Network Management: A Tutorial Overview

Richard E. Caruso

INFORMATION, AS DEFINED IN WEBSTER'S Dictionary, is "the communication or reception of knowledge." If knowledge is power, then communications and the networks that support that communication are the keys to the kingdom. The term "information networks" represents an interesting "marriage" of information processing and telecommunications networks, which are the enablers of the new "Information Age." Information networks encompass exciting opportunities and challenges that must be addressed to unlock the true potential of this new age. Much has been written about the new opportunities, but not nearly as much about the challenges. Among these challenges, there is perhaps none greater than the need to efficiently and effectively manage the resources involved. This is the task of Network Management (NM). This article and the rest of this Special Issue will explore the difficulties of managing information networks from the perspective of today's and tomorrow's typical enterprise, whether small and large businesses, government agencies, universities, or other organizations, and eventually even residential customers.

Information networks of the modern enterprise are characterized by computerization and automation of important daily corporate activities. These activities range from payroll, accounting, and inventory to reservations, manufacturing and process control, publishing, computer-aided design and manufacturing, funds transfer and financial services, customer support, and many other areas. These applications are used not only within the enterprise, but increasingly also provide electronic connection to both suppliers and customers, and interconnection to information networks outside the control of that enterprise. At the same time, applications have been developed to support many clerical and managerial functions such as word processing, spreadsheet, presentation preparation, and electronic mail. Video, videotext, facsimile, graphics, and other media are also becoming very important. As these trends have emerged, the information network has grown rapidly in size and importance to the enterprise.

What trends have emerged in managing the modern enterprise information network? There has been an exponential increase in complexity. The modern enterprise often contains a wide variety of network wiring schemes, access methods, protocols, equipment, and networking technologies, as discussed later. Many vendor-specific Network Management Systems (NMSs) exist, but there is very little correlation and integration between these. This makes it difficult to have any single point of operational control or platform to allow automation of management functions, and to find and retain qualified network management personnel. Thus, staff costs are becoming an ever larger percentage of the information network budget, now running almost 30% of total expenses [1]. Another trend is that voice and data communications are frequently becoming physically integrated and are often supported by a common organization because many customers want one integrated information network.

There are two kinds of people within the enterprise that need network management support. First, each and every employee needs the ability to control his/her own use of information services. This trend is easily understood in terms of current advanced voice services such as call forwarding, speed calling, and multi-party calls. These users will have similar but more complex NM needs for data services to update their user profiles and interactively signal the network in real time to control their own services. However, most NM responsibilities reside with the communications manager[1] job position, which may be combined within a single organization or have separate positions responsible for voice communications management and data communications management. The communications manager has the responsibility, at the enterprise level, to provide NM for the enterprise information network, including such specific functional tasks as planning, ordering and installing, configuring, repairing, tuning, accounting and billing, reporting, and controlling network security. The communications manager needs the ability to integrate and correlate both the NMSs within the enterprise and the NMSs provided by other network service providers such as public carriers. This integration of private and public management systems is often referred to as "hybrid" network management. It is within this broad definition and context that the challenges and needs of customer network management will be discussed in the rest of this article.

Historical Review

Telephony

The oldest communications network to be managed is, of course, the telephone network. Network management is essen-

[1] In this article, we use the term "communications manager" to refer to the people who manage the network from an enterprise's perspective, and we use the term "network manager" to refer to both the people who manage the network from an enterprise's perspective and the people who manage the network from a service provider's perspective.

0163-6804/90/0003-0020 $01.00 © 1990 IEEE

tially as old as the telephone itself. As a matter of fact, the first network managers were telephone operators. With their direct contacts with end users, telephone operators were the first people who could detect network-affecting problems such as network equipment failure and traffic overloads, activate real-time controls such as rerouting traffic or blocking traffic from entering a congested network, and initiate maintenance activities such as sending trouble reports to technicians.

