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TELEPROCESSING NETWORK ORGANIZATION

JAMES MARTIN

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An overall review of technical considerations and calculations in the design and implementation of real-time systems.

PROGRAMMING REAL-TIME COMPUTER SYSTEMS

Programming mechanisms, program testing tools and techniques, problems encountered, implementation considerations, project management.

TELECOMMUNICATIONS AND THE COMPUTER

A description of the working of the world's telecommunication links and their uses for data transmission.

TELEPROCESSING NETWORK ORGANIZATION

An explanation of the many types of devices and procedures for controlling and organizing the flow of data on today's telecommunication lines.

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Any book about the state of the art in a complex technology draws material from a vast number of sources. While many of these are referenced in the text, it is impossible to include all of the pioneering projects that have contributed to the new uses of telecommunications. To the many systems engineers who contributed to this body of knowledge, the author is indebted.

The author is very grateful for the time spent reviewing and criticizing the manuscript by Mr. J. W. Greenwood in New York and Dr. D. R. Doll at the University of Michigan, Ann Arbor. The concepts in it were discussed in seminars organized by NOMA in Japan, whose hospitality I shall always remember. The long-suffering students of IBM's Systems Research Institute in New York also used the manuscript and suggested many changes. Miss Charity Anders (Fig. 1.10) prepared the index. To all these the author is indebted. Mr. R. B. Edwards' staff helped enormously in typing and reproducing the manuscript. The author is particularly grateful to Miss Cora Tangney for her help in this.

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JAMES MARTIN

New York

STATEMENT OF INTENT

In years ahead an understanding of data transmission will be of great importance to the systems analyst. Our systems and to some extent our society will be dominated by the ability of separate machines to transmit information to one another.

This book is an attempt to set into perspective the principles behind the different types of data transmission hardware and organization. It discusses control methods and mechanisms, with illustrations of different types of networks. It explains the techniques possible for organizing the flow of data on today's telecommunication lines.

We may state the main problem of teleprocessing network organization simply: If we have a data transmission network, possibly with long lines and possibly with many terminals, how can we minimize the cost of that network and still have it work effectively?

Many time-sharing systems and commercial real-time systems today have had a small number of terminals. They have given a valuable service to a small community of users. The industry now needs to extend that service to a *large* community. A corporation would like all of its locations to have on-line access to a scientific computing system. It would like to deploy many hundreds of terminals on its factory shop floors for production control. We would like doctors in certain hospitals throughout the country to have access to a medical data base. Airlines must connect offices around the world to one reservation system. The police need a vast network of information terminals. All of a firm's sales offices should be connected to a central computer. . . .

How do we organize the data transmission links so that they are reliable, give fast service to the user, and are not too costly? How do we achieve a fast response time on a network with many users? Furthermore, how do we organize these links and keep the cost of the terminal low?

Can we lessen today's telecommunication bill? Many firms in the U.S.A. are paying the common carriers a million dollars a year for data transmission, and this will increase considerably in the next decade. But small firms also need to organize their transmission more efficiently.

To answer these problems a multitude of devices and techniques have been created. Many more are on their way. Some systems have more control characters flowing on their lines than data. The choices facing the systems analyst in the area of network design are becoming bewilderingly complex.

The material in this book is the basis of a course given at IBM's Systems Research Institute and it is thought important that such a course be given in universities and industry elsewhere. The book may be used in conjunction with the author's other books, and is intended to be complementary to the author's *Telecommunications and the Computer*, Prentice-Hall, 1969. Design calculations and algorithms are not discussed in this book, but are included in a more comprehensive work by the author entitled *Systems Analysis for Data Transmission*, Prentice-Hall, in press.

It is intended that some of the more detailed sections be used by computer personnel for repeated reference, and that the book will be of value to them in forwarding their careers. It is hoped, therefore, that this book will be owned by such people rather than meeting the sad fate of only being borrowed from a library and read once.

J.M.

CONTENTS

1 TYPES OF COMMUNICATION LINKS[1]

The facts about the transmission links which most concern a systems analyst are the cost of the links and the rate at which data may be sent over them. This can have a major effect on the feasibility of different systems approaches. All the common carriers issue a price list describing their facilities. Let us begin our description of communication networks with a summary of the links that are available.

The illustrations in the following summary are taken from the offering of the carriers in the United States and Britain. Those of other countries are broadly similar. Countries with less well-developed data transmission have less to offer in the way of wideband (high-capacity) facilities.

The services that a common carrier offers to the public are described in tariffs. A tariff is a document which, in the United States, is required by the regulating bodies that control the carriers. The United States Federal Communications Commission must eventually approve all interstate facilities, and similar state commissions control those within state boundaries. By law, all tariffs must be registered with these bodies. In most other countries, the telecommunication facilities are set up by government bodies and thus are directly under their control.

