ANALYTICAL STUDY ON BIT-SYNCHRONIZATION PROBLEMS IN A CODED COMMUNICATION SYSTEM

Wai-Hung Ng
The Aerospace Corporation
Los Angeles, California

ABSTRACT

Many bit-synchronization techniques in digital communications depend on bit transitions for successful operation. In this paper, we first categorize the four main sources of generating transitionless signals. Then we describe general properties of channel coding and explain that, by injecting a well-selected detectable error pattern into the transmitted and coded signal, this bit transitionless problem can be eliminated without any additional bandwidth penalty. Finally, examples in both block code and convolutional code are selected for illustrating this simple but useful application.

INTRODUCTION

The basic functional diagram of a digital communication system could be characterized in Fig. 1. Without loss of generality, we shall assume that this is a binary communication system and thus the output of the information source, $\tilde{I}$ is a binary sequence. By properly selecting the contact points, a or b and c or d, from the synchronized switches SW1 and SW2, we can let the message signal feed in or bypass the scrambler/descrambler and/or the channel encoder/decoder. The typical scrambler/descrambler given in Fig. 1 is a model for ready reference. One can extend it to other kinds of scramblers/descramblers without affecting the following presentation.

In this paper, we concentrate on the case that points a and c of SW1 and SW2 are contacted. Thus, $\tilde{I}$ is fed into the scrambler and generates a signal sequence $\tilde{S}$, which is then encoded as $\tilde{C}$ and modulated as $\tilde{T}$. At the receiving end, the received signal is demodulated, decoded, descrambled and then delivered to the users. If the system is operating normally and the channel condition is within the error controlling capability of the error correcting code used, we shall have $\tilde{I}' = \tilde{I}$, $\tilde{C}' = \tilde{C}$, and $\tilde{T}' = \tilde{T}$.

Four factors can cause $\tilde{T}$ to become a transitionless signal: a transitionless message signal (i.e., all-zero or all-one), a common but inappropriate scrambling configuration, certain modulation techniques, and combinations of the above three factors.

ANALYSIS OF THE SCRAMBLER CONFIGURATION

Among the four transitionless signal sources, the first two sources cause most of the trouble in obtaining the bit synchronization, and we shall discuss them in more detail. There are three different forms of $\tilde{I}$ appealing in everyday communication channels: a transitionless signal, a continuous binary random signal, and a signal sequence consisting of discrete and binary message blocks. In the following, we shall investigate the scrambling operation in these three cases.

Let us consider the first case that I is an all-zero sequence, as in the case that no message is being transmitted; then $\tilde{S}$ is the pseudorandom noise (PN) sequence generated by the scrambler. The typical scrambler given in Fig. 1 is a single-feedback s-bit (s = 3) linear shift register which generates a binary PN sequence with period of (2^s - 1) bits. Since any s-bit shift register has a total of 2^s states (i.e., there are 2^s different binary combinations), a period of (2^s - 1) bits indicates that among 2^s states there is at least one idle state in which the scrambler fails to operate properly [1]. The idle state for the scrambler given in Fig. 1 is an all-zero state. If the initial state of the scrambler is an idle one, the $\tilde{S}$ sequence would be an all-zero sequence and the scrambler remains in the idle state forever. As long as the initial state is not an idle state, any practical scrambler would generate a perfect PN sequence with maximum period equal to (2^s - 1).

Suppose, secondly, that $\tilde{I}$ is a continuous binary random sequence such as a continuous message with no pause at all, then the sequence $\tilde{I}$ is a continuous random sequence independent of the operation of the scrambler. However, because $\tilde{I}$ is continuously fed into the scrambler, the probability of being driven into its idle state at any instant is equal to 2^{-s}. But, as new random message digits continuously feed into the scrambler, the idle state even if occurring would be driven off and replaced by an active state again. In this case, the length of $\tilde{S}$ to be transitionless simply obeys the probability distributed law.

Now, consider the third case, the most common in transmitting message signals: $\tilde{I}$ consists of discrete and random binary message blocks which are separated by all-zero sequences (i.e., there are guard spaces between random message blocks) such as pauses between sentences in a speech. As we mentioned in the second case, the probability of the scrambler being driven into its own idle state by the random incoming signal at any instant is 2^{-s}. This is also true at the instant when the first zero of the guard space shifts into the scrambler. Therefore, the probability of any guard space (i.e., those all-zero sequences separating the random message blocks) remaining all zeros is also equal to 2^{-s}. In other words, if we transmit 2^s random message blocks per second, we would expect one transitionless event to occur every second. Thus, the probability of losing bit synchronization in the receiver due to this common but inappropriate scrambling configuration is very high. When this event happens, the idle state will cause the scrambler to fail to randomize the binary input bit stream and thus it can not break a long sequence of zeros or ones. This can be a serious problem in digit communication systems, and it still awaits solution.

A case that rarely occurs is that $\tilde{I}$ is a transitionless all-one sequence. When $\tilde{I}$ feeds into the scrambler described in Fig. 1 where the initial state of the scrambler is equal to all ones, the $\tilde{S}$ sequence will also be an all-one sequence. The general solution for this case described above.

