Networking of Welding Applications: A Tutorial

William Rippey, Jim Gilsinn, Lance Flitter

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In the near future, power sources may have a network connector on them instead of separate plugs for the robotic interface, wire feeders, gas control devices and operator panels. Compared to present welding cells, the new ones will have fewer cable maintenance headaches, and it will be easier for users and system integrators to replace or add devices. The power source will download weld schedule and pulse shape program data, and provide measurement information for process control and quality monitoring. Eventually, users will get these benefits without paying more for the equipment. This article describes the basics of network technology. Its goal is to help users of welding equipment identify opportunities where network technology may be beneficial. It will hopefully prepare non-network-experts to follow up with more in-depth reading and investigations.

The Variables in Communications

The exchange of information can be described using these variables. They apply to communications between people having conversations or mailing letters, as well as to computers.

- **Number of users.** The simplest cases are information moving between two places, either one-way (e.g. from a safety sensor to a programmable logic controller (PLC)) , or two-way (e.g. robot controller to power source). A welding cell or transfer line may have 10 or 100 sensors, and a factory floor may have 10 cells that can receive program data from a database and report production status information to a monitor. Two people may speak privately to each other, or 435 may speak publicly on the floor of the US Congress.
- **The distance between users.** Users may be in the same room, the same office or welding cell, the same plant, same country, or different country. Increased distance requires more expensive transmission methods, and more complex ways to logically and physically connect users.
- **Information Size.** The information sent in a transfer may be a single number, like a weld current setting, a ROBOT-STOP! command, thousands of text characters and numbers comprising a weld procedure specification (WPS), or the millions of bytes in a CAD file.
- **Frequency of information flow.** How many times per hour or per second does information flow? PLCs may download one program per day, upload one status report per part processed, and they may send commands to drive motors and read position sensors at 100 times per second.
- **Required rate of information transfer.** Short messages exchanged at high frequency, or large messages sent at lower rates add up to high required capacity. The capacity for networks, called *bandwidth*, is expressed as maximum bits per second. Units are thousands (kbps) or millions (Mbps).
- **Robustness against environment.** The environment can interfere with communications signals, or can damage physical components. On factory floors more expensive (more

complex, costly, or slower) communications are needed to protect from noise such as electrical emissions from motors, switches, and arc welding.

- **Cost.** This is the justifiable cost of communications relative to the cost of the user components. A $50 network interface card for a $2000 PC is a low cost - how much can you spend on communications to link twenty $50 sensors?

Communications Before Networks

Before computers and digital information were so widespread, welding information was stored and conveyed using paper and voice. Humans interacted with machines using manual controls. Letters, faxes, and the telephones have been especially important for interactions between people. Electronics gave us point-to-point electrical links, like analog signals (e.g., send 3 volts to set weld current to 200 amps), interlocks (24 volts DC sends a command to start gas flow, or to report arc-on status). Morse code was early digital data. In 1969, RS-232 was developed to transmit digital data using low cost cable. Carrying a floppy disk from one computer to another, or sneaker net was the next popular digital communications method.

Manufacturing Communications

Information processing is now dominated by computers and digital data. Computer applications range from Computer Aided Design of finished products, weldments and welds, generation and storage of WPSs, to real-time synergic control of power sources. Programmable automation requires that machines acquire a great deal of data to do useful work. The data must be easily and quickly available so machines can be reprogrammed for different operations, or so status data can be used as feedback to control or improve manufacturing processes. Data communications must be automated, fast, error-free, and flexible -- sneaker net just won't do.

Networks provide:

- Automated exchange of digital information between welding applications.
- Linking of processes on different computers, and linking of computers with low-level devices
- Efficient and cost-effective connection of a variety of users that may be geographically dispersed
- Flexible connection of devices with reduced number of different connectors and wiring schemes.

How are Networks Implemented?

