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The Mathematical Analysis of Digital Electronics Data Transmission

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Research Article

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Abstract

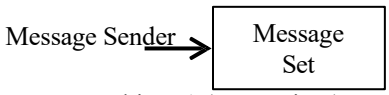
A comprehensive investigation of discrete data transfer in different electronic devices has been attempted. The theory of conditional probability serves as the foundation for the current research. In order to get the ideal data transmission channel, various useful characteristics of a noise matrix known as a crossing matrix have been addressed. The daily development of electronic gadgets in the current era of digital technology makes this topic crucial.

Key words: Digital electronics, noise matrix, the current technological era,

INTRODUCTION

The data or signal may travel in the form of electromagnetic, electrical, light, or even acoustic waves thanks to the transmission channels, also known as telecommunication channels, which are composed of many segments. In a vacuum, these signals travel at the speed of light (300,000 km/sec), whereas in materials, they move a little more slowly (200,000 km/sec). Therefore, it is really a vibratory phenomena that spreads across the physical medium. When a single piece of data (any energy) is delivered to two devices (transmitter and receiver), it is often referred to as communication. For a better understanding of data transfer in digital electronics, Figure 1 displays a block diagram (1-2).

The transmission of one message from a limited collection of messages across a communication channel is known as the discrete data transmission channel, as shown in Figure 1. A communication travels from the transmitter to the recipient. The transmitter uses the communication channel to deliver a matching signal, or "waveform," that represents the message that the sender has chosen from the limited set. By looking at the channel output, the recipient determines the message that was transmitted. Digital communication is the sequential delivery of discrete data messages (1-2). The receiver employs a process called detection to determine which message, or series of messages, was transmitted based on the noisy signal received at the channel output. The optimal detection reduces the likelihood that the recipient would mistakenly determine which message was sent.



$$\sum^{m} r\left(\frac{q_j}{}\right) = 1 \text{ and } \sum^{n} r\left(\frac{q_j}{}\right) = 1 \quad (3)$$

Figure 2 shows a block diagram for a simple explanation of a communication route. Thus, in addition to the transmitter and the receiver, the discrete data transmission channel also consists of the following elements:

- Signal source
- Signal source coder
- Data transmission channel coder
- Signal source decoder
- Data transmission channel decoder.

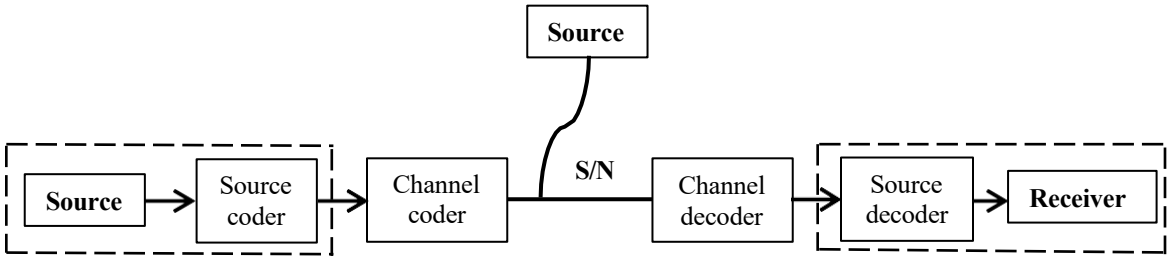


Fig. 2. A block diagram of data transmission channel.

Additionally, we must consider the fact that communications channels include sounds. Thus, a modulator and a demodulator may also be included in a block diagram from figure 2. Additionally, a quick categorization of data transmission routes is:

Continuous channel: The data signals P and Q are continuous sets.

Discrete channels: P and Q are discrete signal sets.

The crossing matrix R(Q/P) of a symmetric channel has the following characteristics: each line of the crossing matrix may be acquired by a circular permutation of another line, and any column can be obtained by a circular permutation of another column.

The stationary and non-stationary channels with or without memory, deterministic or non-deterministic, and with or without removal may all be distinguished. The following will make reference to each of them. But,

We shall only provide discrete type details due to the vast array of data transmission routes and their infinite categorization.

Study of Few Channels in Term of the Transition Matrix

(I) Study of Binary Symmetric Channel

The binary symmetric channel i.e. CBS is characterized with the data sets $P = (p_1, p_2)$ and $Q = (q_1, q_2)$ and also along with the following relations:

$$\begin{cases} r(q_1/p_1) = r(q_2/p_2) = 1 - r \\ r(q_2/p_1) = r(q_1/p_2) = r \end{cases} \quad (4)$$

And the specific crossing matrix for the binary symmetric channel (CBS) will be such as:

$$R(Q/P) = \begin{pmatrix} 1-r & r \\ r & 1-r \end{pmatrix} \quad (5)$$

The above mathematical relation of CBS can represent by a simple pictorial representation (Figure 3).



Fig. 3. A

simple pictorial representation of binary symmetric channel (CBS).

In the above Figure 3, "r" is the probability that a symbol is received incorrectly. And this depends on the physical parameters of data transmission channel.

