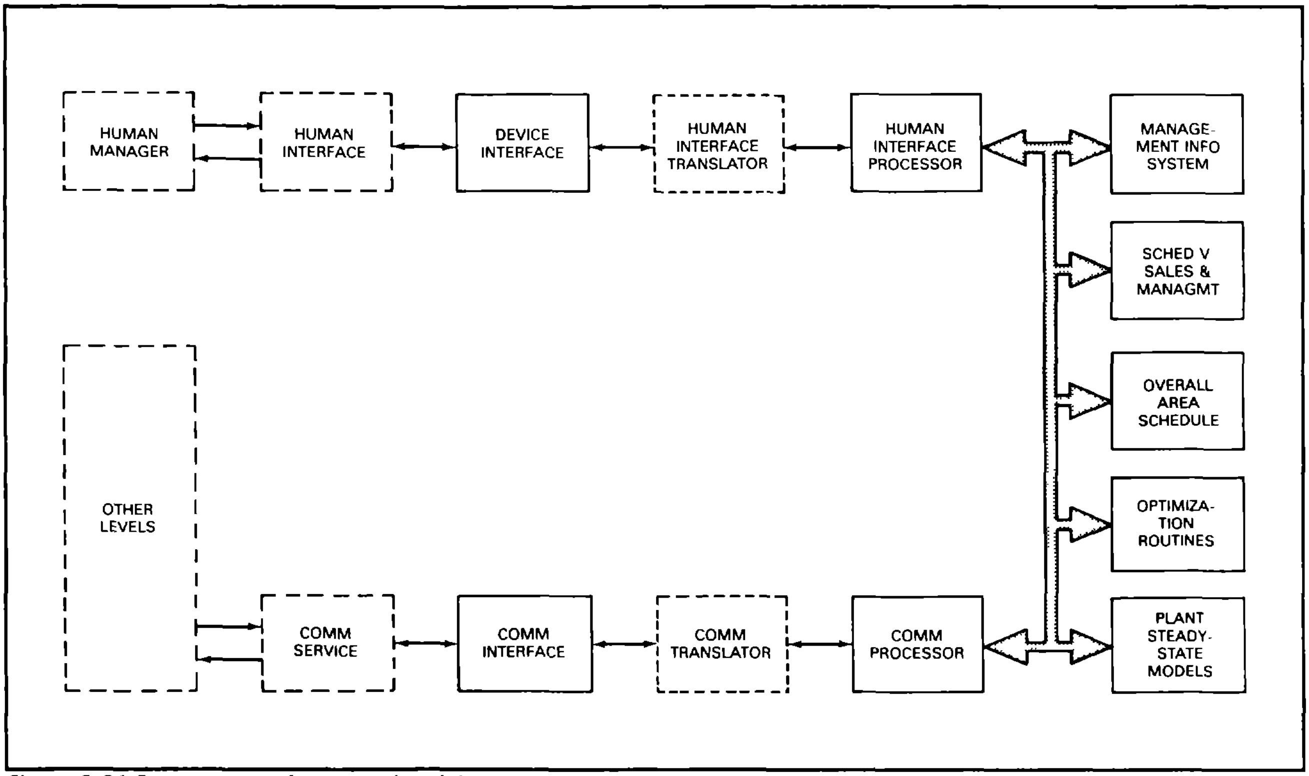



*Figure 9-21 Process control system - Level 4.*

**Other Levels** (Levels 1, 2, 3, and 4)

This box represents the conduit through which messages pass to and from other levels.

Human Interface (Levels 1, 2, 3, and 4)

The human interface is the entity that physically transfers information to and from the human operator. It communicates with the device interface.

**Device Interface** (Levels 1, 2, 3, and 4)

The device interface is dependent upon the human interface device (hardware and software) and interfaces with it idiosyncratically. At its other end it interfaces in a yet-to-be-standardized way with the human interface translator.

**Human Interface Translator** (Levels 1, 2, 3, and 4)

The human interface translator is a yet-to-be-standardized mechanism that mediates between the device interface and the human interface processor. It provides device independence to the human interface processor. See Translators, above.

**Human Interface Processor** (Levels 1, 2, 3, and 4)

The human interface processor provides the residence for the human interface applications logic. It provides the tightly coupled relationships with the process values, e.g., measurements and setpoint-entry feedback. It also communicates with the other local (this level) applications modules via the local communications service shown by the large arrows.

**Process Sensor** (Level 1)

A process sensor is a data-gathering device connected to the process. It provides information about the process through the sensor interface.

