Module 6

Channel Coding

Lesson 36

Coded Modulation Schemes

After reading this lesson, you will learn about

- ***Trellis Code Modulation;***
- ***Set partitioning in TCM;***
- ***Decoding TCM;***

The modulated waveform in a conventional uncoded carrier modulation scheme contains all information about the modulating message signal. As we have discussed earlier in **Module #5**, the modulating signal uses the quadrature carrier sinusoids in PSK and QAM modulations. The modulator accepts the message signal in discrete time discrete amplitude from (binary or multilevel) and processes it following the chosen modulation scheme to satisfy the transmission and reception requirements. The modulating signal is generally treated as a random signal and the modulating symbols are viewed as statistically independent and having equal probability of occurrence. This traditional approach has several merits such as, (i) simplified system design and analysis because of modular approach, (ii) design of modulation and transmission schemes which are independent of the behavior of signal source, (iii) availability of well developed theory and practice for the design of receivers which are optimum (or near optimum).

To put it simply, the modular approach to system design allows one to design a modulation scheme almost independent of the preceding error control encoder and the design of an encoder largely independent of the modulation format. Hence, the end-to-end system performance is made up of the gains contributed by the encoder, modulator and other modules separately.

However, it is interesting to note that the demarcation between a coder and a modulator is indeed artificial and one may very well imagine a combined coded modulation scheme. The traditional approach is biased more towards optimization of an encoder independent of the modulation format and on optimization of a modulation scheme independent of the coding strategy. In fact, such approach of optimization at the subsystem level may not ensure an end-to-end optimized system design.

A systems approach towards a combined coding and modulation scheme is meaningful in order to obtain better system performance. Significant progress has taken place over the last two decades on the concepts of combined coding and modulation (also referred as coded modulation schemes). Several schemes have been suggested in the literature and advanced modems have been successfully developed exploiting the new concepts. Amongst the several strategies, which have been popular, trellis coded modulation (TCM) is a prominent one. A trellis coded modulation scheme improves the reliability of a digital transmission system without bandwidth expansion or reduction of data rate when compared to an uncoded transmission scheme using the same transmission bandwidth.

We discuss the basic features of TCM in this section after introducing some concepts of distance measure etc., common to all coded modulation schemes. A TCM scheme uses the concept of tree or trellis coding and hence is the name 'TCM'. However some interesting combined coding and modulation schemes have been suggested recently following the concepts of block coding as well.

Distance Measure

Let us consider a 2-dimensional signal space of **Fig.6.36.1** showing a set of signal points. The two dimensions are defined by two orthonormal basis functions corresponding to information symbols, which are to be modulated. The dimensions and hence the x- and y-axes may also be interpreted as 'real' and 'imaginary' axes when complex low pass equivalent representation of narrowband modulated signals is considered. The points in the constellation are distinguishable from one another as their locations are separate. Several possible subsets have been indicated in **Fig.6.36.1** capturing multiple modulation formats.