(II) Study of Channel with Removal of Signals

We consider some signals i.e. events of data sets P and Q, those can be defined and also denoted such as: $P = (p_1, p_2)$ and $Q = (q_1, q_2, q_3)$. Such type of channels has a crossing matrix of the order of 2×3.
If we denote the probability **"r"** with the symbol p_1 that is received incorrectly and the probability **"s"** that is also received incorrectly with the symbol p_2, therefore the channel's crossing matrix will be as following:
A simple pictorial representation of the above mathematical relation / channel has been depicted in Figure 4.

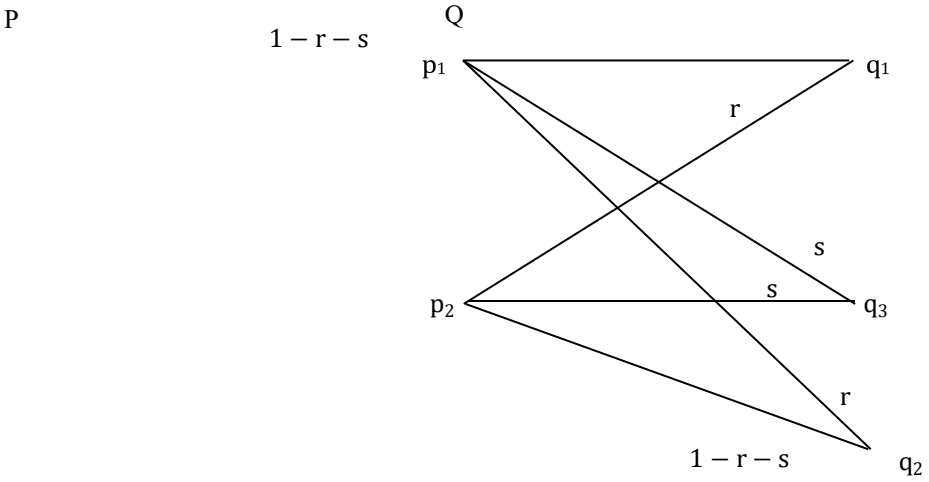


Fig. 4. A Pictorial representation of channel with removal of signals.

Since the rows and columns of the crossing matrix that defines it cannot be produced from one another using permutations, it is evident that this kind of channel (with the removal of data sets) is not symmetrical. Since symbol q3 is consistently received wrongly with probability "s," it is known as a channel with removal data

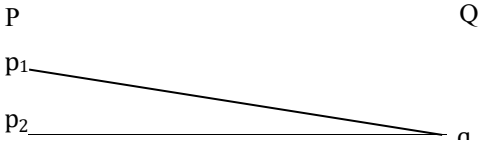
sets. In essence, it removes all information about the sent symbols p1 and p2.

(III) Study of Deterministic Channel

A channel is considered deterministic if in its transition matrix each row contains a single crossing probability of "1" value (and only one) and all remaining crossing probabilities are "0". An example of crossing matrix of the order of 6×3 is given such as:

$$R(Q/P) = \begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad (7)$$

In this case sets of signals i.e. events are $P = (p_1, p_2, p_3, p_4, p_5, p_6)$ and $Q = (q_1, q_2, q_3)$ with Card P = 6 and Card Q = 3.
According to its crossing matrix, a pictorial structure of this type of channel (represented as a graph) has been shown in the Figure 5. The channel is deterministic in terms of the set of transmitted signals (P's).



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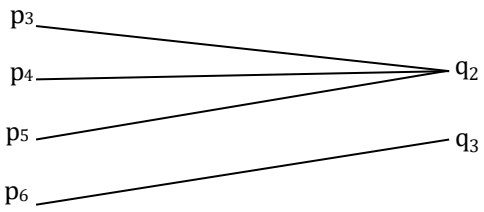


Fig. 5. A representation of deterministic channel.

(IV) Study of Noiseless Channel

For the study of noiseless channel, the crossing matrix contains on each column only one nonzero element (and only one), the rest of its elements are null (4-5). The crossing matrix for the sets of signals P and Q with Cards P = 3 and Card Q = 6 will be such as:

Figure 6 provides a visual illustration of it. In terms of receptors (set Q of signals), the channel is silent. We claim that the emission is clearly determined by the reception. A telecommunications channel is said to have noise if its crossing matrix differs from the one shown in relation (8).

Although the majority of telecommunications channels are noisy, the signal may theoretically be impacted when information is sent across them. However, the choice (signal reception in excellent condition) may not be impacted. The reception can be accurately interpreted even if the signal is distorted. Different ideas and techniques exist for separating the signal from the noise. As shown in Figure 2, many of them consider the signal/noise ratio (represented by S/N).