**Sensor Interface** (Level 1)

The sensor interface is dependent upon the sensor device (hardware and software) and interfaces with it idiosyncratically. At its other end it interfaces in a yet-to-be-standardized way with the sensor translator.

**Sensor Translator** (Level 1)

The sensor translator is a yet-to-be-standardized mechanism that mediates between the sensor interface and the sensor processor. It provides device independence to the sensor processor. See Translators, above.

**Sensor Processor** (Level 1)

The sensor processor provides the residence for the sensor applications logic. It provides the tightly coupled relationships with the human interface. It also communicates with the other local (this level) applications modules via the local communications service shown by the large arrows.

**Actuator** (Level 1)

A process actuator is a transducing device connected to the process. It provides physical adjustments to the process as dictated by the actuator driver.

**Actuator Driver** (Level 1)

The actuator driver is dependent upon the actuator device (hardware and software) and interfaces with it idiosyncratically. At its other end it interfaces in a yet-to-be-standardized way with the actuator driver translator.

**Actuator Driver Translator** (Level 1)

The actuator driver translator is a yet-to-be-standardized mechanism that mediates between the actuator driver and the actuator driver processor. It provides device independence to the actuator driver processor. See Translators, above.

**Actuator Driver Processor** (Level 1)

The actuator driver processor provides the residence for the actuator applications logic, e.g., direct digital control. It also communicates with the other local (this level) applications modules, primarily the process-control system, via the local communications service shown by the large arrows.

**Comm Service** (Levels 1, 2, 3, and 4)

The communications service is the entity that physically transfers information to and from the other levels of the hierarchy. It communicates with the communications interface.

**Comm Interface** (Levels 1, 2, 3, and 4)

The communications interface is dependent upon the communications service (hardware and software) and interfaces with it idiosyncratically. At its other end it interfaces in a yet-to-be-standardized way with the communications translator.

**Comm Translator** (Levels 1, 2, 3, 4)

The communications translator is a yet-to-be-standardized mechanism that mediates between the communications interface and the communications processor. It provides device independence to the communications processor. See Translators, above.

**Comm Processor** (Levels 1, 2, 3, and 4)

The communications processor provides the residence for the communications applications logic. It also communicates with the other local (this level) applications modules via the local communications service shown by the large arrows.

**Information Processing System** (Levels 1, 2, and 3)

The information processing system is the residence of all the data processing applications code (MIS) required at its level. It communicates with the other local applications modules at its level via the local communications shown by the large arrow.

**Process Control System** (Level 1)

The process control system is the residence of all the process control applications code at this level. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

**Human Supervisor** (Level 2)

The human supervisor is the person or persons responsible for the supervision of the manufacturing process -- the user of Level 2 (Figure 9-19) of the process control system.

**Optimization Computations vs. Detailed Schedule** (Level 2)

The optimization computations vs. detailed schedule module is the residence of the applications logic that optimally assigns the detailed production schedule to the production facilities under its control. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

**Human Manager** (Levels 3 and 4)

The human managers are the persons responsible for the management of the manufacturing process; the users of levels 3, and 4 (Figures 9-20 and 9-21) of the plant control system. The managers of Level 4 also have contact with the outside world, for example, sales and marketing.

**Detailed vs. Overall Scheduling** (Level 3)

The detailed vs. overall scheduling module is the residence of the applications logic that sends optimal assignments from the overall schedule to the detailed unit scheduling module connected to it. It communicates with additional applications modules at this level via the local communications service shown by the large arrows.

**Detailed Unit Scheduling** (Level 3)

The detailed unit scheduling module is the residence of the applications logic that optimally assigns the detailed schedule from the detailed vs. overall scheduling module to the units under its control. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

**Optimization Routines** (Levels 3 and 4)

The optimization routines interact with the plant steady-state models to provide high-level control of the production facilities. They communicate with the other local applications modules at their level via the local communications service shown by the large arrows.

**Plant Steady-State Models** (Levels 3 and 4)

The plant steady-state models provide the steady-state response predictions needed by the other applications modules at their level to perform their prescribed functions. They communicate directly with the optimization routines and with the other local applications modules at their level via the local communications service shown by the large arrows.

**Management Information System** (Level 4)

The management information system is the residence of all the data processing and management information system applications code required at this level. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

**Scheduling vs. Sales and Management** (Level 4)

The scheduling vs. sales and management module is the residence of the applications logic that sends optimal assignments from sales and management to the overall area scheduling module connected to it. It communicates with additional applications modules at this level via the local communications service shown by the large arrows.

**Overall Scheduling** (Level 4)

The overall scheduling module is the residence of the applications logic that optimally assigns the overall schedule from the scheduling vs. sales and management module to the units under its control. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.