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Standardizing Communications and Networks in the ICU

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Communication is one of the most important tasks of health care professionals. Data underlie every medical decision, and except for the personal observations made by and acted upon by the physician at the bedside, all data must be communicated. Oftentimes, the data are communicated through several people and by several media before getting to the medical decision-maker. Each step in this process, especially if it involves people and handwritten records, can result in delays and errors.

For example, data from a "stat" laboratory test for potassium (K+) may be phoned to an intensive care unit from the clinical laboratory. Let us say that the K+ value was 4.6 meq/dl, but that in the process of transmission and recording, the ward clerk in the ICU transposes the result as K+ = 6.4 meq/dl and passes it on to the nurse. Seeing that the K+ is elevated and perhaps life threatening, the nurse informs the physician, who then acts to reduce the supposedly high potassium level by prescribing an appropriate therapy. The consequence of such an error may be of no importance, or it could lead to a totally inappropriate or life-threatening treatment. To minimize these errors and to establish accurate data transmission, communications networks in hospitals are essential.

Communications Needs of ICUs

Intensive care units have become an integral part of most hospitals. Their concentration on the treatment of critically ill patients requires that data be readily available to medical personnel, so that quick and accurate decisions can be made in life-threatening situations. The recent development of instruments and techniques assisted by microcomputer technology has resulted in an unprecedented flow of physiological data to clinicians. It is hoped that additional data can improve the timeliness and appropriateness of medical decisions, reduce the number of oversights, and facilitate training. From studies of data communication and storage which we conducted in the ICUs at LDS Hospital, we found that, depending on the severity of the illness, between 2 and 16 kilobytes of data are acquired on each patient each day.

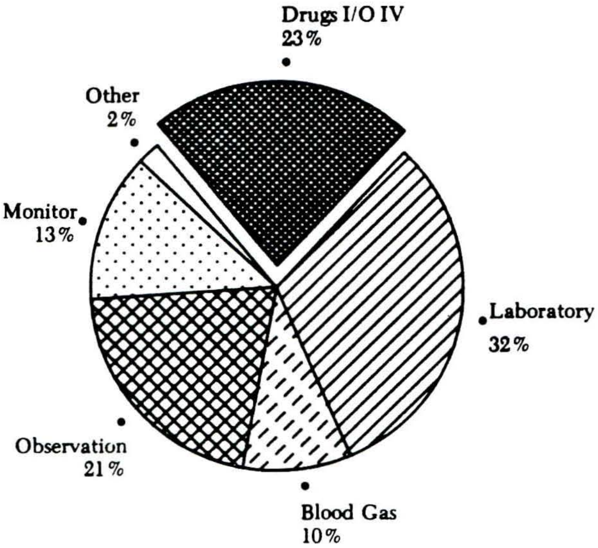

Figure 1. Pie chart of data used by physicians for decision-making in ICU teaching rounds. Based on data from Bradshaw et al. 1984.

The process of caring for a critically ill patient requires data from many sources (Bradshaw et al. 1984). We recorded the kinds of data used by physicians to make treatment decisions during ICU rounds (Figure 1). Laboratory data (with blood gases included) account for 42 percent of the data relied on by physicians in decision making. Prompt and accurate communication of laboratory data is crucial to patient care. The second most used sources of data in the ICU are the intake/output and intravenous manipulation of drugs (see Figure 1). Most of the I/O and IV data must now be collected by hand and can only be done at hourly or longer intervals.

It seems that communication of I/O and IV data would be almost trivial in these days of personal computers, standardized ASCII* data formatting, and increasing standardization of computer networks. Unfortunately, this is not true. Communication is difficult precisely because of the lack of overall standardization. For example, several investigators are now attempting to draw up standards which will allow more uniform sharing of data between laboratory and other systems (McDonald 1984; McDonald et al. 1984). Many forms of data communications networks have been used or are under development. To understand the problems associated with these networks it is important to become acquainted with some of the communications systems.

Local Area Networks

Given the proliferation of personal computers and local area networks, there should be an ideal LAN for application to the intensive care unit. Even though LAN technology is quite mature, no one has yet come up with a universally applicable local area network (Black 1983; Durr 1984; Friend et al. 1984; Simborg 1984; Simborg et al. 1983). Moreover, no single set of hardware technologies is perfect for every situation. Although we may not be able to settle on a single solution for local area networks, there is agreement on the structure of the LAN. This structure is promulgated by the International Organization for Standardization (ISO) and is known as the Open Systems Interconnection, or OSI network model (Black 1983; Durr 1984; Friend et al. 1984).

