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RESEARCH ARTICLE

The Mathematical Study of Data Transmission in Digital Electronics

Anghel Drugarin Cornelia Victoria[1], *M. Ayaz Ahmad[2], N. Ameer Ahamad[3] and Draghici Silviu[4]

1. Department of Electronics and Informatics Engineering "Eftimie Murgu", University of Resita, Resita, Romania.
2. Physics Department, Faculty of Science, P.O. Box 741, University of Tabuk, 71491, Kingdom of Saudi Arabia.
3. Department of Mathematics, Faculty of Science, P.O. Box 741, University of Tabuk, 71491, Kingdom of Saudi Arabia.
4. Department of Electronics and Informatics Engineering "Eftimie Murgu", University of Resita, Resita, Romania

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Corresponding Author

M. Ayaz Ahmad

Abstract

An attempt has been made for a systematic study of discrete data transmission in various electronic devices. The present investigations are based on the theory of conditional probability. Finally, some valuable features of a noise matrix so called crossing matrix have been discussed to obtain the perfect data transmission channel. This study is an important issue as day by day advancement of electronic devices in the modern age of digital technology.

INTRODUCTION

The transmission channels so called telecommunication channels are made up of several segments that allow the data / signal to circulate in the form of electromagnetic, electrical, light or even acoustic waves. These signals propagate at the speed of light (300,000Km/sec) in the vacuum or slightly slower (200,000Km/sec) in materials. So, in fact, it is a vibratory phenomenon that is propagated over the physical medium. In general the data transmission is called the communication between two machines (i.e. transmitter and receiver), when a single piece of data set (any energy) sent to such machines. A block diagram has been shown in Figure1 for better understanding of data transmission in digital electronics (1-2).

Figure 1 demonstrates the discrete data transmission channel, which is the transmission of one message from a finite set of messages through a communication channel. A message sends to the transmitter and communicates to the receiver. The sender selects one message from the finite set, and the transmitter sends a corresponding signal (or "waveform") that represents this message through the communication channel. The receiver decides the message sent by observing the channel output. The successive transmission of discrete data messages is known as digital communication (1-2). Based on the noisy signal received at the channel output, the receiver uses a procedure known as detection to resolve which message, or sequence of messages, was sent. The ideal detection minimizes the probability of an erroneous receiver decision on which message was transmitted.

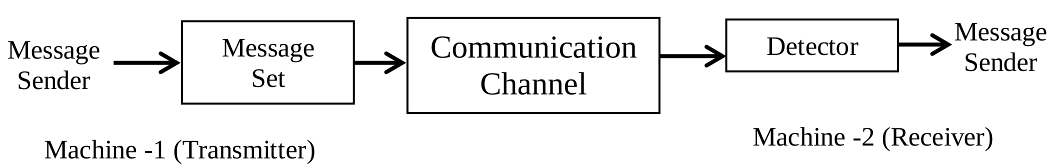

Fig. 1.A block diagram of discrete data transmission.

Due to advancement in technology, there are innumerable ways of discrete data transmission channels. At present, we have followed a unique way for data transmission channels. This assortment is illustrated by a probabilistic model which was defined such as:

$$\begin{cases} P = (p_1, p_2, \ldots . p_n) \\ Q = (q_1, q_2, \ldots . q_n) \\ r(q_j/p_i), i = 1, \ldots, m \text{ and } j = 1, \ldots ., n \end{cases} \quad (1)$$

where, $r(q_j/p_i)$, represent a data set of transition probabilities between P and Q and are referring the binary-valued of random variables.

Practically, any data transmission channel can be expressed in such way; $\{P, Q, r(q_j/p_i)\}$. And the data set of **crossing probability** is a matrix structure so called **noise matrix**, will be in the following form (3 and references therein):

$$R(Q/P) = \begin{bmatrix} r(q_1/p_1) & r(q_2/p_1) & r(q_n/p_1) \\ r(q_1/p_2) & r(q_2/p_2) & r(q_n/p_2) \\ r(q_1/p_m) & r(q_2/p_m) & r(q_n/p_m) \end{bmatrix} \quad (2)$$

The above matrix (eqn. 2), the left hand side "R(Q/P)" is of the order of m×n and is called the output probabilities, whereas the right hand side of eqn. (2) is called input probabilities. In general, for such type of matrix named as crossing matrix or noise matrix, all rows and columns of eqn. (2) can be further explained such as:

$$\sum_{i=1}^{m} r\left(\frac{q_j}{p_1}\right) = 1 \text{ and } \sum_{j=1}^{n} r\left(\frac{q_j}{p_i}\right) = 1 \quad (3)$$

