Multiprotocol Ethernets on the Shop-Floor

J. Pütter
Chalmers University of Technology
Department of Production Engineering
S–412 96 Gothenburg, Sweden
Phone: +46 31–7721291, Fax: +46 31–7723819
E-mail: puetter@pe.chalmers.se

Abstract

Computer networks are indispensable for any CIM implementation, since a computer network is the only transport mechanism available for sharing computer-based information. The rapidly developing computer and IT fields has given manufacturing industry new opportunities to increase its competitive strength. It can make efficient use of new developments by adapting itself to widely spread standards and *de facto* standards. This article aims to show that the popular Ethernet technology can be successfully used as a multiprotocol CIM network on the shop-floor. Examples of Ethernet-based networking practices from three different European manufacturing companies are given.

Keywords

Computer networks, communication protocols, computer-integrated manufacturing, Ethernet

1 INTRODUCTION

1.1 CIM and networking

The basis for an enterprise-wide CIM (computer-integrated manufacturing) concept is the integration of various functions and technologies. One of the key factors to compete effectively in manufacturing is operational flexibility. Integration by linking computer-based tools over a common network has been widely accepted as one of the main ways to achieve this flexibility. 'The key to CIM is systems integration and an incremental CIM approach', according to (Ahmadi *et al.*, 1991).

J. Goossenaerts et al. (eds.), *Information Infrastructure Systems for Manufacturing*

In general, computer networks connect different computer types, running different operating systems and using different network protocols – a distributed, heterogeneous, networked, multivendor computing environment. Such an environment is utilized to share:

1. *Data* stored in files or databases.
2. *Resources* such as printers, backup devices, modems, WAN (wide-area network) links, etc.
3. *Programs* where users should be able to run all software tools required to get their job done efficiently – even if some programs need a computer platform different from what the user has on his desktop. This can be accomplished in two completely different ways (Pütter, 1995):
   a. *Through emulation*: e.g. the software *SoftPC* emulates a personal computer (PC) running MS-DOS (Microsoft disk operating system) on a Macintosh;
   b. *Over the network*: Remote control, e.g. telnet, rlogin, X-Windows, etc.

A literature review on CIM networking problems (Snyder, 1991) found that 'the networking solution for CIM may be considered as a part of the total organization's establishment of a rational and effective network architecture'. Snyder categorized the problems he found into:

- multiple vendor installations;
- the scarcity of off-the-shelf software packages for CIM;
- immaturity of connectivity products;
- network management.

A survey (Penning, 1994) conducted in mid-1993 asked 164 small (less than 200 employees) U.S. manufacturing enterprises about, among other things, their current networking status. Penning found that nearly all of the 84 respondents with on-site networks reported that they were used for office and administrative functions. Networks for shop-floor applications were operative in 43 of the 84 enterprises with networks installed. About two-thirds of those familiar with their network topology were using Ethernet. Computer platforms used were PCs (87 respondents), workstations (31 respondents), minicomputers (17 respondents), dedicated systems (10 respondents), and mainframes (6 respondents). This indicates that computer environments are often heterogeneous, a conclusion also found in (Ahmadi *et al.*, 1991) and (Snyder, 1991).

1.2 Shop-floor networks and their protocols

A modern shop-floor network is utilized much the same way as office networks, but three additional communication aspects have to be considered:

1. *Electromagnetic interference* (EMI) is often higher due to the presence of high-current power lines, electric motors, arc welders, arc furnaces, motor generators, etc., which can disrupt network communications.
2. *Real-time requirements* are common, the network must be able to successfully deliver packets to their destination under a deterministic time-frame.
3. *Computer-to-computer communication* without human intervention, e.g. automated transactions between distributed control systems in a manufacturing cell.

A designer of shop-floor networks should take these aspects into consideration.

