TELEMATICS and INFORMATICS Vol. 7, No. 1, pp. 33–41, 1990

0736-5853/90 $3.00 + .00

# MULTIFUNCTIONAL COMPUTER NETWORKING TECHNOLOGY FOR DEVELOPING COUNTRIES

*V. Vemuri*

**Abstract** – This article explores the intriguing and challenging idea of building a hierarchy of multimedia networks to share information. Although the solutions to many of the technical problems are at various stages of exploration in the developed world, it is not too early to investigate the potential benefits and the practical difficulties in transplanting this technology to the developing countries. An overview of the challenges and the prospects of a "global village" are explored.

## INTRODUCTION

It is becoming impossible to ignore the impact of the revolution that is taking place in information technology. The continuing increase in computer speeds, the falling costs of data processing and data storage, and the emerging technologies for multimedia communications are creating remarkable new possibilities for enriching our informational environment.

It has been well recognized that recent developments in computer and communications technologies rival those of the Industrial Revolution primarily because they give us the opportunity to control the acquisition, processing, and distribution of information. It has been widely accepted that timely investment in computer and communications technologies is one secure method of increasing productivity, which, in turn, will contribute to the maintenance of a competitive edge in the world market. The scope of this new revolution need not be confined to market-oriented productivity. For example, "telehealth" networks can provide a mechanism for improving both communications and access to health care facilities in rural areas in developing countries by creating sharable regional facilities and services (e.g., diagnostic, consultation, etc.). "Teletutorials," along with real-time dialog capabilities, can rapidly replace "instruction by mail." In fact, the importance of the field of information sciences has grown to the extent that it is beginning to claim a place alongside the three R's of knowledge, namely Reading, wRiting, and aRithmetic. The essence of this ongoing revolution, which has been confined so far to the developed countries, is captured by terms such as *informatics* and *networking*. This is the technology of interconnecting computers and databases using a hierarchy of local, regional, national, and global networks. The purpose of this article is to summarize the state of the art of this technology and put together some thoughts on its potential role in the development plans of emerging countries at a cost that promises to be affordable.

---

V. Vemuri is with the Department of Applied Science, University of California, Livermore, CA 94550.

The basic theme explored here is *resource sharing*. The resources in question include computing facilities such as high-performance processors; input/output facilities such as mass storage or printing facilities; software facilities like databases, text formatters, and software tools; and communications facilities such as networks, *gateways*, and *bridges*. These resources can be shared through remote computation, that is, the execution of a program or service on a computer other than the one used by the client. The shared resources can be used not only for transmitting multimedia information (e.g., alphanumeric data, text, voice, graphics, video, facsimile, etc.) but also for a variety of other applications such as teleconferencing (Sticha, Hunter, & Randall, 1981), multimedia communications (*IEEE Computer*, 1985), computer-based message systems (CBMS) (Cunningham et al., 1982) and so on (*Proceedings of the IEEE*, 1986; Thomas et al., 1985). In multilingual communities such as India, the European Economic Community, and the USSR, the scope of CBMS can be extended to both inter- and intraoffice communications across heterogeneous language barriers. An associated theme is *load sharing*. Regional load sharing networks, not unlike the electrical power grids, can provide greater computer capabilities to all participating parties at a minimum additional cost.

## NATURE OF THE TECHNICAL PROBLEM

The central technological issue to be explored in this paper can be succinctly stated as follows: to design and develop a communications network, composed of a hierarchy of local and regional networks, capable of interconnecting heterogeneous computer and information resources, at geographically dispersed locations, so that the representation and dissemination of machine processable information expressed in multiple media can occur in an intelligent, practical, and cost-effective manner.

Functions supported by this network might include one or more of the following:

1. Multimedia document creation and processing for office applications.
2. Both store-and-forward and real-time electronic mail.
3. Telebrowsing, bibliographic search, and information retrieval.
4. Teleconsultations and teleconferencing.
5. Teletutoring.
6. Resource sharing in higher education and research.

### *Example 1: Bibliographic search*

Communication is the essence of scholarship. Libraries and electronic databases play an important and indispensable role in this communication process. Legal databases such as *Lexis* and *Westlaw* now contain virtually all the material that used to comprise the core of a practitioner's library.