With the advent of Direct Distance Dialing (DDD) in the 1950s, when end users no longer had to go through telephone operators to make long distance calls, the role of the first network managers (the telephone operators) decreased significantly. A mechanized substitute was needed to take up the previously mentioned NM role of the telephone operators. Technology came to the rescue in the 1960s and 1970s with the introduction of Stored-Programmed-Control (SPC) switches and computerized Operations Systems (OSs). With SPC switches, the fabric that governs their operation is software-controlled instead of hardware-controlled. This means that more sophisticated network monitoring, data collection, and network control capabilities could be added. With OSs, many manual operations could be mechanized. Furthermore, since a single OS can monitor and control a large number of switches, OSs make centralized NM possible. For example, a single network traffic management OS can monitor and control hundreds of switches over a large geographical area. Today, hundreds of OSs are helping to manage telecommunications networks.

Historically, telephone companies considered network management mostly from their perspective as network providers, not from the perspective of customers. As network services became more sophisticated and as telecommunications became a critical part of a customer's business success, Customer Network Management (CNM) services were made available. One familiar example is the CNM service allowing end users to change their service profiles, e.g., call forwarding number or speed-dialing list. Other examples are CNM services allowing customers, usually the communications managers of business corporations, to reconfigure their private-leased-line network through digital cross-connect systems or to make station rearrangement of their Centrex service.

Computer and Information Processing

Before we continue the discussion of the evolution of telecommunications networks, we first discuss computer and information-processing NM. In 1954, the Transceiver, a terminal attached to telephone lines, was first introduced to transmit punched-card data to a computer [2]. As the use of computers became more widespread through the early 1970s, remote data communications access was supported through the use of public switched or private leased lines. By today's standards, these networks were small and simple, and NM techniques were primitive. A major emphasis was on correcting faults and other problems. Customer diagnostic techniques isolated faults in one of four primary network components: a central processing unit, terminals, customer-owned data communications equipment, and carrier circuits [3]. These techniques were frequently far from satisfactory, and customers were often forced into a "finger-pointing" game in trying to resolve whether the problems lay with their equipment or the phone lines.

The advent of the modern era of customer-based NMSs began in earnest in the mid-1970s, when modem vendors began to introduce intelligent test modules that communicated with a main controller located at a central communications site. Modems communicated with the controller using a low-speed (75–100 b/s) secondary channel, independent of the user's data channel but sharing the same telephone line. This equipment allowed communications managers to better isolate failed components. Some systems also supported simple self-healing capabilities, such as switching to spare modems or backup telephone lines within seconds after a failure, so that information services could remain available to end users as repairs were made off-line; this greatly increased the availability of the enterprise information network.

During the late 1970s, IBM also developed mainframe-based NMSs for its modem networks, but used in-band interleaving of management and user data on the same channel. Diagnostic data about modems could now be combined with diagnostic data about front-end processors and host computers, processed by software on their mainframes. Mainframe software was used to support not only fault management, but other NM areas as well.

Throughout the 1980s, microprocessor-based test units have been built into many types of multiplexors, X.25 PAD equipment and other switches, Local Area Networks (LANs) and Private Branch Exchange (PBX) managers, and other network components, in addition to modems. Many of these units also support performance and other functional areas of network management in addition to fault management. Software systems have also been introduced by many vendors and service providers to assist in such areas as network design, accounting, and security. Hundreds of NMSs are available on the market today [4].

Faced with the vital importance of their information network and the vastly increased complexity of network management, today's communications managers have had to take a pro-active approach in carrying out their jobs. Pro-active communications managers start with end-user requirements and service-level agreements to define overall information network objectives, and derive a strategy that not only takes into account the selection of proper hardware, software, and management database tools, but also addresses the procedures and other human factors that will be carried out by the network planning and operational staffs [5].