In the early eighties, General Motors stated that 30% to 50% of their automation budget was spent on building custom interfaces between incompatible factory systems. This led to the development of MAP, the manufacturing automation protocol. The use of a standard communications protocol, well suited for shop-floor automation, should obviate the need for expensive customized interfaces and thereby significantly reduce costs and lead times. However, MAP is still very expensive, it is not widely spread, open systems interconnection (OSI) communications are very complex, and a competitive MAP market, so far, has not evolved. Also, the MAP 3.0 specification initially only allowed two cable types: the expensive IEEE 802.4 Token Bus broadband and the uncommon 5 Mbps IEEE 802.4 Token Bus carrierband.

In 1992, the IEEE 802.3 CSMA/CD (carrier sense multiple access with collision detection) networks were included in the MAP standard. This should pave the way for a broader acceptance of MAP as a shop-floor protocol. It should be noted that the IEEE 802.3 standard and Ethernet, being almost identical, are incompatible due to a difference in the two-byte type/length field in their respective frame formats. Both 802.3 and Ethernet can be used to transport the MAP protocol; it is a question of how the network interface board is set up. Also, a few different Ethernet versions have been presented since 1980. This paper deals exclusively with the latest version often referred to as 'Ethernet' or more specifically, DIX Ethernet version 2.0 (Digital-Intel-Xerox).

As Ethernet became part of the MAP standard, it resolved several pending issues:

1. The network infrastructure can be more easily and inexpensively implemented by using popular and readily available Ethernet technology.
2. The knowledge and experience with Ethernet-based networks is far more extensive than it is with any other network type.
3. Connectivity to Ethernets is simpler and cheaper than it is to Token Bus networks. The CSMA/CD media-access method used in Ethernet has one well-known drawback – the network can get congested, resulting in increasing response times, when subjected to high loads under certain conditions (Boggs *et al.*, 1988). The end effect is that real-time demands cannot be guaranteed in all situations. A family of networks, collectively called fieldbus, has found a market in interconnecting sensors, actuators, or to distribute I/O points in relatively limited areas. A fieldbus is inexpensive, has good real-time performance, is uncomplicated, and can cover a manufacturing cell. Popular fieldbuses are Profibus, CAN bus, Interbus-S, and FIP. A fieldbus typically is limited to 100 meters, 30 nodes, small packets (a few bytes), and 1 Mbps of bandwidth.

A closer analysis of the MAP protocol suite reveals that most application-layer functions can be successfully replaced with other, more widely used, protocols. There is one important exception: the manufacturing message specification – MMS or ISO 9506. The MMS protocol is probably the most interesting application-layer OSI protocol to the manufacturing environment. This extensive protocol is designed for the remote control and monitoring of industrial devices such as CNC (computerized numerical control) machines, robots, PLCs (programmable logical controllers), AGVs (automated guided vehicle), cell controllers, etc. It is an internationally standardized messaging system for exchanging real-time data and supervisory control information between networked devices. The messaging services provided by MMS are generic enough to be appropriate for a wide variety of devices, applications, and industries. There are no alternatives to MMS today, at least no standardized ones. MMS would facilitate shop-floor integration considerably; therefore is it highly desirable that MMS gain wider use.

1.3 Multiprotocol Ethernets, Internet, and TCP/IP

In Europe, about 50% of all installed local-area networks (LAN) are based on Ethernet technology (Smythe, 1993). It is stated that in the U.S., Ethernet comprises over 61% of the installed LANs in use today (Adams, 1990). This market penetration has lead to widespread knowledge and experience with the technology and a highly competitive LAN market with a rich array of products. (Smythe, 1993) and (Shaw, 1989) mention six different integrated cable architectures (10BASE5, 10BASE2, 10BASE-F, 10BASE-T, 10BROAD36, and 1BASE5) as well as several vendors of network interface cards, terminal servers, repeaters, hub units, bridges, switches, and routers – the necessary components to build a flexible networking infrastructure for both office and shop-floor environments. Lately, the 100 Mbps Ethernet (100BASE-TX, 100BASE-F) is establishing itself on the market as the high-speed Ethernet alternative to the traditional 10 Mbps version. Also, IEEE currently is working on the GigaEthernet standard; products are expected to appear on the market during 1997.

