Linear Block Codes

The trellis structure of linear block codes (LBCs) is discussed. The state and branch complexities of a trellis diagram (TD) for a LBC is investigated. The TD with the minimum number of states is said to be minimal. The branch complexity of a minimal TD for a LBC is expressed in terms of the dimensions of specific subcodes of the given code. Then upper and lower bounds are derived on the number of states of a minimal TD for a LBC, and it is shown that a cyclic (or shortened cyclic) code is the worst in terms of the state complexity among the LBCs of the same length and dimension. Furthermore, it is shown that the structural complexity of a minimal TD for a LBC depends on the order of its bit positions. This fact suggests that an appropriate permutation of the bit positions of a code may result in an equivalent code with a much simpler minimal TD. Boolean polynomial representation of codewords of a LBC is also considered. This representation helps in study of the trellis structure of the code. Boolean polynomial representation of a code is applied to construct its minimal TD. Particularly, the construction of minimal trellises for Reed-Muller codes and the extended and permuted binary primitive BCH codes which contain Reed-Muller as subcodes is emphasized. Finally, the structural complexity of minimal trellises for the extended and permuted, and double-error-correcting BCH codes is analyzed and presented. It is shown that these codes have relatively simple trellis structure and hence can be decoded with the Viterbi decoding algorithm. Lin, Shu Unspecified Center NAG5-931

The idea of concatenating smaller codes to obtain a composite code with longer blocklength is important in block coding theory. This is because longer codes correct a larger fraction of errors than smaller codes of similar rates and relative minimum distances over a channel with independent and identically distributed errors. This thesis adopts a transform approach to the construction of such longer codes. This approach which is a generalization of the two-dimensional discrete Fourier transform, enables the construction of two-dimensional codes (array codes) on the basis of optimizing "zero" sets in the transform domain. The algebraic structure and properties of these codes are explained on the basis of the structure of the zero sets and the relationship of these codes to cascaded codes is detailed. The class of Hyperbolic Cascaded Algebraic Geometric codes is constructed with the aid of a suitable transform. This approach also facilitates the construction of two-dimensional burst error correcting codes. A class of such codes with low redundancy is demonstrated. Finally the interplay between the transform approach and the cascade coding approach is exploited in a decoding algorithm for HCRS codes (and their extended versions) which is simpler than the existing Sakata algorithm based method for these codes. The general decoding algorithm for cascade codes is also examined from the point of view of the transform domain.

We investigate the creation of linear block codes using Hadamard matrices for block fading channels. The aforementioned codes are very easy to find and have bounded cross correlation spectrum. The optimality is with respect to the metric-spectrum which gives a performance for the codes very close to optimal codes. Also, we can transform these codes according to different characteristics of the channel and can use selective transmission methods.

A code trellis is a graphical representation of a code, block or convolutional, in which every path represents a codeword (or a code sequence for a convolutional code). This representation makes it possible to implement Maximum Likelihood Decoding (MLD) of a code with reduced decoding complexity. The most well known trellis-based MLD algorithm is the Viterbi algorithm. The trellis representation was first introduced and used for convolutional codes [23]. This representation, together with the Viterbi decoding algorithm, has resulted in a wide range of applications of convolutional codes for error control in digital communications over the last two decades. There are two major reasons for this inactive period of research in this area. First, most coding theorists at that time believed that block codes did not have simple trellis structure like convolutional codes and maximum likelihood decoding of linear block codes using the Viterbi algorithm was practically impossible, except for very short block codes. Second, since almost all of the linear block codes are constructed algebraically or based on finite geometries, it was the belief of many coding theorists that algebraic decoding was the only way to decode these codes. These two reasons seriously hindered the development of efficient soft-decision decoding methods for linear block codes and their applications to error control in digital communications. This led to a general belief that block codes are inferior to convolutional codes and hence, that they were not useful. Chapter 2 gives a brief review of linear block codes. The goal is to provide the essential background material for the development of trellis structure and trellis-based decoding algorithms for linear block codes in the later chapters. Chapters 3 through 6 present the fundamental concepts, finite-state machine model, state space formulation, basic structural properties, state labeling, construction procedures, complexity, minimality, and sectionaliza...