> Much of the world's scientific and technical information is contained in the more than 2,800 databases that are now available online, and that number is increasing weekly if not daily. The problem for many scientists and engineers is learning what databases there are and what systems allow access to them. . . . [Online services (be they search and retrieval services or time-sharing services), which may be called *information utilities*], permit the wide sharing of tremendous resources: databases, large computers, and sophisticated software through communication networks. (Williams, 1985)

The above quotation in conjunction with the following facts gives us an idea about the complexity of the bibliographic search problem. The number of bibliographic references available on-line, worldwide, has been estimated to increase at the rate of 8.7 million references per year. In North America alone, the number of searches on public systems has increased 18-fold during the period of 1975 to 1985. The number of databases available on-line increased 5-fold during the period 1980 to 1985. And the number of citations increased from 70 million in 1976 to 1.68 billion in 1985. Not only is the sheer volume of available information overwhelming, but also several of the on-line systems use different retrieval languages and structure their databases differently. Thus, the information specialist not only may need to know several retrieval languages, but also must maintain an awareness of the advantages/disadvantages of one system over another where the same database is available from more than one source. The following are a few of the databases that would be of interest to chemists. These databases contain not only reference information, but also text, structures, data, graphs, and so on.

### *A sample list of chemical databases*

1. CAS—Information on chemical substances referenced in the world's scientific and technical literature. The information includes references to published literature, molecular structure diagrams of over 6.5 million substances, and over 9 million names of those substances. [Chemical Abstract Services, P.O. Box 3012, Columbus, OH 43210.]
2. CRYSTMET—National Research Council of Canada's Metal Crystallographic Data File containing information on metallic structures determined by defraction methods. [Canada Institute for Scientific and Technical Information (CISTI), National Research Council, Montreal Road, Ottawa, Canada KIA OS2.]
3. FDMB—Fusion Reactor Material Database. Contains information on the fundamental properties of materials that are likely to be useful in fusion research. [University of Tokyo, Department of Nuclear Engineering, 7-3-1 Hongo, Bunkyo-ku, Toyko, Japan.]

Suppose a researcher is interested in searching the DARC, the *Chemical Structure and Nomenclature File*, which is a master directory of over 6 million chemical substances and is located in Paris. For this master directory or database to be truly useful, an authorized user, who may be located anywhere in the world, should be able to perform the search, possibly for a fee, by logging on at a local terminal and typing a command such as CONNECT DARC. That is, the details and complexity associated with the access should be "invisible" (or *transparent*, as it is called in the jargon) to the user. Subsystems which provide this capability are often called "transparent systems," "user-friendly front-ends," "intelligent intermediaries," and "intelligent gateways," depending upon the features and capabilities they offer. For example, an intelligent gateway automatically routes a user request to an appropriate system without the user needing to know the access codes, telephone numbers, passwords, and protocols. Several such gateway systems have been built. Some of the more important ones are the IGC (intelligent gateway computer) of the Lawrence Livermore National Laboratory (LLNL) in the U.S.A., iNET of Bell Canada, and the TPA/70 gateway of the International Institute of Applied Systems Analysis in Austria.

At LLNL, for example, extensive work is being done to transfer IGC technology to solve problems in a variety of application areas such as Fact Retrieval for Transportation Systems Research, International Information Networks for Material Properties, Crosslinking of Computer Terminals for Nationwide Tutorial Instruction, to mention a few. The power of this technology was demonstrated in 1984 at the Ninth International CODATA Conference in Jerusalem when scientists at the conference searched a bibliographic database in Paris, forwarded the French text to a computer-aided translation service in Los Angeles, and viewed the English translation within an hour on the screen in the auditorium. Communications for this experimental demonstration were performed via a 1200-baud ISRANET link to TYMNET, which, in turn, provided a connection to the IGC at LLNL. Once the IGC made the connections, which took about 60 seconds, users in Jerusalem were able to choose one of the several available information centers and direct their search query to that database.

