# On Communications and Data Processing: A Foreword

Communications has historically been acknowledged as the pace-setter in the development of electronics technology. In recent decades automatic data processing has emerged as another vital and energetic source of progress in the same area of technology. Although advances in one field have generally been made independently of those in the other, many workers in both communications and data processing have come to realize, in the course of making further progress, that the two fields are becoming more interdependent. In a steadily increasing number of cases, developments in one field have resulted in, or been reinforced by, developments in the other.

The most obvious bases for such interactions have been the physical extension of data processing systems and the increasing complexity of traffic in, and control of, communications systems. Accordingly, the major areas of interaction can be identified as (1) high-speed digital data transmission, (2) digital modulation techniques, and (3) computer-controlled communications. This foreword is intended to alert the reader to some of the interactions that have been occurring in these areas and to point out the key problems in each. Where appropriate, papers in this issue are cited as examples.

- *High-speed digital data transmission*

High-speed digital data transmission is a vital requirement in many data processing systems. The reasons vary widely and include (1) the need for rapid processing of remotely gathered data, as in a satellite tracking and control system, (2) the desirability of load sharing among remote processors, and (3) the need for rapid information exchange between processors or files in large management information systems.

It should be noted that in the present context, "high-speed" is used to indicate the rates at which data are transmitted for automatic processing. These rates are "high" with respect to those of conventional telegraph and teletype data transmission. While the term may not be completely satisfying, it is useful in identifying an area of strong interaction between communications and data processing.

The technical problems in this area do not stem merely from the need to transmit a large number of bits per second; rather, they arise from the objective of realizing high transmission rates while using a channel of minimum capacity, as given by the Shannon formula. It is only when this practical restriction is imposed that transmitting data over telephone lines at, say, 4800 bits per second, rather than at teletype speed of 75 bits per second, becomes a challenging problem.

A measure of the effectiveness of efforts to solve the problem is the fact that with present technology it is possible to get within a factor of about 4 of the theoretical capacity of a low-noise channel ($S/N \geq 25$ dB). Transmission of 2400 bits per second over a voice-grade leased telephone line is not uncommon, though, in such cases, distortion, as well as noise, is a critical factor. Hence, the paper on distortion equalization by Gorog exemplifies an aspect of communications that has great significance to automatic data processing.

But higher speed is not the only new data transmission requirement. Depending on the particular application, tolerable error rates may be many orders of magnitude less than those which are acceptable for transmission of other forms of information. In judging the current status of technology with respect to this situation, one observes that for the speed and conditions just given, bit error rates in the range of 1 per million are being achieved without resort to redundant coding. Of course, with the application of such coding, substantial improvement in error rates can be attained, albeit at some increase in the delay before the data entered into a channel can be recovered from it.

The problem of determining codes with optimum tradeoffs between data speed and error rate has been prominently and consistently treated in the literature. Within the last few years engineering implementation has moved rapidly to consolidate the theoretical gains made previously. It seems apparent that the reason for this is the timely combination of the pressure for high-speed, low-error data transmission and the availability of low-cost digital components. The paper by Ullman treats problems in this area that are of typical engineering interest today.

The problems noted thus far in the discussion have been related to the new communications requirements that have originated from the concerns of data processing. An interesting reversal of this situation arises from the need to transmit even very low-speed information through a very noisy channel. Communication with a deep-space probe such as Mariner is a particular example. Solutions to the problems involved here have required advances in the development of logic and computer techniques. The practical problems of transmitting information through channels in which the received signal power is of the same order as, or even less than, the noise power, are different from those discussed previously. In the case of a noisy, uncoded, binary symmetric channel, the guiding relationship is the theoretical lower limit for the probability of error: $P_e = \frac{1}{2}(1 - \operatorname{erf}\sqrt{WT(S/N)})$, where $S$ is the signal power, $T$ is the bit duration, $N$ is the noise power and $W$ is the signal bandwidth. From this it is clear that large $WT$ products are necessary for low $P_e$. But for $WT \gg 1$ (i.e., 1 bit per cycle) the simple technique of synchronizing the receiver to the bit stream by detecting transitions becomes unreliable. One solution to this problem is based on modulation by maximum length, shift-register generated sequences, or pseudo-noise codes. The technique is utilized together with processing by a general-purpose digital computer in the Mariner communication system.

- *Digital modulation*

The pseudo-noise technique just mentioned is a complex form of a type of digital modulation that is more familiarly exemplified by pulse code modulation. Basically, the potential advantage of digital modulation over the more conventional analog modulation is analogous to the advantage of digital computers over analog computers. That is, digital circuits are better able to regenerate signals without amplifying noise. Moreover, the rapidly declining costs and increasing reliability of digital components pave the way for an increasing use of digital modulation techniques.

A type of pseudo-noise modulation has been developed recently for use in random-access communications systems. Here, many users may communicate simultaneously without going through a central switch or control. Time-division multiplexing and frequency-division multiplexing can be employed for this purpose, but they have limitations in bandwidth utilization and difficulties in synchronization for many types of systems. Code-division multiplexing using pseudo-noise modulation is an alternative technique in which each transmission is modulated with a code that identifies the user and to which the addressed receiver is set to respond. The situation resulting from the use of this technique is similar to that of transmitting signals over very noisy channels, except that now the noise consists mainly of other pseudo-noise modulated signals in the same frequency band. Some problems in the design of such random-access communications systems are addressed in the three papers on pseudo-noise modulation in this issue.

- *Computer-controlled communications*

General purpose computers are beginning to be put to extensive use in controlling switched systems either in the capacity of automatically storing and forwarding messages or operating automatic telephone exchanges. In addition, there are many other functions in a communication system which can be improved or made feasible by the use of computers. Automatic alternate routing in telephone systems, automatic maintenance, transmission quality monitoring and control are but a few. An example of this area of interaction between communications and data processing is provided in the paper on a telephone intercept system.

The following papers, then, represent work on communications that has been generated in a data processing environment. As such, they tend to bear out the idea of interaction between the two fields; we hope their publication will stimulate further efforts towards solutions that will benefit both.

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