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INTRODUCTION OF CHANNEL LINEAR CODING TECHNIQUE IN MOBILE SATELLITE COMMUNICATIONS

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ABSTRACT

This paper describes introduction of channel linear coding techniques used in Mobile Satellite Communications (MSC) for maritime, land (road and rail) and aeronautical applications. The design of modern channel coding structure includes both encoder and decoder part that can be used in a communication system for encoding a message at the transmitter and decoding it, detecting error and correcting it on the receiver part. As is known, MSC systems are generally limited by the available power and bandwidth. Thus, it is of interest if the signal power can be reduced while maintaining the same grade of service for Bit Error Rate (BER). This sequence can be achieved by adding extra or redundant bits to the information content by using a channel coder. The complete transmission loop requires any type of encoder followed by modulation in transmitter via transmission channel to receiver, namely to demodulator and decoder. In coding theory, a linear code is an error-correcting code for which any linear combination of codewords is also a codeword. Linear codes are traditionally partitioned into block and convolutional codes, although turbo codes can be seen as a hybrid of these two types. Linear codes allow for more efficient encoding and decoding algorithms than other existing codes. Among the total channel schemes implemented in MSC, only two most widely used block or cyclic and convolutional encoders are described. Here will be not discussed decoding techniques as the reverse method of coding and every type of decoding on the transmit side needs the convenient decoding method on the receive side.

Kew words: MSC, VDV, MES, Coding, BER, Block Codes, Cyclic Codes, Convolutional Codes

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INTRODUCTION

Linear codes are used in forward error correction and are applied in methods for transmitting symbols (bits) on a communications channel so that, if errors occur into the links, some errors can be corrected or detected by the recipient of a message block. The codewords in a linear block code are blocks of symbols that are encoded using more symbols than the original value to be sent. In fact, a linear code of length transmits blocks containing n symbols.

The matter of a MSC system depends on how it deals with the noise that may interfere with the Voice, Data and Video (VDV) to be transmitted. Noise generally is encountered in the channel phase of a different communication system, which could be transmission lines, optical fibers, space, air etc. The coding theory is an important tool for encoding a given message, decoding and correcting the received message. As is known, MSC systems are generally limited by the available power and bandwidth. Thus, it is of interest if the signal power can be reduced while maintaining the same grade of service for BER. This can be achieved by adding extra or redundant bits to the information content by using a channel coder. Excepting several main classes of channel coder, the most widely used in MSC are block, cyclic and convolutional encoders. These coding techniques are one such tool that can be used both for encoding and decoding of the information represented in the form of binary numbers.

The complete transmission loop requires any type of encoder scheme followed by modulation and transmitter via transmission channel to receiver, namely to demodulator and decoder. In such a manner, decoding is the reverse method of coding and every type of decoding on the transmit side needs the same convenient decoding method on the receive side.

The VDV or telex information used in MSC is transmitted in digital form through a channel that can cause degradation of these transmission signals. The noise, interference, fading and other obstacle factors experienced during transmission could increase the probability of bit error at the receiver of Mobile Earth Station (MES). Anyway, the coding process uses redundant bits, which contain no information to assist in the detection and correction of errors. The subject of coding emerged following the fundamental concepts of information theory laid down by the US scientist Claude Elwood Shannon in 1948, which is the relationship between communication channel and the rate at which information can be transmitted over it. Basically, the theorems laying down the fundamental limits on the amount of information flow through a channel are given [1, 2, 3].

Block Codes

Block coding was the first type of channel coding implemented in early mobile communication systems. There are many types of block coding, but among the most used the most important is Reed-Solomon (RS) code, which is

IIOAB JOURNAL
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highly used in MSC applications. In addition, Hamming, Golay, Hadamard, Expander, Multidimensional Parity, Bose, Chaudhuri and Hocquenghemand (BCH) codes are other well-known examples of classical block coding.