LINEAR CODES AND ERROR PATTERNS

We shall describe general properties of channel coding and explain why using detectable error patterns can eliminate the transitionless signal.

There are 2^k distinct codewords in a well defined (n,k) code, and each codeword is n bits long. Let us consider that a (n,k) code forms a subgroup H. Then H has a zero element (i.e., the codeword consists of n zero digits), and all elements in H obey the closure property under the operation of addition modulo-2. Furthermore, this subgroup and the other disjoint (2^{n-k} - 1) cosets, each consisting of 2^k elements, form a group G, where G has a total of 2^n elements. The above statement is called a standard array [2]. If there are two elements $\tilde{X}$ and $\tilde{C}$ in G, and if $\tilde{X} \notin$ H but $\tilde{C} \in$ H, it implies $\tilde{X} \oplus \tilde{C} \notin$ H. Therefore, $\tilde{C}$ is a codeword and $\tilde{X}$ is a detectable error pattern.

The basic property of the standard array provides an important and useful device which so far been neglected. Instead of directly feeding $\tilde{C}$ into the modulator as shown in Fig. 1, we can feed in $\tilde{X} \oplus \tilde{C}$, where $\tilde{X}$ is a pre-selected detectable error pattern. Since $\tilde{X} \oplus \tilde{C} \in$ H, it implies that $\tilde{X} \oplus \tilde{C}$ is not the zero element. Then if we select the $\tilde{X}$ according to the criteria to be described in the next section, we can guarantee that the transmitting signal is not a transitionless one. The reverse operation in the receiver is very simple; it only requires the modulo-2 sum of the pattern $\tilde{X}$ and the output of the demodulator to recover the transmitted codeword $\tilde{C}$.

APPLICATION

In the following, we shall use examples to illustrate additional considerations in the utilization of detectable error patterns in a practical system.

Let us assume that the code used is the popular (24,12) Golay code [2]. We select three representative error patterns in our discussion. First, we know that the all-zero and all-one elements are two Golay codewords, and the minimum weight of nonzero elements is equal to eight, so the simplest error pattern would be 23 zeros followed by a one. When this error pattern is being selected as $\tilde{X}$ it requires an additional counter to count the 23 zeros before sending a one (or to binary complement the 24th code digit) and thus we further recommend the second error pattern. Second, by using the Golay encoder, we found that the binary clock sequence (i.e., 0101... or 1010...) is also a detectable error pattern which has the advantage of eliminating the counters normally required in both the transmitter and the receiver. We would consider that the binary clock sequence is the simplest detectable error pattern in implementation since it only requires reversing every other bit (i.e., either the even bits or the odd bits) in $\tilde{C}$. Third, if we would like to maximize the minimum number of transitions in the transmitting signal, we would pick any $\tilde{X}$ that has weight equal to half of the minimum distance of the code (i.e., $\tilde{X}$ has weight of 4 in this special application). Thus, weight of ($\tilde{X} \oplus \tilde{C}$) is $|\tilde{X} \oplus \tilde{C}| \geq || - |\tilde{X}|| \geq 4$ which implies that there are at least four transition digits in a 24-bit transmitting coded signal.

The technique is also applicable to convolutional codes. In a previous study [3], we proved that the two code paths in a non-catastrophic code tree in which all consecutive code branches are always equal must be encoded from the two transitionless message signals. Let us use the rate 1/2, constraint length 7 convolutional code used in the standard Viterbi decoder as an example. The generator sequence of this code is J = 11 10 11 11 00 01 11. Then, each zero of an all-zero sequence $\tilde{I}$ is encoded into two zero code digits, and each one of an all-one sequence $\tilde{I}$ is encoded into a code branch which is equal to the modulo-2 sum of all the branches in J (i.e., it is equal to $11 \oplus 10 \oplus 11 \oplus 11 \oplus 00 \oplus 01 \oplus 11 = 11$). Therefore, an all-zero $\tilde{I}$ is encoded into an all-zero $\tilde{C}$ and an all-one $\tilde{I}$ is encoded into an all-one $\tilde{C}$, and the code is transparent. The above mentioned considerations of selecting, $\tilde{X}$ for Golay code can directly apply to this convolutional code. Because to maximize the number of transitions is generally not required for most practical communication systems, we would suggest choosing the binary clock sequence to be the detectable error pattern $\tilde{X}$ in order to simplify the hardware implementation.