The complexity of network communications is analyzed and implemented in layers. This discussion uses a simplified three layer model of computer communications. From the bottom up, the layers are: transmission, networking protocol, and application. This description should enable interested readers to tackle the more complicated and standardized seven layer Open Systems Interconnection (OSI) Model. [2,4,10] The OSI model rigorously specifies the components of communications systems so standards may be developed that ensure compatibility of commercial hardware and software products.

An example of the three layer model of communications is shown in *Fig. 1*. *Fig. 1*(a) shows two applications that run on the same computer. These applications do not require a network, since they use function calls or communication services provided by the operating system. *Fig. 1*(b) shows two applications running on separate computers. They communicate though layered communications which is hidden from the applications. The independence of the applications from the layers below it is shown using the horizontal line that indicates an apparent connection between applications. In implementation the application interacts directly with the network layer below it.

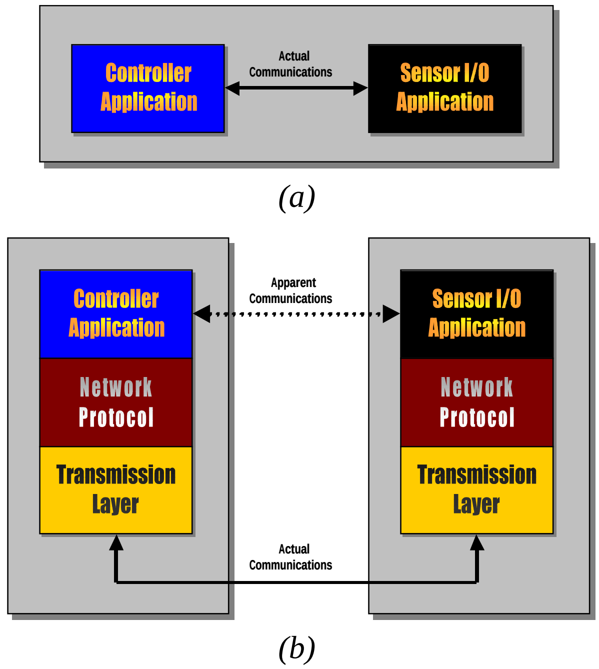


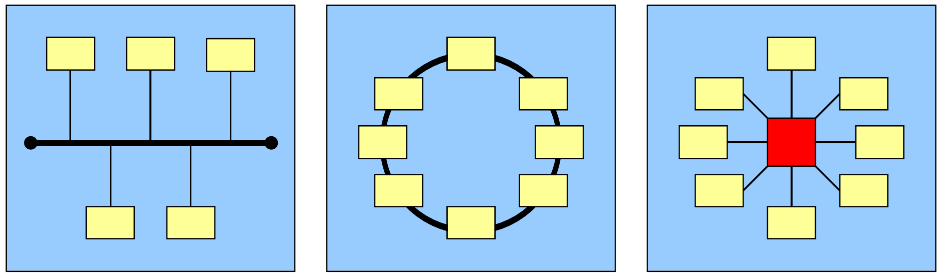
Fig. 1 — Communications example between applications (a) on the Same Computer, (b) between 2 computers using the 3-layer Networked Communications

The Transmission Layer

The transmission layer conveys digital data using energy signals. Electrical and light signals are conducted by a *medium* that conducts the energy. Some examples are: wire pairs, twisted wire pairs (for higher signal speed), coax cable (even higher speed), and fiber optics. Network data can also be transmitted using infrared light and radio waves. The cost of media tend to go up as they are engineered to accommodate the physics of higher signal rates and of better immunity to electrical noise from the environment. Characteristics of media include: number of conductors (if electrical), presence/absence of device power, noise shielding, and signal technique (e.g., broadband, baseband, optical).

