COST-EFFECTIVE CODING IMPLEMENTATIONS FOR COMPUTER COMMUNICATION SYSTEMS*

R. T. CHIEN
Coordinated Science Laboratory
University of Illinois

Summary. Due to the recent developments in computer hardware and cost reduction, many powerful coding techniques can now be implemented to achieve high reliability at low cost. In this paper we examine the necessary ingredients for successful applications and delineate the systems variables and their inter-relationships. A number of sample applications will be presented to illustrate a systematic procedure to evaluate, select design and implement high performance and low cost systems for error correction and error detection. Implementation approach is considered including hardware, software, microprogramming ROMs, RAMs and LSI.

1. The Role of Coding in Telemetering - What It Can Do and What It Cannot Do.

It is well-known that error-correction and error-detection codes exist for various code length and percentages of redundancy, and that they can be implemented by computer hardware or software. What is not well-known is the fact that the performance of a properly designed coding system which matches the error statistics of the channel could be vastly superior to one casually designed out of standard textbook schemes. What is even more surprising is the fact the cost of implementation could vary by several orders of magnitude depending upon the experience of the person involved in the work. To achieve such a high pay-off cost-effective system it often involves the combination of extensive experience, familiarity of hardware available and ingenious design of codes to fit the occasion. The purpose of this paper is to examine the ingredients necessary for achieving such optimal solutions.

A common misconception is that codes can be used to correct all errors of the system. This is certainly not true. Given a certain amount of signal redundancy one tries to correct the set of most probable errors. Although the correction procedure usually improves the reliability of the system it by no means takes care of all errors. Furthermore, if a message is delivered with no error correction needed it does not mean no error can be present. It simply implies the fact that it is a valid codeword. On the positive side it should be said

* This work was supported in part by the Joint Services Electronics Program (U. S. Army, U. S. Navy and U. S. Air Force) under Contract DAAB-07-72-C0259 and in part by the National Science Foundation under Grant GK-24879.

that many codes exist to improve the reliability of the system drastically provided sufficient redundancy is available. The effectiveness of coding is also strongly dependent upon the initial state of the channel. If the initial error rate is reasonably low it is possible to design fairly simple systems to meet the needs. This is, however, not a typical situation. In the real world channel statistics are not stationary. The error rate varies over a range. The distribution is complex. Hence, it is often necessary to comprise the design for the normal and the worst situations.

2. Error Correction Approaches - Voting, Estimation, and Solution of Equations. Coding schemes for error correction are based on some very basic concepts. The majority-logic codes are based on a voting principle. It is necessary to have a sufficient number of good bits to out-vote the bad bits. It is further necessary to have a scheme of voting that guarantees the proper result inspite of the statistical and, therefore, unpredictable occurrence of the errors. Most of the majority scheme are based upon Euclidean geometry or Projective geometry. The votes are first taken at high-dimensional flats (hypersurfaces). The results at the high-dimensional flats are used for voting at the lower dimensional flats. Final results are obtained at the zero-flat level. The structure of the geometry guarantees the correctness of the voting procedure (not the outcome) and allows one to estimate the capabilities of majority-logic codes.

The Viterbi decoding algorithm is based upon statistical estimation. At any particular point in time a number of possible received sequences are considered and the probability of the occurrence of each sequence is calculated. The most probable one is, therefore, picked. This, however, only fixes the decision on the earliest bit in the stream. At this point the next received bit is incorporated into the decoding procedure and the process proceeds iteratively.

In the case of BCH (Bose-Chaudhuri-Hocquenghem) codes the structure is algebraic in nature. One basically sets up a set of equations which operates as a set of constraints on the codewords. When errors present themselves the constraints are not satisfied. As a result, if the situation is what is expected the system of equations are used to solve for the unknown intruders.

3. Implementation of Coding - From Shift Registers to LSI. The question of implementation is a very important one, especially when we are concerned with practical applications. For many years it has been assumed that shift registers are used for most or all coding systems. The shift registers are useful in serving as a buffer memory and it facilitates computation on bit streams that come in serially. Several things have changed drastically during the years. Many systems have a high data rate and it often transmits serial by word but parallel by bit. Many sources and sink of information are indeed computers. Hence, the systems for which coding is applied to runs in high speed. It is often

not attractive to follow the serial processing modes of a shift register. Furthermore, the advances in computer technology has led to a multiplicity of circuits and chips. Some of them are suitable to shift register implementation and others are not. In order to achieve a simple and cost effective implementation it is vital to take into consideration the specific technologies available, including software and microprogramming techniques.

A note of caution is in order when software or microprogramming is used. It is almost always a good idea not to emulate the shift register. Emulations of the shift registers are expensive and slow. It is always better to start from the decoding algorithm and implement the algorithm directly. The best approach is to design or modify the code to fit the technological idiosyncracies that are present.

4. The Proper Approach to a High-Quality Coding System - Means to Optimize Your Gains in Coding Hardware, Software and Systems. The most important thing to remember in the design of a coding system is to start early, before all the system parameters are fixed. When the system parameters are fixed the flexibility is gone and it becomes very difficult to design and fit in the parameters.

The basic idea of coding success is dependent upon the matching of the channel statistics and the code capabilities. Hence, it is important to study the statistical properties to make sure it matches the code class selected.

Most codes have their natural code length, that usually does not match the block length required. Modifications are often needed to fit the situation. Use of tables and read-only memory are often quite useful in reducing complexity in decoding implementation. The most important factor involved in design is certainly experience. It has been discovered that a person with a great deal of experience in this area can put together a superior system in much shorter time which is very attractive from cost-effectiveness point of view. A number of examples will be given in the talk.