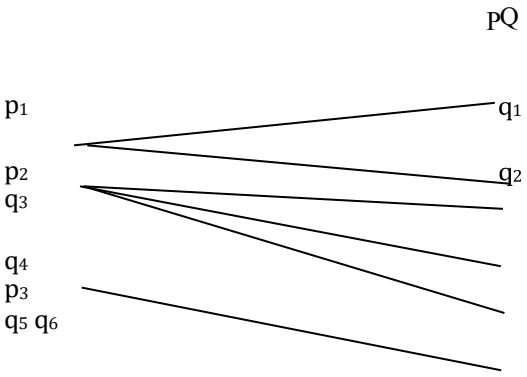


Fig. 6. Deterministic channel representation.

(V) Study of Stationary Channel

According to this last relationship, the crossing matrix of the stationary data channel is a vector itself, and represented such as; $R(\overline{Q}\overline{P})$. In this type of data channel, conditional probabilities do not depend on a particular moment of time.

(VI) Study of Channel with Memory

A data channel is said to have memory if its output statistically relies on both the current entry and the inputs and outputs from the past.

Results and Discussions

We can see that we can quickly determine the sort of data channel we have by examining the pattern and characteristics of the crossing matrix type.

Because digital data transmission can take advantage of the cost-effectiveness of digital integrated circuits, it is becoming more and more common. For a number of years, specialized digital signal processing capabilities have been implemented as large-scale integrated circuits (1-3), and an increasing number of modem functions are being implemented in ever-tinier packages (e.g., the modem card in a laptop computer). Data transmission systems may now be built as software thanks to advancements in microcomputers and special purpose programmable digital signal processors. This is helpful since a specific design is not "frozen" (1-3 and references therein) as hardware; instead, it may be modified or replaced in response to better designs or evolving specifications.

There is no perfect data transmission channel, as may be shown by analyzing the channels. In real-world scenarios, a data transmission channel is often a combination of several channel types; for instance, a channel may be both stationary and deterministic.

It may be said that a noiseless data transmission channel can be obtained by transposing the crossing matrix of a deterministic transmission channel and applying certain mathematical logic to it.

We may utilize a certain form of data transmission channel based on the intended outcome at the receiver and the signal-to-noise (S/N) ratio.

The results of our current research are in excellent accord with those of the other authors (1–9), and such work is also ongoing by other workers in the area of telecommunication channels and data transmission in digital electronics.

Conclusions and Final Remark

Both the channel's crossing matrix and the conditional probabilities of output signals in relation to input signals (the signal source) were used to analyze these data transmission channels. Without going overboard, the most typical kinds of data transmission routes have been selected. Shot noise, white noise, Gaussian, jitter, crosstalk in telephone channels, various forms of electromagnetic interference in radio channels, etc. are only a few of the many different types of noise that may arise in a channel.

The following are examples of similar data transmission channels: Markov sources, discrete or continuous sources, stationary and non-stationary sources, sources with or without memory, ergodic sources (one source is always ergodic and stationary, but not vice versa), etc.

A new categorization of data channels may be made by considering the kinds of sources that produce symbols that pass via data channels. The set "Q" of output signals must also be taken into account (for instance, there are two types of homogeneous channels: one homogeneous towards input and one homogeneous towards output).

References

1- 1. Kioskea.net (2014). Chapter/Book: Overview of Digital Data Transmission

2- 2. Taraborrelli, S., Verstraeten, B., and Sevenhans, J. (2000). "Trends in Silicon Radio Large Scale Integration," IEEE Commun. Mag., Vol. 38, pp. 142–147, Jan. 2000, is a contraction of modulator/demodulator for advancements in IC implementation of radio functions.

3- 3. Ardavan, M.T., Cioffi, J.M., and Hassibi, B. (2000). Adaptive equalization of multiple-input multiple-output channels (MIMO), IEEE International Conference on Communications (ICC 2000), Vol. 3, pp. 1670-1674.

4- 4-C. Vertan (1999). Prelucrarea si analiza semnalelor at Bucureşti's Editura Printech, 1999.

5- 5. Freeman, T., Szeliski, R., Kang, S.B., and William, C.L. (2006). Noise Estimation from a Single Image, published in 2006 at the IEEE Conference on Computer Vision and Pattern Recognition.

6- 6-Ferenc – Emil MěZES, Zoltán GERMěN – SALLüge (2012). IMAGE PRE-PROCESSING BASED ON FPGA

7- The sixth edition of the International Conference on Interdisciplinarity in Engineering, "Petru Maior," University of

Tîrgu Mures, Romania, 2012 7-Reuter, M., Quirk, K., Zeidler, J., Milstein, L. (2000). Proceedings Symposium on Adaptive Systems for Signal Processing, Communications and Control, 141-146, Lake Louise, Alberta, October 2000, Nonlinear effects in LMS adaptive filters.

8- 8. Zeidler, J.R., and A.A. Beex (2002). IASTED International Conference on Signal Processing, Pattern Recognition, and Application, 2002, pp. 474–479. Non-Linear Effects in Interference Contaminated Adaptive Equalization.

9- 9. Polgar Z., Varga, M., and Bota, V. (2004). Date transmissions. Authorii, A book in Romanian language, 2004; Aplicaňii practice, Cluj Napoca ianuarie, 2004.