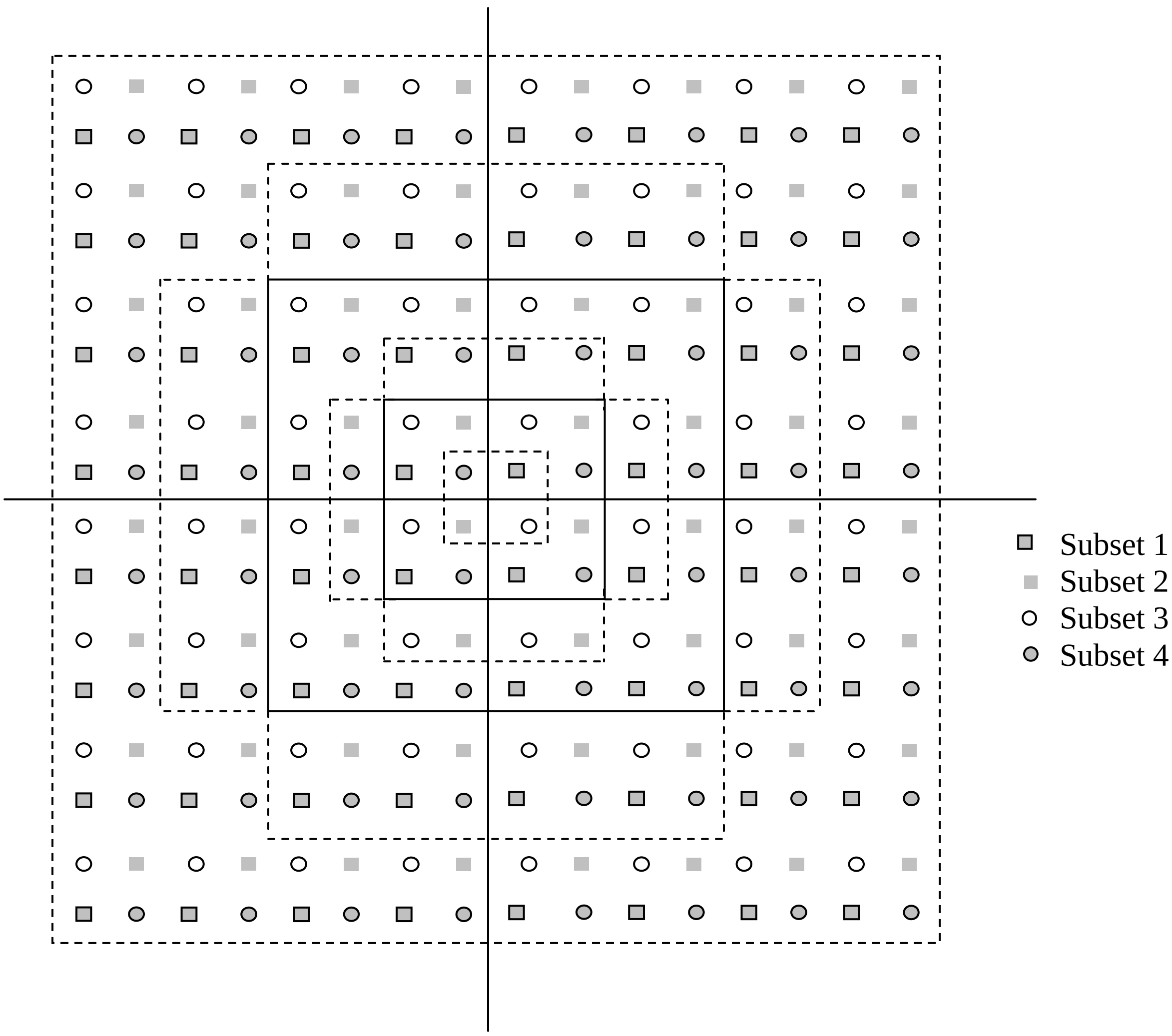

Fig.6.36.1 *Some two-dimensional signal constellations ($M = 2^m$, m= 1,…,8) of TCM codes.*

Let there be 'N' valid signal points, denoted by $(x_i + jy_i)$, $1 \le i \le N$, in the two dimensional signal space such that each point signifies an information bearing symbol (or signal) different from one another. Now, the Euclidean distance d_{ij} between any two signal points, say (x_i, y_i) and (x_j, y_j) in this 2 –D Cartesian signal space may be expressed as, $d^2ij = (x_i - x_j)^2 + (y_i - y_j)^2$. Note that for detecting a received symbol at the demodulator in presence of noise etc., it is important to maximize the minimum distance (say, d_{min}) between any two adjacent signal points in the space. This implies that the N signal points should be well distributed in the signal space such that the d_{min} amongst them is the largest. This strategy ensures good performance of a demodulation scheme especially when all the symbols are equally likely to occur.

Suppose we wish to transmit data from a source emitting two information bits every T seconds. One can design a system in several ways to accomplish the task such as the following:
(i) use uncoded QPSK modulation, with one signal carrying two information bits transmitted every T seconds.

(ii) use a convolutional code of rate r = 2/3 and same QPSK modulation. Each QPSK symbol now carries 4/3 information bits and hence, the symbol duration should be reduced to 2T/3 seconds. This implies that the required transmission bandwidth is 50% more compared to the scheme in (i).

(i) use a convolutional code of rate r = 2/3 and 8-Phase Shift Keying (8PSK) modulation scheme to ensure a symbol duration of T sec. Each symbol, now consisting of 3 bits, carries two bits of information and no expansion in transmission bandwidth is necessary. This is the basic concept of TCM.

Now, an M-ary PSK modulation scheme is known to be more and more power inefficient for larger values of M. That is, to ensure an average BER of, say, 10^{-5}, 8-PSK-modulation scheme needs more E_b/N_o compared to QPSK and 16-PSK scheme needs even more of E_b/N_o. So, one may apprehend that the scheme in (iii) may be power inefficient but actually this is not true as the associated convolutional code ensures a considerable improvement in the symbol detection process. It has been found that an impressive overall coding gain to the tune of 3 – 6dB may be achieved at an average BER of 10^{-5}. So, the net result of this approach of combined coding and modulation is some coding gain at no extra bandwidth. The complexity of such a scheme is comparable to that of a scheme employing coding (with soft decision decoding) and demodulation schemes separately.