The Viterbi algorithm is indeed a very simple and efficient method of implementing the maximum likelihood decoding. However, if we take advantage of the structural properties in a trellis section, other efficient trellis-based decoding algorithms can be devised. Recently, an efficient trellis-based recursive maximum likelihood decoding (RMLD) algorithm for linear block codes has been proposed. This algorithm is more efficient than the conventional Viterbi algorithm in both computation and hardware requirements. Most importantly, the implementation of this algorithm does not require the construction of the entire code trellis, only some special one-section trellises of relatively small state and branch complexities are needed for constructing path (or branch) metric tables recursively. At the end, there is only one table which contains only the most likely code-word and its metric for a given received sequence r = (r(sub 1), r(sub 2), ..., r(sub n)). This algorithm basically uses the divide and conquer strategy. Furthermore, it allows parallel/pipeline processing of received sequences to speed up decoding. Lin, Shu and Fossorier, Marc Goddard Space Flight Center NAG5-931; NAG5-2938.

Linear block codes are used in modern communication and digital storage systems to combat random errors that are introduced by communication channels (e.g., telephone lines, atmosphere, and compact discs). The idea is that the redundant bits contained in each codeword of a code can be used by the receiver to recover the actual transmitted codeword or message. The process of recovering the original codeword from a corrupted version of it is called decoding. It is implemented by an algorithm located at the receiver's end. Informally speaking, a good code is one that has a high rate, that is, it does not use much redundancy to allow error correction, but it also has an efficient decoding algorithm. Therefore, finding good codes is a relevant problem in the design of communication systems. Decoding a general linear code is an NP-hard problem: The best known general decoding algorithm for linear codes, a.k.a. syndrome decoding, increases exponentially in complexity with the length of the code. The objective of the present work is to implement/analyze a statistical decoding algorithm in a robust manner that is efficient with regards to both the amount of storage space needed and computation complexity. At least for codes of lengths less than 100, it has proven to

work much faster than syndrome decoding and even some well-established decoding algorithms. The application of the algorithm is mainly illustrated with quadratic residue codes. The choice was due to the fact that QR codes have a high rate, but finding efficient decoding algorithms for them is still a challenging problem.
Most coding schemes used in today's communication systems are designed for memoryless channels. These codes break down when they are transmitted over channels with memory, which is in fact what real-world channels look like since errors often occur in bursts. Therefore, these systems employ interleaving to spread the errors so that the channel looks more or less memoryless (for the decoder) at the cost of added delay and complexity. In addition, they fail to exploit the memory of the channel which increases the capacity for a wide class of channels. On the other hand, most channels with memory do not have simple and mathematically tractable models, making the design of suitable channel codes more challenging and possibly not practical. Recently, a new model has been proposed known as the queue-based channel (QBC) which is simple enough for mathematical analysis and complex enough for modeling wireless fading channels. In this work, we examine the performance of linear block codes when transmitted over this channel. We break down our focus into two parts. First, we investigate the maximum likelihood decoding of binary linear block codes over the QBC. Since it is well known that for binary symmetric memoryless channels, maximum likelihood decoding reduces to minimum Hamming distance

decoding, our objective here is to explore whether there exists a similar relation between these two decoding schemes when the channel does have memory. We give a partial answer for the case of perfect and quasi perfect codes. Next, we study Reed-Solomon (RS) codes and analyze their performance when transmitted over the QBC under the assumption of bounded distance decoding. In particular, we examine the two interleaving strategies encountered when dealing with non-binary codes over a binary input channel; namely, symbol interleaving and bit interleaving. We compare these two interleaving schemes analytically and show that symbol interleaving always outperforms bit interleaving. Non-interleaved Reed-Solomon codes are also covered. We derive some useful expressions pertaining to the calculation of the probability of codeword error. The performance of non-interleaved RS codes are compared to that of interleaved ones for the simplest scenario of the QBC which is the additive (first-order) Markov noise channel with non-negative noise correlation.