Information Networks

While new technology and business and social needs are transforming computing and information processing into distributed environments with sophisticated communications networks connecting various components, the same new technology and business and social needs are also causing Plain Old Telephone Service (POTS) to transform into sophisticated telecommunications networks with a great deal of processing power. Intelligent databases are being introduced in the public telephone network to offer services such as 800 Service; Common Channel Signaling (CCS) is being introduced to allow faster and more complex signaling between different parts of the network, leading to more sophisticated intelligent network services; packet switches and broadband transmission facilities are being introduced to provide data and multimedia services; Switched Multi-megabit Data Service (SMDS) is being introduced to provide high-speed data services (e.g., 45 Mb/s) for applications such as connecting LANs together; integrated access to voice, data, and video services is being provided first with Integrated Services Digital Network (ISDN) and then with Broadband ISDN (BISDN). The conclusion that one draws is that the distinction between information processing and telecommunications networks has blurred so much that it is no longer meaningful to talk about them as separate entities. Instead, one should combine them and refer to them as the information network. Information and rapid access to information is so critical to many enterprises that they do not want to rely completely on a third party to manage "their" information network. This is why customer network management is becoming so important. Since the focus of this article (and this Special Issue) is on NM from the enterprise's perspective, NM and CNM are often used interchangeably.

Table I.

Category	Examples
Fault Management	Fault detection, trouble reports
Performance Management	Performance monitoring, alerts
Configuration Management	Network topology database, bandwidth allocation, routing changes
Accounting Management	Traffic usage statistics, billing reports
Security Management	Secured access, intrusion detection/recovery
Capacity Management	Forecasting, engineering
Provisioning Management	Service ordering/tracking, pre-service testing
Administration Management	Customer-controllable service profiles, management reports

The ISO/CCITT NM standards use only the first five of these eight functional categories. This is because ISO/CCITT concentrate more on the real-time aspects of NM, and furthermore, some of the functions that are associated with the other three categories can be considered to be implicitly included in ISO/CCITT's first five categories.

Summary of Customer Needs and Market Segmentation

As discussed in the previous section, enterprise information networks are very complex, involving many different types of hardware and software components. These components include modems, multiplexers, front-end processors, Personal Computers (PCs) and workstations, minis, mainframes, T1 backbone networks, LANs, Wide Area Networks (WANs), Systems Network Architecture (SNA) networks, Very Small Aperture Terminals (VSATs), microwave networks, satellite networks, phones, PBXs, circuit switches, packet switches, local and interoffice transmission facilities, OSs, etc., as well as many different operating systems, database management systems, other systems programs, and innumerable application programs. Providers of information network services need network management capabilities to manage all these components. Furthermore, information network service providers need to provide significant subsets of these NM capabilities to their large business customers (i.e., provide CNM capabilities). To their smaller business customers, the CNM subsets would be significantly smaller, and to their current residential customers, the CNM subsets of capabilities would be even smaller.[2]

There are a large variety of NM products, supplied by many vendors, to support these various components. Most of these NM products traditionally support specific components. For example, modem NMSs provide NM for modems only; Transmission Resource Managers (TRMs) provide NM for essentially T1 networks only (but are beginning to extend to T3 networks); various SNA NM packages provide NM for SNA networks only; various telephone company OSs provide specific NM functions (such as performance monitoring, trouble report generation, and billing) for the public network switches and transmission facilities. Furthermore, these various products in general do not interoperate, often even for different products provided by the same vendor. This means that a large enterprise would need to purchase a large number of NM products or services from many vendors. Such an enterprise's network management center(s) consists easily of a dozen or more terminals and/or workstations and printers connected to various NMSs. Not only is it costly in terms of equipment, personnel, and training to manage the enterprise's information network; but network management is done in a fragmented and nonintegrated manner. Essentially, all integration is provided by the human mind. The highest-priority item on the customers' NM wish list is interoperability and integration.