Another important Ethernet quality is its ability to simultaneously accept several communication protocols. Most, if not all, popular LAN protocols can use Ethernet, for example:

1. TCP/IP (transmission control protocol/Internet protocol).
2. Apple's EtherTalk.
3. Novell's IPX/SPX (internet packet exchange/sequential packet exchange).
4. NetBIOS (network basic input output system) and NetBEUI (NetBIOS extended user interface).
5. Digital's DECnet and LAT (local area transport).

Different protocols can successfully exist side by side on an Ethernet cable without knowing about each other – interprotocol *integration* is not the case. Instead of using gateways to convert between protocols, one protocol can be selected as the integrating protocol – *the network Esperanto* (Pütter, 1995).

The global Internet has experienced a tremendous growth during the nineties; up to 50 million users have access to it, according to some estimates. The reason behind the rapid growth is Internet's useful content and its ability to interconnect people – features advantageous to all companies, organizations, and individuals, just like the telephone system. An example of how the manufacturing industry can use Internet in the future is given in (Coyne *et al.*, 1994). This is a research project aimed at creating an 'advanced collaborative open resource network (ACORN)' – an infrastructure to create an electronic manufacturing community able to design and sell engineered products in competitive markets as well as conduct research and development by collaborating over a network.

Only TCP/IP is allowed on the Internet. The TCP/IP family of protocols can be used to transport data around the world as well as across the hallway. This made TCP/IP the most widely spread and used protocol available. Most, if not all, computers can use the protocol suite for its communications. Other reasons for wanting to use TCP/IP on the shop-floor are:

- TCP/IP is a widely used *de facto* standard. The specifications are publicly available, for free.
- TCP/IP is the only protocol used on Internet. Due to Internet's popularity, TCP/IP will probably end up being used on the shop-floor anyway.
- Some 50 million users have knowledge and experience with it.
- It scales extremely well, an important flexibility issue – there is no risk for outgrowing it.
- MAP's application-layer protocols can be successfully replaced by TCP/IP protocols, except for MMS, as mentioned earlier.

2 THREE INDUSTRIAL EXAMPLES

This section briefly describes computer networking practices in three different European manufacturing companies. Their common denominator is the successful use of multiprotocol Ethernet implementations.

2.1 A wheel-axle manufacturing plant

The Ethernet-based plant-wide office and shop-floor LAN connects more than 150 nodes of various types: approximately 100 PCs running MS-DOS, WfW (Windows for Workgroups) or OS/2, 40 UNIX and VMS workstations, 15 terminal servers, and several PLCs are connected to the network. The LAN carries TCP/IP, DECnet, LAT, OSI, NetBIOS, and NBT (NetBIOS-over-TCP/IP – Aggarwal *et al.*, 1987a; Aggarwal *et al.*, 1987b; Hunt, 1995) – a multiprotocol Ethernet in a heterogeneous computing environment. A router/bridge interconnects the LAN with two leased 64 kbps WAN lines. Only TCP/IP is routed; DECnet and LAT are bridged over the WAN. Also, a dial-up Internet connection is currently being evaluated.

The network has been used for several years, while continuously being extended and upgraded as new computers or manufacturing devices needed access to resources available over it. An analysis showed that this one-segment Ethernet violated three of the five Ethernet guidelines presented by (Boggs *et al.*, 1988):

- the network used very long cables to cover all buildings;
- there were many hosts on the single segment;
- real-time nodes where not separated from bulk-transfer nodes.

Therefore, the network recently was split into seven logical segments by means of a high-performance, multiport Ethernet switch (i.e. a fast, multiport bridge). The primary objective was to decrease the network's vulnerability to malfunctioning nodes. The secondary objective was to increase bandwidth by making more effective use of Ethernet technology. The introduction of the switch reconfigured the network into a collapsed backbone topology with bridged segments. This significantly shortened the length of each segment and decreased the number of hosts per segment. As a consequence of this reconfiguration (1) the network now better conforms with the guidelines presented by (Boggs *et al.*, 1988), (2) available bandwidth has increased significantly because local network traffic will stay local, instead of flooding all nodes as it did before the switch was installed, and (3) the entire network is more flexible for future changes and expansions due to the modular switch design. Both points (1) and (2) above increase the network's real-time characteristics.