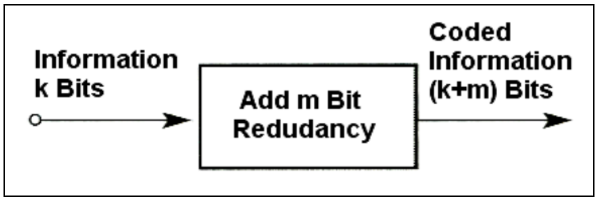

Fig.1: Block Coders - Courtesy of Book: by Richharia [2]

Binary linear block codes are expressed in the (n, k) form, where (k) is the information bits number that is converted into (n) code word bits. There are (n, k) party bits in each encoded block, where the difference between (n) and (k) bits are added by the coder as a number of redundancy bits (r). In the other words, a coded block comprising (n) bits consists in (k) information and (r) redundant bits expressed as follows:

$$n = k + r \qquad (1)$$

Such a code is designated as a (n, k) code, where the code rate or code efficiency is given by the ratio of (k/n). Mapping between message sequences and code words can be achieved using look-up tables; although as the size of the code block increases such an approach becomes impractical. This is not such a problem as linear code words can be generated using some form of linear transformation of the message sequence. Thus, a code sequence (c) comprising of the row vector elements (c_1, c_2,..., c_n) is generated from a message sequence (m), comprising the row vector elements (m_1, m_2,..., m_k) by a linear operation:

$$c = m\,G \qquad (2)$$

where G = generator matrix. At this point, in general, all (c) code bits are generated from linear combinations of the (k) message bits.

A special category known as a systematic code occurs when the first (k) digits of the code are the same as the first (k) message bits, namely if input message bits appear as part of the output code bits. The remaining n-k code bits are then generated from the (k) message bits using a form of linear combination, and they are termed the party data bits.

The generator matrix for a linear block code is one of the bases of the vector space of valid codewords. The generator matrix defines the length of each codeword (n), the number of information bits (k) in each codeword and the type of redundancy that is added; the code is completely defined by its generator matrix. The generator matrix is a (k · n) matrix that is the row space of V_k. Thus, one possible generator matrix for a typical (7, 4) linear block code has to be presented in four rows as blocks:
G = 1101000/0110100/1110010/1010001. Thus, the distance between two coded words (for example, first 2 and second 2 digits) in a block is defined as the number of bits in which the words differ and is called the Hamming distance (d_h). The Hamming distance has the capability to detect all coded words having errors (e_d), where $e_d < (d_h - 1)$; to detect and correct (e_{dc}) bits, where $e_{dc} = (d_h - 1)/2$ and to correct t and detect (e) errors, where the Hamming distance as a minimum space between two coded blocks is given by:

$$d_h = t + e + 1 \qquad (3)$$

Basically, in the detection process, two coded words separated by (d_h) are most likely to be mistaken for each other. The extended Golay code offers superior performance to Hamming codes but at a cost of increased receiver complexity. In practice, code words are conveniently generated using a series of simple shift registers and modulo-2 adders.

In [Fig. 1] is illustrated the concept diagram of block codes and rate, which operate on groups of bits organized as blocks, namely information bits for transmission are assembled as blocks before coding.

1. **Cyclic Codes** – Cyclic Codes were first studied in 1957 by Prange. After that they became an important part of the coding theory. Cyclic codes are easy to study and implement because: 1) Encoding and syndrome computation can be done easily using shift registers with feedback connections. 2) Due to the inherent algebraic structure, they are easy to decode.
2. In coding theory, a cyclic code is a block code, where the circular shifts of each codeword gives another word that belongs to the code. They are error-correcting codes that have algebraic properties that are convenient for efficient error detection and correction.
   These code methods are a subclass of linear codes, where a code word is generated simply by performing a cyclic shift of its predecessor. In other words, each bit in a code sequence generation is shifted by one place to the right and the end bit is fed back to the start of the sequence, hence the term cyclic. Both the linear Hamming and extended Golay codes have equivalent cyclic code generators.