TCM is extensively used in high bit rate modems using telephone cables. The additional coding gain due to trellis-coded modulation has made it possible to increase the speed of the transmission.

Set Partitioning

The central feature of TCM is based on the concept of signal-set partitioning that creates scope of redundancy for coding in the signal space. The minimum Euclidean distance (d_{min}) of a TCM scheme is maximized through set partitioning.

The concept of set partitioning is shown in **Fig. 6.36.2** for a 16-QAM signal constellation. The constellation consists of 16 signal points where each point is represented by four information bits. The signal set is successively divided into smaller sets with higher values of minimum intra-set distance. The smallest signal constellations finally obtained are labeled as D0, D1, … , D7 in ***Fig. 6.36.2.*** The following basic rules are followed for set-partitioning:

Rule #1: Members of the same partition are assigned to parallel transitions.

Rule #2: Members of the next larger partition are assigned to adjacent transitions, i.e. transitions stemming from, or merging in the same node.

Assumption: All the signal points are equally likely to occur.

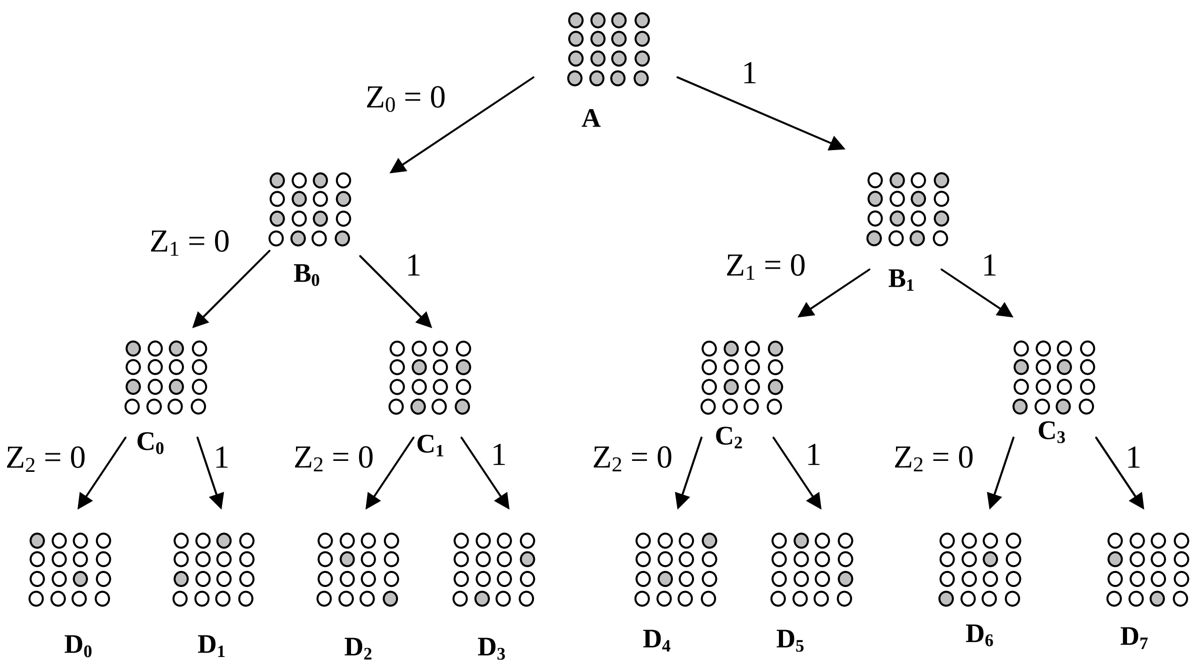

Fig. 6.36.2 *Set partitioning of the 16QAM constellation*

A TCM encoder consists of a convolutional encoder cascaded to a signal mapper. **Fig. 6.36.3** shows the general structure of a TCM encoder. As shown in the figure, a group of m-bits are considered at a time. The rate n/(n+1) convolutional encoder codes n information bits into a codeword of (n+1) bits while the remaining (m-n) bits are not encoded. However, the new group of (n+1+m-n) = m+1 bits are used to select one of the 2^{m+1} points from the signal space following the technique of set-partitioning.