### *Example 2: Teletutorials*

The use of worldwide multimedia computerized communications networks for educational and training purposes is an intriguing possibility whose time has come. While teaching science courses, which traditionally involve laboratory demonstrations, compelling arguments can be made for the combined use of video, sound, and computer graphics to supplement traditional hands-on laboratory experience. With this technology not only special phenomena can be demonstrated with audio and video cues, but one can also show a much wider variety of experimental apparatus than could conveniently be shown in a college or university laboratory.

From a purely pedagogical viewpoint, certain advantages can be derived from computer-controlled interactive courseware. For example, many academic skills amount to the ability of applying certain algorithmic skills rapidly and correctly. Application of these skills often depends upon other subskills. Computer-controlled methods can focus on imparting to the student one skill at a time while relegating other aspects to the computer (*Academic Computing*, 1989).

The above two examples, with an admittedly academic slant, are given for illustrative purposes only. If a nation builds an information network, it would be a national resource; it can be used in a variety of ways. For example, researchers in the laboratory as well as practitioners in the field will be able to exchange information by transferring extensive computer files, watching animated graphic results of a simulation on a remote supercomputer, or participating in a conference taking place in a remote place.

### *Technical challenges*

Although the visionary scenario presented above is appealing, computer networks, designed to link researchers through their individual workstations, are "fragmentary, overloaded, and poorly functioning," according to a report by the National Research Council (NRC). The report also points out a serious mismatch between today's high-performance computers and low-performance computer networks.

A major implementation challenge associated with the bibliographic search example described above is the need to resolve probable incompatibilities among different databases. These incompatibilities include different underlying data models, different domain definitions for comparable attributes, and inconsistent data formats. Equally important is the need to resolve incompatibilities among different types of computers, operating sytems, and different communications protocols used by different vendors.

One possible method for solving the database incompatibility problem is to create a *global schema* and require that all local database management systems (LDBMS) be interfaced with this global schema. This concept is somewhat analogous to a *modified United Nations model* where the speech of any leader is first translated into a "global dialect," and the individual nations provide their own translators to render a second translation from the global dialect to their own local dialects. Another approach is the use of a common command language which carries out a translation between the user's language and the targeted retrieval system. The American National Standards Institute (ANSI) Draft Common Command Language provides the basis for much of the work in this area.

One method of addressing the system and communications incompatibilities is to connect locally homogeneous groups of users in one system (e.g., PC LAN, Appletalk, etc.) and to offer gateways or terminal emulation connections to heterogeneous hosts like VAXes and IBM mainframes. Terminal emulation requires the user to learn the user interface of the host operating system, rather than letting the user interact with the familiar operating system. This problem becomes severe if the required information resides on many different types of hosts. The gateway approach is slow. Also, data transferred to a local host is most likely to be in the wrong format for immediate use; either the byte ordering is wrong, the engineering units are in the wrong system (FPS or metric systems), or the data format is unsuitable for immediate use by the local data manager or some such utility.

What is needed is a mechanism to interact with remote data and programs, regardless of the type of system on which they are located, through a unified interface. Access to the remote information should be quick and transparent. Methods of realizing this capability are often based on the so-called *client–server* model or the *networked windowing* systems. In the client–server systems, the *client programs* usually run on the user's desk-top computer or workstation; they accept requests from the user and display the results. The *server programs* usually run under the control of a multiuser operating system on the host computer. The clients communicate with the servers via messages on a common communications network. In the networked windowing systems, the client–server model is reversed; the server program resides on the user's workstation and the client program runs on the host. Since the window server may accept outputs from many client programs, the operating system of the desktop computer must be multitasking.

NeWS/PostScript and X/Windows are two of the more popular heterogeneous network windowing systems. Both use a reversed client–server architectural model with the window servers running on the desktop workstation. NeWS is a network/extensible window system developed by Sun Microsystems. X/Windows is a public domain product developed by M.I.T. and is perhaps the most popular windowing system.