Even with the support of current network management systems, communications managers still need to do many manual functions. For example, they have to correlate alarms and exception reports, analyze large amounts of data to isolate faults, and formulate work-around solutions to problems at hand. This is partially due to the noninteroperability of NMSs mentioned earlier, and partially due to the nonexistence or limited sophistication of expert system techniques in the NMSs. Therefore, another important NM customer need is to automate, as much as possible, human integration capability through expert system and artificial intelligence techniques.

The rapid increase in size, complexity, and importance of enterprise information networks results in a great demand for, and therefore a shortage of, skilled NM personnel. On one hand, corporations do not want to leave the management of one of their critical corporate assets completely in the hands of a third party; but on the other hand, they may not have enough qualified staff to perform that function. Meeting the two previously mentioned needs of integrated NM and automated NM would greatly reduce the need for a large number of skilled NM personnel. Improving the ease of operability of NMSs with better user interfaces would also help to solve this problem.

In the past, the network that carried voice traffic and the network that carried data traffic were often distinct. With the blurring distinction between information processing and telecommunications networks, it is becoming more common that various types of traffic (voice, data, video, and multimedia) are all carried in the same information network. The increased complexity of the network makes the network manager's job more complex. For example, a wider distribution of call holding times makes capacity planning more difficult; the inclusion of voice calls in a packet switched network makes it more difficult and urgent to analyze abnormal performance delay statistics; and the different bandwidths required for various types of traffic make customer-controllable bandwidth-on-demand more critical and configuration management more difficult. Therefore, more sophisticated NM tools are needed to manage such integrated information networks.

The above discussion of market needs also points to several possible segmentations of the NM market. First, there is a segmentation of "component NM service providers" versus "integrated NM service providers," or "NM systems integrators." The former concentrates their products/services on one or a small number of components, such as modems, T1 multiplexers, packet switches, etc. The latter concentrates their products and services on the whole, or at least a large portion of the information network of an enterprise. These two segments are, of course, not necessarily mutually exclusive; a company could be a provider of both types of NM products and services.

[2]However, in the future, as information networking services for smaller business customers and residential customers become more sophisticated, their need and demand for CNM capabilities will increase significantly.

Since divestiture, information networks in the U.S. are divided into three major domains: Customer Premises Equipment (CPE), Local Exchange Carrier (LEC), and Inter-Exchange Carrier (IEC). These three domains provide another possible segmentation of the NM market. Still another segmentation of the NM market is obtained by classifying NM products and services by the type of technology supported, e.g., PBXs, modems, LANs, TRMs, packet switches, SNA, ISDN, broadband, etc. This could be considered to be a sub-segmentation of the previously mentioned "component NM service providers." An additional possible segmentation of the NM market is obtained by classifying NM products and services according to the supported NM functional category. There are several ways of dividing NM into functional categories. One possible division is into the eight functional categories shown in Table I. A product could, of course, support more than one functional category.

One could think of other ways of segmenting the market, e.g., by the size of the enterprise or by the relative focus on providing NM for communications managers or end users, etc. Because an NM product or service is often applicable to more than one segment of the market, there is not always a clean way of segmenting the market. Therefore, the different ways of segmenting the market should be considered to be complementary.

Industry's Response to the NM Challenges

There are four major thrusts in the industry's response, as summarized in Table II and discussed below.

First, new or improved CNM capabilities are introduced in various Network Elements[3] (NEs) and existing NMSs, and new NMSs are constantly being introduced. A wide spectrum of CNM capabilities are provided. A few examples are protocol analyzers; second-generation T1-multiplexer-based NMSs, also called TRMs, that can combine rapid reconfiguration and other capabilities with multiplexing; PBX NMSs; a proliferation of LAN NM software packages and NMSs; NMSs that monitor carrier transmission facilities and provide mapping between facilities and trunk groups; network design software packages; consolidation of previous NM software packages; graphical user interfaces; multi-tasking/multi-windowing NM work stations; expert systems techniques; etc.