SUMMARY

We have shown that, by injecting a detectable error pattern $\tilde{X}$ into the well-defined codeword $\tilde{C}$, the resulting $\tilde{C} \oplus \tilde{X}$ would never be a transitionless signal. This is also applicable to most modulation techniques in which all-zero (for all-one) codeword is modulated into an all-zero (or all-one) waveform $\tilde{T}$. However, few modulation techniques do not obey this general rule. For example, in differential phase-shift keying (DPSK), both all-zero and all-one codewords are modulated into an all-zero waveform $\tilde{T}$ and the binary clock sequence (i.e., both 0101... and 1010...) is modulated into an all-one waveform $\tilde{T}$. Therefore, to use the binary clock sequence as the detectable error pattern x to eliminate the transitionless signal for DPSK, we must apply modulo-2 of $\tilde{X}$ to the modulated signal $\tilde{T}$ instead of modulo-2 of $\tilde{X}$ to $\tilde{C}$ (i.e., reverse the phase of every other bit in waveform $\tilde{T}$). The three error patterns investigated in the previous section represent three different considerations in selecting $\tilde{X}$ and one could use other choices of $\tilde{X}$ as preferred. As long as we understand the distribution property of $\tilde{I}$, the common but inappropriate configuration of the scrambler, the distance, structure and standard array properties of linear codes, and the characteristics of digital modulation techniques, there are enough detectable error patterns (i.e., a total of $(2^n - 2^k)$ different $\tilde{X}$ for any given (n,k) code for us to select a suitable one to eliminate the possibility of transmitting a transitionless signal.

REFERENCES

[1] Spilker, J. J. : Digital Communication by Satellite , Prentice-Hall, New Jersey, 1977

[2] Peterson, W. W. and Weldon, E. J. : Error-Correcting Codes , MIT Press, Cambridge, 1972.

[3] Ng, W. H. “Study on Decoding Behavior for Convolutional Codes”, IEEE Trans. 1970, IT-16, pp. 795 - 797.

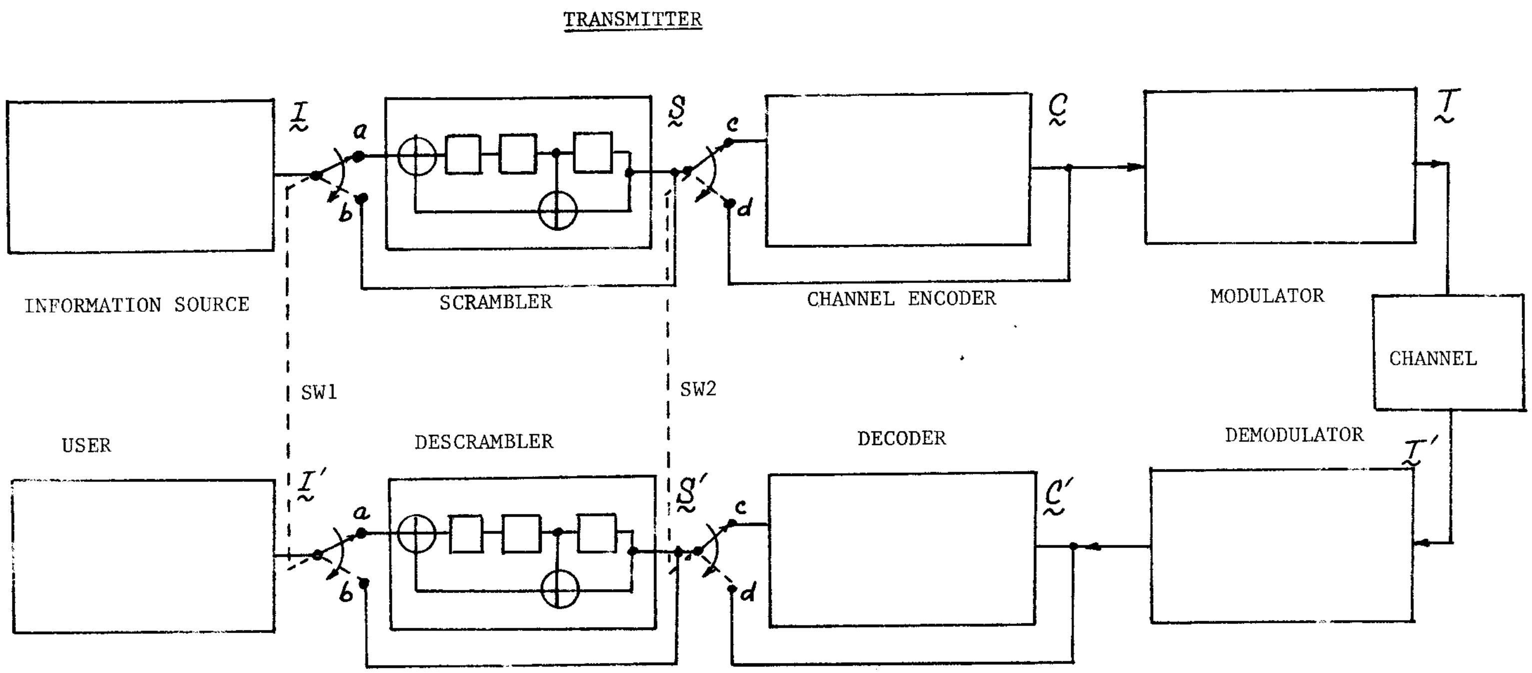

FIGURE 1. BASIC FUNCTIONAL DIAGRAM OF A DIGITAL COMMUNICATION SYSTEM