## AVAILABLE TECHNOLOGIES

The present and prospective technologies for these possibilities are numerous. Single chip processors are already attaining computational speeds of 10 million instructions per second. Laser videodisks are already capable of storing the information contained in 6,000 books of 500 pages each. Encoding techniques, such as Huffman coding, have the potential to permit the storage of well over 24,000 volumes of printed information on a single disk. Database machines that are capable of searching and retrieving information based on string matching algorithms are available. Local and global communications networks in various hues and colors (e.g., voice grade, data, multimedia) are already proliferating. Many of the interfacing devices to render this technology "user friendly" are already available in some form or another. A partial list of these devices and capabilities includes: high-quality computer generated voice and voice recognition devices; high-fidelity digital audio output devices; touch screens; powerful graphics that allow the fusion of graphics images, text overlays, and animated images; and surround screens, or multiscreens, on which these images can be presented (Schwartz, 1987).

### *Problems of technology transfer*

Although the necessary technological developments are taking place, one critical need remains to be filled before these multimedia dreams can become a reality. This pertains to the need for a standardized, cost-effective delivey system. Both the creation of databases in the bibliographic search example and the production of courseware in the teletutorials example are expensive. Unless there is a system that can deliver these products and services to very large audiences, these dreams would come to a naught very quickly. Even if one leaves the responsibility of producing the databases and courseware to the more affluent countries, there still remains the problem of disseminating this resource.

In technologically advanced countries, the necessary infrastructure exists (such as digital and analog communication links, interfacing and protocol standards, databases, computer facilities, and so on). But, what about the suitability of this technology for developing countries? Many developing countries have telecommunications systems of questionable quality (see *The Institute*, 1987, p. 10; Mehta, 1987), a fact that has to be reckoned with. Furthermore, a recent survey indicates that among the countries with more than 1 telephone per 100 people, only six Asian countries made the list. They are Israel @34.6, Taiwan @23.5, South Korea @13.8, Saudi Arabia @13.7, Turkey @5.4, and Iran @5.2. China and India, the two most populous nations in the world, are not even in the list, and neither are any of the emerging African countries (AT&T, 1983; *IEEE Spectrum*, 1985, p. 68).

A satisfactory solution to the communications problem is a necessary prerequisite for the implementation of a nationwide information network. Consider the case of the recently implemented CGNET which links members of the CGIAR (Consultative Group on International Agricultural Research) via TYMNET (Balson, 1987). Due to the unavailability of compatible capabilities in several parts of the world, many of the member institutes are not currently participating. Nevertheless, researchers at the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), located in Hyderabad, India, once expressed the feeling that a link to the CGNET is very valuable even if it entails accessing the network by direct dial telephone.

An equally critical infrastructural problem stems from the lack of reliable power supplies; for all the advanced technology embodied in them, today's networks, even in technologically advanced countries, are at the mercy of unreliable electrical power. Whereas the quality of hardware and software can be controlled by the manufacturing process, the quality of the electrical supply is often controlled by an exogenous agency. The quality factors of interest here are sags, surges, failures, oscillations, and spikes. A sag, which is a cycle-to-cycle decrease in power line voltage, can trigger an *unmaskable power-loss interrupt* and cause a computer to shut itself, if the sag lasts longer than one or two cycles. From this viewpoint, power outages like brownouts and blackouts are similar to sags. Surges, on the other hand, can create not only component stress and premature failure but they also can wreak havoc in unforeseen ways. When line voltage rises, it does so in a series of sharp surges, producing a phenomenon known as *hammering*. Hammering can cause the read/write head to crash onto the surface of a hard disk instead of gliding over a cushion of air. This will cause data loss as well as severe damage to the head. Solutions to the plethora of power supply problems include surge suppressors, uninterrupted power supplies, and intelligent power systems.

## A PROPOSAL

A possible interim solution to this communications problem is the use of hierarchy of local and regional networks. In this configuration, local clusters are typically connected to regional backbones, which are in turn connected to national and global networks. Until appropriately designed transparent gateways to international networks are available, CD/ROMs (compact disk, read only memories) can play a useful role in providing information (dated, of course) to the regional networks. The technology for building inexpensive local networks connecting personal computers and workstations is now available.

It is a fact that poor but technologically advanced countries already have huge investments both in the communications and computer arenas. A perennial problem planners in such countries face is the choice of a location to house a newly acquired or developed facility. Often the final choice is made on political considerations because a high-tech facility means more jobs for people in that area. Also, according to the *gravity model* of demographic development, urban areas always show a tendency to grow bigger and bigger with the attendant problems of overcrowding, pollution, and poor sanitation. One way to arrest, and perhaps reverse, this trend is to provide employment opportunities for people independent of where they live and when they wish to work. Such an opportunity through flexibility presents itself through networking.