The second thrust is that many alliances or acquisitions have occurred. These alliances and acquisitions have been stimulated by the fact that, although working to establish NM standards, the industry cannot wait until these standards are established before taking action to meet customer demand for interoperability and integrated NM. Some notable alliances and acquisitions are IBM's alliance with Network Equipment Technologies, AT&T's alliance with Cincom, AT&T's acquisition of Paradyne, and Unisys's acquisition of Timeplex. Such alliances and acquisitions may result in some interoperability and integration of the NM capabilities of these vendors' products.

The third thrust is to provide an overall NM architecture. Since the focus of this article is from the perspective of the enterprise customer, it is more accurate to use the term CNM architecture. This CNM architecture should indicate a framework for NM system interoperability in a multi-domain environment and how customers access the CNM capabilities. Although there are many different CNM architectures, most of them do have some commonalities. For example, CNM services could be offered through NEs,[4] Gateway-NMSs (GW-NMSs), or any combination of these. In order to offer these CNM services, new capabilities, including security capabilities, may be required in these components. In general, there are two methods for customers to access these CNM services. One access method is mostly for the communications managers of enterprises; its access is through a CPE NMS. The second access method is mostly for individual end users; its access is through the same CPE that an end user normally uses for communications. Within each domain there may exist one or more GW-NMS(s). The GW-NMS provides integrated access to the NMSs of a particular domain; it also serves an important security function. To help meet the customers' end-to-end CNM needs, the different domains' NMSs must be able to communicate with each other, preferably on an application-to-application basis.

Table II.

Thrust	Description
First	New/improved CNM capabilities and new NMSs
Second	Alliances and acquisitions
Third	CNM architecture
Fourth	Standards and standards-related activities

Besides the above features, which are fairly common across many CNM architectures, there are several features that differ among CNM architectures. For example, what kind of interface protocols should be used for the above application-to-application interface between two inter-domain NMSs? Should it be based on the Open Systems Interconnection (OSI) application-layer management protocol Common Management Information Protocol (CMIP), a simpler protocol like Simple Network Management Protocol (SNMP), protocols based on SNA, or some other protocols? Even if agreement can be reached that the target should be OSI-standardized protocols, what should be used during the transition period and how long is that transition period? Another example of differences is the relative importance placed on an Integrated Network Management System (INMS). Some argue that with proper intelligent CNM capabilities built into the various NEs and NMSs, a distributed CNM architecture with proper interactions between the various components is sufficient. Others argue that for the foreseeable future, it is necessary to have an INMS (or multiple INMSs) that provides a global, unified network management view of the entire enterprise information network. Similar to the inter-domain NMS-NMS interface, there is also the question of the type of protocols that should be used in the INMS-NMS interface. Another question is the urgency to standardize the NE-NMS interface. Some argue that as long as there is interoperability at the NMS level, one could live with different NE-NMS interfaces. Others argue that without standardizing the NE-NMS interfaces, it is very difficult, if not impossible, for an NMS to manage NEs from different vendors. This reduces customers' options when buying equipment from multiple vendors and increases the number of needed NMSs.

Within the discussion presented above, the most general CNM architecture is shown in Figure 1. This generic CNM architecture contains the INMS concept, and has standardized interfaces both for inter-domain NMS-NMS interfaces and for NE-NMS interfaces.

The fourth thrust includes three standards and standards-related activities designed to lead to wide-scale NM interoperability. These activities are development of a set of OSI Management standards for network management, specification of companion implementation agreements, and provision for

[3]The term "Network Elements" as used in this article includes CPE.

[4]Recall that NEs include CPE.