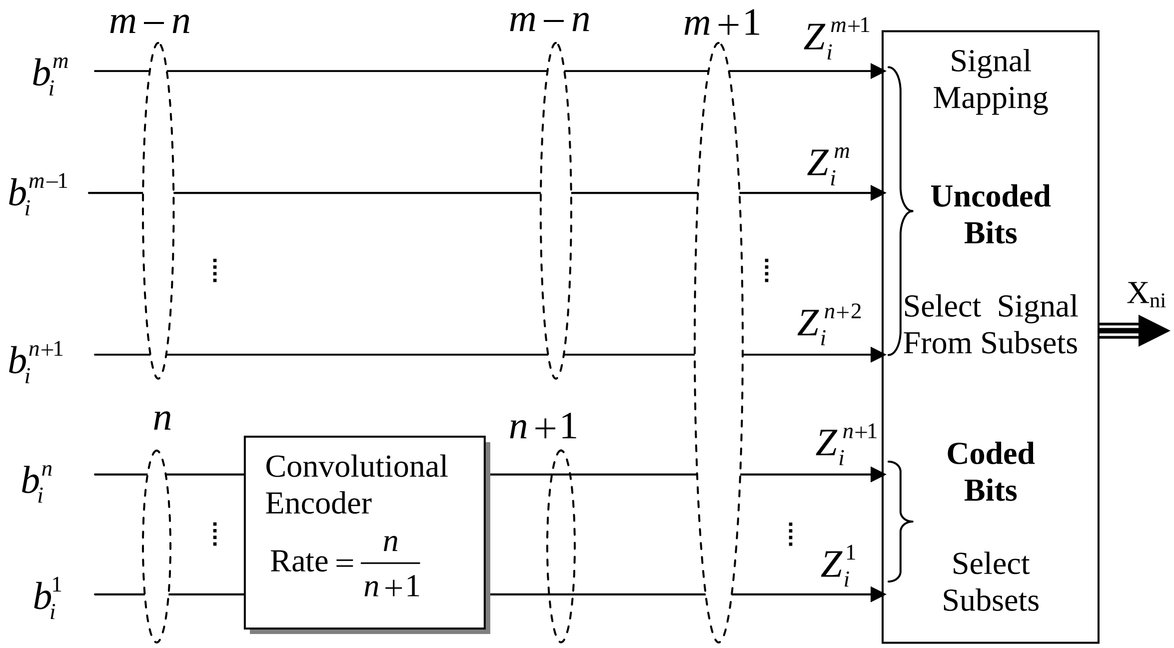

Fig. 6.36.3 *General structure of TCM encoder*

The convolutional encoder may be one of several possible types such a linear non-systematic feed forward type or a feedback type etc. **Fig. 6.36.4** shows an encoder of r = 2/3, suitable for use with a 8-point signal constellation.

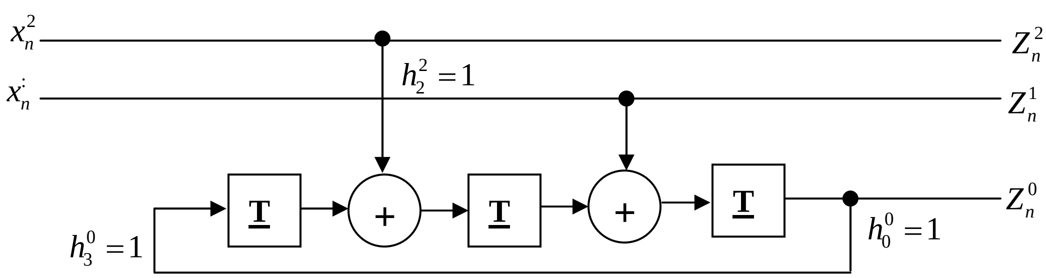

Fig. 6.36.4 *Structure of a TCM encoder based on r=2/3 convolutional coding and 8-PSK modulation format*

Decoding TCM

The concept of code trellis, as introduced in Lesson #35, is expanded to describe the operation of a TCM decoder. Distance properties of a TCM scheme can be studied through its trellis diagram in the same way as for convolutional codes. The TCM decoder-demodulator searches the most likely path through the trellis from the received sequence of noisy signal points. Because of noise, the chosen path may not always coincide with the correct path. The Viterbi algorithm is also used in the TCM decoder. Note that there is a one-to-one correspondence between signal sequences and the paths in a trellis. Hence, the maximum-likelihood (ML) decision on a sequence of received symbols consists of searching for the trellis path with the minimum Euclidean distance to the received sequence. The resultant trellis for TCM looks somewhat different compared to the trellis of a convolutional code only. There will be multiple parallel branches between two nodes all of which will correspond to the same bit pattern for the first (n+1) bits as obtained from the convolutional encoder.