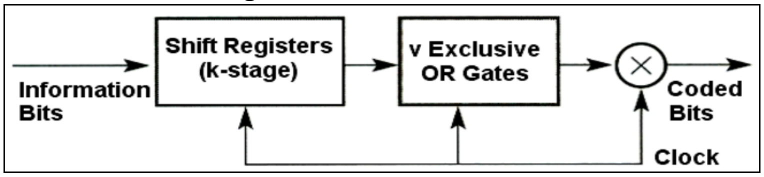

Fig.2: Convolutional Coders – Courtesy of Book: by Richharia. [4]

BCH Codes – The BCH codes are the most powerful of all cyclic codes with a large range of block length, code rate, then alphabets and error correction capability. These codes are superior in performance to all other codes of similar block length and code rate. Most commonly used BCH codes have a code word block length as $n = 2^m - 1$, where (m = 3, 4 ...). For instance, Inmarsat-A MES onboard ships uses 57 bits plus 6 party bits encoded with BCH (63, 57 code in TDM channels and for the return request channel burst employs Aloha BPSK (BCH) 4800 b/s.

RS Codes – The RS codes are a subset of the BCH codes specially suited for correcting the effect of the burst errors. The latter consideration is particularly important in the context of the MSC channels and hence, RS codes are usually incorporated into the system design. This set of codes has the largest possible code minimum distance of any linear code with the same encoder input and output block length. Thus, the RS codes are specified using the convention RS (n, k), where n = number of code symbols word length per block; k = data symbols encoded and the difference between (n) and (k) is the number of parity symbols added to the data [2, 4, 5, 6].

CONVOLUTIONAL CODES

The second family of commonly used codes is known as convolution codes, which in MSC are a type of error-correcting code that generates parity symbols via the sliding application of a Boolean polynomial function to a data stream. The sliding application represents the so-called convolution of the encoder over the data, which gives rise to the term convolutional coding. The sliding nature of the convolutional codes facilities trellis decoding using a time invariant trellis. Time invariant trellis decoding allows convolutional codes to be maximum likelihood soft decision decoded with reasonable complexity. The ability to perform economical maximum likelihood soft decision decoding is one of the major benefits of convolutional codes. This is in contrast to classic block codes which are generally represented by a time variant trellis and therefore are typically hard decision decoded.

Convolutional codes are simply often described as continuous. However, it may also be said that convolutional codes have arbitrary block length, rather than that they are continuous, since most real world convolutional encoding is performed on blocks of data. Convolutionally encoded block codes typically employ termination. The arbitrary block length of convolutional codes can also be contrasted to classic block codes, which generally have fixed block lengths that are determined by algebraic properties. The ability to perform economical soft decision decoding on convolutional codes, as well as the block length and code rate flexibility of convolutional codes, makes them very popular for MSC systems.

However, convolutional codes are generally more complicated than linear block codes, more difficult to implement, and have lower code rates (usually below 0.90), but have powerful error correcting capabilities. They are popular in satellite and deep space communications, where bandwidth is essentially unlimited, but the BER is much higher and retransmissions are infeasible.

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Convolutional codes are more difficult to decode because they are encoded by finite state machines that have branching paths for encoding each bit in the data sequence. Decoding of convolutional codes is performing very quickly by the Viterbi Algorithm. The Viterbi algorithm is a maximum likelihood decoder, meaning that the output code word from decoding a transmission is always the one with the highest probability of being the correct word transmitted from the source.

Unlike block codes, which operate on each block independently, convolution codes retain several previous bits in memory, which are all used in the coding process. They are generated by a typed-shift register and two or more modulo-2 adders connected to particular stage of the register. The number of bits stored in the shift register is termed the constraint length (K). Bits within the register are shifted by (k) input bits. Each new input generates (n) output bits, which are obtained by sampling the outputs of the modulo-2 adders. The ratio of (k) to (n) is known as the code rate. These codes are usually classified according to the following convention: (n, k, K), for example (2, 1, 7), refers to a half-rate encoder of constraint length 7. It is important to know what sequence of output code bits will be generated for a particular input stream. There are several techniques available to assist with this question, the most popular being connection pictorial, state diagram, tree diagram and trellis diagram [2, 4, 7].