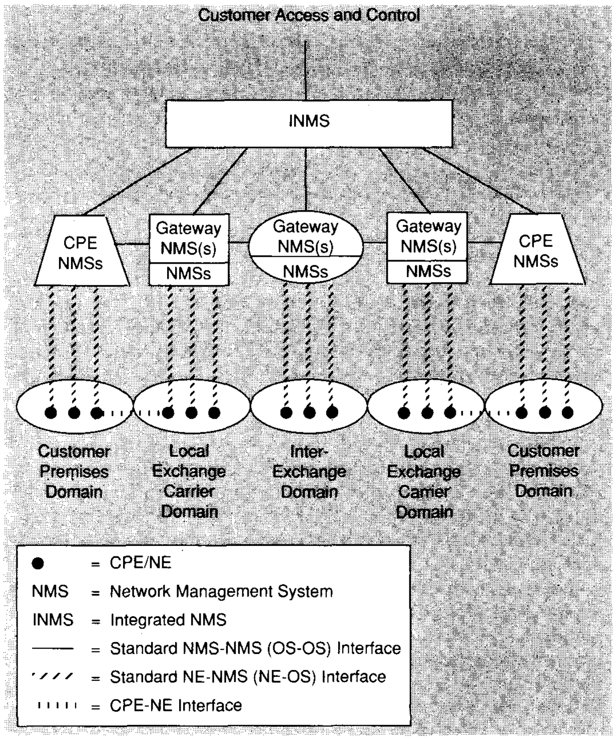

Fig. 1. Generic CNM architecture.

conformance testing capability. These activities are described in the remainder of this section.

OSI Management Standards

The aim of OSI Management standards is to allow interoperability and true integration between the large number of separate, isolated NM products and services in today's information networks, and the many different network components that are managed. Numerous articles and papers summarize the nature of standards activities [6] and review the various groups involved within International Consultative Committee for Telephone and Telegraph (CCITT) [7] and International Organization for Standardization (ISO) [8] as well as other organizations contributing to the standards process.

Establishing NM standards is extremely challenging for four reasons. First, the multitude of today's NM products and services were originally developed and optimized for the particular proprietary requirements of each vendor or carrier without anticipating the need to support open interoperability. Second, because NM is complex and must satisfy many requirements, a successful solution for interoperable network management requires careful and detailed work in defining the necessary open architecture, protocols, distributed management mechanisms, and structuring of information exchanged in messages about managed components. Third, the work must be done so that minimum constraints are placed upon the way vendors and network service providers will implement the standards. This makes it possible to implement standards across a wide variety of equipment types—from small, relatively simple, and inexpensive systems to large, complex systems. This approach will speed the acceptance of standards by all suppliers of NM products and services as well as shorten the time and cost in their implementation. Finally, standards must be designed in a flexible manner that anticipates their evolution needs. Standards have to evolve to accommodate both new technologies as well as ever expanding capabilities meeting increasing user needs. This trend must be planned for in the initial OSI Management standards.

OSI Management standards draw heavily on the principles of object modeling. A very simple model of OSI Management can be described as a set of interactions between one or more managing processes and one or more managed processes, also known as "agent processes" (see Figure 2). A managed process is responsible for one or more managed objects. A managed object is an abstract representation of any resource from a management perspective. A managed object may represent a physical thing (e.g., a multiplexer) or it may represent something that is itself an abstraction (e.g., a customer account). The shared conceptual repository of all managed object information is known as the Management Information Base (MIB). A managing process manipulates information maintained by an agent process using the services provided by the Common Management Information Service (CMIS) and conveyed in corresponding CMIP operations.

Within the MIB, information is largely embodied in terms of the attributes associated with objects. Each attribute of an object has a value. The CMIS provides services to retrieve (Get) and modify (Set) attribute values, and create (Create) and delete (Delete) objects. In addition to objects, information may be embodied in notifications using the CMIS service EventReport. Notifications signal the occurrence of some event related to an object, e.g., a state change. These five services provide the capability for manipulating and reporting managed object data. CMIS also provides the Action service to control managed objects. The Action service is used to cause specific physical activities, e.g., to request the execution of a diagnostic test.

