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ON THE IMPACT OF COMPUTER NETWORKS

by

Leonard Kleinrock

ABSTRACT

Computer networks are here. Not only are they here, but they are growing in number and size. Fortunately, we understand much about their design, construction, maintenance and operation. In this paper, we briefly discuss the technology of computer networks as it now exists (with special emphasis on the ARPANET), and then proceed to investigate the predictable impact these networks are likely to have. This impact will be felt in office, corporate and government operations and may even reach beyond that to such fields as urban development.

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I. INTRODUCTION

The 1970's will be the decade of computer networks. During the previous decade we had seen time-shared and multi-accessed computer systems develop enormously. During this time it was recognized that the special capabilities (specialized hardware, software and databases) built up at each of many separate computer facilities could profit by resource- and load-sharing. It was perfectly natural that computer networks should evolve as the next phase in the evolution of information processing systems to make this sharing possible. These networks permit remote access to large computing resources and large distributed databases. It is the impact of this network technology which we wish to discuss in this paper.

The sophistication of these networks varies over a considerable range from the highly specialized networks designed to handle specific tasks in a carefully controlled environment to the more generalized networks which handle a variety of tasks in a highly unstructured environment. The successes and failures of these networks in terms of economy, service, response-time, throughput, coverage, reliability, use and convenience is certainly not uniform from network to network.

The complexity of the issues which one faces in such distributed multi-access systems is staggering. The considerations range from the highly technical, mathematical and engineering design questions (many of which have the terminals and the computing complexes. For example, remote terminals come in many types, have widely varying speeds, are geographically distributed, transmit at unpredictable times, have very low duty-cycles, generate data in bursts, typically have incompatible coded versions of the common alphanumeric symbols, and are usually unsophisticated. On the other hand, the main computer complex typically consists of one or at most a few large central processors, are large-scale high-speed computers operating synchronously with a high duty-cycle, use a standard representation for alphanumeric symbols, are expensive, are highly sophisticated, and usually are designed to cooperate in the processing associated with a specific task.

In addition, the telephone network which is the common vehicle for data communication was originally designed to carry voice traffic. The difference between data and voice traffic lies at the source of many difficulties in the design of data communication networks; the principal characteristic of data coming from terminals is that is is a bursty, low duty-cycle traffic source which requires buffering, smoothing, multiplexing, concentrating, etc.

Thus we see that the task of creating a computer network involves a complex interaction of partially incompatible systems; the technological task is to provide an economical high-performance message service which is invisible in the sense that the remote terminals may pretend that they are connected directly to a processor. A high throughput must be maintained in an efficient fashion, and message delivery must be rapid in order to provide acceptable response times to the demands of the terminals. This network should be expansible with ease as the set of terminals shifts or grows and as new computer complexes spring up or enlarge and also as needs change. It is gratifying to be able to report that significant progress in that direction has been made in the last five years, the most obvious example of which is the ARPANET which has satellite link to Hawaii) and extending overseas (by satellite) to Europe. The computers (called HOSTs) are in many ways incompatible with each other, coming from different manufacturers and using specialized software, databases, etc. The topological connection is in the form of a distributed network and provides protection against total line failures by providing at least two physically separate paths between most pairs of nodes. Each HOST is connected to a small computer called an Interface Message Processor (IMP) which are themselves interconnected mainly by leased 50 kilobit per second full-duplex circuits; currently there are roughly 40 IMPs which act as network gateways for the message traffic. In order to send a message, a HOST delivers its message, including a destination HOST address, to its local IMP. The communications (sub-)network then takes responsibility for delivering this message to the destination HOST, and manages the routing, error control, handling of all message buffering and transmission functions, and finally of notifying the sender of the eventual receipt of this message at the destination HOST. The collection of IMPs and circuits form the message service for the HOST computers. Note that a dedicated path is not set up between HOST computers which are in communication but rather this communication involves a sequence of message transmissions sharing the communication lines with other messages in transit. Messages are limited to a maximum size of 8063 bits; thus a pair of HOSTs will typically communicate over the net via a sequence of transmitted messages. To obtain delays of a few tenths of a second for such messages and to lower the required IMP buffer storage, the IMP program partitions each message into one or more (up to eight) packets each containing at most 1008 bits. Each packet of a message is transmitted independently to the destination where the message is reassembled by the IMP before shipment to that destination HOST. Thus we have the concept of a packet-switching network [4].

now discuss some of the impacts of this technology.

III. SOME IMPACTS

The growth in the need for remote data processing has come from a large number of varied application areas. For example, the finance industry, including banking and insurance firms, has a growing need for teleprocessing. In the field of medicine and health, there is a demand for large information banks with remote access. Educational computing needs currently emphasize interactive use as opposed to data entry, retrieval and acquisition. Large government agencies have vast data exchange requirements, both military and non-military. Point-of-sales terminals by retail organizations is a fast-growing applications area. Information retrieval is currently of great importance in the transportation field and traffic control may soon be handled by remote computers. Large corporations now are exchanging, recording and updating data among their many central and regional offices. Other industries have a natural need for computer networks (for example, airline reservation systems, travel services, stock market quotation systems, etc.) A vast use is foreseen for access to information processing directly from the consumer's home (shopping, voting, the use of electronic file cabinets, home education, etc.). It is applications such as these and many others which are providing the manpower, time and money behind the enormous growth of the information processing industry. It is estimated [7] that at the end of 1971 almost a quarter of a million terminals were in use. Four to five million terminals are projected for 1980. It is expected that voice I/O for a limited set of commands will have a major growth by 1975; when voice I/O is available with a large set of commands, then all speech transmitting instruments could become computer terminals and this will further snowball the need for remote data processing. A similar their many distributed offices and plants, connected through such a "public" network and gaining access to their own files and processing machines in a reliable, secure, and economical fashion. This may well replace many of the private networks which currently exist. In any event, corporate networks for data and equipment sharing can provide significant efficiencies in operations if done properly. Beyond this, there is the entire concept of office automation through which we see the eventual decline of the paper bureaucracy in which we find ourselves today. For example, as has been demonstrated with the ARPANET already, it is possible to cut down on the use of interoffice memoranda as well as interoffice telephone communication by using a message service available through computer networks. In fact, this has been one of the more popular uses of the ARPANET. There is in the ARPANET a message service facility whereby one may send messages to any other party on the network and have that message delivered instantly to his "mailbox." These messages for a given addressee will collect over some period until such time as that individual happens to look at his mailbox; he may then read all of his mail at his leisure, and answer that which he chooses (again at his leisure), in a fashion which is highly efficient of his time. No longer does one operate in the devastating interrupt mode we so often find in offices today. Thus a convenient means for personnel management may be developed around such a facility. Not only does this eliminate interruptions, but it may also eliminate the quantitites of paper which we handle today and free the people required to manage all that paper. In fact, it is estimated that more than three hundred thousand employees of the Department of Defense have as their only required skill the ability to type. The enormous mountains of paper which emanate from such an organization are frightening in terms of cost, bulk, slow delivery and difficult control. Another predictable change in the way business

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