However, to illustrate how these methods are applied, the simple example of half-rate (1/2) encoder will be considered with constraint length k = 3. The system has two modulo-2 adders, so that the code rate is 1/2. The input bit (m) placed into the first of the shift register causes the bits in the register to be moved one place to the right. The output switch samples the output of each modulo-2 adder, one after the other, to form a bit pair for the bit just entered. Thus, the connections from the register to the adders could be one, two or three interfaces for either adder. The choice depends on the requirement to produce a code with good distance properties. A similar encoder used by the Inmarsat-A and aero standards is a half-rate convolutional encoder. At this point, in terms of connections to the modulo-2, adders can be defined using generator polynomials in the encoder configuration.

Thus, convolutional codes are forming in convolutional coder by convolving information bits R with the impulse response of a shift register encoder, which block diagram is shown in [Fig. 2]. These types of codes use previous information bits in memory (v) and continuously produce coded bits. The constraint length of convolutional code defines the number of information bits, which influence the encoder output. In such a way, the constraint length is decided by the number of shift registers or code memory. The error correcting property of the convolutional code depends on the constraint length and its value improves as code memory is increased, and in such a way decoding complexity increases.
The polynomial for the generating arm (n) of the encoder $g_n(p)$ and the generator polynomials representing encoder $g_1(p)$ can have the following relations:

$$g_n(p) = g_0(p) + g_1p^1 + \dots g_np^n \qquad (4)$$

$$g_1(p) = 1 + p + p^2 = 1 + p^2 \qquad (5)$$

where the value of g_1 takes on the value of 0 or 1 and a 1 is used to indicate that there is a connection between a particular element of the shift register and the modulo-2 adder. Thus, to provide a simple representation of the encoder, generator polynomials are used to predict the output coded message sequences for a given input sequences. For instance, the input sequence 10110 can be represented by the polynomial relation:

$$m(p) = 1 + p^2 + p^3 \qquad (6)$$

The Inmarsat-A analog MES onboard ships uses a HSD channel encoding configuration for the information data stream at 56 Kb/s.

The scrambling sequence on the input data stream shall be provided by the scrambler before the convolutional encoder described in CCITT Recommendation V.35 scheme. The data stream then passes differential encoder state stage 1 followed by 1/2 (half) convolutional encoding with constant length k = 7. The half (1/2) rate convolutional encoder can provide two data streams to the QPSK modulator using two generator polynomials rates as follows: $G_1 = 1 + x^2 + x^3 + x^5 + x^6$ and $G_2 = 1 + x + x^2 + x^3 + x^6$. The encoder provides two parallel data streams to the modulator: I and Q, while (Q) should lag (I) by 90^o in the modulator. The Inmarsat-B digital MES and aero standards onboard aircraft for transmission and out-of-band signaling channels uses digital modulation and FEC in order to efficiently utilize satellite power and bandwidth.

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The basic modulation and coding techniques are filtered by 60% roll-off O-QPSK and 40% roll-off BPSK, both with convolutional coding at either rate: 1/2 or 3/4 FEC and 8-level soft decision Viterbi decoding (constraint length = 7) [2, 4, 8].

CONCLUSION

In this paper have been reviewed basic and state-of-art coding, decoding and error correction techniques for MSC. Those techniques have been used extensively in digital MSC, because they are providing cost effective solutions in achieving efficient and reliable digital transmissions. Coding now plays an important role in the design of modern MSC and forthcoming generations of technology are expected to continue this trend with development more complicated, but more economic coding schemes.

Linear block codes are so named because each code word in the set is a linear combination of a set of generator code words. They are very easy to implement in hardware of MES terminals, and since they are algebraically determined, they can be decoded in constant time. They have very high code rates, usually above 0.95. They have low coding overhead, but they have limited error correction capabilities. They are very useful in situations where the BER of the channel is relatively low, bandwidth availability is limited in the transmission, and it is easy to retransmit data.

In this innovative age of ICT it is becoming essential to provide reliable communications of information to people on the move at sea, on the ground (road and Rail) and in the air, having sometimes difficulties to locate some of them precisely. Therefore, the deployment of channel coding and interleaving will enhance the bit-error performance of MSC links addressed for digital speech and data transmissions.

CONFLICT OF INTEREST

There is no conflict of interest.

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None

FINANCIAL DISCLOSURE

None

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