There never was a problem with EMI radiation at this site as its EMI levels are considered low. Fiber-optic cables are used between buildings, being immune to EMI, while factory segments use shielded cables as a way to decrease the influence of EMI.

The network is used for sharing data, resources, and programs. Most PCs are used either as desktop computers or as cell controllers. Workstations are used as engineering workstations, MRP II (manufacturing resource planning) servers, AS/RS (automatic storage/retrieval system) controllers, and AGV controllers. The manufacturing equipment is connected to the network either through terminal servers or indirectly through cell controllers.

The WAN connection is used to convey production plans, e-mail, and product specifications, such as CAD (computer-aided design) files and assembly structures, to the headquarters some 300 km away.

An increasingly important part of the company's core business relies on the network. Network downtime would quickly lead to halted production processes, resulting in costly logistic problems. Thus, reliability and flexibility are crucial.

2.2 An automotive body-shop

In 1994, a new body-shop line was taken into production. It is a highly automated and flexible, robot-based, spot-welding line that manufactures automobile bodies. More than 80 robots, 50 PLC systems, 25 PCs (MS-DOS, WfW, NT, and OS/2), 12 VMS and UNIX workstations, 100 terminals, 10 printers, 50 read/write units for an ID system, and 9 cameras are connected to the Ethernet-based factory LAN. The network used more than 40 km of copper and fiber cables interconnected with two multiprotocol routers and six hub units. Fiber cables are used throughout the shop-floor to eliminate the influence of EMI radiation since the line incorporates many EMI-generating spot-welders. Real-time demands are secured by separating bulk-transfer nodes from real-time nodes and by keeping segment length down. The Ethernet factory LAN carries TCP/IP, DECnet, LAT, 3270-emulation (DECnet to an SNA gateway), and MMS (OSI on Ethernet) – a multiprotocol Ethernet in a heterogeneous computer environment.

The factory LAN is connected to the company WAN through both routers for redundancy. The WAN has a connection to the Internet, the two being separated by a comprehensive firewall system to protect the LAN from intruders.

The network is used to share data, resources, and programs, such as production control, on-line geometric measurements, quality monitoring, historical production records, production monitoring, synchronization of real-time clocks, backups, off-line programming, e-mail, access to shop-floor software from development departments etc.

The network is a mission-critical component for the line to properly operate. Network downtime would, after less than *one minute*, lead to halted production processes, resulting in costly shortages of car bodies downstream.

2.3 A small electronics manufacturing company

For several years, this 40-employee company has been using an Apple LocalTalk network with about 8 Macintoshes, a file server, and a laser printer in the office environment. This was an office-only network; the factory PC initially did not need a network connection. A traditional serial-line terminal network also was used to access the minicomputer that ran MRP II and administrative software such as accounting, storage, purchasing, salaries, and sales. This setup, in terms of performance and flexibility, was not able to exploit major advances in computers and IT (information technology) that offer significantly improved performance and functionality. It is complicated to connect PCs and terminals to the LocalTalk, and the network was limited to the AppleTalk protocol. A major upgrading was necessary to maintain the company's competitive strength.

Recently they installed a 40-node 10BASE-T Ethernet network to replace their now obsolete LocalTalk and serial-line networks and to extend the network into their factory. Special attention to protect the network from EMI influence was not needed since EMI levels are low, comparable to normal office levels. Real-time demands are not present. The new network hosts about 10 Macintoshes, 10 PCs (MS-DOS, WfW, Windows95, and OS/2), a laser printer, and a UNIX server. It carries TCP/IP, NBT, and EtherTalk protocols. Also, a dial-up Internet connection is currently being evaluated.