Signal output is controlled by arbitration rules that determine when multiple users may speak. The rules are needed because most networks supply a shared medium to all of their users. Arbitration ensures that signals sent from the different users don't interfere with each other. Network arbitration schemes can be either distributed among the users, like rules of politeness at the dinner table, or centralized, like the role of the chairman at a committee meeting. The transmission layer for human verbal communications uses air as a medium, sound energy generated by vocal chords, and some rules of politeness for determining who may speak next. Ethernet, token ring, and Controller Area Network (CAN) are examples of transmission schemes for networks. Sub-categories of ethernet are 10Base-2, 10Base-T, and 100Base-TX (they vary in data rate and cable type).

The physical arrangement of media connections that link users is the network *topology*. Common topologies are bus, ring, and star. These are shown in Figure 2. Each offers wiring, reliability, and performance features. Reference [3] discusses these features.



(a) (b) (c)

Fig. 2 — Common network topologies (a) Bus Network, (b) Ring Network, (c) Star Network.

The Networking Protocol Layer

Our networking protocol layer has two functions: control the flow of information and route messages to users. Examples of commercial protocols for this layer are IPX/SPX, NetBIOS, and TCP/IP.

Flow control implements rules for exchanging information, for network devices and for the network users. The basic unit of network information flow is the *packet,* a chunk of information a few bytes to a few hundred bytes long. There are several network flow control techniques that are "unseen" by network users. One is breaking large pieces of data into packets, so that transmissions from many different users can be interleaved. This ensures that no user gets starved out of the network while large pieces of data are being sent. Other hidden functions are reassembly of packets into the original information format, error recovery (identifying and resending packets damaged or lost by noise or network failure), priority assignment for user messages of varying time urgency, and encryption.

Network users specify a message destination, or *address,* expressed as a name or number. The network handles navigating the topology to find the destination. Network addressing schemes are analogous to postal zip code systems, e.g. American (20899-8230), or Canadian (L3N 7C8). (Note that both zip systems accomplish the same function but use different syntax.)

The Welding Application Layer

All computer applications that exchange data use definitions of nouns, adjectives, and verbs of their conversations. (In some communications models the formal terms are *objects* , *attributes*, and *services*). People discuss weld inspection, spot welding, and brazing using terms whose meaning is very specific to each process. Examples of definitions in welding controls is:

- Nouns: constant voltage mode, arc current, wire feed speed
- Adjectives: 400 amps, 1/2" offset
- Verbs: set level, turn on/off.

Applications also define their sentences, information sent to elicit an action or to respond. Controls applications may define very short sentences to ensure faster message delivery.

The data defined must be represented precisely, according to rules of *syntax*, so that applications written by different authors can communicate. A human example of syntax is choice of language: 2 people can discuss weld defects in English or in French. In a weld cell the message to set current to 450 amps might be expressed as text characters SET CURRENT=450, or as three numbers, the command number (from a list), the variable number, and a quantity, e.g. 10 04 450.

Networks of Networks

A *local area network* (LAN) is a system of users, network links, and link connections that implement communications. Users of a LAN are close to each other, e.g., in the same building or in the same welding cell. A *wide area network* (WAN) is formed by linking LANs, to cover a large geographic area. Within a LAN, if the transmission signal is weakened by long cables or the addition of users, a *repeater* can be added in the transmission layer to boost signal strength. Two identical LANs can be connected using a *bridge*. When two LANs that differ in any or all of the three layers are connected, a more complex *gateway* is needed. The gateway translates between the different protocols and/or media of the LANs. To connect an office network in Maryland with another in Miami requires technology that is suited to spanning the distance and dealing with the complexity of finding a specific computer among all the computers on earth. *Routers* receive addressed packets and send them to adjacent networks or other routers that can deliver the packet to its destination. Routers translate a named address like william.rippey@nist.gov (email) into a physical network node that receives the message, and the cross-planet-earth network paths to reach it.

What is the Internet?

The internet is an interconnection of LANs and WANs around the world. They are physically linked by gateways and routers, and logically linked by using a shared protocol and addressing scheme. Unlike international mail, different country addressing schemes are not allowed. Most internet messages are sent using the TCP/IP protocol [2].

Why are There So Many Types of Networks?