## ECONOMIC ISSUES

The cost of building a new digital communications network is high. The cost of piggybacking digital communications on existing facilities is, perhaps, one cost-effective alternative. For example, the IEEE 802.3 Ethernet standard running at 10 Mbits/sec requires a coaxial cable. At $1.50 per foot, and the attendant installation costs, the costs could run high. On the other hand, StarLAN with data rates of 1 Mbit/sec can carry Ethernet protocols on an unshielded twisted-pair telephone lines. Since telephones lines can be found almost in any office that is contemplating the use of computers, the StarLAN alternative looks attractive at first sight. This initial cost advantage should be weighed against the cost of a bridge to connect StarLAN to other high-speed networks if this StarLAN is to serve as the bottom rung of a hierarchy of networks. Recognizing the potential, IEEE came up with a Twisted-pair Ethernet standard which also supports a speed of 10 Mbit/sec.

The essence of the economic problem can be distilled down to one overriding issue: how to reshape the existing $850 billion investment in a worldwide telephone network to meet both the data and voice communications needs of the global society. The accelerating research and development activities of ISDN are expected to provide an answer to this.

Modern high-bandwidth communication channels (such as satellites and fiber optic media) do provide a cost-effective alternative to traditional twisted-wire and coaxial cable technologies. Satellites, so far, have dominated in providing reduced long-distance communication costs, particularly when mobility and access to remote areas were primary considerations. Satellite transmission can also be used in places where the existing phone services are of substandard quality. For normal digital communication, fiber optic cables are offering advantages that far surpass satellite channels. A single fiber cable laid along a railroad right-of-way, for example, to connect major communications hubs can serve multiple needs of multiple agencies. A 400-kilometer long fiber can carry digital information at 1.6 gigabits/sec at one-fifth the cost of a traditional coaxial cable at 400 megabits/sec (Inoue & Tazaki, 1983).

In a high-cost environment, educational institutions, national laboratories, and other government and private agencies can each specialize in a different area and yet share their resources throughout the multimedia, multipurpose communication network. One example belonging to this category is the Magnetic Fusion Energy Net or MFEnet (which is really not a multimedia net), which makes available the supercomputer resources at LLNL to various physics departments scattered all over the U.S. as well as Japan, West Germany, and Switzerland. Another example is JANET, a private X.25 network serving the U.K. academic community, which is a backbone network comprised of trunk lines connected via Packet Switching Exchanges (PSEs). An example of a network from developing countries is India's ERNET (Education and Research in Computer Networking), an experimental network connecting eight educational and research institutions (Mathur & Ramakrishnan, 1987). Another resource sharing example of a different hue is SIMBAD (Set of Identifications, Measurements, and Bibliography for Astronomical Data), a French astronomical database. This database allows an astronomer to look up an astronomical object by its astronomical designation and retrieve nearly all known information and a listing of related papers published since 1950. In the U.S., the NSF and NASA have teamed up to make this database available to U.S. scientists. In spite of this, the use of this database is hampered by differing interconnection standards as well as the $100-per-connect cost of a computer call to the Centre de Donnees de Strasbourg, France. A recent report by NRC (headed by Prof. Leonard Kleinrock of UCLA) recommends that a high-speed, easily accessible, and user-friendly network that charges low fees for basic services is essential for a research network.

## SOCIAL AND ADMINISTRATIVE ISSUES

In addition to the immediate practical utility for which networks were originally designed and built, there are a number of other side effects (Chambers & Poore, 1975) worthy of consideration. First, networks, by way of Electronic mail (or E-mail), improve human interaction. If communication is allowed to occur in non-real-time mode, problems of communicating across time zones and the frustrations of making connections over the telephone (the "telephone tag" problem) disappear. However, networks also tend to create an information overload by way of "junk mail" and "junk bulletin" syndromes. Some advisers on E-mail etiquette caution that the medium may escalate disputes because tactless, emotionally charged messages can be fired off—and instantly delivered—without sufficient time for reflection. Another potential problem with E-mail is the opportunity it gives to bypass the chain of command in an organization and the associated question of "accountability." If these pitfalls can be avoided, networks provide an ideal environment for quick and timely exchange of ideas and references.