In the United States the subject of communication rates has become complex. The amount and structure of charges differ from one state to another. In other countries, such as England and Germany, the rates for more conventional channels remain relatively straightforward; however, as the carriers there are government organizations, they are not obliged to

[1] This opening chapter summarizes material discussed in more detail in the companion book *Telecommunications and the Computer* by James Martin, Prentice-Hall, Inc. 1969. It is recommended that the reader should read that book in conjunction with this.

publish tariffs for all of their facilities. The price for less common channels, such as broadband, may have to be obtained by a special request to the carrier. In general it is desirable, when one is designing a system, that the carrier in question be called in to quote a price for the facilities needed.

TELEPHONE CHANNELS

When from your home telephone you dial a number in the same locality, your call goes to a nearby public exchange. (Referred to as a *central office* in American parlance.) The equipment in this building connects the wires from your telephone to those of the party you call. These wires are permanently connected from your local central office to your telephone and are referred to as a *loop*. No other subscriber uses them, unless you have a party line. Thousands of such wire connections lie under the streets of a city in cables like that in Fig. 7.6.

Loops to a company building normally terminate at a switchboard, which has several extension lines to telephones in the building. The switchboard may be manual, with interconnections made by an operator using cords, or it may be automatic, in which case the user can dial his own connections. Switchboards at such premises are described as private branch exchanges (PBX), private automatic exchanges (PAX) or sometimes private automatic branch exchanges (PABX). Use of private exchanges in data-processing systems is discussed in Chapter 8.

A circuit between two switching equipments is referred to as a *trunk*. When you dial a person whose telephone is not connected to the same central office as your own, your call is routed over an *interoffice trunk*. The switched *public network* consists of a complicated system of switching offices and interconnecting trunks, which will be described in a later chapter. Trunks between switching offices are normally designed to carry many telephone conversations, not just one as on the local loop.

A *tie line*, or tie trunk, is a private, leased communication line between two or more private branch exchanges. Many companies have a leased system of telecommunication lines with switching facilities. To telephone a person in a distant company location, an employee must first obtain the appropriate tie line to that person's private branch exchange. On an automatic system this is done by dialing a tie-line code before the extension number.

The tie line (or lines) to that location may be busy, in which case a "busy tone" ("engaged signal," in British parlance) can be heard before the extension number is dialed.

As we will see in subsequent chapters, tie lines often form an important feature of data processing networks. All of the lines above can be used for data transmission as well as voice transmission. Where one voice line is used the transmission speed is limited to a few thousand bits per second, depending, as will be discussed later, on the equipment used at each end of the line. This is the data capacity of a telephone line. Often, however, the tie-line system has more than one voice line connecting two locations. At the time of writing, the common carrier tariffs in the United States make a channel giving 60 voice lines (or their equivalent) considerably less expensive than leasing 60 individual voice channels. If such a channel is used, a group of voice lines may be taken over *together* for data transmission at a speed many times higher than that possible over a voice channel.

One typical large corporation uses its tie-line groups in this manner as a broadband data network during its second and third shifts. The lines are transferred to data automatically, as a group, and so telephone calls in progress on those lines may possibly be interrupted. The corporation tie-line directory contains the following note:

> "When a transfer is about to occur, callers will hear a special interrupt tone that is introduced during a conversation. Callers hearing this tone should hang up and redial the call after a 30-second interval. Normally, these transfers will only occur after 6:00 p.m. Eastern Time."

LEASED VERSUS SWITCHED LINES

Voice lines and telegraph lines can be either switched through public exchanges (central offices), or permanently connected. Facilities for switching broadband channels are also coming into operation in some countries, although these channels, today, are usually permanent connections.

When you dial a friend and talk to him on the telephone, you speak over a line connected by means of the public exchanges. This line, referred to as a "public" or "switched" line, could be used for the transmission of data. Alternatively, a "private" or "leased" line could be connected permanently or semipermanently between the transmitting machines. The private line may be connected via the local switching office, but it would not be connected to the switch-gear and signaling devices of that office. An inter-office private connection would use the same physical links as the switched circuits. It would not, however, have to carry the signaling that is needed on a switched line. This is one reason why it is possible to achieve a higher rate of data transmission over a private line. Another reason is that private lines can be carefully balanced to provide the high quality that makes higher-speed data transmission possible.

There are also in operation several large *private* line systems that are also *switched* (Chapter 8). It is possible to engineer these to the same quality as private lines, and hence provide a switching system of better quality than the public network.