A block diagram for a simplified description of a telecommunication channel has been depicted in Figure 2. In this way the discrete data transmission channel have the following components in addition to the transmitter and the receiver:

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

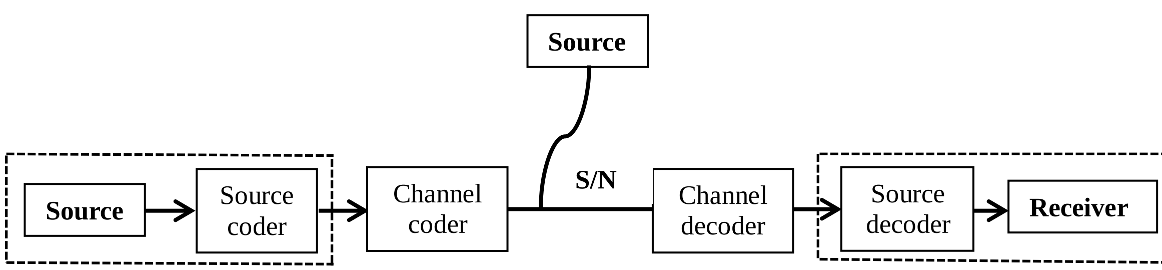

Fig. 2. A block diagram of data transmission channel.

Further, we have to take into account that noises can be found in telecommunication channels. Therefore, a block diagram from figure 2 may also include a modulator and a demodulator. And a brief classification of data transmission channels is:

- Continuous channel: P and Q are continuous sets of data signals.
- Discrete channels: P and Q are discrete sets of signals.
- Symmetric channel: channel's crossing matrix **R(Q/P)** has next features: any line of crossing matrix is obtained by a circular permutation of another line; any column of crossing matrix is obtained by a circular permutation of another column.

One can differentiate the stationary and non-stationary channels with memory or without memory, deterministic or non-deterministic, with or without removal. All these will be referred to in the following. However, considering the large variety of data transmission channels and their immeasurable classification, we will give the detail only of discrete type.

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).

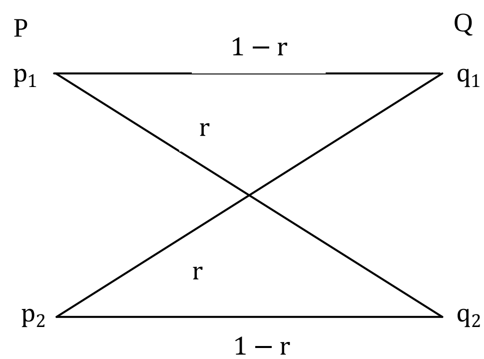

Fig. 3. A simple pictorial representation of binary symmetric channel (CBS).

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:

$$R(Q/P) = \begin{pmatrix} 1-r-s & r & s \\ r & 1-r-s & s \end{pmatrix} \quad (6)$$

A simple pictorial representation of the above mathematical relation / channel has been depicted in Figure 4.

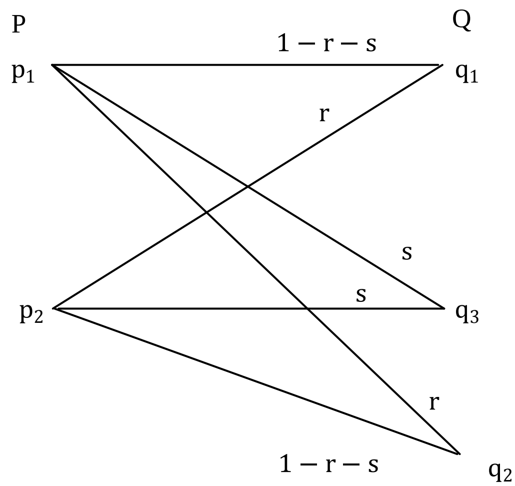

Fig. 4. A Pictorial representation of channel with removal of signals.

Obviously, this type of channel (with removal of data sets) is not symmetrical because the rows and columns of the crossing matrix which defines it cannot be obtained from one another by using permutations. It's called channel with removal data sets as symbol q_3 is always received incorrectly with probability "s". it basically deletes any information about the transmitted symbols p_1 and p_2.

(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:

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

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).

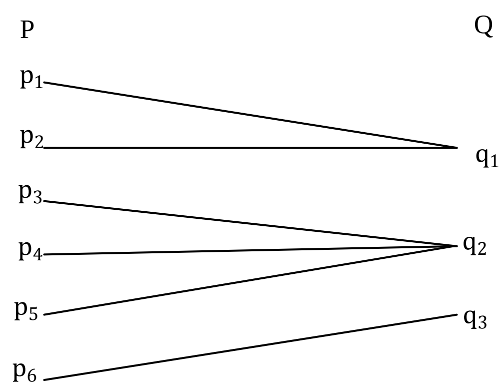

Fig. 5. A representation of deterministic channel.