The network is utilized much the same way as before, to share data, resources, and programs across computer platforms. Now, however, it is a multiprotocol Ethernet in a heterogeneous computing environment. They successfully integrated this environment into a versatile and flexible system. Office and factory are integrated and several new technologies, e.g. CAD, CAT (computer-aided testing), CAE (computer-aided engineering), DNC (direct numerical control), CAM (computer-aided manufacturing), a simulation package, and shop-floor control, were easily added to the new network. The new system is flexible and has enough bandwidth for future growth. Their business process is relying heavily on the network – that has not changed.

3 DISCUSSION

The examples given above, each representing a different type of manufacturing industry, indicates that multiprotocol Ethernet-based CIM networks can be successfully implemented and used in shop-floor environments. Another common denominator is the use of modern *client/server technology* as found in many downsized (Baker, 1992) office environments. The literature reports similar setups (Ahmadi *et al.*, 1991; Snyder, 1991; Baker, 1992; Bartlett *et al.*, 1994; Casey, 1990), to mention but a few.

It is necessary to follow major trends in the computer and IT fields in order to utilize its rapid development. For the past few years, those trends include Ethernet, personal computers, workstations, UNIX, the Internet, downsizing, TCP/IP, LAN, and graphical user interfaces. The office and consumer markets are the main followers of these trends.

Routers, switches, bridges, repeaters, and nine media-options (six 10 Mbps and three 100 Mbps) make Ethernet very flexible. Gigabit Ethernet and new developments on VLAN technologies (virtual LAN) for switches and 'one-armed' routers promise new possibilities for the near future. The Ethernet technology can easily be designed to meet most demands on bandwidth and topology. An Ethernet has a nominal bandwidth of 10 or 100 Mbps. The normal network load, however, should be kept significantly lower, 10% of nominal bandwidth is normal procedure, as a margin for sporadic peak loads. When the load increases, the result will be more packet collisions, jams, and subsequent retransmissions. This can lead to a congested network under certain conditions (Boggs *et al.*, 1988). This is a well-known aspect of the CSMA/CD media-access protocol used in Ethernet. By closely following the design guidelines presented by (Boggs *et al.*, 1988), congestion can effectively be avoided and real-time performance will not suffer. However, it is often advantageous to use a fieldbus-based network on the lowest levels of shop-floor automation. Higher automation levels normally implies lower real-time demands, higher bandwidth needs, and more sophisticated protocols. This is where an Ethernet is better suited than a fieldbus network.

Although an Ethernet easily carries most common LAN protocols, it does not integrate disparate protocols. However, all devices connected to the same Ethernet and using the same communications protocol do understand each other; this can be described as *islands of integration*. The *interprotocol* integration has to be made elsewhere, by gateways or by selecting one protocol to be the Esperanto – *the integrating protocol* (Pütter, 1995).

Noise, such as EMI, is a threat to all electronic devices and they are all exposed to it to various degrees. The noise induced by EMI onto the network can affect data integrity. Error detection and retransmission features in the protocols will guarantee error-free data transmissions, but at the cost of additional network traffic. High noise levels would lead to high retransmission rates, degrading network performance. (Adams, 1988) conducted a comprehensive study on the correlation between EMI and Ethernet performance. The EMI levels he measured during several manufacturing site visits, turned out to be at least one order of magnitude lower than the Ethernet specification allows. Later laboratory tests, he reports, showed that Ethernet cables were unaffected up to a field strength twenty times the specification for 10BASE2. The 10BASE5 specification tolerates even higher levels. (Casey, 1990) states that 10BASE-T is not considered suitable on the factory floor. The reason is that a properly installed coaxial cable has better noise immunity at Ethernet frequencies than does an unshielded, twisted-pair cable. Fiber cables are immune to EMI, making their use a suitable strategy in harsh environments.

The three industrial examples presented above experienced some of the four main CIM networking problems reported by (Snyder, 1991):

- *multiple-vendor installations*: were a problem mostly with older equipment;
- *the scarcity of off-the-shelf software packages for CIM*: was not investigated;
- *immaturity of connectivity products*: could affect single computers or even Ethernet cards but did not imply any problems in the total system;
- *network management* is still a problem, especially with bigger or complex networks.