## LEGAL, REGULATORY, AND SECURITY ISSUES

To what extent can one control and regulate messages and information sent on a computer or communications network? For example, what will happen if users use the computer network to transmit defamatory or obscene material? If privacy requirements are violated? Who is responsible if erroneous or faulty messages transmitted lead to loss of life or property? There are legal precedents covering liabilities of more traditional communications media like newpapers, radio, and television. Computer networks do not fit neatly into these. They also do not fit into the category of common carrier services like telephone and telegraph. For example, in the United States common carriers are not required to maintain as strict a standard as radio and TV insofar as what gets transmitted on the channel.

Worms and viruses, which are becoming serious security problems, are programs that can enter a computer system in an unauthorized manner and disrupt the normal operation of the system. These programs can replicate themselves and can cause havoc either (a) by erasing the contents of a memory completely, or (b) by spawning an unlimited number of processes (tasks), thus tying up the computer from doing any useful work. The most notable breach of network security occurred on November 2, 1988. On this day, a worm entered the ARPAnet and created havoc of the second kind by disrupting ongoing activities on a national scale. Thousands of hours of human labor were spent to bring the situation under control, and thousands more were lost in opportunity costs.

Perhaps the easiest way for a worm to enter a system is through a network. To control what is posted on the network requires a control of access to the network. At this time, the safest policy is to assume that any network can be easily broken into and that any transmission can be recorded and forging is easy. Encryption techniques that are capable of providing a very high degree of security do exist but they are expensive in terms of CPU time.

These problems are further exacerbated if information crosses corporate, national, political, and ideological boundaries. There has been a general consensus among experts that the "greatest impediments to the implementation of international computer conferencing systems would be legal and regulatory rather than technical" (see *The Institute*, 1988, pp. 1, 8).

## REFERENCES

*Academic Computing*. (1989, January).

AT&T. (1983, January). *The world's telephones: A statistical compilation as of January 1, 1983*.

Balson, D. A. (1987). CGNET: A data transfer network for the CGIAR. *IAALD Quarterly Bulletin*, *XXXII*(1), 39–45.

Chambers, J. A., & Poore, R. V. (1975, April). Computer networks in higher education: Socio-economic-political factors. *Communications of the ACM*, *18*(4), 193–199.

Cunningham, I., et al. (1982). Emerging protocols for global message exchange. *Proceedings of COMCON* (IEEE Catalog number 82CH1796-2). Piscataway, NJ: IEEE Service Center.

The future of telecommunications. (1985, November). [Special issue]. *IEEE Spectrum*.

IEEE. (1987, February). India on the phone: Modernizing communications. *The Institute*.

IEEE. (1988, February). NSF takes the first steps toward a national computer network. *The Institute*, *12*(2), 1, 8.

Inoue, N., & Tazaki, K. (1983, October). Steps to enhance the telecommunication networks towards advanced information society. *Telecom 83 Forum*, Geneva (pp. 3.11.5.1–3.11.5.6).

Linking anybody to anybody. (1986, September). [Special issue]. *Proceedings of the IEEE*.

Mathur, M. N., & Ramakrishnan, S., (1987). Project ERNET: Perspectives, plan and approach of an academic and research network program in India. *ICCC Special Conference*, India.

Mehta, V. (1987, January 19). Letter from New Delhi. *The New Yorker*, pp. 52–69.

Multimedia communications. (1985, October). [Special issue]. *IEEE Computer*.

Schwartz, J. (1987, Summer). Dreamworld. *Daedalus*, *116*, 165–185.

Sticha, P., Hunter, G., & Randall, L. (1981, February). *Research into teleconferencing* (Technical Report TR80-9-314). Mclean, VA: Decisions and Designs, Inc.

Thomas, R. H., et al. (1985, December). Diamond: A multimedia message system built on a distributed architecture. *IEEE Computer*, *18*(12), 65–78.

Williams, M. E. (1985, April). Electronic databases. *Science* [Special issue on computers], *228*(4698), 445–456.