The initial OSI Management standards described above are projected to be completed during 1992. Many parts will reach final standards status before that. Standards defining CMIS and the CMIP protocol have already achieved this status. Work by various layer-expert groups throughout CCITT and ISO specifying managed object definitions can be projected for completion in roughly the same time frame, though some may feel this is an optimistic projection. Some parts of this layer management work will also be completed before this date.

Implementation Agreements

OSI Management standards are the first step to NM interoperability. The next step is to specify implementation agreements, also known as profiles. Implementation agreements serve several needed purposes. There are many protocol options at each OSI layer. Profiles specify which particular options must be implemented, include conformance statements related to these selections, and may discuss testing concerns related to conformance. Profiles also specify many implementation details not included in the standards.

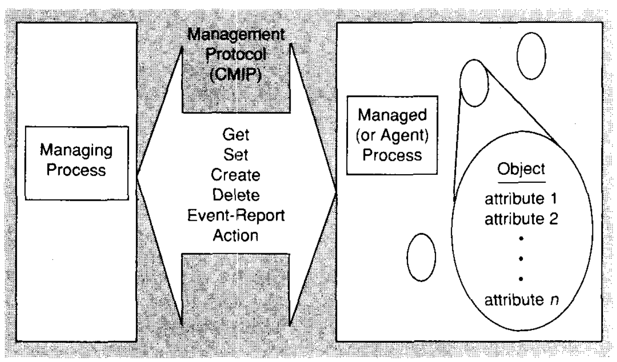

Fig. 2. Management domain.

An NM Special Interest Group has been working since July 1987 in the OSI Implementors Workshop (OIW) and is writing implementation agreements for the emerging OSI Management standards. Most of the participants in the OIW are from North America. The European Workshop for OSI Standardization (EWOS) and the Asian Workshop for OSI Standardization (AWOS) are two other implementation workshops. All three have agreed to resolve any differences and submit their input to ISO, which will then issue International Standardized Profiles (ISPs). Although draft ISPs exist for other areas of OSI standards, there is as yet no draft ISP for OSI Management, due to the premature state of some of the requisite OSI Management standards.

Conformance Testing

Another important step in helping to support interoperability is conformance testing. Conformance testing determines whether an implementation complies with the relevant OSI standards and profiles, and thus greatly increases the probability that different implementations can interoperate, although it cannot ensure this.

OSI testing agencies have been established around the world. In the U.S., the Corporation for Open Systems (COS) was established for this purpose in March 1986. In Europe, Standards Promotion and Application Group (SPAG) Services, and in Japan, the Promotion of OSI (POSI) organization also serve as testing agencies. These three groups are working cooperatively, and formal agreements to share work exist between COS and SPAG Services. No conformance testing for OSI Management exists yet, but COS and SPAG provide conformance testing for the interim MAP/TOP 3.0 NM specification. COS and SPAG have also agreed to provide conformance testing for the emerging interim specification currently being developed by the OSI/NM Forum. The OSI/NM Forum is an international consortium of information network equipment vendors, service providers, and users working to accelerate the development and promote the use of OSI standards in order to achieve and demonstrate multivendor NM interoperability.

Summary And Outlook

Developments in the past two decades in information processing and telecommunications networks have resulted in a proliferation of computing networks of distributed processors and the placement of processors in telecommunications networks. This has blurred the distinction between information processing and telecommunications networks, and combined them into information networks. Information—and rapid access to information—is becoming a critical competitive tool for large business customers. Their information networks are so important that they do not want to leave their management completely in third-party hands; they want CNM.

To meet customers' needs for CNM, a large variety of CNM products have been supplied by a large number of vendors. Unfortunately, these products in general do not interoperate, often even among different products of the same vendor, resulting in the customers' cry for interoperability and integrated NM. The current family of products also still requires many manual functions, resulting in a second customer need, automated NM. The rapid growth of information networks and the need for customer control of their information networks have resulted in a shortage of qualified network management personnel, giving rise to the need for better user interfaces to improve the usability of NMSs. The increased complexity of information networks, especially combining voice, data, video, and multimedia services on the same network, makes the network manager's job much more complex, and therefore, more sophisticated NM tools are needed.