Some private line systems are wholly owned by their users rather than leased. Typical of such systems are communication links within a factory, private microwave connections and other radio links, lines along railroad tracks, and, today, in some laboratories, private wiring of terminals to a time-sharing computer.

As you can either dial a telephone connection or else have it permanently wired, so it is with other types of lines. Telegraph lines, for example, which have a much lower speed of transmission than is possible over voice lines, may be permanently connected, or may be dialed like a telephone line using a switched public network. Telex is such a network; it exists throughout most of the world, permitting transmission at 50 bits per second. Telex users can set up international connections to other countries. Some countries have a switched public network, operating at a somewhat higher speed than Telex but at less speed than telephone lines. In the United States, the TWX network gives speeds up to 150 bits per second. TWX lines can be connected to Telex lines for overseas calls. Also, certain countries are building up a switched network for very high-speed (wideband) connections. In the United States, Western Union has installed the first sections of a system in which a user can indicate *in his dialing* what capacity link he needs.

BANDWIDTH OF A VOICE CHANNEL

The signal-carrying capacity of communication links can be described in terms of the frequencies that they will carry. A certain physical link might, for example, transmit energy at frequencies ranging from 300 hertz to 150,000 hertz. (The word *hertz* has replaced "cycles per second" in describing frequency and bandwidth. Their meaning is identical.) Above 150,000 and below 300 hertz, the signal is too much attenuated to be useful. The range of frequencies is described as the *bandwidth* of the channel. The bandwidth is 149,700 (=150,000−300) hertz (or cycles per second). In fact, the upper cutoff point is not as sharp as is suggested by this, and we would probably say a bandwidth of 150 kilohertz.

Figure 1.1 shows the attenuation of different frequencies on a typical voice channel. It will be seen that between about 300 and 3400 hertz (cycles per second) different frequencies are attenuated roughly equally. Frequencies outside these limits are not usable, and hence we would say that this channel had a bandwidth of 3100 hertz.

The quantity of data that can be transmitted over a channel is approximately proportional to the bandwidth.[2]

The frequencies transmitted in Fig. 1.1 are not sufficient to reproduce the human voice *exactly*. They are, however, enough to make it intelligible and to make the speaker recognizable. This is all that is demanded of the telephone system. Hi-fi enthusiasts strive to make their machines reproduce frequencies from 30 to 20,000 hertz. If the telephone system could

[2] *Telecommunications and the Computer*, Chapters 10 and 11.

transmit this range, then we could send high fidelity music over it. Sending music over the channel in Fig. 1.1 would clip it of its lower and higher frequencies, and it would sound less true to life than over a small transistor radio.

The physical media that are used for telecommunications all have a bandwidth much larger than that needed for one telephone conversation, so between towns one link is made to carry as many voice channels as possible. The bandwidth of one physical channel is electronically cut up into slices of 4000 hertz and each of these slices becomes one voice channel.[3] The result is shown in Fig. 1.1. The frequencies of Fig. 1.1 fit easily into the 4000 hertz slice.

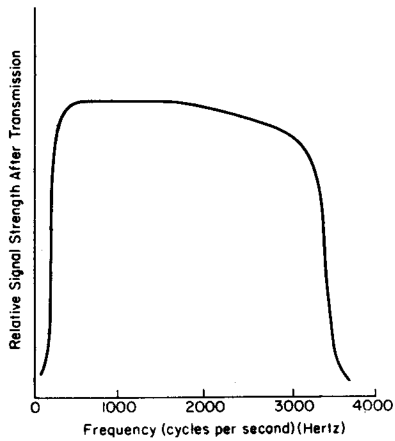

Fig. 1.1. Variation in signal strength with frequency after transmission over a typical voice line.

To transmit data over the telephone line, then, we must manipulate it electronically so that it fits into the frequencies of Fig. 1.1. This is done by a device called a *modem*, which will be discussed shortly.

Nonvoice channels have bandwidths different from that in Fig. 1.1—subvoice grade channels are lower in bandwidth, and broadband channels are higher. If desirable, channels of extremely high bandwidth can be obtained.

SIGNALING

We must add one complication to Fig. 1.1. On *public* voice lines we are not completely free to use all of the bandwidth shown. Certain frequencies are used by the telephone company for their own signaling, and we must not interfere with this.[4]

Figure 1.2 shows the signaling frequencies used on Bell System and British telephone lines. Unfortunately the frequencies are not the same, and in some other countries they are different from either of these. Signals are sent at these frequencies to indicate, for example, when a subscriber puts down his telephone so that the line may be disconnected.

[3] *Telecommunications and the Computer*, Chapters 10 and 15.

[4] *Telecommunications and the Computer*, Chapter 17.