This practical resource provides you with a comprehensive understanding of error control coding, an essential and widely applied area in modern digital communications. The goal of error control coding is to encode information in such a way that even if the channel (or storage medium) introduces errors, the receiver can correct the errors and recover the original transmitted information. This book includes the most useful modern and classic codes, including block, Reed Solomon, convolutional, turbo, and LDPC codes.You find clear guidance on code construction, decoding algorithms, and error

correcting performances. Moreover, this unique book introduces computer simulations integrally to help you master key concepts. Including a companion DVD with MATLAB programs and supported with over 540 equations, this hands-on reference provides you with an in-depth treatment of a wide range of practical implementation issues.
A comprehensive introduction to the basic principles, design techniques and analytical tools of wireless communications.
Channel coding lies at the heart of digital communication and data storage, and this detailed introduction describes the core theory as well as decoding algorithms, implementation details, and performance analyses. In this book, Professors Ryan and Lin provide clear information on modern channel codes, including turbo and low-density parity-check (LDPC) codes. They also present detailed coverage of BCH codes, Reed-Solomon codes, convolutional codes, finite geometry codes, and product codes, providing a one-stop resource for both classical and modern coding techniques. Assuming no prior knowledge in the field of channel coding, the opening chapters begin with basic theory to introduce newcomers to the subject. Later chapters then extend to advanced topics such as code ensemble performance analyses and algebraic code design. 250 varied and stimulating end-of-chapter problems are also included to test and enhance learning, making this an essential resource for students and practitioners alike.

List Decoding of Linear Block CodesSequential Decoding of Linear Block CodesOptimal Encoding, Trellis Structure, and Normalized Weight of Linear Block CodesTrellises and Trellis-Based Decoding Algorithms for Linear Block CodesSpringer Science & Business Media

In a coded communication system with equiprobable signaling, MLD minimizes the word error probability and delivers the most likely codeword associated with the corresponding received sequence. This decoding has two drawbacks. First, minimization of the word error probability is not equivalent to minimization of the bit error probability. Therefore, MLD becomes suboptimum with respect to the bit error probability. Second, MLD delivers a hard-decision estimate of the received sequence, so that information is lost between the input and output of the ML decoder. This information is important in coded schemes where the decoded sequence is further processed, such as concatenated coding schemes, multi-stage and iterative decoding schemes. In this chapter, we first present a decoding algorithm which both minimizes bit error probability, and provides the corresponding soft information at the output of the decoder. This algorithm is referred to as the MAP (maximum aposteriori probability) decoding algorithm. Lin, Shu and Fossorier, Marc Goddard Space Flight Center NAG5-931; NAG5-2938

For long linear block codes, maximum likelihood decoding based on full code trellises would be very hard to implement if not impossible. In this case, we may wish to trade error performance for the reduction in decoding complexity. Sub-optimum soft-decision decoding of a linear block code based on a low-weight sub-trellis can be devised to provide an effective trade-off between error performance and decoding complexity. This chapter presents such a suboptimal decoding algorithm for linear block codes. This decoding algorithm is iterative in nature and based on an optimality test. It has the following important features: (1) a simple method to generate a sequence of candidate code-words, one at a time, for test; (2) a sufficient condition for testing a candidate code-word for optimality; and (3) a low-weight sub-trellis search for finding the most likely (ML) code-word. Lin, Shu and Fossorier, Marc Goddard Space Flight Center NAG5-931; NAG5-2938...

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The coding problem; Introduction to algebra; Linear codes; Error correction capabilities of linear codes; Important linear block codes; Polynomial rings and galois fields; Linear switching circuits; Cyclic codes; Bose-chaudhuri-hocquenghem codes; Arithmetic codes.

As the demand for data reliability increases, coding for error control becomes increasingly important in data transmission systems and has become an integral part of almost all data communication system designs. In recent years, various trellis-based soft-decoding algorithms for linear block codes have been devised. New ideas developed in the study of trellis structure of block codes can be used for improving decoding and analyzing the trellis complexity of convolutional codes. These recent developments provide practicing communication engineers with more choices when designing error control systems. Trellises and Trellis-based Decoding Algorithms for Linear Block Codes combines trellises and trellis-based decoding algorithms for linear codes together in a simple and unified form. The approach is to explain the material in an easily understood manner with minimal mathematical rigor. Trellises and Trellis-based Decoding Algorithms for Linear Block Codes is intended for practicing communication engineers who want to have a fast grasp and understanding of the subject. Only material considered essential and useful for practical applications is included. This book can also be used as a text for advanced courses on the subject.