Faced with these NM challenges, the industry has responded with four major thrusts. The first is to introduce new or improved NM capabilities in various NEs and existing NMSs, and introduce new NMSs. The second is to form strategic alliances or make acquisitions to broaden a company's base and result in partial interoperability. The third is to provide an overall CNM architecture to establish a framework for CNM interoperability and indicate how customers can access CNM capabilities. The fourth thrust is to establish industry standards to support wide-scale interoperability and integrated NM.

We end this article with a few words about the future. Besides moving toward the goal of interoperability and integrated NM, the industry is also moving toward automated NM. Many vendors have already introduced expert systems products; this will be a major trend in the decade of the 1990s. There is already a lot of work on improving user interfaces, e.g., using more, as well as more sophisticated, graphic displays; this area will continue to expand. Another trend is more management of the customers' applications, and integration of that management with the management of the physical and logical network. Future NMSs should also allow communications managers to customize NMSs to their own particular needs. Currently, the main users of CNM are mostly the communications managers of large enterprises. However, as the end users' (including smaller enterprise and residential end users') information services become more sophisticated, providing CNM services directly to the end users will become more significant. Thus, the second access method in the generic CNM architecture, directly from the end user's normal communication equipment to the information network, will become significantly more important. Finally, as information networks are designed to become self-healing networks, i.e., more reliable, survivable, and available, the need for certain aspects of CNM will actually decrease!

References

[1] D. K. Goyal, "Digital's Network Management Perspective," *Proc. of the Nat'l. Commun. Forum*, vol. 42, no. 1, pp. 855–856, Sept. 1988.
[2] R. J. Cypser, *Communications Architecture for Distributed Systems*, Reading MA: Addison-Wesley, 1978.
[3] J. McDowell, "Building a Network Management Strategy," *Bus. Commun. Rev.*, pp. 41–47 July-Aug. 1988.
[4] "Network Management Systems," C38-10-101, *DATAPRO Research*, Delran, NJ: McGraw-Hill, 1988.
[5] K. Terplan, *Communication Networks Management*, Englewood Cliffs, NJ: Prentice-Hall, 1987.
[6] S. M. Klerer, "The OSI Management Architecture: An Overview," *IEEE Network*, vol. 2, no. 2, pp. 20–29, Mar. 1988.
[7] R. C. Boyd and A. R. Johnson, "Network Operations and Management in a Multi-Vendor Environment," *IEEE Commun. Mag.*, vol. 25, no. 7, pp. 40–47, July 1987.
[8] A. H. Grossman, "OSI Management Standards," *Proc. of the Nat'l. Commun. Forum*, vol. 42, no. 1, pp. 843–847, Sept. 1988.

Biography

Richard E. Caruso is the Assistant Vice President of the Network Services Planning Center, Bell Communications Research (Bellcore). The Center provides product management, network architectures, services planning, and implementation support for the Advanced Intelligent Network (AIN).

Since starting his career at Bell Laboratories in 1969, he has been involved in the systems engineering, design, and development of operations support systems for the Bell Operating Companies. In 1983, he was appointed Assistant Vice President of Interoffice Mechanization at Bellcore. In November 1985, he assumed the position of Assistant Vice President of Planning and Engineering Applications. In July of 1988, he assumed the position of Assistant Vice President of Major Network Projects Implementation. He assumed his present position in January 1989 and is located at the Bellcore Navesink location.

Mr. Caruso received a Bachelor of Science degree from Rutgers University in 1968 and a Master of Science degree from New Jersey Institute of Technology in 1971, both in industrial engineering and operations research.