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*The 8-bit American Standard Code for Information Interchange, adopted to achieve compatibility between data devices, is the coding structure used on all personal computers.

The OSI Network Model

The OSI network model does not establish any particular standard, but it does define a hierarchical structure for all data communications network functions, identifying seven different levels of functional requirements (Table 1). The levels are independent, but each layer has an interface with the adjacent layer.

Each independent layer has interdependent functions, which are defined in the following paragraphs (see Black 1983; Durr 1984); examples are given where appropriate. In order to illustrate the similarity between the OSI structure and telephone communication by people, a "phone" analogy is given for each level (Friend et al. 1984).

Layer 7 is the applications layer, which defines how to enter the network. Phone: Am I talking to the right person? Who is paying for the call? Is this the best time for the call? Do you have a pencil and paper to take notes?

Layer 6 is the presentation layer, which defines the syntax used on the network. Phone: Are we speaking the same language and dialect?

Layer 5, the session layer, defines the binding and unbinding of communication links as well as the passage of data. Phone: Can this situation be handled in one call or several? Will other people be needed in the conversation? Who will call whom if we're cut off?

Layer 4, the transport layer, establishes a connection between two users that best matches the cost, quality, and speed needed. Phone: What is the most cost-effective way to make this call?

Layer 3 is the network layer. It defines the switching and routing of information (e.g., the X.25 packet-switching standard is one possible protocol for accomplishing this). Phone: Dial the number and listen for a busy signal. Redial if necessary. Hang up when finished.

Layer 2, the data-link, is primarily concerned with message packaging and link management (e.g., HDLC, or high-level data link control). Phone: Talk when one is supposed to and listen when one is supposed to. Ask for repetition if something is not understood.

Layer 1, the lowest, defines the physical connection (e.g., RS-232 or RS-422).* Phone: The actual sounds being uttered into the mouthpiece and heard at the other end through the receiver.

Setting up a LAN

There are lots of choices and many standards to deal with in setting up a LAN in an ICU (Durr 1984). When making a selection, one of the primary criteria will be speed (Dickinson 1984). To understand this criterion one must know something about hardware for network communications.

The transmission medium can be twisted-pair wire, coaxial cable, or fiberoptics. Twisted-pair wire and coaxial cable are the least expensive and easiest to install. For instance, one can put a single network on the coaxial cable by employing "baseband" methods, or multiple networks by using "broadband" methods (similar to the way cable television works). Most LAN systems transmit at a rate of between 500 and 10 million bits per second.

Table 1
ISO Model for Open System Interconnections

Layer 7:	Application
Layer 6:	Presentation
Layer 5:	Session
Layer 4:	Transport
Layer 3:	Network
Layer 2:	Data-Link
Layer 1:	Physical

Existing networks allow only one message at a time on the line. If two computers transmit information at the same time, a collision occurs and the transmission is garbled. Most LANs use one of two mechanisms to avoid collisions: token passing* or carrier sense multiple access with collision detect (CSMA/CD)**.

Token Passing Network

Token passing allows a computer to transmit a message only when it has a token. The token is a unique bit pattern. There is only one token circulating on the network at a time, and the token passes from computer node to computer node around the network. If a computer node on the network has nothing to transmit, it immediately passes the token to the next computer node. Collisions never occur in this type of network, because each computer node takes an ordered turn.

The advantages of the Attached Resource Computer Network token-passing approach are better performance when there are higher throughput rates and longer cable lengths. The disadvantage of this kind of network is that if the net is opened up, it is difficult to add another computer while the system is in operation. Most token-passing systems overcome this problem by reconfiguring the system at regular intervals or after a set period of time, if no token has been circulated.

CSMA Network

In a CSMA network system, all computers monitor the line and refrain from transmitting until the line is clear. It is easy to see that in a pure CSMA system the possibility of collisions exists, since two computers could sense a clear line and begin transmitting simultaneously. To avoid this potential clash, a Collision Detection scheme is employed. Each computer monitors its own transmission; if it detects a collision, it waits for a random amount of time and then tries again.

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*Three relevant standards are: RS-232-C, Interface between data terminal equipment and data communication equipment employing serial binary data interchange (1981 revision); RS-422-A, Electrical characteristics of balanced voltage digital interface circuits; and RS-485, Standard for electrical characteristics of generators and receivers for use in balanced digital multipoint systems (April 1983). These are available from the Electronic Industries Association, 2001 Eye St., N.W., Washington, DC 20006.

*IEEE 802.4, a standard similar to Attached Resource Computer Network ARCNet developed by Datapoint Corporation.