A major MAP software manufacturer has recently announced an MMS-over-TCP/IP product. This could lead to a commercial breakthrough for MMS; running this application-layer protocol on top of the widely used TCP/IP protocol eliminates the need for complicated and expensive OSI products. If MMS-over-TCP/IP were to gain status as a *de facto* standard, integrating shop-floor control systems would be greatly simplified.

4 CONCLUSIONS

The three examples of CIM networking practices, presented above, show that multiprotocol Ethernet-based networks can be successfully used as an information highway for CIM on the shop-floor. Networking problems reported in the literature are recognized but do not imply serious problems for a successful implementation if systems are carefully designed.

5 REFERENCES

Adams, W.M. (1988) Manufacturing network performance and environmental measurements, in *Proceedings of the ISA/88 International Conference on Advances in Instrumentation*, **43**, part 2, 573–588.

Adams, W.M. (1990) Why 802.3/Ethernet LANs flourish in manufacturing operations. *Computer-Integrated Manufacturing Systems*, **3** (1), 53–56.

Aggarwal, A., Agrawal, A., Aguilar, L. *et al.* (1987) Protocol standard for a NetBIOS service on a TCP/UDP transport: concepts and methods. Internet RFC 1001. Available at URL= ftp://ftp.chalmers.se/rfc/rfc1000–1099/rfc1001.

Aggarwal, A., Agrawal, A., Aguilar, L. *et al.* (1987) Protocol standard for a NetBIOS service on a TCP/UDP transport: detailed specification. Internet RFC 1002. Available at URL= ftp://ftp.chalmers.se/rfc/rfc1000–1099/rfc1002.

Ahmadi, J., Nayak, N., Ow, P.S., *et al.* (1991) Key Technologies for CIM in the USA, in *Proceedings of the 4th International IFIP TC5 conference on computer applications in production and engineering.*

Baker, R.H. (1992) *Downsizing – how to get big gains from smaller computer systems.* McGraw-Hill, New York.

Bartlett, B. and Harvey, J. (1994) The Modelling and Simulation of a Pick & Place Computer Integrated Manufacturing (CIM) Cell, in *Proceedings of the Advanced Summer Institute 1994*, in *Computer-Integrated Manufacturing & Industrial Automation*, **1**, 53–60.

Boggs, D.R., Mogul, J.C. and Kent, C.A. (1988) Measured Capacity of an Ethernet: Myths and Reality. *ACM Computer Communication Review*, **18** (4), 222–234.

Casey, B.J. (1990) Implementing Ethernet in the industrial environment, in *Proceedings of the 25th IEEE IAS Annual Meeting*, **2**, 1469–1477.

Coyne, R., Finger, S., Konda, S. *et al.* (1994) Creating an advanced collaborative open resource network, in *Proceedings of ASME Design Theory and Methodology (DTM)*, **68**, 375–380.

Hunt, W.C. (1995) *Networking Personal Computers with TCP/IP.* O'Reilly & Assoc., Sebastopol, CA, USA.

Penning, D.C. (1994) Computer Networking Practices in Small Manufacturing Enterprises. *Blue book series.* CASA/SME, Dearborn, MI, USA.

Pütter, J. (1995) Integrating computer platforms for higher productivity in manufacturing industries. *Journal of Materials Processing Technology*, **52**, 115–121.

Shaw, W.T. (1989) Ethernet-based plant automation architectures, in *Proceedings ISA/89 International Conference on Advances in Instrumentation*, **44**, part 2, 669–678.

Smythe, C. (1993) ISO 8802/3 local-area networks. *Electronics & Communication Engineering Journal*, 25–33.

Snyder, C.A. (1991) CIM networking: promise and problems. *International Journal of Production Engineering*, **23**, 205–212.

6 BIOGRAPHY

In 1989, Johan Pütter received his Master's Degree in electronics and electrical engineering from Chalmers University of Technology (Gothenburg, Sweden). From 1989 he is a Ph.D. student in the Department of Production Engineering at the same university. In 1993, he received the degree of Licentiate of Engineering. His research topics include computer integration in heterogeneous manufacturing environments and computer network technologies for open systems.