The cost of media varies widely with maximum speed and ability to protect signals from noise. The cost of media relative to the cost of user devices is a strong factor in media selection.

Media are designed to resist a range of potential physical damage. Offices are typically less harmful to cables than factory or outdoor settings. Further, some network cables conduct power for users (e.g. actuators or sensors) to reduce the number of wires and power conditioning circuits.

Message size and delivery time requirements are met using specific topologies and protocols. File-access protocols and topology connect thousands of users and move large files with acceptable, but not necessarily predictable time delays. Real-time control protocols restrict the number of users and use very short messages on lower bandwidth media to convey messages in a short, known maximum time period.

Application needs determine the design of data and protocols. A large file, an email message, and an arc on command are widely different in size and meaning to their users. They are conveyed using data definitions designed for effective, efficient communications. Also, some application protocol differences are due only to the language-style preferences of their designers.

Some networks have all three levels specified as a package to ensure interoperabililty of products at all three levels. Examples are DeviceNet [8], a sensor and actuator network, and BACNet for building control [7]. IEEE 1451 [**Error! Reference source not found.**], for sensors, defines the application level, and the lowest transmission level, leaving the in-between level up to each network vendor.

Where Can Networks be Used?

Do you need a computer to use a network? No, you don t, and that is the biggest factor in the last 10 years that is contributing to greater network use. Circuits that handle the complexity of all three network layers are being built into small, cheap semiconductor chips. Another contributing factor is the availability of network products that are interoperable (due to standards).

Network communications technology gives the biggest direct benefits when used to connect many devices, that are spread over a large area, needing fast communications. In manufacturing cells, networks can reduce the amount of cabling and connectors, decreasing maintenance and enhancing reliability. Network technology also offers flexibility in extending communications capabilities that point-to-point techniques do not. Figure 3 shows analog link cables and network cables. To add information to an analog link, like the robotic interface of a power source, requires adding a wire for each function: network information is expanded by defining additional messages in software.

Network technology can be more complex and expensive than a point-to-point link. Network troubleshooting requires a tap onto the network medium, node/receiver hardware, and software that can interpret the messages. You can troubleshoot an interlock line with a volt meter. If a controller already has input/output hardware and software, additional sensors are most easily wired directly to the controller. Further, RS-232 driver chips, their communications software, and their cable and connectors are so common and cheap that a direct line from one device to another can be the best solution. If files are needed infrequently at a device, sneaker net is cheap and reliable, though not automated or fast.

Figure 3. Multi-pin cables carrying analog signals can be replaced by network cables

The Role of Standards

Standards facilitate the interoperability of products from different vendors, making a system integrator's job of assembling a system easier, faster and cheaper, and giving purchasers flexibility in equipment selection. Guaranteed compatibility with other products assures developers of a larger market, which can lead to lower cost through mass production and competition. In addition, users can expand or upgrade existing systems using multi-vendor components. The OSI 7-layer communications model has speeded standards development by allowing concurrent efforts for the different layers. Challenges for standards groups are to generate standards quickly enough to harness developing technology without restricting advances. Standards and open specifications that facilitate multi-vendor interoperability come from the International Organization for Standardization (ISO), IEEE, and industry consortiums like Open DeviceNet Vendors Association (ODVA), and Foundation Fieldbus.

Future of Welding Networks

The computer industry is advancing the technology of networking toward higher bandwidth and less expensive hardware. Networks will be used increasingly in real-time control applications due to lower cost, enhanced performance and the emergence of intelligent sensors that can identify themselves and perform functions beyond simple measurement. [6] Wireless networks, using infra-red or radio transmission, will be used more. The welding industry can harness these advances by defining the communications information needs and developing standard specifications, either through AWS standards committees or through industry associations. The use of network technology with related standards will promote interconnectivity of commercial products, which will lead to better capabilities at lower cost.

Trade names are used only to specify adequately the techniques used.   Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor that the materials or equipment identified are necessarily the best available for the purpose.

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