**IEEE 802.3, a standard similar to Ethernet developed by Xerox Corporation.

The principal advantage of the CSMA/CD scheme is that it is simpler to set up and operate. In the CSMA/CD system, however, throughput deteriorates quite rapidly under a heavy volume of communications or when network cable lengths are longer than one mile.

Medical Information Bus

The ICU has special needs in addition to "global" data communication from outside its walls and local transmission and processing of physiological signals. The problem of ICU communication has expanded dramatically in the past decade as microcomputer-based instruments have begun to abound. First it was the IV infusion pump, next the noninvasive blood pressure monitor, then the ventilator, and now a wide variety of noninvasive oximeters and other devices. Each device has its own processor and display, but communicates only with humans.

It is clear that in view of the data generated and the possibility of accurately controlling and linking these devices, communication among them is necessary. Unfortunately, until recently there has been no unifying or driving force to standardize the communications process. A group at Phoenix Baptist Hospital in Arizona has taken a lead and instigated a Medical Information Bus committee, active now for about two years. The group has also established a MIB standards group according to the guidelines of the Institute of Electrical and Electronics Engineers.

It is not unusual for an ICU patient to be connected to a bedside monitor, one or more IV infusion pumps, a noninvasive blood pressure monitor, a ventilator, a urine-output measuring system, wound-drainage measuring devices, and perhaps a finger-pulse oximeter (Figure 2). Each of these devices will likely be made by a different manufacturer, and each will have its own display and communications interface. To overcome the difficulty of manually acquiring data from this multitude of electronic sources, the MIB should provide a local area network around the patient for the purposes of obtaining data from all these bedside devices.*

The MIB should also provide for a continually changing situation at the bedside. Devices should be easy to add and remove from the network. The MIB should be "inexpensive" to implement; that is, an added cost of less than $500.00 per instrument. Many of the existing networks cost $1,000.00 or more per instrument.

Control and Communication

The MIB uses a master-slave communications protocol (Figure 2), along with a multi-drop communications scheme. The physical communications medium will be a single-shielded twisted-pair cable operating with the RS-485 physical-layer protocol.** The system will run at a relatively fast rate (375 K bits per second) and is self-clocking (i.e., requires no separate wire for timing).

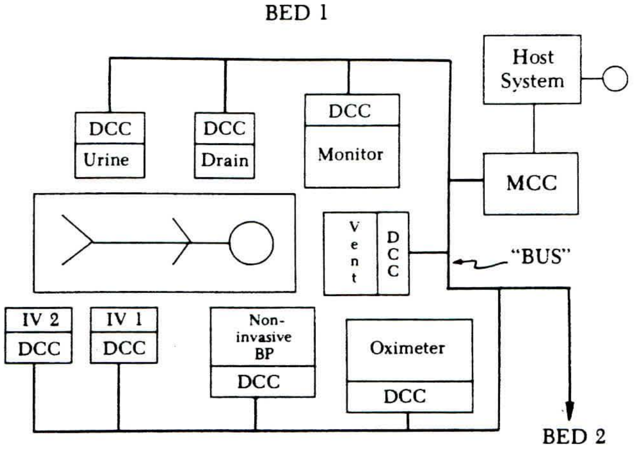

Figure 2. Block diagram of the Medical Information Bus showing it attached to several bedside devices being used to monitor an ICU patient.

The Master Communications Controller oversees all bus communications. It accepts, processes, and relays information between the host computer and the MIB. It is responsible for adding and deleting and thereafter polling all "on-line" medical devices and for reporting significant events to the host.

The Device Communications Controller is the slave that provides an interface between the MIB and the particular medical instrument. The DCC accepts the MIB protocol messages, then processes and converts them to instrument-specific codes. The DCC also converts the instrument-specific outputs into the MIB protocol and returns a response to the MCC, which polls each of the DCC's sequentially and expects a response from each.

The MIB uses a subset of the highly reliable Synchronous Data Link Control protocol (Black 1983). SDLC messages are transmitted across the line in a format called a frame (Figure 3). The beginning and ending flags each consist of an eight-bit byte pattern of 01111110. These flags serve as a reference for the start and finish of the message. SDLC is code transparent, meaning that it can send binary, ASCII, or other data codes. The only unique bit stream is the flag bytes.

The hardware (now almost all on a single silicon chip) will not allow the flag byte pattern (01111110) to be transmitted in other parts of the frame. At the transmitting end, the frame contents are examined and a "0" is inserted after any succession of five consecutive "1"s within the frame. The receiving site receives the frame, recognizes the two flags, then removes any "0" that follows five consecutive "1"s. As a result, SDLC is not dependent on any specific code such as ASCII.