(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:

$$R(Q/P) = \begin{pmatrix} \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{3}{5} & \frac{3}{10} & \frac{1}{10} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \quad (8)$$

Its pictorial representation has been depicted in Figure 6. The channel is noiseless in terms of receptor (set Q of signals). We say that the reception determines unambiguously the emission. Any telecommunications channel characterized by a crossing matrix that has a different structure than the one shown in relation (8) is considered a channel with noise.

Most of the telecommunications channels are with noise, but in theory of information of transmission through the telecommunications channels, the signal may be affected. But the decision (signal reception in good condition) may not be affected. The signal may be distorted, but the reception can be decoded correctly. There are various theories and methods of extracting the signal from the noise. Many of them take into account the signal / noise ratio (denoted by S / N), as it is already mentioned in Figure 2.

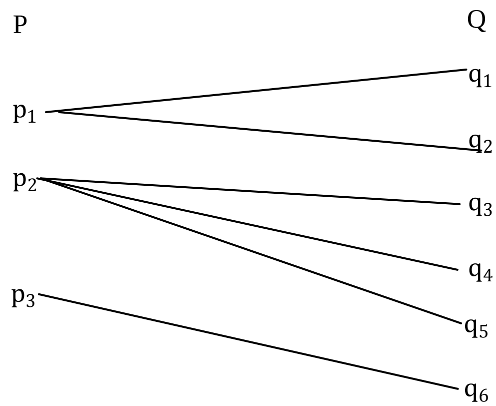

Fig. 6. Deterministic channel representation.

(V) Study of Stationary Channel

It is characterized by the fact that the sets of signals (or events) of P and Q can be vectors or represented as vectors and elements of crossing matrix. Therefore, the conditional probabilities "$r\ (q/p)$", are written in the vector form, as products of other conditional probabilities:

$$r(\bar{q}/\bar{p}) = \prod_{i=1}^{k} r(q_i/p_i) \qquad (9)$$

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

If the output of a data transmission channel statistically depends on current entry, as well as on the previous inputs and outputs, we say that the data channel is a channel with memory.

Results and Discussions

We can observe that by studying the pattern and features of the crossing matrix type we can easily establish what kind of data channel we have.

The increasing popularity of digital data transmission is that it can be used to exploit the cost effectiveness of digital integrated circuits. Special purpose of digital signal-processing functions have been realized as large-scale integrated circuits for several years, (1-3) and more and more modem functions are being implemented in ever smaller packages (e.g., the modem card in a laptop computer). The developments of the microcomputer and of special purpose programmable digital signal processors mean that data transmission systems can now be implemented as software. This is useful in that a particular design is not "frozen" (1-3 and also references therein) as hardware but can be altered or replaced with the advent of improved designs or changed requirements.

Analyzing the data transmission channels it can be noticed that there is no ideal data transmission channel. A data transmission channel met in practical situations is usually a mixture of channel types, for example a channel can be deterministic and stationary all together.

It can be stated that, by transposing crossing matrix of a deterministic transmission channel and subjecting it to certain mathematical calculus, one can obtain a noiseless data transmission channel.

According to desired result we want to obtain at receiver and to signal-noise (S/N) ratio, we can use a certain data transmission channel type.

Such type of work also continue in progress by various worker in the field of telecommunication channels / data transmission in digital electronics (1-9) and the outcomes of our present study are in good agreement by the others authors (1-9).

Conclusions and Final Remark

The study of these data transmission channels was made in terms of channel's crossing matrix and also in terms of conditional probabilities of output signals relative to input signals (the signal source). The most representative types of data transmission channels have been chosen, without exhausting by far existing types. Only in terms of noise occurring in channel we can have a multitude of other new situations, because a wide variety of noise types is known: shot noise, white noise, Gaussian, jitter, crosstalk in telephone channels, all kinds of electromagnetic interference at radio channels etc.

Similar data transmission channels, we can consider: stationary and non-stationary sources, sources with memory or without memory, ergodic sources (one source is always ergodic and stationary, but not vice versa), Markov sources, discrete or continuous sources etc.

Taking into account the types of sources that generate symbols which cross through data channels, a new classification of data channels can be stated. Must also be taken into consideration the set “Q” of output signals (there is, for example, a type of homogeneous channel towards output, as well as one homogeneous towards input).

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