The address field follows the beginning flag. The address identifies the secondary station. The control byte defines the function of the frame and invokes the SDLC logic at the receiving and sending stations. Next is the MIB user data section of the frame. After the MIB user data is the frame check

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*Proposed standard IEEE P1073, being developed by the Medical Information Standardization Group. For information about the standard, write to the chairman, Ron Norden-Paul, c/o Emtek Health Care Systems, 1702 W. Harmont, Phoenix, AZ 85021.

**See footnote about RS-485 standard, on p. 60.

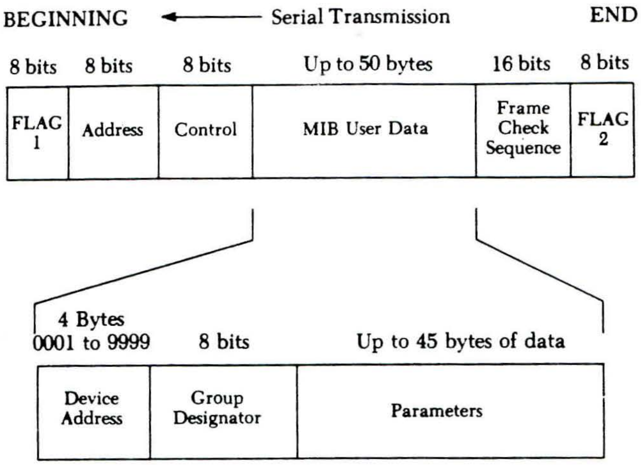

Figure 3. An SDLC frame. The upper portion shows the format of data within the frame. The lower portion shows the format of the MIB User Data.

sequence field, which contains 16 bits computed (using cyclic redundancy checking, or CRC) at the transmitting station from the contents of the address, control, and MIB user section of the frame. The receiver performs a similar computation to determine whether errors have been introduced during the transmission process. This error-checking ensures nearly error-free data transmission (less than one error for each billion bits transmitted), a prerequisite for this medical application.

More about the MIB

Up to 255 devices can be attached to the MIB (address 0 to 254; 255 is reserved for broadcast). Each device will have an identification code. The present design allows for up to 10,000 device ID codes. The unique ID code will be hardwired (using circuit board switches), or, alternatively, each device might be named at system start-up time. Since the transmission rate is 375 K bits/sec, it will be possible, if no errors are detected, to interrogate each device controller at least once a second.

Each class of machine will be given a common descriptive name. The group designations allow for one hundred different (0 to 99) classes of machine (Table 2). Each instrument type will be classified according to a standard set of descriptors (Table 3).

Table 2
Group Designations

Group	*Instrument Type*
00	Generic—used by all instrument types
01	Fluid delivery devices (e.g., IV pumps)
02	Fluid collection devices (e.g., urine, drainage)
03	Ventilators and respiratory devices
04	Noninvasive measurement devices (e.g., blood pressure, temperature, oxygen saturation)

Table 3
Example of Descriptors Used for Fluid Delivery Devices

Descriptor	*Description*	*Units*	*Data Format*
RT	Delivery rate	ml/hr	dddd.d
VI	Volume infused	ml	ddddd.d

The MIB protocol is set up to allow communication among many different kinds of instruments made by different manufacturers. For example, a patient might be connected to two IV pumps of different manufacture. Under the control of the host computer, the MCC could ask each device for the fluid flow rate. The DCC on each IV pump would interrogate the device and send the requested information in a common (standard) format to the MIB.

The final details of the MIB and its communications protocol are still under development and will probably take another two to three years to complete. Industry-wide standards are essential to make the scheme work. Those interested in participating in further definition of the MIB standard should get in touch with Ron Norden-Paul (see footnote, page 61).

Conclusion

Communication and the establishment of communications standards are crucial to all facets of modern life. Medicine is no exception. Although the standards and technology developed for the business and communications industry may help the medical professional, they will not solve all of our communications problems. Therefore, medical information handlers, instrument manufacturers, bioengineers, physicians, nurses, and other health care professionals must join together to solve the problems unique to medicine.

We might compare the present state of medical communications to the early days of the automobile industry in the United States. Around 1915, the "Model T" Ford was being mass produced, but there were few roads and no freeways to carry the traffic. Today's computer and medical instrumentation industries are in a similar situation. We have powerful personal and database computer systems as well as computerized medical instrumentation, but we must "travel" on dirt "communications" roads. We need to build a network for computers similar to the freeways which criss-cross the country. Let us hope that the network, unlike the U.S. interstate highway system, won't take seventy years to complete.

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